GEAR TECHNOLOGY

MAY/JUNE 2002

The Journal of Gear Manufacturing

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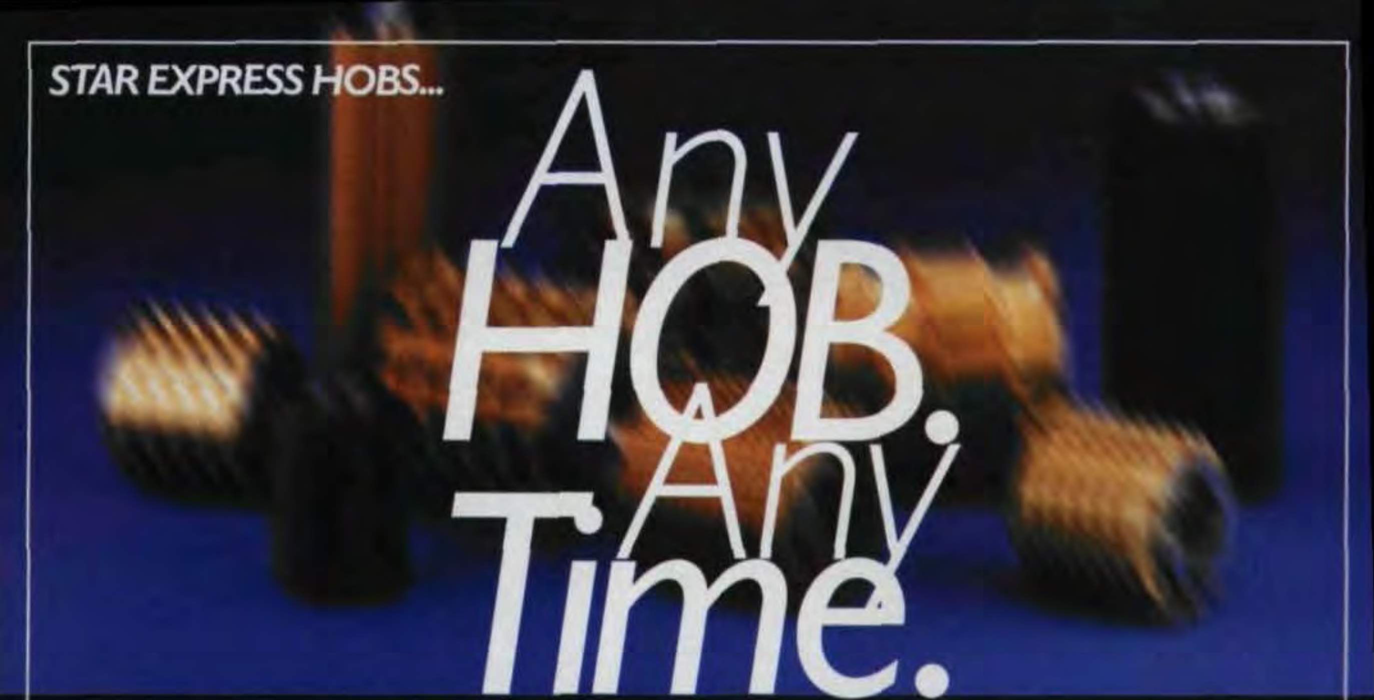
GEAR DESIGN FOCUS

- Optimizing Plastic Gear Geometry
- Developing Spur Gears with Pro/E
- Optimizing Worm Wheel Bronze

ALSO IN THIS ISSUE:

- Carbide Hobbing Case Study
- Free Listings in our CD-ROM Buyers Guide (See p. 40)

THE GEAR INDUSTRY'S INFORMATION SOURCE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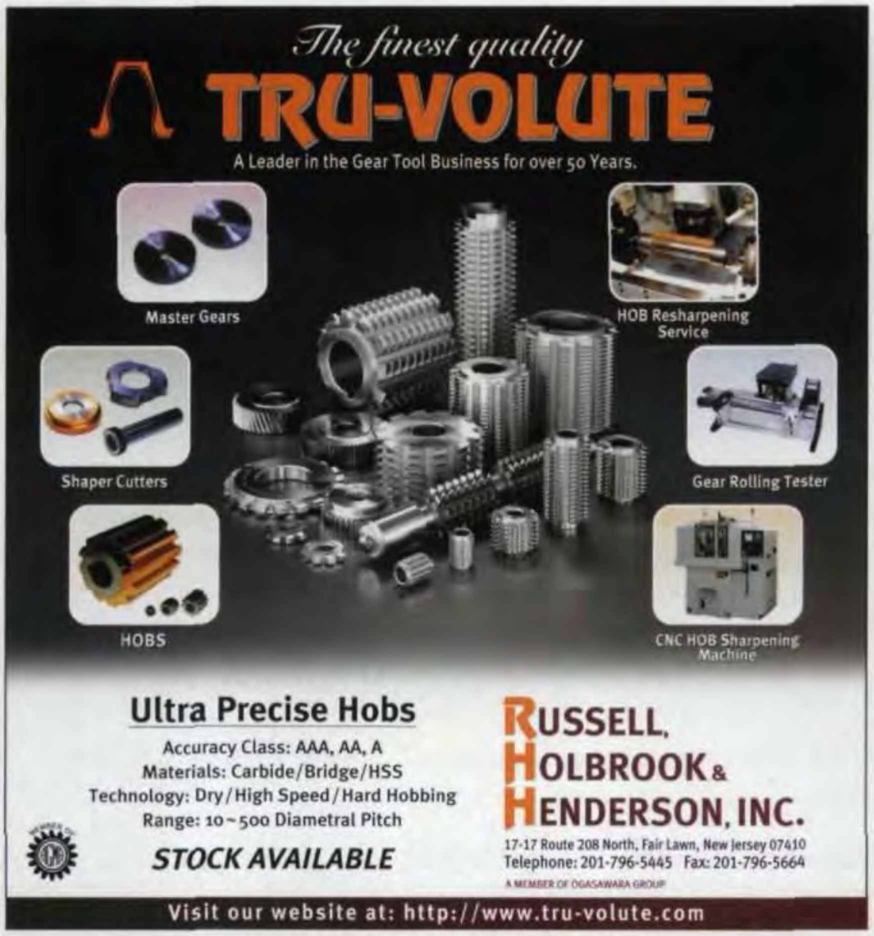

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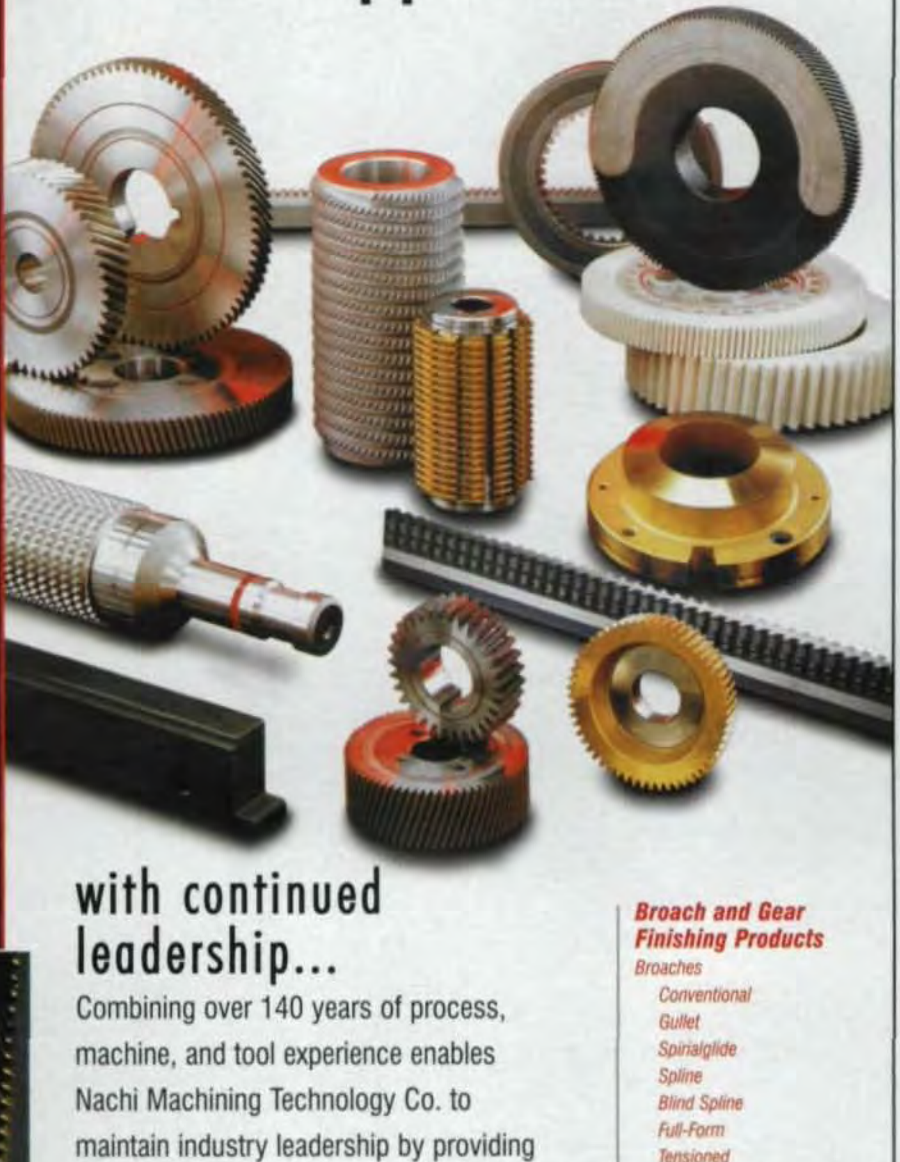
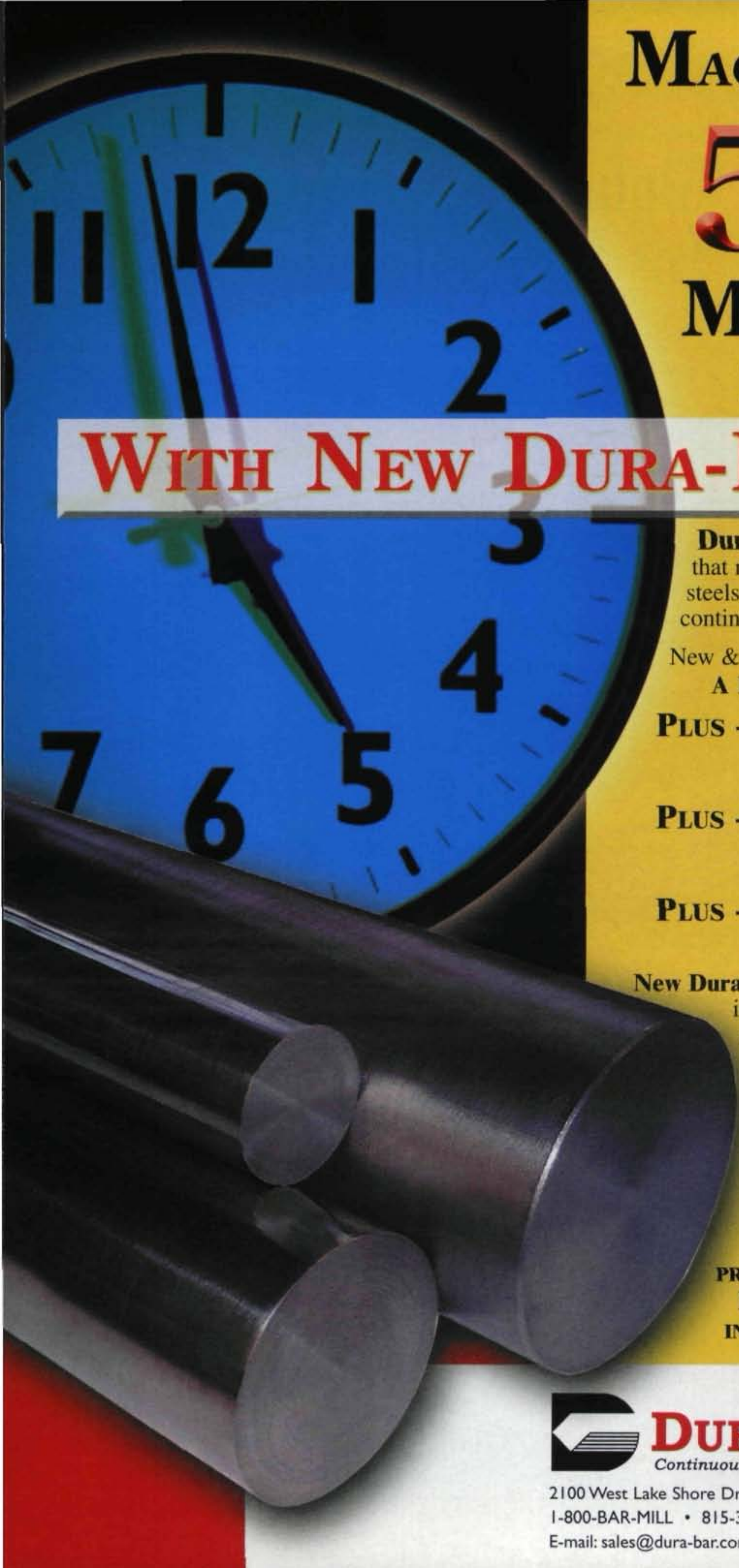




Industrial Evolution

The gear industry, like any other, is constantly changing. Companies vie for customers, resources, employees and time. They come, go and shuffle for position. Usually, the changes are small, affecting only a few companies. But sometimes, many changes happen at once, and when those changes are large, it can seem as though an earthquake has struck and transformed the landscape of the industry.

I feel as if such an earthquake has recently struck. Two months of tumult have left us with a different gear industry than we had the last time I wrote this column. In particular, two old friends have closed their doors. Also, we've seen realignment among some of the key suppliers.

We were saddened to hear that one of the gear industry's oldest suppliers—Fellows Corp.—was forced to close its doors in February. Located in North Springfield, VT, Fellows served the gear industry for more than 100 years. It was founded in 1896 by Edwin R. Fellows, the inventor of the American version of the gear shaping machine.

Fellows closed when its parent company, the Goldman Industrial Group, filed for Chapter 11 bankruptcy protection. Goldman's Bridgeport Machine Co. continues to operate, but the group's other subsidiaries, Bryant Grinder, Hill-Loma Inc., J&L Metrology and Jones & Lamson Machinery, closed along with Fellows. Those closed subsidiaries are now up for sale.

Hopefully, someone who wants to continue making gear machine tools will buy Fellows so that the name doesn't fade into obscurity.

Shortly after we heard the news about Fellows, we were shocked to learn that one of the gear industry's oldest and most respected manufacturers—The Cincinnati Gear Co.—had also closed its doors. Cincinnati Gear was founded in 1907.

Details about Cincinnati Gear's closing have been sketchy, and the company may yet emerge in some form from its difficulties. The company had been having troubles, like much of industrial America, and it laid off a number of workers over the last year. But those troubles turned to crisis with the bankruptcy *of Enron Corp., whose wind turbine division was a major customer of Cincinnati Gear.* On Feb. 28, Cincinnati Gear was forced to lay off most of its employees.

According to a letter we received from the company in late March, Cincinnati Gear is working with a management consulting firm to "explore all available options to maximize the value of its business and assets." What this means at this time is unclear, but what is clear is that if Cincinnati Gear emerges from these difficulties, it will be a much leaner company than it once was.

We've all watched the manufacturing economy struggle over the past two years. We've seen it contract, as Americans have imported more of the manufactured goods we used to make for ourselves. It's no surprise then that some gear industry companies are having problems and have been laying off employees over the past couple of years. Hopefully, the companies that survive these times—perhaps including Fellows and Cincinnati Gear—will be in much better position to take advantage of the market when it improves.

In the face of slower manufacturing activity, plants are closing and new, foreign suppliers from places like India, Pakistan, Poland, China, Taiwan and South Korea are taking their place. This process is not unique to the United States. England, the birthplace of the Industrial Revolution, is seeing an exodus of manufacturing at a frightening rate. This process is also occurring in Germany and Italy. With the possible exception of Spain, Western Europe's manufacturing is contracting, at different rates in different countries, but contracting nonetheless. Japan is also seeing manufacturing flee to lower-cost areas. We all still do the designing, engineering and marketing, but increasingly, we are becoming importers and assemblers, and less manufacturers.

In addition to and maybe as a result of the changes I've

already mentioned, the gear industry has also seen a lot of shifting among the major machine tool suppliers. For example, Bourn & Koch Machine Tool Co. has purchased a controlling interest in Roto-Technology. Nachi Machining Technology Co. has promoted Butch Wisner to president and CEO. M&M Precision Systems Corp. has named Douglas Beerck its vice president of sales and marketing. In the United Kingdom, Dathan Tool & Gauge has purchased David Brown's gear cutting tools division.

Perhaps the most significant news was the announcement that Star Cutter Co. has left the Sigma Pool alliance to consolidate its cutting tool sales operations with that of SU America Inc. With this new alliance, the SU group has quickly broadened its product offerings, joining Gleason Corp., Mitsubishi International Corp. and the remaining Sigma Pool brands of Liebherr, Lorenz, Klingelnberg and Oerlikon as full-service suppliers.

In most industries, the major suppliers compete for the bulk of the industry's business like hungry siblings around the dinner table. Like older brothers, the bigger suppliers take the lion's share, while the smaller suppliers have to settle for what's left over. In the gear industry, another hungry kid has arrived at the table at a time when there's less food to go around.

Adding another major supplier will result in fierce competition here in the United States, for machine tool and cutting tool sales, meaning those suppliers will find it harder to maintain profitability. The result is that you, the gear manufacturer, will have more choices among suppliers and technology—probably at lower prices.

All of these changes should make this year's IMTS very interesting. I will be watching the dynamics of this increased competition. As we emerge from the manufacturing recession, I can only guess that these competitors will be clamoring for your business.

Michael Goldstein

Michael Goldstein,
Publisher and Editor-in-Chief

Welcome to **Revolutions**, *the column that brings you the latest, most up-to-date and easy-to-read information about the people and technology of the gear industry.* **Revolutions** *welcomes your submissions. Please send them to* **Gear Technology**, *P.O. Box 1426, Elk Grove Village, IL 60009, fax (847) 437-6618 or e-mail* **people@geartechnology.com**. *If you'd like more information about any of the articles that appear, please use Rapid Reader Response on* **www.geartechnology.com**.

Cleaning Gears with Ice Chips—and Nothing Else

Residue from cleaning solution.

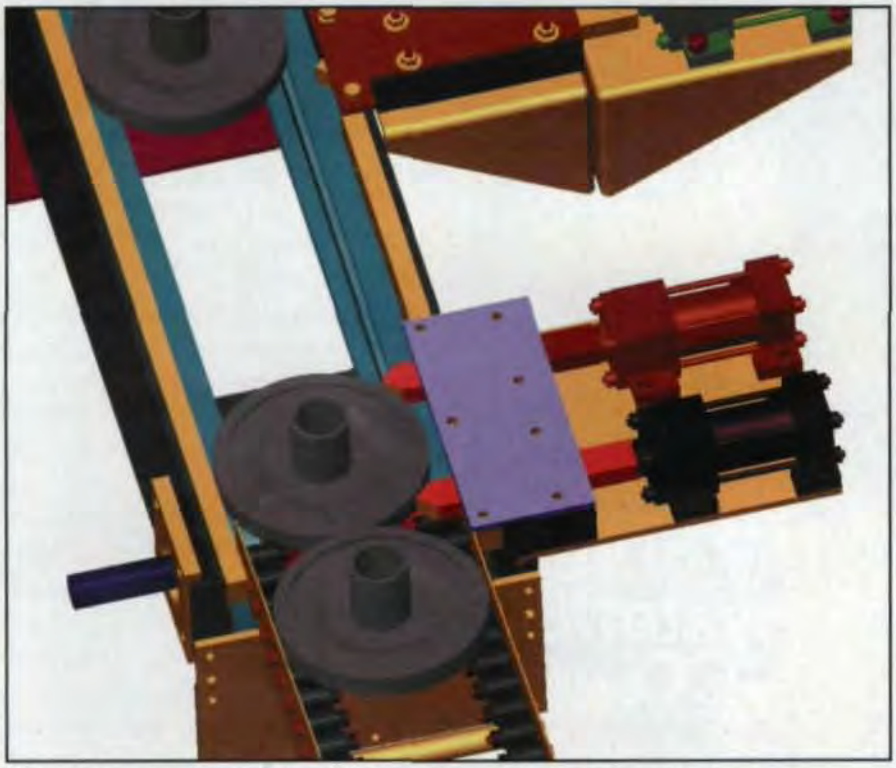
You wash your gears as best as you can, but it's there. Then, it gets on the master gears of your gear checker. After a while, enough residue collects on the master gears that it throws off your checker, which starts rejecting good gears.

Your solution? Stop the checker, pull out the master gears, clean them, put them back in the checker, and recheck your rejected gears.

Not much of a "solution"—especially when you have to do it every couple of hours. That's been the problem at several Ford Motor Co. plants for many years.

Ford has a possible solution, though—clean gears with ice chips.

The solution is a new system that cleans gears by spraying them with ice chips instead of using solvents or water-based cleaning solutions. The system was developed by Universal Ice Blast Inc. of Kirkland, WA. UIB manufactures ice-blast machines for commercial and industrial use.



Universal Ice Blast Inc. of Kirkland, WA, conceived and designed a machine that cleans gears by spraying them with ice chips. The machine doesn't use solvents or water-based cleaning solutions.

The system was installed for production cleaning at Ford's transmission gear plant in Sharonville, OH.

With this system, ice chips are sprayed through a nozzle at a pressure ranging from 65–75 pounds per square inch. Hitting a gear, the chips deform and create a scrubbing action, displacing the gear's contaminants. After impact, the chips melt into water and wipe away the gear's debris and contaminants.

The chips are created in a refrigerated drum. The drum uses ordinary tap water to form an ice layer. The layer then cracks into small chips, which are moved into a stream of compressed air and sprayed through the system's nozzle.

"You have an environmentally friendly process," says Tony Tonello, UIB's vice president of marketing and engineering sales. "You save the cost of supplying these soaps or solvents, as well as the cost of treating these solvents in the waste stream."

As for its effectiveness, the cleaning system was placed online at the Sharonville plant in March. The new system has been operating 16 hours a day, five days a week, cleaning the input transfer gear used in the transmission of the Ford Focus.

The input transfer gear is a helical gear with an internal spline that has undercut. The gear arrives at the cleaning system straight from grinding, so gear and spline have swarf on them. The system has a fixture that lifts and rotates each gear so ice chips can reach all the gear's surfaces.

The old system cleaned gears with water and a soaplike cleaner, and included a rust inhibitor. The gears' residue of cleaner and inhibitor would build up on the master gears in the end-of-line gear checker. The build-up would result in 30–35% false rejects.

Reinspecting rejected gears uncovered the good ones and raised the pass rate to 95%.

Universal Ice Blast built the machine, its first ice-blast gear-cleaning system, for Ford Motor Co. The Ford plant in Sharonville, OH, is using the machine to clean the input transfer gear used in the transmission of the Ford Focus.

With the new system, the first-time pass rate is about 98%. "That's what we were really hoping for; that's a biggie," says Mike Gourlay, a Ford manufacturing engineer.

Gourlay is responsible for the final drive and transfer gears used in the Ford Focus transmission.

With the new system though, Ford must add the rust inhibitor to the gears after they're checked, using a machine built by UIB.

Other companies also make systems that clean gears. Located in Cincinnati, OH, Ransohoff Inc. makes water-based gear-cleaning systems. But, Tonello says UIB's system at the Ford plant is the first application of ice blasting for cleaning gears.

A 17-year Ford employee, Gourlay has worked with gears for 10 years. Before the UIB system, he knew of no viable alternative to the plant's old gear-cleaning system.

The plant also checks the UIB system's effectiveness at achieving a set level of cleanliness. The plant takes samples of its cleaned gears and checks their cleanliness with a second washing. The samples, groups of five gears, are washed with an inert liquid. The liquid's resulting contaminant level is then measured. The level must be 2.5 milligrams or less for each group.

Early tests showed the system met that requirement.

Using a six-sigma approach, the plant's data has indicated the UIB system would successfully clean more than 99% of the gears.

Ford hasn't accepted the system yet, but plans to use it for three months, through the end of May. It will then compare performance data from the system's first three months and the old system's last three months to make a final evaluation and decide whether to accept the system.

"I think it represents a very big potential to solve a long-standing problem," Gourlay says. "But, I guess—being an engineer—I'm reluctant to say we're successful until I see the data.

"But, we're expecting to be successful."

The system consists of a gear-cleaning unit and an ice-making unit. The Ford system's gear-cleaning unit is 8 feet X 12 feet and is 12 feet tall. The ice making unit is 4 feet X 6 feet and is 5 feet tall.

The two units are connected by an industrial hose, so the ice-making unit can be as much as 100 feet from the gear-cleaning unit. Tonello says the hose lets a company place the ice-making unit in a dead space in its plant.

The Ford system uses about 20 gallons of water an hour. But, 50% of that water evaporates. The compressed air that accelerates the ice chips creates a wind that causes forced evaporation of the resulting droplets.

Tonello compares that forced evaporation to a man rubbing his wet hands together in front of a warm fan.

So, gear manufacturers have to deal with about 10 gallons of water an hour.

A fully automated ice-blast system—able to process a gear every 20 seconds—costs between $250,000 and $300,000. An air delivery system increases the system's cost by $15,000–$40,000, depending on the air pressure required.

Manual systems that handle fewer gears start at $50,000 apiece.

The costs assume air and water will be supplied by the purchasing companies.

Gourlay hopes the system will reduce the checking of master gears to just once a shift, at the start of a shift, just to make sure they're OK—that the system gets rid of the problem of good gears being falsely rejected.

"That's what I thought was the big carrot," Gourlay says. "This really does have the potential to deal with a problem that we've had for a long time."

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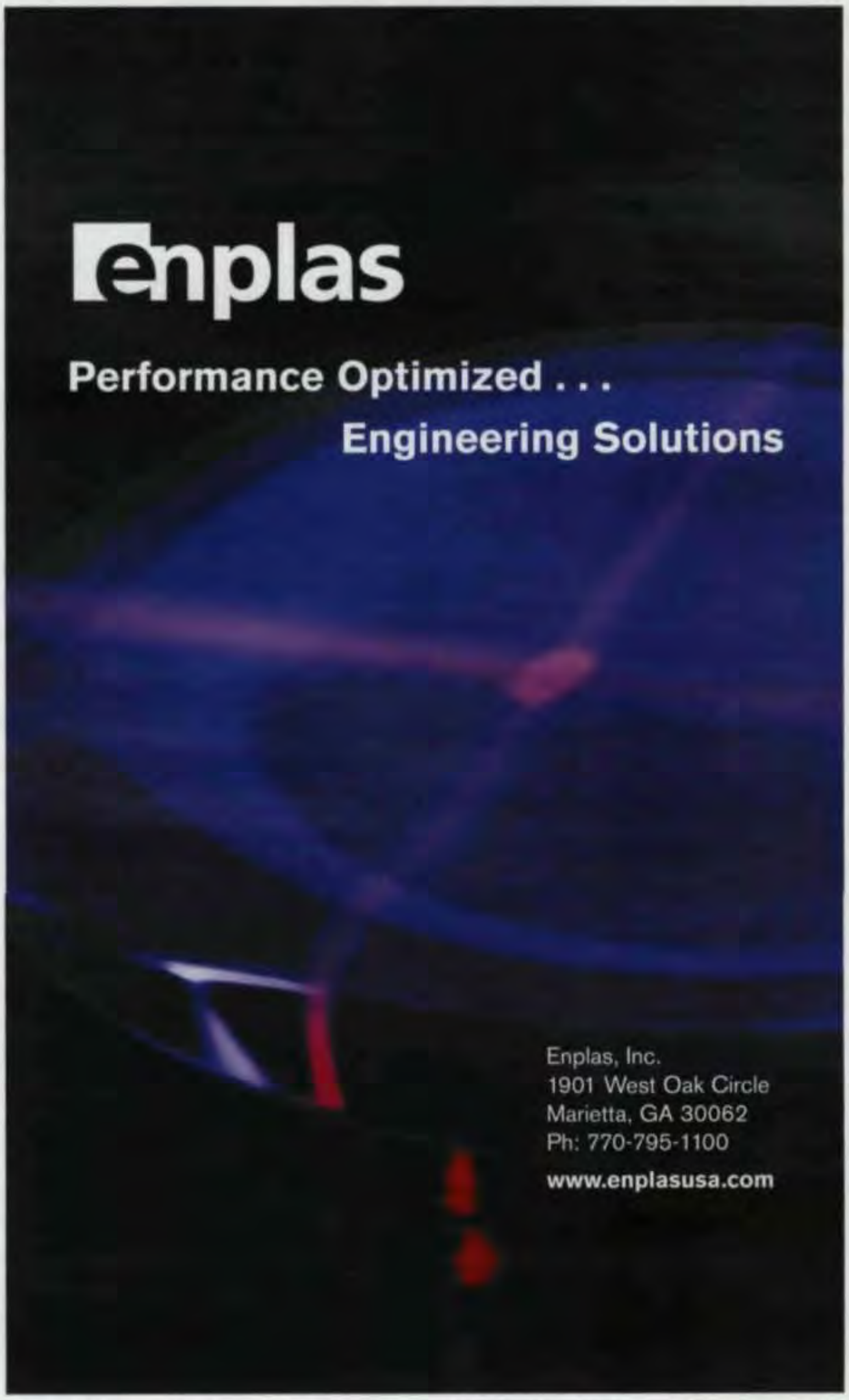

Carbide Hobbing Case Study

Yefim Kotlyar

This article was first published at the AGMA 2001 fall technical meeting.

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Introduction

Bodine Electric Co. of Chicago, IL, has a 97-year history of fine- and medium-pitch gear manufacturing. Like anywhere else, traditions, old systems, and structures can be beneficial, but they can also become paradigms and obstacles to further improvements. We were producing a high quality product, but our goal was to become more cost effective. Carbide hobbing is seen as a technological innovation capable of enabling a dramatic, rather than an incremental, enhancement to productivity and cost savings.

Nowadays, no one denies that carbide hobbing is feasible. Many questions remain, however, regarding the best applications, carbide material, hob sharpening, coating and recoating, hob handling, hob consistency, optimum hob wear, best cutting conditions, concerns for the initial cutting tool investment and production cost. In short, "the devil was in the details." The industry had few, and sometimes conflicting, recommendations on these details. This is why many companies, manufacturing in small to medium lot sizes, have not rushed to implement carbide hobbing. Also, some companies tried and then abandoned this technology altogether.

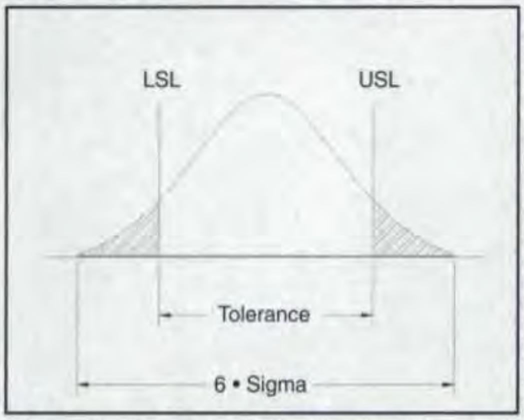

Figure 1—Process variation for the "flat gear" family was out of control.

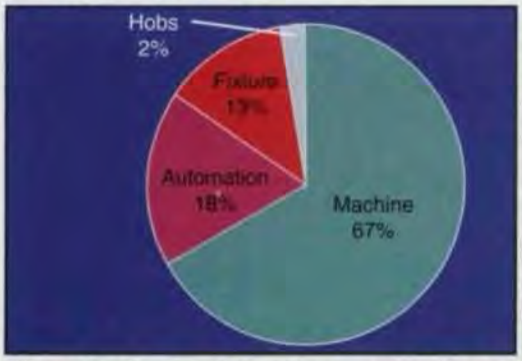

Figure 2—Cost breakdown by percentage for new carbide hobbing cell.

This article is a case study featuring one manufacturing cell solely implemented with carbide hobbing technology. The annual output is 250,000–300,000 gears, with an average just-in-time lot size of about 200–300 gears. Approximately 150 different sizes and pitches are produced, with an average of four setup changes over two shifts. Most of the gears are finish hobbed to AGMA 9 quality level. The pitches range from 12–64 DP.

The successful performance of carbide hobbing is predicated on various contributing factors, such as machine, fixture, blanks, hob maintenance, and process management systems. These factors will also be discussed.

Application and Historical Perspective

Bodine Electric produces a large variety of parts with gearing elements—spur and helical gears and shafts, solid- and bore-type pinions, worms, and worm gears. For the introduction of carbide hobbing, we decided to select the "flat" gear family because of its large volume.

Machines. Initially, we had only outdated hobbing machines in the flat gear cell. The average machine age was 20 years. The use of longer- and higher-performance hobs was limited by the machines' rpm and shifting capability. Only two (out of five) hobbing machines had an automatic shifting feature. There was not precise control on hob positioning relative to the workpiece or the hob shifting distance. These machines were in constant need of maintenance.

Fixturing and Automation. Only two machines in the cell had automatic loaders. Fixturing and automation documentation was not readily available. Some of the fixture items were reverse engineered and not always compatible with each other. Our company relied mostly on the experience of setup people. This led to a wide variation in setups, fixture, and cutting conditions.

Cutting Tools. A long-standing tradition in fine-pitch gear manufacturing was the use of so-called "square" hobs made out of high-speed steel (HSS). Use of carbide and longer hobs was limited by each machine's rpm capability and shifting length, respectively.

Cutting Conditions. Our practice was to use very conservative cutting conditions that were outdated. Different machines had different limitations with respect to rigidity and rpm capability. The performance of each machine was not monitored. The cutting conditions and cycle times could vary depending on the setup person, machine, inspection results, and cutting tool used at the time.

Blanks. All blanks were outsourced. The suppliers would grind one face of the gear blanks, enabling us to stack three to five parts per load during the hobbing process. Despite this effort, the bore's quality and face parallelism were inconsistent.

Outsourcing. In addition to five machines making flat gears in-house, we were outsourcing hobbing and skiving at an annual cost of $281,000. Adding to that the annual blanking outsourcing of $563,000, our total flat gear outsourcing cost came to $844,000. Other concerns with outsourcing were quality and on-time delivery.

Quality. The flat gear process variation was out of control, as shown on the graph in Figure 1. Although we had extremely knowledgeable people who were able to produce quality parts despite using old technology, many setups would turn into development projects, which took its toll on our productivity and profitability.

The high quality of the product was maintained at a cost. Extra, non-value-added steps of 100% inspecting and sorting were necessary. In short, the cost of flat gear manufacturing was high. We wanted to improve the process and replace "product control" with "process control."

Productivity. Cycle times were very long. Frequently, to achieve the desired quality, setup personnel would use more conservative cutting conditions, thus further increasing cycle times and reducing productivity. On average, there was less than one setup per machine per day. The inexpensive, conventional, off-the-shelf "square" hobs had to be re-sharpened quite frequently, thus disrupting production flow. Lean manufacturing stresses the importance of just-in-time manufacturing and continuous reduction of work-in-progress. This leads to smaller lot sizes and greater setup frequency per day.

In summary, we had an abundance of opportunities:

Figure 3—New CNC hobbing machine.

Quality Improvements

- Process capability improvements.
- Further tightening of the tolerances to produce a higher quality product.

Productivity Improvements

- Reduce cycle times and increase production with the same number of people.
- Reduce setup time.
- Reduce process debugging time.

Cost Improvements

- Cost reductions as a result of productivity improvements.
- Lower cutting tool cost per gear or keep it the same as HSS.
- Reduction in rework cost.

Additional Capacity

- Skiving Capabilities.
- Reduction in outsourcing.

Considerations for New Technology

We could have benefited by improving the process in small incremental changes. Some examples are reworking the machines, buying better cutting tools, improving the fixtures, buying better blanks, and even stressing greater control of our processes. These would have all brought some semblance of success.

Nonetheless, we felt that we needed drastic, rather than incremental, improvements to bring the process under control and achieve cost reduction. This is why we decided to blow up everything, investigate new carbide hobbing technology, and bring a new spirit into the factory.

At the same time, we wanted to bring in technology that would work from the onset. We wanted to be conservative in our estimates, making sure that there would not be excessive process

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is the gear technology and processing manager at Bodine Electric Co., located in Chicago, IL. For more than 20 years, he worked in different capacities on the development and implementation of various gear manufacturing and inspection technologies. He is also an author of many articles on gear-related subjects.

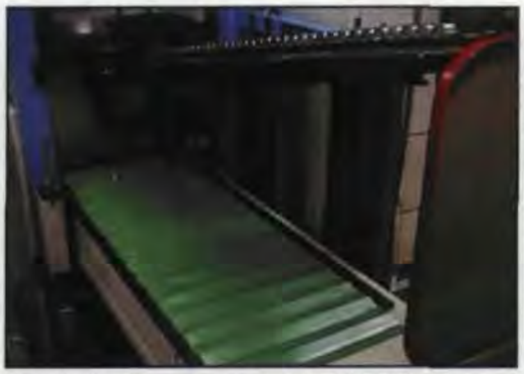

Figure 4—New system included flexible automation with gantry loader.

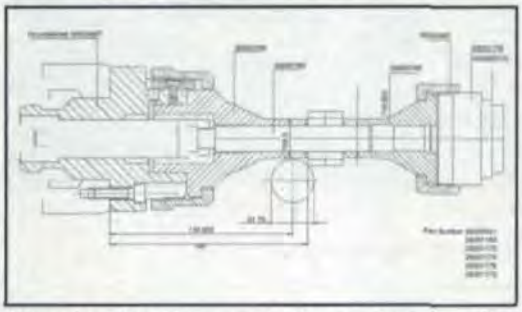

Figure 5—Precision quick-change, face-clamping fixture for clamping more than 150 types of parts.

debugging. So we decided that a test would be the ideal first step toward a successful implementation of new carbide hobbing technology.

Hobbing Test

Test Objectives

- To learn more about potential challenges.
- To understand the pros and cons of carbide hobbing as applicable to our pitch and size ranges.
- To have the process debugged prior to purchasing the machine.
- To specify the machine acceptance criteria based on challenges experienced during testing.
- To compare machine suppliers.
- To start developing carbide hobbing support systems.

We anticipated a need for a better engineering support system as well as a simpler, more disciplined process monitoring system that would give us reliable feedback. We knew that after the major investment, the flat gear cell would be scrutinized.

Test Findings & Potential Challenges.

- This is an emerging technology, although it started 30 years ago.
- Many tried but abandoned carbide hobbing.
- Greater engineering support will be required.
- There was no industry consensus on recommendations.
- The mistakes are much more expensive.
- The tool cost per gear was an unknown factor.
- The initial cutting tool investment is much greater.
- We found three vendors all capable of achieving our tighter quality requirements.
- The selection was based on business reasons rather than technical reasons.

Dry or Wet—That Was the Question. We tested both wet and dry hobbing. Eventually, we selected the wet process because we felt it was a safer approach to the introduction of new technology. At that time, our perception was that dry hobbing required more engineering involvement and R&D. Each pitch and size had to be tested and fined-tuned for optimum hob geometry and cutting conditions. The machine was to be placed in a gear-manufacturing cell that was producing more than 150 different sizes and pitches. So, the testing and development of every part could become quite overwhelming. Also, we experienced less tool wear with wet carbide hobbing. Nevertheless, we acquired a dry hobbing option. This was just in case the process is further developed and better information about dry hobbing becomes readily available.

Best Carbide Hobbing Applications? It seems that the fine- and medium-pitch finish hobbed gears are the best candidates for the carbide hobbing technology. The finish hobbing feed rate is restrained by the feed scallop limitations; thus, productivity improvements cannot be achieved by increasing the feed rate. Another option for productivity improvement—multistart hobbing—cannot be employed for precision hobbing either. The only viable option for productivity improvement was increasing the hob speed.

Support Systems Needed. We came to the conclusion that in-depth engineering support systems would be needed for successful carbide hobbing. Mistakes with carbide hobs cost much more than they do with traditional HSS hobs.

Those systems would include:

- Database with simple means of extracting setup data for every part.
- Ease of database maintenance.
- A detailed hob monitoring system, which is unprecedented in a production environment.
- Detailed production and value-added monitoring.

New Hobbing Technology

The Initial Investment. After conducting tests and selecting a vendor, we purchased the equipment with cost distribution as shown in the graph in Figure 2. The total package included machine, automation, quick-change fixture, and carbide cutting tools. In addition, we purchased a new turning machine and developed corresponding support systems.

New CNC Hobbing Machine Highlights (Fig. 3).

- 8 CNC axes, including gantry.
- Higher cutting speed available.

Figure 6—K-grade, TiN-coated carbide hob (left) and P-grade, TiAlN-coated carbide hob.

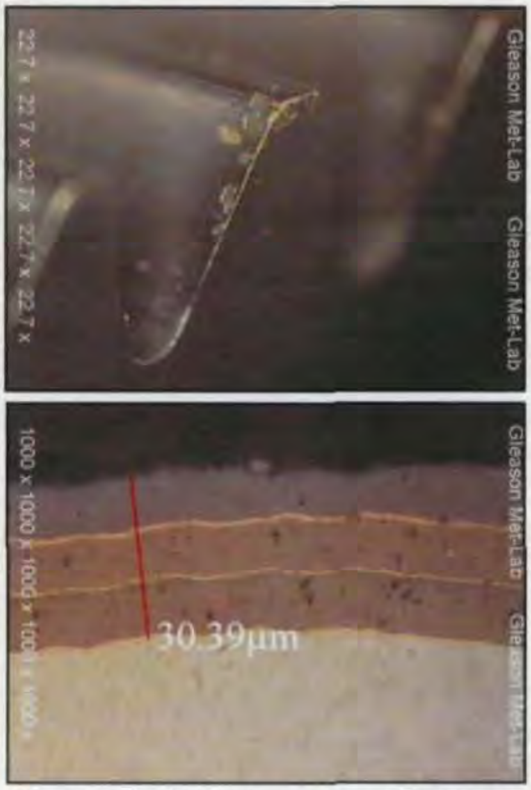

Figure 7—Coating fractures can contribute to poor hob performance. Multiple coating layers chipped on the outer surface (top), while the lower coating layers have remained intact (bottom).

- Longer hob shifting capability.
- Capable of wet and dry hobbing.
- Hydraulic hob arbor clamping.
- Skiving capability.
- Flexible Automation with Gantry Loader (Fig. 4).
- Six seconds load/unload.
- Capable of handling both bore- and shaft-type parts.
- Large unload storage capacity.
- CNC controlled loader positions.

The Fixturing. Because the fixture quality is critical to process capability, we acquired a precision, quick-change, face-clamping fixture (Fig. 5). The fixture had a modular design for more than 150 parts. The design was also based on the consideration of clamping the parts as close as possible to the cutting action. At most, there are three fixture items that need to be replaced when changing over from one part to another: backing, clamping and arbor.

The number of parts per load was reduced to two. CNC hobbing diminishes the effects of stacking gears per load because: a) a higher feed rate can be used during the hob approach travel, and b) the load/unload time is minimal. Incidentally, a smaller number of parts per load improved the gear quality. All fixture drawings were computerized and became a part of setup documentation.

The Blanks. A turning process was developed on a newly purchased CNC lathe. It provided 0.0002–0.0005" face parallelism and bore-to-face perpendicularity. This kind of turning quality eliminated the need to grind gear faces. In fact, the blank quality coming out of our CNC lathe was more consistent than our outside-purchased blanks having the one face ground.

The new turning machine also made it possible to tighten the tolerances of the bore size. The lathe was strategically placed next to the CNC hobbing machine to enable one-piece flow.

Carbide Cutting Tools. We started with K-grade hobs and TiN coating (Fig. 6). However, in addition, we purchased a few P-grade hobs with TiAlN coating (Fig. 6). Carbide hobs were run at 600 surface feet per minute (SFM) of circumferential speed. The feed rate was just as conservative as in the case of HSS hobs. The conservative feed rates were necessary because of feed scallop depth limitations. The first peek at the carbide hob life provided impressive results. The first run resulted in 765 parts without a hob change. Making 3.4 times as many gears meant that the tool cost per gear would be approximately the same as in the case of HSS. We were glad that we were able to reduce the cycle time threefold while enjoying approximately the same tool cost per gear. (Note that carbide hobs were three to five times more expensive when compared to traditional "square" HSS fine-pitch hobs.) However, we continued to use the same hob. Before we sent it for sharpening, we achieved the hob life improvement of elevenfold (2,639 gears) as compared with HSS "square" hobs.

After the first hob sharpening, we realized there was work to be done in mastering this technology. Lesson #1 learned: Without recoating the hobs, they failed miserably. We also learned that, with respect to the cutting tools, our limited initial test provided few comforting answers. Recommendations from hob suppliers and machine builders continued to be inconsistent and, at times, even contradictory. We still had a lot of questions. Should we use P-grade or K-grade? What was the best coating for our application? What was the

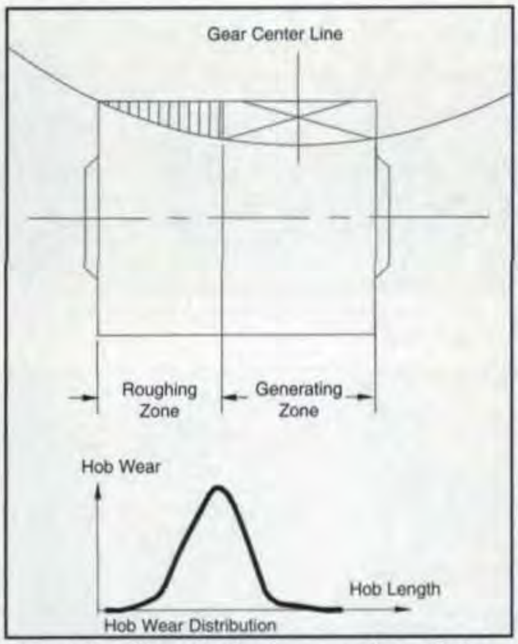

Figure 8a—Wear distribution on a shorter hob.

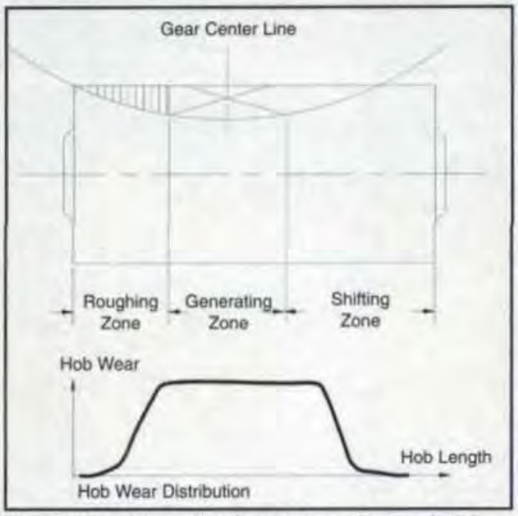

Figure 8b—Wear distribution on a longer hob.

optimum wear? What were the sharpening nuances (i.e. edge preparation)? When was the right time to strip the coating, and was it possible? What was the hob life and tool cost per gear? Was there any predictability in carbide hobbing?

Figure 7 is an example of one of the many challenges that we experienced. Coating fractures can contribute to poor hob performance. Coating on the illustration is breaking away from the tool. Close inspection within these areas reveals multiple coating layers that chipped on the outer surface, while the lower coating layers have remained intact.

Layer Buildup. Each coating is approximately 0.0004" thick. The top layer is a single layer of TiAlN. Underneath that are two layers of Futura coating, each composed of 27–35 alternating sublayers of titanium nitride (TiN) and titanium aluminum nitride (TiAlN). The yellow lines between layers are TiN. The light-colored substrate is seen near the bottom of the illustration.

We have yet to find overall consistency in hob performance. Although the greatest performance factor is probably how people use the hobs, other contributing factors are sharpening, coating quality, and the ability of the coating layers to stick to the previous layer.

Every single carbide hob has a history worksheet. Currently, we have more than 80 carbide hobs that service our flat gear cell. Every time the hob is used, the setup people record the date, the gear number, and the number of gears hobbed. The rest of the worksheet is calculated automatically. One of the important characteristics is material removal per cutting edge of the hob.

Hob Length Significance. In addition to changing the hob material to carbide, we introduced longer hobs. This further reduced the cutting tool cost per gear and reduced downtime caused by hob changes because longer hobs make more gears per sharpening. Conventional thinking implies that the improvement would be proportional to the hob length increase.

However, in reality, the improvement is proportional to the shifting increase. Figures 8a and 8b show the load and wear distribution on short and longer hobs. Short hobs may have little or no shifting length available. Frequently, a small hob length increase can result in manyfold hob performance improvements.

Cutting Tools Cost Reduction. A conservative estimate of per-gear tooling cost reduction is close to threefold (Fig. 9).

Support Systems

To understand and maintain the carbide hobbing process, our company introduced a system for monitoring process performance. A setup database was created to include all process documentation, such as fixture, cutting tools, gear parameters, cutting conditions, cycle time and other necessary setup information. For every setup, the database query creates a single sheet of paper with the latest setup information.

The original tooling has been expanded to process more than 180 different part numbers. Machine part programs are backed up periodically. Fixture and automation change parts are stored in a clearly marked storage area adjacent to the machine. As was mentioned before, every hob has a worksheet with a history of usage, sharpening, and recoating. Figures 10 and 11 demonstrate productivity over a three-month period.

Improvements Summary

Productivity Improvements. Major productivity improvements were realized due to carbide hobs having speed capabilities three times higher than HSS hobs. Other factors contributing to the productivity improvements were setup time reduction, CNC-controlled hob travels, more consistent setups and cycle times, a drastic reduction in process debugging time for lead/involute/runout problems, and precise calculations of hobbing cycles and goal setting.

Despite all of the challenges with carbide hobs, the productivity improvement made it possible for us to replace four machines. In addition, we increased production by in-sourcing all gear hobbing and skiving, with a $280,000 annual volume.

Quality Improvement. Prorated annual scrap savings was $47,000 as compared with three mechanical pinion cells using old machines and HSS cutting tools and producing approximately the same amount of parts (Fig. 12).

Other cost improvements resulted from process capability improvements. Figure 13 shows that the six-sigma process variation became smaller than the tolerance due to improving upon all of the process variables: new machines that were statistically evaluated for the process capability during the runoff, AA quality cutting tools, precision fixtures, better quality blanks, ISO-compliant quality systems, and having setup and cutting parameter consistency. The improvements in the process capability made it possible to reduce the inspection and rework expenses.

In closing, the investment in new carbide hobbing technology made us look at our operation under a microscope and improve upon other contributing factors that lead to successful gear manufacturing. These are fixtures, machines, cutting tools, blanks, and quality systems. The results are better quality gears at a lower cost. ○

Acknowledgment
The author would like to express his gratitude to Mark Ryba and Paul Ruff for their editing help.

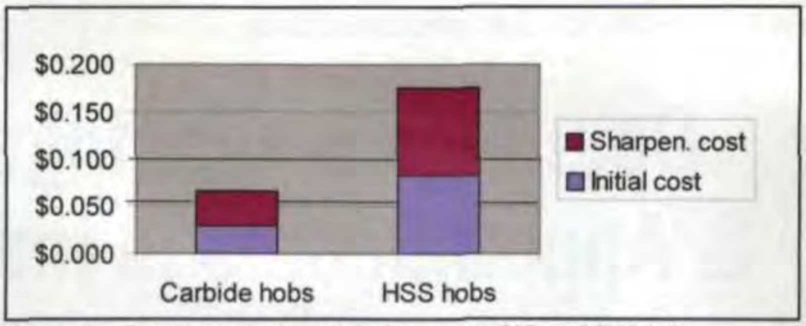

Figure 9—Cost-per-gear comparison between carbide and HSS hobs.

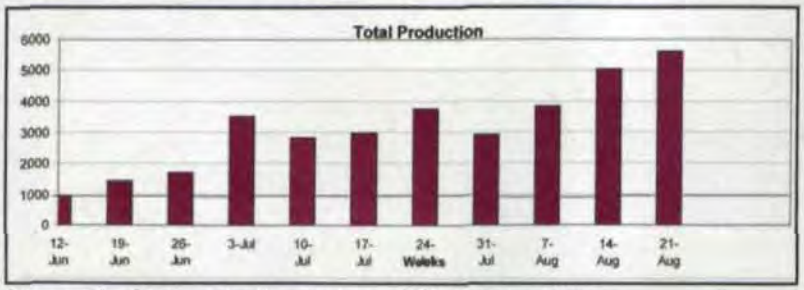

Figure 10—Total production during carbide hobbing trial.

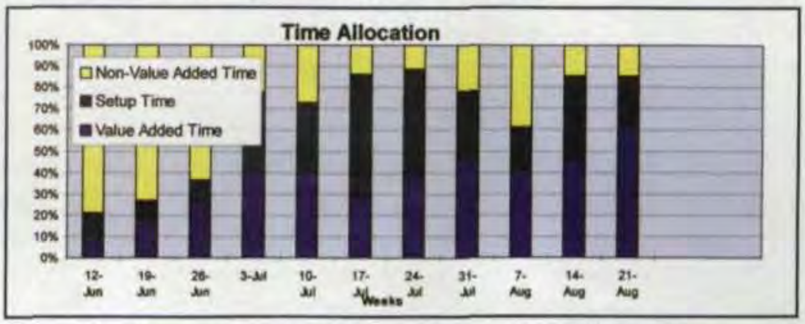

Figure 11—Time allocation breakdown during carbide hobbing trial.

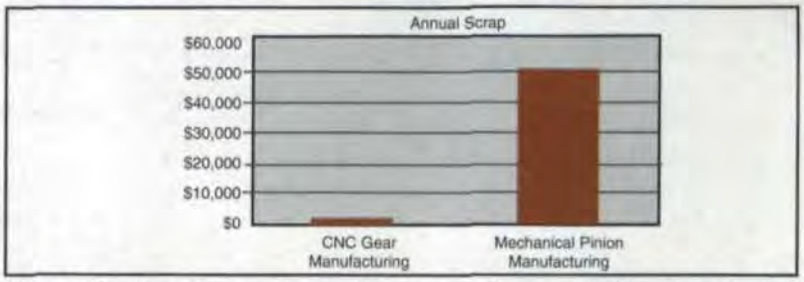

Figure 12—Comparison of annual scrap rates between CNC and mechanical manufacturing.

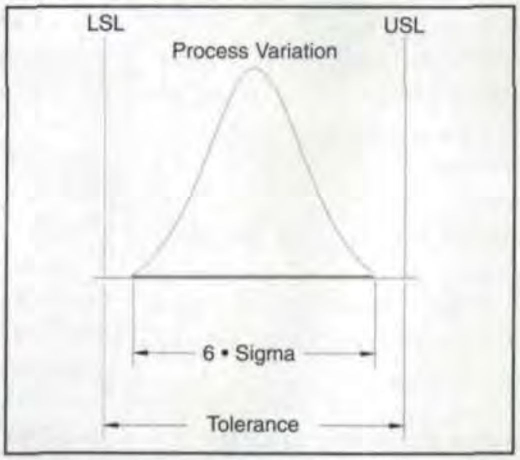

Figure 13—Improving process variables resulted in process variation becoming smaller than the tolerance.

Openings & Closings, Promotions & Appointments in the Gear Industry

SU America and Star Cutter Consolidate Sales

SU America Inc., a unit of Samputensili S.p.A. of Bologna, Italy, and Star Cutter Co. of Farmington Hills, MI, announced a mutual agreement to consolidate sales activity of each company's gear cutting tool product lines. The new entity will be owned equally and managed by executives from both companies.

According to SU America's press release, the merger creates a company offering a comprehensive gear tool product line that includes hobs, shaper cutters, shaving cutters, milling cutters, form relief milling cutters, bevel gear cutting tools, plated grinding wheels, and deburr/chamfering tools, as well as coating and tool maintenance centers located throughout North America for recoating and resharpening tools.

Cincinnati Gear Closes After 95 Years

Mariemont, OH-based Cincinnati Gear Co. closed its doors Feb. 28.

The manufacturer of gears and gearboxes was founded in 1907. Due to financial difficulties, the company has laid off a significant portion of its workforce. Further details about the company's future have not been released.

Cincinnati Gear owns two factories in the Cincinnati area. The subsidiary, BHS-Cincinnati of Sonthofen, Germany, is a financially independent entity and will not be affected by the closing, according to a letter from the BHS-Cincinnati supervisory board, which was posted on the BHS-Cincinnati website.

Fellows Corp. Closes, Parent Company Files for Bankruptcy

Fellows Corp. ceased operations Feb. 13, according to an article in *The Connecticut Post.*

The company, along with J&L Metrology Co. Inc., Bryant Grinder Corp., Hill-Loma Inc. and Jones & Lamson Vermont Group, is up for sale. All five were subsidiaries of the Goldman Industrial Group, which filed for Chapter 11 in the U.S. Bankruptcy Court in Delaware.

A single subsidiary, Bridgeport Machine, plans to continue manufacturing machine tools.

Founded in 1896, Fellows Corp. produced gear shaping machines and cutting tools from its North Springfield, VT, headquarters.

Nachi Promotes Vice President to CEO

Senior management announced the promotion of Francis J. (Butch) Wisner to president and CEO of Nachi Machining Technology Co. of Macomb, MI.

Wisner joined the company in 1994 and most recently served as vice president of product development. Prior to that, he worked as a senior-level engineer at General Motors Corp. for 23 years.

Nachi Machining is the result of a 1991 merger between National Broach and Machine Co. and Nachi-Fujikoshi Corp. of Tokyo, Japan.

Dathan Tool & Gauge Buys David Brown Gear Tools

Dathan Tool & Gauge Co. Ltd., a U.K.-based manufacturer of precision gear cutting tools, has acquired the business and assets of David Brown Gear Tools, which also is in the United Kingdom and designs and manufactures gear cutting tools.

According to Dathan's press release, the acquisition will enable the company to increase its manufacturing capabilities to include more comprehensive design and development work.

Founded in 1924, Dathan added gear cutting tools to its range of products in the late 1930s and currently manufactures and supplies precision gear tools.

Gleason Opens Gear Manufacturing Support Center in Mexico

Gleason Corp. announced the opening of a technical support center in Queretaro, Mexico, to bring its gear manufacturing services to that country.

According to Gleason's press release, the new facility will ensure that Gleason customers receive increased local access to training resources, process and application engineering support, tool inventory management, tool sharpening services and spare parts inventory and on-site service personnel.

Mitutoyo Names New Vice President

Mitutoyo America Corp. of Aurora, IL, appointed Dennis Traynor to vice president, product support services.

His responsibilities include guiding the company's calibration labs and the Mitutoyo Institute of Metrology, as well as field service, repair and contact inspection operations. Additionally, he will be accountable for the ongoing accreditation initiative throughout the company for compliance with the ISO/IEC 17025 standard.

Prior to his promotion, Traynor served for 14 years in sales, regional and product management roles.

Mitutoyo provides measuring instruments, including a roundness measuring system for gears and other cylindrical forms.

M&M Precision Names Vice President

Douglas Beerck was appointed vice president of sales and marketing at M&M Precision Systems Corp. of Dayton, OH.

According to the company's press release, he had worked in the company's sales and marketing departments from 1984 to 1999. He then joined AK Steel Corp. of Middletown, OH, as a senior analyst.

M&M serves the automotive, truck, aerospace, off-road vehicle and agricultural equipment industries, as well as contract gear manufacturers, machine tool, power tool, medical equipment, semiconductor, electronics and special machine builders. M&M Precision Systems Corp. is a subsidiary of Danaher Corp.

Ticona Appoints Global Marketing & Sales Director

Ticona announced the appointment of Michael Maguire as global marketing and sales director for the company's Topas cyclic olefin copolymer business line.

Maguire will work from the Summit, NJ, headquarters.

He was recently vice president of sales and marketing for Progressive Plastics Inc. of Cleveland, OH. He holds an MBA in marketing from Fairleigh Dickenson University and a bachelor's degree in chemistry from Rutgers University.

Among Maguire's new responsibilities is the implementation of the current Topas COC strategy and development of marketing to different demographics. He will rank as the most senior member of the Topas business line in the United States.

Philadelphia Gear Corp. Opens Alabama Facility

A new facility in Birmingham, AL, will open to offer service and repair capabilities for Philadelphia Gear customers throughout the southeastern United States.

According to the company's press release, the Birmingham employees are specialists in power transmission life cycle support, including the repair and rebuilding of all major gearing brands. The facility includes 14,000 square feet of workspace, as well as 25-ton crane capacity.

John Brace, general manager of Philadelphia Gear's Houston facility, will run the Birmingham branch as well.

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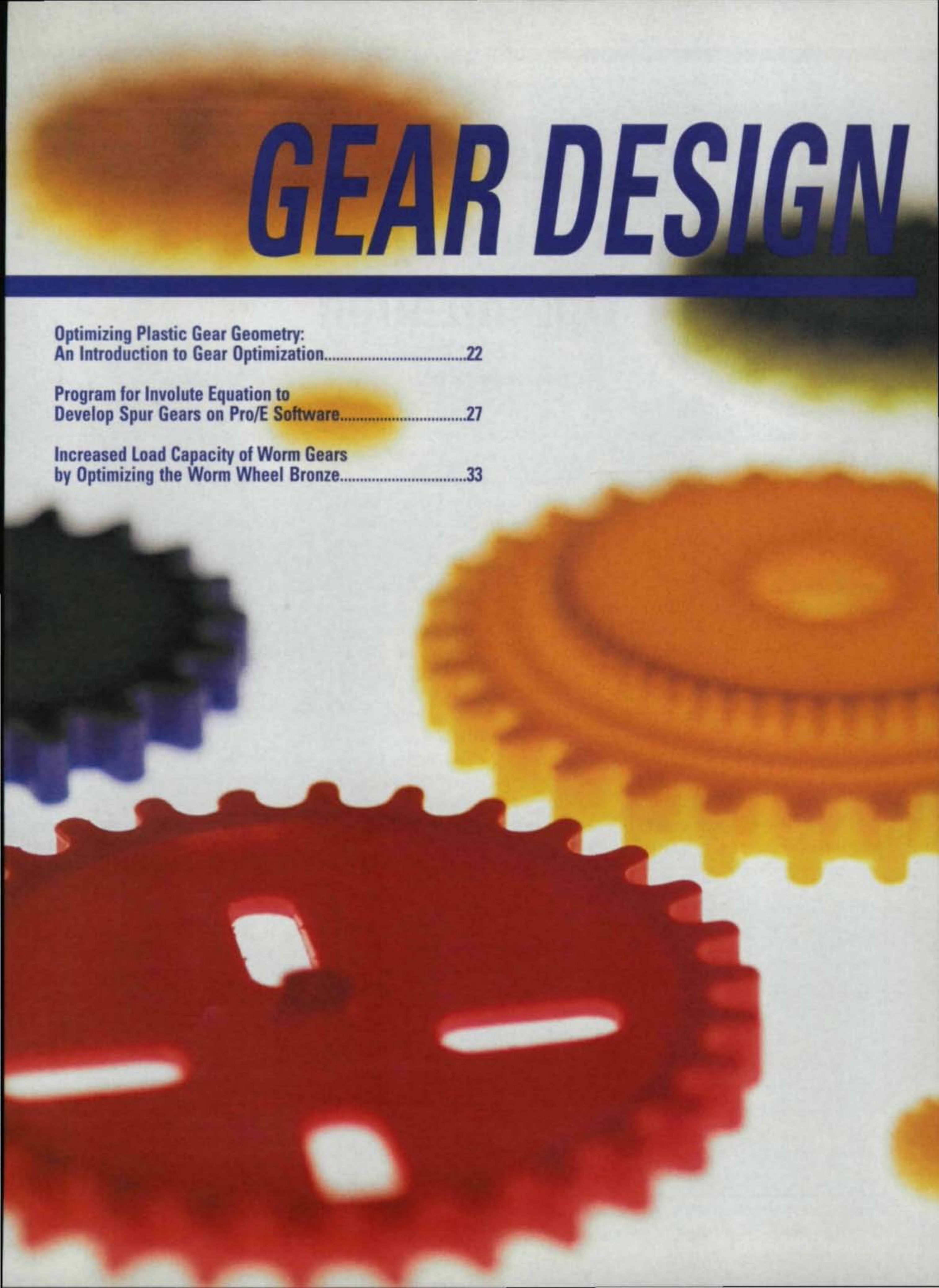

Optimizing Plastic Gear Geometry: An Introduction to Gear Optimization

Richard R. Kuhr

There are numerous engineering evaluations required to design gear sets for optimum performance with regard to torque capacity, noise, size and cost. How much cost savings and added gear performance is available through optimization? Cost savings of 10% to 30% and 100% added capacity are not unusual. The contrast is more pronounced if the original design was prone to failure and not fit for function.

Development of the gear geometry is a critical part of the total design process. This article will summarize the design issues relating to optimizing gear geometry. All interrelated parameters that comprise the gear description are candidates for optimization. Those parameters include pitch, pressure angle, helix angle, addendum modification, root clearance, face width, root and tip radii, tooth thickness, center distance and profile modifications. One design parameter, total working depth, will be evaluated as an example of the potential benefit of gear optimization.

Gear Optimization Definition

An optimized gear design is the best possible gear arrangement, gear design and material selection that facilitates the lowest total cost for the performance and reliability required.

Optimization Cost Effects

The design benefits and cost savings of optimizing with practical solutions are substantial. Conversely, the costs associated with a non-optimized or poorly designed gear set are a real liability. The incremental cost of optimizing is minimal compared to the ongoing costs associated with an overdesigned gear arrangement using more costly material or larger gears and housing than required. The warranty costs soar as do the costs of lost user confidence if the gears are poorly designed or underdesigned.

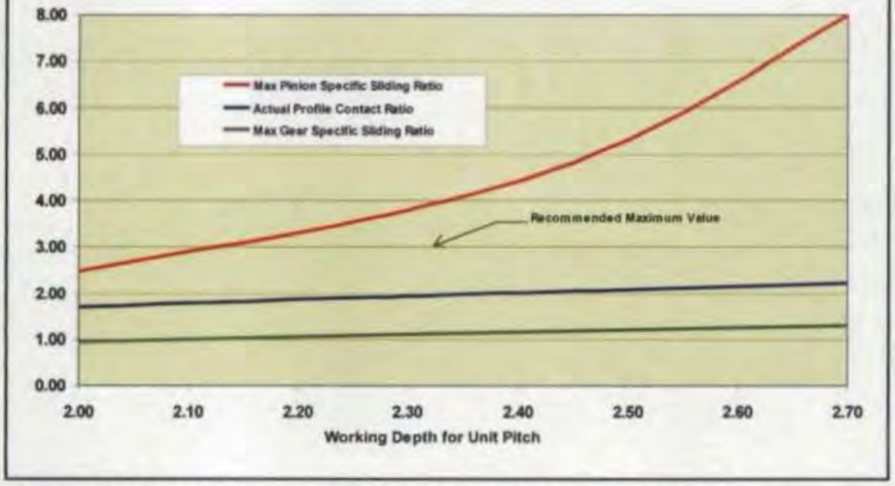

Figure 1—Tooth depth influence on sliding and contact ratios (equal addendums).

The cost of optimization is only a small fraction of product introduction cost. Optimization does, however, require attention to the details of the gear geometry, gear accuracy, material selection, duty cycle and a detailed analysis of the mounting conditions of the application. Added cost savings are derived from using the most cost-effective material from a physical property perspective.

Then that material is configured in the most economical shape and size. The result is a very robust and cost-effective gear molded to the required accuracy level. The specific goals of optimization vary from application to application. What is required in one case may not meet the need in another. While optimization is application specific, the process can be applied to all applications.

Design Goals

The transmission of uniform motion under the operating load throughout the range of the operating environment is common to most gear applications. A number of design challenges arise from this basic goal of uniform motion under load. One of the challenges is the interdependence of the design parameters.

For example, a design change can have a positive influence on one set of design parameters and a negative influence on another set. It is not possible to have the optimum values for all the design parameters. It is necessary to determine which parameters are most important to the success of the gears operating in the specific application. A knowledgeable compromise is required to set the design limit of each gear geometry parameter.

One of the benefits of working with plastic is the potential of modified tooth proportions. The use of standard gear proportions will seldom yield optimization. Multiple design iterations are typically required to optimize new applications. Fully utilizing the optimization process will help in designing the best gear set for the performance and reliability the application requires.

Optimization Process Steps

To understand how this geometry optimization process fits into the total process, here is a summary of the steps in the plastic gear performance optimization process.

1. Define the specific application—including the processing accuracy—for the housing and gears.
2. Account for the extreme conditions of temperature, moisture, and tolerances.
3. Compute the loads and speeds over the entire duty cycle and the number of desired life cycles.
4. Select the appropriate combination of gear types—spur, helical, worm, bevel, face, crossed-axis helical, internal, external, planetary—their arrangement and the power path.
5. Calculate the ratios for minimum total volume if more than a single-stage drive.
6. Determine the required accuracy level and verify it matches the process capability.
7. Select the material for the application that provides the necessary strength and durability at the lowest possible cost.
8. Develop the gear geometry to meet the necessary limits of contact ratio, specific sliding ratios, root clearance, backlash, and deflection over the range of extreme conditions.
9. Design the minimum-weight structure that supports the gear teeth and provides the required stiffness, strength, and molded precision. This structure comprises the rim diameter that supports the teeth, strengthening rings, webs, ribs and hub diameter for the application.

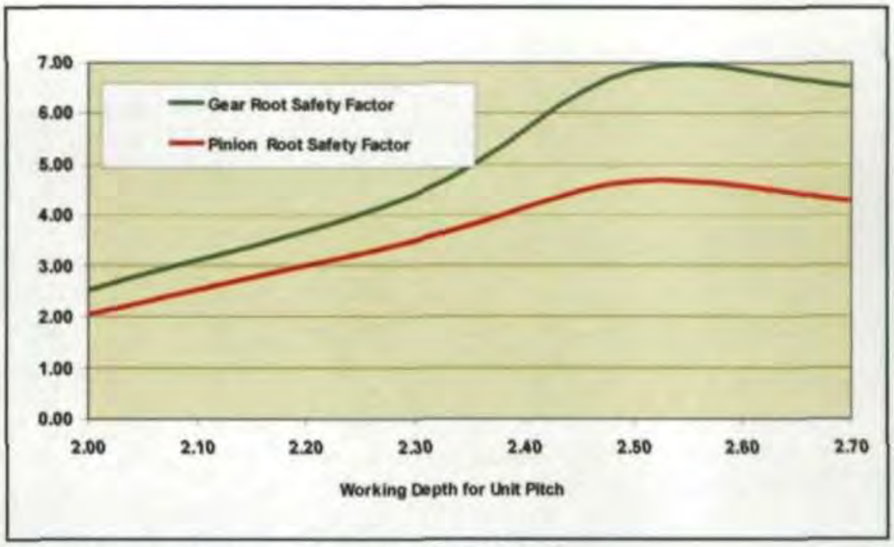

Figure 2—Root bending strength factors (equal addendums).

Evaluation Conditions

Nominal Center Distance Evaluations. The gear designer needs to design the gear set to operate over the full range of extreme conditions. Note that acceptable design parameters at the nominal housing center distance will not assure acceptable parameters at the extreme conditions. The typical range of effective center distance can be three to five times that of the specified center distance tolerance of the housing. It is always desirable to minimize mounting and assembly tolerances to improve gear performance.

Minimum Effective Center Distance Check. Optimizing gear geometry requires that each design iteration be checked at two extreme conditions. The first extreme condition for external gears is the maximum material condition (MMC) at minimum effective center distance. The minimum effective center distance is the tightest mesh condition considering the location tolerances, bore-to-shaft clearances, total runout, gear and housing materials, temperature, humidity, and gear accuracy.

The primary design parameters that are evaluated at this closest mesh condition are backlash, root clearances, profile contact ratio, percent of recess action, and specific sliding ratios. Under heavy load conditions and higher temperatures, more backlash is required to avoid the coast side profiles from coming into contact as the teeth

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is global gear design manager for Enplas Corp., a worldwide injection molder with manufacturing facilities in seven countries for molding critical-to-function plastic components. He is responsible for customer gear design training, as well as development and optimization of Enplas commercial gear designs. He has more than 25 years of gear manufacturing and design experience. Kuhr has a bachelor's degree in mechanical engineering from the University of Illinois. He is vice chairman of the AGMA plastics gearing committee. He has provided gear design services for many industries, and he has presented numerous papers related to gear design and metrology at SME conferences.

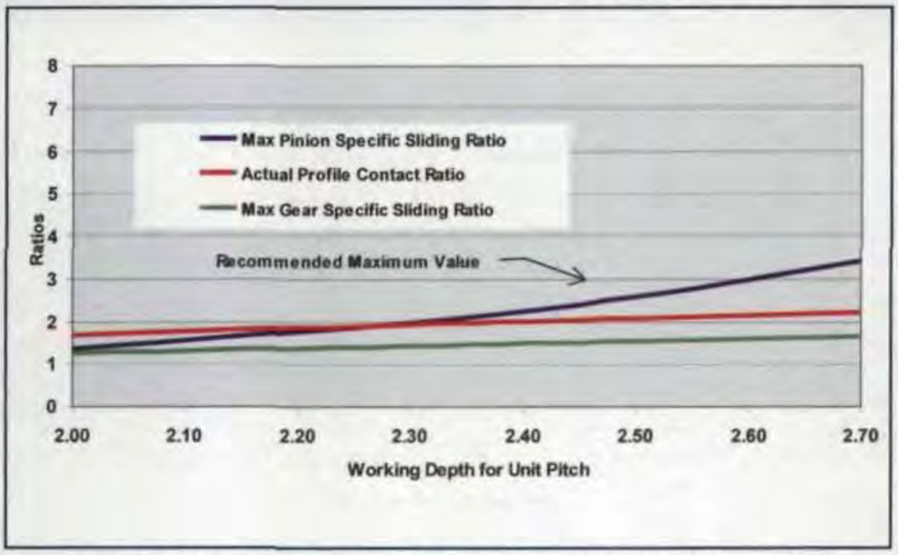

Figure 3—Tooth depth influence on sliding and contact ratios (addendum factors +/- 0.20).

are deflected. Another issue related to backlash determination is gear accuracy. More accurate gear teeth require less thinning to maintain the design backlash.

Sufficient root clearance is needed to avoid the risk of interference. Too much root clearance reduces the tooth working depth and the profile contact ratio. Higher profile-contact-ratio gear sets reduce noise levels and increase tooth strength by increasing the load sharing. It also reduces the deflection variation as the tooth loads are alternately distributed between one and two tooth pairs as they rotate.

For single-direction lubricated drives, the percentage of recess action should be greater than the percentage of approach action since the coefficient of friction in recess is less than approach. Long-addendum pinions increase the amount of recess action and also reduce the chance of undercutting the profile in the root area of the pinion.

Low specific sliding ratios promote surface durability and reduce operating temperatures. High specific sliding ratios can lead to overheating and a loss of capacity. Applying long-addendum modification and using enlarged operating center distances reduces the amount of sliding.

Maximum Effective Center Distance Check. The second extreme condition is at the least material condition (LMC) and the maximum effective center distance. The maximum effective center distance for external gears is the farthest apart the gears' centers can be considering the tolerances, bore-to-shaft clearances, component runout, temperature, humidity, and gear accuracy. The separating forces of the gear mesh influence this condition.

The profile contact ratio is the primary design parameter that is checked at this most widely spaced condition. If the effective contact ratio falls below 1.000, loss of smooth-motion transmission will result. Excessive wear and vibration will result because the radius on the driven tooth tip will be the first point of contact. This results in high load concentration and a loss of conjugate action.

Since mesh and mounting errors reduce the effective contact ratio, a design contact ratio larger than 1.0 is required. A typical minimum design profile contact ratio for spur gears is 1.200, although this is difficult to obtain with gear sets that have pinions with a low number of teeth. Designing gears for higher profile contact ratio is one of the goals of optimization.

Gear Geometry

Tooth Forms. Molded plastic gear design offers a striking potential for optimization because the mold is designed for a specific gear. The tooth form must be compatible with all mating gears but does not need to conform to any given standard. The AGMA standard *1006-A97, Tooth Proportions for Plastic Gears,* discusses four plastic tooth forms ranging in working depth from 2.000/(Diametral Pitch) to 2.700/(Diametral Pitch). The increasing tooth depth provides greater potential for higher profile contact ratios. These tooth forms have full fillet radii and represent sound engineering practice. Use of these forms alone does not produce optimum gear geometry; however, they do provide a very good start.

Tooth Depth Optimization Example

Here is an example of one of the design parameters—working tooth depth—evaluated for optimization. The specification of gear geometry includes number of teeth, pitch, pressure angle, helix angle, outside diameter, tooth depth, tooth thickness, face width, root and tip radii, along with any required tooth profile modification.

Equal Addendum Design. Equal addendum design demonstrates the positive and negative results of changing tooth depth. A common design goal is to design gears with the highest profile contact ratio and the lowest specific sliding ratio possible. The profile contact ratio increases as the working tooth depth is increased. That is a benefit for the design.

At the same time, the specific sliding ratio increases as the tooth depth increases. This is a detriment because of the increase in heat generated in the tooth mesh. The designer must balance the two opposing parameters to maximize the net benefit. For continuously running applications, a maximum specific sliding ratio of 3.0 is recommended. Exceeding 3.0 raises the probability of premature failure. Intermittent applications can tolerate higher values.

Figure 1 relates the influence of tooth depth on profile contact ratio and specific sliding ratio for pinion and gears that have equal addendum (Ref. 1). This example does not represent an optimized design and is only presented to illustrate the relative changes.

The example is a 24-tooth pinion meshed with a 72-tooth gear having a 20° pressure angle. The tooth form is full fillet. The "Working Depth" axis is scaled to a unit measure of pitch. It would apply to either a 1.00 diametral pitch or a 1.00 module gear set.

Figure 1 indicates that the contact ratio increases as the tooth depth increases. There is also a marked increase in the specific sliding ratio. The increase in sliding raises the amount of heat generated in the mesh and will, at some point, reduce the bending strength. The effects are shown in Figure 2.

These strength factors apply to gear sets with equal addendums. The result is unbalanced root bending strengths. In this case, the gear member, with the larger number of teeth, is stronger than the pinion. Usually a stronger pinion is desired for equal life because it sees more contact cycles.

It is apparent in this example and the next that there is an increase in strength as the working tooth depth increases. This assumes that the teeth are accurate enough to share the load. This reduces the diameter of the lowest point of single tooth contact and reduces the bending stress. A peak value at the 2.55-unit working depth illustrates that the negative effects of the higher specific sliding ratio exceed the positive effects of the increased contact ratio as the tooth depth increases beyond that point. The next example shows a root strength balance in favor of the pinion.

Modified Addendum Design. If the pinion is made with a long addendum and the gear is made with a short addendum, the bending strengths are closer to a balanced condition. Figure 3 shows the positive effect of the addendum change on the specific sliding ratios. The pinion specific sliding ratio is reduced from 8.0 to 3.4, a 57% reduction.

As shown in Figure 4, the strength factor of the pinion is now increased 40%. This is a more favorable condition. At the optimum tooth depth, the pinion strength is higher than that of the gear. This comparison of a 24-tooth pinion represents a condition that readily allows for deeper tooth depths.

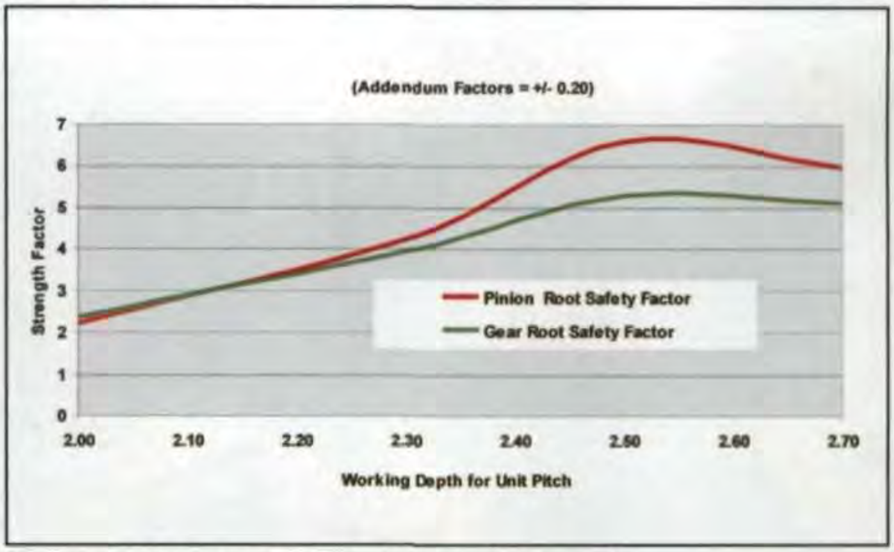

Figure 4—Root bending strength factors (addendum factors +/- 0.20).

Often it is necessary to select a lower number of teeth for strength and/or for the increased depth to accommodate an acceptable profile contact ratio over the range in the effective operating center distance. As the numbers of teeth in the pinion get smaller, the outside diameter further restricts the tooth depth due to pointed teeth preventing larger tooth depths.

Working Depth Conclusions

The optimization example using the parameter of tooth working depth increased the strength factor by more than 100% for both equal-addendum and modified-addendum designs. This demonstrates that shallow depth or stub teeth are NOT stronger than teeth with a greater working depth as long as the tooth accuracy allows for load sharing. It points out that the gear profiles must be accurate to maintain the load sharing, assure smooth-motion transmission and deliver the performance required.

Other Parameters

All other gear specifications are also candidates for optimization. They include the pitch, pressure angle, helix angle, addendum modification, root clearance, face width, root and tip radii, tooth thickness, center distance and profile modifications. Every application has its own unique requirements. Every gear design can benefit from optimization. Plastic gears offer the greatest optimization opportunity because the gear design and the required tool are not constrained by tooth form standards.

The best time to apply the results of optimization is when a new tool is required. Optimization is an integral part of a robust design and tool manufacturing process. It represents a significant opportunity to reduce total costs, size, noise, and improve time-to-market with increased customer satisfaction. ○

Reference

1. Universal Technical Systems, TK Solver Program *60-610 Plastic Gear Geometry and Load Analysis* utilized.


You make the gears...
...we'll help you sell them

Program for Involute Equation to Develop Spur Gears on Pro/E Software

Sandeep Singal

In effect, this article continues a previous *Gear Technology* article, "Modeling Gears In Pro/Engineer," published in the January/February 1999 issue. The previous article discussed drawing involute gear teeth using a program built into the Pro/E software.

However, the program does not include the effect of the "profile shift" in the involute equation. The outside diameter and root diameter needed as input data may be obtained from the article "Profile Shift in External Parallel-Axis Cylindrical Involute Gears," published in *Gear Technology*, in its November/December 2001 issue.

For true modeling of spur gears, especially in terms of gear tooth profile, it is very important to include the effects of profile shift.

The technique depends on generating the involute curve in such a fashion so it is formed exactly symmetrical about one of the planes and a mirror image of the curve can be formed by using the mirror commands. The technique can be automated so all parameters—like number of teeth, correction factor, module, pressure angle, outside diameter and root diameter—are already present and ready for input. That way, a person can generate another gear just by changing the input parameters.

Reference for generation of this involute equation is taken from the June 1980 edition of *Gear Cutting Tools*, published by Verzahntechnik Lorenz GmbH & Co., Ettlingen, Germany.

The procedure given here is based on the following assumptions:

- Only spur gears are considered,
- Tooth thinning for backlash is ignored,
- Tooth profile protuberance for grinding relief is ignored,
- Tooth profile is not undercut, and
- Root fillet is approximated with a circular curve joining the involute and root circle.

The step-by-step procedure for generation of the involute is as follows:

- Step 1: Create the three Default Datum planes using the commands Feature, Create, Datum, Plane, Default.
- Step 2: Create the protrusion, taking into account that the gear's outer diameter is known. To create the protrusion, use the commands Feature, Create, Solid, Protrusion, Revolve.

(Note: The Extrusion command also can be used.)

- Step 3: Create the coordinate system for generation of the involute equations using the commands Feature, Create,

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is manager, transmission design in the product development-transmission design department of Eicher Tractors Engineering Centre, located in Faridabad, India. An engineer, he has worked for seven years in that department, which works on gears, shafts, casings and bearings.

Datum, Coord sys, 3 Planes. (Note: Refer to the three default datum planes created in Step 1; take care that the Z-axis has to be in the direction of the gear's center axis.)

- Step 4: Generate the involute profile of one tooth flank. To do this, use the commands Feature, Create, Datum, Curve, From Equation, Choose Cylindrical, and use the just-created coordinate system.

At this point, there will be a window in which the involute equation will need to be written. The equation will need the following input data: number of teeth (not), pressure angle (pangle), module (m), correction factor of the gear under consideration (x), outside diameter (od) and root diameter (rd). These data will change with each specific gear to be drawn.

As an example, the following input data will be used:

not = 46
pangle = 20
m = 3
x = 0.55
od = 146.7
rd = 133.8

The equation is as follows:

```
pcd = not*m
bcd = pcd*cos(pangle)
rbase = bcd/2
tt = (((3.141592654)*m)/2)
    + (2*m*x*tan(pangle))
k = bcd*((tt/pcd)
    + ((tan(pangle)
    – ((pangle
    *(3.141592654)))/180)))
gamma =
    (((bcd*(3.141592654))
    – (not*k))/(not*2))
    *(360/(bcd
    *(3.141592654)))
r = rbase/(cos(t*40))
inv = tan(t*40) – (((t*40)
    *(3.141592654))/180)
theta = (((inv*180)
    /(3.141592654))
    + gamma)
z = 0
```

The output is:

pcd = Pitch Circle Diameter
bcd = Base Circle
rbase = Base Circle Radius
tt = Tooth Thickness at the pcd
k = Tooth Thickness at the bcd
gamma = Basically, this is my own term for calculation of the angle subtended by the end point of the start of involute profile from the base circle diameter towards the gear center. (Note: This is an important parameter, which helps generation of the involute profile exactly at a point where, if we take a mirror image of the profile, then both generated profiles will create the exact space width in the gear tooth.)
r = This calculates the r function for involute profiles in terms of cylindrical coordinates.
inv = This is $\tan(\alpha) - \alpha$, where α = the pressure angle in radians.
theta = This calculates the theta function for involute profiles in terms of cylindrical coordinates.
t = Pro/E internal variable, which varies from 0 to 1
z = the gear axis (For the program, the axis has to be zero.)

(Note: This program will generate involute profiles up to 40°, only as the variable "t" given in the output for r and inv is 40°. However, this

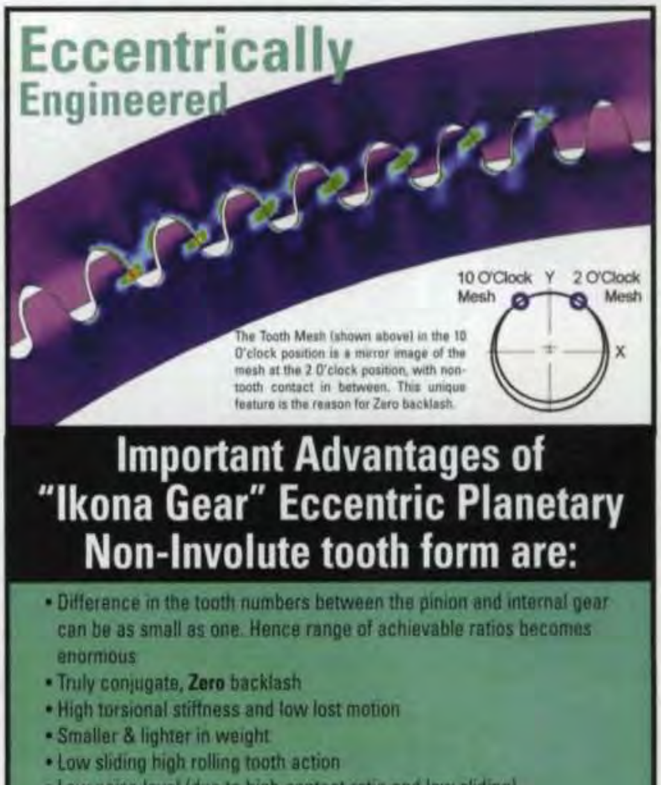
function can be changed to any extent based on individual requirements.)

This step will generate an involute profile curve, which will be found at an angle with respect to one of the Datum planes.

- Step 5: To create a mirror image of this datum curve about the plane, use the commands Feature, Copy, Mirror, Dependent. Select the curve and say Done, then choose the Datum plane along which the curve is to be mirrored.
- Step 6: To create the cut using the already generated curves, use the commands Feature, Create, Solid, Cut, Extrude. Choose the plane containing the datum curves as the Sketching plane. Use Geometry Tools in the Sketcher mode. Use the edges of the datum curves. Use Outer Diameter as the boundaries of the cut. Also, draw the root circle radius for closing the boundary. Extrude the cut along the entire face width. This procedure should be restricted to gears without undercut. The involute can be joined with the root circle by giving a suitable value for the fillet radius. For this example, the value is 0.8 mm. The gear designer can choose how to join the profile with the root circle diameter.

After Step 6, one tooth space will have been created. From here, any method for the gear generation can be used. In this case, the method used was as follows:

- Step 7: Create another cut using the Copy command. Use the commands Feature, Copy, Move, Dependent, Done, Rotate. Select the center axis as the axis around which to rotate. For the rotation angle, put 360/number of teeth as the input and say Done.
- Step 8: Generate the entire gear using the Pattern command. Use the commands Feature and Pattern, using the just-copied cut as the feature for the pattern. This step will show various dimensions on the just-copied cut. Select the



rotation angle given in Step 7, and fill in the same value, i.e. 360/number of teeth. Afterward, the program will ask for the number of features in the pattern. Give it a value that is one tooth less than the number of teeth. One tooth is subtracted because one cut—the original one—is already there.

This completes generation of a spur gear with the actual involute profile using nominal values, but without the actual profile being produced in the root fillet area. Helical gears also can be generated, but the involute equation is slightly different.

This program can be converted into parametric form, in which only input values are needed to completely generate a gear.

A number of gears used in tractor transmissions were checked. The gears had modules in the range of 3–5.75 mm. The accuracy observed on the values for diameter over pins and measurement over number of teeth varied in the range of 1–4 microns. Therefore, these steps can be used to reliably generate spur gears. ○

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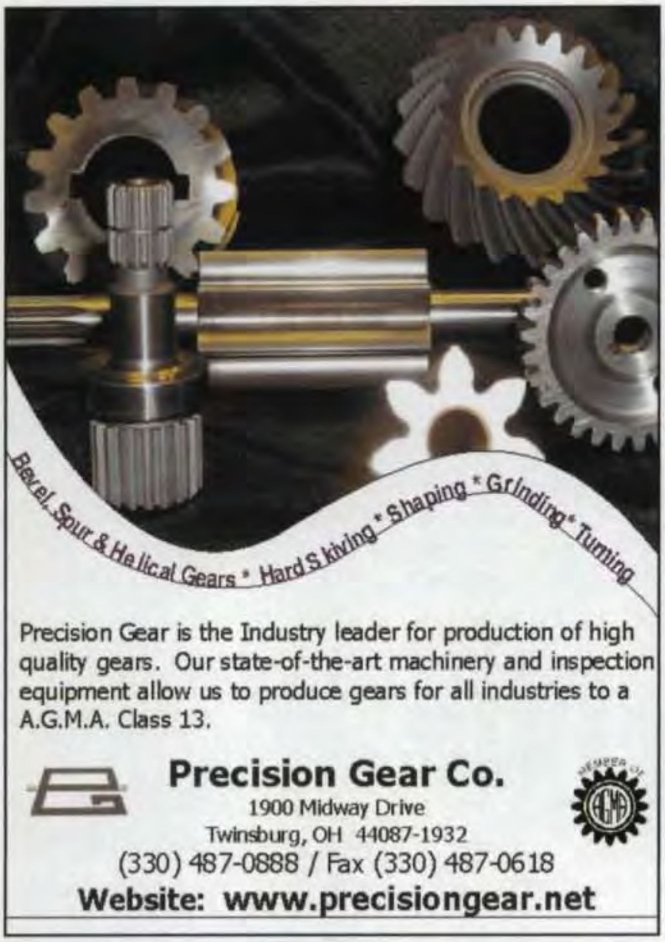

May 14–17—Plastic Gear Design and Manufacturing. UTS Inc., Rockford, IL. Class topics range from design, terminology and operation of plastic gears to discussions of issues like accounting for extreme conditions, maximizing contact ratio and applying tip relief, as well as other topics. $995. For more information, contact UTS by telephone at (815) 963-2220 or by e-mail at *sales@uts.com.*

May 20–22—Fundamentals of Parallel Axis Gear Manufacturing. Pheasant Run Resort, St. Charles, IL. Designed for entry-level manufacturing professionals, this seminar offers sessions on gear nomenclature, the hobbing and shaping processes, automation systems and skiving, among other topics. $600. For more information, contact Koepfer America L.L.C. by telephone at (847) 931-4121 or on the Internet at *www.koepferamerica.com.*

June 4—Gear Metrology. Drawbridge Inn & Convention Center, Fort Mitchell, KY. This forum is dedicated to metrology and inspection issues unique to the gear manufacturing and processing industries. $445 for SME members, $545 for non-members. For more information, contact the Society of Manufacturing Engineers on the Internet at *www.sme.org/training* or by telephone at (313) 271-1500.

June 5–6—Gear Shaping Manufacturing Dynamics. Drawbridge Inn & Convention Center, Fort Mitchell, KY. This two-day educational program instructs people on the basics of design, material selection, available tooling, coatings and cutters for different project needs. $745 for SME members, $845 for non-members. For more information, contact the Society of Manufacturing Engineers on the Internet at *www.sme.org/training* or by telephone at (313) 271-1500.

June 18–20—AGMA Gear School. Mitsubishi Gear Technology Center, Wixom, MI. This session will feature the latest CNC technology for wet and dry hobbing, shaping, shaving and honing. $750. For more information, contact AGMA by telephone at (703) 684-0211 or by e-mail at *webmaster@agma.org*.

June 24–27—Basic Gear Fundamentals Course. Gleason Cutting Tools Corp., Loves Park, IL. Program consists of a series of lectures by engineering, production and inspection staff members. The session is geared towards people seeking a basic understanding of gear geometry, nomenclature, manufacturing and inspection. $895. For more information, contact Gleason Cutting Tools Corp. on the Internet at *www.gleason.com.*

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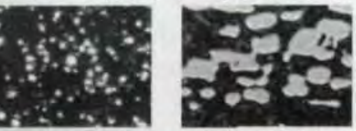
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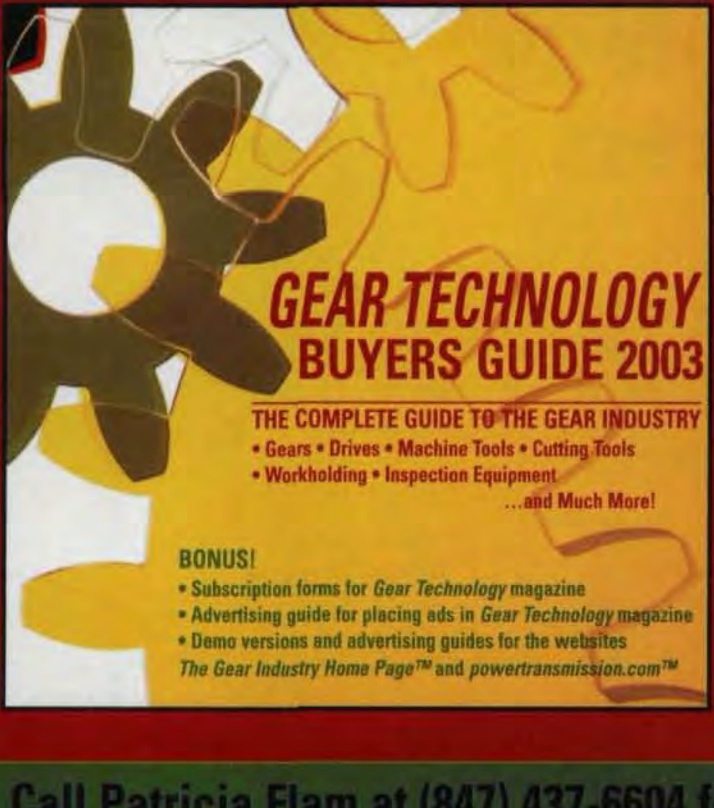
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Increased Load Capacity of Worm Gears by Optimizing the Worm Wheel Bronze

Wolfgang Predki and Ulrich Nass

This paper was published in *Antriebstechnik*, December 2001, as the article "Tragfähigkeitssteigerung bei Schneckengetrieben durch optimierte Schneckenradbronzen."

The lifetime of worm gears is usually delimited by the bronze-cast worm wheels. The following presents some optimized cast bronzes, which lead to a doubling of wear resistance.

Introduction

Worm gears are of growing importance in the field of power transmission. Above all, increasing environmental consciousness, which comes along with strict legal restraints concerning noise control, leads to an increased spread of this low-noise type of gearing. Apart from soundproofness, the great range of gear ratios ($i = 5–80$) that can be realized within a single stage, is counted among the positive properties.

The low noise levels result from high sliding rates during meshing. High sliding velocities in combination with relatively high hertzian pressures at incomplete initial contact patterns require a pairing of materials that enables running-in. Therefore, material pairings of the combination soft/hard are used in worm gears. Normally, case-hardened steel worms are paired with worm wheels made of CuSn alloys (bronze). This material selection causes wear, which might restrict the lifetime of such gears. On the other hand, wear is of little importance for other types of gears with different material pairings. Thus, strong efforts are made for substituting the bronze with materials of higher wear resistance at lower costs.

Today, research work focuses on materials like steel (Ref. 1) or cast iron (Refs. 2 and 3). The results show that bronze can be partially replaced. However, these materials do not reach the well-balanced properties and the wide range of use of bronze. Consequently, bronze will remain the universal material for worm wheels in the future. The aim of today's work on optimizing the bronze is to increase wear resistance while keeping the specific advantages of the material. This will lead to an improved efficiency and a higher endurance in worm gears.

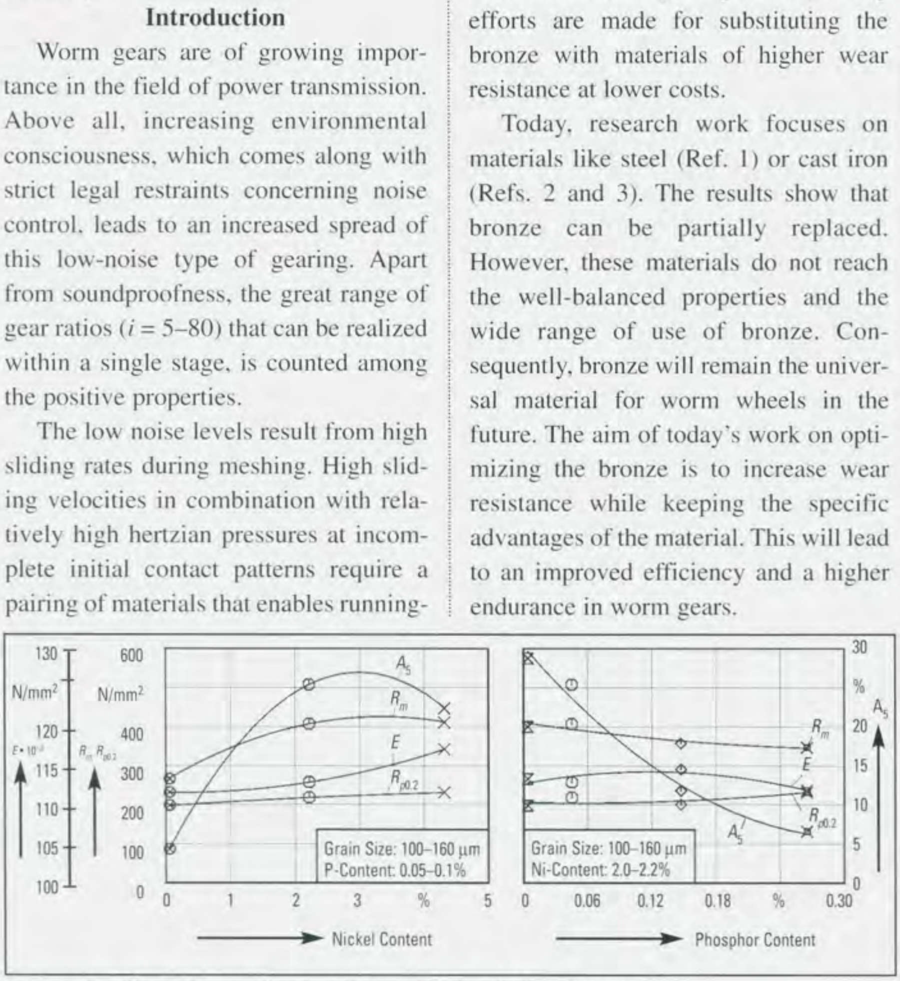

Figure 1—Dependence of strength on nickel and phosphor content.

Copper-Tin Alloys

The bronze GZ-CuSn12Ni according to DIN 1705 (Ref. 4) is seen as the standard worm wheel material nowadays. It is composed of approximately 12% tin, 2% nickel, 0.2% phosphor and 0.2% lead. Copper-tin alloys feature a heterogeneous structure, which consists of α-solid solution (mixed crystals) and an incorporated fraction of (α + δ) eutectoid. The wide solidification range of copper-tin alloys leads to significant segregation, which causes varying concentrations of tin within the α-solid solution.

Adding nickel to the binary copper-tin alloy leads to an increased fraction of eutectoid and consequently improves the strength of the bronze. Phosphor is added for casting reasons, as it reduces the viscosity of the melt and thus improves the foundry characteristics. Phosphor additives higher than 0.075% cause embrittlement. Lead additives enhance machin-

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is the head of the chair of mechanical components, industrial and automotive power transmission at Ruhr University, located in Bochum, Germany. The chair employs 16 assistants, three of whom perform research on worm gears. The research focuses on wear optimization of worm wheels, contact pattern, oil optimization and plastic worm gears.

Dr.-Ing. Ulrich Nass

is manager, global concept development for Kiekert AG, located in Heiligenhaus, Germany. He develops technical concepts for automotive locking systems. He has worked on a worm wheel bronze project, on a German standard for worm gears, and on several industrial projects involving worm gear applications, from vacuum cleaners to tunnel fans.

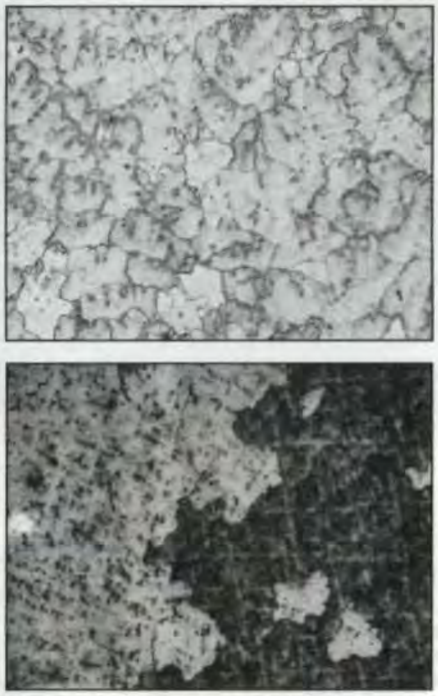


Figure 2—Micrographs of centrifugally cast bronze (top) and conventional continuously cast bronze.

ability and resistance to galling. The lead is not dissolved in the melt but dispersed in the structure. The influence of nickel and phosphor additives on the macroscopic strength is shown in Figure 1.

Young's modulus E, flexural strength A_5, limit of elasticity $R_{p0.2}$ and tensile strength R_m increase unless they reach 3% nickel content. Compared to the rest, the bronze without addition of nickel shows inferior physical properties. Phosphor additives cause embrittlement. Tensile strength R_m and limit of elasticity $R_{p0.2}$ nearly remain the same.

Today, sand casting, centrifugal casting and continuous casting are the most commonly used casting procedures. Centrifugal casting provides an optimal fine-grained and uniform structure. However, the use of centrifugal casting is restricted to medium diameter worm wheels. The minimum outer diameters of centrifugally cast worm wheel rims are in the range of around 100 mm. Smaller diameters are realized by continuous casting. Especially for small worm gears, the wear behavior is of particular importance for the life cycle of the gearing. Continuously cast materials often feature very poor wear behavior, which shows high variance. Large diameter wheel rims are manufactured by sand casting.

Results

Experiments on cylindrical worm gears with a center distance $a = 100$ mm and a gear ratio $i = 20.5$ clarify the influence of the different material parameters on the wear behavior of the bronze. Overall, 13 different bronzes are provided. Based on the standard bronze, GZ-CuSn12Ni (Ref. 4), a specific variation of the parameters medium grain size, nickel content, phosphor content and casting procedure is executed. Among others, a new, specially treated continuously cast bronze is examined and shows a modified crystal structure. Centrifugally cast bronze features circular shaped grains, while the grains of the conventional continuously cast bronze are elongated and aligned in a preferred orientation. The structure of the modified continuously cast bronze is similar to the structure of the centrifugally cast bronze. This was obtained by a specific variation of parameters, like the speed of raking out the slag, the intensity of cooling or the casting temperature. Figure 2 compares the polished micrograph sections of centrifugally cast bronze and conventional continuously cast bronze.

The experiments provide the operational wear rates depending on the output torque T_2 at two different values of rotational speed n_1. As an example, Figure 3 gives the experimentally determined operational wear rates Δm_B of the standard bronze, GZ-CuSn12Ni. They form the reference for the evaluation of the following experiments. The operational wear rate represents the mass loss of the worm wheel in relation to the operating time. Wear of the harder worm is insignificant.

In DIN 3996 (Ref. 5), the wear intensity J_W is defined as the flank loss in normal section related to the wear path of the toothing. Charting the wear intensity by the lubricant film thickness parameter K_W in a double-logarithmic diagram reveals a linear dependence. Figure 4 represents the calculated wear intensity values $J_{W.B2}$ of the standard bronze, GZ-CuSn12Ni.

The marked interval results from a statistical evaluation of the wear intensi-

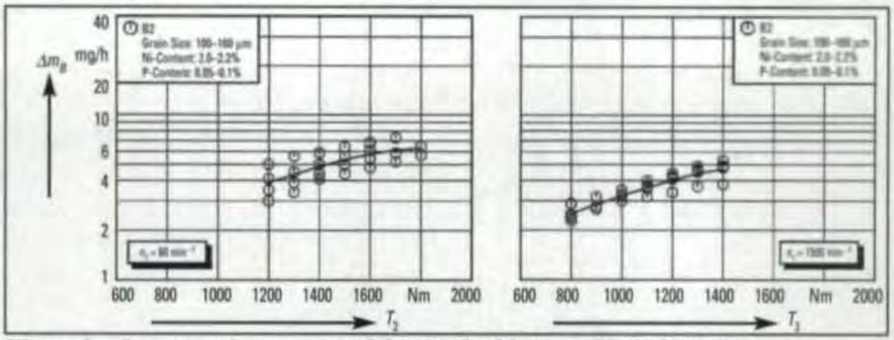


Figure 3—Operational wear rates of the standard bronze, GZ-CuSn12Ni.

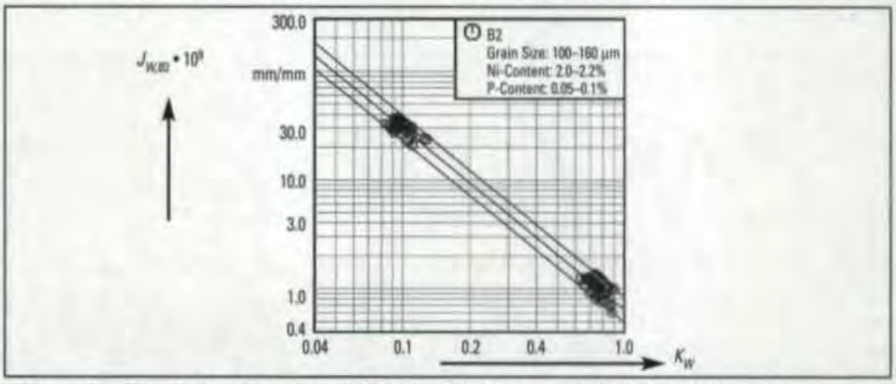


Figure 4—Wear intensity values of the standard bronze, GZ-CuSn12Ni.

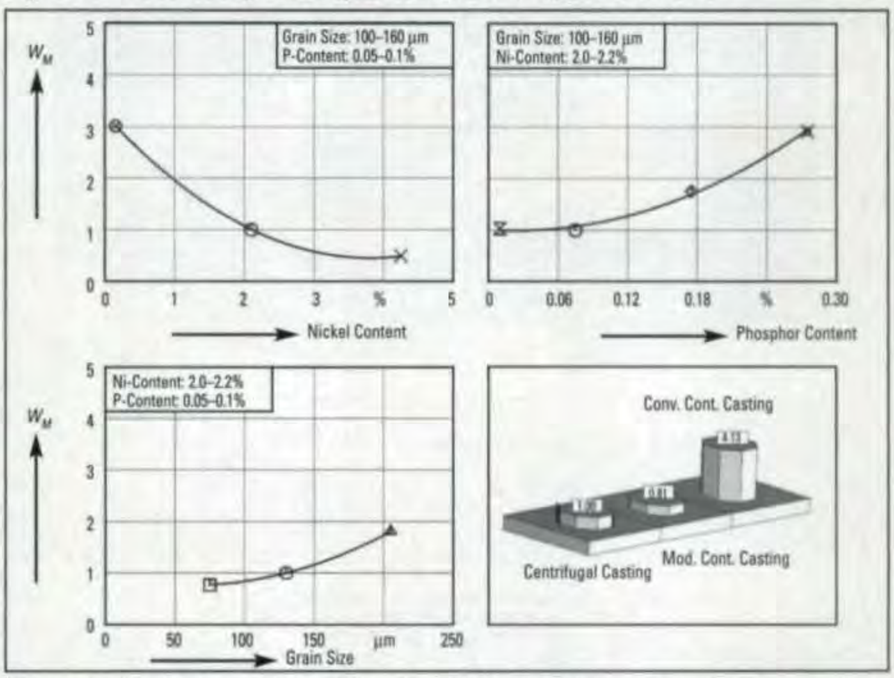


Figure 5—Material wear factor W_M, depending on nickel content, phosphor content, grain size and casting procedure.

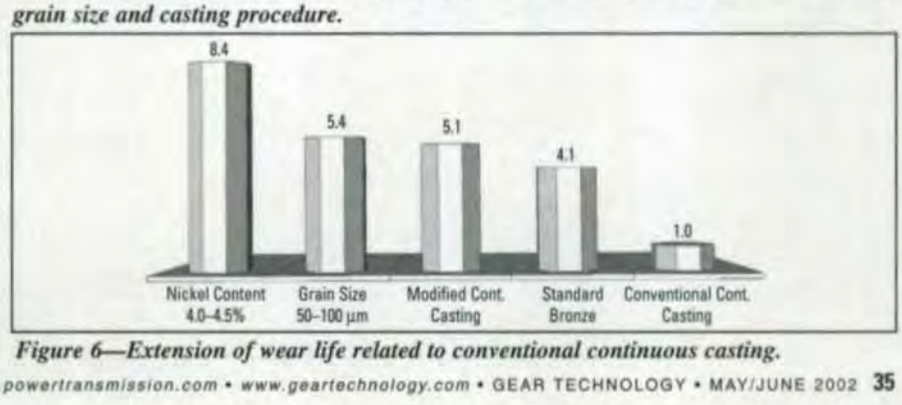


Figure 6—Extension of wear life related to conventional continuous casting.

ties. This interval indicates the range where the wear intensity of the next test run will occur with a probability of 90%. The best-fit straight line gives a reference standard for the other test bronzes. The material wear factor W_M results in

$$W_M = \frac{J_W}{J_{W,B2}} \qquad (1)$$

Figure 5 illustrates the influence of the nickel and phosphor content and of the grain size and casting procedure on the material wear factor.

In reference to the standard bronze, GZ-CuSn12Ni, material wear factors < 1 denote a better wear behavior while material wear factors > 1 stand for a worse wear behavior. Figure 5 leads to the following conclusions:

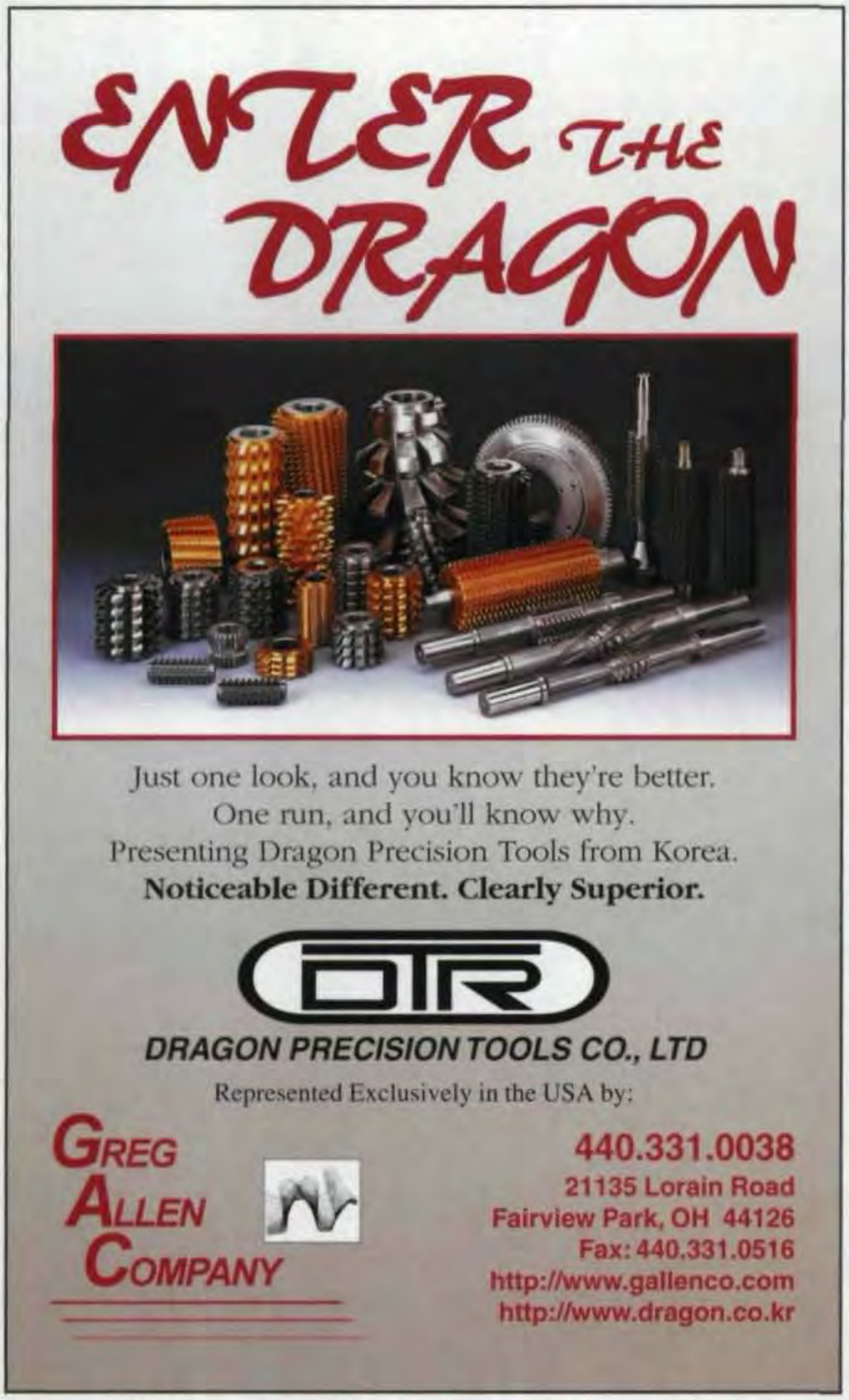
- With increasing grain size, the wear increases along with the material wear factor W_M.
- Adding nickel results in a strong wear reduction. Bronze with a nickel content higher than 4% reveals the best wear behavior of all bronzes examined.
- Phosphor contents of more than about 0.06% lead to increased wear.
- The conventional continuously cast bronze features the most inferior wear behavior of all bronzes tested. In contrast, the modified continuously cast bronze shows a wear behavior similar to centrifugally cast bronze. So, for the first time, a bronze material with a superior wear behavior is available even for smaller worm gears.

Based on the determined wear intensities, the wear life can be calculated according to DIN 3996 (Ref. 5). The life factor is defined as the respective wear life divided by the wear life of the conventional continuously cast bronze. According to Figure 6, the life factors give the extension of wear life in relation to conventional continuous casting.

The figure clarifies that, when substituting a conventional continuously cast bronze with a bronze having an increased nickel content of 4.0–4.5%, an extension of the wear life by the factor 8.4 is possible. Even compared to the common standard bronze, GZ-CuSn12Ni, the wear life can be nearly doubled.

It is evident to the caster and the designer that it is necessary to predict the wear behavior of a bronze from its physical properties and that, starting from a desired wear behavior, it should be possible to specify the appropriate physical properties of a bronze and therefore to choose a suitable casting procedure. These considerations led to a first approach to calculate a wear characteristic W_{Mcal} from physical basics, which permits estimating of the wear behavior of CuSn alloys from their material parameters. Developed from wear fatigue theory, the following equation is derived:

$$W_{Mcal} = 230.47 \cdot \left(\frac{E_{red}}{165{,}211}\right)^{-10.71} \cdot (R_m \cdot A_5)^{-0.61} \qquad (2)$$



E_{red}: Equivalent E-module in N/mm^2, DIN 3996

R_m: Tensile strength in N/mm^2

A_5 : Flexural strength, as a percent

Equation 2 permits prediction of the material wear factor from tensile testing data with high accuracy. The equivalent E-module denotes the actuating variable on the expected wear behavior.

Summary

This article presents some new results on how to select and influence material parameters of worm wheel bronzes regarding wear resistance. Extensive studies on cylindrical worm gears lead to the following recommendations concerning an advantageous wear behavior:

- Higher nickel contents cause a drastic decrease of wear,
- Phosphor contents higher than 0.06% should be avoided,
- A homogenous and fine-grained crystal structure is favorable, and
- In smaller worm gears, modified continuously cast bronze should be used instead of conventional continuously cast bronze.

Further information on this topic can be found in the final report on the *Forschungsvorhaben 205* (Research Project No. 205) of the Forschungsvereinigung Antriebstechnik e.V., Germany (Ref. 6).

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New Planetary Gearhead from HD Systems

The new Harmonic Planetary HPG Series from HD Systems incorporates a ring gear design to reduce backlash to less than one arc minute for the life of the gearhead. This eliminates the backlash creep commonly associated with conventional planetary gearing.

Available in both flange output and shaft output configurations, applications for this product include packaging, automation and machine tools.

The flange output model is suitable for turntable applications because the flange is supported by a precision cross roller bearing that provides low runout and high concentricity.

For more information, contact HD Systems Inc. of Hauppauge, NY, by telephone at (631) 231-6630 or by e-mail at *info@HDSI.net.*

New Right Angle Planetary Gearmotors and Reducers from Groschopp

Groschopp's new right angle planetary products are designed for space-saving applications. A right angle attachment makes it possible for the gearmotor to fit into tight places.

According to Groschopp's press release, these products feature sun gear design and equal load sharing. Floating sun gears are designed to provide true involute action, which occurs when the rolling motion between the mating gears is complete. The benefit of this complete meshing of gears is longer reducer life since less internal gear slippage means fewer broken gear teeth.

Other features include heat-treated miter gears for low noise and high load capacity. Single and double output shaft designs are available. A synthetic gear oil is used to carry heat away from the gears, reducing wear and increasing efficiency and longevity.

For more information, contact Groschopp of Sioux Center, IA, by telephone at (800) 829-4135 or on the Internet at *www.groschopp.com.*

Worm Gears Without the Need for Grinding from Leistritz

Worm gears can be constructed by Leistritz Corp. without needing grinding due to advances in machining and heat treating techniques. The company says the procedure involves soft cutting done to finish tolerances, and the operation is stress-free to eliminate possible distortion during induction hardening or vacuum/atmospheric heat treating.

According to Leistritz's press release, the company's whirling machines form the foundation for soft cutting at finish tolerances. These machines produce parts to AGMA Grade 6 specifications with lead, pitch and profile tolerances of less than 0.0005".

The company says that because whirling does not require undercuts at the ends of the worm area, the worm face width can be optimized and the overall shaft length reduced. Eliminating undercuts also negates the need for deburring worm teeth ends at each undercut.

For more information, contact Leistritz Corp. of Allendale, NJ, by telephone at (201) 934-8262 or on the Internet at *www.leistritz.com.*

Drop-In Gear Drives from Falk Renew

Falk Renew is now offering remanufactured gear drives that are dimensionally identical to original equipment. This eliminates foundation changes and modifications.

According to the company's press release, Falk reviews the drive nameplate information and researches the original records to ensure an identical replacement. A complete drive assembly—including base plate, couplings and guards—is supplied, as are new bearings, seals and seal surfaces, gears and shafts.

For more information, contact Falk Renew of New Berlin, WI, by telephone at (262) 317-1420 or by e-mail at *renew@falkcorp.com.*

CNC Gear Shaping Machine from Mitsubishi

The ST40CBC from Mitsubishi Gear Technology Center has been modified to include a programmable lead guide feature. According to Mitsubishi's press release, this permits helix angles up to +/-36° to be shaped without the need to install expensive hydrostatic guides.

With programmable stroke length up to 135 mm, the machine's latest version has been enhanced with optional quick return stroke. Mitsubishi says, depending on the stroke length used, savings up to 35% in cycle times are possible.

According to Mitsubishi, the system for quick return stroking involves specially developed software in combination with enhanced servomotor performance. This software works in unison with the programmable helix angle generation to achieve accurate lead control for the return and cutting stroke.

For more information, contact Mitsubishi of Wixom, MI, by telephone at (248) 668-4141 or on the Internet at *www.mitsubishigearcenter.com.*

New DC Gearmotor from Thomson Airpax Mechatronics

The TAM58-3E is a new family of brushless DC gearmotors that combine 9-slot stator and 12-pole rotor construction design. This motor provides a gear reduction transmission with a standard brushless motor and controller in one package.

Modular motors can be ordered with an internal Hall sensor wire harness assembly or full on-board drive electronics. The motors are combined with heavy-duty, permanently lubricated gear trains. According to Thomson's press release, the products bring the benefits of long-life brushless motor power to small-space applications.

These products work in damp, dusty and harsh environments and conform to the IP44 construction and NEMA Size 34 mounting standards. They are designed for use in industrial applications like automated conveyor systems, bar code labeling, printing, pumps, valves, machine tools and agricultural equipment.

For more information, contact Thomson Airpax Mechatronics of Port Washington, NY, by telephone at (516) 883-8000 or by fax at (516) 883-9039.

Send your new product releases to:
Gear Technology
1401 Lunt Avenue
Elk Grove Village, IL 60007
Fax: 847-437-6618
E-mail: *people@geartechnology.com*

Tell Us What You Think . . .
Visit *www.geartechnology.com* to
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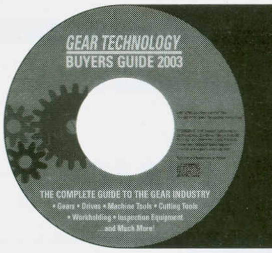
- **Request more information**
- **Contact companies mentioned**
- **Make a suggestion**

Or call (847) 437-6604 to talk to one of our editors!



GET YOUR FREE LISTINGS IN THE *GEAR TECHNOLOGY* CD-ROM BUYERS GUIDE!

You MUST fill out this form to be included.

You can also fill out this form at *www.geartechnology.com*

STEP 1—COMPANY INFORMATION (Please be careful! This is how your information will appear in the directory!)

Company Name: ____________________

Address 1: ____________________

Address 2: ____________________

City: __________ State: __________ Postal Code: __________ Country: __________

Phone: __________ Fax: __________

E-mail: __________ Website: __________

STEP 2—YOUR CONTACT INFORMATION
(For our records only. This information will not appear in the directory.)

Name: ____________________

Title: ____________________

STEP 3—CHOOSE YOUR LISTING STYLE

☐ $125 Enhanced Listing with Active Hyperlink (CD-ROM users will be able to click on your Web address to automatically bring your Website up on their computer screens).

☐ Charge my Visa, MasterCard or American Express # ____________________

Exp. __________ (authorized signature) ____________________

☐ Invoice me

☐ Free Listing with No Hyperlinks

OH YES!

I'm interested in advertising on the CD-ROM!
Send me information about:

☐ **A 1/8-page VIPS (Very Important Products and Services) advertisement (Only $795)**

☐ **A Full-Page ad in the directory. (Only $1,995)**

Listings in *Gear Technology's* CD-ROM Buyers Guide are ABSOLUTELY FREE, but this complete directory of the gear industry is also a great opportunity for you to demonstrate how your company stands out as one of the industry's leading suppliers. We have several advertising options on the CD-ROM. Just check below to let us know you're interested in more information.

STEP 4—FILL OUT YOUR CATEGORIES

(Please indicate ONLY categories that you sell.)

GEAR MACHINERY

Gear Cutting Machinery

☐ Bevel Gear Cutting Machines
☐ Broaching Machines
☐ Gear Cutting Machinery
☐ Generators, Herringbone
☐ Generators, Spiral Bevel
☐ Generators, Straight Bevel
☐ Hobbers/Hobbing Machines
☐ Rack Millers & Cutters
☐ Shapers, Gear
☐ Spline Hobbing Machines
☐ Spline Milling Machines
☐ Thread, Worm & Flute Milling Machines
☐ Other Gear Cutting Machinery: ____________________

Gear Grinding/Finishing Machinery

☐ Bevel Gear Lapping/Testing Machines
☐ Burnishing Machines
☐ Chamfering, Pointing & Rounding Machines
☐ Deburring Machines
☐ Gear Grinders, Crossed Axis
☐ Gear Grinders, External
☐ Gear Grinders, Internal
☐ Gear Grinders, Parallel Axis
☐ Gear Shaving Machines
☐ Hard Gear Finishing Machines
☐ Honing Machines (Hard Gear Finishing)
☐ Rack Grinders
☐ Spline Grinding Machines
☐ Worm Grinders
☐ Other Gear Grinding/Finishing Machinery: ____________________

Gear Measuring/Testing Machinery

☐ Bevel Gear Lapping/Testing Machines
☐ Gear Inspection Machines, Analytical
☐ Gear Inspection Machines, Functional
☐ Gear Roll Testers, Double-Flank
☐ Gear Roll Testers, Single-Flank
☐ Testers, Computer-Controlled
☐ Testers, Hob & Worm
☐ Testers, Hypoid & Spiral Bevel
☐ Testers, Involute
☐ Testers, Lead
☐ Testers, Lead & Involute
☐ Testers, Miscellaneous
☐ Testers, Pitch
☐ Testers, Rolling & Redliners
☐ Testers, Sound
☐ Testers, Straight Bevel
☐ Testers, Tooth Space
☐ Testers, Universal
☐ Other Gear Measuring/Testing Machinery: ____________________

Gear Forming Machinery

☐ Gear Roll-Forming Machines
☐ Spline Roll-Forming Machines
☐ Other Gear Forming Machinery: ____________________

Other Gear Machinery

☐ Bevel Gear Quenching Presses
☐ Cutter Inspection & Setting Machines
☐ Cutter Sharpeners
☐ Hob Grinders
☐ Other Miscellaneous Gear Machinery: ____________________

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Company Name ____

NON-GEAR MACHINES

Automation & Material Handling

☐ Automation Systems/Equipment
☐ Conveyor Systems
☐ Gantry Systems
☐ Parts Handling Systems
☐ Robots
☐ Other Automation & Material Handling:
____

Heat Treating and Related Equipment

☐ Austempering Equipment
☐ Batch Furnaces, Atmosphere
☐ Batch Furnaces, Vacuum
☐ Brazing Equipment
☐ Continuous Furnaces, Atmosphere
☐ Continuous Furnaces, Vacuum
☐ Cryogenic Processing Equipment
☐ Flame Hardening Equipment
☐ Fluidized Bed Heat Treating Equipment
☐ Gas Nitriding Systems
☐ Induction Heating Equipment
☐ Laser Heat Treating & Welding Equipment
☐ Ovens
☐ Quench Presses
☐ Stop-off Paints & Coatings
☐ Other Heat Treating or Related Equipment:
____

Metal Cutting Machinery

☐ Automatic Screw Machines, Multiple Spindle
☐ Automatic Screw Machines, Single Spindle
☐ Automatic Screw Machines, Swiss Type
☐ Boring Mills, Horizontal
☐ Boring Mills, Vertical
☐ Broaching Machines, Horizontal
☐ Broaching Machines, Vertical
☐ EDM Machines
☐ Grinders, Cylindrical, Plain
☐ Grinders, Cylindrical, Universal
☐ Grinders, Drill
☐ Grinders, Form
☐ Grinders, Internal
☐ Grinders, Jig
☐ Grinders, Surface
☐ Grinders, Thread
☐ Grinders, Tool & Cutter
☐ Grinders, Universal
☐ Keyseating Machines
☐ Lathes, Chucking
☐ Lathes, Combination (See also Turning Centers)
☐ Machining Centers, Horizontal
☐ Machining Centers, Vertical
☐ Milling Machines, Horizontal
☐ Milling Machines, Vertical
☐ Mills, Jig
☐ Saws, Band
☐ Turning Centers
☐ Waterjet Cutting Machines
☐ Other Non-Gear Metal Cutting Machinery:
____

Metal Forming Machinery

☐ Powder Metal Presses
☐ Press Brakes, Hydraulic
☐ Press Brakes, Mechanical
☐ Shears, Hydraulic
☐ Shears, Mechanical
☐ Stamping Machines
☐ Other Non-Gear Metal Forming Machinery:
____

Other Machinery

☐ Automatic Chuckers, Multiple Spindle
☐ Automatic Chuckers, Single Spindle
☐ Coating Equipment
☐ Coordinate Measuring Machines
☐ Filtration Equipment
☐ Injection Molding Machines
☐ Lapping Machines
☐ Lasers
☐ Special Machines
☐ Waterjet Cutting Machines
☐ Other Miscellaneous Machinery: __________
____

GEAR MATERIALS

☐ Bar Stock
☐ Cast Iron
☐ Forgings
☐ Gear Blanks
☐ Plastic Resins
☐ Plastic Stock Forms
☐ Powder Metal Materials
☐ Steel
☐ Other Gear Materials: __________
____

GEAR TOOLING, SUPPLIES & ACCESSORIES

Cutting Tools

☐ Broaches & Broaching Tools
☐ Cutter Bodies for Straight/Spiral Bevel Gears
☐ Cutting Tools/Blades for Straight/Spiral Bevel Gears
☐ Cutting Tools, Misc.
☐ Hobs
☐ Keyseat Cutting Tools
☐ Shaper Cutting Tools
☐ Shaving Cutters
☐ Spline Roll-Forming Racks
☐ Other Gear Cutting Tools: __________
____

Fixturing & Workholding

☐ Arbors
☐ Broach Pullers
☐ Chucks
☐ Collets
☐ Mandrels
☐ Modular Fixtures
☐ Tool Holders
☐ Other Fixturing & Workholding: __________
____

Gages & Measuring Instruments

☐ Gages & Measuring Instruments, Misc.
☐ Hardness Testers
☐ Master Gears
☐ Plug Gages
☐ Ring Gages
☐ Spline Gages
☐ Thread Gages
☐ Other Gages & Measuring Instruments:
____

Grinding & Finishing Tools

☐ Borazon/CBN Wheels
☐ Chamfering Tools
☐ Deburring Tools
☐ Diamond Wheels
☐ Dressing Diamonds
☐ Grinding Wheels
☐ Honing Tools & Wheels
☐ Lapping Compounds
☐ Wheel Truing & Dressing Devices
☐ Other Grinding & Finishing Tools: __________
____

Other Tooling, Supplies & Accessories

☐ Coatings
☐ Coolants
☐ EDM Tooling & Supplies
☐ Heat Exchangers
☐ Index Plates
☐ Injection Molds
☐ Lubricants, Cutting & Quenching Oils
☐ Other Miscellaneous Tooling, Supplies & Accessories: __________

GEAR-RELATED SERVICES

Gear Manufacturing Services

☐ Bevel Gear Manufacturing
☐ Broaching
☐ Custom Gear Manufacturing
☐ Deburring
☐ Gear Finishing
☐ Gear Forging
☐ Gear Grinding
☐ Gear Hobbing
☐ Gear Honing & Burnishing
☐ Gear Lapping
☐ Gear Rack Manufacturing
☐ Gear Shaping
☐ Gear Shaving
☐ Prototype Manufacturing
☐ Spline Rolling
☐ Stock Gear Manufacturing
☐ Other Gear Manufacturing Services:
____

Heat Treating Services (Commercial)

☐ Age Hardening
☐ Aluminum Treating
☐ Annealing
☐ Austempering
☐ Black Oxiding
☐ Blast Cleaning
☐ Boronizing
☐ Brazing
☐ Carbonitriding
☐ Carburizing
☐ Cryogenics
☐ Die Quenching
☐ Flame Hardening
☐ Hot Oil Quenching

PLEASE CONTINUE → TO THE NEXT PAGE

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Company Name ____

Heat Treating Services (Commercial) Cont'd.
☐ Induction Hardening
☐ Ion Nitriding
☐ Laser Hardening
☐ Nitriding
☐ Nitrocarburizing
☐ Normalizing
☐ Plasma Carburizing
☐ Press Quenching
☐ Salt Bath Nitriding
☐ Sintering
☐ Steam Treating
☐ Straightening
☐ Stress Relieving
☐ Tempering
☐ Vacuum Treating
☐ Other Heat Treating Services: ____________
____

Gear Consulting Services
☐ CAM Services
☐ Gear Design Consulting
☐ Gear Engineering Consulting
☐ Gear Failure Analysis
☐ Other Gear Consulting Services: ____________
____

Other Services for Gear Manufacturers
☐ Assembly
☐ Calibration Services
☐ Gear Coating Services
☐ Gear Finishing Services
☐ Gear Inspection & Testing Services
☐ Gear/Gear Unit Repair
☐ Hob Sharpening
☐ ISO 9000 Consulting
☐ Metallurgical Testing
☐ Shot Peening, Blasting & Beading
☐ Tool Coating
☐ Tool Sharpening
☐ Other Services for Gear Manufacturers:
____

GEAR-RELATED SOFTWARE
☐ Custom Software
☐ Gear Design Software
☐ Gear Grinding Software
☐ Gear Hobbing Software
☐ Gear Inspection Software
☐ Shop Management Software
☐ Other Gear-Related Software: ____________
____

TRAINING & EDUCATION
☐ Colleges/Universities
☐ Gear Schools
☐ Government Agencies
☐ Research Institutions
☐ Trade Associations
☐ Other Training & Education: ____________
____

DISTRIBUTORS/MANUFACTURERS' REPS
(Please list the manufacturers and types of equipment you represent.)

____
____
____
____
____
____
____
____

GEARS

☐ Aerospace Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Automotive Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Breakdown/Emergency Suppliers	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Cast Tooth Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Coarse Pitch Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Face Gears	Diameter Range ________	DP/Module Range ________	Max. Quality ________	
☐ Fine Pitch Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Forged Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Ground Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Helical Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Herringbone (Chevron) Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Hypoid Gears	Diameter Range ________	DP/Module Range ________	Max. Quality ________	
☐ Internal Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Marine Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Medium Pitch Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Miniature Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Mining Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Miter Gears	Diameter Range ________	DP/Module Range ________	Max. Quality ________	
☐ Noncircular Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Pinions	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Plastic Gears, Cut	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Plastic Gears, Injection Molded	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Powder Metal Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Punched Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Racks	Max. Face Width ________	Max. Length ________	DP/Module Range ________	Max. Quality ________
☐ Ratchets	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	
☐ Ring Gears (Bevel)	Diameter Range ________	DP/Module Range ________	Max. Quality ________	

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Company Name ____

☐ Rotors	Diameter Range ________	Max. Length ________		
☐ Segment Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Serrations	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	
☐ Skived Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Spiral Bevel Gears	Diameter Range ________	DP/Module Range ________	Max. Quality ________	
☐ Spline Shafts	Diameter Range ________	Pitch Range ________	Max. Length ________	Max. Quality ________
☐ Sprockets	Diameter Range ________	Pitch Range ________	Max. Face Width ________	
☐ Spur Gears	Diameter Range ________	DP/Module Range ________	Max. Face Width ________	Max. Quality ________
☐ Starter Ring Gears				
☐ Steering Sectors				
☐ Straight Bevel Gears	Diameter Range ________	DP/Module Range ________	Max. Quality ________	
☐ Timing Pulleys	Diameter Range ________	Pitch Range ________		
☐ Worm Wheels	Diameter Range ________	Min # Teeth ________	Max. # Teeth ________	Max. Quality ________
☐ Worms	Diameter Range ________	DP/Module Range ________	Max. Length ________	Max. Quality ________

☐ Other Gears ____

GEAR DRIVES

☐ Bevel Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Combination Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Cycloidal Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Differential Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Epicyclic Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Gear (Shift) Transmissions	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Gearboxes	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Gearheads	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Gearmotors	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
	Motor Types________________________________			
☐ Harmonic Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Helical Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Herringbone (Chevron) Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Hypoid Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Miter Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Planetary Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Shaft Mounted Reducers	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Speed Increasers	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Speed Reducers	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Spiral Bevel Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Spur Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________
☐ Worm Gear Drives	Min. Ratio________	Max. Ratio________	Min. hp________	Max. hp________

☐ Other Gear Drives ____

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You can also fill out this form at *www.geartechnology.com*

ADVERTISER INDEX

USE RAPID READER RESPONSE to contact any advertiser in this issue
www.geartechnology.com/rrr.htm
Rapid Reader Response: It's FAST! It's EASY! It's ONLY ONLINE!

Advertiser	Page	Phone	E-mail	Internet
Aero Gear Inc.	8	(860) 688-0888	buygears@aerogear.com	www.aerogear.com
Ajax Magnethermic Corp.	47	(800) 547-1527	ajaxsales@ajaxmag.com	www.ajaxmag.com
American Metal Treating Co.	46	(216) 431-4492	mark@americanmetaltreating.com	www.americanmetaltreating.com
Arrow Gear Co.	4	(630) 969-7640	bevels@arrowgear.com	www.arrowgear.com
A/W Systems Co.	10	(248) 544-3852		
Barit International Corp.	34	(847) 272-8128	people@barit.com	www.barit.com
Bourn & Koch Machine Tool Co.	8, 46	(815) 965-4013	bournkoch@worldnet.att.net	www.bourn-koch.com
Crucible Service Centers	32	(800) 365-1185	crucible@crucibleservice.com	www.crucibleservice.com
Dr. Kaiser (S.L. Munson)	37	(800) 775-1390	info@slmunson.com	
Dragon Precision Tools Co. Ltd. (Greg Allen Co.)	36	(440) 331-0038	gallenco@msn.com	www.gallenco.com www.dragon.co.kr
Dura-Bar	6	(800) 227-6455 or (815) 338-7800	sales@dura-bar.com	www.dura-bar.com
Enplas Inc.	11	(770) 795-1100	sales@enplasusa.com	www.enplasusa.com
Fässler Corp.	31	(414) 769-0072	usa@faessler-ag.ch	www.faessler-ag.ch
The Gear Industry Home Page™	28, 45	(847) 437-6604	people@geartechnology.com	www.geartechnology.com
Gear Motions Inc.	45	(315) 488-0100		www.gearmotions.com
Gear Technology Buyers Guide 2003	32	(847) 437-6604	patricia@geartechnology.com	www.geartechnology.com
Gleason Corp.	45	(585) 473-1000	dmelton@gleason.com	www.gleason.com
Gleason Cutting Tools Corp.	1, 45, 46	(815) 877-8900	dmelton@gleason.com	www.gleason.com
The Gleason Works	IFC	(585) 473-1000	dmelton@gleason.com	www.gleason.com
Ikona Gear International Inc.	29	(604) 513-9552	info@ikonagear.com	www.ikonagear.com
IMTS 2002	20	(703) 893-2900 or (800) 322-4687		www.imtsnet.org
Insco Corp.	28	(978) 448-6368	sales@inscocorp.com	www.inscocorp.com
Interstate Tool Corp.	46	(216) 671-1077		www.interstatetoolcor.com
ITW Heartland	29	(320) 762-8782	itwgears@itwgears.com	www.itwgears.com
Jamal Group of Companies Inc., Gears & Transmissions Div.	46	(91) (80) 841-0239	jamalgrp@bgl.vsnl.net.in	www.jamalgears.com
Koepfer America L.L.C.	47	(847) 931-4121	sales@koepferamerica.com	www.koepferamerica.com
Koro Sharpening Service	47	(763) 425-5247	steve@koroind.com	
Kreiter Geartech	46	(713) 237-9793	kreiter@kreiter-geartech.com	www.kreiter-geartech.com
Lambert & Wahli	45	(41) 323-56-0272	sales@lambert-wahli.ch	www.lambert-wahli.ch
LeCount Inc.	34	(802) 296-2200 or (800) 642-6713	lecount@sover.net	www.lecount.com
Midwest Gear & Tool Inc.	19	(586) 754-8923	rosscr@attglobal.net	
Midwest Gear Corp.	46	(330) 425-4419	ronh@mwgear.com	www.mwgear.com
Nachi Machining Technology Co.	5	(586) 263-0100	sales@nachimtc.com	www.nachimtc.com
Okamoto Machinery Co. Ltd.	46	(847) 520-7700	bkojima@okamotocorp.com	www.okamoto-kouki.co.jp
Perry Technology Corp.	IBC	(860) 738-2525	sales@perrygear.com	www.perrygear.com
powertransmission.com™	26, 45	(847) 437-6604	ptsales@powertransmission.com	www.powertransmission.com
Precision Gear Co.	30	(330) 487-0888	sales@precisiongear.net	www.precisiongear.net
The Purdy Corp.	39	(860) 649-0000	sales@purdytransmissions.com	www.purdytransmissions.com
Russell, Holbrook & Henderson Inc.	4	(201) 796-5445	sales@tru-volute.com	www.tru-volute.com
Star Cutter Co.	2	(248) 474-8200	sales@starcutter.com	www.starcutter.com
Star Cutter Co. (West Branch Industries)	46	(888) 737-4277 or (989) 345-2865	sales@starcutter.com	www.starcutter.com
SU America Inc.	BC	(847) 649-1450	sales@suamerica.com	www.samputensili.com
Toolink Engineering	30	(303) 938-8570	support@toolink-eng.com	www.toolink-eng.com
United Tool Supply	19	(800) 755-0516	unitedtool1@aol.com	www.unite-a-matic.com

CLASSIFIEDS

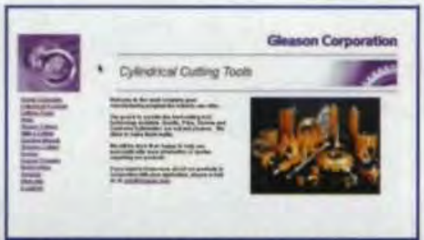
WEBSITES

LAMBERT & WAHLI

Lambert & Wahli are worldwide the most innovative manufacturers of fine-pitch gear hobbing, worm and thread milling equipment. State-of-the-art design facilities and Switzerland's best engineering personnel are at your disposal to help you meet the market's challenges.

To learn more about us, see our website at

www.lambert-wahli.ch



GLEASON CUTTING TOOLS CORPORATION

Gleason Cutting Tools Corporation is the leading gear cutting tool manufacturer in North America. We offer a wide variety of form-relieving milling cutters, hobs, shaper cutters, shaving cutters and CBN-plated form grinding wheels as well as our engineering, coating, heat treating, metallurgical, tool sharpening and reconditioning services.

www.gleason.com

GLEASON CORPORATION

Gleason is the world's most comprehensive resource for gear manufacturing technology. We offer a comprehensive gear cutting machine program for every gear hobbing, milling and grinding application for cylindrical and bevel gears. To learn more about our products and services or to find key contact information, see our Web site.

www.gleason.com

Learn more about the Gear Motions Ground Gear Network modern fleet of CNC gear grinders at our multi-plant locations. Our Oliver Gear facility in Buffalo, NY, has the new Höfler 700 Grinder while our Nixon Gear facility in Syracuse, NY, has one of the most modern fleets of Reishauers in the country.

The Gear Motions companies also provide CNC hobbed gears for commercial requirements.

www.gearmotions.com

THE GEAR INDUSTRY HOME PAGE

Explore the world of gear manufacturing from your desktop! With more than 75 of the gear industry's leading suppliers, the buyers guide on *The Gear Industry Home Page*™ is the only online resource you need for machinery, tooling and service providers in the gear industry.

www.geartechnology.com

powertransmission.com™

If you sell gears or gear drives, there's no better place to reach your potential customers than on *powertransmission.com*. The online buyers guide there helps design engineers, purchasing agents and manufacturing professionals find power transmission components from more than 100 leading suppliers. See our full-page ad on p. 26.

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FROM RUSSIA, WITH TEETH

In a little-known incident, Soviet machinists at Mil Helicopter worked in 1988 and 1989 on a special project to be used against Americans.

They were given the work by a gear engineer, Boris Zakoldaev, who now uses a different name.

Working at Mil's Panki factory, the machinists made only the metal parts. The composite pieces were made 25 miles away, in Moscow.

The completed machine was later transported by air into America's heartland, arriving at Chicago's O'Hare International Airport. The machine was taken to Milwaukee, WI, and unleashed against Americans—at a competition for human powered vehicles.

The machine was a reclining bicycle with an egg-shaped shell.

Human powered vehicles include bicycles and other vehicles—trikes, rickshaws, pedal boats—that are powered by people, not motors or engines.

"The attempt was to beat the Americans," says Zakoldaev, now Stepan Lunin, a transmission engineer who works in Chesapeake, VA, for Volvo Penta of the Americas Inc.

Lunin's bicycle didn't win its race.

Ridden by another Soviet man, the bicycle wasn't suited for the race course. The bicycle's shell had a narrow slot for its steering wheel, so it needed race courses with very gradual or no curves. The race course had sharper curves than the bicycle could easily manage. Also, the bicycle was pushed around by the wind.

The bicycle was designed with an egg-shaped shell to decrease its aerodynamic resistance. It was made as a reclining bicycle to reduce the shell's front area, further decreasing its aerodynamic resistance.

But, the bicycle wasn't in the shell—it *was* the shell. The wheels and large sprocket were mounted on the composite shell, with no conventional bicycle frame.

Lunin recalls the shell's drawbacks: little space, danger and no cup holders.

His bicycle was the product of Soviet generosity. Lunin explains that the Soviet Union was very enthusiastic about building high-speed bicycles 15 years ago. So, he got money for his bicycle and three others through grants from three private businesses involved in developing new ideas in sports.

He recalls receiving a budget of about 350,000 rubles. At an exchange rate of 60 cents a ruble, the sum amounted to about $210,000. He next hired a manufacturer to make the bicycle's main metal parts.

"I went to my own company," he says, "and they did the job for me."

The major plastic parts—the shell pieces—were manufactured at a location in Moscow: Lunin's garage.

"I had experience with the composites," he says, "so I did that myself."

Lunin made four molds for creating complete shells. He then combined the plastic parts with the metal parts: the sprocket set, the large sprocket's bearings, two aluminum beams (one for holding the large sprocket, the other for holding the first beam), and a fork for supporting the steering wheel. Standard bicycle parts, like brakes and brake levers, were also added.

Each bicycle weighed about 77 pounds. Each large sprocket weighed a little more than 2 pounds—"definitely heavy for a bicycle," Lunin says.

Despite the bicycle's weight, Lunin reached a speed of 80.6 miles per hour on it in the summer of 1988, in Moscow. He held that speed for about 7 seconds, setting a 200-meter speed record in the Soviet Union.

Lunin's speed and time that day were recorded by the Sport Committee of the Soviet Union, an official government committee.

Stepan Lunin rides one of his four specially-made bicycles. Aeroflot, a Russian airline, was a sponsor, providing Lunin with free flights and cargo delivery of his bicycles for international races.

Each of Lunin's bicycles had a 21" diameter, 131-tooth sprocket with involute teeth and round roots. The large sprocket combined with a 13-tooth sprocket to create a speed increaser with a 10:1 ratio.

Today, Lunin's too busy for bicycling. Among other things, he's building his own house in Chesapeake, VA.

Regarding his name, Lunin explains that Boris Zakoldaev was probably listed with the KGB because of his work at Mil. So, he used his dead maternal grandfather's name to more easily obtain a travel visa. Becoming a permanent U.S. resident, he Americanized that name slightly to Stepan Lunin.

As for his bicycles, he recalls that one is in a showroom of Flevobike Technology in Holland. Another is in the Washington, D.C., area. The other two bicycles disappeared from a Moscow warehouse, along with part of the grant money. ⚙

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