August 2008

GEAR TECHNOLOGY

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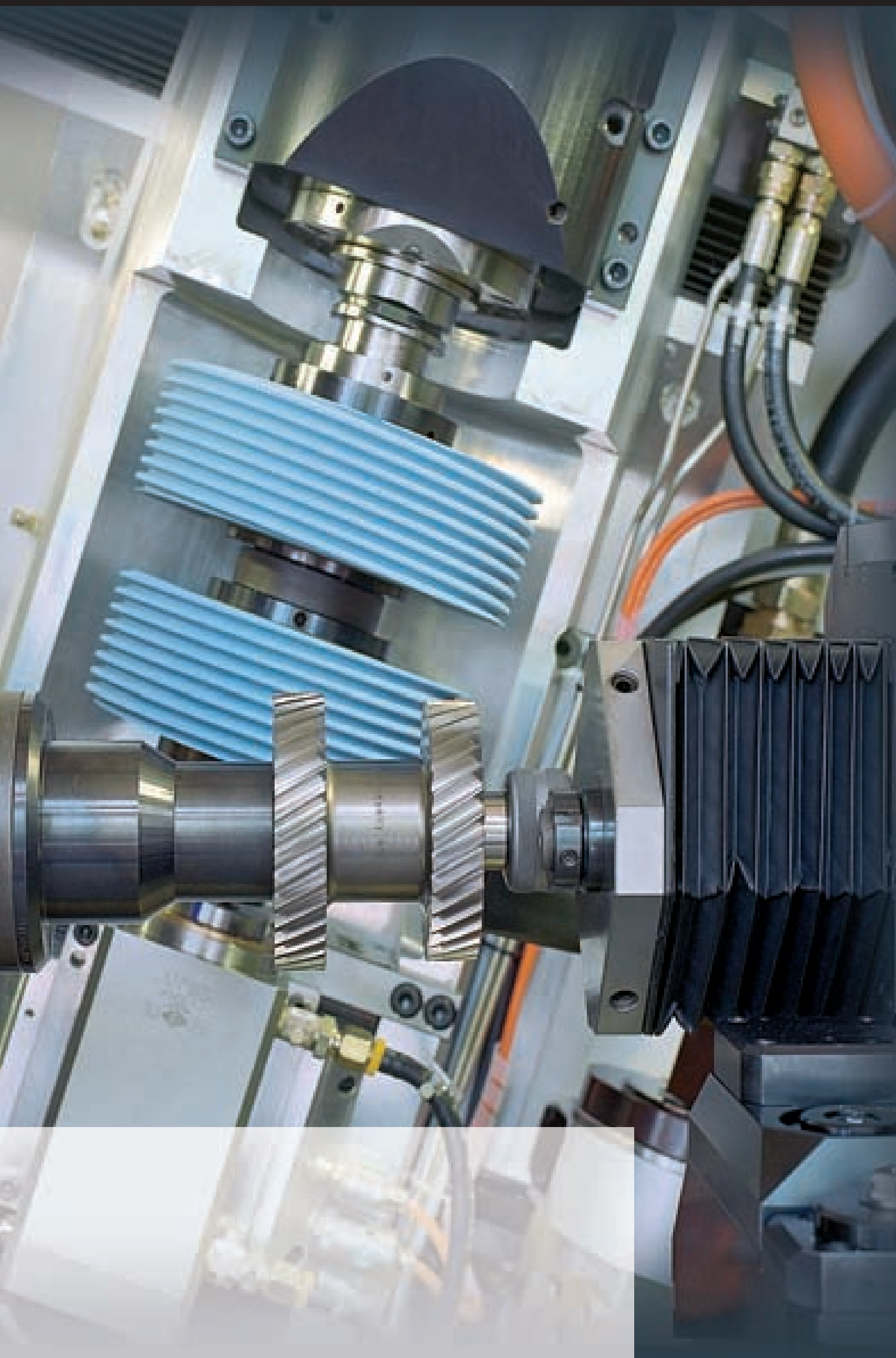
The Journal of Gear Manufacturing



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- New Jet Engine Technology Spells Relief for Embattled Airlines
- IMTS—Two Days Shorter, but Big as Ever
- "Green" Heat Treating—An Oxymoron No Longer

Technical Articles

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- Innovations in Heat Treating Provide Distortion Control for Automotive Applications
- How Grinding Burn Impacts Pitting Capacity

Plus

- Addendum: How Gears and Movies Mesh

THE GEAR INDUSTRY'S INFORMATION SOURCE

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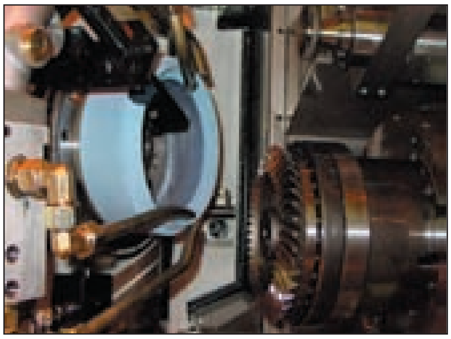

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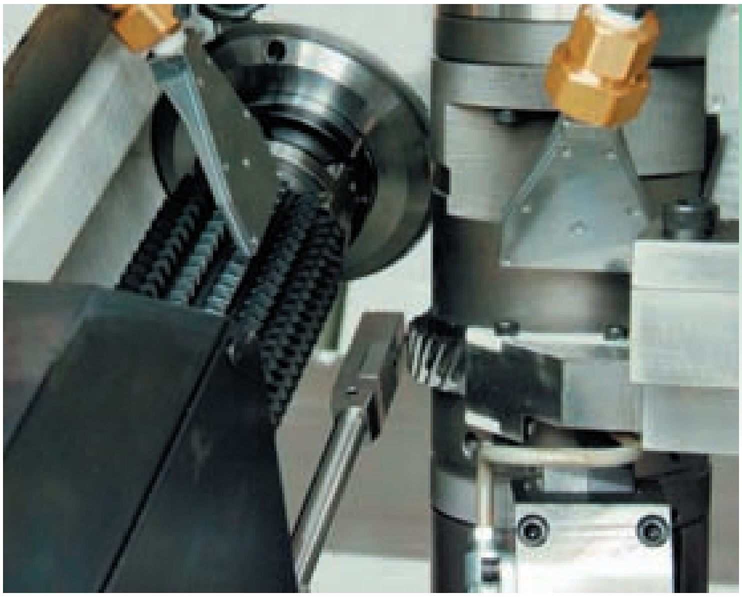

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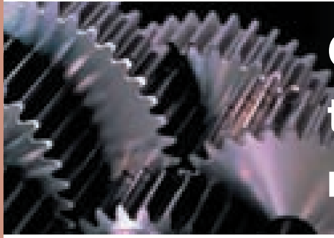

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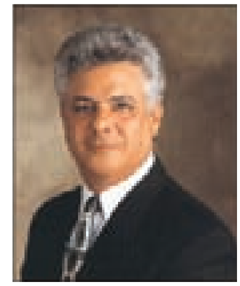

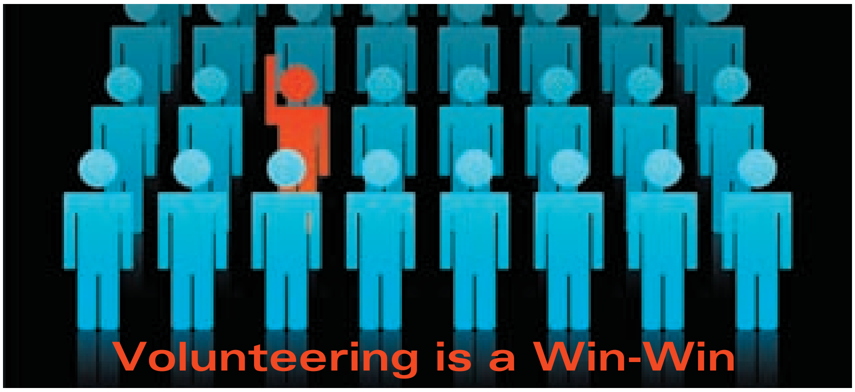

You know the classic comedy routine where the military commander lines up his troops and asks for volunteers for a suicide mission? The one where, instead of stepping forward, all the smart ones take a giant step backward, leaving the dim-witted heroes as unwilling volunteers.

Very often, those "volunteers" end up saving the day by using skills and talents they never knew they had. Volunteering can be like that. It forces you to grow and puts you in positions you may not have thought you were ready for. But in the end, the payoff can be big.

A lot of important activity in the gear industry—like most industries—is run by volunteers. They serve on countless committees and special work groups under the auspices of AGMA, ISO, SAE and many other organizations. These are not paid positions, but their work is vitally important to the ongoing success of the manufacturers and industries they serve.

Many of you probably feel that volunteering would be just one more duty piled on an already full plate of obligations. Your work schedule is already hectic. When you get home, you want to spend time with the kids, the grandkids or the dog. You'd spend time with your spouse if you could just finish all the things on the honey-do list. You're wishing you could just watch a ball game or go fishing.

Volunteering for one more thing would be like signing up for a suicide mission, right?

I'll admit, these volunteer projects take up a lot of time. But I've always believed that learning is a never-ending process. And few experiences provide the tuition-free learning opportunities that working on industry volunteer projects offer.

For example, you might be a very good gear designer or manufacturing engineer. But getting involved in one or more of the AGMA technical committees would force you to develop a much broader understanding of the areas you work in. Instead of working only on your company's products, you'd be helping develop standards that cover a wider variety of applications and configurations. Working through the meticulous details and talking with other engineers over the course of many weeks, months or even years might make you not just a very good gear engineer, but an expert.

Recently I spoke with a corporate executive at a major worldwide gear manufacturer, and we got to talking about the value of working as a volunteer for industry organizations. He told me that his company's VP of engineering had been involved with AGMA's technical committees for many years. In the beginning, he was the committee gofer—the one who grunted through all the hard mathematical work that no one else wanted to do. Over time, he gathered a significant body of knowledge and understanding that made him one of the foremost experts in his area of gearing. I asked the corporate executive if this man could have risen to his present position if not for his experience on AGMA's technical committees. Probably not, the executive said.

For many years, I served as a volunteer for the Machinery Dealers National Association. As a volunteer, I took on a lot of responsibilities that had nothing to do with my career as a machine tool dealer, but which broadened my experience and gave me new opportunities. Most importantly, I got my start in publishing as publisher of the *Locator*, MDNA's directory of used machinery. That experience gave me the background I needed to launch *Gear Technology*.

In the engineer's case, and in my case, volunteer work was vital in developing knowledge and expertise. But it can also help you develop in other ways, particularly with leadership and people skills. Most of us come out of school with training in engineering, accounting or management. But there's no college degree in how to deal with, lead and inspire people. Working on volunteer projects can help you build those skills.

When you're on a committee with other volunteers, you're working with people who aren't beholden to you. They can tell you to take a flying leap if they don't like your attitude, your approach or your solution. So even if you think you're right, you have to listen to them, find ways of convincing them, and communicate your vision. Those are skills that can be valuable down the line, especially when you find yourself in a leadership position. You can lead employees instead of just having them follow your orders.

Although volunteer projects can be extremely valuable in developing knowledge and expertise, perhaps most important is the sense of accomplishment and self-worth you get from being involved on an industry level and seeing projects come to completion. When you take on these roles, you begin to see yourself as much more than just a worker with a particular job title. When you look in the mirror, you're proud of the person you see staring back. The knowledge you gain, the leadership skills you develop, the broader vision you acquire and an improved self image stay with you, long after you leave the volunteer position.

When you see an opportunity to volunteer, don't be the one who steps back from the line because you're afraid to take on the challenge. Recognize the opportunity and be the one who steps forward. You can help not only your industry and your company, but yourself as well.

Michael Goldstein,
Publisher & Editor-in-Chief

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The GT Series of lathes from Haas Automation is capable of high power and a range of speeds at affordable prices. Both models, the GT-10 and GT-20, occupy minimal floor space and offer short cycle times as a result of 710 ipm rapids and a high-speed cross slide.

The GT-10 has a maximum capacity of 10" x 8", part swings of 16.25" over the front apron and 12.75" over the cross slide. A vector drive spindle operates at 7.5 hp, providing high torque and a wide, constant power band. One optional feature is a pneumatic chucking system with a 5", three-jaw chuck, rotating union and drawtube.

The GT-20 model has a maximum capacity of 11" x 12", part swings of 13" over the front apron and 9.25" over the cross slide. The vector drive spindle runs at 20 hp. A high-productivity hydraulic chucking system with an 8.3" three-jaw chuck, rotating union and drawtube are optional with this model. The GT Series' base configurations allow speeds up to 3,000 rpm, but with the respective optional systems, speed is increased to 4,000 rpm.

Haas offers high productivity options for the GT Series that include the Haas Intuitive Programming System, two-position, quick-change tool posts for 0.75" tools, a high-volume coolant system, user-definable macros and program memory space for 16 MB, according to the company's press release.

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Mahr Federal Inc. introduces a surface finish gage designed to index and measure numerous small parts, such as gears, fuel injector components and inner or outer bearing components. The gage can support as many as eight measuring stations incorporating a Perthometer M1 or M2 surface measuring instrument. Most common profile parameters are supported, including DIN, ISO, ASME and SEP.

"With most surface measuring systems, the concept is to fix the part and maneuver the measuring head around it," says Ron Lavoie, director engineered solutions for Mahr. "What's interesting about this solution is that we have fixed the measuring device and present the parts to it. This provides a very economical way to measure many different characteristics on a series of parts without having to replicate the measuring system."

The original design was custom-made to accommodate a series of different types of gears that required measurements on the inside diameter and on the end face. "The fixture we designed uses a lazy susan type

continued

staging table to stage up to three varieties of different parts," explains Charles Toffling, Mahr Federal product engineer. "The part tooling holds the parts either on their IDs at two different measurement depths or on their end faces so you can measure the front face. The tooling is designed at a known height so that the measurement altitude is always the same. In operation, you put the part on the gage, rotate the table to index over to the centerline of the gage head, then rotate the handle to position the probe for measuring."

The gage is 18 inches long by 12 inches deep, with the drive unit and measurement head enclosed. A diamond stylus probe is protected by a metal shroud and only contacts the part if it is positioned correctly for measurement. "The probe is automatically lowered and raised when the measurement head is positioned on the part," Toffling says.

"The only thing the operator has to do is rotate the table, index the measurement head to the calibration standard and press the start button. Everything else is automatic."

Lavoie says, "The system has been designed to be as easy to operate and maintain as possible. Yet the result is a highly sophisticated device that provides a precision platform for fast, accurate surface measurement on a variety of parts in a production setting."

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The Mida OGP70 optical spindle probe from Marposs Corp. provides high-precision machining and milling. The product has unidirectional repeatability of 0.1 micron. Measurement data is transmitted to the CNC by a wireless receiver and interface, and the probe is integrated into the transmitter module. With 360 degree transmission for activation and deactivation, the OGP70 has a wide transmission angle. RS232, ethernet or digital I/O can be used to connect the probe to a CNC machine. The Mida OGP70 will be introduced at IMTS in booth D-4514.

For more information:

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The HyperMach H4000, from MAG Cincinnati—a subsidiary of MAG Industrial Automation Systems—cuts parts up to 2 x 4 meters. The five-axis, horizontal machining center is designed to make parts for aircraft components. It uses a vertical x-axis moving table, full-portal open center for high-volume chip/fluid collection and a fixed column to provide y- and z-axis position of a curving a- and c-axis spindle.

The machine comes with a 30,000 rpm, 60kW HSK63A spindle or 20,000 rpm, 85kW HSK100A spindle. The y and z axes are driven by high-speed ball screws, and the spindle carrier moves at 25 rpm in a and c axes. The standard machine includes a 96-tool automatic tool changer, but it is capable of a 190-tool capacity.

"The H4000 addresses industry needs for leaner, faster, more automated production of large, complex-geometry parts made to today's tighter tolerances," says Rand Von Moll, MAG Cincinnati platform manager for aluminum machining. "We designed it as a game-changer to give part producers a competitive edge. It lets them take advantage of two major shifts in aerospace and manufacturing: the need for precision fits required for determinate assembly and accelerated production schedules with shorter ordering/delivery cycles."

The HyperMach H4000 is being introduced and demonstrated at IMTS at booth A-8281.

For more information:

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The honing system's work envelope is 1,016 mm x 1,778 mm, and it has a maximum weight capacity of 909 kg. The bore profile is displayed during cycle by a straightness sensing feature, so along with a servo stroking system, the SV-310 can auto-dwell at any point to adjust bore straightness. The system is capable of honing parts up to 710 mm long with inside diameters ranging from 19–200 mm.

The machine was configured with full-height access doors and enclosure, so robotic part loading systems can be used to produce medium to high part volumes. Automation is controlled by a 20-amp power supply while a three-axis hand wheel helps place x-axis position, vertical stroke and tool feed. The touch-screen control allows operators to program multiple bore positions with an unlimited capacity for job setups.

The SV-310 has a rigid base made from malleable iron. A ballscrew drives the straight-line stroke motion at 1–160 strokes per minute, and torque is provided by a 5.5 kW spindle for removing metal quickly. The machine's horizontal and vertical guide ways are lubed-for-life.

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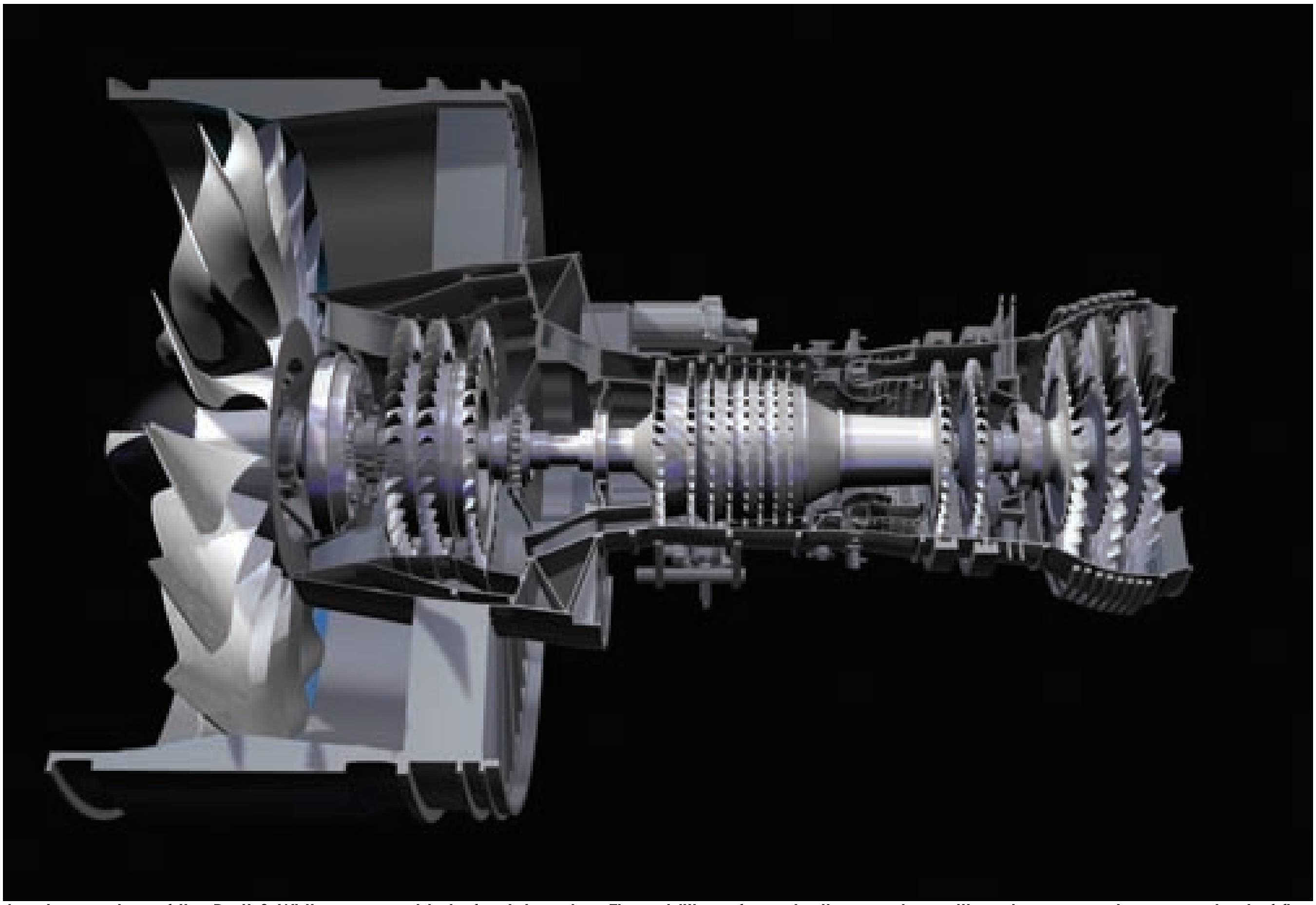
Jack McGuinn, Senior Editor



A cutaway view of the Pratt & Whitney geared turbofan jet engine. The addition of a reduction gearbox with a star gear system comprised of five stationary gears made the breakthrough possible. (All photos courtesy Pratt & Whitney)

Today's ever-evolving global economic engine is, in many ways, a wonderful phenomenon; you know—a rising-tide-lifting-all-boats, trickle-down-theory-of-economics dynamic at work.

Unless, that is, you run an airline.

News today abounds with headlines announcing major carrier personnel layoffs, new or higher customer fees, flight cut-backs and, worst case—bankruptcy. Airlines of course run on jet fuel—their most expensive business cost—and while the price of your car's regular unleaded is skyrocketing, the same applies to jet fuel, and in significant numbers. An April 9th *New York Times* story reports that a 1 cent increase in the per gallon price of jet fuel translates to an additional cost to the industry of $200 million per year.

But don't dump all that airline stock just yet. Help is on the way, and a unique—some say revolutionary—

outside-the-box design for incorporating gears into a jet engine is part of the reason why.

A propulsion revolution. That "revolution" is in full bloom at East Hartford, CT-based Pratt & Whitney (a United Technologies subsidiary), the designer and builder of aircraft engines, space propulsion systems and now—cue drum roll—the *geared*, turbofan (GTF) engine. The gear set speed reducer (transmission) is what helps make this engine a truly cutting-edge technological advance, with what the company calls a "state of-the-art gear system" enabling the engine fan to function independently of a low-pressure compressor and turbine, which results in significant fuel efficiency and reduced fan speed for a quieter ride.

"We believe the Pratt & Whitney geared turbofan engine offers a technological breakthrough that will provide the best economy and performance for the Mitsubishi Regional Jet," says Mitsubishi Heavy Industries, Ltd. president Kazuo Tsukuda in a P&W press release. "The (new engine) will offer airline customers best-in-class fuel efficiency and environmental performance, with superior cabin comfort."

That the engine was also developed to address environmental concerns should come as no surprise, as industries of all stripes are making "green" a best-practice marketing platform. Estimates vary, but available data show that airplane transit results in approximately two percent of the world's greenhouse gases. And any airline that develops new technology in alleviating that concern stands to benefit with customers and airspace providers alike.

Enterprise becomes necessity. According to Bob Saia, Pratt & Whitney vice president/next-generation product family, the GTF engine is the realization of 20 years' development, during which design challenges such as engine durability, weight reduction and installation optimization were resolved. But he says that with the ongoing reality of exorbitant fuel costs, the project assumed greater urgency.

"For several years, growing economic and environmental pressures have made the geared turbofan engine even more attractive. With sky-high fuel prices, increased emissions regulations, noise pressures and airlines looking for every opportunity to cut costs, an engine that can deliver double-digit reductions in fuel burn, emissions, noise and maintenance cost is the right product at

continued

the right time," he says. "Today, we are investing more than $100 million (U.S.) a year to develop and demonstrate this technology so that we can be ready for entry into service in 2013." Saia adds that while the current GTF is intended for next-generation regional jets and single-aisle mainline craft, "There are no limitations that prevent the GTF engine to power wide-body aircraft."

As proof that good things are worth waiting for, there was that long, 20-year slog of constant research and development. In developing the GTF engine, P&W in 2007 designed and built a $12 million test facility in nearby Middleton, CT to challenge the GTF's gear system with robust testing conditions exceeding those typically experienced in flight. The gear system test rig is capable of handling up to 60,000 shaft hp and simulating flight altitudes of up to 45,000 feet.

"I was impressed at how quiet the (GTF engine) was at idle and full takeoff power, requiring only minimal hearing protection and allowing the ability to

hold a conversation while the engine was running at those high speeds," says Bob Pekarek, director of power plant and component engineering for Northwest Airlines. "Typically, being that close to an engine at takeoff power requires maximum hearing protection and there is no chance of holding a conversation.

"The dramatically reduced fuel burn, noise and emissions of (the GTF engine) are significant advantages."

The program has thus far logged more than 40,000 takeoff rotations, 200 hours at "maximum red line speeds" and endurance testing in the initial gearbox test evaluation, according to Saia. Post-test hardware inspections, he says, "were very good with no visible wear found." In fact, he adds, "Gear teeth surfaces still showed the original production machining surface conditions." To date, P&W's GTF engine demonstrator has completed 250 hours of ground testing, says Saia, and the engine "will begin flight testing later this year on our 747 flying test bed."

The thrust of things to come. Gear professionals, engine designers and others in the industry know, of course, that turbofan jet engines are not new, and they are in fact standard for today's jets. P&W's Saia provides for the rest of us a short course in conventional jet propulsion.

"Jet engines produce thrust by pushing air through a large fan at the front of the engine. A small portion of that air is compressed, mixed with fuel and ignited to power a turbine at the back of the engine, which in turn spins a shaft that runs through the engine to drive the engine's fan. To improve fuel efficiency, engine makers work to maximize the amount of air pushed through the fan (bypass air), while using as little fuel as possible to drive the fan. The ratio of air pushed through the fan to the air mixed with fuel to drive the fan is called bypass ratio; the higher the bypass ratio, the more fuel-efficient the engine."

But, P&W's Saia explains, conventional turbofan engines have limits, in that "As the fan diameter increases to increase bypass ratio, the turbine must also grow to create more power to drive the larger fan. Fans want to turn at slow speeds, while turbines want to turn at high speed. With the fan and turbine directly connected by the shaft, a compromise must be made to maximize fan diameter (low speed) at the best turbine speed (a slower-than-optimum speed).

"Slower-turning turbines require more stages and higher airfoil counts to power the fan; the additional stages and airfoils increase the engine's weight and operating costs. There becomes a point where the added weight and inefficiency of the larger turbine has cancelled out any fuel efficiency gained by a larger fan."

Which presents the challenge—how to reduce the speed of the outer ring gear in a significant way?

Answer: the addition of a reduction gear box—or transmission system—comprised of a star gear system with five stationary gears. As Saia explains, the gear box decouples the fan from the turbine so that each component can turn at its optimum speed, while also allowing for a lighter, more efficient turbine to turn at a higher speed in driving a much larger, slower-turning fan. The marrying of a faster-turning turbine with a slower-turning fan results in new-found fuel efficiency at a much-reduced noise level. In fact, the addition of the gearbox provides a low-pressure turbine speed of three times that of the fan. The system also includes a "swept," aerodynamically enhanced fan for additional efficiencies.

Burning "greener" gas. So how does all of this reduce fuel consumption, cabin noise and pollutants? To break it down further, Saia says, consider that with a typical, direct-drive turbofan engine the limitation is that its turbine is most efficient, i.e.—creating the most power for the least fuel consumption—when it is rotating at optimum speed. And, as mentioned, this type of engine's turbine and fan are unalterably linked, presenting an unavoidable compromise in speed.

But, says Saia, "The GTF engine breaks this paradigm. This game-changing engine architecture introduces a reduction gear system allowing both

continued

the fan and turbine to operate at their optimum speed. By turning a large fan—increasing the bypass ratio of the engine—fuel efficiency is improved by more than 12 percent. This is directly related to a 12 percent improvement in CO_2 emissions. The slower-moving fan produces much less noise—50 percent less than today's engines. We've also introduced an advanced combustor to reduce NOx emissions by 55 percent.

"The GTF engine also delivers an engine design which is shorter and lower-weight than today's power plants."

With the critical, grind-it-out R&D completed, Pratt & Whitney has big plans for the GTF engine. And why not?

"(Last year), Pratt & Whitney's Geared Turbofan engine was selected as the exclusive power for the new (aforementioned Mitsubishi Regional Jet; officially launched this March with an order from All Nippon Airways) and the proposed Bombardier CSeries mainline aircraft," says Saia. "The CSeries is expected to launch later this year. Both aircraft are scheduled to enter service in 2013."

What next—alternative jet fuel?

A close-up of the five stationary gears in the geared turbofan engine speed reducer gearbox.

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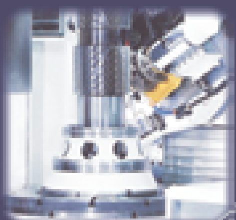
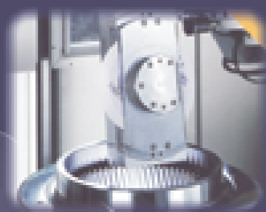

Double helical gear


Grinding of ball splines


Internal grinding with dressable grinding wheels and measuring probe arm.


Measuring

NILES Profile Grinding Machine ZP40

Tip Diameter	157"
Grinding face	60"
Modul	1.7"
Rotary table dia.	89"
Bore of rotary table (dia & depth)	54" x 10"

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havlik@sympatico.ca www.havlikinternational.com

<u>Just the Facts</u>

International Manufacturing Technology Show 2008

September 8–13, 2008

McCormick Place

2301 S. Lake Shore Drive, Chicago, IL 60616

Sponsored by the Association for Manufacturing Technology (AMT)

www.imts.com

www.meetinchicago.com

(the official visitors' site for Chicago)

<u>Show Hours</u>:

Lakeside Center— 9 a.m. to 5 p.m.

North, South and West buildings—10 a.m. to 6 p.m.

<u>Pavilions</u>:

Abrasive Machining/Sawing/Finishing—North Building, Hall B

Controls & CAD-CAM—East Building, Hall D

EDM—East Building, Hall D

Gear Generation—North Building, Hall B

Machine Components/Cleaning/Environmental—East Building, Hall D

Metal Cutting—South Building, Hall A

Metal Forming & Fabricating/Laser—North Building, Hall B

Quality Assurance—East Building, Hall D

Tooling & Workholding Systems—West Building, Hall F

IMTS 2008 The Focus—Global Technology

Lindsey Snyder, Assistant Editor

It's that even-numbered-year time-of-the-year again. The International Manufacturing Technology Show, IMTS 2008, is right around the corner. This 27th installment of the biennial trade show is focusing on connecting global technology, and visitors can expect to see exhibits from 1,500 companies spanning 1.2 million net square feet of space at Chicago's McCormick Center. Over 90,000 buyers and sellers typically come from 119 countries to look at more than 15,000 machine tools, controls, computers, software, components, systems and processes.

IMTS planners have been busy at work filling the schedule and extending the show's features. This year's conference, the Manufacturing Business and Technology Forum, has expanded. The forum sessions provide current technical information surveying the latest technologies that impact how companies manufacture and enhance the effectiveness of workforce efficiency and productivity. Forum sessions are designed to supplement what is seen on the trade show floor and are conducted by several industry partners: Society of Manufacturing Engineers (SME),

continued

Center for Automotive Research (CAR), American Society for Precision Engineering (ASPE), National Tooling and Machining Association (NTMA), ToolingU and the Association for Manufacturing Technology (AMT).

"By expanding the number of partners participating in our educational efforts, we can offer broad and relevant content to our IMTS attendees," says Peter Eelman, IMTS vice president–exhibitions. "More than ever before, we are designing this education experience for the end user."

One special session will be showcasing MTConnect, a new communication technology that provides an open standard for passing information between devices, equipment, systems and higher level applications. MTConnect combines manufacturing technology and computer science to access data on a regular basis. The goal is to create "a seamless 'manufacturing pipeline' from design to production," according to *mtconnect.org*. MTConnect will be open and free of royalties. The session will provide an overview of MTConnect with detailed presentations demonstrating how to develop an adapter for retrieving data from a device or piece of equipment. IMTS 2008 will be the first public demonstration of the standard's use. The forum session is free and sponsored by the AMT on Wednesday from 10 a.m. to 11:30, Thursday from 2 p.m. to 3:30 p.m. and Friday from 10 a.m. to 11:30 a.m.

"MTConnect may be the most exciting development in our industry since the introduction of NC almost 40 years ago," Eelman says. "We are mirroring the success occurring in the information technology world. That is, allowing devices, equipment and systems to output data in an understandable format that can be read by any other device using the same standard format to read the data. MTConnect will enable everyone in the production supply chain to be part of making the manufacturing enterprise more productive."

MTConnect will also be featured in several ways at the Emerging Technology Center (B-1000). At this location, people who are not familiar with the standard can watch a video presentation, learn about where it currently stands and watch live demonstrations where about 20 exhibitors, including Gleason, will connect from their booths on the show floor, and an illustrative computer dashboard will show MTConnect in action.

An international student competition will take place where contestants are challenged to use MTConnect to develop inventive theories. This competition concludes in October 2009 at EMO Milano in Italy. The Emerging Technology Center will also showcase recent research from universities and research labs including the Penn State Machine Dynamics Research Lab, University of New Hampshire, University of Kentucky, the Machine Tool Research Center at the University of Florida, the American Society for Precision Engineering, the Industrial Diamond Association and many others.

A new feature of IMTS this year is the Innovation Center, which will feature theater-style presentations each day between 11 a.m. and 2 p.m. Located in the Lakeside Center (East Building), the Innovation Center aims to bring specific themes to life by industry experts. The theme will differ from day-to-day as follows: Monday's theme is automotive, sponsored by Ward's Automotive Group; Tuesday is quality, sponsored by *Quality* magazine; Wednesday is aerospace/aeronautics, sponsored by *Aerospace Manufacturing and Design* magazine; Thursday is power generation/green day, sponsored by *Today's Energy Solutions*; Friday's theme is medical, sponsored by *Today's Medical Developments* magazine; and Saturday is job shop day, sponsored by *American Machinist* magazine.

"As we continually assess the desires of our exhibitors, it is clear that to increase the attendance at IMTS, we must market to specific industries," Eelman says. "For the future we will be offering more and more industry-specific information and programs to make the IMTS experience highly meaningful for our attendees.”

For the second time, IMTS will present a battle of the robots at two locations. Robots will show off their skills on office equipment and kitchen appliances at the Lakeside Center in the East Building. Bots battle each other at the “You Drive Them” station in the North Building, and there will be a live bot-on-bot competition using robots built by manufacturing companies from the Midwest. Battles will take place daily.

Students from middle school through vocational college levels are invited to be special guests at IMTS as part of the Student Summit, sponsored by the National Institute for Metalworking Skills (NIMS) and the AMT. Educators and their students can attend the Career Development Center (CDC) and a self-guided tour of the exhibition for free. The NIMS Student Summit gives students the opportunity to approach student-friendly exhibitors—such as Haas Automation, Agie Charmilles, L.S. Starrett, ToolingU and Mastercam—and inquire about career opportunities and other questions pertaining to the precision manufacturing industry.

“By offering the opportunity for students and educators to experience IMTS and interact with exhibitors, as well as take advantage of the outstanding program NIMS has planned for our student attendees, we hope that students will see first-hand the outstanding, well-paying career opportunities precision manufacturing has to offer,” Eelman says.

At the CDC, students will hear young professionals speak about their experiences in the industry, and they will see exhibits from colleges and universities, companies, human resource representatives and industry associations. Door prizes will be awarded, and CDs containing industry-related career information will be distributed. New to this year’s show, graduating high school and college students are invited to drop-off their resumes for participating companies to review for entry-level job openings. More than 6,600 students and educators participated in the 2004 NIMS Student Summit at IMTS.

continued

Registration:

-For individuals, $25; $50 after August 1

-Groups of 5 or more from the same company,$15 per person, before August 1

- Unlimited conference and exhibit floor access all week, $600; $700 after August 1

- **Single-day conference pass includes full exhibit floor access, $400; $500 after August 1**
- **Free registration for international manufacturing industry visitors**
- **Free registration for educators and students with proper identification; students without a group must register on-site in the NIMS Student Summit Area (West Building)**
- **IMTS Registration Customer Service Department:** *imt081.attendee@experient-inc.com*, **Phone: (301) 694-5243**

Product Preview

Liebherr Focuses on Efficiency and Wind Energy Technology B-7016

With three machines in tow, Liebherr Gear Technology, Inc. will highlight flexibility, lean standards and a new contribution to wind energy applications.

The Klingelnberg P 26 Gear Measuring Center will be at Liebherr's booth representing the P series of analytical gear inspection machines equipped to handle gears with diameters as large as three meters. The line was designed with wind energy applications in mind. A surface sensor developed by Klingelnberg measures the surface roughness of gears, in place of a stylus, by functioning right on the 3D sensing head.

The measurement system logs roughness values alongside the gear measuring tasks. This feature eradicates the use of non-automated measurements that require separate equipment. With cylindrical gears, the tooth flank roughness can be documented in both the profile and longitudinal flank axes.

The P 26 is compact and intended for smaller workpieces with diameters up to 260 mm. The measurement center is appropriate to test spur and helical gears, hobs, shaper and shaving cutters, worm gears, bevel gears and other workpieces. Ted Klemm, a regional sales manager for Liebherr, will be demonstrating the Klingelnberg P 26 Gear Measuring Center.

The LCS 150 generating and profile grinding machine is capable of applying CBN or corundum grinding tools. Tool use is combined, so generating grinding can be applied alone or along with profile grinding. Productivity was the key in designing the LCS 150 with loading and meshing idle times cut in half. The machine bed was designed to perform grinding using 35 percent less floor space.

Liebherr will also feature the PHS 1500, a flexible pallet handling system for machining centers capable of manual or fully automatic loading. Versatility was crucial in this system, which features a modular design and *Soflex* software. Maximum part dimensions are 1,150 x 1,000 x 1,050 mm pallet with part. The buffer has nine storage slots that can each store 1,500 kg–pallet with part.

For more information:

Liebherr Gear Technology, Inc.
1465 Woodland Drive
Saline, MI 48176
Phone: (734) 429-7225
Fax: (734) 429-2294
www.liebherr.com
info.lgt@liebherr.com

Seven CNC Machines Showcased by Star-SU, B&K Open House in Rockford B-6912

In adddition to displaying machines from Bourn & Koch, Samputensili S.p.A., Star Cutter Company, Sicmat and Process Equipment on the show floor, Star SU is inviting attendees to an open house at the new Bourn & Koch facilities 88 miles west in Rockford, IL. The open house, on Friday and Saturday, September 12–13 from 10 a.m. to 3 p.m., offers tours of the 25,700-square-foot office and engineering center and the 800-square-foot demonstration center. Visitors can view a Blanchard 11-20AD rotary surface grinder and a B&K 100H CNC horizontal hobbing machine in action. Reservations are strongly recommended, and Bourn & Koch will offer van trips from the bus station in Rockford to the plant and back. For information about transportation, including driving directions, contact Cathy Manske at *cmanske@bourn-koch.com* or call (815) 965-4013 ext. 2305.

The Star PTG-6 tool and cutter grinder is equipped with six axes to grind, sharpen and recondition a variety of cutting tools. The 60 kW direct-drive grinding spindle has six-station HSK grinding wheel mounting that places the grinding wheel on the B-axis pivot's center. Using the *NUMROTOplus* software package, the PTG-6 makes

continued

cross-sectional representations with 2D simulation, and there is an optional 3D grinding simulation that can detect machine collision. Heat build-up in the direct drive headstock and the grinding spindle is controlled by a closed-loop chiller, and glass scale feedback is provided for all linear axes. The new CTG3 tool and cutter grinder offers most of the same features but with a small footprint and a three-station HSK grinding wheel pack.

The Bourn & Koch 400H CNC horizontal hobbing machine has 7 axes capable of hobbing spur and helical gears and splines and threads on cylindrical blanks or shafts. A standard model features a NUM 1060H CNC control, tail center with variable load control, and it can hob wet or dry.

The Samputensili S 400 G generating and profile grinding machine was designed to mass-produce gears and shafts with straight and helical gear teeth. The machine is modular and has a small footprint. It features a Siemens CNC Sinumerik 840D control with more safety features and internet connections.

The B&K Fellows MS450-125 CNC gearless gear shaper has six axes, direct drive spindles, electronic indexing, optional electronic helix setting, and elevating cutter spindle housing. The mechanical stroking gear shaper was designed to shape both internal and external gears. Features with the standard model include storage for approximately 100 part programs, a Fanuc 30iB CNC system, hydrostatic spur guide, 15" color LCD touch screen, GFI duplex outlet and a manual pulse generator.

For shaving shafts and gears in varying sizes, the RASO 400 from Sicmat uses an open "C" structure. Combining internal and external automation allows the machine to manage auxiliary operations such as chamfering, deburring, and centrifugation marking. The RASO 400 is strong and stiff enough to shave gears with large modules and face widths like those in agricultural equipment, earthmovers and industrial vehicles.

The PECo ND300 is a 4-axis

CNC-controlled inspection system that measures gears, splines, worms and gear-cutting tools. The system features non-contact, linear motor technology and a "Crash Protected" precision scanning probe head by Renishaw to make a

variety of measurements including profile-total, form and slope/angle; helix-tooth alignment (lead)-total, form and slope/angle; pitch, index, spacing and pitch-line runout; tooth thickness and size over/under pins; and datum geometry roundness, form and runout per ANSI and ISO geometric standard callouts.

For more information:
Star-SU LLC
5200 Prairie Stone Parkway
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Hoffman Estates, IL 60192
Phone: (847) 649-1450
Fax: (847) 649-0112
sales@star-su.com
www.star-su.com

Large Capacity Hob Sharpening from Koepfer America B-6907

The KFS 250S is a new product from Koepfer America which sharpens large hobs using a high-speed, direct-drive grinding spindle. Other features include a GE Fanuc CNC panel, software equipped for conversational programming and an integrated crane to load and unload large hobs without difficulty.

"The KFS 250S offers several advantages," says Dennis Gimpert, president of Koepfer America. "Importantly, the machine has a maximum grinding capacity of 254 mm hob diameter and 305 mm hob length. The KFS 250S sharpens to AGMA 'AAA' quality, is suitable for either high-speed steel or carbide tools and has pre-loaded linear guide ways."

Several other machines will also be displayed at Koepfer's booth. The Monnier & Zahner MZ 130 CNC gear hobbing and worm milling machine produces spur gears, worm gears, worms and threads in large and small amounts. The Wenzel WGT 350 gear inspection machine has air-bearing technology on all four axes of CNC control standard, and the Koepfer Model 300 gear hobbing machine uses new technology flexibly in eight square meters of area.

For more information:
Koepfer America, LLC
635 Schneider Drive
South Elgin, IL 60177
Phone: (847) 931-4121
Fax: (847) 931-4192
www.koepferamerica.com
sales@koepferamerica.com

Mitsubishi's Gear Hobber Employs Environmentally Friendly Cutting Tools B-7025

The fully automated GE15A gear hobbing machine will be on display by Mitsubishi Heavy Industries of

continued

America, Inc., Machine Tool Division. Mitsubishi's SuperDry II cutting tools are used in a coolant-free, high-speed cutting process. The features were designed to promote flexibility with quick-change pallet adapters and cutter arbors as well as an enhanced operator screen. The pallet conveyor was supplied by Creative Automation, Inc. (B-6445).

Mitsubishi is also displaying the ZE15A generating type gear grinder for rapid, high-quality machining. Its features include fully automatic 8-axis control, ring type automatic loader, automatic dressing and grinding wheel balancing units, in addition to direct-drive motors.

For more information:
Mitsubishi Heavy Industries
America, Inc.
Machine Tool Division
46992 Liberty Drive
Wixom, MI 48393
Phone: (248) 669-6136
Fax: (248) 669-0614
www.mitsubishitoday.com

Reishauer Displays Hard Gear Finishing and Automation Technology B-7005

The RZ 303C Precision Gear Grinding Machine from Reishauer Corporation uses gearless planetary drives, acoustic sensors to align dressing diamonds, and low noise shifting (LNS), which prevents excitation on gear teeth. The work area helps make quick changeovers. Fast machine uptime is achieved by the dressing unit's setup location, ease of wheel change and nearly unrestricted location of the gear on the shaft or arbor. The machine axis is used to move the wheel to produce

continued

root, flanks and tip modifications. The main onboard loading system transports un-ground parts in the gear grinder, and they are organized in stacks of steel or plastic baskets, which are served by an in-plant conveyor style, table or basket buffering handling systems. The cell utilizes decoupling individual processes for flexibility and efficiency.

For more information:
Reishauer Corporation
1525 Holmes Road
Elgin, IL 60123
Phone: (847) 888-3828
Fax: (847) 888-0343
www.reishauer.com

Kapp Gear Center Combines Application Production Solutions
B-6748

Two machines and a range of CBN and diamond-plated tools will be on display by the Kapp Group. The new Kapp KX 500 FLEX provides continuous generating grinding, discontinuous profile grinding or a combination of both. The 500 FLEX is capable of grinding external spur and helical gears up to 10 mm with an outside diameter of maximum 500 mm and gear width up to 520 mm. The machine is suitable for single- or twin-spindle dresser use, and automation options are available. The gear center has a multi-station turntable and twin-spindle dresser, so different tooling concepts can be used, such as dressable and non-dressable ceramic tools for prototype machining and grinding of medium- to high-volume series.

The NILES ZE 400 machine will also be at the Kapp booth, which has been one of the company's best selling products. The bed casting of the NILES ZE 400 is fashioned from thermally-optimized ductile iron to support a maximum workpiece weighing 2,650 pounds. The machine includes tailstock, CNC dressing device, on-board measuring and a Siemens 840D control. Siemens 611D simo-drives run the axes while data is placed directly into the control or prepared for transfer via network.

For more information:
The Kapp Group
2870 Wilderness Place
Boulder, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131
info@kapp-niles.com
www.kapp-usa.com

Modular Honing Machine Sizes, Finishes Bores to Submicron Accuracy
B-7200

The SV-1000 vertical CNC honing machine series from Sunnen is capable of scaling up from a single-spindle machine to a fully automated multi-spindle unit for precise bore sizing and finishing with accuracies of 0.25 µm. The machine is designed for diameters of 3–65 mm for gears, diesel fuel injectors, small engine cylinders or connecting rods, hydraulic or pneumatic components and medical devices in medium to high volumes.

The SV-1000 series' base is made of polymer, allowing for vibration damping and rigid structure. For fixture control, it is available with a fixed tooling plate or servo rotary table with 12-position rotary air union, and up to four spindles are offered. Integrated post-process air gaging provides closed-loop control of bore size and geometry to 0.25 µm accuracy.

continued

A servo-controlled stroking drive responds smoothly to the control's motion profiles. This feature provides the capability to perform conventional honing and single-pass honing using adapters and any Sunnen tool. The high-torque spindle is driven by a belt and is rated at 7.5 kW, so a range of sizing and finishing work can be performed from 100–4,000 rpm.

Sunnen will introduce the VSS Series Single Stroke Honing systems at the show. The spindles on these machines are factory aligned independently in order to achieve precision centering of the spindles and tooling plate. The VSS-2's alignment accuracy exceeds DIN 8635 requirements for vertical honing machines. As many as six spindles can be incorporated to size and finish part bores with tools that have preset diameter and grit size. Precision sizing of bores 3.9–50 mm diameter in stamped parts such as hydraulic valve bodies, gears, sprockets, parking pawls, rocker arms and turbocharger housings are ideal for the series.

"The VSS Series 2 sets a new standard for single-pass bore sizing efficiency," says Phil Hanna, product manager for machines at Sunnen. "If a part is best suited for single-pass honing, the VSS-2 provides a level of precision not available in other designs. And, with the new touch screen control, this machine is very operator friendly. No custom electronics or special training are needed and the control is designed to interface with part handling automation systems."

For more information:

Sunnen Products Company
7910 Manchester Ave.
St. Louis, MO 63143
Phone: (314) 781-2100
Fax: (314) 951-2718
www.sunnen.com

Mahr Gear Tester Analyzes Wide Range of Gears
D-4324

The GMX 400 Universal Gear Tester will be displayed by Mahr Federal. The GMX 400 is a class 1 gear tester capable of evaluating gear and gear tool applications with maximum ODs of 400 mm. It combines a four-axis power PC controller with an automatic tailstock and 3D scanning probe head to automatically inspect straight and helical cylindrical gears; spiral and hypoid bevel gears; crown gears; cylindrical worm shafts; conical cylindrical gears; gear segments; shaving cutters and hobs; pinion-shaped cutters; beveloid gears; synchronous gears; 3D geometry; and form and positional measurements, diameters and distances. The GMX 400 is appropriate for both stand-alone shop floor and gear lab use.

A similar machine from Mahr was introduced a few years ago, but this latest version offers some new features. "It has a new controller and is therefore faster than it was," says Pat Nugent, Mahr Federal vice president of Metrology Systems. "The biggest change is in the development of software since that time. That was why we were waiting to bring it back to the U.S. market. We felt that we needed substantially more software option packages and features within those packages. We believe that we now have those, and this is the time to bring this back to the U.S. market under the Mahr banner."

Mahr is also bringing to IMTS the MarSurf WS 1 Optical Surface Metrology System, which records surface topography on a range of materials, air gages for machine tool tapers and the Digimar 817 CLM Height Measuring Instrument that offers three measurement modes.

For more information:
Mahr Federal Inc.
1144 Eddy Street
Providence, RI 02905
Phone: (401) 784-3275
Fax: (401) 784-3246
information@mahr.com
www.mahr.com


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Companies Exhibiting Products for Gear Manufacturers

*boldface indicates Gear Pavilion exhibitors

Exhibitor, Booth No.

ABB Inc., B-6114
Abrasit, B-7144
Accu-Cut Diamond Tool Co., Inc., B-7243
Accurate Diamond Tool, F-2131
Acme Manufacturing Co., B-7241
Advent Tool & Manufacturing, F-2750
American Broach & Machine Company, B-6821
AM Machinery Sales, Inc., B-6746
ANCA Inc., B-7432
Anderson Cook Inc., B-6439
Applied Recovery Systems, LLC D-4623
Automated Precision, Inc. D-4652
Automation Innovation, Inc., D-4409
Bates Technologies, Inc., B-7535
Blum Laser Measuring Technology Inc., D-4558
KK Blum LMT, D-4558
Blum-Novotest GmbH, D-4558
Bourn & Koch Inc., B-6912
Broaching Machine Specialties Co., B-7220
Broach Masters/Universal Gear, B-7103
Brown & Sharp, D-4303
Cameron, F-2369
Carl Zeiss IMT, D-4501
Centric International, Inc. B-6938
Ceratizit, F-2886
Dan di De Antoni Srl, B-7144
Dr. Kaiser, B-7121
Drake Manufacturing Services Co., B-7407
DTR (formerly Dragon Precision Tools), F-2814
Dura-Bar, F-2845
Edgetek, B-6760
Eitel Presses, Inc., B-6516
EMAG L.L.C., B-6907
EMAG Maschinenfabrik Gmbh, B-6907
Emuge Corp., F-2667
Engis Corp., B-7422
Hommel – Etamic, D-4535
Euro-Tech Corporation, F-2310
Extrude Hone Corporation, B-7100
Fette / LMT USA, F-2419
Finishing Associates, Inc., B-7150
Fred V. Fowler Co., Inc. D-4316
Frejoth International Ltd., D-4258
Frenco GmbH, F-2310
Froemag, B-6907
***Gear Solutions* magazine, B-6780**
***Gear Technology* magazine, B-7116**
Gehring GmbH & Co. KG, B-6740
Gehring L.P., B-6740
Gleason Corporation, B-6902
Gleason Cutting Tools Corporation, B-6902
Gleason-Hurth Maschinen und Wekzeuge, B-6902
Gleason - M&M Precision Systems Corp., B-6902
Gleason-Pfauter Maschinenfabrik GmbH, B-6902
The Gleason Works, B-6902
Gould & Eberhardt Gear Machinery, B-6919
GPA Engineering Corp., B-7021
Guyson Corporation of U.S.A., B-7131
Haas Automation, A-8000
Hainbuch America Corp., F-2973
Hammond Machinery, Inc., B-6953
Hammond Roto-Finish Co., B-6953
Hassay Savage Co., F-2212
Havlik International, B-6874
Hexagon Metrology, Inc. D-4303
Höfler Maschinenbau GmbH, B-7045
Hoglund Technology, B-6919
Holroyd, B-6760
Horn USA, F-2227
IMEXSU-DeBurring, B-7256
Ingersoll Cutting Tools, F-2050
I-TECH International Corp., B-7415
ITW Workholding, F-2486
Izar Herramientas, F-2466
Jones & Shipman, B-6760
Kapp GmbH, B-6748
Kapp Technologies, B-6748
Kashifuji Works, Ltd., B-7021
KGK International Corp., D-4725
Klingelnberg GmbH, B-7016
Koepfer America, LLC, B-6907
Lapmaster International, LLC, B-7437
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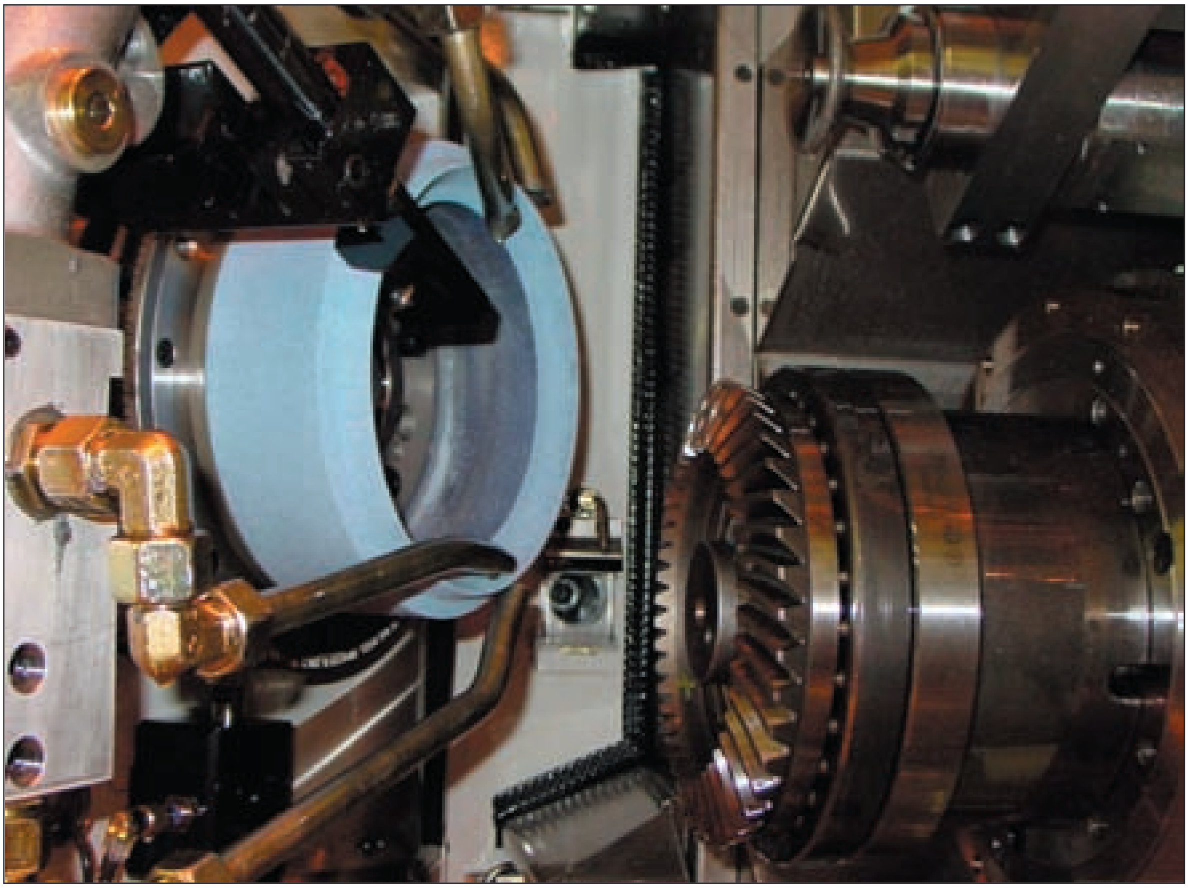
Mahr Federal Inc., D-4324
Marposs Corporation, D-4514
MD Tooling, F-2586
Micro-Vu Corporation, D-4506
Mitsubishi Heavy Industries – MI, B-7025
Mitts & Merril L.P., B-7212
Monnier + Zahner AG, B-6907
Mycrona of North America, Inc., D-4429
Nachi America, Inc., B-7021
Nachi-Fujikoshi Corp., B-7021
Nachi Robotic Systems Inc., B-7021
NILES Werkzeugmaschinen GmbH, B-6748
Normac Inc., B-7505
Optimet, D-4522
Osaja Seimitsu Kikai Co., LTD., B-7021
Osborn International, B-7214
Parker Majestic, B-6830
Performance Tooling Solutions Int'l., F-2959
Pratt & Whitney Measurement Systems Inc., D-4513
Process Equipment Company-Metrology Systems Division, B-6912
Profiroll Technologies USA, B-6657
Promess, Inc., B-6540
Quick Change Specialties, F-2339
Reishauer Corporation, B-7005
Rhodes Mktg, B-6672
Roto-Flo, B-7511
R.P. Machine Enterprises, Inc., B-6919
Saacke North America, B-7321
SAMP S.p.A., B-6912
Schenck Balancing and Diagnostic Systems, D-4541
Senjo Seiki Co., Ltd., B-6938
Setco, D-4609, B-7108
Sicmat S.p.A., B-6912
S.L. Munson, B-7121
SMW Autoblock, F-2040
Solar Atmospheres, B-6325
Speedgrip Chuck, F-2369
SPS Spindle Parts & Service, D-4099
Star SU LLC B-6912
Steelmans Broaches, F-2470
Studer, B-6700
Suhner Industrial Products Corp., F-2601
Sunnen Products Company, B-7200
TTB Engineering, B-7321
Ty-Miles, Inc., B-6917
United Grinding, B-6700
U.S. Equipment Co., B-7511
U.S. Gear Tools, Inc., B-7511
U.S. Union Tool Inc., F-2732
Wendt, B-7054
Wenzel GearTec GmbH, B-6907

Guidelines for Modern Bevel Gear Grinding

Dr. Hermann J. Stadtfeld



Management Summary

This paper acknowledges the wide variety of manufacturing processes—especially in grinding—utilized in the production of bevel gears and that gear designers and engineers cannot always be expected to have an informed understanding of them. To address that information gap, guidelines—both documented and as yet unwritten (experiential)—are presented here in support of state-of-the-art grinding of bevel

Introduction

Guidelines are insurance against mistakes in the often-detailed work of gear manufacturing. Gear engineers, after all, can't know all the steps for all the processes used in their factories, especially those used in the grinding of that most complicated type of gear—bevels.

And even when the steps are known, there are all the unwritten guidelines, the ones learned through experience rather than from a design or manufacturing handbook. Those guidelines are numerous and require time to think about—and finally see—whether the time to do so is taken while standing on the shop floor or by going back to an office desk. Gear engineers' work would be much easier if some of the major guidelines were documented, and thus the reason for this presentation.

Semi-Finish Strategy

Several technological and geometrical factors are central in guaranteeing high-quality ground gears. The first factor is a smart strategy for semi-finishing gears. This strategy requires a gear manufacturer to think about its processes in reverse order, making certain the gears it wants to work on at the start of step four are the ones created by the end of step three. For example, uniform stock allowance on the flank surface is important, but only if the semi-finish cutting summary is derived from the finish grinding summary. Figure 1 shows the basic idea—how the semi-finish soft profile relates to the finish profile.

Also, sections of progressively increasing ease-off should not be ground without preparing them in the previous cutting operation. This particularly applies to universal-motion heel or toe sections (UMC) as well as to second-order protuberance (blended Toprem) and flank relief.

With heel or toe relief sections, a gear grinder sometimes has to remove 50% or more stock in some areas of the tooth if the sections are not prepared properly during soft cutting. For example, a green gear may have a regular stock removal of 0.13 mm per flank. Variation from heat treat distortion may add 0.07 mm in certain areas. Also, the hardened gear may require removal of an additional 0.10 mm of stock within the relief section. If the green gear isn't cut properly, a worst case could require the removal of 0.30 mm of stock in one grinding pass.

Possible results of such grinding include burn marks, new hardening zones, or a reduction of surface hardness due to the reduced thickness of the case depth. The case depth of bevel gears in the module range of 3–6 mm is recommended to be between 0.8–1.2 mm after heat treatment. The worst-case scenario would reduce the case depth during grinding to 0.5 mm, perhaps less, reducing the surface and subsurface strength.

Also, grinding of root relief, the so-called blended Toprem, leads to a critical condition on the grinding wheel because the small, sensitive tip of the grinding wheel might have to remove 10–30% more stock than the main profile section. Heavy material removal at the tip of the wheel causes a deterioration of the protuberance section and the edge radius after grinding only a few slots. Subsequently, the remaining slots have reduced or no root relief, and an unacceptable blend into the root-fillet radius. This effect cannot be cured by subsequent redressing.

An important part of the semi-finish strategy for modern bevel gear grinding is a root fillet area which is not ground. The optimal protuberance of the cutting blades relieves the transition between flank and root by a value between 60% and 100% of the stock allowance on the active flanks. The cutting blades should have an edge radius 0.1 mm smaller than the edge radius of the final grinding wheel profile. They also should cut 0.1 mm below the theoretical grind depth.

The transition between the grinding profile and the unground root area can be optimized on the drive side of both members, using a grinding wheel tip extension and a setover, to get a smooth blend of the ground to the unground root surface and clean up the root radius to the area of 30° tangent.

Figure 2 shows the superimposition of an outside blade profile (blue), an inside blade profile (green) and the finish grinding profile (red). The cutting silhouette cuts 0.1 mm deeper, and in this example relieves 100% of the stock, in that a blend between cutting and

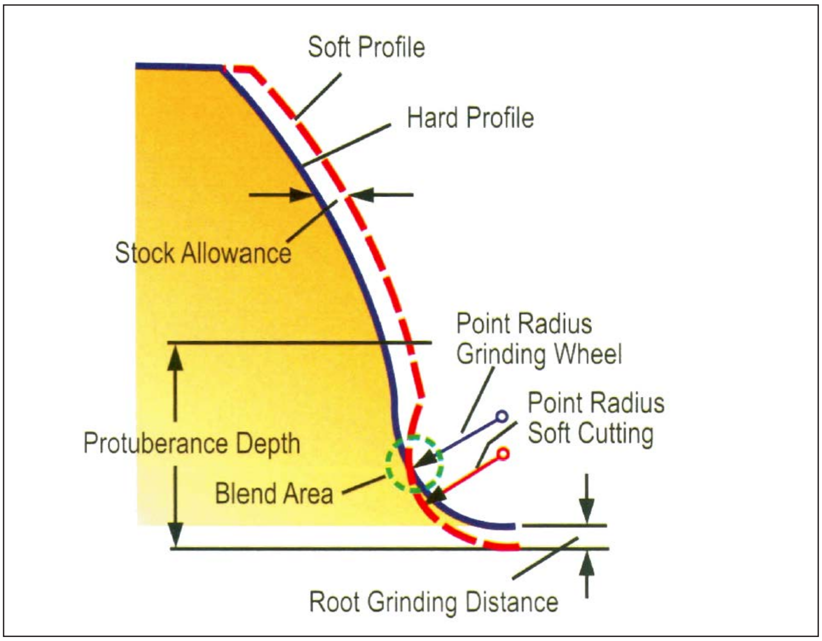


Figure 1—Root fillet relief, derived from finish profile.

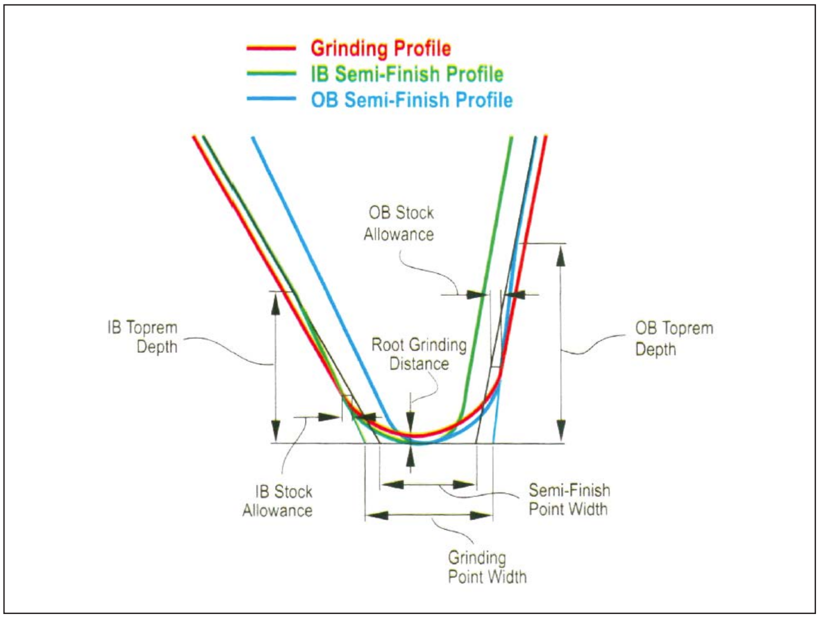


Figure 2—Superimposed profile plots, cutting blades and finish grinding profile.

grinding surfaces occurs below the active flank working area. All parameters of the correct semi-finish blades follow a tight rule as soon as the amounts of relief on flanks and root are defined. For example, the edge radii of the blue and green cutting sides should blend seamlessly with each other, as should the clearance side radii with the same side (same color) cutting edge radii. This is necessary in order to achieve the maximal radii on the cutting blades but also to avoid fins and grooves in the root bottom. Gleason has developed a software module called *Semi-Finish Calculation*. This module will automatically calculate blade parameters and new basic settings for semi-finish cutting from a few input items such as stock allowance percentage of relief, applied Toprem angles and amount of deeper cutting. If no input is given to the semi-finish input screen, default values that represent best practice in bevel gear grinding are instead used.

Figure 3—Unground root bottom in a ring gear.

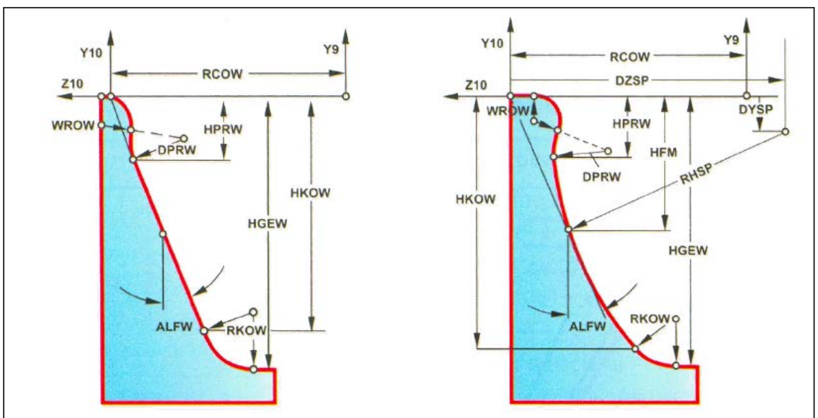


Figure 4—Blended Toprem in straight (left) and curved (right) blade profile.

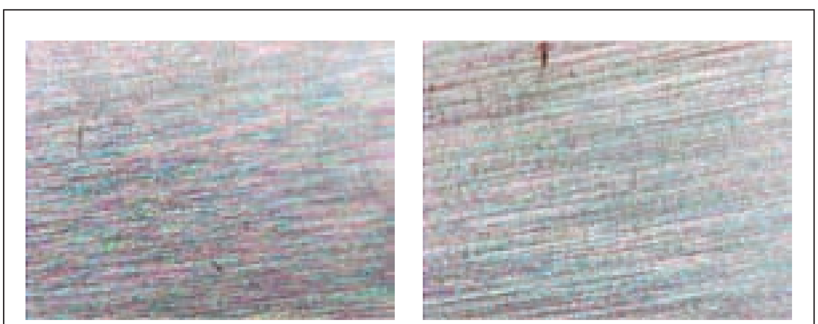


Figure 5—Surface structure after grinding (left conventional, right MicroPulse).

The distortions due to heat treatment cause an unequal cleanup along the face width and from slot to slot around the circumference. Also, the first- and second-order corrections—applied after coordinate measurement to achieve correct flank geometry—influence the angle of the ground root line versus the semi-finish cut root line. This root-angle difference might result in a partially ground root bottom.

The rule is that the root bottom should not be ground in a section that contains 30% or more of the face width. Stock removal in the root bottom should also be contained to a range of 0 to 0.05 mm. The variation from slot to slot can change the unground section between 30% and 100% without disadvantage to the performance of the gear set. Figure 3 shows an example of a completely unground root—with no disadvantages for the strength performance of the ring gear.

Interference and Blended Toprem

If a face-milling geometry shows a high transition line between root and flank that was generated by the profile generating process, and not by a too-large point radius of the tool, then an interference of the top edge of the mating teeth can initiate surface damage and noise excitation. This interference zone can be relieved via a second-order protuberance, which is a radius that connects the grinding wheel main profile and the edge radius with a tangential blend.

The standard definitions associated with the grinding wheel profile include the point radius RCOW; the edge radius WROW; the pressure angle ALFW; and the blade curvature (RHSP). Figure 4 shows these standard profile parameters and the additional parameters required to define blended Toprem in a straight grinding wheel profile (left, Fig. 4) and a curved grinding wheel profile (right, Fig. 4).

Surface Finish and Surface Treatment

A finish-ground bevel gear set should have an R_z equal to or less than 5 µm and an R_a equal to or less than 0.8 µm.

The ground surfaces of hypoid gears always carry the risk of scoring during the initial wear-in period. To eliminate this risk, the flank surfaces of at least the ring gear should be phosphate-coated. (The risk of scoring may also be eliminated during the first operating period through the use of synthetic hypoid oil.) Nevertheless, the risk of scoring during operation is reduced due to the enhancement of the surface finish.

Enhancement of the surface also can be achieved through a Gleason method called MicroPulse (patent pending). Certain additional machine movements in the micron range can generate a more irregular surface texture. In Figure 5 (right side), such a texture is compared to a conventionally ground surface finish (left side). The irregular texture reduces higher harmonic amplitude levels and creates desirable side bands in the frequency spectrum. MicroPulse-treated surfaces are superior to the conventional grinding structure on bevel gear flanks (Ref. 1).

Grinding Wheel Specifications and Performance

Keys to efficient grinding are the abrasive material and the abrasive bond. Recommended for bevel gear grinding are grinding wheels with an 80-grit, sintered, aluminum oxide abrasive with an open-pore, soft-ceramic bond. Results of extensive process development have shown that non-uniform particle size, e.g.—80-grit wheel specification that contains particles between 80 and 240 size—increases the grinding wheel wear and the need for redressing. Uniform particle size, say between 80 and 120 grit (for an 80-grit wheel specification), requires fewer redressings because the grinding wheel retains shape and dimension longer.

The automatic resharpening effect of a wheel is based on the radial and tangential cutting forces on a grinding grain. The three cases of wheel wear are:

Case 1: Grain breaks out of ceramic bond (bulk wear)—Wheel stays sharp, but loses size.

Case 2: Grain dulls (attritional wear)—Wheel keeps dimension; surface finish improves; grinding force is high; risk of burning.

Case 3–a: Grain fracture of mono crystal (fracture wear)—Wheel dulls somewhat and loses some dimension.

Case 3–b: Grain fracture along particle boundaries of sintered grain—Dimension is stable; wheel is always very sharp.

Sintered aluminum oxide grains consist of particles in a size range of a tenth of a micron. This explains the difference in fracture characteristic between conventional aluminum oxide and sintered grains. Conventional grains, as shown in Figure 6a, left-break like a mono crystal (see indicated fracture). A grain, sintered from several hundred million aluminum oxide particles—as shown in Figure 6b—will develop a fracture that nearly preserves the original size of the grain and creates a high number of cutting edges. It often appears that the sintered grain structure has rake and relief angles. The wheel wear rate versus the metal removal rate is an indication of how much wheel wear occurs during a certain material removal. This

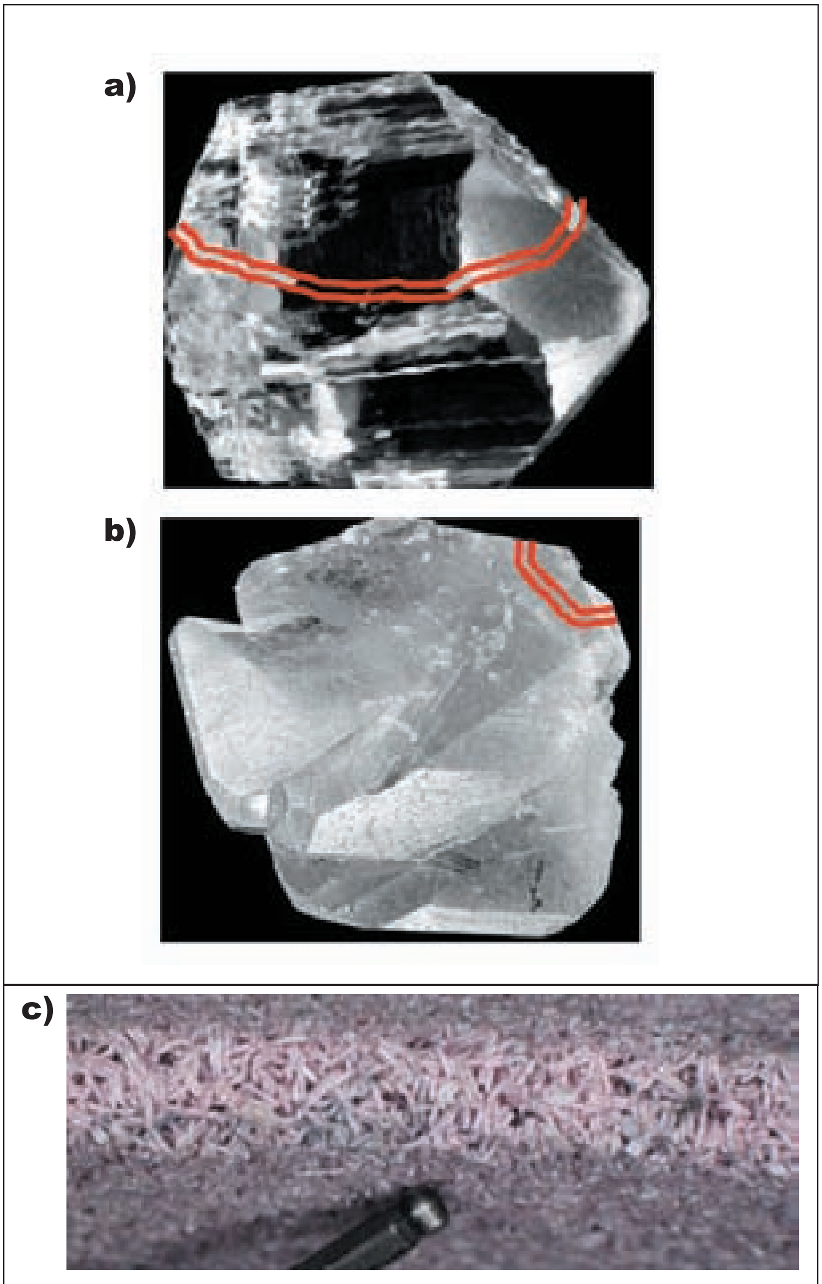


Figure 6—a) conventional aluminum oxide grain; b) SG sintered aluminum grain; c) ZG grinding wheel structure with worm shaped grains.

indicator also reveals how frequently redressing is required and what the life will be of a complete grinding wheel. Regarding sintered aluminum oxide, the wheel wear is almost independent from the metal removal rate. Usual metal removal rates in bevel gear grinding lead to about a third of the grinding wheel wear, as compared to conventional aluminum oxide.

Modern, high-performance sintered aluminum oxide grinding wheels may contain optimized grain shape and advanced ceramic binders, allowing higher surface speeds and much higher removal rates compared to standard sintered aluminum oxide wheels. Examples of these advanced wheels include the Targa TG and TG 2 brands from Norton/Saint-Gobain Abrasives. Today, Gleason and Norton collaborate in grinding research in order to qualify the Targa wheel technology for bevel gear grinding. It is anticipated that grinding with Targa wheels will not require any wheel wear compensation, and will reduce dressing frequency to every third to tenth part (instead of dressing after every part today) for high-quality automotive bevel gear grinding applications. Other new and promising types of grinding wheels worth mentioning are Altos and Vortex brands, with aluminum oxide grains Norton refers to as ZG. The grains of those wheels are "worm shaped" with a radial orientation, and the binder provides a very open wheel structure that allows light to pass through the wheel (Fig. 6c). These types of grinding wheels—similar to the Targa wheels—require low dressing frequency and work best above 30 m/min.

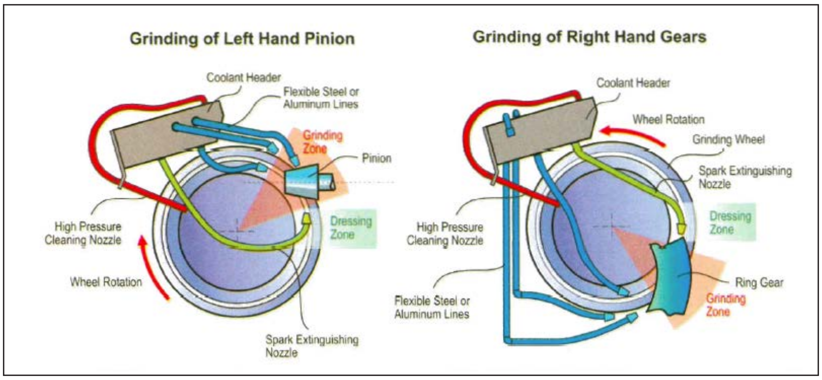


Figure 7—Coolant application (Ref. 2).

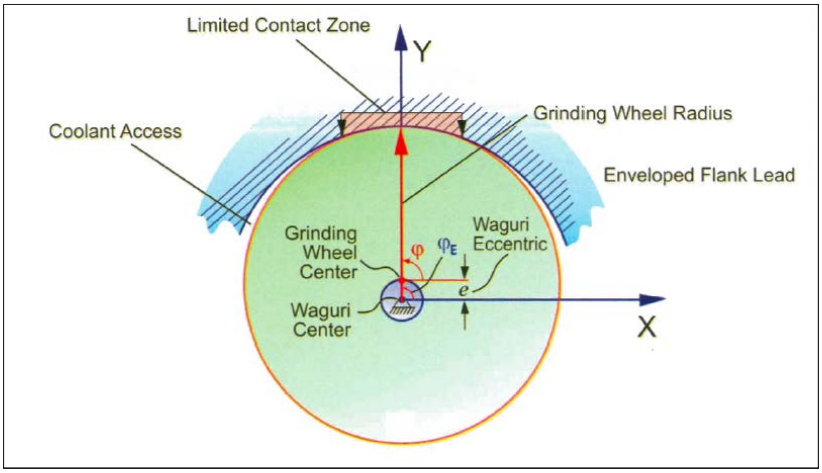


Figure 8—Waguri eccentric principle with coolant access and limited wheel contact.

Coolant and Grinding Wheel Cleaning

Applying the proper amount of coolant to the correct area between the work and grinding wheel is of great importance in avoiding surface defects and achieving good surface finish and flank form accuracy. Three or four coolant pipes are directed tangentially to the grinding wheel circumference—with a coolant speed of 75% to 100% of the grinding wheel surface speed—to apply a layer of coolant to the grinding profile surface just before it engages the grinding zone. Additional pipes are located behind the grinding zone and are directed opposite to the grinding speed to extinguish the sparks, which would burn into the wheel bond and get into the grinding zone (Fig. 7). The coolant pipes are connected to the high-volume coolant pump. This pump has a pressure of 4.5 bar, but it is rated for a high flow of 130 liter/min (Phoenix II 275 G) or 150 liter/min (Phoenix II 600 G). The utilization of more coolant pipes than is shown in Figure 8 will reduce the flow through the process-critical nozzles. Here, the rule is "less can be more."

In addition, the wheel's surface has to be cleaned continuously with a high-pressure coolant jet that's connected to an extra pump, which supplies the coolant at a pressure of at least 20 bar. The minimum required flow of the high pressure system is 24 liter/min (275 G), or 36 liter/min (600 G). The high-pressure jet has to be located roughly opposite the grinding zone and has to shoot coolant perpendicular to the profile surface (Fig. 7). Because of centrifugal force, the chips tend to clog up the inside profile more, so appropriate attention must be paid to the design and function of the high-pressure cleaning system.

The recommended grinding oil requires a flashpoint above 190°C. The viscosity for bevel gear grinding should be greater than, or equal to, 20 c St at 40°C. Lower viscosity, e.g., 10 c St, is better, but the available oils have flashpoints below 190°C. The grinding oil must not contain any sulfur (active or inactive). Even inactive sulfur, which typically is bound in compounds like the ones contained in the EP package, become active after grinding oil is used. Sulfur reacts with machine components and may, over time, cause deterioration.

Grinding Cycles

In the automotive industry, bevel gear grinding requires only one rotation of the gear, and each slot requires generally only one pass. The so called double roll cycle may be required if heat treat distortions are large. This cycle consists of one prefinishing pass, during which the grinding machine moves the grinding contact from toe to heel (uproll), and one fine-finishing pass, rolling from the heel back to the toe. Dressing should be done after a rotation is finished, not before, while a part is being ground.

In contrast, some gears for high-quality machine tools require two rotations, and aircraft parts are ground in four or more rotations.

In all cases, though, the rule is: After each rotation, the grinding wheel should be redressed. However, skip indexing should be avoided. This technique was developed in order to distribute wear more uniformly around the work in order to avoid ramp-shaped spacing errors. Rather than grinding successive slots, skip indexing skips a preset number of slots, thus requiring several revolutions to finish all slots.

Subsequently, though, it was discovered that many acoustic phenomena were caused by skip indexing. Experience with the technique showed that the many resulting small ramps generate noise with amplitudes in the tooth mesh frequency, the gear rotational frequency, and a frequency that corresponds to the number of ramps per revolution. In some cases, there even appears to be an additional modulation.

Thus, wear compensation is the best way to reduce ramp-shaped spacing errors and other wear patterns.

The surface speed to achieve good surface finish in connection with minimal grinding wheel wear is 20–24 m/sec—a rather low value when compared with conventional grinding processes.

When finishing Formate ring gears, they should be ground using Waguri motion to make the process more stable and faster. Normally, Formate gears are ground in a plunge-cut cycle. Without Waguri motion, the grinding wheel would have simultaneous contact with both complete flank surfaces of the tooth slot. As coolant cannot reach the grinding zones, burning and fast grinding wheel contamination with metal particles may result.

The process can be stabilized, however, through an eccentric motion applied to the rotating grinding wheel spindle. This so called Waguri motion should be about e = 0.10 mm to 0.12 mm eccentric in the plane of rotation about the theoretical grinding wheel axis. The Waguri speed should be 200–500 rpm lower than the grinding wheel speed, with a typical value of 2,000 rpm and the same hand of rotation as the grinding wheel itself. This grinding technique is named for its inventor. Figure 8 shows the Waguri principle and the limited contact zone with coolant access on both sides of that zone.

Waguri grinding is extremely fast. It can achieve grinding times of one second per slot. A Waguri-ground gear with 35 teeth is ground more quickly than a conventionally ground pinion with 13 teeth.

Grinding Wheel Dressing

The function of the dressing operation is to shape and true up the grinding wheel profile, and to condition the wheel surface topography for proper material removal performance. On Phoenix grinders, truing and dressing are performed in one step.

Dressing the grinding wheel requires that modern bevel gear grinders be equipped with a diamond-plated dress roller and an appropriately accurate and powerful dressing spindle. The dress roller can rotate in the opposite direction of the grinding wheel (negative dresser speed ratio), or in the same direction (positive dresser speed ratio). The upper diagram in Figure 9 shows the dresser speed ratio, versus the

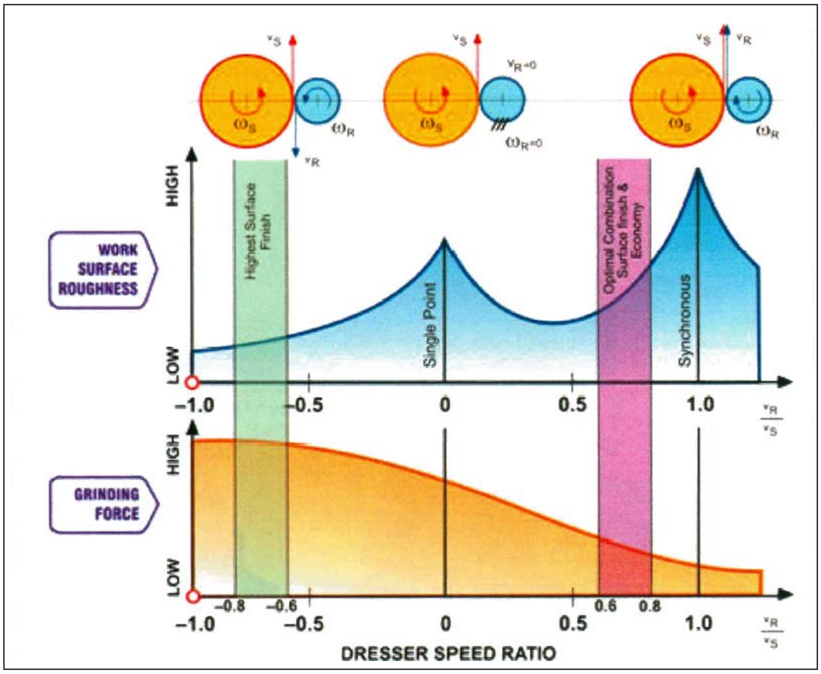


Figure 9—Dress roller ratio with preferred working sections (Ref. 2).

surface roughness, for the ground gears (Ref. 2). The lower diagram in Figure 9 shows the dresser speed ratio versus the grinding force (between grinding wheel and work), as a result of the dressing.

Dressing with negative as well as positive dresser speed ratios generates a grinding wheel-based approach path which has a trochoidal shape, excepting a dresser speed ratio of zero. Figure 10 shows the different approach paths for dresser speed ratio: –1.0 and +1.0. The right diagram in Figure 10 has a very steep slope, which makes the diamond crystals of the dress roller approach the grinding wheel grain almost perpendicular to the grinding wheel circumference (pure crushing action for dresser speed ratio +1.0). In case of dresser speed ratio –1.0 (left hand diagram in Figure 10), the diamond crystals of the dress roller approach the grinding wheel surface grains tangentially to the wheel circumference. This provides dressing with maximal abrasive action on the grinding wheel's surface grains, which in turn delivers low wheel profile roughness with high profile accuracy, as well as the fewest possible open pores for coolant and chip removal during the gear grinding.

Dressing with a dress roller axis, which is collinear to the grinding wheel as shown in Figure 11, is problematic since it leads to a large, relative curvature radius ρ_{IB} at the inside profile and to a small ρ_{OB} at the outside profile. The contacting length l_c between dresser and grinding wheel depends on the relative radius ρred—or reduced radius—and the normal dressing amount a_n. A dressing method according to Figure 11 leads to a good contact length l_c at the inside profile and an insufficient short l_c at the outside profile, caused by ρ_{redIB} and ρ_{redOB}.

The axial dressing amount, used for topping the profile back without radius changes, will translate to a smaller, normal dressing amount in case of a low profile angle. This presents an additional problem on the commonly low, outside pressure angle, and results in an even smaller l_c at the outside profile. Small l_c translates into noticeable feed marks or grooves, which require a very low dresser feed rate on the outside profile (Ref. 3). Dressing according to Figure 11 requires a time-consuming reversal of the hand of rotation between dressing of the outside profile and dressing of the inside profile in order to keep the sign of the dresser speed ratio constant. A constant change of the dresser speed ratio sign would open the cavities of the diamond bond and eventually lead to a loss of diamond crystals.

Gleason has developed dress rollers and a dressing configuration in which the dress roller is positioned at an angle to the grinding wheel, thereby optimizing the relative curvature radius ρ_{red} between inside and outside profile dressing. The relationships in the diagram in Figure 12 deliver a ρ_{red} three times the common value of the method shown in Figure 11. The correct observation of curvature radii uses for the dressing method—according to Figures 11 and 12—the normal cone radii to calculate relative curvature. Modern grinding machine summary calculations compute the optimal angular position of the dress roller individually for every different bevel pinion or gear, and also propose feed rates which are optimally suited to provide—on both inside and outside wheel profiles—a favorable dressing feed mark characteristic with low peak elevations.

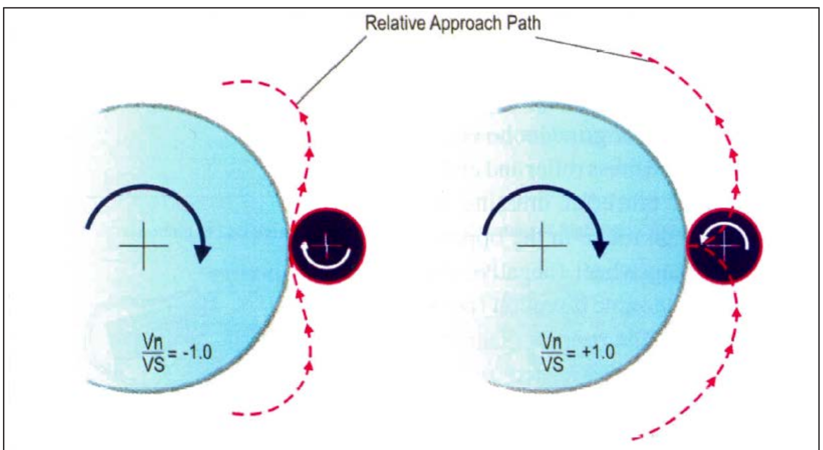


Figure 10—Cyclical relative approach path between dress roller and grinding wheel.

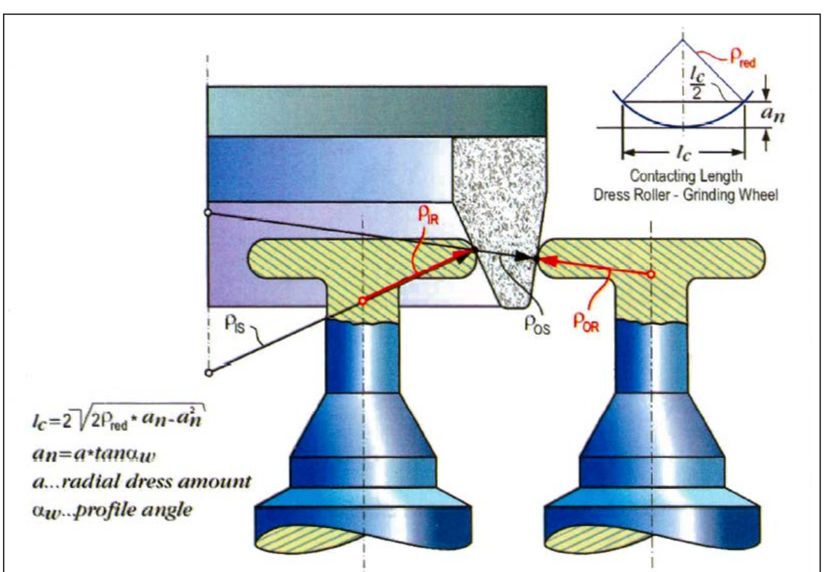


Figure 11—Unbalanced IB/OB dresser contacting length l_c.

A dresser speed ratio of zero should be avoided; this is equivalent to single-point dressing, which occurs when the dress roller is locked. The rotating grinding wheel would cause, in addition to a bad dressing result, a flat spot in the dressing wheel. Single-point dressing is possible with the tip of a single diamond. Older mechanical machines (from the 1950s and 1960s), some of which are still used in the aircraft gear industry today, use them. Dress rollers, however, are designed to dress around their wheel circumferences.

Also, the wheel must not be dressed when the roller's surface speed is equal to the wheel's surface speed (speed ratio 1.0). At that ratio, the roller only crushes the abrasive grain out of the wheel bond. The crushing breaks complete grains out of the bond for the most open-pore wheel surface structure possible and consequently causes rough surface finish. Also, when the grinding wheel has first-grinding contact with a gear surface, additional grains that have been loosened partially during the crush-dressing will break out, which acts like an excessive, initial wear with negative influence upon the gear tooth spacing.

The combination of crushing and abrasive action creates open pores on the wheel surface and reshapes the abrasive grains. And while the abrasive action improves the wheel's ability to grind gears, it also reduces the ability to move metal particles out of the grinding zone. However, the combination of crushing and abrasive action is optimal. The abrasive action between dress roller and grinding wheel surface reduces the open space between crystals by changing the remaining crystal-shaped grains; specifically, by flattening their sharp corners towards the surface. Consequently, very small flats are generated.

This flattening is beneficial because the grains' original shape is good only for roughing. There are grinding operations that use rough grinding passes, as with very large gears. For a rough grinding, the original grain shape would be acceptable. Their crystal shape can't accurately represent the grinding wheel's dimensions and profile shape. The very small flats can, however, accurately represent the wheel's diameter and profile shape. The changed crystals mean surface roughness of ground gears will be low, but coolant will still be able to access the grinding zone, and removed material will thus be eliminated from the grinding zone.

For high-productivity grinding, a dresser speed ratio of 0.6–0.8 is recommended. For the best possible surface finish, the recommended speed ratio is between –0.6 and –0.8. In the negative ratio range, the roller only shapes the abrasive grains—it doesn't crush them—and results in a grinding wheel surface with minimum pores. Grinding wheels are dressed for this type of grinding by directing the roller speed against the grinding wheel speed and using revolutions per minute, which are calculated from the velocity ratio (between –0.6 and –0.8), leading to high relative velocities.

In addition to the aforementioned rules, the following should also be applied in order to improve the grinding result:

Grinding of non-generated gears using Waguri: Start with negative dresser speed ratio; depending on wheel type, positive dresser speed ratio may be optimal.

Grinding of generated gears without Waguri: Positive dresser speed ratio.

Pinion grinding without Waguri: Positive dresser speed ratio.

If the surface finish is too rough:

- Reduce the dress roller traversing feed rate.
- Move to the left side of the dress roller speed ratio band.
- Change to negative dress roller speed ratio, but now go to the right side of the dress roller speed ratio band and use high dress roller traversing feed rate to preserve some open-pore surface structure.
- Apply a dual rotation cycle without

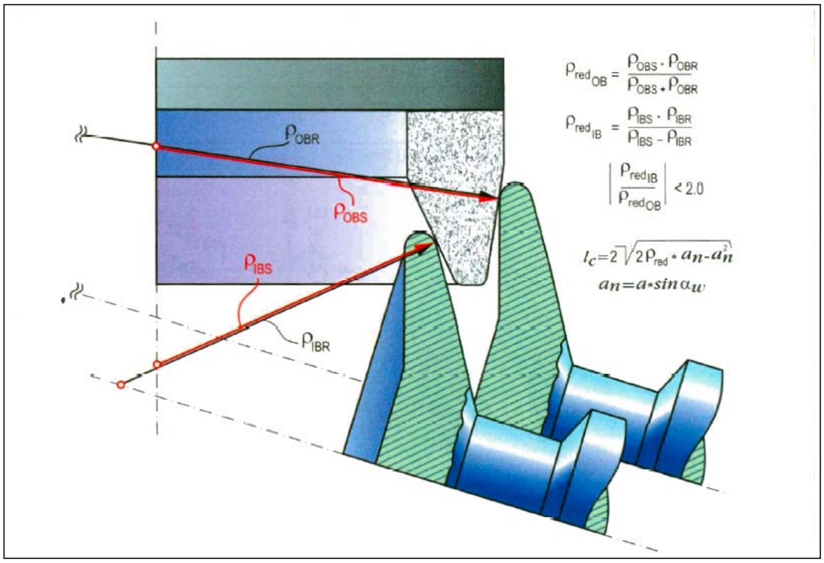


Figure 12—Dresser configuration for best balanced curvature between IB and OB.

redressing.

If spacing of first to last tooth is bad:

- Increase dress roller traversing feed rate.
- Move to the right side of the dress roller speed ratio band.
- Change to positive dress roller speed ratio, but go first to the left side of the dress roller speed ratio band and use a low dress roller traversing feed rate to preserve a high surface finish.

Burn marks on pinion surface or root:

- Increase dress roller traversing feed rate.
- Move to the right side of the dress roller speed ratio band.
- Change to positive dress roller speed ratio, but now go to the left side of the dress roller speed ratio band and use a low dress roller traversing feed rate to preserve a high surface finish.

Burn marks on Formate gear surface or root:

- Increase dress roller traversing feed rate.
- Move to the right side of the dress roller speed ratio band.
- Reduce grinding plunge feed rates.

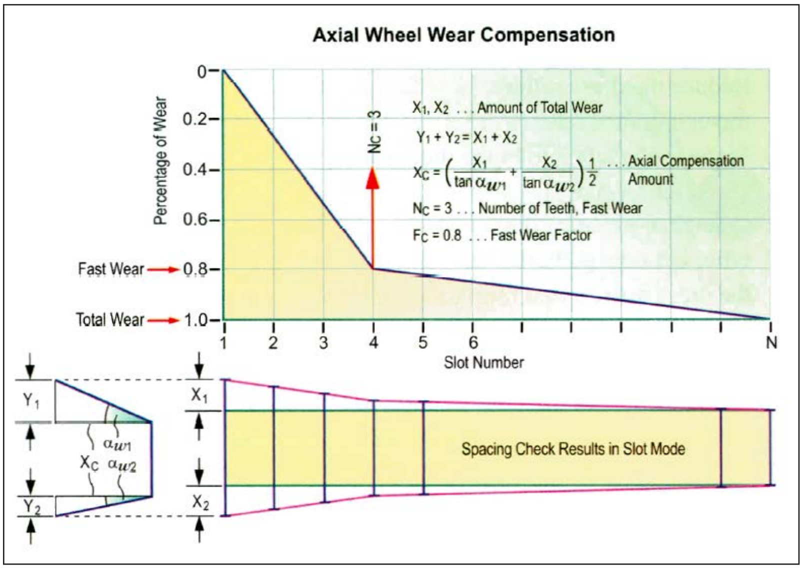


Figure 13—Grinding wheel wear compensation parameters (Ref. 2).

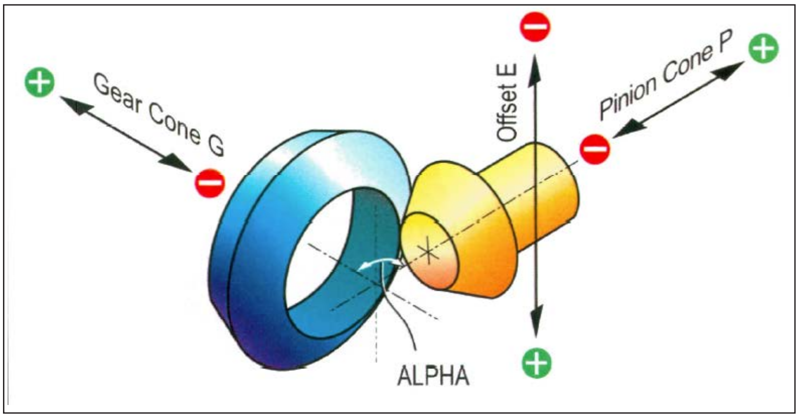


Figure 14—Testing of different pinion cone positions P, backlash compensated with G.

Wheel Wear Compensation

Gear manufacturers can also remove the grinding wheel's wear pattern from the gear finish by entering the number of teeth into the grinding machine's controller for fast wear and the percentage of this wear from the entire amount of wheel wear.

Wheel wear occurs rapidly during the first few slots and then with near-linearity for the following slots. Modern Gleason grinding machine controls have wheel wear compensation features that allow total wear compensation for the entire part and a fast wear compensation for the first slots. After total wear is compensated for, the spacing measurement will show whether the first slots require additional compensation and whether that amount should also be removed from the remaining slots.

After grinding a number of development gears, a manufacturer can obtain the numbers needed for eliminating the wheel wear pattern; specifically, the amount of total wear on the wheel (X_c), the number of teeth for the fast wear (N_c) and the percentage of fast wear (F_c). Those data are based on the spacing check, as explained in Figure 13.

Roll Testing of Ground Gear Sets

Ground bevel gears require roll testing in pairs in order to find their best operating conditions regarding tooth contact and noise. The axial pinion cone position (with the ring gear set to proper backlash) is varied in three to five positions (Fig. 14).

Pinions and gears have to be handled in pairs after the testing because the interaction of an individual pair may vary, even in case of ground bevel gear sets. Most manufacturers today use the freedom of small axial pinion position changes to improve the rolling quality in regards to motion transmission characteristics. Axial pinion shimming to individual pinion cone values generally delivers a result which would require manufacturing both members one quality level higher in order to achieve the same gearset performance in the zero build position.

Roll testing in pairs allows gear manufacturers to maintain an important advantage of grinding to gain a quality of a pair which is over the quality of the single components. Grinding lets gear manufacturers continue to deal with pinions and gears individually, until the roll testing operation, so companies can retain the less-complicated logistics and more flexible manufacturing via grinding.

After roll testing, each gear must be kept with its mated pinion and both must be labeled with the individual axial pinion shim value for them. Moreover, roll testing should be combined with a structure-borne noise evaluation in order to gain some non-subjective test results.

Strength of Ground Bevel Gear Sets

The spacing quality of ground gear sets is higher than that of lapped sets. However, the interaction of the tooth pairs in the lapping process eliminates relative spacing errors to a degree that makes them comparable to ground sets. Although the effective load sharing of gearsets increases with increased spacing accuracy, it is not possible to conclude that ground gearsets have generally better load sharing than lapped sets.

Surface durability might be negatively affected in lapped gearsets due to lapping grain incorporated in the lapped surface. Besides this, it can be stated that the lapped surface has, during the break-in process, better hydrodynamic properties than the ground surface. But after the break-in period, both surfaces have basically equal properties regarding surface durability issues such as pitting, scuffing, etc.

It can then be concluded that the gear quality differences between good lapped and ground gears have no influence on the fatigue bending strength or the pitting resistance of those gearsets.

Grinding allows the gear engineer to employ a completely different strategy when designing the ease-off in ground versus lapped gears. Figure 15 shows—at the left side a conventional ease-off, which is the result of length and profile crowning—how it is used in most of today's lapping applications. The Gleason development of blended Toprem, blended Flankrem and Universal Motions (UMC) with three flank sections results in quite different ease-off topographies, which result in the so called "selective crowning." The selective crowning uses a conjugate flank center area and crowned top, root, heel and toe sections. The selective crowning also defines in the path of contact section a flat center and progressively increased crowning on toe and heel. This results in low motion error and high effective contact ratio with optimized load sharing. Also in the contact line section, the crowning is very low in the center and increases only close to top and root. This results in low flank surface stress, yet still provides sufficient protection against top and root edge contact.

Figure 15 shows on the bottom a surface stress reduction of $\Delta\sigma_H$ of a contact line with selective crowning versus the conventional crowning. $\Delta\sigma_H$ can realistically be a reduction of 25% surface stress of the selective crowned surface pair versus a conventionally designed gearset.

The most significant influence on the root bending stress derives from the fillet radius, the root tooth thickness, the load sharing between adjacent teeth and the surface stress distribution along contact positions. Regarding the root fillet, a concrete advantage can be achieved in applying the semi-finish strategy, shown in Figures 1 and 2. The described semi-finish strategy provides, in cases of no mutilation or interference risk, a fully rounded root fillet, without steps and fins. In case of interference or mutilation risk, the wheel edge radii have to be chosen somewhat smaller, which will result in a flat root bottom, and which blends smoothly

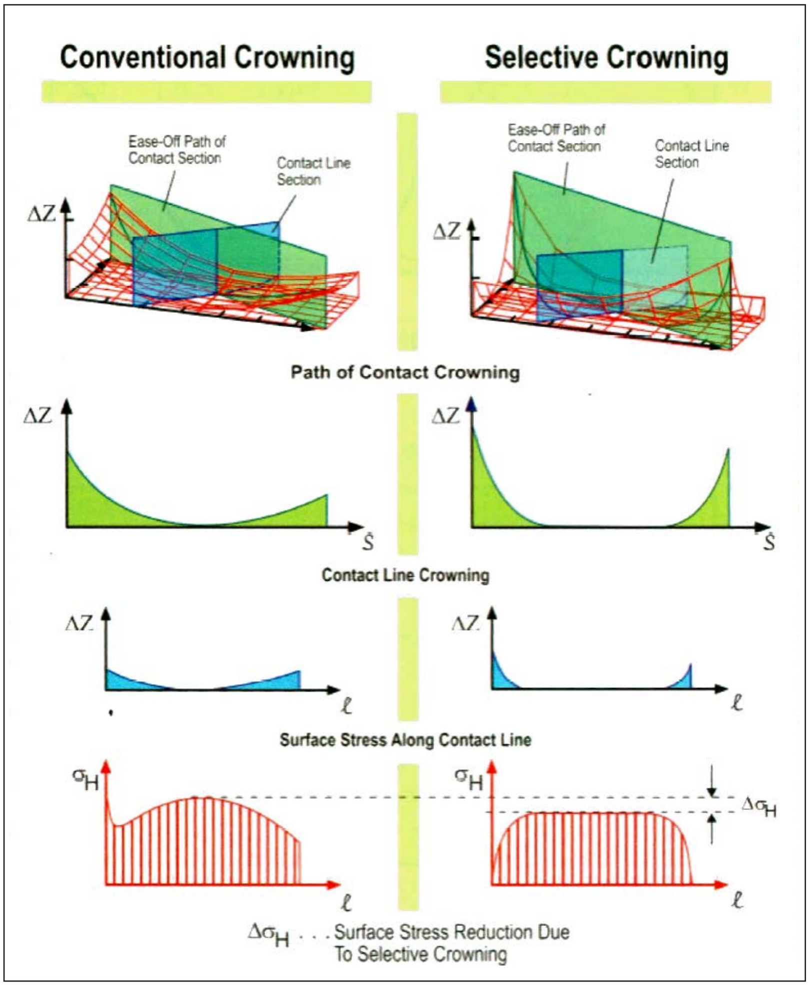


Figure 15—Stress reduction by selective crowning.

into the two fillet radii. Both cases apply the maximal possible root fillet radii and deliver the lowest possible root bending stress in the area of the stress critical 30° tangent. Face hobbed designs have a slot width taper, which has the smallest root width at the toe end of the slot. The fillet radii have to be chosen in order to fit through the small toe width of the slot, which renders them much less than optimal in the wider heel root region.

The tooth thickness along the face width of face hobbed and face milled parts might be different, but it is tapered in both cases and depends more on the spiral angle, which is not subject to change in the scope of this paper.

The load sharing, on the other hand, will change quite remarkably between the two different paths of contact crownings shown in Figure 15. The contact ratio is given on the dimension sheet and states what the maximum contact ratio, in case of full flank contact, can be. Any particular load below that will result in a lower effective contact ratio. However, even if the effective contact ratio is at a certain value (like 2.35 in Figure 16), this means that, 35% of the time, only three pairs of teeth are in contact and, 65% of the time, only two teeth are in contact. This, however, doesn't reflect how intensive this transmission contact is. Only the load sharing calculation will show how good the participation of each involved tooth pair in the load transmission really is.

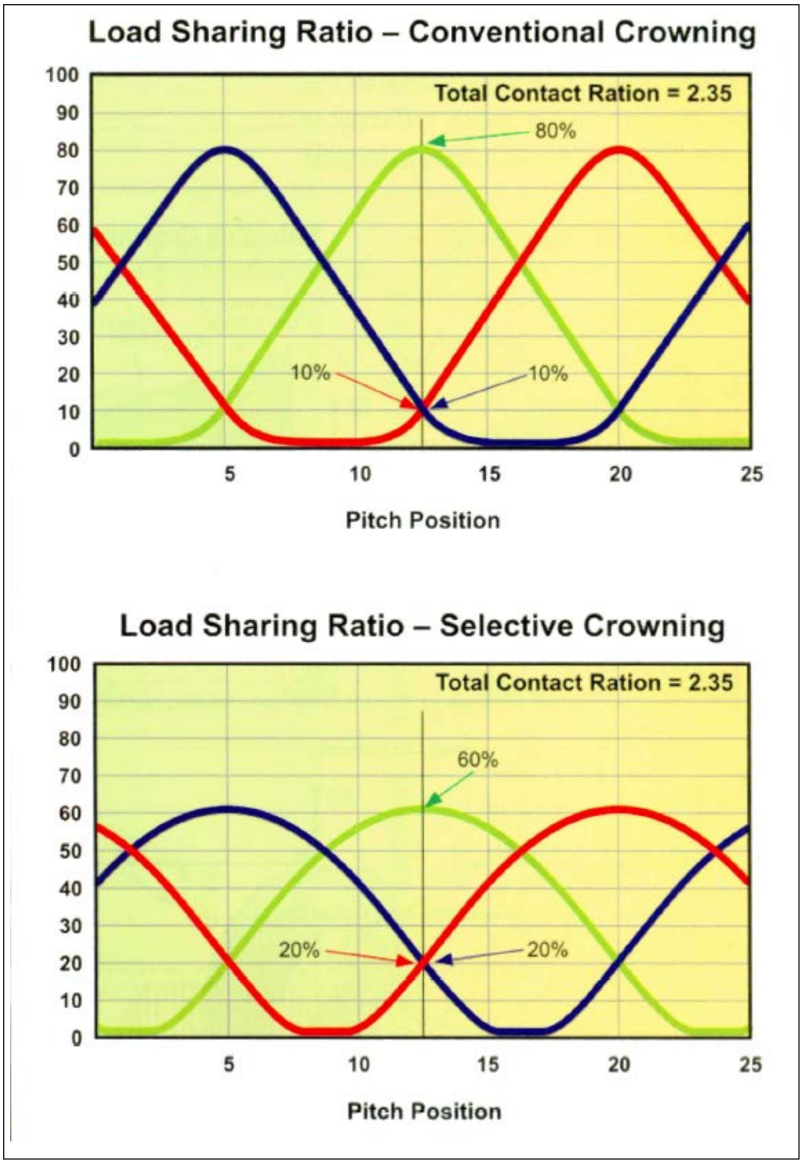


Figure 16—Load sharing improvement due to selective crowning.

The load sharing is calculated by use of a true finite element approach. Three adjacent pairs of teeth are observed for flank contact, considering the elastic bending due to this contact and, in turn, the resulting flank contact if equilibrium is established. This approach duplicates with high accuracy the condition in a gearbox under a given load.

The flank surface load distribution is then used in connection with the matrix of element spring constants to calculate three dimensional stresses, which are significant for fatigue fracture in the fillet region. The load sharing diagram shows in three different colors the maximum percentage of load that each of the three adjacent pairs of teeth is subjected to. Figure 16 shows two load sharing diagrams—on top, the load sharing in case of conventional path of contact crowning; on the bottom, the result of the selective path of contact crowning. Because of the conjugate path of contact center section, the lower diagram in Figure 15 shows a 20% reduction in the maximum load of each pair of teeth (conventional crowning 80%, selective crowning 60%). In turn, the two adjacent tooth pairs of the observed pair have to transmit a higher load. In that case, as the green graph shows, a vertical line through the maximum of the green graph, the adjacent graphs (blue and red) have to each share 20% of the load. In the case of conventional crowning in Figure 16, the adjacent tooth pairs share only 10% load each. This, and the fact that conjugate contact will cause less point load concentration, results in bending stress values expected to be reduced by 25% in the case of selective crowning, versus conventional crowning.

Grinding Economics

Admittedly, grinding is slower and more expensive than lapping. For example, grinding a pair of bevel gears requires two grinding machines and two minutes for each gear. Lapping also takes two minutes for each gear, but it requires only one lapping machine. Moreover, the grinding machine cost-per-ground set is about three times the lapping machine cost-per-lapped set.

However, rejected parts and customer complaints are 1% or less for typical grinding production compared with 3–7% for lapping, depending on the requirements for certain jobs. Rejected gear sets include the cost of all previous operations plus the material. Consequently, the cost related to this difference in reject rate often makes grinding the more economical process. Figure 17 represents an estimated cost comparison between lapping and grinding (Ref. 4). Only 5 years ago, the difference between the two processes was considerably larger, in favor of lapping. The advances in that time—including machine technology, new grinding wheel abrasives, conclusive semi-finish strategy and many other accomplishments—place grinding in a completely new light, which makes it a very attractive process today.

Conclusion

These guidelines cover topics from the transition line between root and flank of pinions and gears to the grinding wheels' abrasive bond; but this list isn't all-encompassing. A major reason so many unwritten guidelines remain undocumented is because they're infinite in number and change with advances in materials, processes and equipment. Still, these guidelines should help gear engineers to skillfully grind their bevel gears sooner, rather than later.

Item	Lapping	Part Cleaning	Testing	Log of Manufac-turing Pairs	Log of Transporting from Lapping to testing in pairs	Quality
Machine Rate/Hour	$62.50		$60.00			
Operator /Hour	$17.50 (=35.00/2)		$40.00			
Door to Door time/part	0.07		0.05			
Rate per Part	$5.28	$1.50	$5.00	$2.00	$0.50	
Warranty resulting of skipped oil change						$1.25
Cost of 3.5% reject $45.00 per set						$1.58
					Total Finishing Cost	$17.11

Item	Pinion Grinding	Gear Grinding	Testing	Coordinate Measure-ment		Quality
Machine Rate/Hour	$88.50	$88.50	$62.50	$50.00		
Operator /Hour	$17.50 (=35.00/2)	$17.50	$40.00	$40.00		
Door to Door time/part	0.07	0.03	0.05	0.03 (.25/10)		
Rate per Part	$7.00	$3.50	$5.13	$2.25		
Warranty resulting of skipped oil change						
Cost of 0.5% reject $45.00 per set						$0.23
					Total Finishing Cost	$18.09

Figure 17—Comparison of finishing cost, lapping vs. grinding.

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Distortion Control by Innovative Heat Treating

TECHNOLOGIES IN THE AUTOMOTIVE INDUSTRY

K. Loeser, V. Heuer and D. R. Faron

Management Summary

The proper control of distortion after thermal treatment of powertrain components in the automotive industry is an important measure in ensuring high-quality parts and minimizing subsequent hard machining processes in order to reduce overall production costs. To fulfil these requirements, innovative heat treatment technologies and corresponding furnace system technologies have in the last few years been developed. Vacuum carburizing with subsequent high-pressure gas quenching is an innovative heat treatment technology for reducing distortion in surface-hardening processes (Ref. 1).

Introduction

Vacuum carburizing induces a high carbon transfer, which leads to a reduction of process time compared with atmospheric gas carburizing. The use of oxygen-free hydrocarbons prevents surface oxidation on the part surface. High carburizing temperatures up to 1,000°C and higher lead to additional productivity. However, there is the risk of grain growth during high-temperature carburizing that can increase the potential for distortion by the formation of a mixed-grain area in the material. But recent developments in the steel industry have shown that it is possible to prevent grain growth at temperatures higher than 1,050°C by using steels with alloying elements such as Nb, Ti and Al (Ref. 2).

High-pressure gas quenching is a dry quenching method that has many important ecological and economical advantages when compared with liquid quenching (Refs. 3–4). The quenching gases used, such as nitrogen and helium, are inert and leave no parts residue, negating the need for additional investment in washing machines or fire monitoring devices.

But the most significant advantage of gas quenching is a very uniform heat transfer. The predictability of movement during quenching is more certain and uniform throughout the load, thereby reducing hard machining costs. High-pressure gas quenching was successfully introduced for the heat treatment of parts in the automotive industry some years ago, and numerous investigations have shown that distortion can be significantly controlled as opposed to liquid quenching. However, there were examples where the simple change from oil to gas quenching did not improve all distortion parameters of a gear, e.g.—lead, profile or run-out data (Ref. 5). Thus there remains a lack of knowledge regarding the dependencies between different gas quenching parameters with respect to the influence on shape and size changes of the parts to be heat treated. In fact, additional factors like quenching chamber design, proper fixtures and loading have to be taken into consideration (Refs. 6–7). Although distortion can be influenced by any facet of heat treatment—including heating, carburizing and diffusion and quenching—the greatest potential for minimizing it is the proper control of the quenching process. Therefore the following is focused on the quenching process.

Gas Quenching Chamber

Proper design of the gas quenching chamber is an important precondition for minimizing distortion. The quenching chamber (Fig. 1) is the result of intensive, numerical flow calculation and experimental studies; it has been successfully integrated in heat treating systems for the automotive industry.

Two high-powered gas circulators, arranged to the left and right of the cylindrical housing, accelerate the quenching gas to a high velocity in the chamber. A very homogeneous flow through the charge is reached by means of several flow guides.

The design of the chamber is modular and can be equipped with a gas flow reverse system. The motors for the circulators are suitable for vacuum start-up in that they accelerate to maximum speed prior to gas flooding and so ensure maximum quenching performance at the outset. This is especially important for hardening of thin-walled parts made of low-alloyed steels. The quench chamber is suitable for standard gas quenching processes with steady gas pressure and gas velocity, as well as for new quenching processes such as dynamic quenching (patent pending), for example.

Fixturing

As in the case of liquid quenching, proper fixtures and optimized loading of the parts are also important for gas quenching. But contrary to liquids, fewer restrictions exist because there is no risk of quenching residue in the parts, such as with blind holes, for example. Alloy fixtures are widely used for grids in heat treatment. These grids have a rigid design and they have—as long as sufficient high-temperature-resistant material is used—an acceptable lifetime. However, these fixtures limit the net weight to be loaded due to the high fixture weight. After long-term service, the fixtures tend to deform due to high-temperature deformation, which has a negative effect on the distortion of the loaded parts. Moreover, due to the pick-up of carbon and the subsequent formation of carbides, the grids undergo dimensional growth, creating further problems during handling in automated, external transportation devices.

As an alternative, carbon-composite materials—CFC (chlorofluorocarbon), for example—were introduced for use as fixtures in heat treating applications, but with little success due to the liquid quenching process, risk of drastic wear during use in atmospheric pusher-type furnaces and their high price. On the other hand, vacuum carburizing furnaces with high-pressure gas quenching are perfectly suited for the use of CFC fixtures (Fig. 2). By way of walking beam transportation, any wear and overstressing of the fixtures are avoided. The use of oxygen-free hydrocarbons in a vacuum environment, and the inert quenching gases during the quenching process, avoid any surface reactions with the fixtures. In this service environment, one can take full advantage of the excellent material properties of CFC, which has a very high deformation resistance at high temperatures, low thermal expansion coefficient and very low specific weight. Fixtures made from CFC are designed to carry more parts, as they exhibit less gross weight, thereby increasing productivity and reducing energy costs. But the major advantage is that CFC fixtures do not show deformation during the heat treatment process, assuring optimum positioning of the parts. This has a significant, positive effect on part distortion, as shown later.

Figure 1—ModulTherm heat treatment system with gas quenching chamber.

Figure 2—Load of internal rings on a graphite composite fixture.

Gas Quenching Process

To achieve optimum quenching results regarding microstructure, hardness and distortion, the gas quenching parameters need to be well-adjusted. To achieve the required core hardness in gears of low-alloyed case-hardening steels, helium as a quenching medium and a high gas pressure of 20 bar is necessary. The usage of this low-density gas allows quenching with very high gas velocity by using reasonable motor power. In combination with an advanced gas-recovery technology, exhibiting a recovery rate of > 99.5%, gas quenching is very economic despite the helium gas price. The positive experiences with gas quenching have induced gear suppliers to use case hardening steels with better hardenability. This presented the opportunity to reduce helium-quenching pressure and to minimize distortion. Moreover, it provided the chance to use alternative gases with lower quenching capability, such as nitrogen.

To further reduce distortion—particularly of thin-walled automotive parts—a quenching process has been developed where the quenching parameter's gas pressure and/or gas flow velocity are varied during quenching (Fig. 3).

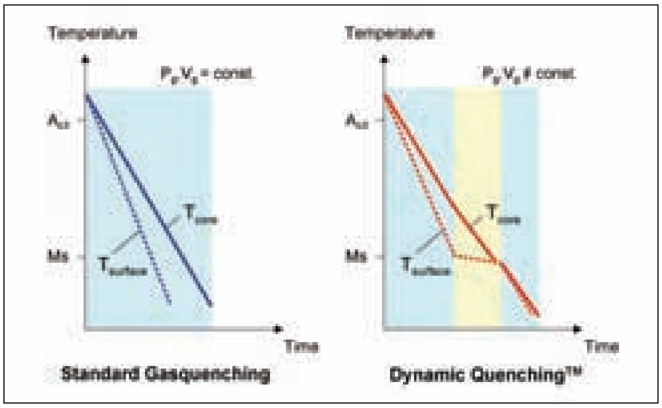

Figure 3—Schematic comparison of gas quenching process.

Dynamic quenching starts in the first quenching step with high quenching severity. After a period of time, when a certain part temperature is reached, the next quenching step follows where the quenching severity is reduced for a set time to allow for temperature equalization in the part. This is followed by a third and final quenching step, where the quenching severity is increased again until the end of the quenching process. The control system in the quenching chamber serves to provide differing steps of dynamic quenching with enhanced accuracy and reproducibility.

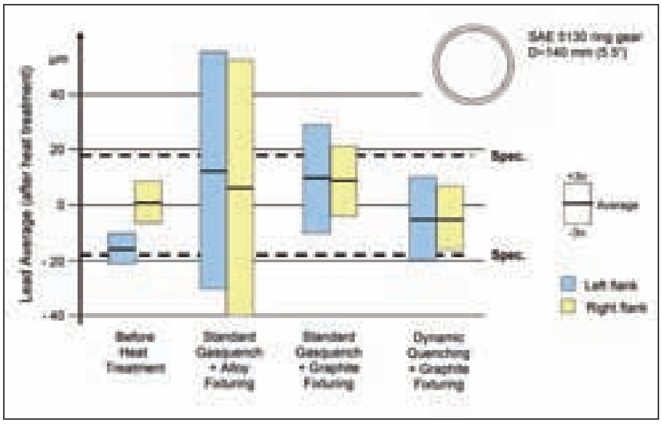

Figure 4—Lead average of ring gears before and after heat treatment.

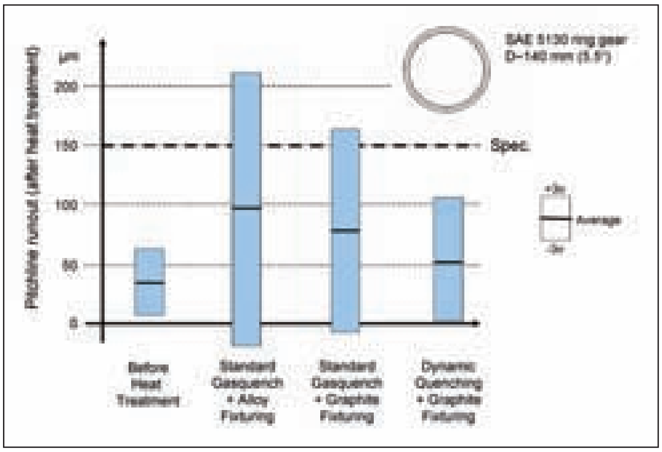

Figure 5—Pitch line run-out of ring gears before and after heat treatment.

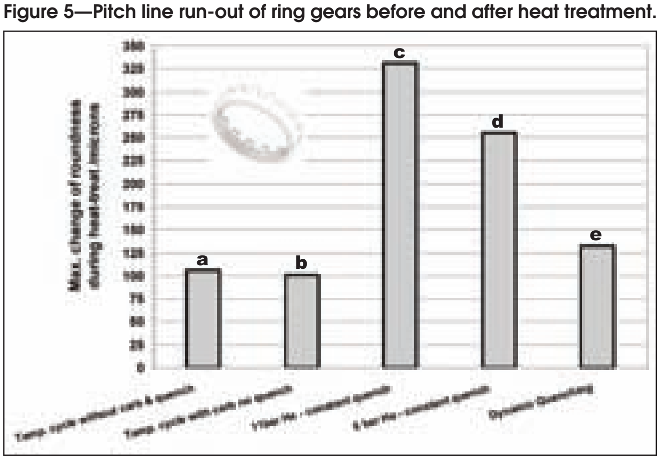

Figure 6—Maximum change of roundness (Dmax –Dmin) during heat treatment (Distance Between Balls (DBB) measurement).

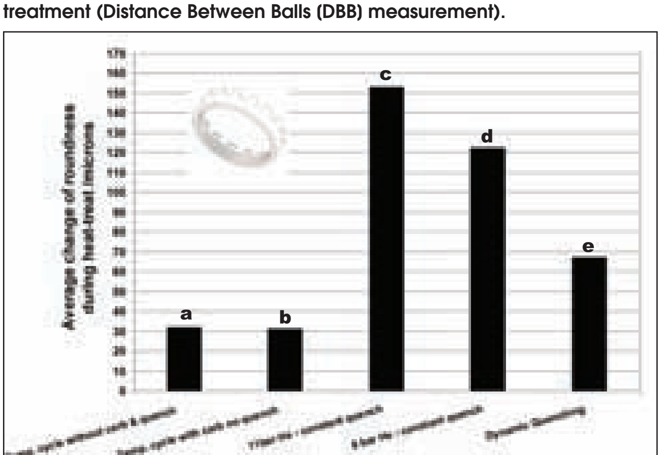

Figure 7—Average change of roundness (Dmax –Dmin) during heat treatment (DBB– measurement).

Distortion Study and Results

Case hardening as a heat treating process was chosen for gears of a new generation of six-speed, automatic transmissions. In order to meet automotive's high quality demands, vacuum carburizing and high-pressure gas quenching are used as heat treating technologies. Due to the geometry and manufacturing process, these parts are susceptible to distortion during heat treatment. Therefore, an intensive process optimization program has been started where transmission manufacturers and furnace suppliers work in cooperation. To optimize the heat treatment process, it is important to differentiate between the distortion created by heat treatment and distortion created by the release of internal stresses resulting from the steps preceding the final heat treatment process. While the former can be minimized by optimizing the heat treatment process parameters, the latter can only be influenced by changes in the pre-processing route after an intensive study of the entire manufacturing chain of the part.

The results of the optimization of the heat treatment with particular focus on the gas quenching process are shown in Figures 4 and 5. Full loads with multiple layers of ring gears of SAE 5130 were heated in a ModulTherm system by using convection and vacuum heating. Convection heating was used to secure a fast but uniform heat-up of the parts and to keep heating-induced stresses to a minimum. After being properly heated, the parts were vacuum-carburized at 900°C to a case depth of 0.3 mm to 0.5 mm by using acetylene. After vacuum carburizing, the temperature was reduced to austenitizing temperature and the parts were then gas-quenched with helium by using different quenching procedures and fixtures. Although the ring gears have a small wall thickness and the base carbon is relatively high, it has been demonstrated in preceding comparison tests that distortion results were better for gas quenching with helium than with nitrogen. Dimensional studies were performed on 15 parts, which were located on different layers in the load. Lead and profile deformation and pitch line run-out were measured using a CNC gear checker.

Figure 4 shows mean values and scatter of lead average after different heat treatments, compared with the green data. After heat treatment using standard gas quenching with constant gas pressure and velocity, the mean value of lead average increases moderately; but scatter increased significantly. By using the same quenching process—but changing from alloy to graphite fixturing—the scatter could be reduced by 50%. The best result was obtained by applying the dynamic quenching technique and by using graphite fixturing.

Figure 5 shows the results of the pitch line run-out after heat treatment. As with lead deformation, pitch line run-out could be significantly improved. The best result regarding mean value and scatter was again obtained by using dynamic quenching and graphite fixturing; with this technology, it is possible to reach the specified values. In all the performed tests, no influence regarding the position of the parts in different layers on the distortion behavior was observed.

In a further test series, internal gears, also made of

SAE 5030, were heat treated in a ModulTherm system by using different quenching process routes to investigate the distortion potential. The gears were convection-heated and vacuum-carburized with process parameters as described in the test series before. Graphite grids were used for fixturing in all tests. After the test, roundness measurements on 10 to 20 rings per load were performed using a DBB (distance between balls) machine. The resulting change of maximum and average roundness data before and after the test for the different heat treatment processes is given in Figures 6 and 7.

The first set of parts had an original temperature cycle—but without carburizing. Afterwards, the parts were slow cooled in the furnace (a). This so-called "dead run" releases the internal stresses from the preceding manufacturing processes and forms a baseline for the effort of any quenching optimization for the subsequent heat treatment process. This test was repeated, but the parts were carburized (b); this had no influence on the result. For the next test, the parts were carburized and standard-gas-quenched by using 11 bar helium (c). This led to a significant increase in the maximum and average change of roundness after the heat treatment. Because core hardness after quenching of the parts was well within the specification, the quenching pressure was reduced to six bar in the next trial (d) to minimize distortion. The result was an improvement of the change-of-roundness data. In the last trial (e), the parts were carburized and quenched using the dynamic quenching technology, resulting in a further significant improvement of roundness data. Compared to the data of the dead run, maximum change of roundness is only increased by 25%. Compared to the data of the test using the standard gas quenching practice with constant parameters, distortion could be reduced by almost 60% with dynamic quenching technology. The results shown above are only a small portion of the complete optimization program performed together with the end-user in the automotive industry. However, they demonstrate the potential for distortion optimization using a proper quenching system and process technology, as well as fixturing. As a result, vacuum carburizing and gas quenching in this case were determined as the key technology for the heat treatment of a new generation of 6-speed, automatic transmissions worldwide.

Summary

The proper control of distortion after thermal treatment of powertrain components in the automotive industry is an important measure to ensure high part quality and to minimize subsequent hard-machining processes, thereby reducing the overall production costs. Vacuum carburizing (low-pressure carburizing) with subsequent high-pressure gas quenching represents an innovative heat treatment technology to reduce distortion in surface-hardening processes.

A series of heat treating tests, including distortion measurements on internal gears of a new 6-speed automatic transmission, were performed. It was demonstrated that by using innovative heat treating technologies—i.e., vacuum carburizing and high-pressure gas quenching, distortion of the gears can be effectively controlled. Optimum results were achieved by using proper furnace technology, graphite fixtures and application of dynamic quenching technology.

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Influence of Grinding Burn on Pitting Capacity

Christof Gorgels, Fritz Klocke and Tobias Schröder

Management Summary

This paper intends to determine the load-carrying capacity of thermally damaged parts under rolling stress. Since inspection using real gears is problematic, rollers are chosen as an acceptable substitute. The examined scope of thermal damage from hard finishing extends from undamaged, best-case parts to a rehardening zone as the worst case. Also, two degrees of a tempered zone have been examined.

Introduction

The demand for continuous improvement of the economic efficiency of products and processes leads in turn to an increasing cost stress in both the design and manufacture of power transmissions. Therefore, the power density of each gear inside a transmission has to be increased, resulting in a demand for higher gear quality. Increasingly, more and more gears of this quality can only be produced via hard-finishing processes.

Indeed, the use of gear grinding processes has increased over the past years. This desire for greater and greater productivity from grinding machines has led to an increasing risk of inducing thermal damage to the external zone of gear flanks (Refs. 1–4). Worse, the consequences of such thermal damage on the performance of a gear are rarely predictable. Therefore, even slightly damaged gears are scrapped in many instances, with a tangible effect on the bottom line.

Along with the lack of knowledge concerning the influence of thermal damage on the performance of a gear, each company has different rules for the acceptable limit of thermal damage. Baseline knowledge is therefore needed in order to have a basis in deciding what to do with gears with grinding burn.

A degree of understanding exists about the influence of grinding burn on the tooth root load-carrying capacity of gears (Refs. 4–5). Quantifying the influence on the flank load-carrying capacity, however, is much more difficult. With gear profile grinding, thermal damage only occurs locally. Thus, one cannot be certain that the damaged area is also the highly loaded one. The interpretation of test results—and especially their generalization—is at best problematic (Refs. 6–7).

This report serves to determine the load-carrying capacity of parts under rolling stress in conjunction with the degree of thermal damage. The performance of rollers thermally damaged via laser treating is determined on a roller test rig. This trial setup ensures that the highly loaded area on the part is also the damaged area. The loading and load distribution on the rollers are comparable to that of a gear tooth flank.

Previous investigations: round-robin test on nital etching. Previous to this report, WZL and member companies of the WZL Gear Research Circle conducted a "round-robin" test on nital etching. This test sought to determine the reliability of the nital etching procedure in detection of grinding burn.

Different samples from two case-hardened materials were sent to the participating companies. On each sample, tracks with differing degrees of laser damage were applied. The task of the companies was to subject the samples to their standard nital-etching procedure in order to evaluate the degree of grinding burn and to decide if a gear with such damage would still be acceptable or scrapped.

The results from all 15 participating companies showed that grinding burn can be detected using the nital etching procedure. Yet, significant differences were found concerning the actual evaluation of the etching result. This was especially true with slightly damaged areas, where opinion about the possible use of the samples differed significantly. This reveals a high degree of uncertainty about the significance of varying degrees of thermal damage on a gear's performance.

Workpieces and Execution of the Trials

Roller test rig and geometry. The roller geometry is derived from the contact conditions between two gear flanks. The roller radius is taken from the curve radius of the gear flank involute profile in the contact. In this example, the pitch circle was chosen as the basis for the determination of the roller radius. The outer diameter for both rollers is $D_1 = D_2 = 42$ mm. The thermal-damaged test roller has a cylindrical shape. The contra roller is crowned in order to prevent wear in the area of the roller edges. In order to prevent edge pitting on the contra roller, a diameter in the axial direction of $D_3 = 166$ mm is applied for crowning. Further data can be found in Figure 1.

Figure 2 shows the test rig and the technical data. The motor drives a transmission; the drive gear of the transmission is coupled with the test roller and the driven gear is connected to the contra roller. Gohritz determined that for this gear set, pitting would be most likely to occur in the area of a negative slippage of s = –24% (Ref. 8). Therefore a slippage between the two rollers of s = –24% is realized through a gearing between the two mating rollers. The revolution speed on the drive side is $n_1 = 2{,}850\ \text{min}^{-1}$.

The oil is supplied by an injection system with a temperature of $\vartheta_{oil} = 55°C$ and a tolerance of $\Delta\vartheta_{oil} = \pm\ 3°C$; a typical oil for industrial gear box applications with typical additives is used. The contra force in order to arrive at the Hertzian stress is realized by a hydraulic pressure system.

It is known that, as a rule, a roller test does not fully represent an exact analogy to a real gear flank. Therefore, typically higher Hertzian stresses can be applied to rollers as opposed to gear flanks, due to geometrical effects. Nevertheless, the relationship between a roller, e.g., one for material testing, can be extrapolated from roller tests to real gears. Therefore a reference within the roller tests is needed (Refs. 9–10).

External Zone of the Rollers Before Testing

Within the examinations described in this report, and in addition to a non-damaged reference, three test rollers are used with different degrees of thermal damage. The thermal damage is realized using a laser. In order to eliminate the influence of the oxide layer after laser damaging, a very small amount of stock has been removed from the roller surface by grinding. The surface of the thermally damaged samples, after the laser process, grinding and nital etching, can be seen in Figure 3.

continued

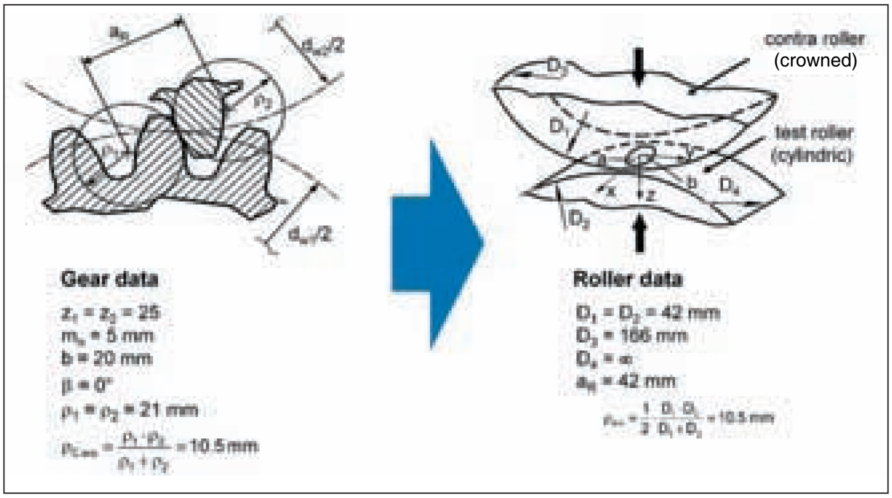

Figure 1—Geometry of gear flank and test roller.

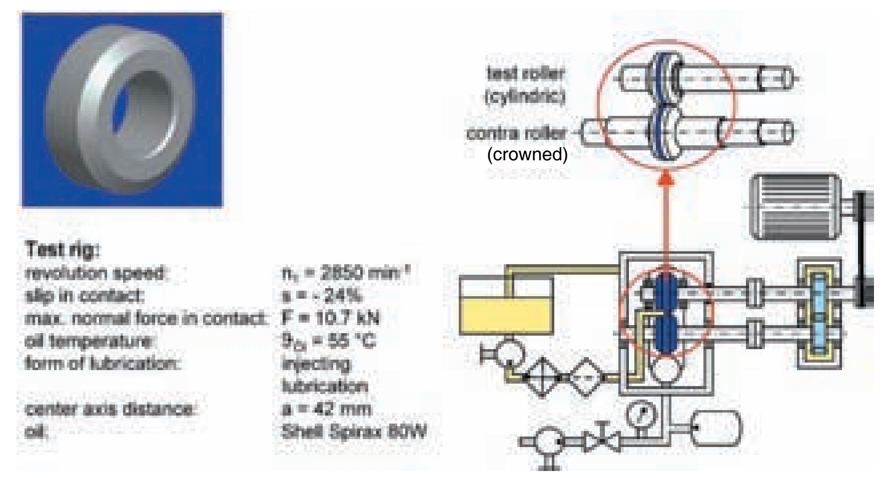

Figure 2—Twin-roller test rig.

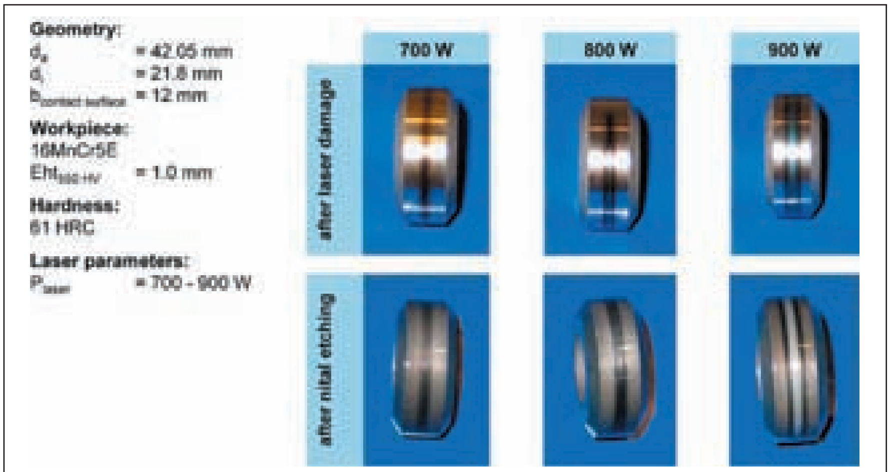

Figure 3—Test rollers.

Four different variants are to be examined:

1. Undamaged (reference)
2. Slightly tempered zone (P_{Laser} = 700 W)
3. Strong-tempered zone (P_{Laser} = 800 W)
4. Rehardening (P_{Laser} = 900 W)

An important factor in the analysis of the laser-damaged rollers is to make sure that the induced damage is comparable to typical grinding burn seen in the gear profile grinding process. In order to analyze the characteristics of the damage, the material structure (Fig. 4), the hardness profile (Fig. 5) and the residual stress profile (Fig. 6) have been analyzed.

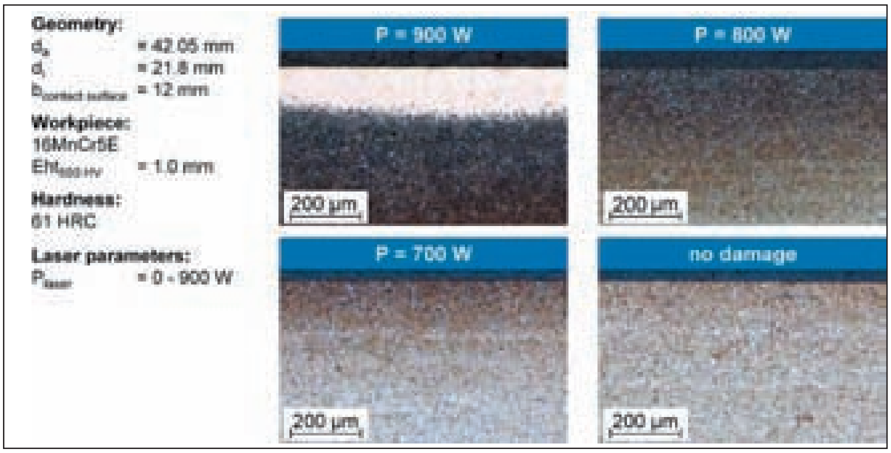

Figure 4—Material structure of damaged test rollers.

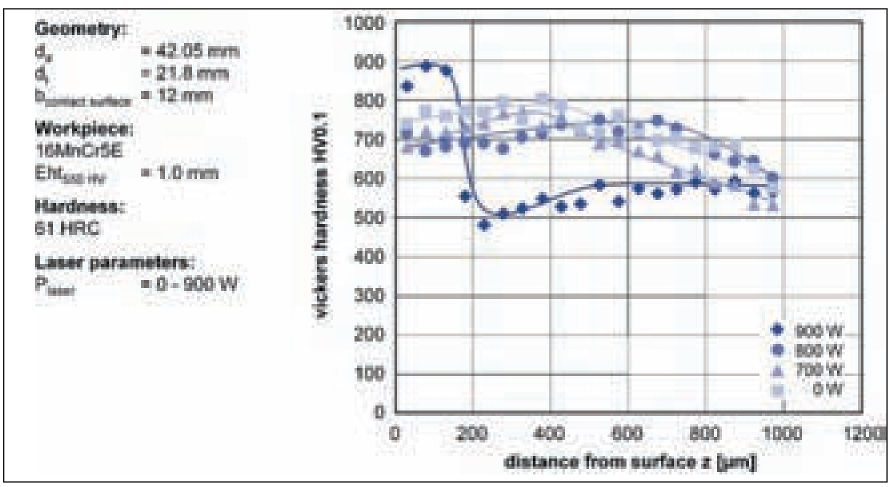

Figure 5—Microhardness profile of selected test rollers.

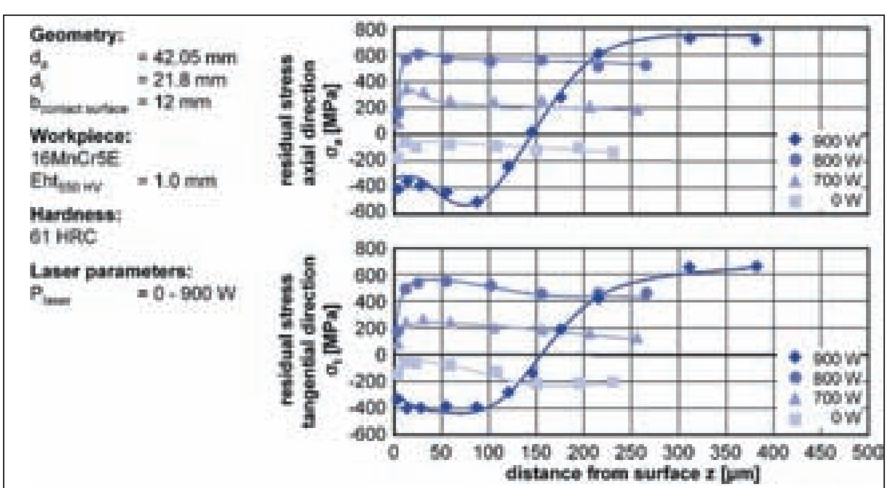

Figure 6—Residual stress profile of selected rollers.

The analysis shows that the occurrence of the thermal damage reveals a good correlation to what would typically be observed on a damaged gear flank; the structural damage goes well below the surface. The tempered samples have a decrease in hardness close to the surface as well as residual tensile stresses. The rehardened sample shows a very high hardness close to the surface layer, with the hardness decreasing inside the tempered zone below the rehardened area. Very high-compressive stresses are also in evidence near the surface, changing into very high tensile stresses at a distance from the surface of z = 200 µm.

It can thus be concluded that the thermal damage caused using a laser shows a very useful correlation to a thermally damaged gear. As such, an acceptable correlation between the load carrying capacity from the roller tests and real gears can be expected.

Test Rig Trials Using Thermally Damaged Rollers

To determine the load-carrying capacity of the thermally damaged rollers, test rig trials have been conducted. The objective was to determine the sustainable load cycles of damaged rollers under high loading when compared to an undamaged reference. The focus was on the sustainable load cycles as well as on the occurring failure mechanisms.

Running time of rollers depending on the degree of thermal damage. To determine the load-carrying capacity of thermally damaged rollers, damaged and undamaged rollers were tested on a twin-disc test rig. The cylindrical test roller on the test rig was in contact with the crowned contra roller. The normal force between the rollers was F_n = 8,708 N, resulting in a Hertzian stress of σ_{Hertz} = 2,800 N/mm^2. The injected oil was a typical lubricant for gearbox applications—Shell Spirax 80 W—at a temperature of $\vartheta_{Öl}$ = 55°C with a tolerance of $\Delta\vartheta = \pm$ 3°C. The test roller is rotated at a speed of n = 2,850 min^{-1}, and the sliding between the two rollers amounted to s = –24%.

To determine the fatigue life of the

different rollers, the maximum load cycles—depending on the degree of thermal damage—are shown in Figure 7. After reaching N = 50,000,000 load cycles, the limit for the fatigue strength would be reached. Testing was carried out in the area of fatigue life; in this way a comparison of the differing, thermally damaged rollers could be accomplished.

The undamaged reference had an average sustainable number of load cycles, until pitting occurs, of $N = 38.8 \cdot 10^6$, and was therefore near the limit for fatigue strength. The failure mechanism was a pitting on the sliding surface. The rollers with a slight tempering (P_{Laser} = 700 W) failed after an average of $N = 35.1 \cdot 10^6$ load cycles. These results demonstrate that a slight tempering results in only a small reduction of sustainable load cycles.

However, the two variants with a more extreme structural thermal damage showed a drastic reduction of fatigue life.

The rollers damaged with a laser power of P_{Laser} = 800 W with a strong tempering failed after an average of $N = 5.4 \cdot 10^6$ load cycles. This is a reduction of fatigue life of more than 80% compared to the undamaged reference. Also, the failure mechanism changed in that pitting occurred not only on the test roller but also on the contra roller.

The rollers damaged with a laser power of P_{Laser} = 900 W with rehardening failed after an average fatigue life of only $N = 3.3 \cdot 10^6$ load cycles. The failure mechanism changed again compared to the undamaged reference. The pitting on the test roller did not occur in the middle of the sliding surface but on its side. In this area the thermal damage changes from rehardening to tempered zone.

Analysis of the wear mechanisms. The wear phenomenon to be found on the test rollers after damage occurs is displayed in Figure 8. The non-damaged roller and the two rollers with tempering (P_{Laser} = 700 W and 800 W) show pitting in the middle of the contact area, while the rehardened roller shows pitting on the edge of the contact area.

An explanation for the migration of the pitting out of the middle is supplied when Figure 9 is taken into account. The material structure in the area of the pitting is shown. The middle of the contact surface is marked where the hardness profile was measured. The hardness profile shows a high hardness near the surface and a low hardness (tempered zone) below the surface. The pitting occurs on the side of the contact surface.

The line showing the start of the annealing zone below the rehardening shows that the middle of the pitting is in the area of the changeover from the rehardening to the tempered zone on the surface. This shows that the rehardened area breaks off the tempered zone

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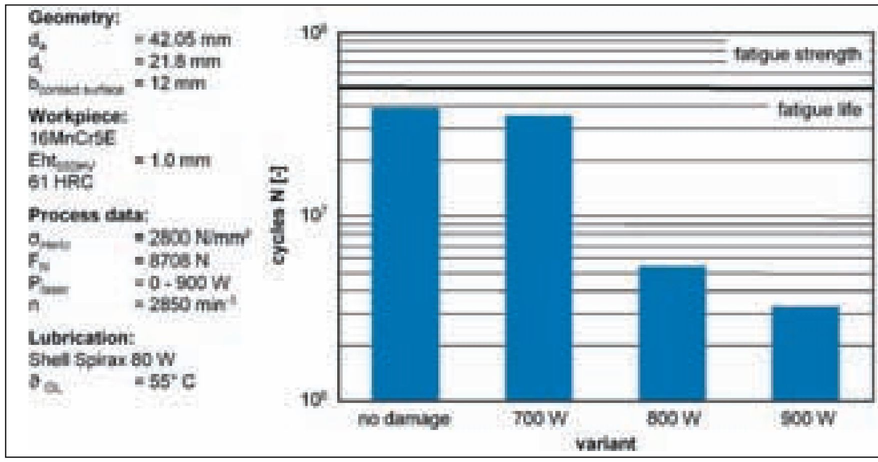

Figure 7—Fatigue life impacted by thermal damage.

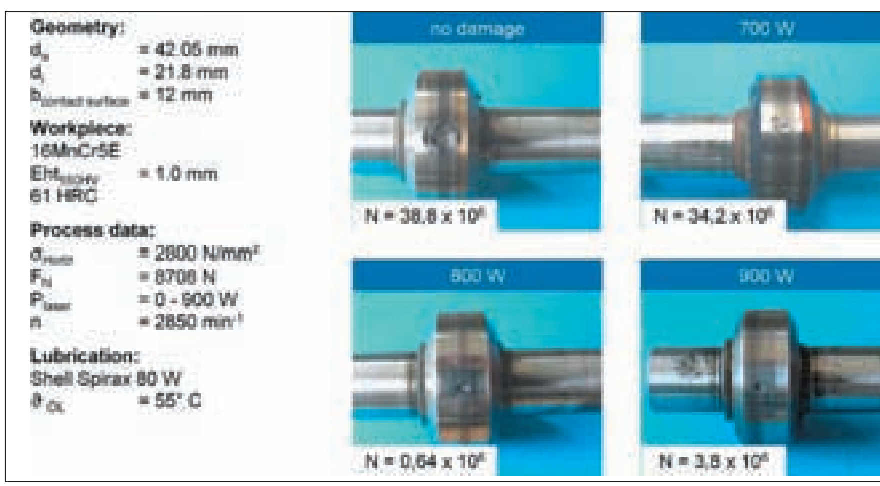

Figure 8—Comparison of pitting depending on degree of thermal damage.

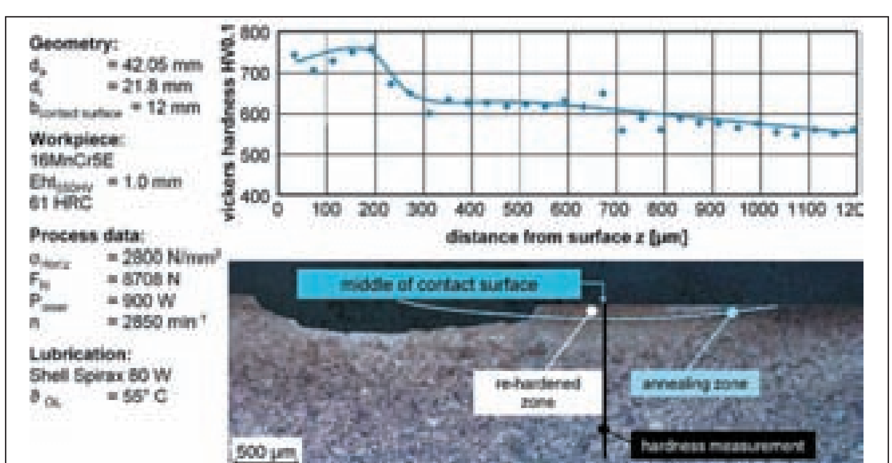

Figure 9—Analysis of pitting on roller with rehardened zone.

below, due to the high tensile stresses in this area (Fig. 6).

In Figure 10, pictures of the pitting of all four variants are shown via electron microscope. The undamaged and the slightly damaged variants show pitting with no surrounding cracks. The strongly tempered roller (P_{Laser} = 800 W) shows a crack around the pitting. In this area, the pitting would have enlarged had more load cycles been run. On the other hand, below the pitting on the roller with a rehardened zone, cracks transverse to the sliding direction are found. This documents that the surface is strongly affected and indeed shattered, due to the high hardness of the rehardened area leading to a very low ductility of the material.

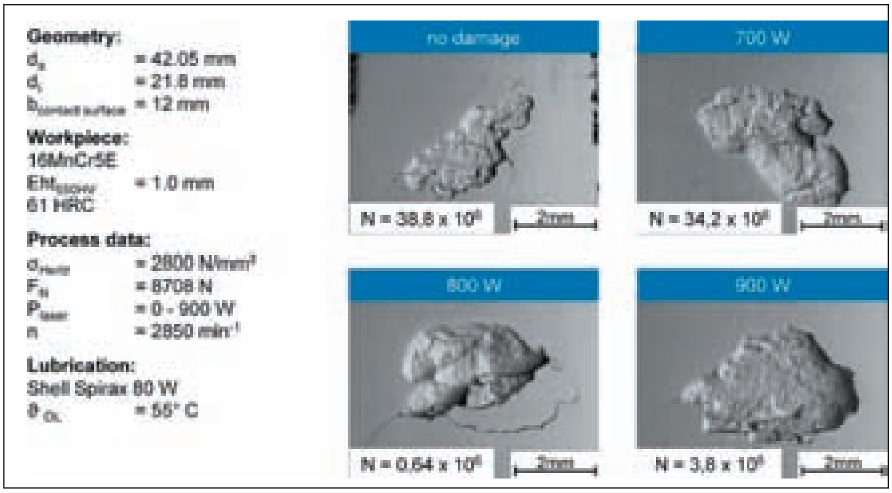

Figure 10—Comparison of pitting using scanning electron microscope.

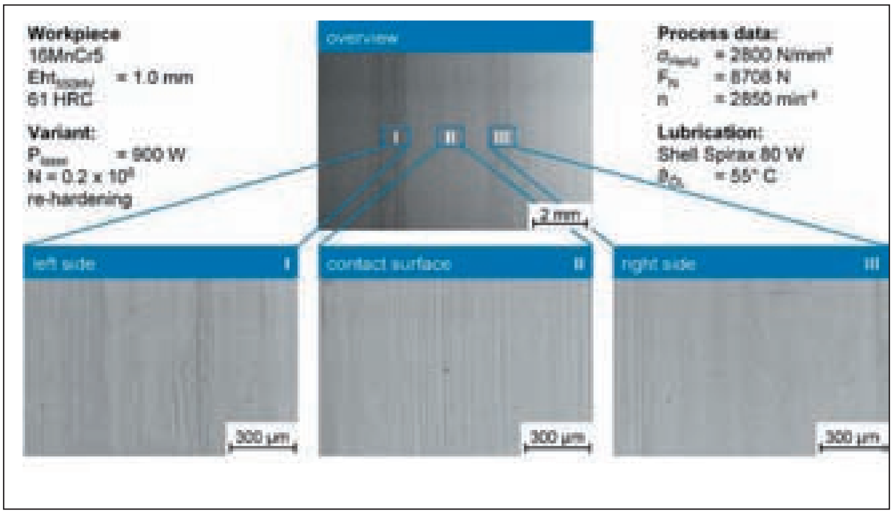

Figure 11—Surface structure of roller with rehardened zone after 200,000 load cycles.

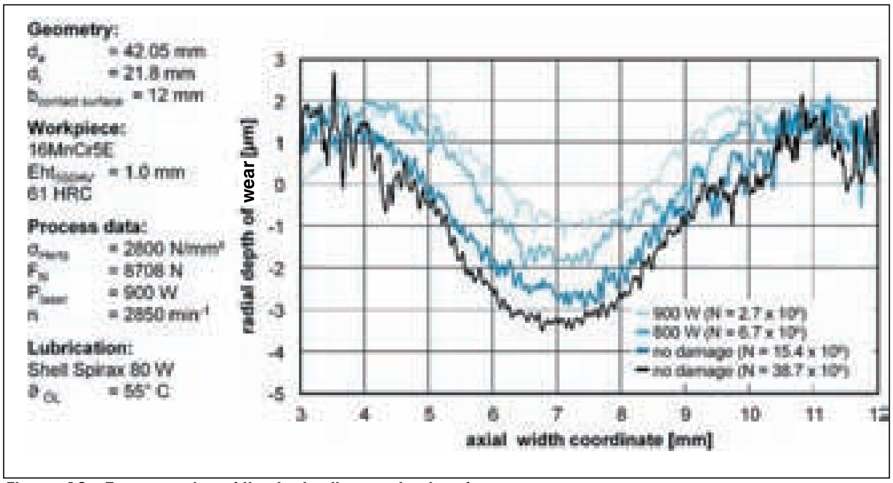

Figure 12—Topography of the test roller contact surface.

To gain a more detailed analysis of the surface wear mechanisms occurring on a rehardened roller, the surface has been examined with a scanning electron microscope after a very short time frame of N = 200,000 load cycles; the photos are shown in Figure 11. The upper photograph shows an overview of the sliding surface, and the three lower photographs display a more-detailed image of the middle, left and right areas. In the middle, the ground surface structure remains visible. This is the rehardened area that shows a high resistance to abrasive wear. On the sides, where the tempered material can be found, this structure is no longer visible. The typical grinding structure has been leveled, showing that in this area—even though the Hertzian stress is lower—higher wear occurs.

From these results it is concluded that the rehardened area is not the critical factor concerning the fatigue life and the load-carrying capacity of ground parts. Rather, the tempered zone—and especially the area of the changeover between rehardening and tempering—are critical. This demonstrates that rehardening-related grinding burn is very critical since there is always a large, tempered area making the fatigue life of the part unpredictable.

In order to determine the degree of influence of the damage and attendant wear on the sliding surface, the topography of the test roller sliding surface in the axial direction has been analyzed. The undamaged rollers have been analyzed after reaching half the sustainable load cycles (N = 15.4 x 10^6) and at the full sustainable load cycles (N = 38.7 x 10^6). The rehardened roller (P_{Laser} = 900 W) and the strong-tempered roller (P_{Laser} = 800 W) were analyzed after the full sustainable load cycles. The profiles are shown in Figure 12.

Results show that in the middle of the sliding surface there is a change in geometry of up to 5 µm. It can also be demonstrated in Figure 12 that the geometrical change does not depend on the degree of damage, but mainly on the number of load cycles. Only the rehardened roller shows a change on the side of the sliding surface similar to the results shown in Figure 11. Also it must be stated that the crowned shape of the contra roller and the geometrical change of the test roller lead to an increasing contact width, resulting in a reduced Hertzian stress with an increasing number of load cycles.

Summary and Outlook

When using gear grinding processes in a production environment, thermal damages to the external zone—such as grinding burn—can occur. Even with maximum care in process design, grinding burn cannot be fully eliminated. As the round-robin test on nital etching has shown, in the gear industry grinding burn can be reliably detected using a nital etching procedure. The evaluation of the etching result—and the maximum amount of grinding burn that can still be accepted—differ from company to company. This shows that there is a high uncertainty regarding the influence of grinding burn on the load-carrying capacity of gears.

Within the investigations described in this paper, test rig trials were carried out in order to determine the load-carrying capacity of thermally damaged parts under rolling stress. The contact conditions between two gear tooth flanks were simulated using rollers in order to deliver a constant load over the lifetime, and a constant thermal damage in the area under maximum load.

The results show that slight thermal damage to a small tempered zone, and significant tensile stresses, result in only a relatively small reduction in fatigue life. In contrast, more severe thermal damage with a larger tempered zone and a significant decrease in hardness lead to a dramatic reduction in fatigue life. If the part shows a rehardened zone, the fatigue life decreases even further.

From the results it can be concluded that grinding burn always leads to a reduction of fatigue life of parts under generating load. Furthermore, the analysis shows that slight thermal damage has a rather small influence, while significant damage causes a dramatic decrease in fatigue life. Also, it remains very problematic in determining the true level of thermal damage that can be tolerated by using only non-destructive analysis methods.

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The Business of Going Green

HEAT TREATMENT INDUSTRY REINFORCES ENVIRONMENTAL/ENERGY CONSERVATION

Matthew Jaster, Associate Editor

With furnaces commonly known for expelling smoke and flame, it's hard to believe energy and environmental awareness is even a possibility in the heat treating industry. Discussions on oil quenching, salt quenching and waste streams don't exactly lead to rally cries of "Save the Planet." It comes as no surprise that the heat treating industry is known more for its energy consumption and waste than its green policies and practices.

As green technology dominates the headlines this election year, there's an added interest for many industries in maintaining environmentally safe working conditions as well as minimizing energy consumption. Not an easy task for an industry that is currently using 17 percent of the electrical power in the United States, according to a recent report from the Metal Treating Institute (MTI).

Green technology, however, is infiltrating most sectors of the manufacturing complex, including the heat treatment industry. Experts are finding ways to minimize their waste and energy consumption through new technologies, sound business models and focusing on product development.

Promoting a Green Product

Green heat treating has become a hot topic, particularly in vacuum carburizing, as the technique is seen as one of the more environmentally friendly processes in the industry. According to Janusz Kowalewski, vice president of vacuum systems at Seco/Warwick Corp., the vacuum method doesn't create any harmful constituents for the environment.

"If you're using atmospheric furnaces, you have a protective atmosphere which could create CO_2 and the gases can be harmful," Kowalewski says. "The vacuum furnaces are not generating heat, there are no flames and it's much cleaner with gas quenching."

Despite the many benefits of the technique, Kowalewski notes that vacuum heat treating currently makes up a small percentage of the overall market. Companies such as Seco/Warwick, ALD-Holcroft Vacuum Technologies Co. and Solar Atmospheres, Inc. are working to increase the visibility of the method. Discussing its environmental impact and its potential as a green product is a good place to start.

"Our electrically heated, low-pressure carburizing furnaces produce significantly less greenhouse gases than the traditional method of carburizing in atmosphere-based furnaces," says William Gornicki, vice president of sales and marketing at ALD-Holcroft. "Traditionally, high volumes of carburized components could most cost efficiently be processed in big, atmosphere furnaces. These types of furnaces are less capital intense. However, the vacuum capabilities now on the market are making that argument less effective."

Photo courtesy of Solar Atmospheres.

By minimizing or even eliminating downstream operations like straightening or post heat machining, significant costs are removed from the manufacturing structure. "A far more uniform case depth is possible with vacuum carburizing. This most often provides higher power densities enabling smaller or lighter components with the same capabilities," Gornicki says.

While there have been innovative developments for burner efficiency, tighter furnaces and insulation, Gornicki believes the heat treating industry is lagging behind in energy conservation.

"The best we can do is to continue to promote vacuum processing," Gornicki says. "An improved culture will make selling our equipment easier. "

This Dualtherm 2-Chamber, LPC/HPGQ, from ALD-Holcroft produces less greenhouse gases.

Trevor Jones, project engineer at Solar, agrees that vacuum heat treating with gas quenching is the most environmentally friendly process on the market. He states that the only continuous negative byproduct is the electricity use.

Solar, with the help of its subsidiary, Magnetic Specialties, Inc., has developed a power supply called the FCS 2000 that runs more efficiently than the industry standard power supply from 5 to 20 percent. This improved efficiency is partly due to the fact that the FCS is a "dry" power supply and uses no cooling water to maintain the required operating temperatures.

"The power supply saves money for those who are being charged a power factor penalty from the utility company because the FCS runs at unity power factor," Jones says.

Seco/Warwick recently patented a power management system for high-pressure quench vacuum furnaces in an effort to reduce electrical consumption.

"Everyone is looking to save energy right now and this is giving us some advantage in the marketplace," Kowalewski says. "Our power management system regulates how much of the power is coming to the furnace, according to the temperature.

Kowalewski says it's critical to monitor the temperature of your load and to regulate or control how much power is coming to the heating elements. "We're seeing a 20 to 30 percent improvement of energy costs with this system."

The purpose of the original design was to create a single system of alternate control of heating and cooling processes that would be controlled by a single frequency converter whose output, through contactors, are simultaneously connected.

In a standard vacuum furnace, the cooling process is not controlled, and the blower motor (3-phases, induction motor) forcing gas circulation through the workload is not adjustable.

The operational benefits of the power management system include step-less control of heating and cooling power; programmable cooling rate controlled according to the load temperature; martempering quench capability; working with various cooling gases; no blower motor start-up over current and fewer electrical components; and a reduction in both equipment and maintenance costs.

Conservation Efforts vs. Customer Needs

While power management is just one of the ways companies can cut down on energy consumption, most don't have a specific committee or policy in place for green business practices. "We continually look for ways to become friendlier toward the environment by other means," Jones says, "typically in the form of energy and resource conservation."

In addition to controlling power supply demands, Solar has come up with several other steps, big and small, to augment its green infrastructure. The company has installed variable speed drives on all its pumps and motors to slow down or stop the pumps when there is no demand. The company also strives to save gas wherever possible, primarily using nitrogen, argon, hydrogen and helium, which pose little or no risk to the environment.

"Another small contribution Solar is making is to send used materials to recycling facilities such as our used thermocouple wire," Jones says. "These thermocouples have historically been thrown into the garbage, but now the scrap will end up back in the metals refining industry, reducing mining costs."

The trouble with promoting green standards in the heat treating industry is that the companies still have to address the specific needs of the customers.

"Many times the requirements specify how the heat treating process must be performed," Jones says. "A

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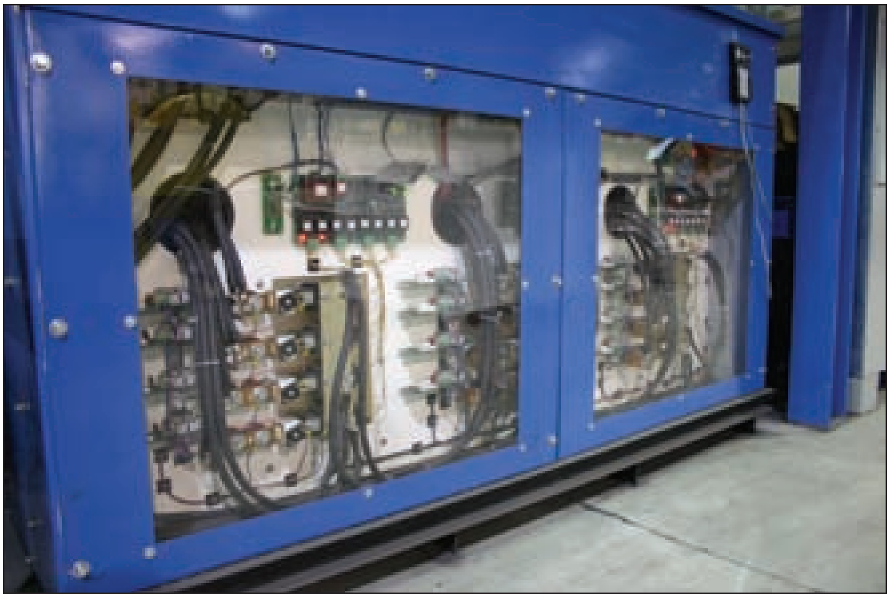
Solar Atmospheres boasts an energy efficient dry power supply.

vast number of jobs require the parts to be quenched in oil or salt in order to meet the specifications for the customer. These are notorious for being unfriendly to the environment."

Jones says the only way to change this is to change the specifications, some of which have been around for 60–70 years. "It would be difficult to get these specifications changed because some of the requirements on certain materials would not be satisfied unless it was quenched in oil or salt."

While Solar only uses high-pressure inert gas to quench parts, the company believes the industry needs to develop new materials for quenching. "These challenges can only be overcome by going to the engineers that initially developed the specs and convince them to change it," Jones says.

If these specifications can't be altered, the company is at least attempting to govern its green culture in other areas of the workplace. "Providing and maintaining a work environment that is safe, clean and reflects our respect for human dignity," is taken directly from Solar's mission statement.

The lighting at the office buildings at Solar has been replaced with electronically-ballasted fixtures and the company boasts a paper recycling program. They are proud to report in a recent newsletter that 90 percent of the employees at Solar have work spaces that include a view outside.

"Some of the areas of the industry may not allow for much improvement in terms of becoming green because of the nature of the process or costs to the company may put them out of business," Jones says.

If a company cannot find justifiable means to promote green standards and initiatives in its own backyard, there are still many viable ways to remain environmentally conscious.

A. Finkl & Sons Co. is a supplier of forging die-steels, plastic mold steels, die casting tool steels and custom open-die forgings. With operations that include melting, re-melting, forging, heat treating and machining, the Chicago-based manufacturer was interested in lowering the effects of the carbon dioxide released during production runs.

Due to the nature of the operation,

Solar Atmosphere sends used materials to recycling facilities.

there wasn't much internally the company could do to lower its carbon footprint. Instead, the company created a green program long before the term popped up in every newspaper, magazine and blog dealing with environmental issues.

Since 1990, the "Forging a Fresher America" program has planted trees in protected forests in Wisconsin and Illinois in an effort to balance out some of the company's carbon and energy output. Recently, the company donated $261,500 to plant 2 million trees in Wisconsin.

While A. Finkl & Sons may not be able to control some of its internal waste and energy consumption, they're taking responsibility for it and have been for several years. Hopefully, other organizations will follow suit.

Jones at Solar states that an improved green culture can help companies become more efficient with energy consumption as well as heighten awareness of the negative impacts to the environment.

"This could potentially lead to cost savings which may be passed down to the customer who will greatly appreciate it."

According to Jones, companies that are environmentally conscious have a tendency to have a cleaner working environment that is visually pleasing and gives the employers/employees the will to maintain it.

While the heat treating industry as a whole may not be winning any conservation awards, there are plenty of individuals hoping to make a significant difference in the future.

"There are many people in heat treating that are working to lower pollution and expend less energy, and very innovative systems are being developed for this purpose," Kowalewski says. "As an industry, however, there is still much more we can do."

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Basic Gear Noise Short Course Covers Fundamentals

More than 1,350 engineers and technicians from more than 320 companies have participated in this basic course, which The Ohio State University's Gear Dynamics and Gear Noise Research Laboratory (GearLab) has conducted for more than 29 years. Gear designers and noise specialists with little to no knowledge of noise analysis learn about the mechanisms of gear noise generation, the methods used to measure and predict gear noise and the techniques for reducing vibration and gear noise.

Engineers and technicians who analyze, manufacture, design specs and use gear systems in industries such as automotive, transportation, machine tool, process machinery, aircraft, appliance and general manufacturing will study how to reduce transmission error, dynamic friction forces. Some companies that have attended in the past include Caterpillar, John Deere and General Motors, according to Dr. Donald Houser, Emeritus Professor and founder of the GearLab. Houser has organized the course since its inception and lectures on gear noise measurement and modeling. Dr. Rajendra Singh also instructs the course.

Even perfect gears make noise, and this is the basis for the first day's lectures. Qualitative and quantitative terms are used to describe how design factors and manufacturing mistakes play into the noise equation. Houser and Singh teach attendees how these details can help predict transmission errors. Demonstrations of the GearLab's custom-made equipment and software occur throughout each day. "We run a very accurate spur gear set that is in an offset gearbox of a UH-1 helicopter," Houser says. "It is a demonstration of how a tremendously accurate gear can be tremendously noisy.

"We do a lot of signal processing demonstrations of how you look at the data in different ways using spectrum analysis to view different properties of the signal. We can compare predictions of noise with measurements of noise," Houser says.

Past attendees have commented on the practical nature of the curriculum. The workshop aims to discuss real-life problems of gear noise and dynamics. The highlight of this goal is a case history workshop that takes place on the third day. The attendees are asked to present issues of gear noise they've come across, and the group responds by offering possible solutions to each problem. This segment of the program typically takes up two or three hours, but there is no limit.

"We spend sometimes as much as a half a day just talking about problems they bring to class," Houser says. "They make a brief presentation of their problems, and then everyone sits down and discusses; what they're doing, what they need to do, ask them questions. It's kind of a brainstorming session on how do we go about solving this problem."

The course is continuously being modified to reflect new technology. The analysis techniques in particular are constantly changing, Houser says. Some material is added to a two-day advanced course offered every other year, which is designed to follow up the basic short course.

The advanced course will be offered in 2009. Information will be available on the GearLab website (*www.gearlab.org*). It is designed for people who attended the basic course or work at a more advanced level.

For companies with more than a few interested attendees, Houser has offered the course at individual companies. This allows for more flexibility because it can take place a day at a time over the course of a few weeks depending on what the company prefers. Bringing the course directly to a specific company also allows Houser to customize it, and feature information that applies directly to the company's needs. "Last year we were up at Ford. We gave this course over six days, two days at a time," Houser says.

The 2008 Basic Gear Noise Short Course is being held September 16–18 at The Ohio State University, Columbus, OH. For registration, contact Jonny Harianto at (614) 688-3952 or *harianto.1@osu.edu*. To inquire about a customized version of the course, contact Dr. Donald Houser at *houser.4@osu.edu*. For general information, visit *www.gearlab.org*.

September 8–10—Furnaces and Atmospheres for Today's Technology Seminar. Holiday Inn Express, Meadville, PA. Seco/Warwick organizes this three-day seminar providing heat treating equipment information and best practices. Attendees will learn the vital furnace design and plant management options to better assess their equipment options with various heat treat furnaces and atmospheres. Dan Herring, aka "the heat treat doctor," is the seminar's guest speaker. He will discuss the heat treating industry's future in North America and how it will progress. Herring will also focus on new quality standards, training, education and how to keep heat treating affordable. Seco/Warwick intends that content be non-commercial and objective. The tuition includes hospitality, lunch and dinner meetings where staff, colleagues and Herring participate. The program also includes a tour of Seco/Warwick's manufacturing facility. Equipment operators, heat processing supervisors, plant engineers, metallurgists and manufacturing personnel should attend as well as equipment owners who will learn how to improve efficiency and minimize waste. For more information, contact Elisha Schreiber at *emink@secowarwick.com* or (814) 332-8576.

September 22–23—Geometric Dimensioning and Tolerancing Seminar. Hilton St. Louis Airport, St. Louis. As more enterprises add Geometric Dimensioning and Tolerancing (GD&T) requirements to their conventional engineering drawings, an understanding of GD&T is required in order to accurately interpret them. This seminar will review the basics of GD&T including the symbols, terminology and rules that are based on the current version of the ASME Y14.5M-1994 standard. Once the seminar is completed, participants will know how to identify datums and their use; understand the relationship of size dimensions to the form of the part; interpret feature control frames; compute maximum and least material condition values; compute positional tolerance zones; interpret the general rules of GD&T; inspect to composite positional tolerancing requirements; and apply graphical inspection analysis to GD&T control. The course is repeated September 25–26 in Kansas City, MO and September 29–30 in Minneapolis. For more information, including registration, visit *www.hightechnologyseminars.com*, e-mail Ben Marguglio at *ben@hightechnologyseminars.com* or call (845) 265-0123.

September 22–23—Fastener Fair. SYMA Event Centre, Budapest, Hungary. The Fastener Fair represents every aspect of the fastener and fixing market by bringing together manufacturers, machine suppliers, wholesalers, distributors, importers, exporters and tool suppliers. The fair aims to create an environment for new ideas and partnerships, so professionals can come away with new business. The event also intends to highlight Europe's near East as an appealing market for manufacturing and assembly because of low-cost labor and economies and new members of the EU. The primary objective of the exhibition is to be cost- and time-efficient, meaning all booths will be closely monitored in size. The Fastener Fair is marketed to large end users in order to gauge both ends of the market. For more information, visit *http://www.fastenerfair.com/page2153/budapest-2008.aspx*.

September 23–25—Canadian Manufacturing Week/Weld Expo Canada. International Centre, Mississauga, ON, Canada. Design engineering, maintenance products and industrial support services are showcased at Canadian Manufacturing Week. The event, sponsored by the Society of Manufacturing Engineers, is for OEMs that deal with overall product design, fluid power, motion control, electronics or materials. Attendees will watch demonstrations, participate in technical sessions and learn how to reduce downtime and get the most out of MRO operations and machines while cutting costs. Weld Expo is co-located concurrently where companies will show new productive welding equipment, machinery, products and services. Within Weld Expo is the Metal Finishing and Coatings Pavilion where finishing and coating systems are on display and demonstrated. For more information, visit *www.sme.org*, e-mail *canadasales@sme.org* or call (888) 322-7333.

September 24–25—AWEA Wind Resource and Project Energy Assessment Workshop. Portland Marriott Downtown Waterfront Hotel, Portland, OR. This third installment of the annual American Wind Energy Association's two-day workshop will discuss current practices in the industry and their effectiveness, how to reduce bias and uncertainty in energy estimates, up-and-coming tools and new industry concerns. Turbine manufacturers are encouraged to attend along with project developers/operators, government agencies, consultants, academics and landowners. Other topics addressed include recent studies of wind speeds in North America and how to identify and reduce bias and uncertainty in data analysis, flow modeling and technical loss estimates. A pre-conference seminar will take place the day before as an introduction to wind energy, with a separate registration. For more information, contact Lori Rugh at *lrugh@awea.org* or (661) 821-2149.

September 29–October 1—Tooling for Composites. Doubletree Hotel, Seattle. Sponsored by the Society of Manufacturing Engineers, this event focuses on the approaches and materials needed to manufacture tooling for composites. Attendees will learn some common pitfalls and best practices for production. Tooling for Composites provides cross-industry information about tooling in aerospace, wind energy and transportation industries. For more information, visit *www.sme.org*, e-mail *service@sme.org* or call (800) 733-4763.

Outstanding PM Parts Awarded

The 2008 Powder Metallurgy Design Excellence Awards Competition took place at the PM2008 World Congress in June. Several of the winning parts recognized were gears.

Mitsubishi Materials PMG Corporation, Tokyo, took home a grand prize in the automotive chassis category for a gear set with high strength used in a new tilting and telescoping steering column. The tooth lock and two cams making up the gear set were produced from diffusion-alloyed PM steels. They have a density of more than 7.05 g/cm³, a tensile strength more than 159,000 psi and a 57 HRA hardness.

In the hardware/appliances category, Capstan Atlantic of Wrentham, MA won the grand prize for a PM steel gear set used in a high-volume business machine printer. Roll densified to a surface density of 7.8 g/cm³, the gear has an AGMA quality 10 precision level, and the pinion has an AGMA 8 level. The gear and pinion have a core density of 7.3 g/cm³, and the gear-tooth-surface fatigue resistance matches that of a wrought steel 8620 carburized gear. The single-pressed gear replaced two machined gears and saved more than 40 percent in cost.

A grand prize was awarded to Parmatech Corporation, Petaluma, CA, in the medical/dental category for a 17-4 PH stainless steel articulation gear that was used in a surgical stapling unit. This part was formed by injection molding to a density greater than 7.65 g/cm³ with tensile strength of 130,000 psi, a yield strength of 106,000 psi and a 25 HRC hardness. Finishing processes were unnecessary in the gear's production, which saved 70 percent in cost.

A low-alloy steel intake and exhaust sprockets, used in a variable valve timing system for a high-performance, double-overhead cam V-6 engine, received an award of distinction in the automotive engine category. Produced by Cloyes Gear & Products Inc., Paris, AR, the sprockets used warm compaction to form to a density of 7.25 g/cm³. The high-strength timing sprocket achieves cam phasing functions. The sprockets have a typical tensile strength of 170,000 psi, a 52,000 psi fatigue limit and compressive yield strength of 183,000 psi.

The PM Design Excellence Competition is held annually to demonstrate how powder metallography is an analytical tool in research and development, problem solving and quality control areas of powder metallurgy. Participants include manufacturers, users, researchers and suppliers of powders and powder-related equipment. The PM World Congress was sponsored by the Metal Powder Industries Federation, which hosted the biennial event in Washington, D.C.

The AVE-208 by Cloyes Gear & Products, Inc. received the Automotive Engine Award of Distinction.

The HA-300 steel gear set from Capstan Atlantic received the hardware/appliances category grand prize.

The ND-108 articulation gear from Parmatech Corp. received the grand prize in the medical/dental category.

Hannover Fairs USA

APPOINTS KURT MEDERT SALES MANAGER


Kurt Medert

Kurt Medert, formerly vice president of the business management division of AGMA, joins Hannover Fairs USA, Inc. as the sales manager for industrial trade shows. Hannover Fairs USA is the U.S. subsidiary of Deutsche Messe AG, a Hannover, Germany-based trade show organizer.

In his new position, Medert will pursue exhibit sales in the power transmission and motion control; material handling and logistics; and machine tool and metalworking sectors for international events in Hannover such as Hannover Messe, CeMAT, EMO Hannover and extensions of these events in China, India and Turkey.

His former position at AGMA involved supervising commercial activities and programs and directing Gear Expo, the association's main trade show. For 10 years prior, Medert served as deputy executive director of the Packaging Machinery Manufacturers Institute, where he managed day-to-day operations, membership and trade show activities, according to a press release from Hannover.

"We are pleased to have Kurt join our HFUSA team," says Art Paredes, president and CEO of Hannover. "His many years of experience with industrial trade shows and his knowledge of the industry will help us develop new business as we expand the participation of American companies at our worldwide industrial events."

ALD-Holcroft

EXPANDS MANUFACTURING IN NORTH AMERICA

In response to demand for ModulTherm and DualTherm furnace systems in North America, ALD-Holcroft widened manufacturing capabilities in the region. The ModulTherm and DualTherm treatment chambers and quench chambers will be produced at the Wixom, MI facility instead of being imported from ALD Vacuum Technologies GmbH. The first deliveries of the U.S-based systems will be ready in the third quarter of 2008.

"Our manufacturing and supplier base is established and work is under way on the first treatment chambers from the United States. We're pleased the worldwide demand in conjunction with the euro to dollar conversion rate justifies this expansion," says Jason Sisler, president. "These demands are further proof of a concept that the ModulTherm is the system addressing the future needs of the heat treating community."

Sunnen

Appoints Director of Marketing and Business Development

Barry Rogers

Barry Rogers is now director, marketing and business development for Sunnen Products Company. He is responsible for leading Sunnen's global marketing, product development and R&D priorities. "Barry has a significant track record in initiating and managing successful technology launches in the metalworking industry," says Mike Haughey, Sunnen COO. "This background, coupled with his overall manufacturing industry knowledge and contacts, positions him as the ideal person to drive the introduction of Sunnen's new technologies for improving the performance of gears, small engines, hydraulic valves, diesel injectors, diesel cylinder liners and gas and oil products."

Rogers began his career in the manufacturing sector for Honeywell Micro-Switch Division and John Deere. In 1988, he started working for Renishaw and rose through the ranks to become U.S. national sales and marketing manager in 1998.

continued

"Sunnen is on the verge of a new significance in manufacturing," according to Rogers. "Its automated, high-production, precision bore machining technology lets manufacturers elevate their products to 21st century performance levels, with lower emissions, noise and vibration, but with higher power densities, energy efficiency and better sealing.

"I am thrilled to be part of the team that brings this to the market."

Solar Manufacturing

FILLS TWO SENIOR-LEVEL ENGINEERING POSITIONS

John Barron was named vice president of engineering, and Robert Wilson is now the senior mechanical engineer for Solar Manufacturing.

Barron is now in charge of the engineering, quality control and field service efforts of Solar Manufacturing. He is responsible for customer service and technical support, and he provides insight into research projects, the enhancement of current equipment and product development.

"John brings over 35 years of experience and knowledge to our business. He is well respected throughout our industry," says Jim Nagy, vice president of operations. "It is an asset to have him on our team."

Barron was previously Solar Manufacturing's technical director. According to the company's press release, he has worked for Ipsen as an electrical/software manager; Vacuum Furnace Systems as electrical engineering manager and technical director; and Lindberg Furnaces as electrical engineering manager. Barron received a bachelor's degree in electrical engineering from Villanova University.

In his new position, Wilson is responsible for every component of vacuum furnace design focusing on quenching processes. "Bob brings a wealth of knowledge about mechanical engineering to our business," Nagy says.

Wilson previously worked as a senior mechanical engineer for Johnson Matthey, the National Drying Machinery Company and Abar Ipsen Corporation. He earned a bachelor's degree in mechanical engineering from Drexel University.

Gear Research Institute Board Member Resigns

William Bradley stepped down from the Gear Research Institute's Board of Trustees. He was president of the board from 2003–2007 and retired from AGMA in 2007. AGMA nominated Robert Wasilewski, design engineering manager of Arrow Gear, to fill his seat.

Wasilewski received a bachelor's degree in mechanical engineering from The University of Illinois in 1975 and has worked for Arrow Gear since 1976. He designs spur, helical, spiral, Zerol, hypoid and straight bevel gears and gearboxes for Arrow Gear. He is in charge of failure analysis studies at the company. He is a member of the Technical Division Executive Council for AGMA. The association appointed him chairman of the Bevel Gearing Committee, and he received a Technical Division Executive Committee award in 1991 for contributions to gear design and utilization.

Siemens

OPENING SECOND ELGIN PLANT

The largest producer of wind turbine gear drives in the United States, Siemens Energy & Automation, is creating a $20 million second plant in Elgin, IL. A groundbreaking ceremony was held in June, and the plant is expected to be completed by March 2009. Siemens employs 150 people at the existing Elgin plant; the additional plant will create 300 production jobs and 55 office jobs over the next three to four years. The existing plant will continue manufacturing gears and components, which will be assembled and tested at the new plant once it begins production.

"Siemens is committed to providing technologies that promote energy efficiency and reduce costs," says Anne Cooney, vice president of the power conversion division for Siemens. "Combined with the expertise and product knowledge we have in Elgin, the new facility will enable Siemens to increase production of our mechanical drives to help our customers meet the growing demand for sustainable energy resources."

continued

NEWS

Siemens was given incentives from the State of Illinois and the City of Elgin including a Wind Energy Development Grant and Employer Training Investment Program job training funds.

Large In-House Turning

OFFERED BY RIVERSIDE SPLINE

Upon installation of a YOUJI VTL-1000 CNC vertical turning lathe, Riverside Spline and Gear is capable of turning up to 43 inches. "We have seen an increase in larger gears due to the purchase of the Höfler 900 gear grinder," says Aaron Forest, vice president of operations. "The purchase of the YOUJI VTL-1000 is in response to this demand, allowing all our turning to be done in-house."

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SERVICE

Best Supporting Gears

Photos courtesy of Paramount Home Entertainment.

No one seems to appreciate gears more than a Hollywood cinematographer. What image better serves a strong, visual narrative than the steady motion of two gears meshing in unison? Whether depicting a brief moment from the industrial revolution or highlighting the intricacies of a clock tower, gears have always been an aesthetically-pleasing addition to a film's production design and cinematic vision.

Through the years, gears have racked up more screen time than Tom Hanks, Meryl Streep and Paul Newman combined. The Addendum staff had just enough free time to wade through hours of footage searching for films that include our favorite machine element.

2007 Academy Award-Winning Gears: *Sweeny Todd: The Demon Barber of Fleet Street*–Based on the Broadway musical of the same name, gears play an intricate role in the barber's chair the title character constructs to carry out his murderous revenge plot. Merely looking for a quick shave and a "little taken off the top," the unsuspecting customers get more than they bargain for when a musically-inclined Johnny Depp offers his rather unique "cutting" services. *The Golden Compass*–This kid-friendly, epic adventure revolves around an alethiometer that can reveal the answer to any question asked of it. Gears are responsible for turning the needles on the device, giving its supernatural sensibilities some mechanical credibility. *There Will Be Blood*–Gears are prominent on the derricks used by Daniel Plainview (Daniel Day-Lewis), an egotistical tyrant creating an oil empire at the expense of the people around him.

Fantasy Gears: *The Princess Bride* (1987)–When the sword-fighting hero Wesley (Cary Elwes) gets strapped into a diabolical torture device known as "The Machine," viewers are treated to a menacing medieval device that boasts gears spinning in various directions. *Army of Darkness* (1992)–Armed with only a chainsaw and some dry wit, Ash (Bruce Campbell) is sucked into a wormhole and sent back to 1300 A.D. to fight an army of zombies. During his journey, he faces some rather archaic equipment from the Middle Ages that boasts a variety of gearing elements. *Labyrinth* (1986)–If you can look away from David Bowie's ridiculous costume long enough in this musical Muppet adventure, you'll find gears scattered throughout the numerous twists and turns of the gigantic maze (true story).

Symbolic Gears: *The Hudsucker Proxy* (1994)–The gears featured in the Coen Brothers screwball comedy provide an ongoing visual feast on circular motion. Gears spin, kids hula-hoop and the corporate powers that be run around in circles for the duration of this witty, motion picture that explores the insanity of big business. *The Paper* (1994)–Ron Howard's enthusiastic look at journalism begins with computer-animated gears symbolizing the daily grind of life at a newspaper. Editors break deadlines, obsess over story ideas and ignore family and friends in pursuit of the latest headlines.

Gear Directors: Director Terry Gilliam (*Brazil, 12 Monkeys, Time Bandits*) has been quoted as saying he understands gears, pulleys, carts and wheels, but doesn't understand the electronic revolution because he "can't get his hands on it." It's no surprise many of his films include gears and gearing in the production design. Jean-Pierre Jeunet & Marc Caro (*City of Lost Children*, *Delicatessen*), before going their separate ways, this French directing team tackled industrial elements in both their short animated films and full-length features. With gears as an obvious backdrop in certain scenes, the directors had been accused by many critics of being interested more in the machinery in their films than in humanity.

Have you noticed gears prominently displayed at the local Cineplex? Drop us a line at *publisher@geartechnology.com* with some of your favorites.


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