The Perfect Gear

Richard Berry, Haas Automation

MORE THAN ANY OTHER TYPE OF MACHINING, GEAR MAKING RELIES ON A PERFECT MIX OF SCIENCE AND ART," SAYS BILL TANDROW, DIRECTOR OF MECHANICAL ENGINEERING AT HAAS AUTOMATION.

"I HAVE A LOT OF RESPECT FOR ANYONE WHO MAKES GEARS," HE ADDS. "AS MUCH AS ANY OF OUR OTHER EFFORTS, THE QUALITY OF OUR GEAR MAKING DEFINES THE QUALITY OF OUR FINAL PRODUCT."

The science part of gear making is evident—it is well established in theory, with books full of formulas. But it's the less apparent half that makes the dramatic difference. The real art of gear making, according to Tandrow, lies in careful observation and skillful control of the machining process itself. There's no "black magic" required, only complete and dogged attention to detail.

Gears don't make themselves. While that statement may seem obvious, the fact is that both cylinders and spheres, the most common bearing surfaces in

mechanics, often do make themselves. Although a machinist's skill is required to consistently produce them in exact sizes and finishes, these shapes exist naturally, and their geometry can be machined accurately using only the most basic implements and setups. Chuck almost any shape stock into a lathe, run the cutting tool parallel to the turning axis, and you've made yourself a perfect cylinder.

Spheres are formed just as easily, except in three axes. Early machinists found they could make precision ball bearings with nothing more complicated than two rotating grooved plates, a suitable abrasive and lots of patience. The random rolling of rough blanks placed in the grooves automatically produced precise spheres. Perfectly spherical rocks have even turned up in riverbeds, created by nothing more exotic than a combination of the river's current and a hollow depression in the hard bottom.

However, while cylinders and spheres are natural shapes, the involute gear tooth is anything but. Even with modern CNC machines to tackle the problem, skill and careful attention are required to get it right.

"From the beginning," Tandrow says, "this company's success has been built on attention to detail—not just being detail-oriented, but having the observational talents to see and understand what's wrong, and then having the know-how to make it right. That is the single bona fide secret to producing perfect gears."

Haas Automation approaches gear making seriously. The company machines

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every high-precision spur gear, worm and worm wheel for its extensive product line in-house at its manufacturing facility in Oxnard, CA. Out of more than 600 skilled machinists and assembly specialists, only a handful are assigned the task of making these demanding parts.

Machinists Boris Klebanov and Edik Beginian have been with the company for about as long as anyone can remember. They purportedly learned most of what they know about gears from company founder Gene Haas.

"Years back, when we first started making mills," recalls Edik, "Gene wasn't completely happy with the gears we were getting from vendors, so he purchased a Reishauer RZ-80 and started making the gears himself. He did a lot of experimenting and testing to figure out exactly what was going on. He not only solved all of the performance problems, but he learned how to repair and maintain the machine himself. Then he taught us."

"We use those same perfected techniques today," Boris adds. "We're making essentially the gears that Gene evolved, along with 70 or 80 other kinds of gears. We're still doing everything in-house, and we're still solving all of our problems ourselves."

With schedules demanding different machine setups daily, maintaining process control is just one of many demands facing these talented machinists—but it's a big one.

Spur gears were never intended to be precise," Tandrow remarks. "Until recently, nobody had equipment to make them precise. Machinists were often happy if they just fit together. If you open a Machinery's Handbook to the section on spur gears, you'll find a lot of tables for backlash and things. Those tables weren't based on a desire to make a bad gear," Tandrow says. "It's just that when those tables were written, back around World War II, that was the state of the art. CNC gear hobbers and grinders obviously didn't exist then. You just couldn't expect to hold 30 millionths of an inch on a grind. But now we have equipment and processes that can hold down in those ranges repeatedly. We can literally produce an oil-film fit. We manufacture smoother running gears than anyone could even have imagined back then."

Why does Haas insist on making its own gears? "Because," says Tandrow, "quite simply, it allows us to precisely control the outcome. There are so many little tricks and subtleties in the hobbing and finish grinding, that we just would not succeed by having them done externally. We build our own gears to get exactly the right thing for us, at the highest precision possible."

Straight-cut spur gears are the basis for all of Haas Automation's gearboxes. The company started out buying complete assemblies, but they just weren't as perfect as the engineers wanted them, explains Tandrow. "Finally, we just designed our own gearbox. Now we make every part ourselves.

"When you buy gears from someone else, you effectively have to buy through a middleman. Even if their shop is just across the street, you've got to build a relationship with them. You've got two different companies, two different cultures, and you probably have a pretty big disjuncture between the process of using the gears and the process of making them.

"But when you make a gear in-house, you can build things into it that they can't do across the street. For example, you can pre-assemble the gears in a rough state on a single mandrel, put them into a hobber or a grinder, and finish-grind them perfectly. The gears are as exact as you can measure them, and they're already on the shaft they'll run on. 'Across the street' is just not close enough to ensure this kind of quality," Tandrow says. "For most of our gearbox operations, the operator who hobbed or finish-ground the gear is lit-

erally within a hundred yards of where we assemble the gearboxes.

"For a manufacturing environment, that's the ideal. We can make the gears in very tight batches of 10 or 20 and quickly process them through. It's more cost-effective than ordering big batches, and if there are any issues, we're only looking at a small number of reworks to get production flowing again. That's if there are any issues," Tandrow emphasizes. "Honestly, we've not had one since we adopted this approach."

In the same area where the spur gears are cut and ground, Haas also machines precision worm wheels and worms for its rotary products. This is where the dedication to tight process control really pays off.

"The aluminum-bronze worm gears at the heart of our rotary products are actually quite mature concepts," explains engineer Thomas Velasquez, who has been designing these products for more than a decade. "The inherent accuracy is assured by the single-lead hobbers that we use and by the preassembly we do before cutting. We place the shrink-fit gear blank onto the spindle, mount it on the fixture and actually tram it in. The guys (Boris and Edik) try to shoot for a runout of about 50 millionths." This procedure ensures that the pitch diameter of the finished gear is perfectly concentric with its mounting diameter.

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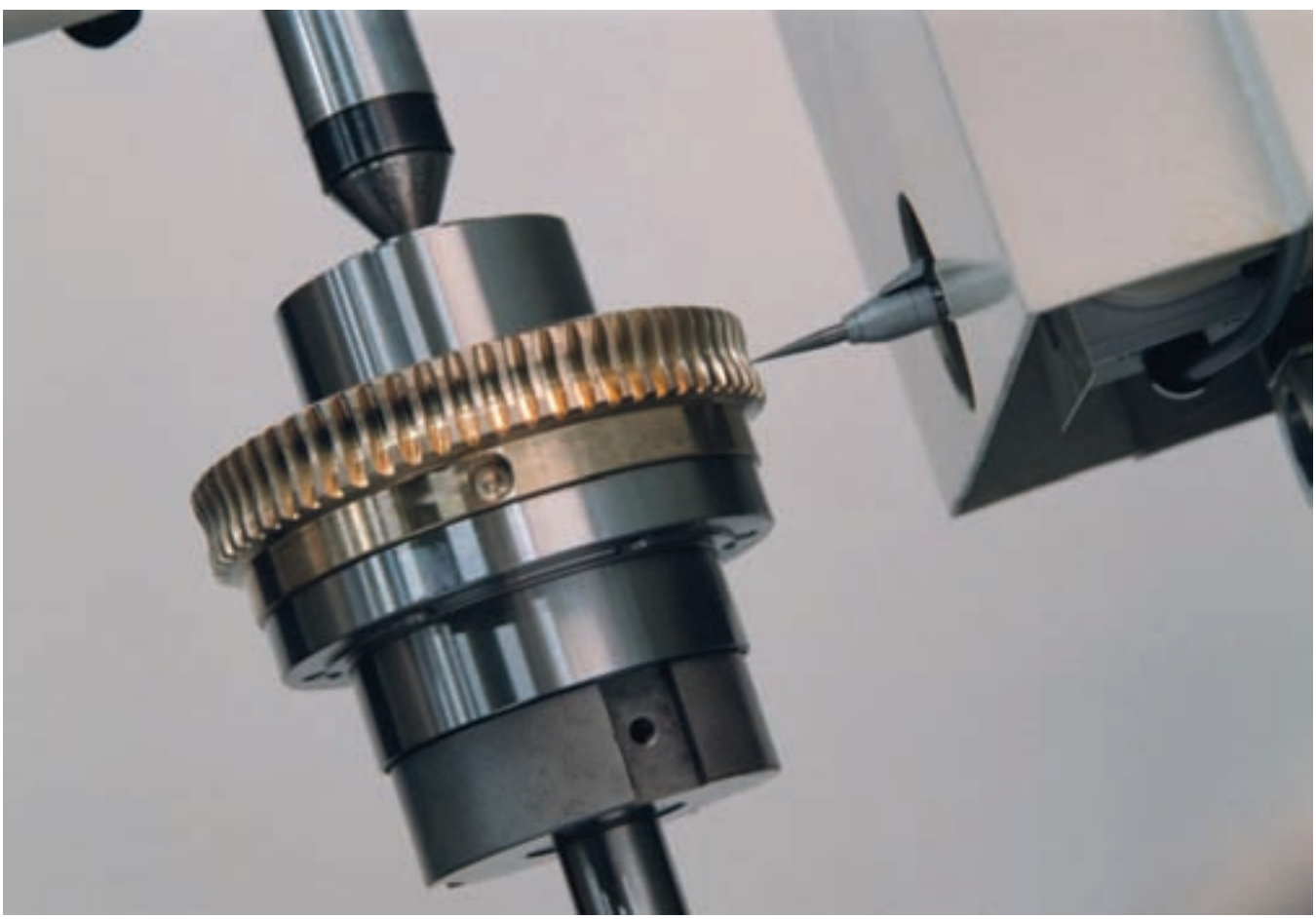

Again, the inherent accuracy of the setup is translated into actual product accuracy through the skill of the machinists, and through their careful control of the process. "Every third or fifth one is checked on the Klingelnberg gear analyzer against a master worm," notes Velasquez. "We can verify tooth-to-tooth and overall pitch accuracies on both the worm and the gear at the same time. We also have special worms that we use to check the gears as we're cutting them, for more immediate feedback. We need to know that they're coming out of the machines right."

"That's another very important aspect," adds Tandrow. "You can't compete at the level just described without having some of the best equipment in the world: like the Reishauer RZ-362A [gear grinder], the Studer S40 grinders and the exceptional inspection equipment we have on the floor. You have to have the best tools to generate these results repeatedly."

"We also have new Mitsubishi GC15 and GC40 gear hobbers," adds Velasquez, "as well as high-quality carbide hobs, and a real passion for maintaining the equipment so that it stays accurate."

Another factor critical to the accuracy of the gears is the careful process of heat-shrinking the worm wheel to the spindle before cutting it. "That all but eliminates concentricity errors," says Velasquez, "and it simply could not be done if the gear was jobbed out. In a nutshell, we keep tabs on everything: We know where we're going and how to get there."

"That's the complementary part," says Tandrow. "We have an assembly staff that can inspect as they build. Since the parts are made in a controlled process, and the assembly staff knows all aspects of it, including the tolerance bands for testing the parts, we have complete control of the quality."

A key member of that assembly staff, Misha Brkic, uses a proprietary inspection setup to verify the accuracy of each final product. With his years of experience, though, he can tell almost as much with his hands during the assembly process. He knows the subtle feel of an exactly machined worm and wheel, and can stop the assembly process almost before it starts if he finds anything unusual.

"This level of skill and experience is the final key to the success of the process," says Tandrow. And while Brkic performs his duties on the opposite side of a long wall separating the machine shop and assembly areas at Haas, he's still only a hundred yards from Boris and Edik. There's a large doorway conveniently located midway between them.

"It's perfect," Tandrow says with a smile, "just like the gears." ■

For more information:

Haas Automation Inc.
2800 Sturgis Rd.
Oxnard, CA 93030
Phone: (805) 278-1800 or
(800) 331-6746
Fax: (805) 278-2255
Website: *www.haascnc.com*