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Hard Choices

Advances in grinding technology give manufacturers more ways to produce hardened parts.

Workpieces harder than 45 HRC are generally considered candidates for hard turning or grinding. Typical workpieces include hardened steel bearings, gears, gear shafts, camshafts, flanged shafts and spindles.

In many cases, hard turning is given preference over grinding. The reason, oftentimes, is because hard turning is compared to outdated or obsolete grinding techniques. However, when the comparison takes into account today's advanced grinding-process technologies and machines, grinding proves to be advantageous in a growing number of instances.

The conventional processing of a hardened workpiece begins by turning it down just short of finish tolerance, leaving only enough stock for grinding. The part is then heat-treated to a specified hardness. It's not uncommon for the heat-treating process to distort the workpiece some, which must be addressed. At the very least, the workpiece will require cleaning after heat treating and before it's loaded in the grinder for processing to finish size and surface specifications.

With hard turning, the workpiece sometimes goes directly from the lathe to the grinder. And in cases where the hard-turned workpiece meets size and finish specifications, it may bypass the grinding operation altogether.

Hard turning, though, should not be viewed as a replacement for the grinding process. Today, hardened parts can be processed completely by using a variety of grinding operations—without any turning. And, frequently, these operations process the parts more efficiently than a combination of turning and grinding.

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Figure 1: Grinding of camshaft bearing journals using high-speed centerless grinding and CBN grinding wheels.

Centerless Grinding with CBN

Advanced grinding machines and processes provide a sound basis for rapid, adaptable, economical machining. The savings in production costs afforded by grinding are achieved by, among other things, an increase in throughput without any loss of workpiece quality and, in many cases, an improved level of quality. Moreover, the grinding process often offsets some of the costs associated with turning, not the least of which are metalworking fluid use, consumption and disposal.

The machining of bearing journals for cast steel camshafts serves as a good example. Centerless plunge-cut grinding is a particularly productive way to process these parts in high-volume, long-run production operations. Significant increases in productivity have been obtained by using high-speed grinding machines and CBN wheels.

During rough grinding on a centerless grinder, five bearing journals were ground in 12 seconds to the specified machining allowance of 4.1mm (Figure 1). This level of efficiency entirely eliminated the need for preliminary turning. And the CBN wheels, compared to corundum wheels, reduced the actual grinding time 40 percent and lowered cycle time, including total nonproductive time, 28 percent.

The external centerless machine used was designed from the ground up to run CBN grinding wheels. Its Granitan machine bed absorbs vibration and maintains thermal stability, while its stiff grinding spindle, supported by bearings at both ends, accommodates a peripheral speed of 120m/sec. Lubricant mist, which forms at these high speeds, can be extracted from the machine enclosure by a vacuum system.

While sets of CBN grinding wheels represent an initial high investment, their cost is justified not only by the increased productivity they afford but also by their extreme durability. Processing over 500,000 camshafts per set of wheels is not unusual. Since surface finish after rough grinding is not critical, the abrasive coating can be designed, without compromise, for high throughput and resistance to wear. Hence, the grinding-wheel-to-workpiece cost is lower than if conventional grinding wheels were employed.

In addition, because CBN lasts so much longer, the time spent changing out wheels is proportionately shorter. Moreover, the service life of regulating wheels is appreciably prolonged, thanks to the marked reduction in grinding forces afforded by the very high material-removal rates.

When finish grinding, tight tolerances for diameters and roundness must be achieved, and there must be a low degree of surface roughness. For such results, centerless grinding with preformed vitrified CBN wheels is recommended. Preformed wheels are important, since they can be trued quickly after mounting. In use, particularly at high speeds, such CBN wheels combine high throughput with exceptional surface quality. Profile wear and changes in roundness take place more slowly than with conventional grinding wheels and, therefore, result in longer intervals between dressing.

Plunge-Cut Grinding

If bearings need to be ground to precise standards of runout or concentricity, machining between centers is essential. Clamping between centers places the workpiece in a specific position that permits not only the grinding of cams, but also the plunge cutting of grooves and the machining of shoulders.

An intricate set of grinding wheels is required to perform angle plunge-cut grinding of a gear shaft. Three individual wheels, mounted as a set measuring 153mm in width, were used to machine seven bearing journals and one shoulder in a single pass (Figure 2). In this case, sintered corundum grinding wheels offered a number of advantages. The cost of a CBN grinding wheel would be considerably higher, and profiling the wheels' width would prove very expensive.

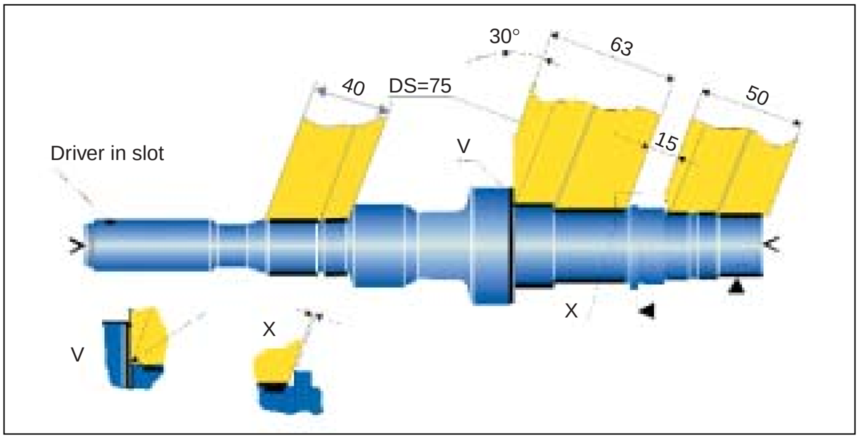


Figure 2: Three grinding wheels mounted as a set can angle plunge-cut-grind a shaft's seven bearing journals and shoulder in a single pass. Dimensions are in millimeters. Key: DS = diameter; x = clearance between grinding wheel and back shoulder of part; v = grinding relief.

A certain portion of the total cycle time is required for finish machining the gear shaft to ensure dimensional and geometric accuracy. Here's where one advantage of plunge-cut grinding becomes evident. The deformation of the workpiece caused by rough grinding is counteracted during finishing and sparking out. This is not possible with hard turning, where the cutting edge of the tool is traveling along the surface line of the workpiece. Below a certain machining depth, no more material can be removed by turning. Instead, other operations, such as reaming, are required.

If the gear shaft were hard-turned, it would have been impossible to approach what grinding offers in terms of a lower cycle time and machining cost, improved workpiece quality and better processing reliability.

High-Speed Peel Grinding

A particular advantage of hard turning is its adaptability to workpiece geometry. If a geometry is modified, the NC tool path can be altered simply. As a result, a wide variety of workpieces can be processed in a single chucking with a small number of tools.

High-speed peel (HSP) grinding also offers considerable flexibility. In contrast to plunge-cut grinding with a profiled grinding wheel, peel grinding involves longitudinal shaping with a narrow, all-purpose CBN wheel.

The entire machining allowance of several tenths of a millimeter is removed in a single pass. The CBN coating features an angled roughing zone—2mm to 5mm wide—that performs the primary metal-removal process. This is adjoined by a zone contoured in parallel for finishing and sparking-out purposes. It is sufficient for this zone to be around 2mm wide, even for roughness limits of $R_Z < 3$um.

Cutting speeds up to 160m/sec.—and greater than 200m/sec., in certain cases—are used when HSP grinding. As with turning, the metal-removal rate (Q_W) is calculated as a product of the axial rate of advance, the circumference of the workpiece and the radial machining allowance (Figure 3). While the peripheral workpiece speed has no direct influence on the work rate, it is nevertheless an important processing parameter. In turning, it represents the cutting speed and can only be varied within narrow limits due to, among other things, tool life. In grinding operations, however, it can be optimized across a wide range when machining in the roughing and sparking-out zone.

In HSP grinding, the relative mrr (Q'_W in Figure 3) is a characteristic value for the stress loading on the abrasive coating and can reach values around 100mm^3/mm/sec. in the roughing zone. With a roughing zone of greater width, which, needless to say, is limited by workpiece geometries and unavoidable overrun distances, the axial rate of advance can be increased at the same rate as Q'_W.

From the standpoint of attainable

rates of advance, HSP grinding is markedly superior to precision hard turning, because roughing can be carried out with an abrasive coating of only a few millimeters in width. In contrast, only a single cutter is available for hard turning, and the chip cross-section is limited to around 0.15mm of feed and advance.

Figure 3 depicts the throughput rate customarily achieved in the processing of $100Cr_6$ bearing steel. The throughput rates for hard turning lie between 20mm/sec. and 70mm/sec. In external cylindrical HSP grinding, the rates can exceed 100mm/sec.

Simultaneous ID/OD Grinding

Chucked workpieces, in particular, appear ideally suited to the hard-turning process. Relatively compact and short, they are not adversely affected by the passive forces that arise during machining. Even the thermal expansion to which tools are subject—particularly during dry machining—can be readily compensated for.

Many chucked workpieces undergo internal and external machining. Examples are the ID grinding, face grinding, taper grinding and beveling of gears. On modern ID/OD cylindrical grinding machines, these processes can be carried out simultaneously, in contrast, for the most part, to hard turning. This appreciably shortens machining times and increases productivity.

Current simultaneous ID/OD grinding machines feature a fixed workpiece headstock and two compound slides on which an external and an internal grinding spindle are arranged.

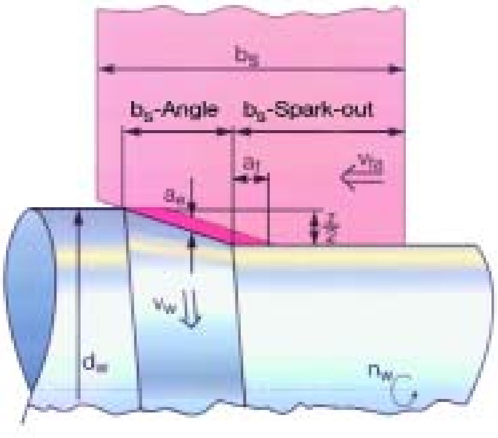
In one gear-processing application involving heat-treated steel, the part is loaded in the chuck by a handling mechanism with double grippers, centered by the previously finish-machined tooth-pitch line and clamped against a plane surface. With this method of chucking, the subsequent grinding operations result in the minimum running deviation of the hole and synchromesh cone, relative to the tooth-pitch line. Diametric tolerances are 16µm for the cone and 23µm for the bore. Cycle time is around 45 seconds, which, in the case of producing gear wheels, is determined by the internal cylindrical grinding process.

A corundum grinding wheel is adequate for the external grinding of the cone, but to permit the fastest internal cylindrical grinding, a CBN grinding wheel capable of being dressed at a peripheral speed of 60m/sec. was used.

Grinding Gains Ground

Today's advanced grinding machines, ultra-efficient grinding wheels and new technological developments increase the productivity and flexibility of the grinding process, reduce manufacturing costs and, in turn, improve competitiveness. In some applications, high-performance grinding is replacing rough turning.

Under certain circumstances, it may be economically advantageous to combine both cutting and grinding operations. In fact, user demand is driving the combination of cutting and grinding processes into a single machine platform. A benefit of this multitasking approach is that it allows processing of part with one fixturing, which improves work flow, reduces setups, requires fewer machines and operators, and enhances part-quality predictability.



Relative metal-removal rate	$Q'_W = a_e \cdot v_W = \pi \cdot d_W \cdot n_W \cdot a_f \cdot \frac{z/2}{b_S\text{-Angle}}$
Metal-removal rate	$Q_W = Q'_W b_S = (\pi \cdot d_W \cdot z/2) \cdot v_{fa}$
Number of Sparking out	$U = \frac{b_S\text{-Spark-out}}{a_f}$

Figure 3: Throughput rate customarily achieved in high-speed peel grinding of $100Cr_6$ bearing steel. Key: b_S = width of wheel; b_S-Angle = grinding angle; b_S-Spark-out = spark-out area; a_e = chip thickness; a_f = rate of advance/rev.; V_{fa} = rate of advance; z/2 = stock removal/radius; n_W = work speed; v_W = surface speed; d_W = work diameter; Q_W = mrr; Q'_W = mrr/stress loading; U = spark-out overlap.

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