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SOLID CONCEPT

A rigid machining system is the key to success when hard turning.

Hard turning is an increasingly popular way to reduce the time needed to finish hardened parts—those with hardness ranging from 50 to 66 HRC. The timesavings result mainly from the elimination of some, or all, grinding operations. In applications where extremely fine finishes, better than 2.5 R_a, are required, a shop can use hard turning to prepare a part so only a short finish-grind is necessary to meet specs.

Where final tolerances are not as critical, hard turning can completely eliminate grinding. In addition, because hard turning involves single-point metal removal, it facilitates the production of complex contours without the need to fabricate custom-formed grinding wheels.

Double Force

Successful hard turning is not as simple as chucking a hardened part in a lathe and applying a ceramic or CBN cutting tool. Numerous factors must be considered, including higher cutting forces. Cutting forces in hard turning can be up to twice as high as those used for a similar operation on a "soft" workpiece.

According to Tom Sheehy, application engineer for machine toolmaker Hardinge Inc., Elmira, N.Y., the higher forces result from the tool geometries required to cut the hard material. The ceramic and CBN tool compositions routinely applied in hard turning are relatively brittle, and toolmakers apply chamfers to the cutting edges to strengthen them. A chamfer protects the edge, but it also reduces the edge's shearing capability. Cutting forces increase because the blunted edge pushes more than it cuts. The higher forces can make the cutting edge and part

All images: Hardinge

Hard turning a shaft.

move relative to each other, producing chatter. At best, chatter degrades surface finish; at worst, it destroys the cutting tool or the part itself.

Lawrence Bruso, CNC machinist at Link Tool & Manufacturing, Taylor, Mich., has concentrated on hard turning and boring for 15 years, machining tool steels from 50 to 66 HRC for punches and dies. He said tool life and chatter are intertwined. Chatter causes a tool to wear out quickly, and "if you have a dull tool, it's going to cause chatter, too." Applied experience—knowing what worked previously—can reduce tool-generated cutting forces. "Putting a different relief on a tool, or using a smaller nose radius, sometimes helps," he said.

Is It Feasible?

The size and shape of the part are the most important factors in making the decision to try hard turning. Sheehy said, "Certain parts can be hard-turned very successfully, but a lot of them can't due to the part configuration. The longer length-to-diameter ratios are usually the most difficult. If a guy is doing a ½"-dia. × 10"-long shaft and he's having a hard time turning it in a soft state, it's going to be even worse in a hard state." Even a large-diameter part, if its unsupported length is more than three times its diameter, can generate chatter when subjected to the forces of hard turning.

The prospects for chatter also depend on how the part is held. According to Jyoti Murkherjee, engineer at machine tool builder Protolab Inc., Ann Arbor, Mich., one answer is a collet or specially designed chuck that provides "a firm, all-around grip of the part. A 3-jaw chuck, in my experience, is not very good for hard turning," he said. However, depending on the workpiece shape and production considerations, setup may be quicker in a 3-jaw chuck. Furthermore, some 3-jaw chucks have features engineered specifically to dampen vibrations in hard-turning applications.

The location of the cutting action relative to the machine's spindle bearings is also important. The greater the distance between the spindle bearings and the point where the cutting edge contacts the workpiece, the larger the potential for the part to flex, and the greater the possibility of chatter.

Sheehy said, "We build the majority of our lathes with a collet-ready spindle. That allows us to bury the collet into the spindle so we are a lot closer to the spindle bearings. The result is more rigidity, better accuracy and better part roundness."

In general, the goal is to minimize long tooling and part overhangs. "You could have a great application for hard turning, but if you take a 1" stick tool and hang it out of the face of the turret 4", it's probably not going to work, because the tool is extended too far," Sheehy said.

Necessarily Rigid

Experts agree that the key to successful hard turning is limiting the movement of the cutting tool and part by maximizing the rigidity of all components of the machining system, from the part itself to the machine tool on which it is turned.

"I know customers who are hard turning on 5- and 10-year-old machines," Sheehy said. "But those machines typically are not ones that have been crashed many times, so they still have quite a bit of rigidity left in them. They're accurate. They don't have a lot of slop in the ways and the ballscrews. You want to look at the rigidity of the machine, and the overall condition of it."

He added that for occasional hard turning, a purpose-designed machine is

Turn & grind together

Typically, shops hard-turn a part as near to its final shape as possible, then finish it with a grinder. This approach, however, still requires workhandling time and effort. In addition, rechucking can negatively affect part accuracy. In response, manufacturers have developed combination hard turning/grinding machines.

The Stratos series of grinding machines from Schaudt Microsa BWF, Stuttgart, Germany, part of the Körber-Schleifring Group, combines a hard-turning capability and integrated material-handling systems with grinding functions. The machines feature a conveyor that brings the hardened part to an inverted spindle. In one area, lathe tools rigidly mounted to the machine bed, or optionally held in an 8-station turret, perform rough turning.

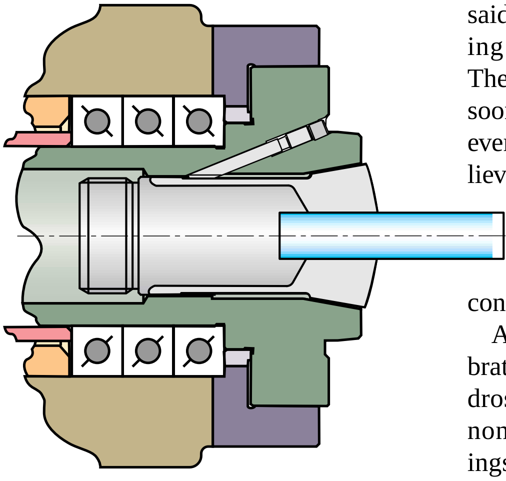
According to Dave Barber, marketing manager for United Grinding Technologies Inc., Miamisburg, Ohio, the U.S. arm of the Körber-Schleifring Group, the turret permits use of redundant tools and, thus, enables the machine to run longer between tool changes. The turret also can be fitted with live tooling for milling and drilling.

After turning, the machine transfers the part to a second area that is enclosed by a sliding door that prevents grinding coolant from entering the area where dry turning occurs. Both OD and ID grinding are possible. The wheel-dressing unit is fitted right next to the spindle head, and continual dressing enhances final part finish. Because the hard turning in this case is basically a preliminary roughing operation, final part quality is less dependent on tool wear.

Another approach, labeled "grind-finishing" by its developer, can facilitate dry grinding when disposal of coolant is an issue. Inverted-spindle vertical turning/grinding centers from EMAG LLC, Farmington Hills, Mich., hard-turn a part and leave only a few microns of material to be ground away. The light grinding required to finish the part is then accomplished in the same chucking, without coolant. The grinding conditions also reduce the need for wheel dressing.

The VSC 250DS and VSC 400DS machines, designed for workpieces up to 250mm in diameter and 400mm in diameter, respectively, feature polymer-granite bases, with Z-axis travels on a hydrostatic guide way. The machines have optional Y-axis travel and tooling system combinations of up to four grinding spindles and a maximum of 12 turning tools, as well as live drilling and milling tools.

—B. Kennedy



Workholding systems that draw a collet into the spindle shorten the distance between the tool/workpiece interface and the spindle bearings and provide maxiumum stiffness.

not necessary. "You can use a standard turning center."

Machine tools designed to handle hard turning on a regular basis feature greater size and weight, and oversized components such as spindles and ways. However, in a technical paper, "Hard Turning and the Machine Tool," Hardinge Director of Workholding Engineering Daniel P. Soroka pointed out that there are practical and economic limits to the amount of rigidity, or "static stiffness"—the ratio of an applied force to an associated displacement—that can be built into a machine tool. The goal becomes increasing the machine's dynamic stiffness, which Soroka defined as a measure of the ratio of the applied force to the displacement, occurring at the frequency of the exciting force.

Increasing dynamic stiffness involves dampening the frequency of vibrations through technologies such as composite-filled machine bases.

In the bases of its machine tools, Hardinge has traditionally used a polymer composite called Harcrete that it says has dampening characteristics up to eight times those of cast iron. Depending on performance and cost requirements, the base can be all composite, or a combination of casting and strategically reinforced composite cavities.

There is more than one way to achieve high dynamic stiffness in machine tools. Murkherjee of Protolab said, "The stiffness and joint dampening have to be optimized together. There is a myth in the industry that as soon as you have a casting, you have everything in this world. I do not believe this." He said he has had success machining 62 HRC material with CBN tools in machine tools built with concrete-filled weldments vs. casting.

Another approach to dampening vibration involves the application of hydrostatic linear ways, which ride on noncontact, pressurized-fluid bearings. Like standard linear ball guide ways, hydrostatic ways exhibit low friction and resist loads in all directions. Additionally, the fluid film in the hydrostatic ways provides dampening when vibration occurs. "Any time you can dampen vibration," Sheehy said, "you're going to get a better surface finish, more accuracy, better flatness and an increase in tool life. It also eliminates witness marks that are left behind after an interrupted cut in hard material."

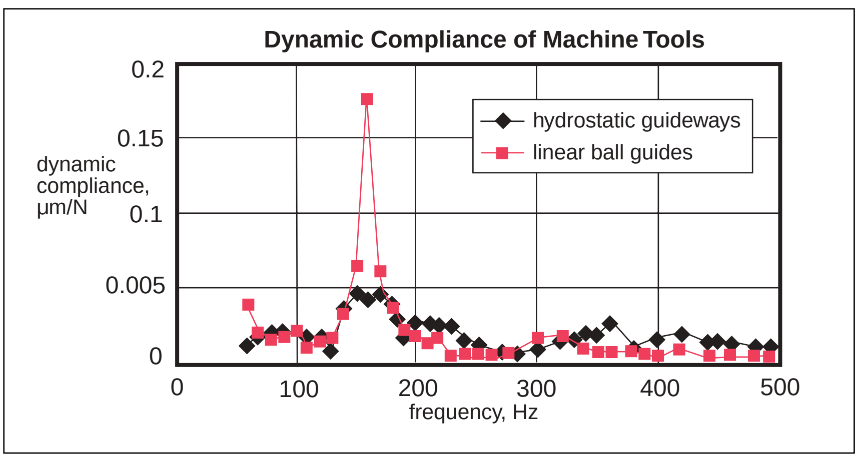
Sheehy noted that hydrostatic ways are not an inexpensive option. "They lend themselves well to heavily interrupted cuts, but they are not something that the run-of-the-mill job shop is going to purchase as an option on a machine unless the shop is going to devote it exclusively to hard turning and interrupted cuts," he said.

Interestingly, Sheehy said machine tools employed for hard turning do not necessarily require high horsepower. Often, workpieces destined for hard turning are machined before being hardened. This machining leaves a small, predetermined amount of material for hard turning. "You're not going to be taking off 0.100" DOC at a 0.015-ipr feed rate. The insert couldn't handle it, again, because of the tool pressures," Sheehy said. "You end up taking perhaps 0.025" to 0.030" DOC at a lighter feed rate. So the horsepower really doesn't come into play."

On the other hand, the machine's spindle-speed capability may determine its viability for hard turning. The ceramic and CBN tools employed in hard turning must be run at high speeds to be effective. Particularly on small-diameter workpieces, a relatively high spindle speed is required to attain the required surface speed. Link Tool's Bruso said he hard-turns some parts under 0.200" in diameter and "runs up to 5,000 rpm."

Sheehy said, "With a ½"-dia. workpiece, to achieve 600 sfm you need roughly 4,500 rpm, and that is going to be the drawback for some of the older equipment that's out there. It may not have the spindle speeds available to effectively run the surface footage that is required."

He said most newer machines are engineered to run at higher speeds. Various Hardinge machines, for example, have top spindle speeds in the 5,000- to 8,000-rpm range, and "we've actually got high-speed ramp spindles that will go up to as high as 10,000 rpm, in some



Comparison of the dynamic stiffness of hydrostatic guide ways vs. linear ball guide ways shows a four-time decrease in dynamic compliance (or increase in dynamic stiffness) in the 159-Hz frequency.

The following companies contributed to this report:

EMAG LLC
(248) 477-7440
www.emag-usa.com

Hardinge Inc.
(800) 843-8801
www.hardinge.com

Link Tool & Manufacturing
(734) 946-1040

Protolab Inc.
(734) 913-9320
www.protolabmachines.com

United Grinding Technologies Inc.
(937) 859-1975
www.grinding.com

cases," Sheehy said.

A Popular Attraction

Bruso pointed out that hard turning can reduce overall job run times by as much as 75 percent, and sometimes enable one machine, in one setup, to do what was previously done on multiple machines. "Hard turning is all about cutting down time and saving money," he said. He added that those seeking machines for hard turning, while focusing on qualities such as the size and rigidity, should not ignore more general productivity-boosting features such as ease of programming and rapid tool-change time.

There's no doubt hard turning is gaining popularity, particularly in the automotive industry, where it reduces costs for producing hardened steel gears and shafts. Aerospace component manufacturers and bearing makers also hard-turn selected parts.

However, Sheehy said, "hard turning is not a catch-all for everything." In certain applications, grinding can't be eliminated. For example, no matter how fine a finish it generates, the single-point nature of hard turning leaves a "lead," or line, on the workpiece. Such a line can compromise the sealing capabilities of a shaft where it passes through a bushing. The line must be ground away before the shaft is put to use.

Whether grinding is needed or not, having the right combination of all the elements of the machining system can make the decision to hard-turn not a hard choice at all.