GEAR TECHNOLOGY

NOVEMBER/DECEMBER 2005

The Journal of Gear Manufacturing

www.geartechnology.com

PLASTIC GEARS

- Smaller, Quieter Gears Take Center Stage
- Laminated Gearing

POWDER METAL GEARS

- Shot Peening P/M Gears

LEAN MANUFACTURING

- Getting Lean in the Gear Industry
- Inventory Control for Job Shops

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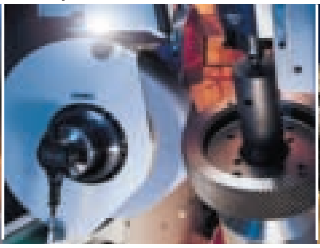
Bevel Gear Production

Cylindrical Gear Production



Full Line of Cutting Tools

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PLASTIC GEARS

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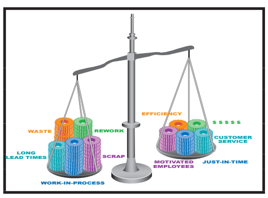

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processes and service
the best does it all.

GEAR TECHNOLOGY

The Journal of Gear Manufacturing

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Technical Editors
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***Gear Industry Home Page*™ Sales**
Ryan King
***powertransmission.com*™ Sales**
Clark Hopkins

RANDALL PUBLISHING STAFF

President Michael Goldstein
Vice President Richard Goldstein
Accounting Luann Harrold

Phone: 847-437-6604
E-mail: *wrs@geartechnology.com*
Web: *www.geartechnology.com*
www.powertransmission.com

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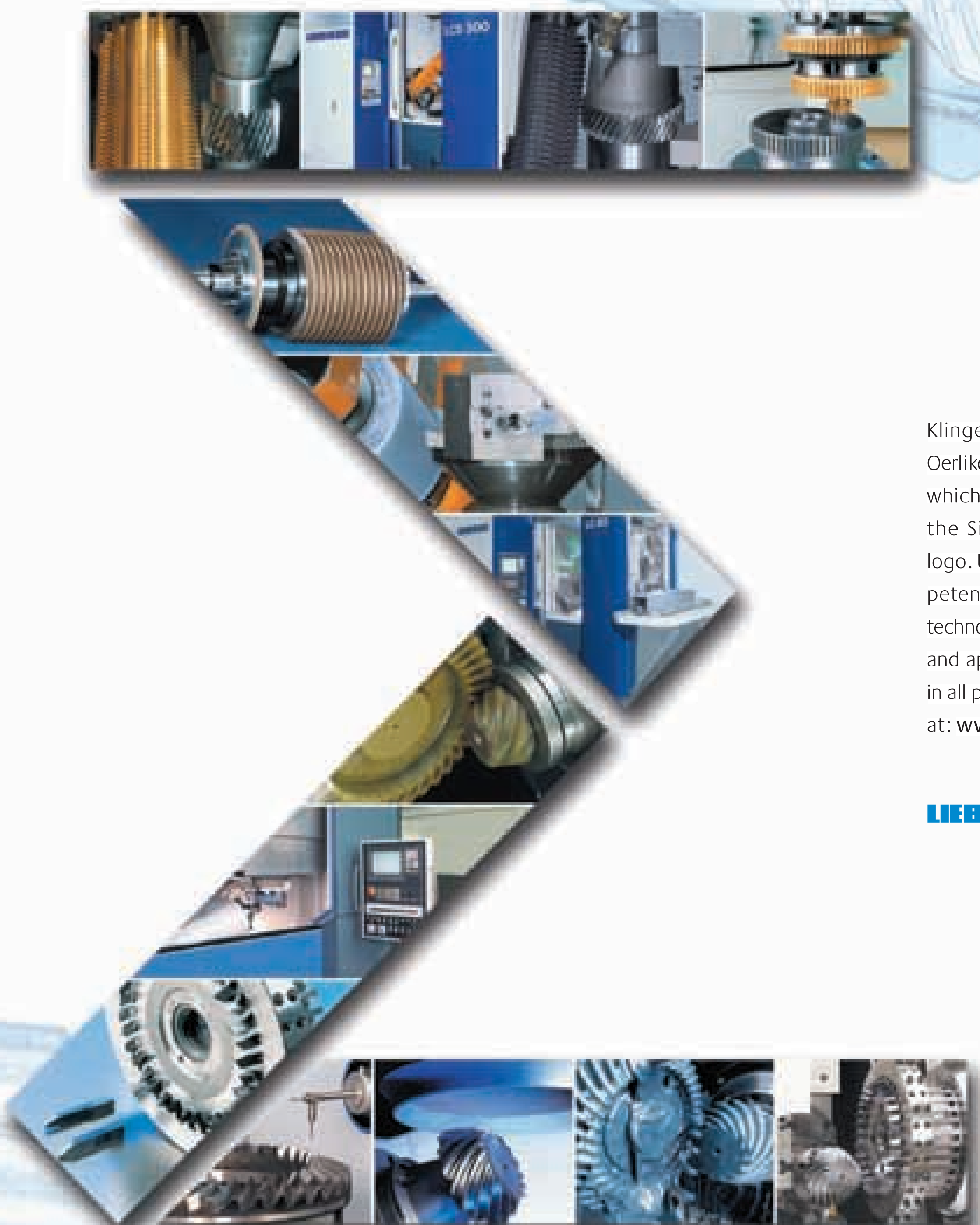


Is Gear Expo Worth It?

If you read the press clippings (even our own), and listen to the comments of many of the major exhibitors, you'll hear that Gear Expo 2005 was a resounding success.

After all, many of the exhibitors told us they did extremely well. At times, the show seemed downright busy, particularly at the booths of some of the larger exhibitors. Sometimes, though, it just looked busy because the booth's sales reps often outnumbered the actual customers. For example, there were twice as many people from Gleason at the show as there were from all the divisions of General Motors, according to the show's registered attendee list.

Of course, everyone likes to put the best possible spin on things, especially when they've just finished spending thousands, tens of thousands or hundreds of thousands of dollars on the show—and believe me, that's what some of the exhibitors spend.

The sad truth is that just 1,400 people—other than the exhibitors—came to Gear Expo. According to official registration numbers, there were 2,500 people at the show, but 1,100 were exhibitors, and although the 30 or so gear manufacturers who exhibited are potential customers of the other 150 exhibitors, the fact remains that this is a small show. Despite what exhibitors are saying publicly, a fair number of them, both large and small, are grumbling. They're disappointed by the amount of energy and money they have to spend on a show that attracts so few.

So when I sit back and think about all the resources being spent on Gear Expo, coupled with how few of you actually go, I can't help but think that the money might be better spent elsewhere.

Don't get me wrong—I've always been a champion of the show, and I still am. This year, our magazines spent a lot of time prepping you for the show. I used this space to encourage you to attend. I believe that Gear Expo provides the greatest collection of gear knowledge, experience and expertise anywhere in the world, all gathered in one building. I believe there's a lot to be gained by attending Gear Expo, whether you design gears, make them, process them, buy them or use them. But judging by your lack of attendance, most of you must feel otherwise.

So where were you? Why didn't you come to the show? I know you're out there, because you continue to subscribe to our magazines. You visit our websites and use the buyers guides there. If *geartechnology.com* can attract 25,000 visitors per month, and *powertransmission.com* can attract 50,000 visitors per month—visitors who are interested in many of the same products and services that were found at Gear Expo—why did Gear Expo attract only 1,400?

I know you're all busy. Manufacturing is extremely competitive these days. But surely you haven't solved all your gear-related problems. I'm certain that a day or two at Gear Expo could have been extremely productive for you and your company.

I have to place at least some of the blame on the AGMA itself—for not getting the word out, for not communicating clearly the advantages of attending, for not selling the show to you, the potential attendees.

Sure, the AGMA has advertised the show throughout the year, including full-page ads in the front of this magazine. Problem is, many of those ads weren't aimed at you, the customers. For most of the year, the AGMA used its advertising to try to sell floor space to potential exhibitors. I kept waiting and waiting and waiting for the advertisement telling people why they should attend the show.

If Gear Expo is to continue, AGMA is going to have to realize that the success of the show depends upon foot traffic, not booth sales and not fall back on counting the exhibitors. In the commercial world, we must be sure our customers are successful with our products—not just consider them a sales opportunity.

However, there may be other reasons why so many people missed Gear Expo. Those reasons might be no one's fault.

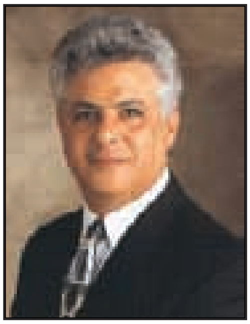
Maybe the gear industry is just too small to support a big machine tool show. Maybe all of you were just too busy cutting gears this year. Maybe you already know all the suppliers and don't feel like there's anything new to learn by attending the show. If so, I can't say I blame you for staying away.

This year, at least one major machine tool manufacturer pulled out of the show. Nachi had reserved space early but changed its mind. Over the years, the major exhibitors have brought less and less gear cutting equipment. Some of them this year told us they had brand new machines, but they couldn't show us the machines because they didn't bring them. To see them, we would have had to go to EMO.

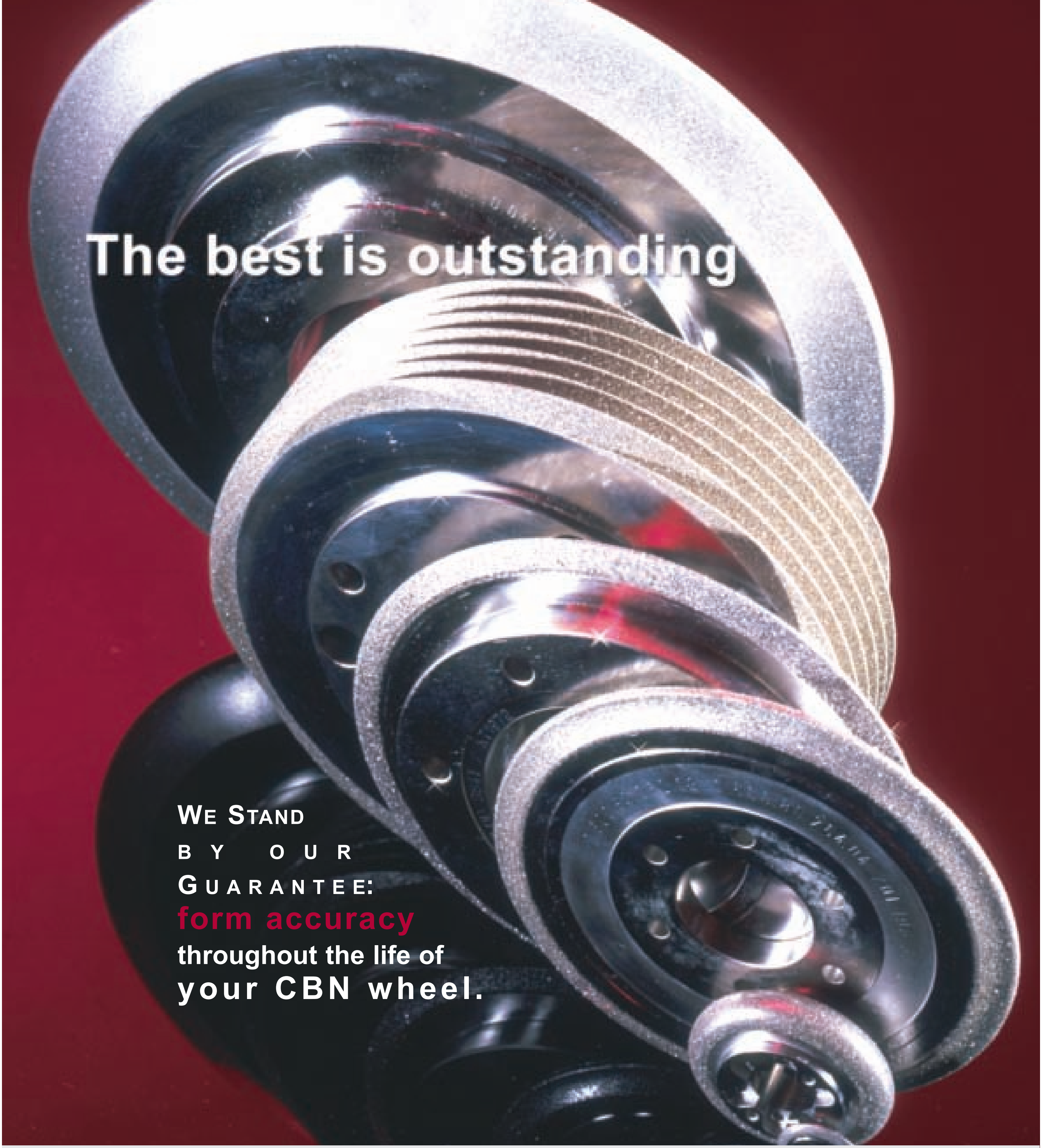
In light of all this, is Gear Expo sustainable?

I often say that I'd appreciate your comments. This time your comments are a must-have. If you went to the show, tell me why it's still worthwhile for you. If you didn't, tell me why. I'm concerned about the show's future, and you should be, too.

publisher@geartechnology.com



Michael Goldstein, Publisher & Editor-in-Chief


The best is outstanding
We Stand
by our
Guarantee:
form accuracy
throughout the life of
your CBN wheel.

High-Speed Inspection System Scans 6,000 Data Points a Second

Introduced at EMO, the Renscan5 high-speed inspection system from Renishaw delivers part inspection speeds up to 20 times faster than conventional technology, according to the manufacturer.

The Renscan5 uses the REVO two-axis, infinite positioning probe head to scan at 500 mm per second while allowing the coordinate measuring machine (CMM) to move in a single axis at a constant velocity. According to Renishaw, this eliminates major sources of CMM dynamic errors that have restricted scanning speeds to 10–20 mm per second in conventional metrology practice. Critical to large gear set manufacturers, the machine can verify fit and form of thousands of data points in a matter of minutes, the company says.

Barry Rogers, Renishaw's national sales and marketing manager, says, "There is no question this is a leap-frog in technology. REVO collects data at 6,000 data points a second, compared to one or two data points a second using touch trigger sensors or 200–300 data points a second using current scanning technologies."

The REVO head performs most of the work in scanning part features, delivering speeds and accelerations beyond CMM capabilities while avoiding the dynamic errors incurred in moving the larger mass of the CMM at high rates of acceleration/deceleration.

According to the company's press release, the ultra-high-speed scanning system solves a production bottleneck for makers of complex parts that require large numbers of data points for process control and data variation.

Both the Renscan5 and REVO head can be installed on existing or new CMMs, due to a universal CMM controller developed by Renishaw.

For more information:
Renishaw Inc.
5277 Trillium Blvd.
Hoffman Estates, IL 60192
Phone: (847) 286-9953
E-mail: *Jeffrey.seliga@renishaw.com*
Internet: *www.renishaw.com*

Koepfer EMAG Machine Turns, Hobs and Deburrs

The VSC 250/400 DUO WF gear hobbing center from Koepfer EMAG offers complete soft machining of gears on a single machine.

According to the company's press release, the gear hobbing center turns, hobs and deburrs the soft component.

For dry machining, direct driven motor spindles facilitate the appropriate spindle speeds and torque rates. Unhindered chip flow to the chip conveyor keeps the temperature growth in the machine to a minimum. Process heat is eliminated with the removal of chips and not through the machine base.

Additional features include an overhead slide unit with a work spindle supported on both sides of the machine, a hydrostatic work spindle guideway that provides vibration damping properties during machining, and fluid cooling of components to ensure a high degree of thermal stability.

In addition, measuring stations and/or workpiece marking devices can be integrated into the automated workpiece flow.

For more information:
Koepfer EMAG
38800 Grand River Ave.
Farmington Hills, MI 48335
Phone: (248) 477-7440
E-mail: *info@usa.emag.com*

Engis Machine Can Bore Finish 480 Gears Per Hour

The six-spindle SPM Series single-pass bore finishing machine from Engis can finish the bores on as many as 480 gears per hour with tool life routinely exceeding 60,000 parts.

According to the company's press release, the bore finishing tools are capable of achieving bore geometries to within 0.0002" in standard, blind and semi-blind bores. The machines feature a series of pre-set barrel-shaped tools with a slow wearing diamond coating that pass once through the bore while the tool, part, or both, rotate. As the single-pass bore finishing tool need not expand or contract over the finishing cycle, the system maintains maximum control over bore size and finish.

A range of standard and customized single-pass bore finishing machines are configurable to a range of gear production processes. The SPM Series is designed for finishing parts with bore sizes up to 1.5", configurable in four-, six- or eight-spindle models.

Customized automation packages are available for both in-bound and out-bound product flow. Additional benefits include more predictable results, fewer rejects, less frequent part inspection and SPC values of more than 2.0 Cpk.

For more information:
Engis Corp.
105 W. Hintz Rd.
Wheeling, IL 60090
Phone: (847) 808-9400
Internet: *www.engis.com*

Power Plant Actuators Feature Bevel Gears

The MT Limitorque Actuation System of bevel gear operators from Flowserve Corp. are designed to perform in power industry valve applications.

Designed as a combination of a bevel gear operator torque housing with a new thrust base design, the series is suited for torque seated valve applications as well as applications involving elevated process temperatures. MT series bevel gears and thrust base housings are made of ductile iron.

Features include thrust bearings and drive sleeve/stem nut design. These combine to offer a rugged bevel gear operator for handling the seating and unseating forces of high pressure gate and globe valves found in power plants worldwide. The stem nut is shouldered in the drive sleeve to capture thrust forces within the thrust housing without transferring those forces to the torque housing.

The series is available in torque ranges to 8,000 ft.-lbs. and thrust ranges to 325,000 lbs.

For more information:
Flowserve Corp.
P.O. Box 11318
Lynchburg, VA 24506
Phone: (434) 528-4400
Internet: *www.flowserve.com*

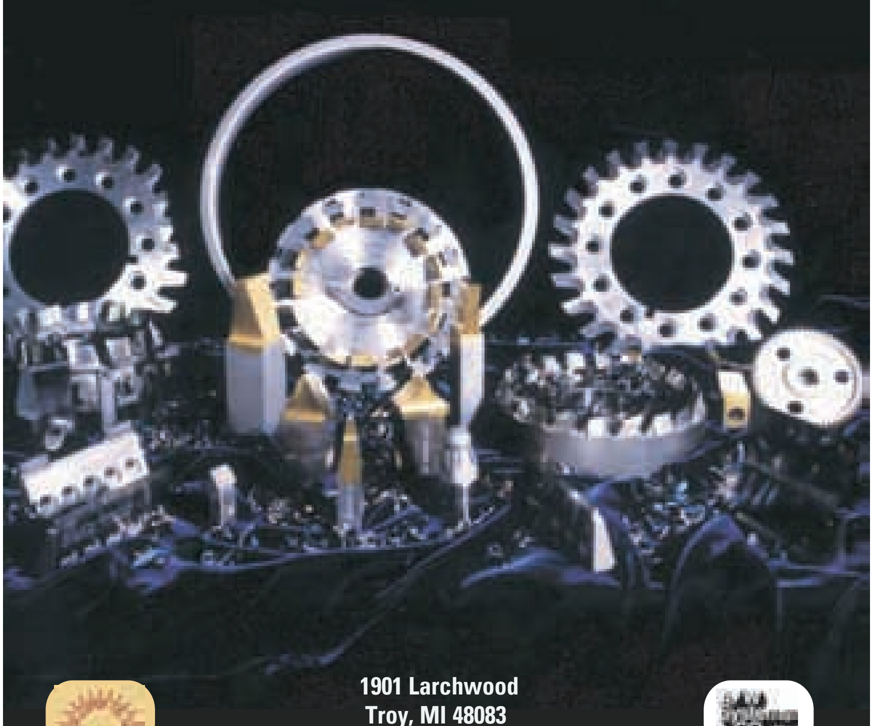
Brushes Tackle Internal Edge Burrs

The Bore-RX line of internal gear deburring brushes from Weiler can increase productivity of in-machine deburring in CNC machining centers. Brushes can remove all burrs found at intersecting holes and other internal edges of the workpiece and can also be used for bore finishing applications.

The brushes provide a solution to the problem of removing internal edge burrs often met with inefficient tube or "bottle" brushes that lack filament density. According to the company's press release, the Bore RX brushes have 10 times the filament density found in those other brushes, and this allows the Bore RX brushes to remove well attached burrs.

In addition, the new brushes operate at high rpms and rotate in both directions to avoid twisting. Off-hand deburring is eliminated as well, resulting in an increase in part-to-part consistency. Available in sizes ranging from ¾–4" in wire or abrasive nylon filament, the brushes can be adapted for use in end mill holders or mounted with 3/8" collets.

For more information:
Weiler Corp.
1 Wildwood Dr.
Cresco, PA 18326
Phone: (570) 595-7495
E-mail: ***info@weilercorp.com***
Internet: ***www.weilercorp.com***



Superabrasive Machine Competes With Hard Turning

The Edgetek SATurn Superabrasive turning system from Holroyd employs CBN wheels to achieve productivity rates far in advance of those obtained with hard turning, according to the company's press release. They are designed to remove stock from the OD of cylindrical parts (including parts with slots, grooves and forms) in all types of materials—including sintered—at rates up to 40% faster than conventional lathes.

The CNC Holroyd Edgetek SATurn system provides cutting speeds up to 12,200 meters/min. due to a high power, variable speed 37kW spindle motor operating at a maximum rpm of 9,000. CBN electroplated wheels provide a long wheel life. Holroyd said this combination is optimized by the new design of the coolant nozzle, which improves control of coolant direction and delivery rate to reduce risk of heat being transferred to the workpiece. The result is a machine that allows heavy stock removal on straight outside diameters or special form diameters to grinding machine tolerances on difficult materials of high hardness.

Paul Hannah, sales director for machine tools and rotors at Holroyd, says, "We already have major expressions of interest in our Edgetek SATurn machines from market leaders in both the automotive and aerospace industries. It's easy to see why. In one Beta site application, we have reduced the cycle time for producing automotive sprockets manufactured from sintered metals from one minute and 10 seconds per compound to just 22 seconds. At the same time, the SATurn CBN technology is cutting consumable parts costs, achieving a reduction from $1 U.S. to just $0.33 per component."

Options include a 30,000 rpm spindle version that provides ID capability for straight- or spherical-shaped bores and a robotic automatic part loading/unloading function. For high production environments, the automated system can also feature dual workheads mounted on an index table facing 180° from one another. This arrangement allows for in-cycle auto or manual loading.

For more information:
Holroyd/Edgetek
North American Sales & Marketing
17 Talcott Notch Rd.
Farmington, CT 06032
Phone: (860) 409-7722
E-mail: ***Jim.Carroll@renold.com***
Internet: ***www.renold.com***

Frenco Adds Gage for Measuring Splines' Circumferential Backlash

Frenco has expanded its product line by starting to produce a circumferential backlash measuring instrument.

According to its press release, Frenco has offered such gages, but they've been provided by third parties. Now Frenco will be making the instrument itself.

Also, Frenco has revised and optimized the gage's design to make its handling easier and more precise. Users can read direct measurement values from the dial indicator using a special probing method. According to Frenco, this feature lets users avoid converting the measuring value ratios, which is necessary with some other circumferential backlash gages.

Frenco offers its instrument with a setting arbor and an inspection one. The setting arbor is used to set up the instrument, the inspection arbor to check the function of the instrument and its dial. Frenco says the arbors reduce the time and effort to monitor and maintain the gage. The inspection arbor, for example, can detect damage on the measuring instrument's teeth, damage that can lead to erroneous measurements.

For more information:
Frenco GmbH
Jakob-Baier-Straße 3
D-90518 Altdorf
Germany
Phone: +(49) 9187-95-220
E-mail: *frenco@frenco.de*
Internet: *www.frenco.de, www.frenco.com*

Rexnord's Gear Reducers Mount Directly on Driven Shaft

The new shaft-mounted Planetgear (SMP) reducers from Rexnord provide an alternative to traditional helical shaft mounted reducers and incorporate standard planet gear features.

According to the company's press release, the reducers' modular design and interchangeable components simplify a change in ratios with minimal spare parts stock. Their size and weight allows them to fit into applications where space is limited.

Because they are mounted directly on the driven shaft, there is no need for a low-speed coupling, chain drive or reducer mounting base. Their self-aligning gear train has at least six teeth in contact per reduction to share the load equally.

SMP reducers incorporate HydroAdvantage, a hydraulics removal system that works with the low-speed shaft. Applying a separating force between the end of the driven shaft and the reducer facilitates easy removal of the reducer.

The shaft mount configuration is available on the Orion, Titan, Jupiter and new Gemini and Hercules sizes with output torque ratings ranging from 280,000 lb.-in. to 2,900,000 lb.-in.

For more information:
Rexnord Corp.
P.O. Box 2022
Milwaukee WI 53201
Internet: ***www.rexnord.com***

Stock Drive's Fastening Device Contains Only Two Parts

The Shaftloc rotating component fastening device from Stock Drive Products secures shaft mounted parts such as gears, pulleys and couplings to unmachined inch and metric shafting.

According to the company's press release, the Shaftloc consists of two slotted sleeves. The outer sleeve has a hexagonal head and is cylindrical on its outside diameter and threaded on its inside diameter. The inner-slotted sleeve is threaded on its outside diameter and cylindrical on the inside diameter. Threads are not symmetrical and create a continuous inclined surface. When the two sleeves are threaded into each other with a component placed between them, tightening the sleeves will cause the outer one to expand and the inner one to contract. Stock Drive Products adds that the shallow angle of the thread produces large amplication of forces, resulting in torque transmission capability between the component and the shaft.

Features include simplicity of design due to the two-part body, no marring of shafts, ease of repositioning or synchronizing and assembly, applicability to small shaft diameters, availability in stainless construction and utilization in stationary breadboard structures.

For more information:
Stock Drive Products
2101 Jericho Turnpike
New Hyde Park, NY 11042
Phone: (516) 328-3300
Internet: ***www.sdp-si.com***

GEAR TECHNOLOGY

The Journal of Gear Manufacturing

Reader Profile:

Name:

Bob Sakuta, President of Delta Research and Tifco Gage and Gear, Livonia, MI.

About your career in the gear industry:

"My dad started the company in 1952. I began working here when I was 10 or 12. Then I went off to college, got a business degree and became a 'big shot' at a large corporation, but it was a hollow experience. So I came back to the family business and have been here ever since."

What keeps you going?

"I love building things...the creativity of the business. The people who work here–they're family."

Your equipment and technology?

"We have millions worth of gear cutting and grinding machines, inspection equipment, machining centers, broaching and spline rolling... to name a few. We usually buy two of everything, just to have a backup. Recently, we installed a completely automated gear production cell that runs 24/7 and produces 3,000 gears a day for a customer in Japan. I'm constantly on the hunt for new equipment and technology."

The future of the gear industry?

"I have a vision to make Livonia the gear capital of the world! A cooperative effort with other gear designers and producers that would provide the innovation and production capabilities to supply major OEM's and compete globally."

Your thoughts on *Gear Technology* magazine:

"It's a great magazine. I've been reading it my whole career. It gives me ideas on how to make better gears. It helps me find the equipment I need to build the best gears."

Gear Technology. **The magazine gear industry buyers rely on.**

To learn more about *Gear Technology,* visit *www.geartechnology.com* or call 847-437-6604.

The Fatigue Endurance Limit: A Myth

Robert Errichello

The well-known fatigue endurance limit is a convenient myth.

That's the thesis presented by Claude Bathias and Paul C. Paris in their *Gigacycle Fatigue in Mechanical Practice*.

Whether a real fatigue endurance limit exists continues to be a controversy. The no-limit side is represented in industry standards such as AGMA 2001, which gives an S-N curve that continually slopes downward after 10^7 cycles. However, other standards, such as ISO 6336, maintain the existence of an endurance limit.

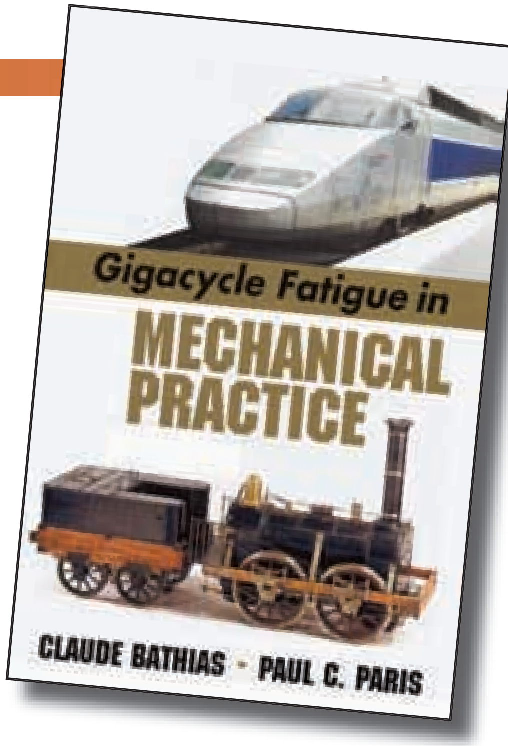
Supporting the no-limit side, Bathias and Paris present important experimental data, including many examples that prove fatigue failures may not occur till well beyond 10^7 cycles and even after 10^{10} cycles.

Bathias, who holds a doctorate in mechanical engineering, is director of the Institut des Technologies et des Matériaux Avancés, Conservatoire National des Arts et Metiers, in Paris, France, and is a Fellow of the American Society of Materials.

His co-author, Paris, is senior professor of mechanics at Washington University in St. Louis, MO. Known for his contributions to fracture mechanics, Paris has received awards from the American Institute of Aeronautics and Astronautics and the American Society for Testing and Materials.

Besides examples, the authors also provide excellent guidance on the intricate details of ultrasonic fatigue testing. In addition, their many useful facts on fatigue phenomena include:

- For a large number of alloys, fatigue crack initiation may occur beyond 10^7 cycles, and the fatigue strength may decrease by 50–200 MPa between 10^6 and 10^9 cycles.
- When fatigue occurs beyond 10^7 cycles in steels, the origin of the fracture is usually not at the surface but in the interior of the specimen.
- Low cycle fatigue cracks are the result of local plastic flow around surface discontinuities, whereas gigacycle fatigue cracks initiate from the interior at inclusions or microstructural defects.
- When fatigue failure occurs at 10^4 cycles, there are multiple crack origins at the surface; at 10^6 cycles, there is a single origin at the surface; and at 10^9 cycles, cracks initiate in the interior of the specimen.
- Equations are given that quantify the effect of nonmetallic inclusions on fatigue strength.
- Corrections are given to account for the different stress states in rotating-bending and tension-compression fatigue tests. After the correction, fatigue data give the same S-N curves regardless of the different loading methods.
- Low temperature causes a shift of the fatigue crack growth curves to higher stress intensity. This is explained by increased tensile properties.



Gigacycle Fatigue in Mechanical Practice,
Claude Bathias and Paul C. Paris,
ISBN: 0824723139,
Marcel Dekker, 2005, 304 pages,
$139.95.

- Gigacycle fatigue tests show the fatigue crack growth threshold ΔK_{th} determined by conventional fatigue testing is reliable for engineering design.
- Equations are given for correcting the fatigue crack growth threshold ΔK_{th} for the effects of the stress ratio $R = \sigma_{min}/\sigma_{max}$.
- A table of threshold stress intensity factors, ΔK_{th}, obtained by ultrasonic fatigue tests, is given for many materials.
- Many useful data are given for fretting fatigue that show fretting can reduce fatigue strength by a factor of three.

Gigacycle Fatigue provides a good overview of recent findings from ultrasonic fatigue testing and discusses many parameters that must be considered when designing machine components for long fatigue life. Given all the above, this book would be an excellent addition to a gear engineer's library.

To order a copy in North or South America:*
KDC Warehouse
7625 Empire Drive
Florence, KY 41042-2919
Phone: (800) 634-7064
Fax: (800) 248-4724
Internet: *www.dekker.com*

Robert Errichello *is a gear consultant and founder of GEARTECH, a consultancy specializing in gear failure analysis. He's also a technical editor for* Gear Technology *and has more than 45 years of experience in the gear industry.*

*As of Oct. 12, 2005, there were no copies in stock. Interested readers may be able to buy copies from other sources via the Internet, such as *www.amazon.com*.

Latest Generation of Quieter Plastic Gears
CAN TAKE THE HEAT

Robin Wright, Assistant Editor

DSM's Stanyl lawn mower starter gears, actuator gears and other products allow for higher torques through a wider temperature range.

Ten years ago, most mainstream gear manufacturers didn't even consider plastics as an option, especially in higher power applications. While metal is still the most popular choice, the plastic gear community is working to raise its visibility.

And the auto industry, at least, appears to be noticing. The increase in fuel costs has led many to consider lighter weight materials as car components, which translates to greater fuel economy.

A variety of other automotive trends is driving the increased attention on plastics, says Steve Wasson, application development engineer at DSM.

"What we're seeing, which plays well with Stanyl (the latest grade of plastic from DSM), is a trend toward more power. The automotive industry has greater requirements, as window glasses get bigger, seats get more stringent so recliners need more strength." Also, Wasson says, "All the 'under the hood' requirements lead to increased heat performance, as does turbo control."

To meet those strength and heat requirements, DSM has developed Stanyl PA46, a thermoplastic resin for molded gears featuring higher endurance and reduced dimensional change for use in high temperature environments and for high torque transmitting situations. According to the company literature, Stanyl can retain mechanical properties between 100–170°C and offers endurance and fatigue resistance at 100°C.

"Where Stanyl is important for gears is that it offers very linear material properties through a wide temperature range, from 85–260°C," says Wasson. "Most other material will go through a blast transition and the slope of the line drops off."

GE-Plastics, a division of GE, manufactures specialty thermoplastic compounds for automotive gears as well as those for business equipment and fluid handling equipment. GE-Plastics also sees the importance of temperature. James Fagan, product manager for Lubricomp and Stat-Kon products, sees the future of plastic gearing divided into two areas.

"There's two trends going on right now," he explains. "Many traditional business equipment gearing applications are now manufactured overseas. On the other end, we have customers who've seen a great need for our plastics to go in gears operating in high temperature environments. In these more demanding applications, customers gravitate towards GE-Plastics' glass or carbon fiber-reinforced materials that go hand-in-hand with high temperature base resins to deliver materials with the thermal and fatigue resistance needed to perform in these demanding applications. Additionally we are seeing a need for some gears which need to be made with flame retardant compounds."

For GE-Plastics, most of the demand for flame retardant plastics comes from business equipment manufacturers whose designs place the gears near a power supply.

Ticona Technical Polymers is also catering to the special high temperature needs of the automotive industry. Its latest material, Fortron linear polyphenylene sulfide (PPS), has been used for actuator housings and gears. Each PPS actuator is comprised of an injection molded body and cover, which are ultrasonically welded to create the final assembly. Importantly, PPS was used in the actuator because of its ability to remain dimensionally stable at temperatures from well below 0° to 180°C.

New Materials Require New Understanding

This continued emphasis on highly engineered plastic materials has led GE-Plastics to more thoroughly characterize materials for easier specification into gearing applications. GE-Plastics is planning an e-seminar to discuss the company's findings, which are also available online at *www.lnp.com*.

"Traditionally, only single point data has been available, which doesn't do a complete job of describing material suitability for use in gear applications. We've developed multi-point data that is much more thorough in describing our materials performance capabilities to a gear designer," says Fagan.

Winzeler Gear, a company that designs and manufactures plastic gears, is also taking proactive steps to teach the gearing community more about the field of engineering material selection for high strength, low cost gears.

To that end, John Winzeler, president of Winzeler Gear, has commissioned a research project with Bradley University in Peoria, IL. Over the past five to six years, 600 graduate students and two professors have analyzed the success of plastic gearing.

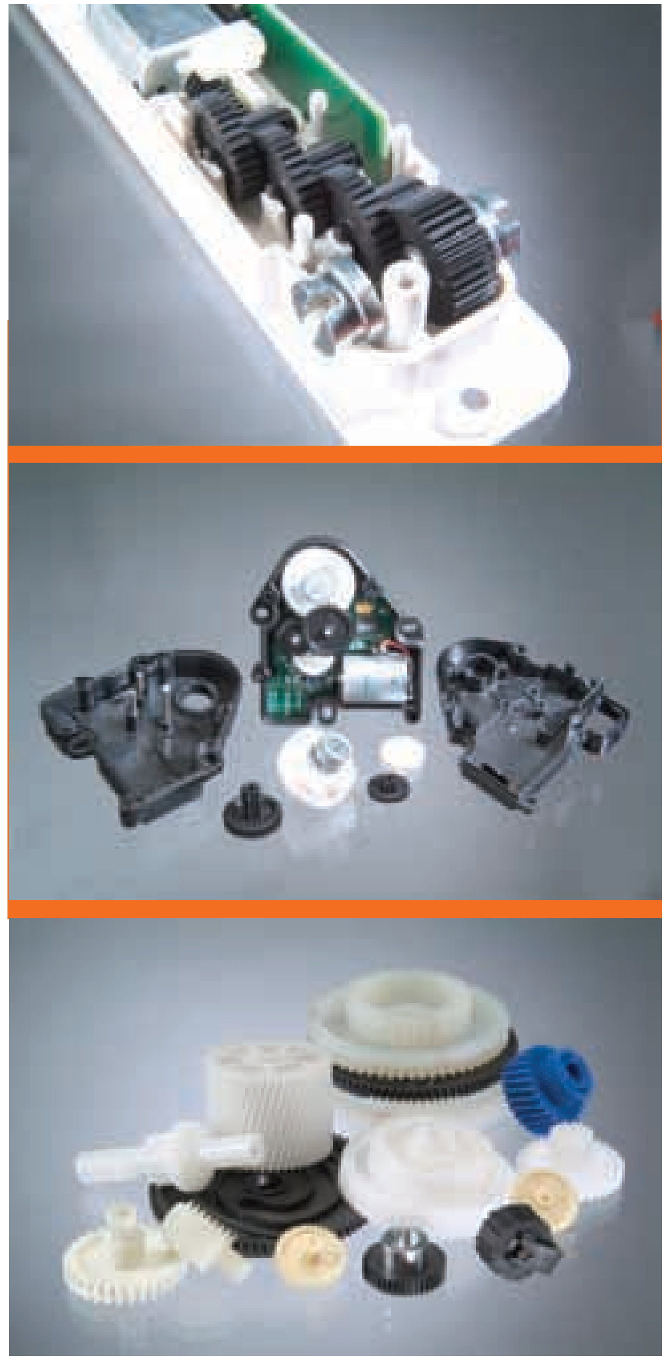
"We're confirming what we've always known. The industry-accepted software for designing plastic gears today creates conservative results that leads the decision makers to select metal over exotic plastic every time," Winzeler says.

New Materials Allow for Stronger, Smaller Gears

Larger gears are used for low volume applications, yet require the same amount of work as a high volume application, says Winzeler. All of this tends to be cost-prohibitive and ultimately makes larger plastic gears less appealing to the customer.

The gears Winzeler supplies are consistently getting smaller. The work typically falls in the range of microsizes up to 3–4" in diameter. Among the company's most notable products are gears tiny enough to be in a watch or a very small motor.

Smaller gears seem to be abounding in the market. Fagan explains one reason for this popularity: "Most gear applications necessitate smaller size gears. Since there's more receptivity to reinforced material design, smaller gears are the obvious material choice for carrying more loads or doing more work."



Seitz Corp. offers a gear train developed to open and close interior plantation shutters for the window fashion industry (top), actuators for HVAC applications (middle), and plastic gears with a variety of resins.

Pushing the Envelope for Low Noise and High Quality

For plastic gear manufacturers, a priority equal to the gear size is the gear's noise. The Seitz Corp. of Torrington, CT, is a full-service plastic gear operation with many of its customers in the medical and specialty auto fields demanding quieter operation.

Karl Seitz, vice president of sales for Seitz Corp., says the company's designs always include customization for less noise. "It's so subjective when people request a noise specification. Everything starts with how quiet the motor is. Finer pitch gears have more tooth engagement and, therefore, less noise. They include less of a gap between the teeth so you get less noise, but not as much torque."

Winzeler Gear is also devoting resources to the noise issue. Specifically, the company is working extensively with single-flank testing as well as looking into metrology methods with sound chambers, Winzeler says.

Plastic gears have also gained in quality. It's now possible for injected molded plastic gears to attain AGMA 11–12 in mass production, but the journey can be a long one, says Richard Kuhr, a member of AGMA's plastic gearing committee and global gear design manager for Enplas Inc.

"For instance, we [Enplas] manufacture to AGMA 12, but the analytical inspection requirements are much more difficult for plastics than for metal gears," Kuhr says. "The quality standard was written for metal gears. One of the things we'd like to do is develop a plastic gear quality standard. There's a lot more education needed on the topic."

Plastics Allow for Unique Designs

Crown gearing adds another dimension to the emergence of plastic gearing, and Enplas has researched this niche of the market.

"Crown gearing is nothing new," Kuhr says. "It just hasn't been widely applied in plastics. In the plastics market, it offers certain advantages inherent in its design to compensate for shaft misalignment. The testing we've done shows more uniform motion transmission results and reduce noise levels."

According to Enplas Corp., plastics can follow any tooth form, so the design technology proven by testing can dictate the profile modifications required to enhance the profile and change the tooth form.

The most recent form of Enplas' work is the backlashless gear, which was displayed at Gear Expo in October. With high positional accuracy, the design reduces contact stresses of impact loading and the problems of noise generation and transmission errors associated with gear slap—a major noisemaker. The backlashless gear keeps both sides of the gear engaged without requiring additional torque.

Because of all these options, along with enhancing material properties and quality capabilities, plastics are becoming more common in more applications. Seitz says they're the preferred material in the ever-growing medical field for disposable prod-

GE-Plastics gearing research focuses on fillers and base polymers.

ucts, due to their light weight and lower cost. Will they ever replace metal gears entirely?

"Never say never," he says.

For more information, contact:
DSM North America
P.O. Box 3333
2267 W. Mill Rd.
Evansville, IN 47732-3333
Phone: (812) 435-7500
Internet: *www.dsmep.com*

GE-Plastics
475 Creamery Way
Exton, PA 19341
Phone: (800) 854-8774
Fax: (610) 363-4749
Internet: *www.lnp.com*

Ticona Technical Polymers
8040 Dixie Hwy.
Florence, KY 41042
Phone: (800) 833-4882
E-mail: *infoservice@ticona.de*
Internet: *www.ticonaservice.de*

Winzeler Gear
7355 West Wilson Avenue
Harwood Heights, IL 60706
Phone: (708) 867-7971
Fax: (708) 867-7974
Internet: *www.winzelergear.com*

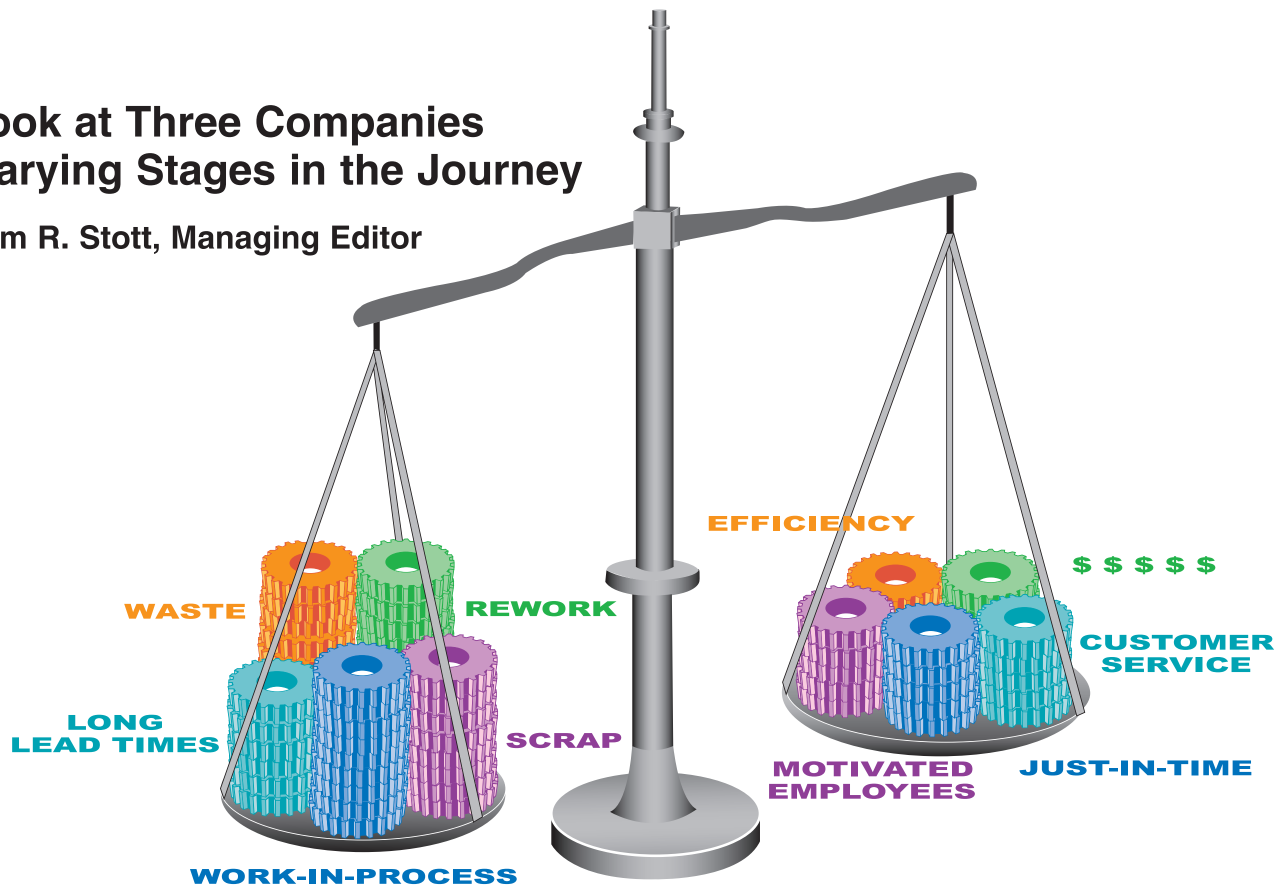
Seitz Technical Products Inc.
729 Newark Road
P.O. Box 338
Avondale, PA 19311
Phone: (610) 268-2228
Internet: *www.seitz.com*

Enplas Inc.
1901 West Oak Circle
Marietta, GA 30062
Phone: (770) 795-1100
Internet: *www.enplas.co.jp*

Getting Lean in the Gear Industry

A Look at Three Companies at Varying Stages in the Journey

William R. Stott, Managing Editor



At Boston Gear in Charlotte, NC, lean is a way of life.

"You won't survive in our company if you're not a believer in lean," says Ed Novotny, general manager of Boston Gear and VP of operations for parent company Altra Industrial Motion.

The Boston Gear facility has been operating under lean principles for about seven years, but the lean journey is never done, Novotny says. "We'll be doing this forever. The deeper you get into it, the more and more opportunities there are."

Boston Gear focuses heavily on continuous improvement, and it holds about one *kaizen*—or continuous improvement—event per week, Novotny says...

David Chisholm of Triumph Gear Systems recently returned from a *kaizen* event in Park City, UT. He was there to oversee an autonomous maintenance workshop designed to improve the performance of a critical machine tool that had been experiencing more frequent downtime than normal.

"The goal of the workshop was to refurbish the machine, identify any problems that were going on with it and identify inspection routes critical to maintaining the availability and reliability of the asset," Chisholm says. "It went really well."

Chisholm is director of lean enterprise for Triumph, which has manufacturing locations in Park City and Macomb, MI. Chisholm and his Park City counterpart, Nigel Ashcroft, have overseen about 30 accelerated improvement workshops. Triumph schedules *kaizen* events about once a week, not just for machine maintenance, but in all phases of its business.

It's all part of the lean manufacturing philosophy, which Triumph began implementing in earnest about two years ago...

Two years ago, another company was in trouble. It was struggling financially, and its factory was inefficient and poorly organized. The business, a real-life, well-established gear company now in the early stages of its lean journey, asked not to be identified. The story of this company is important because it demonstrates how businesses often struggle to make these kinds of improvements.

Company X's director of manufacturing wanted to help turn things around. He'd experienced lean manufacturing at previous businesses, and he was enthusiastic about the possibilities, but he faced an enormous challenge: the resistance of the company's owners and its workforce.

The business had gone through the motions with previous administrations. New strategies and experts had been brought in before. To say morale wasn't high would be putting it gently.

But over the past couple of years, Company X started to experience somewhat of a turnaround and has even managed to complete a couple of successful lean improvements. Despite those successes, there still are struggles with buy-in, and the director of manufacturing doesn't know whether the ideas of lean will ever become a part of the company's culture.

Boston Gear, Triumph Gear Systems and Company X all serve different markets, but they have a number of things in common: All are gear manufacturers. All make a wide variety of components and end products. But most importantly, all are using lean principles to improve their operations.

The three individuals at these companies also have something in common: All are extremely enthusiastic about the power of lean. These guys are believers.

Not too long ago, all three companies had factories set up the old-fashioned way: running high volumes of products in large batches, with segregated departments based on processes—turning, hobbing, heat treating, finishing.

"We were very much batch mode," says Novotny, describing Boston Gear's factory 10 years ago. "We ran high volumes. We were disorganized. Material flow was not what it is today. Each shift would be doing something maybe a little different."

But all three operations have been trimming the waste, increasing productivity and improving their response to customer demands.

Lean the Boston Gear Way

In its loose gear division, Boston Gear manufactures more than 2,700 product configurations. On the speed reducer side, there are more than 9 million possible configurations. That amount of variability can be a big challenge to implementing lean systems, Novotny says. "We need to basically outguess the customer demand without them giving us a forecast."

In the old days, that might have meant keeping a lot of finished inventory in stock, just in case. But today, it means reducing the time it takes to manufacture and assemble products after they're ordered.

So Boston Gear has arranged more than 50 cells in its factory, in both the manufacturing and assembly areas. This cellular approach has allowed the company to shave delivery time. "We've probably taken 10 days out of our standard lead time," Novotny says.

In fact, for its speed reducer lines, Boston Gear offers same-day shipment, even on items that aren't in stock. "If it's not in stock, but you give us an order by noon today, we guarantee it ships today," Novotny says.

This quicker manufacturing means customers have to carry a lot less inventory. For example, a customer that used to keep 2,000 speed reducers on hand when it used a different supplier now requires only 300–400 speed reducers on hand, Novotny says. "Their use of cash and capital goes down. It's a home run for them, and it's a home run for us."

The cellular setup also means less finished inventory and less work-in-process at Boston Gear itself. The company has implemented *kanban* systems to pull inventory through the factory, rather than push it through based on MRP. "Wherever we put kanban in place—which has been the whole factory, pretty much—we've been able to reduce our inventory by 42%," Novotny says.

A Triumph Over Waste

Although it's only been at it for two years, Triumph Gear Systems is taking a very systematic approach toward implementing lean at its two facilities, and the company is already seeing a difference.

"The assembly area is completely cellularized now," Chisholm says, "so we're shipping daily, versus trying to cram most of our stuff out at the end of the month."

Creating cells for assembly has allowed Triumph to better meet its customers' delivery demands, as well as react to changes in demand quickly.

Triumph is also making improvements on the manufacturing floor. Although the company hasn't put together any machining cells yet, it has improved material flow in both plants, Chisholm says, and it has reduced setup times and improved maintenance procedures.

Some of those changes seem very simple, like making sure tools are readily available where they're needed. "Three weeks ago, we recorded one job that the operator walked almost two miles just to set up a part," Chisholm says. "We've reduced the operator travel down to 800 feet now."

The changes implemented have a lot of visual impact, Chisholm says. "It's allowed us to bring customers into the

At Triumph Gear Systems, standardized work allows more than one operator to participate in changeovers. Also, keeping tools close at hand eliminates wasted steps.

shop, show them what changes we're making, what improvements are taking place, and it's directly led to us winning contracts. It's visibly different than six months ago when they were here."

Late this year, the company is planning its first event designed to incorporate machines into manufacturing cells at the Macomb facility. "All this setup reduction, all this scheduling we're doing right now, all the introduction of product families, that's the lead-in to that big event."

Transforming Company X

Because the concepts of lean were so foreign to many of its employees and because previous management didn't endorse lean principles, the director of manufacturing identified a few key projects to try to demonstrate the value of lean thinking to Company X.

One successful project was creating a focused assembly cell for a gear drive product line. The creation of this cell coincided with the launch of a new product at a time of increased demand for it among OEMs.

"We were able to deliver a very high delivery performance during the time when this was ramping up for a couple of key customers," the director says.

Company X also created some machining cells designed to feed the assembly cell, but change on the manufacturing floor of an established business can't be achieved overnight, he says.

Even after two years, most of the company's production is still in irregular batches, but there are some products that are higher and more regular in volume. One example is a particular family of large spur gears the company makes for a couple of regular customers.

A machining cell was set up to handle these parts by moving production equipment from distant batch areas close together. The cell consists of a large vertical turning lathe, two large gear hobbers and a deburring machine. One operator now runs all the machines.

"These parts traveled more than a mile in the previous flow path," the director says. "After we were done, the parts traveled less than 500 feet."

A setup reduction event resulted in a new fixture and quick-change tooling on this Bridgeport milling machine at Triumph Gear Systems.

Although the markets for both product lines (the gear drive assemblies and the large spur gears) improved dramatically over the past two years, the director believes the lean implementations were a big part of their success.

"If we didn't do those things, we would not have captured those sales, and the company's financial performance would not have improved as quickly," he says.

Don't Forget the Office

A lot of people tend to focus on the impact of lean principles in the factory itself, but there are many ways to improve the entire operation by embracing the same ideas in the office as well.

"When you start lean, you work on your manufacturing systems first, generally," says Boston Gear's Novotny. But improvements can also be made in order entry, shipping, accounts payable, accounts receivable and engineering, and these can have a big impact on the customer. "Five years ago, we spent very little time with kaizen events in an office. Now, I would say, 30–40% of our kaizen events are in business systems, not manufacturing."

Training & Expertise

It's not likely that anyone will be successful implementing lean without a lot of help. Tapping someone with experience can be key.

For example, Novotny learned lean prior to joining Boston Gear, when he worked for a Tier 1 automotive supplier. He received training from Toyota in the Toyota Production System, and also received training conducted by a consulting company.

Chisholm learned lean at Lean University, a Triumph Group division located in Spokane, WA.

The manufacturing director of Company X learned lean while working for a number of large companies and also has a certificate in lean systems design and a green belt in six sigma.

All three agree that training and expertise are crucial to the success of lean implementation.

"People really won't have a full understanding by having a cram course by some consultant giving lean manufacturing in two hours," says the manufacturing director at Company X. "That's like saying I'm going to give you a degree online, and all you have to do is complete these 15 courses in 16 weeks. That's true, you'll get your degree, but you won't really have a full understanding of all those things."

But it's much more than just having an expert in charge of lean implementation. You've got to train the employees as well.

At Company X, training has been extensive. The manufacturing director himself has trained key managers in the precepts of the Toyota Production System in four-day sessions just to give them the basics. He's also sent all of the shop floor supervisors and production planners to a hands-on lean manufacturing simulation course. "It's my goal to get all of our lead men—our area coordinators—through this," he says, "so they understand the elements of lean manufacturing and how it can help the productivity of a factory."

You Can't Win Without Buy-In

All of our experts also agree that lean is not a system that can be implemented once. It has to become a part of the company's culture, and that requires buy-in, not just from the employees, but also from management and ownership.

Nowhere is that more true than at Company X, which, despite some successful projects and a lot of training, remains a company where buy-in is not pervasive. The manufacturing director estimates that less than 50% are believers, and he isn't even sure whether complete buy-in will ever be achieved.

"You're not going to be successful trying to implement lean when the ownership or a public board feels that that's a waste of time," says Boston Gear's Novotny. "You'll fail, no two ways about it."

Chisholm goes a step further. "You have to have the top management not only buy in, but also participate. You'll see our company president—just last week in Park City—he was out on the floor, in jeans and a smock, scrubbing a machine, climbing around a machine, getting on the floor and getting dirty, continuously practicing what we're trying to get across. That's huge. That goes a long way."

In order to achieve buy-in, the employees must believe that they have input, Chisholm adds. "You need to listen to the people who add value to your product. The people who actually cut chips, they're the ones adding value. Then react to what they're telling you. If you make that happen, you'll have buy-in."

Continuous Improvement

Moreover, all three experts agree that implementing lean is more than just implementing a set of tools. To be successful, lean systems require discipline and embracing the spirit of continuous improvement. That often requires a change in corporate culture.

"You have to stay at it continuously," Chisholm says. "You can't introduce it and ignore it for a couple of months. You have to continuously be moving."

Continuous improvement helps take big problems and shrink them down to size. "That's the power of kaizen events... The idea is not to just do a kaizen event in an area once, walk away and say you're done. Sometimes you get your greatest improvement after the third or fourth event in an area."

Even at a company where the lean philosophy is pervasive and which has been at it for a number of years, you can never let up, says Novotny. "To me, you can never hit the end game, because there are always improvements that can be made."

Greg Blanchard (left), president of Triumph Gear Systems, participates in *kaizen* events along with employees.

A Lean Strategy for Job Shops

POLCA: An Alternative to Kanban for High-Variety or Custom-Engineered Products

Rajan Suri

Owners of job shops and other manufacturers of custom-engineered or low-volume, high-variety products often struggle with controlling the flow of materials on the shop floor. Kanban-based strategies, which attempt to pull resources through the plant, are often ineffective because of the variety of products being manufactured and the unpredictability of volume requirements for each part.

For more than 10 years, the Center for Quick Response Manufacturing at the University of Wisconsin-Madison has worked with about 50 member companies on implementing a new strategy, called "quick response manufacturing" (QRM), which is designed specifically for manufacturers of custom-engineered and high-variety products. It can be applied on the shop floor, in the office operations, and throughout the entire supply chain.

For example, P&H Mining Equipment of Milwaukee, WI, has implemented QRM in production of large, round parts, including gears, splines and pinions. P&H operates in the high-variety and custom environment just described, and like several other of our center's members, the company wanted to improve material control strategies.

As part of our QRM strategy for these companies, we devised a new material control system called POLCA (Paired-cell Overlapping Loops of Cards with Authorization). POLCA is a hybrid push-pull strategy that combines the best features of pull (Kanban) and push (MRP) systems, while avoiding their drawbacks.

Why Pull Doesn't Always Work

Why doesn't pull work for the environment described above? Pull is part of the lean manufacturing approach, which works by creating "flow"—essentially by synchronizing all the steps in the company to the average rate of sales of the products. Typical concepts used for this include setting the *Takt* time for individual operations. (*Editor's note: Takt is the German word for "rhythm" or "beat," as in the beat of a musical piece. In lean manufacturing lingo, it refers to the pace or heartbeat of an organization. An organization with a takt time of two minutes will complete a finished product every two minutes.*)

However, in a high variability environment, one could define an average Takt time based on a given month's orders, but the daily demands on various machines could be so different that the production would be seriously out of balance.

Further, note that pull is a replenishment system: when one item (or container) is used, a signal is sent to replenish it. For a company that makes thousands of different items, this implies that there is inventory of each of these items at each stage of the operation where a pull signal is being used. Worse, for a company that custom-engineers products, the pull system fails completely. There is no container of products to be replenished, since the parameters of the product are not known till the order is received and design engineering completed.

The QRM Strategy

For a company serving these environments, top management needs to rethink its strategies for capacity, workforce, and organizational structure, to create the capability for flexible and fast response. Here we will focus on the material control aspect, which involves the use of POLCA.

In the POLCA system, the flow of orders through the different workcenters is controlled through a combination of release authorizations and production control cards known as POLCA cards. The release authorizations are generated using a standard MRP system. This creates release authorization times for each order at each workcenter.

However, unlike in a standard MRP system where a workcenter should start work at that time, in a POLCA system the workcenter cannot start unless the corresponding POLCA card is also available. The POLCA cards communicate and control the material movement between workcenters. While this may seem similar to Kanban, there are some important differences. Here are the three key features of POLCA that make it uniquely effective for the manufacturing environments we targeted:

1. POLCA cards are not specific to a product, as in a pull system, but are assigned to pairs of workcenters, and apply to all products going from the first workcenter to the second workcenter in the pair.
2. Whereas a Kanban card is an inventory replenishment signal, a POLCA card is a capacity signal: a POLCA card returning from a downstream workcenter signals that the workcenter has available capacity to process more work. When a workcenter reviews its list of jobs whose start has been authorized, it looks up the next workcenter for each job, and it can only work on a job if it has a POLCA card from that destination workcenter.
3. POLCA cards for each pair of workcenters stay with a job during its journey through both workcenters in the pair before they loop back to the first workcenter in the pair. Since most workcenters will belong to more than one pair of workcenters, there will be multiple loops of cards that overlap in each workcenter (see Figure 1).

The design of the POLCA system gives it several advantages for the high-variability or custom-manufacturing environment we described. First, POLCA helps in managing short-term fluctuations in capacity and also assists in reducing congestion on the shop floor. Essentially, the use of POLCA cards assures that each workcenter only works on jobs that are destined for downstream workcenters that will also be able to work on these jobs in the near future.

Second, it allows for an engineer-to-order environment through flexible routings that use workcenters as needed.

Third, POLCA cards are not linked to part numbers. This ensures that there is no proliferation of inventory for companies that make a large variety of products or components.

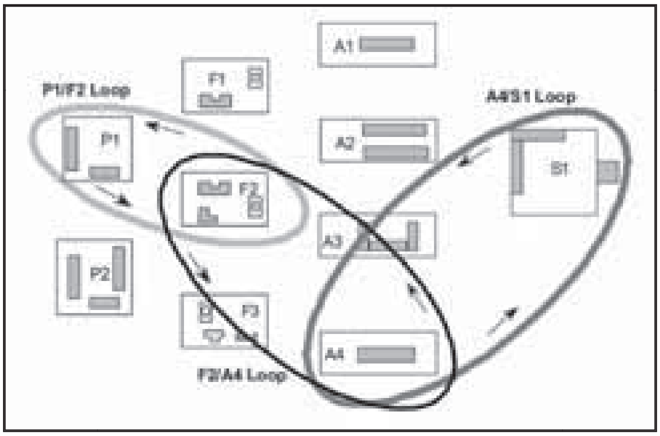


Figure 1—The POLCA system uses production cards circulating between overlapping pairs of workcenters to make most efficent use of production equipment in companies manufacturing custom-engineered and high-variety products.

Finally, when combined with other QRM strategies, POLCA provides the flexibility to absorb variations in demand and product mix.

In partnership with several companies, the Center for Quick Response Manufacturing has implemented POLCA at factories in the United States and Canada. The benefits seen by those companies include reductions in lead time and work-in-process ranging from 30% to more than 80%, increases in percentage of on-time deliveries, increases in throughput of up to 18%, reduction in worker stress due to elimination of expediting, and increases in employee satisfaction.

Rajan Suri *is director of the Center for Quick Response Manufacturing at the University of Wisconsin-Madison (www.qrmcenter.org). The center holds regular tutorials on POLCA, and the next one is April 4–5 in Madison, WI. Suri is also author of the book* Quick Response Manufacturing: A Companywide Approach to Reducing Lead Times (*Productivity Press*).

Development Of Conical Involute Gears (Beveloids) For Vehicle Transmissions

Dr.-Ing. Jörg Börner, Dipl.-Ing. Klemens Humm, Dr.-Ing. Franz J. Joachim

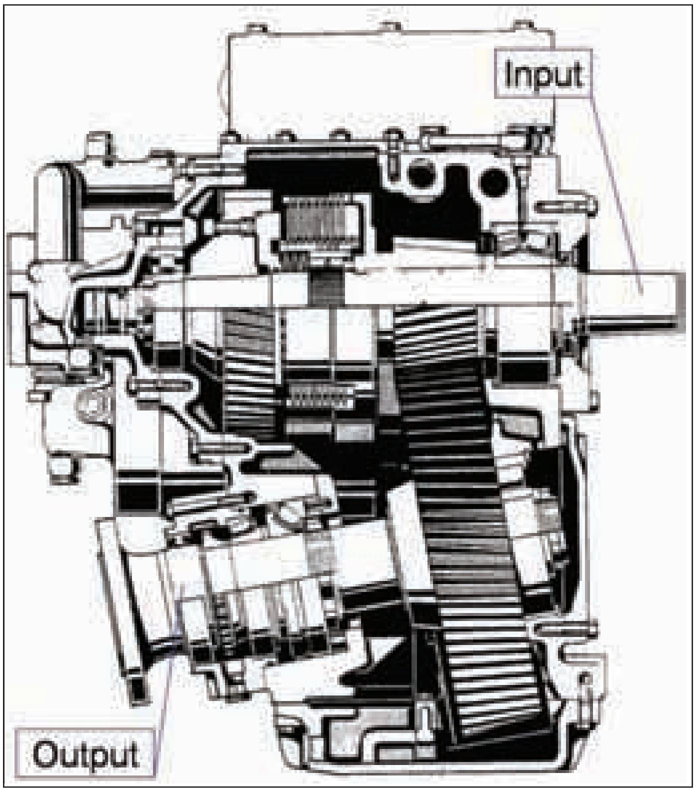


Figure 1—Reversing marine transmission with offset and down angle output shaft (i = 1.2–2.9; max. 1,350 kW).

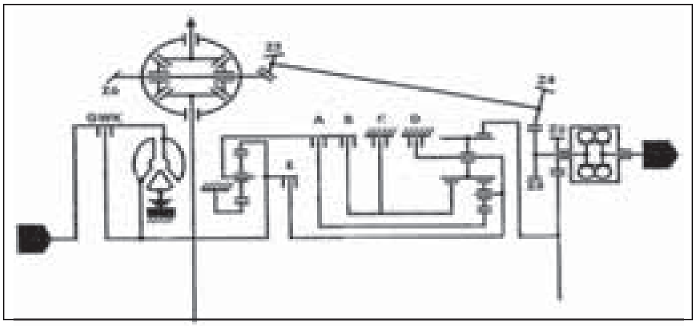


Figure 2—Schematic view of drive train of six-speed automatic gearbox 6HP32.

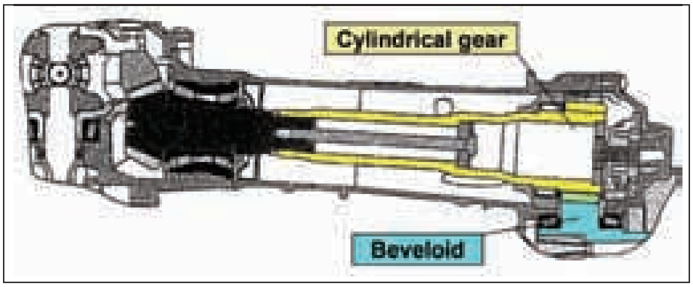


Figure 3—Drive shaft with beveloid gear pair.

Dr.-Ing. Jörg Börner *works in the corporate research and development department of ZF Friedrichshafen AG and is responsible for basic gear design and development. His responsibilities include developing computer programs for gear design, manufacturing and basic investigations of gears. He joined ZF in 2001, after working at Caterpillar.*

Dipl.-Ing. Klemens Humm *is in charge of gear design and development of special drives at ZF Friedrichshafen AG. He has been with ZF for the past seven years, having previously programmed gear software for a German gear manufacturer.*

Dr.-Ing. Franz J. Joachim *is senior manager responsible for the gear development departments in corporate research and development at ZF Friedrichschafen. After studying with the Gear Research Institute, Joachim started with ZF, where he's worked for the past 20 years. In addition, Joachim is an active member of the National Standardization Committee and vice president of the Scientific Council of the FVA.*

Management Summary

Conical involute gears (beveloids) are used in transmissions with intersecting or skewed axes and for backlash-free transmissions with parallel axes. The geometry of such gears is generally known, but applications in power transmissions are more or less exceptional.

ZF applications so far include marine transmissions with inclined output shafts and low-backlash robot transmissions. The latest development has been realized for the all-wheel drive (AWD) version of a six-speed automatic transmission. Here, the torque must be transmitted from a center differential to a front-axle bevel gear. By means of conical spur gears, it has been possible to realize an inclined drive shaft which offers considerable advantages in terms of installation space.

This article deals with the development of conical gears for vehicle transmissions: basic geometry, design, production and testing.

Introduction

In transmissions with shafts that are not arranged parallel to the axis, torque transmission is possible by means of various designs, such as bevel or crown gears, universal shafts or conical involute gears (beveloids). The use of conical involute gears is particularly ideal for small shaft angles (up to 15°), as they offer benefits with regard to ease of production, design features and overall input. Conical involute gears can be used in transmissions with intersecting or skewed axes or in transmissions with parallel axes for backlash-free operation. Conical gears are spur or helical gears with variable addendum correction (tooth thickness) across the face width. They can mesh with all gears made with a tool with the same basic rack.

ZF has developed various applications with conical gears:

- Steering transmissions (Ref. 1);
- Low-backlash planetary gears (shaft angle 1–3°) for robots (Ref. 2);
- Transfer gears for commercial vehicles;
- Marine transmissions with down-angle output shafts (Refs. 1 and 3, Fig. 1); and
- Automatic transmissions for AWD vehicles (Fig. 2).

ZF has developed a six-speed AWD automatic transmission for high-end passenger cars with 750 Nm of torque. For the first time, AWD has been realized for a six-speed automatic transmission. For this project, the AWD concept of VW/AUDI with Torsen differential (Ref. 4) was optimized, functions were improved, and the number of components and tooth engagements was reduced.

Originating from the planetary gear, the power flows via a spur gear to the Torsen differential, where the torque is distributed to the cardan shaft (50%) and via an intermediate stage to the front-axle bevel gear (50%), as shown in Figure 2. The skew drive shaft is an indispensable benefit of the package. With a parallel drive shaft arrangement, the tunnel dimensions would have been too big to permit realization of a right-hand drive vehicle. The skew drive shaft was made possible by a beveloid gear and an adapted bevel gear (85° shaft angle). Transfer gear and bevel gear share a common oil circuit. Lubrication is effected via a separate oil pump, which is driven via the drive shaft, as shown in Figure 3. Development of this beveloid gear is described below.

Basics of Conical Gears

Macrogeometry. In simple words, a beveloid gear is a spur gear with variable addendum correction across the face width. In the process, the tool is tilted by the cone angle δ relative to the gear axis. This results in the following basic gear dimensions:

Nomenclature	
a	center distance
a_s	substitute center distance
d_b	base diameter
m_n	normal module
r	radius
r_w	operating pitch radius
z	number of teeth
P	point
P_a	active point
α_n	normal pressure angle
α_t	transverse pressure angle
β	helix angle
γ	polar angle
δ	cone angle
ω	angular velocity
Φ	local angle
Σ	shaft angle
$\underline{a}$	center distance vector
$\underline{n}$	normal vector
$\underline{r}$	radius vector
$\underline{v}$	velocity vector
c_a	tip relief
c_f	root relief
f_s	profile lean (profile twist)
Index	
0	tool
1	pinion
2	wheel
L	left
R	right
b	base
t	tangential
'	coordinate system 1 (pinion)
"	coordinate sytstem 2 (wheel)

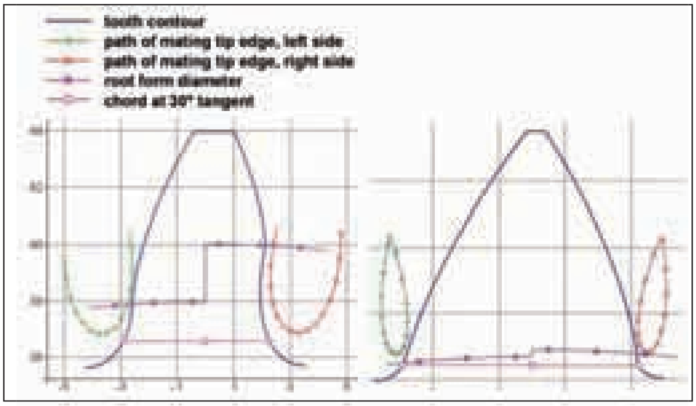


Figure 4—Tooth profile at the inner (toe) and outer (heel) face for helical beveloids.

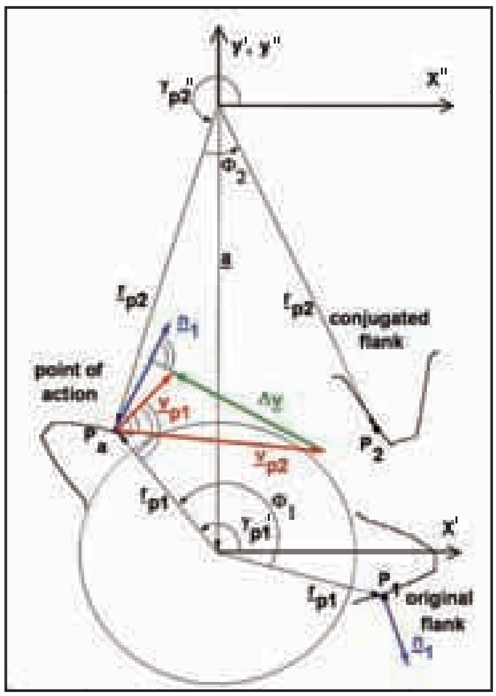


Figure 5—Generating of the conjugate flank point, simplified by showing in one plane.

Helix angle right/left side:

$$\tan\beta_{R,L} = \tan\beta\cdot\cos\delta \mp \frac{\tan\alpha_{n0}\cdot\sin\delta}{\cos\beta} \quad (1)$$

Transverse pressure angle right/left:

$$\tan\alpha_{t\,R,L} = \frac{\tan\alpha_{n0}\cdot\cos\delta}{\cos\beta} \pm \tan\beta\cdot\sin\delta \quad (2)$$

Base circle diameter right/left:

$$d_{b\,R,L} = \frac{z\cdot m_n\cdot\cos\alpha_{t\,R,L}}{\cos\beta_{R,L}} \quad (3)$$

The differing left- and right-flank base circles result in unsymmetrical tooth profiles in helical gears (see Fig. 4).

Manufacturing by means of a rack-type cutter results in a tooth root cone angle equal to the cone angle δ. The addendum angle is designed in a manner that avoids tip edge interference with the meshing gear and to achieve the maximum possible transverse contact ratio. As a result, we have a different tooth height across the face width.

Due to the geometric design limits for undercut and pointed teeth, the face width decreases with increasing cone angle. Sufficiently well-proportioned gears are possible up to a cone angle of about 15°.

Microgeometry. The pairing of two conical gears generally results in a point-like tooth contact. Outside this contact, spacing (separation) occurs between the tooth flanks. The object of gear modification is to reduce spacing (gaping) in order to obtain a planar and even contact.

Exact calculation of the tooth flank is possible through applying the rule of the common normal, as shown in Figure 5 (Ref. 5). To this end, a flank point P_1 with the radius r_{P1} and corresponding normal vector $\underline{n}_1$ is generated on the original flank. We get the speed vector $\underline{v}_{P1}'$ through:

$$\underline{v}_{P1}' = \varpi_1\cdot\begin{pmatrix} r_{P1} * \sin\gamma_1' \\ r_{P1} * \cos\gamma_1' \\ 0 \end{pmatrix} \quad (4)$$

For the point generated on the mating flank, the radial vector $\underline{r}_{P2}$

$$\underline{r}_{P2} = \underline{a} - \underline{r}_{P1} \quad (5)$$

and the velocity vector $\underline{v}_{P2}''$ apply.

$$\underline{v}_{P2}'' = \varpi_2\cdot\begin{pmatrix} r_{P2}\cdot\sin\gamma_2'' \\ r_{P2}\cdot\cos\gamma_2'' \\ 0 \end{pmatrix} \quad (6)$$

The angular velocities result from the gear ratio:

$$\frac{\varpi_1}{\varpi_2} = -\frac{z_2}{z_1} \quad (7)$$

The angle γ is iterated until the rule of the common normal

$$\underline{n}_1 \times (\underline{v}_{P2} - \underline{v}_{P1}) = \underline{0} \quad (8)$$

is fulfilled. The point of action P_a found is rotated through the angle Φ_2

$$\Phi_2 = -\Phi_1\cdot\frac{z_1}{z_2} \quad (9)$$

around the gear axis and thus the conjugate flank point P_2 is obtained.

Gear set arrangements. Beveloids can be installed in the following axis configurations:

- parallel axes,
- intersecting axes and
- skewed axes.

Due to the fact that selection of the cone angle does not depend on the shaft angle, pairing is also possible with cylindrical gears. Beveloids can be produced as external or internal gears, as shown in Table 1, so a whole matrix of pairing options results, and the designer is provided with a high degree of flexibility (Ref. 6).

Load capacity calculation. Certain conditions provided, analytical calculation methods for involute spur gears, such as ISO 6336, DIN 3990 or AGMA C95, can be used for sufficiently accurate determination of the load capacity of beveloids in intersecting axial arrangement. This is, however, only possible if the tooth contact is linear. Since the tooth contact of most beveloid sets without flank modifications is point contact, flank modifications must bring about approximate linear contact.

The tooth profile changes across the face width, and consequently load capacity in the individual face sections across the face width changes. The main influences on tooth root capacity change across the face width in opposite directions, which are shown in Table 2.

Homogenous tooth root capacity across the face width is to be aimed at. The influences on flank capacity also vary across the face width, as shown in Table 3.

The load capacity of the tooth center section can thus be seen as representative for the entire gearing. All geometric gear parameters are determined in the tooth center. Only the center distance must be converted into a substitute center distance a_s and is obtained by adding up the pitch radii.

$$a_s = r_{w1} + r_{w2} \tag{10}$$

Contact pattern quality can be assessed on the basis of the width factors (e.g., $K_{H\beta}$ and $K_{F\beta}$ in DIN/ISO), which are to be determined as precisely as possible on the basis of the contact conditions. Load capacity calculations according to the finite element method are of a higher quality and to be preferred over analytical methods.

Beveloid Gear Sets in Automatic Car Transmissions

Macrogeometry. Based on experience with the design of marine and robot gears, beveloid gear sets for a new range of 6-speed automatic transmissions have been designed. But in car transmissions, macrogeometry is more restricted, and the demands regarding low-noise design are much higher. For the smallest possible transmission error to be attained, the gear was designed with a pressure angle α_n = 17.5° and a helix angle β = 29.5°. This gives a transverse contact ratio of ε_α = 1.7 on the coast side and 1.8 on the drive side. The face contact ratio ε_β is 1.89 on the coast side and 1.63 on the drive side.

Due to the relatively wide helical angle, the

Table 1—Variants of Beveloid Gear Set Arrangement (Ref. 6).

Gear	Type	Axes: parallel	Axes: crossed	Axes: skewed
External	Beveloid Beveloid			
External	Cylindr. Beveloid			
Internal	Beveloid Beveloid			
Internal	Cylindr. Beveloid			

Table 2—Main Influences on the Bending Load Capacity Across The Face Width (S=small, L=large).

	Toe	Heel
Root chord	S ☹	L ☺
Root fillet radius	L ☺	S ☹
Tangential force at operating diameter	L ☹	S ☺
Profile contact ratio	L ☺	S ☹

Table 3—Main Influences on the Contact Pressure Capability Across the Face Width (S=small, L=large).

	Toe	Heel
Radius of curvature	S ☹	L ☺
Profile contact ratio	L ☺	S ☹

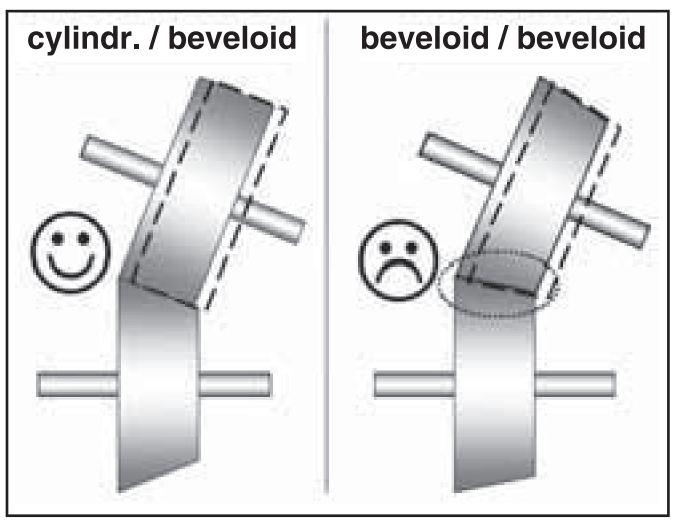


Figure 6—Backlash reduction due to axial offset of the driven gear. Left: No Influence, Right: Jammed.

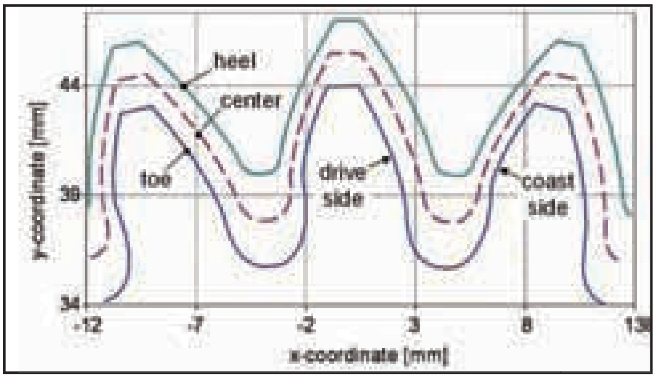


Figure 7—Profiles of the beveloid gear at heel, center, and toe.

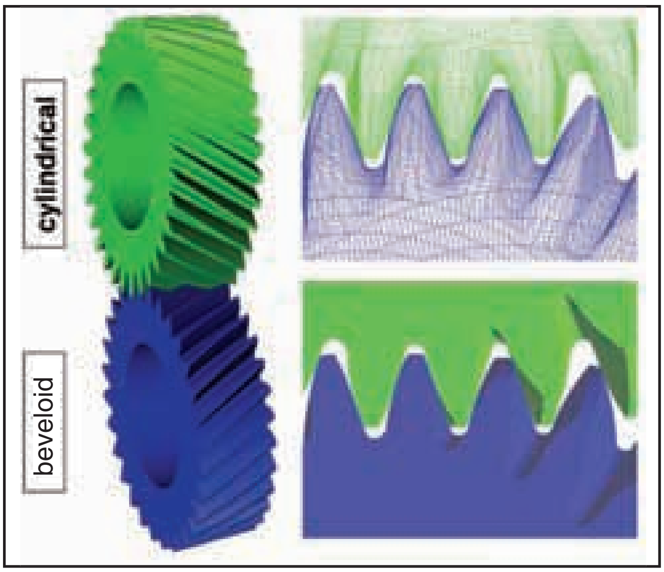


Figure 8—FE model of the beveloid gear set.

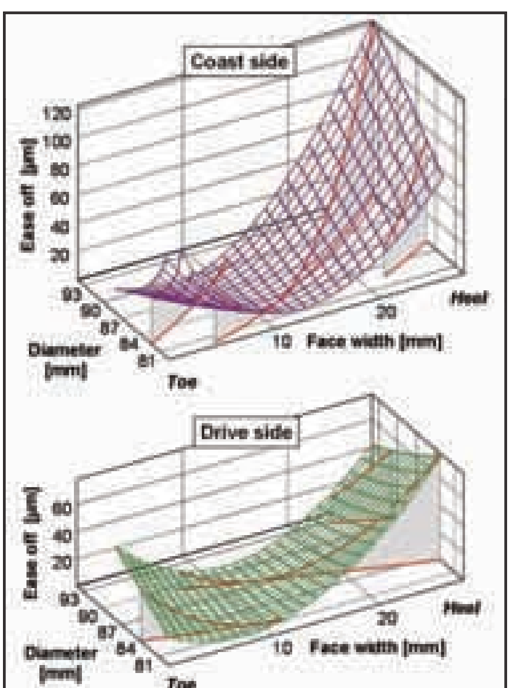


Figure 9—Ease-off for the unmodified gear set on coast and drive sides with emphasized spacing along the line of contact in one mesh position.

transverse pressure angle α_t on the drive side is 15.3° and on the coast side 23.9°. For pairing with a shaft angle of 8°, combination of a beveloid gear (input) with a cylindrical gear (output) was chosen. This resulted in a root angle of 8.6° on the beveloid gear. This combination was necessary because the output gear must be axially displaceable over a relatively wide range for adjustment of the bevel drive pinion on the output shaft. If two beveloid gears were used, axial displacement would result in the tooth backlash being too heavily affected, as is shown by Figure 6. Selectable face width is limited by the limits for pointed teeth on the heel and the undercut on the coast side on the toe of the beveloid gear.

For maximum load capacity to be achieved on the drive side, a relatively large undercut was accepted on the toe of the coast side, with such an undercut being unusual for cylindrical gears. The profiles of the beveloid gear for the inner edge (toe), the center and the outer edge (heel) are shown in Figure 7. Figure 8 shows the FE model of the gear set. This model was used in the FE program PERMAS for calculating precisely the stresses resulting from the contact conditions and the load capacity of the gear set (Ref. 7).

Microgeometry. The point contact of the beveloid gear set is a major problem when it comes to realizing design targets. This unfavorable contact behavior negatively affects load capacity and at low load results in high travel deviations, which cause an inordinately high noise level. The mismatch dimensions (ease-off) determined by means of a tooth contact analysis are shown in Figure 9. On the unmodified gear, we have both crowning and profile twist, which clearly differ for the drive flank and coast flank. Figure 9 also shows the spacing (gap) on the potential contact lines of a mesh position; they illustrate the crowning and tilt caused along the contact line. The effects of spacing (contact gap) on flank pressure were analyzed by a load distribution calculation with the program LVR (Ref. 8). In the computation, the gear set was approximately modeled as a parallel axis drive, and contact gap was considered as flank topology on one gear of the gear set. This permitted adequate representation of the contact conditions, which were verified by a comparison of calculated load distributions with contact patterns measured.

Figure 10 shows LVR-computed load distributions and the contact patterns for the same loads. To significantly improve contact conditions through enhanced contact width, topological flank modifications were computed for the cylindrical gear of the gear set. The object was to compensate as far as possible the existing spacing (gap) without completely eliminating the crowning. Particular attention was paid to the compensation of the profile twist, which causes the diagonal contact pattern and, like the crowning, prevents a full contact. The topologies shown in Figure 11 were generated on test gears on a 5-axis KAPP grinding machine and tested for comparison with the unmodified gears.

The contact pattern was significantly improved, as shown in Figure 12. Gear noise was also clearly reduced with the topologically modified gears. In the following sequence, the topologies were converted into conjugate topologies for the beveloid gear and defined as the specification for batch-production methods. Optimum topology has been very closely realized in the batch production launched in the meantime. In fine adjustment of the topology, great attention was paid to the resulting noise excitation, which needed to be improved—especially for partial loads.

With the present fine geometry, it has been possible to achieve the low noise level aimed at, which corresponds with that of a well designed set of helical gears. Compared to the unmodified variant, a noise reduction of more than 10 dB was achieved in critical speed ranges, especially under partial-load conditions. Assessment of the excitation level was also carried out with the program LVR, which was used in serial computations to determine transmission error for various loads and modifications (Ref. 8). Using the diagrams of the excitation levels calculated on the basis of the transmission error, it was possible to assess the efficiency of individual corrections. Figure 13 shows an example of the diagrams. The transmission error curves for the unmodified gears and the topologically modified gear set are shown in Figure 14 for low partial load. Reduction of the amplitude of transmission error for the topologically modified gears is evident. In tests with the transmission on the test bench and in the vehicle, the low noise level and the improvement compared to the original variant were proven. The gearing also fulfilled all requirements regarding load capacity.

Manufacture and testing. Beveloids are machined on commercial cylindrical gear production machines, which generate the tooth profile via a hobbing process. Hobbing and shaping are the cutting methods used for carburized gears; worm grinding and honing are the methods used for hard/fine machining. The beveloid gears of a car transmission are cut with hobs, and following hardening, they are fine-machined on generating grinding machines (Reishauer RZA and Kapp KX1). It is of particular importance for tool design that hobbing creates different topologies for the drive and coast sides. In order not to lose too much root thickness due to protuberance undercut, the protuberance chosen was equivalent to the machining allowance. Notwithstanding the protuberance, a tip

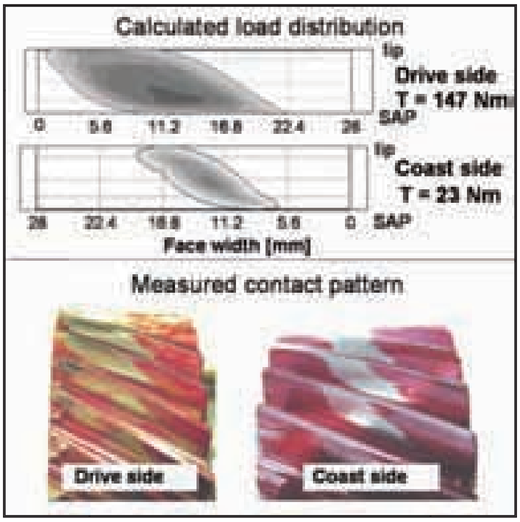


Figure 10—Calculated load distributions in comparison to loaded contact patterns from measurement runs.

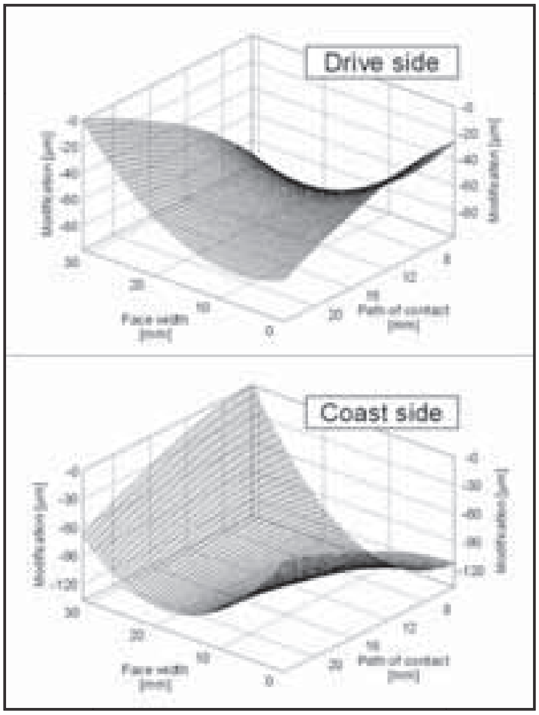


Figure 11—Desired topologies for the driven gear of the beveloid gear set.

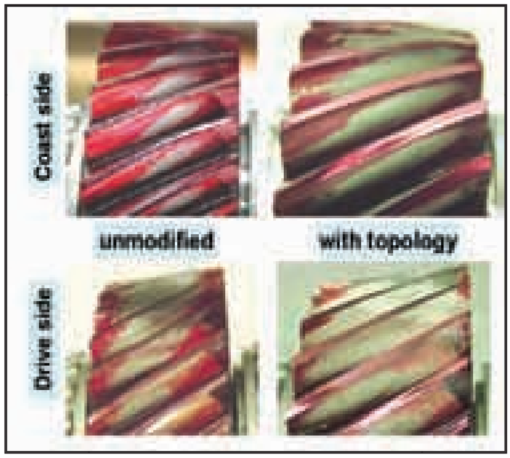


Figure 12—Improvements in the loaded contact pattern achieved with topological modifications.

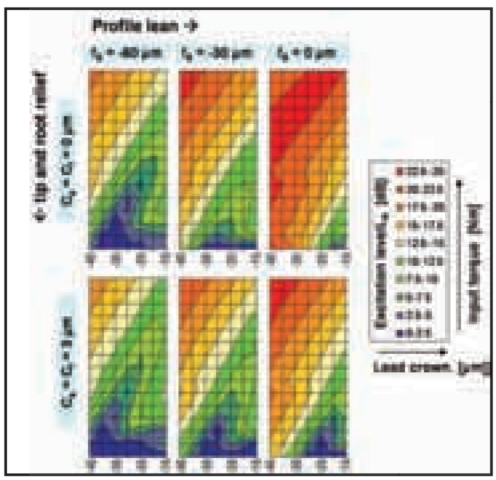


Figure 13—Excitation level for various loads and modifications, calculated for evaluating the noise excitation.

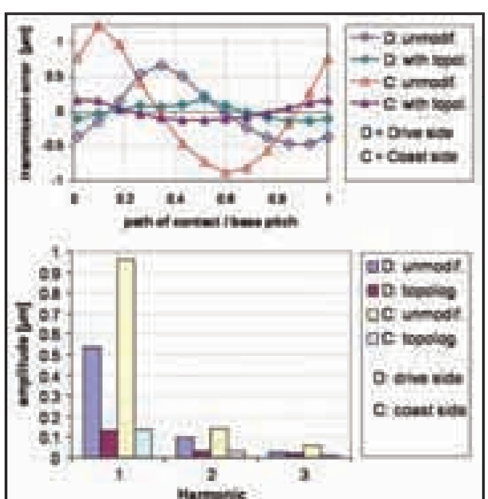


Figure 14—Transmission error, calculated with torque *T* = 100 Nm (15% nominal load) for unmodified and topologically modified gears.

radius on the grinding tool was required to avoid sharp grinding shoulders in the area of the heel. In this area, an addendum modification coefficient of about 1.3 occurs. If there is no tool tip radius, this addendum modification results in a small radius of curvature of the trochoid in the root fillet due to the generating process.

To test the topology required, the traditional measurements on four teeth in the center of tooth width and height are no longer sufficient. Grid measurements need to be carried out, with additional profile records on the heel and the toe and additional line records on tooth tip and tooth root. Permissible tolerance zones have been specified for these measuring records (K diagrams). Measurements can be conducted on any measuring machine used for cylindrical gears. For line measurements, modern measuring machines permitting a conical course of the measuring line should be used. If the measurement device doesn't allow a conical measurement, the face width has to be divided in sections. In each section, the measuring feeler touches the tooth on a certain diameter. The measuring result will then, however, be influenced by profile deviations in the flank record.

Test bench. In addition to theoretical capacity computations, a test bench conforming to the installation conditions of a car transmission was built for basic tests. Figure 15 shows the back-to-back test bench used. Two shafts with their axes intersecting at an angle of $\Sigma = 8°$ are linked via two beveloid gear sets and braced against each other by means of a coupling. The test gear has a center distance of $a = 87$ mm; the transmitting gear set has a center distance of $a = 200$ mm.

The significant center distance difference guarantees that the transmitting gearing is not damaged—not even during overload testing. Compared to the test gearing, the number of teeth of the transmitting gearing has been doubled for the same ratio to be achieved. This test bench is used to determine S/N curves for tooth root and tooth flank capacity.

Summary

For a six-speed automatic transmission with integrated AWD, a beveloid gear set with 8° shaft angle was developed for a skew drive shaft linked to the front axle, as shown in Figure 16. This permitted compact tunnel dimensions. Since mid-2002, the transmission has been in production in a high-end passenger car. Development work included the following tasks:

- Development of specific software for the design and recalculation of beveloids.
- Because of topological corrections, the capacity and noise levels reached are comparable with those of helical gears.
- Beveloids are cut on NC hobbing machines, and after hardening, they are finish-machined on con-

tinuous worm grinding machines.
- Beveloids require comprehensive quality specifications (toe, center, root). Measurements are carried out on the usual measuring machines, with specific setting values being considered.
- A back-to-back test bench with suitable shaft angle was set up for basic testing. Allowable stresses have to be determined under different conditions.

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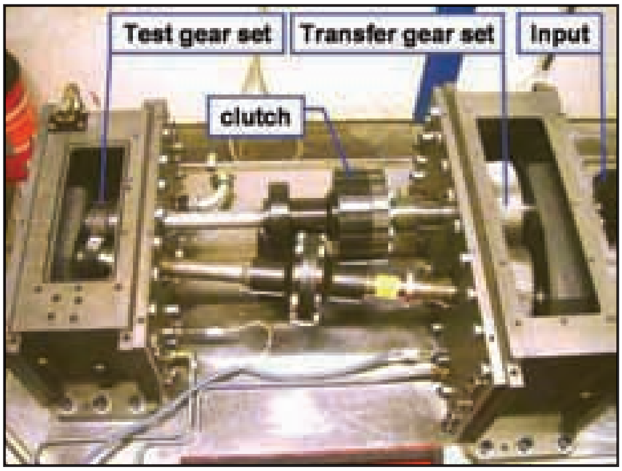

Figure 15—Back-to-back test rig for beveloid gear sets.

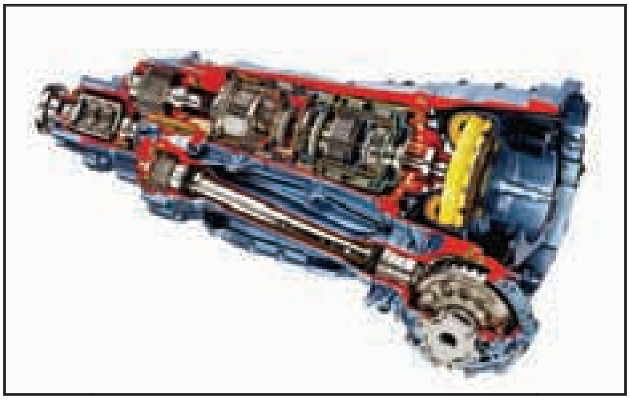
Figure 16—Six-speed automatic transmission for all-wheel drive with side shaft driven by a beveloid gear set.

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Laminated Gearing

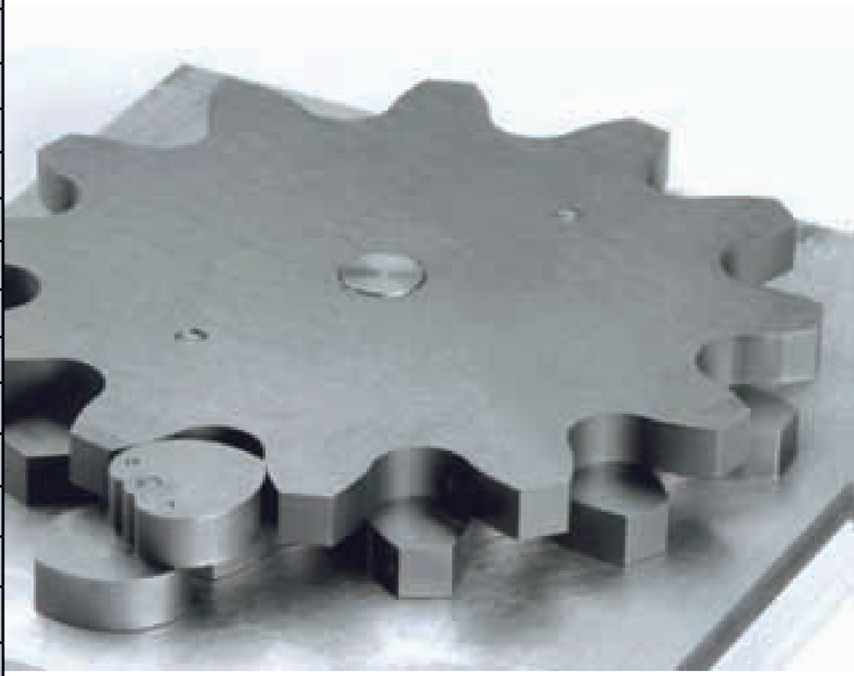
Richard L. Thoen

Richard L. Thoen *is a consultant specializing in medium- and fine-pitch gearing. He has authored several articles and papers on measurement, involute mathematics, statistical tolerancing and other gearing subjects.*

Management Summary

It is a common objective in geared product design that each stage of gearing provide the maximum gear ratio, or the number of teeth in the driven gear divided by the number in the driver. Further increase in the number of teeth in the driven gear is often restricted by an outside diameter limit and the selected diametral pitch or module. The alternate approach is to reduce the number of teeth in the driving gear down to a single tooth. This article points out that very low numbers of teeth lead to inadequate design values of contact ratio. This obstacle may be overcome by using helical gears instead of spur gears, but with noted manufacturing and other disadvantages. Spur gear designs may be maintained by the use of laminated gearing.

Nomenclature	
C	center distance
C_b	Basic center distance, $(N + n)/2P$ or $m(N + n)/2$
m	Module
m_p	Contact ratio
N	Number of teeth on gear
n	Number of teeth on pinion
P	Diametral pitch
p	Circular pitch on reference circles, π/P or πm
$p/2$	Basic tooth thickness
p_b	Base pitch
R	Radius of gear reference circle, $N/2P$ or $mN/2$
r	Radius of pinion reference circle, $n/2P$ or $mn/2$
R_b	Radius of gear base circle
r_b	Radius of pinion base circle
R_{if}	Inside form radius on gear
r_{if}	Inside form radius on pinion
R_{of}	Outside form radius on gear
r_{of}	Outside form radius on pinion
r_p	Radius where tooth becomes pointed
t	Tooth thickness on reference circle
ΔT	Deviation from $p/2$ on gear reference circle
Δt	Deviation from $p/2$ on pinion reference circle
Φ	Profile angle on basic rack
ϕ	Pressure angle
ϕ_p	Pressure angle at r_p



A one-tooth laminated pinion in mesh with a 12–tooth laminated gear. Photo courtesy of ACCU-Prompt Inc.

In this article, a laminated gear consists of two spur gears on the same axis, where the teeth on one gear are aligned with the tooth spaces on the other gear. The contact ratio for each mesh can be as low as 0.5. The basic geometry and circular fillet design are outlined.

Advantages

In some designs, it is advantageous to use laminated gearing instead of helical gearing. Specifically, in fine-pitch formed gearing (molded plastic, die cast, powder metal, stamped), tolerances are often so large relative to whole depth that the contact ratio is less than unity. In that case, it is necessary to use either laminated or helical gearing (Ref. 1). In choosing one or the other, note should be taken of the fact that tooling for laminated gearing is simpler and more accurate than that for helical gearing, since tooling for laminated gearing is made on a wire EDM machine, whereas that for helical gearing is made with a machined electrode guided by a rotating mechanism. Also, inspection equipment for laminated gearing is simpler than that for helical gearing (Ref. 2)

And it should be noted that a worm in mesh with a helical gear has only point contact between mating teeth, with the potential for high wear (Ref. 3), whereas laminated gearing has line contact, and no axial thrust on the bearings.

Basic Geometry

From Figure 1, it is seen that the contact ratio for each mesh is $m_p = z/p_b$, where $z = \sqrt{r_{of}^2 - r_b^2} - u_p$ so that

$$m_p = \frac{\sqrt{r_{of}^2 - r_b^2} - u_p}{p_b} \quad (1)$$

where

$$u_P = \sqrt{C^2 - (r_b + R_b)^2} - \sqrt{R_{of}^2 - R_b^2} \quad (2)$$

For maximum contact ratio, the $u_P = 0$ in Equation 2, i.e.,

$$C^2 - (r_b + R_b)^2 = R_{of}^2 - R_b^2$$

which reduces to

$$C = \sqrt{R_{of}^2 + r_b(r_b + 2R_b)} \quad (3)$$

For a given center distance, the sum of the deviations from basic tooth thickness is (Ref. 4)

$$\Delta t + \Delta T = 2C_b(\text{inv}\phi - \text{inv}\Phi) \quad (4)$$

where

$$\cos\phi = \frac{C_b}{C}\cos\Phi \quad (5)$$

Usually, the R_{of} in Equation 3 and ΔT in Equation 4 can be basic, namely, $R_{of} = (N + 2)/2P$ and $\Delta T = 0$.

If the contact ratio of Equation 1 is somewhat greater than 0.5, then the sliding can be reduced by reducing the outside form radius of the gear (R_{of}) (Ref. 5). For a reduced R_{of}, the

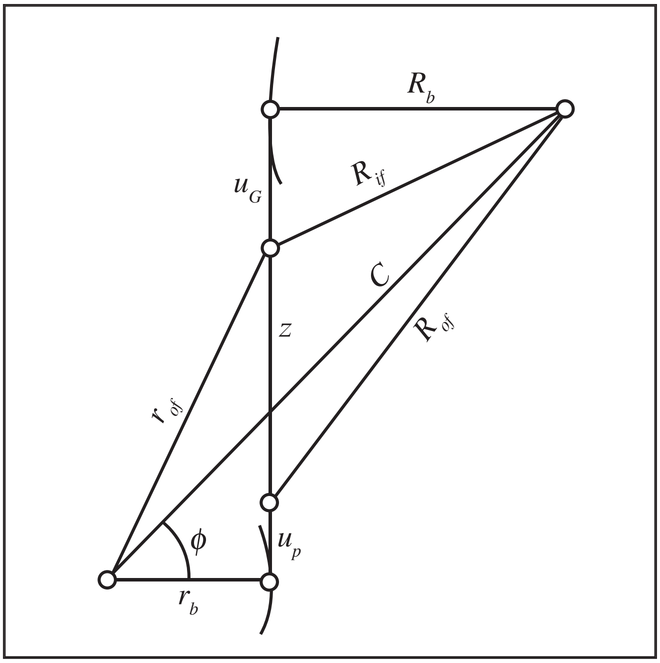


Figure 1—Calculation of contact ratio.

inside form radius of the pinion is

$$r_{if} = \sqrt{r_b^2 + u_P^2} \quad (6)$$

where u_p is that in Equation 2.

Also from Figure 1, it is apparent that the inside form radius of the gear is

$$R_{if} = \sqrt{R_b^2 + u_G^2} \quad (7)$$

where

$$u_G = \sqrt{C^2 + (r_b + R_b)^2} - \sqrt{r_{of}^2 - r_b^2} \quad (8)$$

Circular Fillets

With the advent of wire EDM, it has become common practice to replace the fillet generated by a basic rack with a circular arc of specified radius. Consequently, the designer now has to determine the location and radius of a circular arc that does not intersect the fillet generated by the tip of the mating tooth. If a computer program is not accessible (some programs do not determine the fillet generated by the tip of the mating tooth and some programs do not accept one and two-tooth pinions), then the fillet can be determined graphically—the old-fashioned way (Ref. 6).

To plot the fillets, the mating gears are rolled together in tight mesh (Ref. 7). Rather than draw the rolling circles (also known as operating pitch circles), only the tooth profiles are plotted (which permits greater magnification) on 8½ x 11 vellum, as shown in Figure 2.

It is important to remember that whenever the outside form

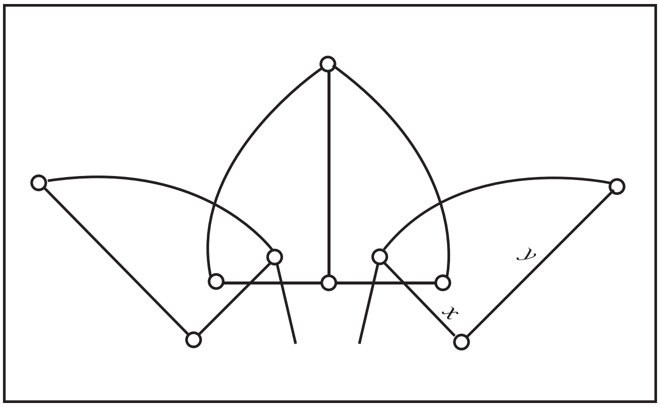


Figure 2—Plot for generation of fillets.

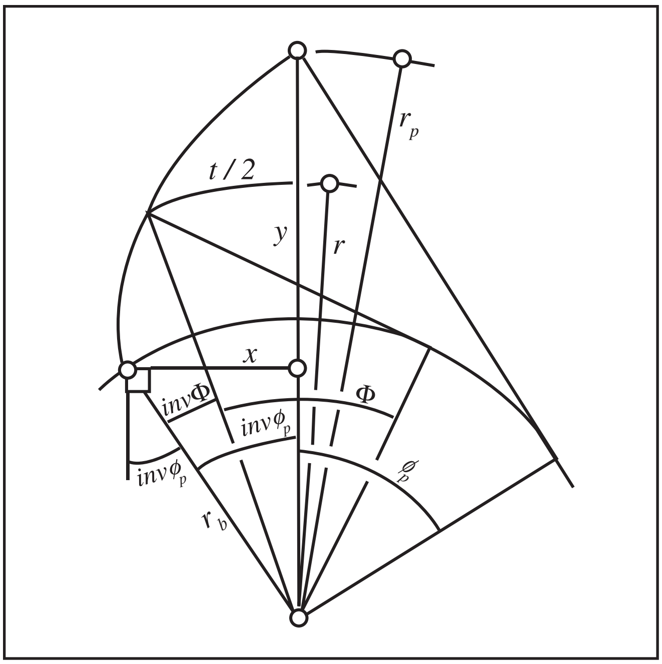


Figure 3—Coordinates of involute endpoints.

radius of the gear (R_{of}) contacts the base point of the pinion profile (as in Equation 3), then the specified circular arc falls on the radial line to the base point, not on the involute.

The four involute profiles in Figure 2 are traced from a single involute plotted on 8 ½ x 11 vellum (Ref. 8). From Figure 3, it is seen that the angle between the base point of the involute and the centerline of the tooth is

$$\text{inv}\phi_p = \text{inv}\Phi + \frac{t/2}{r}$$

where

$$\frac{t}{2r} = \frac{1}{d}\left(\frac{p}{2} + \Delta t\right) = \frac{1}{d}\left(\frac{\pi d}{2n} + \frac{n}{n}\Delta t\right)$$

so that

$$\text{inv}\phi_p = \text{inv}\Phi + \frac{1}{n}\left(\frac{\pi}{2} + \frac{n}{d}\Delta t\right) \quad (9)$$

where

$$\frac{n}{d} = P \quad \text{or} \quad \frac{1}{m}$$

Thus, the endpoints of the involute are at

$$x = r_b \sin(\text{inv}\phi_p) \quad (10)$$

and

$$y = r_p - r_b \cos(\text{inv}\phi_p) \quad (11)$$

where

$$r_p = \frac{r_b}{\cos\phi_p} \quad (12)$$

The locations of the *y* endpoints on the centerline of each tooth in Figure 2 are calculated from right triangles.

Possible Disadvantages

It should be noted that this method does have some limitations. For instance, even though the illustration show both the driver and driven laminated gears with the laminations flat in form and closely side by side, practical manufacturing and assembly conditions may dictate the need for a spacer of some form on at least one of the gears. The benefits of laminated gearing are only available if, in each set of laminations, there is a very accurate rotational orientation of one outline to the other and that the two outlines themselves are very closely matched. Finally, another limit on reducing the number of teeth in the driver is the need for a root diameter of adequate size, either to permit mounting on a shaft or simply of adequate torsional cross-section to transmit torque to the gear teeth.

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UTILIZATION OF POWDER METAL AND SHOT PEENING RESIDUAL STRESS TO MAXIMIZE COST AND PERFORMANCE BENEFIT OF HIGHLY LOADED GEARING

David J. Breuer

David J. Breuer *is a manager of OEM accounts with Metal Improvement Co., a shot peening and heat treating company headquartered in Paramus, NJ. A mechanical engineer, he has worked for MIC as a divisional and regional sales manager for the company's shot peening facilities. Breuer has written several papers related to shot peening, which have been presented at technical conferences and printed in technical publications. In addition, he wrote* Shot Peening Applications—Eighth Edition.

Management Summary

The primary benefit of powder metal (P/M) gearing is reduced cost of manufacturing, making such gearing an obvious choice for lower load applications. The perception that P/M gears are limited to only low load classes has been changing with recent developments in higher density P/M technology and advanced manufacturing techniques, such as powder forging, isostatic pressing, conventional compaction, surface densification, and activated sintering.

This paper will focus on bending fatigue strength improvements of P/M gearing from recent improvements in P/M technology combined with the established technology of shot peening. Factoring in the significant cost savings of P/M manufacturing, P/M gears with shot peening have the potential to replace higher load applications currently served by wrought gearing. This paper addresses gear applications limited by bending fatigue and not other failure modes.

Introduction

Increasing the load carrying capacity of gearing has been of principal importance since gears have been in existence. In modern day manufacturing, the cost of gear production continues to play a significant role in selection and implementation of gear design, materials, heat treatment and subsequent finishing operations.

Generally speaking, conventional press and sinter P/M technology by itself has not achieved the bending performance properties of wrought steel gears. With advanced processing techniques and the addition of shot peening, the performance gap has been significantly reduced or eliminated. Even with the value-added process of shot peening, P/M components can have strong cost advantages compared with wrought steel gearing.

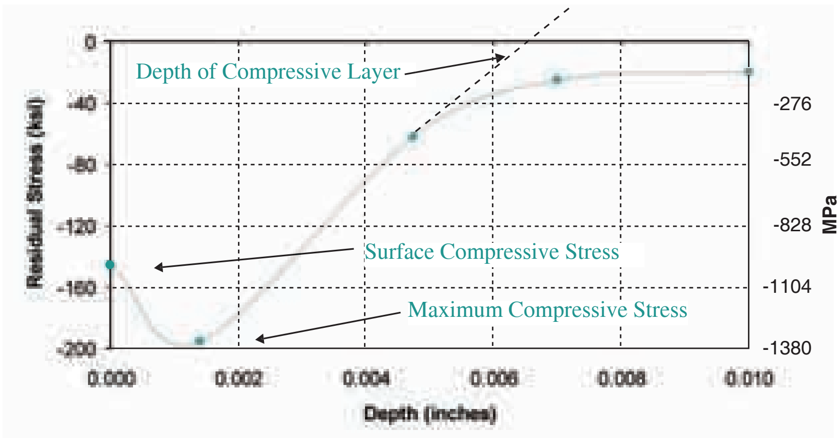

Figure 1—Typical residual stress distribution from shot-peened wrought steel.

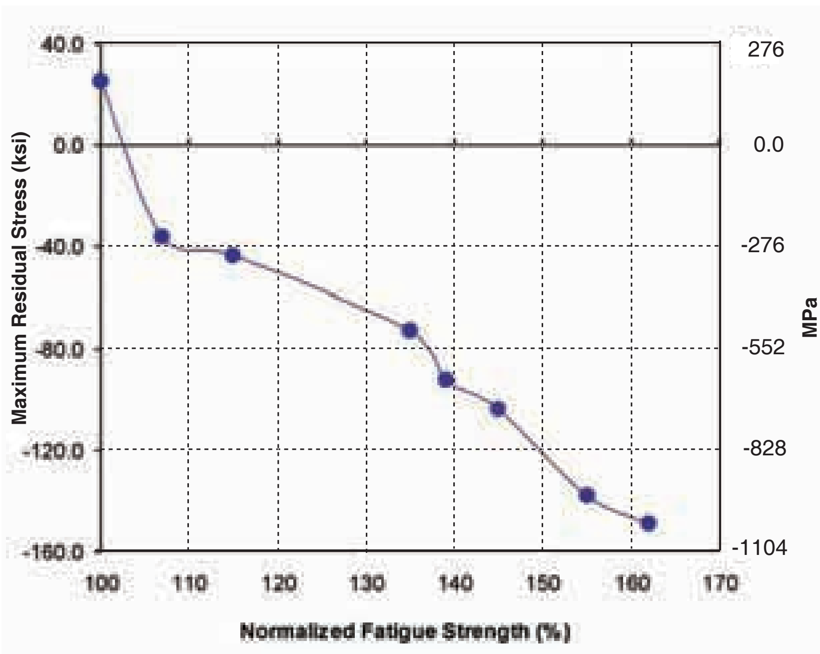

Figure 2—Increased fatigue strength correlated to increased maximum compressive stress.

P/M Technology

Usage of lower cost, higher performance manufacturing technology is heavily driven by, but not limited to, the automotive industry. Long service life, high quality requirements and continued reduction in cost are essential in manufacturing and design. The primary benefit of the P/M process is the ability to eliminate traditional manufacturing steps of machined gears to achieve near-net shapes. This net shape capability translates to significant cost savings.

Emerging P/M technology to increase load carrying capacity is primarily focused on improvements in density. Additional variations of chemistry and heat treatment are not believed to be the main limiting factors in advancing P/M gear applications.

A secondary benefit of P/M technology is very uniform and isotropic material properties. When comparing P/M steels to their wrought steel counterparts, the tendency for alloy segregation may be significantly reduced. Each particle in the powder metal mix is considered a microingot. This uniformity, together with the resulting isotropy from P/M processing, results in very consistent response to heat treating and subsequent machining, grinding and finishing operations.

The P/M industry is currently advancing technologies for producing components with near-fully-dense properties. Near fully dense is defined as less than 1% residual porosity. Two of these technologies that will be discussed are powder forging and isostatic pressing.

Powder forging. This technique is used in mass produced P/M steel parts that essentially have wrought steel properties. High volume components, such as automotive transmission and engine parts, are currently being made with this process. Densities of 7.82–7.84 g/cm^3 are currently possible with powder forging.

Powder forging manufacturing begins with a "green compact." This consists of a preform that has been pressed into shape at room temperature. The preform is then heated to forging temperature and restruck in a forging tool until final density is reached.

Isostatic pressing. Isostatic pressing differs from other methods of compaction in that it is accomplished in a pressurized fluid, such as oil, water or gas. The powder is encapsulated in a flexible, sealed container (or can) that allows forming into near-net shapes of varying size and part complexity.

Hot isostatic pressing is performed in an inert gas atmosphere, most commonly nitrogen, argon or helium, contained in a pressure vessel. Both the powder (to be pressed into a formed part) and atmosphere are heated to temperatures as high as 2,300°F (1,260°C). Common pressure levels are 15,000 psi (104 MPa). Typical densities for hot isostatic pressing are 7.2–7.4 g/cm^3. Some companies reportedly are able to achieve 7.5–7.8 g/cm^3 with their proprietary processes.

The powder to be processed is vacuum sealed within a container that will deform plastically at elevated temperature and pressure. The pressing and sintering operations occur simultaneously in the heated pressure vessel. The container is then separated from the near-net component through methods such as leaching or machining.

Alternatively, a previously formed component of greater than 92% of theoretical density may be pressed to full density without the use of the costly encapsulation stage.

Emerging P/M technologies. Because of some economic and dimensional precision issues with powder forging and hot isostatic pressing, the focus on recent P/M technological advances is on enhancements to conventional compacting, surface densification, and activated sintering technologies as means for achieving gearing-related mechanical properties that are equivalent to wrought steels (Refs. 1–2).

Enhancement through Shot Peening

Shot peening is an established technology used for inducing residual compressive stress at the surface of metal components. The residual stress is a function of the hardness/strength properties of the gear surface such that heat treatment plays a significant role in the resultant residual compressive stress profile.

For applications subject to mechanical fatigue loading, residual stresses are additive with applied stresses. The applied bending stress of a gear root is reduced by the amount of residual compression induced from the shot peen process. Shot peening modifies the residual stress distribution at the outer surface, which is usually the initiation site of a typical fatigue failure. The typical location of a bending failure for a gear is the transition/tangent point between the gear root and gear flank.

For gearing applications, the process is most commonly accomplished with steel shot media in the size range of 0.007–0.046" ø (0.18–1.17 mm ø). The shot media should be fully hardened to 55–62 HRC for maximum compressive magnitude and depth properties. Reduced hardness media (45–52 HRC) is available when tooth flank surface finish is a concern. Figure 1 shows a typical residual stress distribution of a carburized, fully hardened wrought gear steel that has been shot peened with fully hardened shot.

It should be noted that the curve does not cross the neutral axis such that the surface residual compressive stresses are balanced with sub-surface residual tensile stresses for static rebalancing. The reason is that the carburized layer (which is significantly deeper than the shot peen layer) has residual compression prior to the shot peening. The static rebalancing would occur much deeper than what is shown in Figure 1. A dashed line is shown to represent the depth of the shot peen layer by extending the curve from its positively sloping portion.

It is generally accepted for most gearing applications that bending fatigue strength improves with increasing residual compression. Figure 2 demonstrates the trend of improved bending fatigue with increasing residual compressive stress. Figure 2 is a compilation of results using carburized 20MnCr5 in single tooth pulsator tests. The gears were 8.0 mm module with 20 teeth (Ref. 3).

All results in Figure 2 are normalized to 100% on the horizontal axis. The graph shows that the highest magnitude of residual compression (~ 150 ksi or 1,035 MPa) showed an increase in fatigue strength of approximately 60% when compared to the baseline (100%), which had approximately 25 ksi (173 MPa) of residual tension.

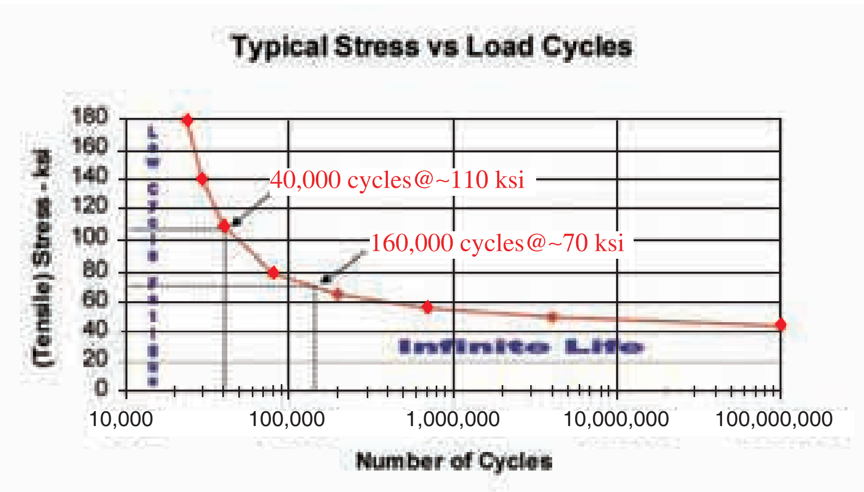

Figure 3—Typical stress vs. load cycles (S-N) curve.

As stated previously, the residual stress induced from the shot peening is heavily influenced by the properties of the material being peened. This applies to both wrought steel and P/M gears. Applying this principle to P/M components, this means that shot peening will produce more compressive stress on higher hardness and higher density P/M components, resulting in optimum load carrying properties. Lower density P/M components will still respond with compressive stress. However, they will lack the strength to retain higher magnitudes of compressive stress.

Discussion of Test Data

This section will present available test data on shot peening of powder metal gears. Several different types of data are presented, including tooth root bending fatigue data. This fatigue data was acquired using single tooth pulsator (STP) tests.

It ought to be noted that fatigue strength data from STP tests should be adjusted downward as the specific tooth (teeth) that were tested are not necessarily the weakest on the gear. In power recirculation tests, which are more applicable to real life conditions (and more expensive to perform), the weakest tooth always fails. Test results indicate a downward adjustment to ~ 80% of the STP testing improvement would be realistic (Ref. 4).

The principles of fatigue failure should also be mentioned. A typical S-N curve plots the applied stress versus number of cycles. The higher the number of cycles prior to shot peening, the greater the enhancement with the addition of shot peening. This is because shot peening lowers the net stress experienced at the surface of the gear. A reduced net stress theoretically brings the resultant stress closer to the endurance limit. Figure 3 (which does not apply to any specific material or application) demonstrates this concept.

Table 1—Tooth Root Load Carrying Capacity Via Single Tooth Pulsator Tests.			
	Wrought Reference Gear	Variation 1 (7.72 g/cm³) MSP4.0Mo	Variation 2 (7.76 g/cm³) MSP4.0Mo-0.1Nb
Non-Peened Fatigue Strength	131 ksi (900 MPa)	100 ksi (685 MPa)	108 ksi (745 MPa)
Shot Peened Fatigue Strength	N/A	145 ksi (1,000 MPa)	145 ksi (1,000 MPa)
Note: All results are shown at 50% failure probability.			

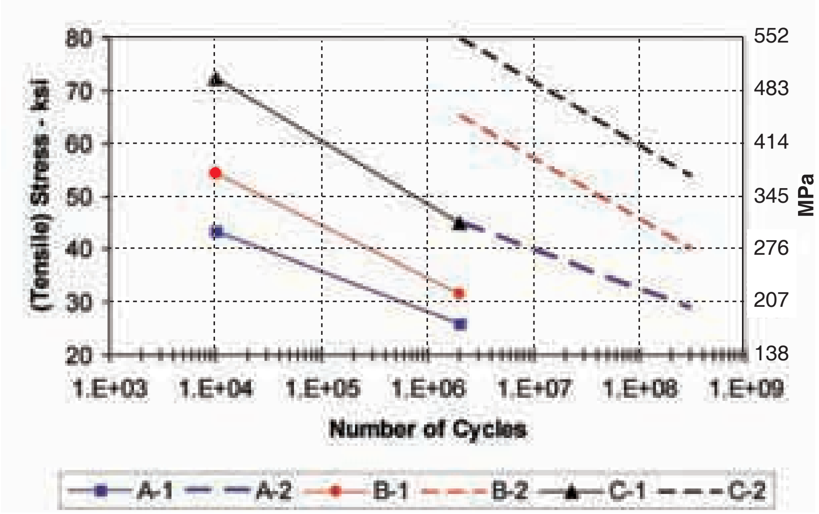

Figure 4—Fatigue life curves of Fe-2%, Cu-2.5%, Ni-with a density of 7.6 g/cm³.

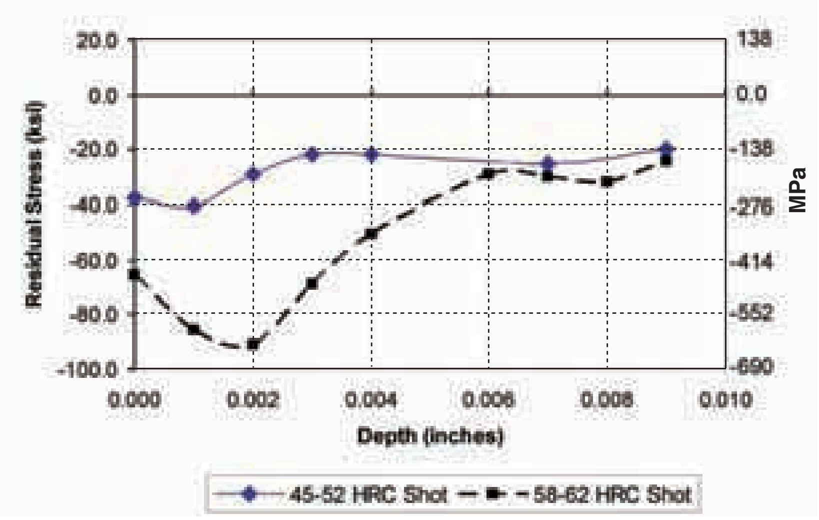

Figure 5—Residual stress plot of shot peened, carbonitrided P/M with different grades of shot hardness.

Using this principle, one could assume that if fatigue strength results were analyzed (before and after shot peening) at 500,000 cycles compared with 2 million cycles, the percent improvement would not be as significant. If fatigue strength were analyzed at 4 million cycles (compared with 2 million cycles), theoretically the fatigue strength improvement should be greater.

Case study #1. The German Federal Ministry of Education and Research tested powder metal alloys and their suitability for gearing applications. MSP4.0Mo-based powder metal gear alloys were tested against 20MnCr5 case hardened, wrought steel gears. Tooth root load carrying capacity tests were performed using single tooth pulsator tests at 2 million cycles. All gears had modules of 3.5 mm. The results are shown in Table 1 (Ref. 5).

The above test study shows a decrease of ~ 20% (25% & 18% respectively) when comparing the non-peened powder metal variations to the non-peened wrought reference gear. With the addition of shot peening, both examples exceeded the wrought reference gear by ~ 9%.

Assuming an average 104 ksi (100 & 108 ksi) fatigue strength prior to shot peening of the non-peened powder metal variations and 145 ksi with the addition of shot peening, the fatigue strength improvement is ~ 39%. With the previously mentioned STP-to-power recirculation adjustment, the shot peened value can be changed to ~ 136 ksi (a 31% improvement) for calculated service requirements.

Case study #2. Another test study was performed on P/M test bars with a machined radius acting as a stress concentration (stress factor, K = 1.49). The material was Fe-2%, Cu-2.5%, Ni- with a density of 7.6 g/cm³. Tests were performed under both uniform and variable loading. In addition to varying test loads, the test matrix examined various sintering treatments. Figure 4 depicts the results. Below the figure is an explanation of the curves labeled in the legend of the graph (Ref. 6).

- A-1: As Sintered, Constant Loading
- A-2: As Sintered, Variable Loading
- B-1: Sintered & Shot Peened, Constant Loading
- B-2: Sintered & Shot Peened, Variable Loading
- C-1: Sintered, Carbonitrided & Shot Peened, Constant Loading
- C-2: Sintered & Shot Peened, Variable Loading

Note: All shot peening performed to a 0.016" A intensity.

These data support the theory that harder, higher strength materials achieve better fatigue performance as they are able to retain higher magnitudes of residual compressive stress. When comparing the constant loading conditions at 1 million cycles, the as-sintered (A-1) condition has a fatigue strength of ~ 28 ksi (193 MPa). When carbonitrided and shot peened (C-1) the fatigue strength increases to ~ 48 ksi (331 MPa), a 71% improvement.

Case study #3. Fe-Mo P/M alloy gears at a density of 7.5 g/cm³ were tested at an endurance limit of 3 million cycles. The gears were hardened to 60 HRC and shot peened (0.016" A intensity) with fully hardened 62 HRC shot. The following results are from single tooth loading (Ref. 7).

- Sintered & Case Hardened (baseline): 130 ksi (900 MPa)
- Sintered, Case Hardened & Ground: 112 ksi (770 MPa)
- Sintered, Case Hardened & Shot Peened: 149 ksi (1,030 MPa)

Shot peening improved the baseline condition by 19 ksi (~ 15%). It is worth noting that t"he endurance limit of the gear tooth roots that were ground decreased 18 ksi (~ 14%) from the baseline condition. It is generally believed that a smoother surface will respond better under fatigue conditions because potential crack initiation sites are assumed to be eliminated. What is sometimes neglected is the fact that grinding under certain circumstances can introduce residual tensile stresses if not properly controlled. Residual tensile stresses will act to accelerate a fatigue failure as they are additive with applied tensile stresses. It is believed this is what contributed to the decrease in fatigue life, however this was not the focus of this study.

Case study #4. Residual stress comparisons were made between shot peening a hardened surface with different grades of shot hardness. A carbonitrided, powder metal Fe-1.5% alloy (density = 7.4 g/cm³) surface was shot peened with fully hardened and regular hardness shot media. Figure 5 shows the residual stress comparison (Ref. 6).

It should be noted that both curves do not cross the neutral axis due to residual compression created from the carbonitriding process prior to shot peening. Figure 5 shows significantly more residual compression when using a harder shot media. Although bending fatigue tests for comparing the two were not available, the residual stress from the shot of higher hardness would most likely produce better results in bending fatigue.

Case study #5. Tooth root bending fatigue studies were performed using pulsator tests to compare a reference wrought gear to a powder metal gear that has a density of 7.5 g/cm³. Both gears had 3.5 mm modules, 25 teeth and were case hardened to 60 HRC. The wrought gear was a 16MnCr5 steel and the powder metal gear was Fe-3.5Mo alloy content.

In Figure 6, the powder metal gear results are depicted with the blue curves. The endurance limit improved ~ 35% with the addition of shot peening. The endurance limit improved from ~ 95 ksi (650 MPa) to ~ 128 ksi (880 MPa). The endurance limit of the shot peened powder metal compares very closely with the non-peened 16MnCr5 material. Shot peening was performed at 0.013" A intensity (0.32 mm A intensity) for all samples.

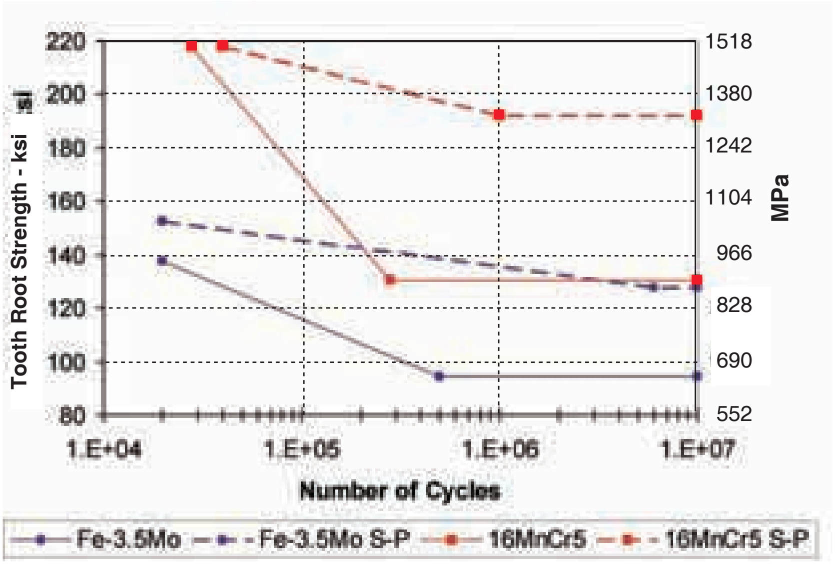

Figure 6—Fatigue life curves comparing a reference wrought steel (16MnCr5) to a powder metal (Fe-3.5Mo) of 7.5 g/cm³ density with and without shot peening.

In Figure 6, the reference 16MnCr5 steel gear results are depicted with the red curves. The endurance limit improved ~ 45% with the addition of shot peening. The tooth root strength was ~ 131 ksi before shot peening and ~ 190 ksi after shot peening. Since the non-peened steel gear has a higher strength than the non-peened powder metal gear, the 16MnCr5 is able to retain more residual compression from shot peening, resulting in more overall improvement in fatigue strength from shot peening.

Using the previously mentioned STP-to-power recirculation adjustment, the endurance strength improvements can be changed to ~ 29% (from ~ 35%) for the powder metal gears and to ~ 36% (from ~ 45%) for the wrought steel gear (Ref. 8).

Case study #6. Via bending fatigue tests, powder forged C-0.5%, Cu-2% components with a density of 7.82 g/cm³ had a fatigue strength 27% greater than the non-peened counterparts (at 90% reliability levels) (Ref. 9). It should be noted that the components in this test were automotive connecting rods, not gears. They were included as part of this paper because they were made from high density P/M and the failure mode was bending fatigue, which is the subject of all other case studies presented in this paper.

Conclusion

The growth of the powder metal market is directly a function of the available applications it can serve with its current cost advantages. The current market for gearing covers a broad spectrum from non-critical, low load applications to critical, high load applications. The P/M gear market is naturally limited by its mechanical performance capability.

Recent improvements in the manufacturing technologies of powder metal have allowed it to be considered for higher strength gear applications. Higher bending strength P/M applications are highly predicated on higher densities and subsequent heat treating and metal finishing operations.

Typical high load gear applications are susceptible to bending fatigue failure in the gear tooth root. Shot peening is a recognized process to induce residual compressive stress. It is also highly dependent on P/M density and heat treatment. Test data were presented to support the consideration of P/M bending fatigue strength improvements through the use of shot peening. P/M gears (even with shot peening) offer significant cost advantages over their wrought steel counterparts.

This paper was presented at the ASME/AGMA 2003 International Power Transmission and Gearing Conference, held Sept. 3–5, 2003, in Chicago, IL, and was published in *Proceedings of the 2003 ASME Design Engineering Technical Conferences & Computers and Information in Engineering Conference*. It's republished here with permission from ASME.

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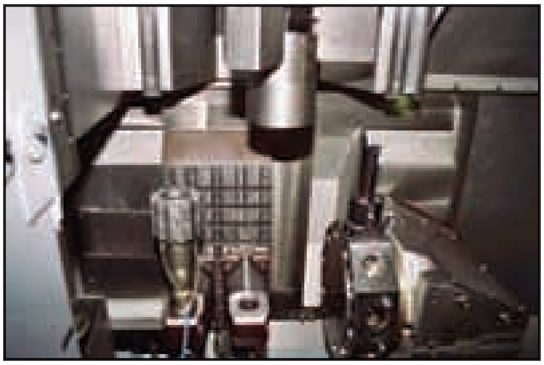
Sigma Pool Merges All Grinding Activities

Sigma Pool partners have merged all activities in the field of cylindrical gear grinding under the roof of Liebherr-Verzahntechnik GmbH in Kempton, Germany.

According to the company's press release, the R&D, production and sales for the OPAL/SIGMA OPAL series will be concentrated under Liebherr-Verzahntechnik GmbH, effective immediately. Customers will have only one contract partner for cylindrical gear grinding over the production range, although existing contracts will be fulfilled by their respective partners.

In addition, future service will tap into a larger knowledge base to secure the most effective customer support. The knowledge transfer will be completed at the end of 2006. Klingelnberg's service organization is available unrestricted to customers until that time.

The new concentration underlines the core competence of Liebherr for cylindrical gears. Klingelnberg, formerly Oerlikon, previously covered the market for small- and middle-series production and will now focus exclusively on large-series production.



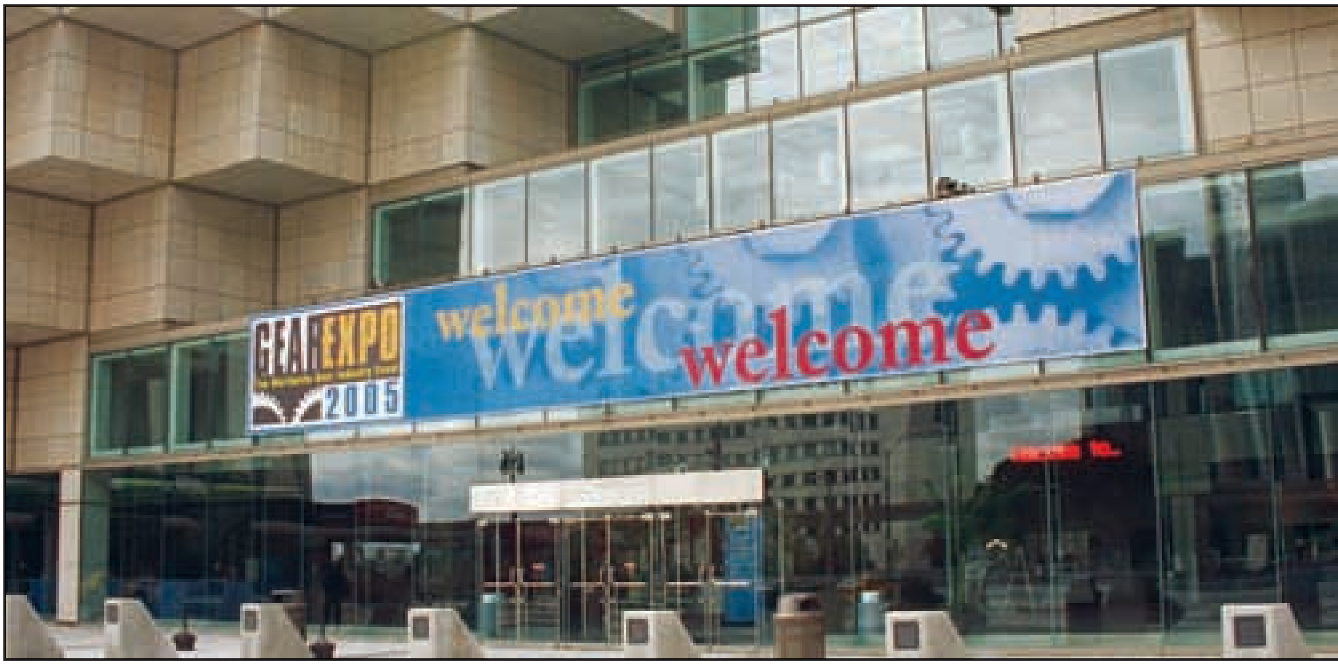
Bates Technologies Acquires Micromatic Textron Line

Bates Technologies acquired the honing tool and abrasive product line of Micromatic Textron.

Included in the acquisition is the Micromatic tooling and abrasive trade names Microsize® and Microhone®. Bates Technologies will continue these operations under their previous ownership team. In addition to its Indianapolis headquarters, Bates will have operations in Berne and Angola, IN.

Bates Technologies is a resource for superabrasive honing stones and tooling. According to the company's press release, it plans to continue to market a full line of products, including the Micromatic CNC integrated tooling and abrasive system, which allows for complete honing operations without dedicated stationary equipment.

Gear Expo: Still a Tool for Business



Gear Expo 2005 had lulls in attendance, times when fewer visitors were walking the aisles looking at products and services, and a number of exhibitors didn't have the business they'd expected or hoped for, but the AGMA show remained a tool for business in the gear industry.

Among the larger exhibitors, several companies said they did well during the expo, with a few citing the quantity and quality of sales leads from the show.

"The potential customer traffic was constant, and the quality of the traffic excellent," said Ian Shearing, vice president–sales for Mitsubishi Gear Technology Center. "We sold some machines directly off the show floor."

Uwe Schmitz, managing director of Kapp Group, agreed about the quality of attendees.

"People come here, they are doing serious research," he said, adding that they talked about lead times and asked the questions usually involved in making a buying decision. "They're not here to look at a couple of machines and go away."

At the Höfler GmbH exhibit, Hagen Hofmann, president and CEO, was most concerned with only a small number of expo attendees. Höfler manufactures gear grinding and hobbing machines for larger diameter gears, so its range of possible customers is narrower than other machine tool manufacturers'.

"Our potential customers can be counted on four hands," Hofmann said, "and they were almost all there."

In total, Gear Expo '05 had 1,396 attendees, according to *Gear Technology*'s own review of the expo's registrant list.

The attendee count didn't include the 1,100+ people present as exhibitors. They can't be counted as regular attendees, but

Kurt Medert, AGMA vice president–business management division, considers them when measuring expo attendance. After all, there's little doubt that a number of exhibitors also walk the aisles as de facto attendees. For example, the president of a gear manufacturing company might leave his exhibit area to co-workers for an hour so he can talk with a gear cutting tool manufacturer about hobs.

"It's two shows in one," Medert said.

So he was encouraged by the measure for this show inside a show. At the '01 expo, the number of employees present for exhibiting companies was 1,145. In '03, it dropped to 738. At 1,100+, this year's number was a sign of recovery for Gear Expo.

Also, in its attendance, the expo showed itself similar to IMTS, the International Manufacturing Technology Show. Like the show, the expo served as a sign of some recovery in the gear industry.

In September '04, IMTS indicated there was recovery, and a number of Gear Pavilion exhibitors said business was improving and expressed optimism about '05. A year later, several Gear Expo exhibitors, including two who exhibited at IMTS, said their companies were doing well and forecasted a continuation.

"The order intake has been good," said Kapp's Schmitz, "and we expect that to be good until the end of '05." He added that he expected the trend to continue into the first quarter of '06. Schmitz's U.S. operation, Kapp Technologies, exhibited at IMTS '04.

Another exhibitor there was Gleason Corp., whose vice president–American sales, Mark Hiscock, had expected his company to finish the year "with a bang" and had predicted '05 would be a strong year.

Last month, John J. Perrotti, Gleason president and CEO, said company sales were record high for '05, and the business had considerable momentum. "Our prospects continue to look good," he added. "We continue to have high expectations for 2006."

Dennis Richmond, Reishauer Corp.'s vice president, had mixed expectations, though. "The weather in my crystal ball is partly cloudy," he said. "I'm hoping for continued sunshine."

Fässler Corp. and Höfler didn't exhibit at IMTS, but the two Gear Expo exhibitors were seeing sunnier skies.

"In general, our company has been doing better since IMTS '04, although it was not a direct result of that show," said Fässler's vice president, Alan Mirsberger. Hofmann added that Höfler business was excellent and he expected the trend to continue into next year.

Gear Expo 2005: Somewhat Recovered

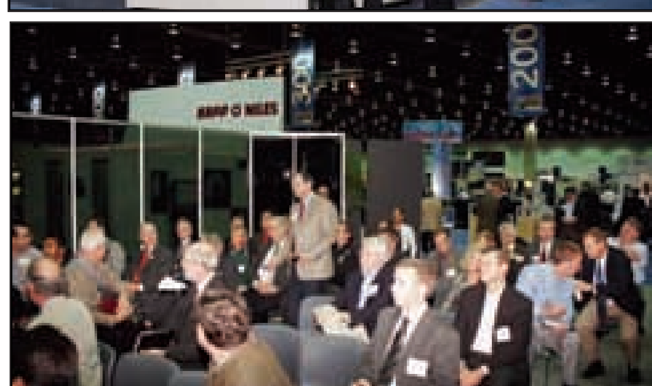
After the economic recession in 2001, Gear Expo lost attendees, exhibitors and occupied less space at its ’03 show, but the ’05 expo showed it had stabilized, and had even somewhat recovered.

The stabilization was in the amount of exhibit space. Gear Expo dropped from 57,400 square feet in ’01 to 39,000 in ’03, but it occupied 40,000 in October. That slight increase was despite a considerable increase in exhibiting companies: 150 in ’03 versus 180 in ’05. On average, companies have been occupying less booth space since the ’01 show, but this year’s higher number of exhibitors was one part of the expo’s recovery.

The other part was attendance. In ’01, Gear Expo attracted 1,700 attendees. Two years later, attendance was down 29 percent, to 1,200 people. That number appears to have been bottom, though. With the U.S. economy somewhat recovered, Gear Expo ’05 attracted 1,400 attendees.

Gear Expo by the Numbers

Gear Expo	2001	2003	2005
Exhibitors	194	150	180
Booth Space Occupied	57,400 sq. ft.	39,000 sq. ft.	40,000 sq. ft.
Attendees	1,712	1,212	1,396
Exhibitor Personnel	1,145	738	1,116



A New High for the Fall Technical Meeting

The AGMA 2005 Fall Technical Meeting enjoyed a high in its number of papers when it convened Oct. 16–18 in Detroit, MI.

The annual event for gear design and manufacturing engineers has averaged about 14 papers since the 1990 meeting. This year, it had 20 papers, a new high. The old high since the '90 meeting was 19 papers at the '99 gathering.

The other major aspect of the meeting was its return to Gear Expo. After '93, the two events were held apart, at different times and locations. In 2001, they were reunited. Both were held in Detroit that year, with the expo ending two days before the meeting started. The next expo year, they were split up again.

In a sense, no Fall Technical Meeting occurred in 2003. That year, the AGMA combined its meeting with the much larger International Power Transmission and Gearing Conference, held by the mechanical engineering society ASME International. Whatever papers the AGMA had were added to the ASME event, which featured a total of 129 papers on power transmission and gearing. Consequently, AGMA has no papers carrying an '03 FTM designation.

The interruption, however, seemed to have no ill effect. The Fall Technical Meeting returned in 2004, with 14 papers and 120 registered attendees. This year's meeting had 90 registered attendees. After looking at attendee surveys, Bill Bradley, AGMA vice president–technical division, said this year's papers received good ratings, which he took as a sign about the meeting: "I think it went well."

'05 papers are available for immediate download via the AGMA Online Store for $35 a paper. A 50% discount is available for AGMA members. The papers can also be ordered by phone from Amy Lane, AGMA technical editor.

For more information:
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AGMA
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Alexandria, VA 22314
Phone: (703) 838-0059
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Papers Presented at the AGMA 2005 Fall Technical Meeting

Session I—Manufacturing and Testing Gears

- "Molded Plastic Face Gears: Design and Manufacture" by I. Laskin and E. Reiter,
- "The Effects of Pre-Rough Machine Processing on Dimensional Distortion During Carburizing" by G. Blake,
- "Modeling Gear Distortion" by P.C. Clarke, and
- "Tooth Meshing Stiffness Optimization based on Gear Tooth

Form Determination for a Production Process Using Different Tools" by U. Kissling.

Session II—Hypoid and Bevel Application Design
•"Simulation of Face-hobbing Process for Hypoid Gears: Surface Generation, Contact Analysis and Fillet Stress Calculation" by A. Piazza and M. Vimercati,
•"A Model to Predict Friction Losses of Face-hobbed Hypoid Gears" by H. Xu, A. Kahraman, and D. R. Houser,
•"Spiral Bevel and Hypoid Gear Cutting Update" by T.J. "Buzz" Maiuri,
•"New Developments in Tooth Contact Analysis for Bevel Gear Drives: A Universal Surface Generation Algorithm and Finite Element Model" by Qi Fan and Lowell Wilcox, and
•"Hypoid Gear Lapping Wear Coefficient and Simulation" by C. Gosselin and Q. Jiang.

The meeting included a special presentation of the new AGMA Bevel Gear Rating Suite by the AGMA Computer Software Committee at the end of the second session.

Session III—Innovative Application Solutions
•"Finite Element Study of the Ikona Gear Tooth Profile" by J.R. Colbourne and S. Liu,
•"Low Loss Gears" by B.-R. Höhn, K. Michaelis, and A. Wimmer,
•"Modal Failure Analysis of a Gear and Drive Ring Assembly" by D.D. Behlke,
•"Evaluation of the Scuffing Resistance of Isotropic Superfinished Precision Gears" by P.W. Niskanen, B. Hansen and L. Winkelmann, and
•"Determining the Shaper Cut Helical Gear Fillet Profile" by George Lian.

Session IV—Making Gears Work for Life
•"Repair of Helicopter Gears" by S. Rao, D. McPherson and G. Sroka,
•"H47D Engine Transmission Input Pinion Seeded Fault Testing" by J. Petrella, J. Kachelries, and S. Holder,
•"Influences of Bearing Life Considerations on Gear Drive Design" by F.C. Uherek,
•"Planet Pac: Increasing Epicyclic Power Density and Performance Through Integration" by D. Lucas,
•"The Application of Very Large, Weld Fabricated, Carburized, Hardened & Hard Finished Advanced Technology Gears in Steel Mill Gear Drives" by R. Drago, and
•"Analysis of a Dual Drive Conveyor Failure" by J. Lisiecki.

December 5–8—Gear School 2005. Gleason Cutting Tools facility, Loves Park, IL. This three-and-a-half day program covers fundamentals, high speed steels, coating, gear cutting and inspection. Participants tour the Gleason Cutting Tools plant and have the option of an off-site tour of a complete manufacturing facility. Training also includes individual instruction and troubleshooting for specific problems. $895 fee includes handbook, a group dinner and all lunches. For more information, contact Gleason Cutting Tools by telephone at (815) 877-8900 or on the Internet at *www.gleason.com*.

December 6–8—POWER-GEN International. Sands Expo Center, Las Vegas, NV. Power generation conference with technical tours of the APEX Generating Station, Silverhawk Power Plant and the Hoover Dam. Keynote sessions include speeches by the president and CEO of GE Energy's Nuclear Division, the Iraqi Minister of Electricity as well as the presidents of Energy Management Inc. and Sempra Generation. Conference costs range from $95–$600. For more information, visit the show's website at *www.power-gen.com*.

December 12–14—Plastic Injection Mold Design Basics. Holiday Inn on the Bay, San Diego, CA. The seminar covers every major component of an injection mold and is designed for tooling engineers, buyers (especially of overseas tooling), tool makers, mold designers, product designers, managers and molders. $990 fee includes materials, a certificate of participation, continental breakfasts and lunches. For more information, contact the University of Wisconsin at Milwaukee School of Continuing Education by telephone at (414) 227-3100 or by e-mail at *oneil@uwm.edu*.

December 15–16—Plastics Injection Mold Design Advanced. Holiday Inn on the Bay, San Diego, CA. This course offers a more detailed look at the specific inner workings of an injection mold, stressing cost savings. $790 includes materials, a certificate of participation, continental breakfasts and lunches. For more information, contact the University of Wisconsin at Milwaukee School of Continuing Education by telephone at (414) 227-3100 or by e-mail at *oneil@uwm.edu*.

January 10–11—KISSsoft Software Training Class. MicroTek Oak Brook Training facility, Oak Brook IL. Content for this seminar is broken into two categories: Theories of Geometry and Strength Calculations for Gears, and Gear Design and Optimization. The first day covers geometry of cylindrical gears with involute profiles, manufacturing tolerances, non-involute tooth forms, strength calculations for gears and for non-involute tooth forms and material selection. The second day focuses on cylindrical calculation, commonly used strategies for gear optimization, cylindrical gear configurations and specialist themes. Class size is limited to 20 and the cost is $1,250. For more information, contact KISSsoft USA by telephone at (815) 363-8823 or via the Internet at *www.KISSsoft.com*.

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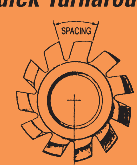

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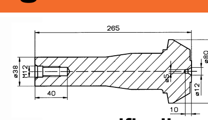

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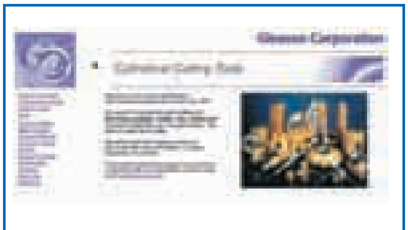
Gear Manufacturing On The Other Side Of The World

Read all about it in the next issue of Gear Technology

January/February 2006



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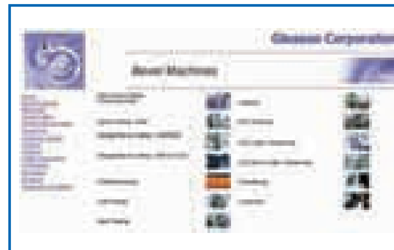

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Sounds Like a Job for Toolman

While the rest of the exhibitors were selling machinery, the Addendum team scoured the floor of Gear Expo in a quest to find the quirky things at the show.

It didn't take long. Barit International Corp.'s booth had the usual assortment of cutting tools, but it was Toolman that was the center of attention.

Toolman watched the activity at the expo from a prime tabletop position at Barit's booth. Visitors were lured in by the mascot's body, which includes hobs, cutting tools, carbide inserts, tapers, a drill, and milling cutters.

Leon Kozlov, Barit's vice president, says Toolman was a gift from a Russian supplier. Though Barit no longer sells Russian-made tools, Toolman has been a constant in the company's office for 15 years.

On its rare trips outside of the company's Northbrook, IL, headquarters, Toolman mingles with the gear industry. He's been at more Gear Expos than many of the sales reps on the show floor.

Schmoozing at the expo is all well and good, but can he be rented out for booth breakdown duty? No job is too big for Toolman!

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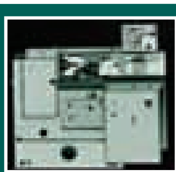
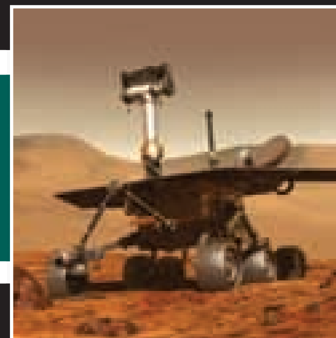
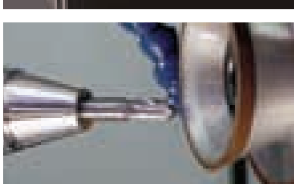




Did you miss
Show & Tell
at Gear Expo 2005?

▶ **Bourn & Koch** demonstrated the 100H Series II CNC Hobbing Machine at the AGMA Gear Expo. The 100H is a 6 axis hobbing machine featuring: NUM 1050H 6 Axes CNC control; full machine enclosure for wet or dry hobbing; pneumatic live center; automatic single – or double – cut hobbing on multiple gears or splines; automatic hob shifting; speed and feed change between cuts; crown hobbing, taper hobbing, radial or tangential feed worm gear cycles; and CNC hob swivel.

▶ **Bourn & Koch** demonstrated multiple spline hobbing on a shaft with two splines with different numbers of teeth; with two hobs with different numbers of starts; and dry cutting in a single clamping.



◀ **Star Cutter** demonstrated the Star Model PTG-1 at the AGMA Gear Expo. The PTG-1 is a 5-axis grinding machine featuring: NUM Axium CNC control; NUMROTO plus software; integrated automatic part probing; automatic wheel probing; and on-board wheel dressing. The PTG-1 sharpens straight and spiral gash hobs, through-hole and shank type, up to 8" in diameter and 10" in length. The resharpening quality meets the AGMA "AAA" standards, with unsurpassed surface finish through the use of super abrasives.

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