GEAR TECHNOLOGY

JULY/AUGUST 2005

The Journal of Gear Manufacturing

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- Opportunities for Gear Grinders
- Gear Superfinishing, The State of the Art, Part II
- Reducing Tooth Profile Error by Finish Roll Forming

FEATURES

- Gear Expo Pre-Show Coverage
- The Outlook for Gear Manufacturing
- Influence of Case Depth in Carburized Gears
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THE GEAR INDUSTRY'S INFORMATION SOURCE

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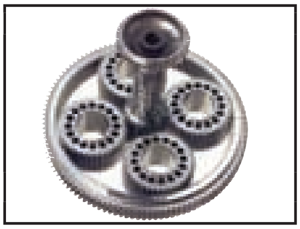

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GEAR TECHNOLOGY

The Journal of Gear Manufacturing

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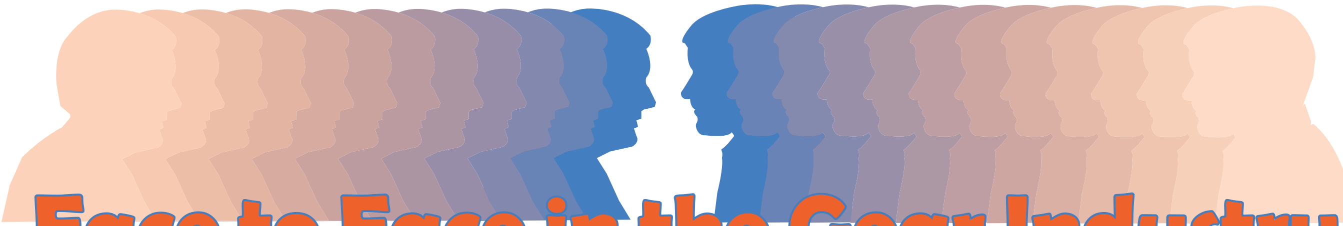


Face to Face in the Gear Industry

Nothing beats the power of a face-to-face meeting.

Recently the city of London was elected to host the 2012 summer Olympics, after a competition that came down to two fierce competitors, London and Paris. For many weeks, it seemed, Paris had the upper hand, but in the end, London won out, largely due to the efforts of Britain's prime minister, Tony Blair.

In the closing days before the decision by the International Olympic Committe, Blair jumped on a plane and headed to Singapore—despite the fact that he was hosting the important G8 summit the following week in Gleneagles, Scotland. According to reports, Blair met with 25 members of the IOC in those waning days, one right after the other, charming them, schmoozing them, lobbying his case.

Many observers, as well as members of the IOC quoted in the press, attributed London's success in large part to Blair's last-minute campaign. The personal face time paid off.

In today's impersonal age of e-mail and text messaging, it's easy to forget how important face-to-face meetings can be, even on a much smaller scale—say, the everyday goings-on of the gear industry.

We all interact with others in the industry. Often, the things you learn in a face-to-face conversation would never come out over the phone or by e-mail. In addition, such a meeting often pays dividends well into the future, as you become a face and an individual—rather than just a name and a title—to the person you're doing business with.

With Gear Expo coming October 16–19, we all have a tremendous opportunity to meet face-to-face with suppliers, customers and colleagues.

Many of you who make gears for a living are now extremely busy. Some of you are even scrambling for capacity. Maybe a little face-to-face time with the sales and technical experts might get your machine tool delivery bumped up the schedule, or maybe you'll at least gain insight about when you can really expect delivery and be able to plan accordingly. The people with the answers will be at Gear Expo.

Maybe you've been making gears the same way for a long time and you need a better understanding of competitive processes. The people with the answers will be at Gear Expo.

Maybe talking over your problems and opportunities with suppliers will provide you with solutions you hadn't thought of. Different tools, different processes, even other potential suppliers. The people with the answers will be at Gear Expo.

If it's answers you're looking for, Gear Expo is the place—even if you don't yet know all the questions you should be asking. I've always described this show as the greatest collection of gear knowledge available all at one time, in one place.

This year, the show's organizers have made some changes to provide even more learning opportunities for visitors. For example, the AGMA Fall Technical Meeting is running concurrently with the show, with more gear-related technical presentations than ever before. Also, three separate sessions of the classroom portion of AGMA's gear school will be held during show hours. Rounding things out will be seminars hosted by the American Bearing Manufacturers Association, the Forging Industry Association and SME, as well as a Solutions Center, where many exhibitors will give presentations on topics related to their expertise.

In addition, Gear Expo will have a wide variety of exhibits, including suppliers of machine tools, cutting tools, materials, inspection equipment, software and much more, as well as providers of services like machine tool rebuilding, coatings and heat treating. Those of you who outsource gears will find a good selection of exhibits featuring leading gear manufacturers as well.

Many of the most important faces of the gear industry will be in Detroit this October. Will one of them be yours? Gear Expo provides many opportunities, but you can't take advantage of them unless you go.

A lot can be accomplished in just a couple of days—just ask Tony Blair. I'm not suggesting that every trip to Gear Expo will result in benefits to your organization of Olympic proportions, but I'm confident there are many victories to be won for those who come to the show.

See you in Detroit.

P.S. For more information about Gear Expo, turn to page 18 or visit *www.gearexpo.com*.

Michael Goldstein, Publisher & Editor-in-Chief

Reishauer's RZ150 Speeds Up Production

Bob Sakuta, president and owner of Delta Research in Livonia, MI, runs one of the world's most highly advanced gear manufacturing cells.

"We're making these gears with total automation," Sakuta says. "They come out of the cell without a person ever touching them."

The cell includes the complete manufacturing process: hobbing, grinding, roll testing, deburring, rustproofing, washing and turning.

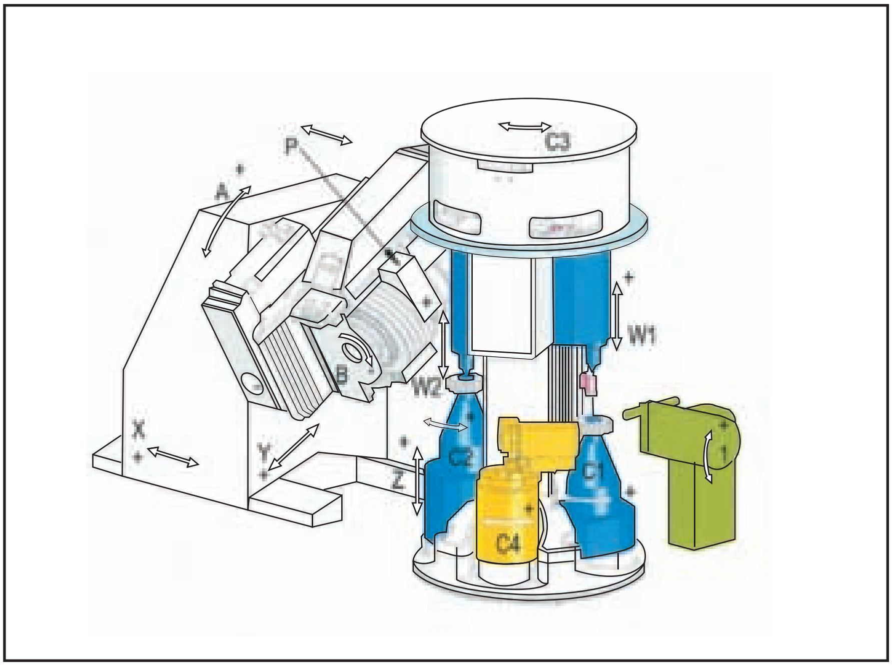
The cell produces left- and right-hand versions of a helical gear for automotive use—at the rate of 750,000 pieces per year. The company runs the cell for one manned shift during the day and, on average, 1.5 unmanned shifts after hours. Its high-tech features include the ability to contact an operator on call during the unmanned shifts.

At the heart of the cell is the RZ150, the newest model gear grinding machine from Reishauer, which was designed from the ground up to reduce cycle time while maintaining the highest levels of quality.

The RZ150 comes equipped with some features that make it especially well suited for high-level production. The most obvious of those features is the machine's dual-spindle design.

"As we're grinding one part, the second spindle is being loaded," says Sakuta. "You have almost no load time. That's the biggest advantage."

"The double spindle is, for us, revolutionary," says Laslo Ferenz, senior project engineer at the Vehcom Manufacturing division of Linamar Corp. in Guelph, Ontario. His company uses the RZ150 to grind transfer shafts for a Big Three customer. "With other machines, you have just one spindle, and you're losing time in the loading and unloading. So here, there's no additional cycle time required for loading and unloading."



The dual-spindle design of the Reishauer RZ150 allows one part to be loaded (C1) while another is being ground (C2), reducing cycle time.

For most workpieces, the part changeover time is about four seconds, says Dennis Richmond, vice president of Reishauer Corp. of Elgin, IL. He adds that the machine shaves cycle time in other areas as well.

For example, while one part is being ground, the next workpiece is pre-synchronized to the thread in the grinding wheel. This helps minimize idle time during the grinding portion of the cycle, Richmond says. And in a high-production environment, every bit of cycle time is precious.

Another key advantage of the machine is its small footprint, Richmond says. The machine itself, not including the coolant system, takes up just 54 square feet of shop floor space. For companies that use a central coolant system, such as Vehcom Manufacturing, that means the RZ150 takes up "about as much space as a small milling machine," Ferenz says.

But even when the machine is equipped with a material handling system and coolant/filtration system, the footprint is just 15 x 20 feet.

The RZ150 takes up just 54 square feet of floor space.

The RZ150 can grind parts with the following specifications:

- OD of 20–150 mm
- Gear face width up to 50 mm
- Shafts up to 350 mm (with the optional tailstock)
- Pitch rating of 1–3 module
- Helix angles to +/– 40º
- Grinding wheel diameter 206–275 mm
- Grinding wheel width up to 125 mm

Like all Reishauer machines, the RZ150 uses the continuous generation method of grinding (similar to hobbing in principle) and employs a threaded wheel. To maximize the productivity, many manufacturers use a multi-start grinding wheel on the machine. The machine at Delta Research is equipped with five-start grinding wheels, for example.

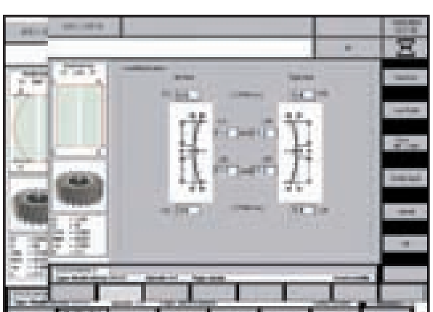
The machine's dressing unit is located on the turret assembly, rotating along with the two work spindles. Alignment of the dressing tools to the thread on the grinding wheel is facilitated by the use of acoustic sensing devices and is completely automatic, Richmond says. This automatic alignment helps assure fast and accurate positioning, eliminates the possibility of damage to the tool and helps extend the life of the diamond tool, he adds.

The machine's automatic stock-dividing sensor ensures a precise mesh for the subsequent grinding operation. Located outside the working area near the second spindle's loading position, this sensor determines the required tooth width and tooth gap for all teeth to be ground and determines the corresponding angular position for best fit of workpiece in relation to the grinding worm thread, Richmond says. Also, the system provides an added safety feature. Because it counts the teeth and determines whether the tooth widths are in the right range, the machine knows if an incorrect workpiece has been loaded and can reject that part.

The RZ150 includes 12 numerically controlled axes, most of which are equipped with absolute encoders. This results in fewer reference movements at machine startup, Richmond says. The encoders also tie in with the machine's Siemens 840 D CNC control system, which continuously monitors NC axes to prevent potentially dangerous movement in the case of hardware or software failure.

Another special control feature is the electronic gearboxes. Developed by Reishauer, these devices synchronize the independent work spindle axes to the corresponding master axis. The EGB module runs on its own computer system, but it is embedded in the Siemens control system.

The RZ150's machine interface allows the entering of all necessary data from a gear blueprint. A wide range of



Users can enter gear parameters via the RZ150's interface.

modifications is possible via the data input screen, and separate screens are available for tooth modifications and tooth corrections. Small deviations to the gear flank form can be corrected via program input without changing the original gear modification data. When the data has been entered, a graphic representation appears on the screen, which allows the operator to visually check whether the input data is correct. This allows the operator to evaluate the topology of a gear flank, Richmond says.

With all these features, though, "It takes a high-level skilled operator to make this thing sing," Sakuta says.

But, he adds, this is not a problem at Delta Research. Even a highly skilled employee is worth the price when considering that it takes just three operators to run the cell and produce 750,000 parts per year.

Also, Sakuta says, the maintenance staff has to pay special attention to the machine's paper bag filtration system. Because of the high volume of gears being ground, the system can fill up quickly with sludge and therefore has to be monitored.

But what matters most to these manufacturers is the reduced cycle times and high throughput that this machine allows.

At Vehcom Manufacturing, the grinding cycle time on the RZ150 is 25–30 seconds. "The machine is very, very fast," says Ferenz.

Sakuta's parts are also being ground in less than 30 seconds. "There was nothing like it at the time for the throughput. If you had shown me this gear five years ago and said, can you grind the teeth in 30 seconds, I would have laughed at you. Today, this machine spits these things out, one right after the other."

The speed is essential to Delta Research. Its customer wants even more parts next year. Sakuta already has another RZ150 on order.

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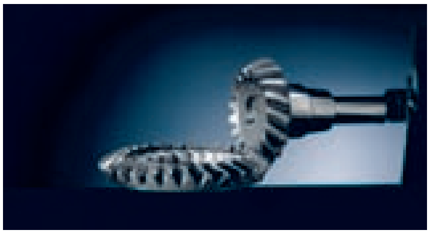

Balzers Introduces Self-Supporting Diamond-Like Carbon Coatings

Balzers AG has created a new PVD coating system designed to permit greater load bearing capacity than its conventional diamond-like carbon coatings.

The coatings are suitable for engine components, high-pressure pump parts and other highly loaded tribological applications. They can also be applied to components made of softer materials that are used in food processing machinery, for medical components and in the aerospace industry.

Balzers developed the coatings to be self-supporting, so they could be used on materials that aren't self-supporting and that tend to have an "egg-shell" effect. These materials have low hardnesses and lack adequate support when placed under high surface pressure. They include metal alloys, stainless steel, and lightweight materials.

"We are able to coat softer substrate material," says Raphael Mertens, Balzers' project manager–R&D for coated components in Liechtenstein.

According to Balzers, its STAR coatings include a hard, tough, metal-based layer of chromium nitride, providing surface hardness and support (load bearing capacity) for the superposed carbon coating. The company adds that the layer also improves the fatigue and corrosion resistance of its parts—and provides good wear resistance under emergency running conditions.

Balzers describes the new coatings as having "superior tribological arrangements," so it calls them STAR coatings. The coatings, BALINIT DLC STAR and C STAR are both modified diamond-like carbon coatings with enhanced load bearing capacity. Also, a special DLC-R coating was designed for superior running-in performance.

DLC-R's extra feature comes from a film of softer carbon. According to

Balzers, the film doesn't affect a coated part's wear resistance, but it eliminates wear on the mating part, especially during the running-in phase.

DLC STAR was designed for heavy-duty valve train components, piston assembly parts and sliding bearings that run against hard surfaces.

The STAR coatings, each with more than two functional layers, can be applied directly onto bronze, steel, case-hardened steel or nitrided steel. Moreover, Mertens says the layers can be applied in one step in a Balzers' coating chamber. Gears wouldn't have to be removed from the chamber during vacuum processing. They wouldn't be exposed to outside air, where they might oxide, damaging the coating.

"We think, especially for gears, this is a very important thing," Mertens says.

Also, the C STAR coating was tested for scuffing resistance at the Technical University of Munich by the Gear Research Centre (FZG). Mertens describes the test conditions and results. The test was conducted on an A-type gear using an FZG test rig and, for comparison, included runs for an uncoated gear and a gear with a regular carbon coating. All the test gears were made of 20MnCr5, case-hardened to 60–62 HRc, and were run with RL 144, a Coordinating European Council reference oil, a mineral oil with no additives.

The runs were conducted with a pinion speed of 2,250 rpm, a pitch-line velocity of 8.3 m/s, an oil temperature of 90°C, and with torques ranging from 3.3 Nm to 714.2 Nm. The test was designed to run the gears through stage 14, with each stage lasting 15 minutes.

The uncoated gear failed in stage 6. The regular carbon-coated gear lasted through stage 12, then started to scuff in stage 13. Mertens says the gear coated with C STAR didn't fail, and it was run through stage 14: "This coating didn't show any scuffing."

Balzers has applied the STAR coatings to the gears of gear manufacturing and automotive companies. The cost to apply a STAR coating to a gear varies depending on its type and size, but Mertens estimates the cost at $10–$50 for common gear geometries in low quantities.

The coatings can be applied at five Balzers sites in Germany, Japan, Liechtenstein, the United States and the United Kingdom.

Balzers created the STAR coatings at the request of customers, mainly automotive racing customers. Appropriately, the company introduced the STAR coatings at a motorsport show, Autosport International, in January in the U.K. Three months later, Balzers introduced the coatings to the U.S. market.

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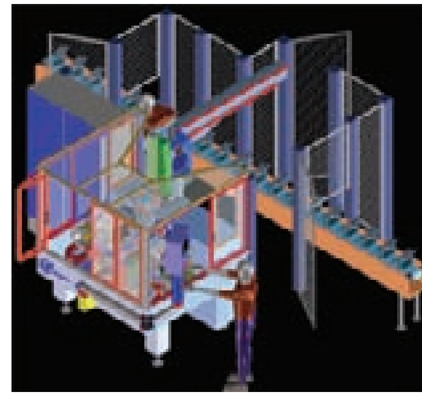
Internet: ***www.bus.balzers.com***

New Chamfer/Deburring Machines from Star SU

The S250CD, S250CDA and S250CDX chamfer/deburring machines from Star SU replace the older SCT and SM series in the U.S. market. A new CDM version integrates with the S150–S300 hobbing series to offer a fully automated hobber-chamfer/deburr machine



as a standalone product for performing all three operations with one unit.

The S250CD is the basic version and operates as a standalone for flexible small and medium lot sizes with manual loading only.

The S250CDA is a standalone machine for production with automatic loading by an integrated gantry loader.

The S250CDX is designed for simultaneous or consecutive chamfering/deburring of shafts with a maximum of five different gears, or a family of different ring gears and pinions that have a common clamping system.

The CDM is a chamfer/deburr unit that can be completely integrated into a hobbing machine to provide mass production solutions.

For more information:
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5200 Prairie Stone Pkwy., Suite 100
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Internet: ***www.star-su.com***

New Process Monitoring System from Marposs

A new tool and process monitoring system from Marposs is designed to provide continuous monitoring of metalworking processes through several different types of sensors that enable control of various machine functions, thus allowing cycle optimization as well a reduction of

scrap and machine downtime.

According to the company's press release, five products are utilized for monitoring. A vibration monitor analyzes vibrations in rotating devices, such as machine tool spindles, to permit the highest possible tool revolutions.

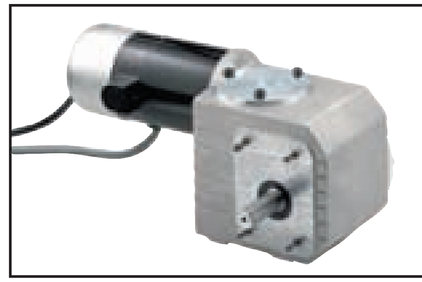
A force monitor is included for the direct and reliable identification and control of the strain and forces acting on the tool to optimize the cutting parameters and production cycles. A power monitor exists for controlling the variations in the cutting process through continuous and absolute surveillance of power absorbed by the machine's axis or spindles. A displacement monitor measures distances in high resolution using wear-free, non-contact sensors for applications such as automatic compensation for thermal drift. Temperature monitors sense temperatures in critical machine tool sub-systems such as near-moving components, like axes, gears and spindles.

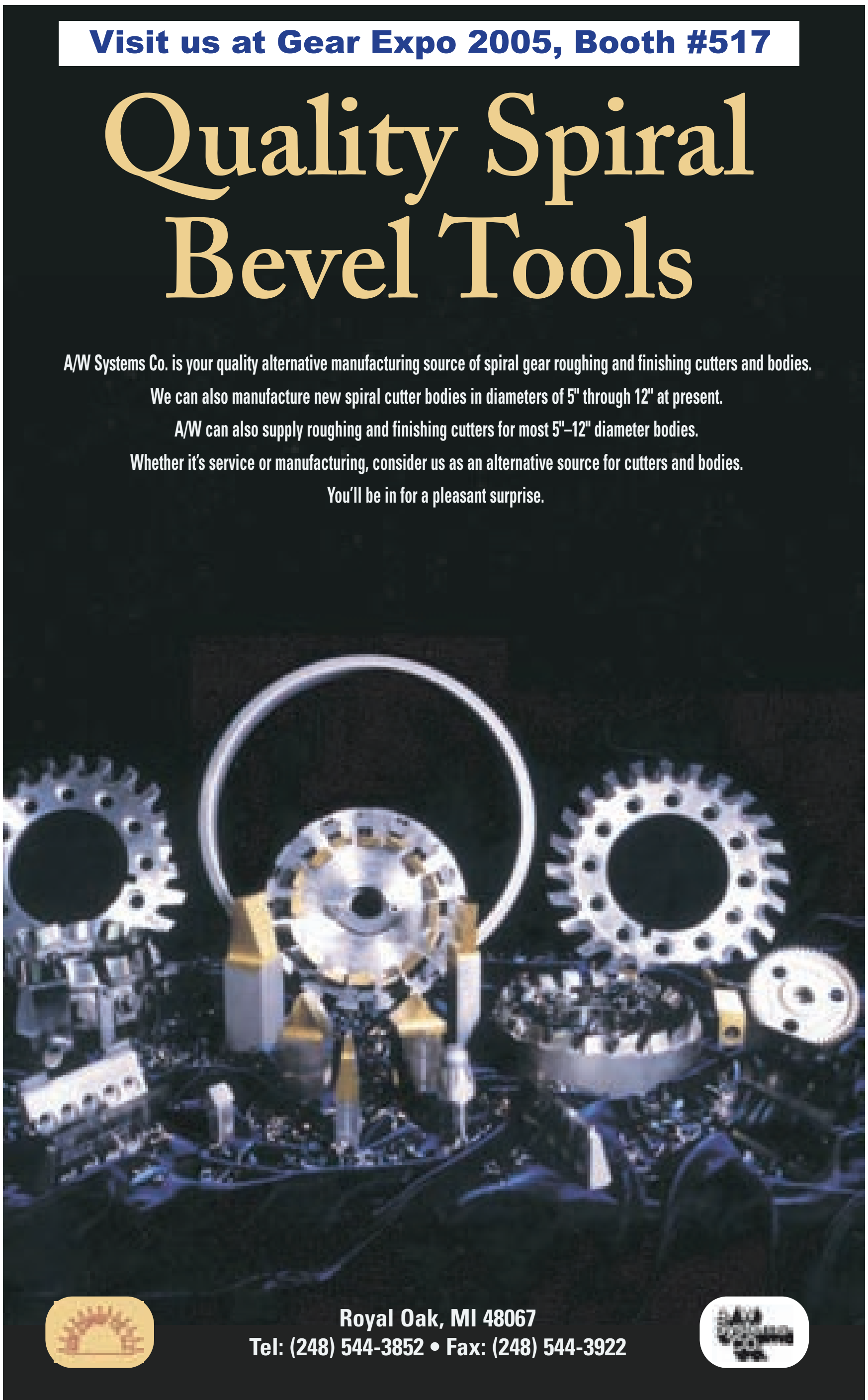
For more information:
Marposs Corp.
3300 Cross Creek Pkwy.
Auburn Hills, MI 48326
Phone: (248) 370-0404
Fax: (248) 370-0991
Internet: ***www.marposs-us.com.***

New Double Reduction Gearmotors from Bodine

The new Type 3RD gearmotors from Bodine Electric are designed for applications requiring slow rotation and high torque, like conveyor systems, food processing and medical equipment and factory automation.

Gearmotors are available with the company's 30R AC, 24A DC and 22B brushless DC motors. The double reduction design provides gear ratios from 80:1 up to 3,600:1, allowing a relatively small motor to produce up to 150 lb.-in. of torque, according to the company's press release. Gearheads are offered with





outputs ranging from 0.5–3.1 rpm. The 3RD models are unvented with bronze and hardened steel worm gears, and gearmotors carry various built-to-order shaft options including single, double or hollow-shaft configurations.

In addition, the gearmotors can be face-mounted on the drive-shaft side, the side opposite the driveshaft, or from the bottom of the gearhead.

For more information:
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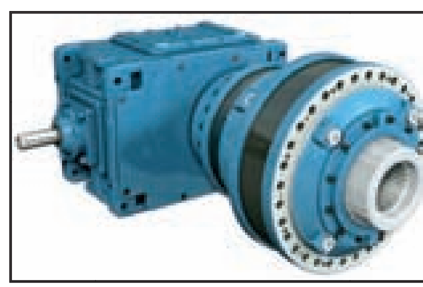
2500 W. Bradley Pl.
Chicago, IL 60618
Phone: (773) 478-3515
Fax: (773) 478-3232
Internet: ***www.bodine-electric.com***



New Power Transmission Package from Brevini

The new High Power Series from Brevini combines the gear design of the S Series planetary gearboxes with modular features of the PIV POSIRED 2 family of helical and bevel-helical gearboxes.

According to the company's press release, the combination of the planetary and bevel/helical technology provides effective cooling and the ability to overcome problems of increased power losses.

Additional features include five harmonically-developed sizes, nominal torque for 37,000–370,000 N-m, transmission ratios of 100–670, and nominal power from 160–950 kW.

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Phone: +(39) 0522-9281
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E-mail: ***info@brevini.it***
Internet: ***www.brevini.com***

New Tool Chuck from Hydra-Lock

The diamond OD tool chucks from Hydra-Lock Corp. increase performance without vibration and chatter.

According to the company's press release, a built-in hydraulic holder has a dampening effect that allows for quick tool changes while eliminating vibration and chatter.

The tool incorporates several diamond cutters on the outside diameter while precisely locating a diamond-chipped tool with the hydraulic chuck. All of the tool holders are precision balanced.

For more information:
Hydra-Lock
25000 Joy Blvd.
Mt. Clemens, MI 48043
Phone: (810) 783-5007
Fax: (586) 783-7576
E-mail: ***weholdit@hydralock.com***
Internet: ***www.hydra-lock.com***

New Gear Lubricant from Klüber

The Klübertop P 39-462 spray from Klüber Lubrication facilitates the adjustment of load-bearing patterns in gears and is resistant to synthetic lubricants.

According to the company's press release, the air drying inspection paint for load bearing patterns provides a contrast to the gear surfaces. Its good adhesion enables inspection in the –40° to +200°C temperature range over longer periods.

For more information:
Klüber Lubrication
32 Industrial Dr.
Londonderry, NH
Phone: (603) 647-4104
Fax: (603) 647-4105
Internet: ***www.klueber.com***

New CNC Honing System from Micromatic Textron

The Microhone CNC tooling and abrasive system from Micromatic Textron is designed to operate as a conventional honing machine in a flexible manufacturing environment.

According to the company's press release, the Microhone was designed for use with CNC machining centers to allow the manufactured part to remain in place throughout the various tool changes.

For more information:
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GEAR 2005 EXPO

DETROIT, MICHIGAN

Gear Expo 2005—The Worldwide Gear Industry Event

October 16–19, 2005

Cobo Conference/Exhibition Center

1 Washington Blvd., Detroit, MI 48226

As always, Gear Expo will be the only chance in two years for much of the industry to meet face-to-face, but this year the American Gear Manufacturers Association is emphasizing the educational component of the event.

New content for 2005 includes the Gear Expo Solutions Center, an on-floor educational exhibit where companies can give 20-minute presentations that are free to attendees. As of July 8, 26 companies had reserved time to promote the latest in equipment, processes and technology in gear manufacturing.

AGMA is sponsoring other training opportunities at the Cobo Center as well. The classroom portion of the Basic Gear Training Course will be led by Ron Green of The Gear Consulting Group. Half-day courses will be offered from Oct. 16–18. It includes standards; nomenclature; gear involute geometry; inspection procedures and interpretation of results; manufacturing processes, including hobbing, shaping and shaving; troubleshooting the gear manufacturing process; improvements in productivity; and discussion of common problems.

Other associations are getting in the education game as well, appealing to both gear manufacturers and those in related industries.

The Forging Industry Association and Forging Defense Manufacturing Consortium will hold a seminar titled "Gear Forging Solutions–Simulation and Rapid Tooling." A segment of the program will cover a rapid tooling process, including its capabilities, applications and benefits.

Also, the American Bearing Manufacturers Association, along with NSK and SKF, is scheduled to hold a primer seminar titled "Why Bearings Fail." End users and OEMs will provide insight on bearing design, features and proper bearing application.

Finally, the Society of Manufacturing Engineers will hold three seminars, as it has every Gear Expo for the past decade. The first is titled "Understanding Gear Metrology & Inspection" and focuses on those metrology issues unique to the gear industry.

On Tuesday, Oct. 18, the SME seminar on "Effective Heat Treating and Hardening of Gears" will include speeches on evaluating alternative heat treating methods and controlling the process.

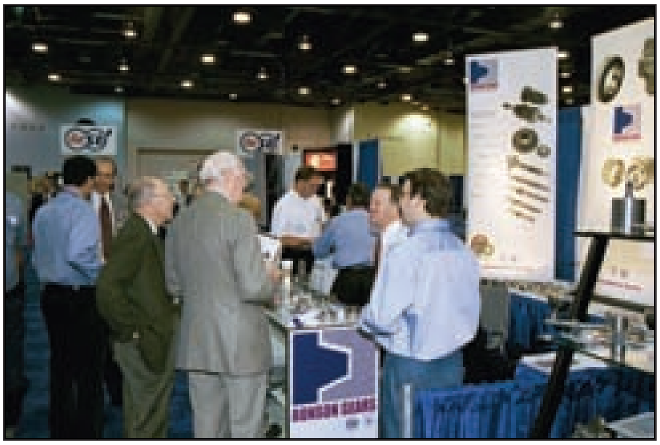
The following day, SME will introduce a discussion on "Advanced Gear Processing and Manufacturing." Participants will discuss the investigation of chronic problems, factors that impact tool life and performance, as well as compare the latest technologies.

Specific times, locations, dates and prices of seminars will be available at *www.gearexpo.com* as Gear Expo nears.

For those who also want the personal interaction of a trade show, Gear Expo 2005 promises not to disappoint. According to Kurt Medert, AGMA vice president–business management division, the figures are adding up. In 2003, there were 152 companies exhibiting at the show. As of July 8, 2005, already 148 companies had made deposits guaranteeing booth space.

"Our goal for 2005 is to get 175 exhibitors," he says. "The economy is good and people are busy, so we are very optimistic."

The registration fee for Gear Expo is $15 through September 30. After that date, registration is on-site and costs $30. For more information, visit *www.gearexpo.com.*



AGMA's Fall Technical Meeting Beefs Up Programming

This year's AGMA Fall Technical Meeting, which will be held Oct. 16–18 in conjunction with Gear Expo at Detroit's Cobo Center, will have a record-breaking 21 presentations.

Bill Bradley, vice president of AGMA's technical division, says that this year's format has been adjusted to accommodate the increased number of presentations. In previous years, the Fall Technical Meeting has consisted of four sessions with four to five papers each. In 2005, each of the four sessions will cover five to six topics. In addition, the first session will be held Sunday, Oct. 16 to allow time on Monday for visiting the exhibition floor.

The exact content of each technical session is yet to be determined, but is tentatively arranged as:

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.

"The Development of a Three Disc Micropitting Test Method" by M.G. Talks.

"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 Gears" by H. Xu, A. Kahraman and D.R. Houser.

"Spiral Bevel and Hypoid Gear Cutting Update" by T.J. 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.

"Hypoid Gear Lapping Wear Coefficient and Simulation" by C. Gosselin and Q. Jiang.

Special presentation of the new AGMA bevel gear rating suite by the AGMA Computer Software Committee at the end of Session II.

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 Anaysis 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.

"Determining the Shaper Cut Helical Gear Fillet Profile" by G. 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.

"The Application of Very Large, Weld Fabricated, Carburized, Hardened and Hard Finishing Advanced Technology Gears in Steel Mill Gear Drives" by R. Drago.

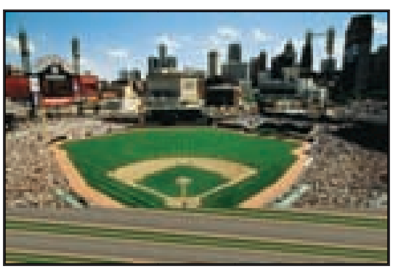
"Planet Pac: Increasing Epicyclic Power Density and Performance Through Integration" by D. Lucas.

"Analysis of a Dual Drive Conveyor Failure" by M. Konruff.

The registration fee for the Fall Technical Meeting is $525 for AGMA members and $795 for non-members. For additional registration information, contact the AGMA by telephone at (703) 684-0211 or on the Internet at *www.agma.org*.

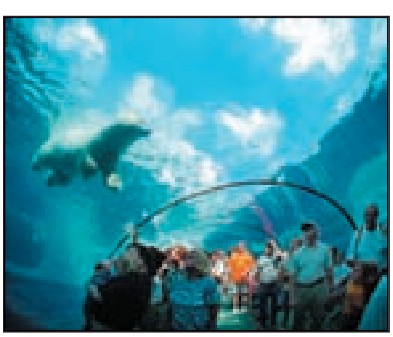
DETROIT Michigan

A Model T accelerates through Greenfield Village. Credit: The Henry Ford.



Comerica Park welcomes the All-Star game. Credit: Vito Palmisano.

A good investment for show-based Commissions. Credit: DMCVB.



The underwater Polar Passage. Credit: Vito Palmisano.

"**The World is Coming**" is plastered on billboards throughout downtown Detroit, and that's never been more true than in the next six months—when thousands of sports fans will descend on the town for Major League Baseball's All Star Game and the NFL's Super Bowl XL. Another important group to hit the new Northwest terminal at Detroit's Metro Airport? The gear manufacturing community!

The face of downtown Detroit has changed since Gear Expo 2001. Notably, a $500 million redevelopment of the GM headquarters at the Renaissance Center (200 Renaissance Center) is now complete. The Marriott Renaissance Center, an AGMA-approved hotel for Gear Expo, is situated in Michigan's tallest structure and opens up to an unobstructed view of the Detroit River. The lower levels of the Renaissance Center include a vehicle center housing 35 GM production or vintage vehicles. The electric-powered cars on the floor can make for great conversation tidbits on the Cobo Center floor or at the Renaissance Center's Coach Insignia restaurant. It's worth a trip to the 72nd floor just to hop on the famous Lily Tomlin (Detroit native) chairs or check out the GM logo that actually stretches more than 20 stories high.

While sipping martinis or swishing wine at the Coach Insignia's lounge, visitors are treated to an uncompromised view of Casino Windsor, located just across the river. This year, gamblers don't need passports to play the slots. The MGM Casino, MotorCity Casino and Greektown are all Las Vegas-sized and bustling with activity at any hour.

Greektown Casino (555 E. Lafayette Ave.) houses Detroit's only blackjack room—perfect for company bonding at the tables. When you cash in your winnings, stop for some saganaki in one of Detroit's most vibrant neighborhoods.

Family-friendly entertainment options are available as well. The Henry Ford Museum (20900 Oakwood Blvd., Dearborn) is home to the vehicle in which JFK took his last ride, as well as the famous Rosa Parks bus.

The Ford Rouge Factory Tour is housed within The Henry Ford Museum and debuted to the public in May 2004.

Visitors take a walkway to the Ford F-150 truck assembly plant for a panoramic view of the 2-million-square-foot facility. Approximately one-third of a mile through the plant, visitors can see key points in the final assembly process. The Legacy Lobby houses a 1929 Ford Model A Roadster, a 1932 Ford V8 Victoria, a 1949 Ford Club Coupe, a 1956 Thunderbird and a 1965 Mustang.

In that same vein, the Detroit Historical Society (5401 Woodward Ave.) contains a car body slowly dropping on the assembly line, using the actual machinery from the Clark St. Cadillac plant. Accompanying exhibits break down each Detroit community's unique contribution to 100 area automobile companies.

Mexican muralist Diego Rivera expanded on life at the Rouge plant in his 1932 fresco that occupies two entire walls at the Detroit Institute of Arts (5200 Woodward Ave.). The mural was commissioned by the Ford Motor Co. and Edsel Ford, president of the Arts Commission, to provide a glimpse into the daily production and manufacturing operations for the 1932 Ford V8.

No doubt, Gear Expo will be time-consuming, but dozens of additional entertainment options exist beyond the boundaries of the exhibition hall. For more information, visit *www.visitdetroit.com*.

Where the Gear Industry Sleeps

**To receive the negotiated group rate, all hotel reservations must be made by September 26, 2005.*

- Detroit Marriott Renaissance Center—$149/night. Reservations: (313) 568-8000 or (800) 352-0831. AGMA discount code: gexgexa. Three blocks from the Cobo Center with indoor access to the People Mover.
- Detroit Downtown Courtyard by Marriott—$139/night. Reservations: (313) 222-7700 or (800) 321-2211. AGMA discount code: AGMAGMA. Located across the street from the Detroit Marriott Renaissance Center and complex. Indoor access to the People Mover. Room renovations currently underway.
- Hotel Pontchartrain—$129/night. Reservations: (313) 965-0200. AGMA discount code: AMGEA. Located directly across the street from the Cobo Center. Guest rooms, common areas, lobby currently under renovation.
- Holiday Inn Express Hotel & Suites—$109/night. Reservations: (313) 877-7000 or (800) HOLIDAY. AGMA discount code: AGM. Located within two blocks from the Cobo Center and a half block from the People Mover. Renovation completed in 2003.

Room reservations can also be made at *www.gearexpo.com.*

The Outlook for Gear Manufacturing

A European Perspective

Hagen H. Hofmann

Hagen Hofmann, *president of Höfler GmbH, the German manufacturer of gear grinding machines, presents his views on global trade, competition and the future of the gear industry.*

In the coming years, we will be faced with increased competition from all over the world. Modern, fast communication systems will increase the pace even more. Global trade invites nations with hungry people to participate in the market, and they are willing to work for any price. Because we are not able to compete with these wages and other price-reducing factors, we must find solutions to maintain our market share and even to increase it, although it would sometimes be better if we changed our traditional businesses completely and became more specialized.

Global Trade

Global trade does not always work in our interest. We cannot depend on the loyalty of our regular customers anymore, who in many cases seek cheaper suppliers on the Internet and purchase gears in online auctions. All of a sudden, many of us are in a situation we had never even thought of.

But it's not the first time something like this has happened. From my own experience, I would like to tell you how my company reacted in a similar situation and what we did to solve the problem.

Höfler has manufactured gear grinding machines since 1966. With the exception of minor improvements, the first design was sold worldwide from 1966 until 1981 almost unchanged. For 15 years, the machines had the same grinding time, the same achievable accuracy, and the same complicated setup. We weren't the only ones who did it like that; it was no different at our competitors. We all slept innocent, with no reason to bother about improvements and higher performance. We all had our customers and market shares, almost without competition.

The bitter wake up came, absolutely unexpected, when the Iron Curtain got holes in it. The Berlin Wall collapsed and communism lost its power over Eastern Europe. Almost everything changed overnight.

The Eastern Bloc stopped buying machines. Germany lost more than 30% of its machine tool export markets. Many companies went broke or out of business, including famous names. Our main East German competitor was all of a sudden a Western company, which received tremendous government support to


restructure and to invest.

And yet, this threat was exactly what the company needed to wake up—to stand up and fight for survival—for the first time in our history.

And it was not only us. Our longtime customers called and asked if we could help them, because they were not able to compete against companies from Poland, Czechoslovakia and East Germany selling in their traditional markets.

Those eastern companies had the same slow machines, but their operating costs were low, with wages being a fraction of ours. The challenge for us was to survive together with our longtime customers.

Many gear grinding machines were installed in companies all over the former Eastern Bloc. Those companies were seeking work because their markets, mostly Russian, were gone, too. They had the advantages of cheap labor, machines that were long written off, and governments helping their clientele to accept orders below cost.

There was only one way for us to survive: Develop faster and less expensive machines—machines our customers would buy in order to stay in business.

We had to redesign our complete manufacturing program and to build completely new and different machines, without compromise, in the shortest possible time. Those machines had to be less expensive to buy, yet run faster and more economically than all the machines we had ever built before.

From the beginning, it was evident that we had to design everything differently from those expensive machines that were already available on the market. We used mineral cast material for the heavy machine parts instead of cast iron, which made us independent from steel prices and lowered machining cost, besides other technical advantages.

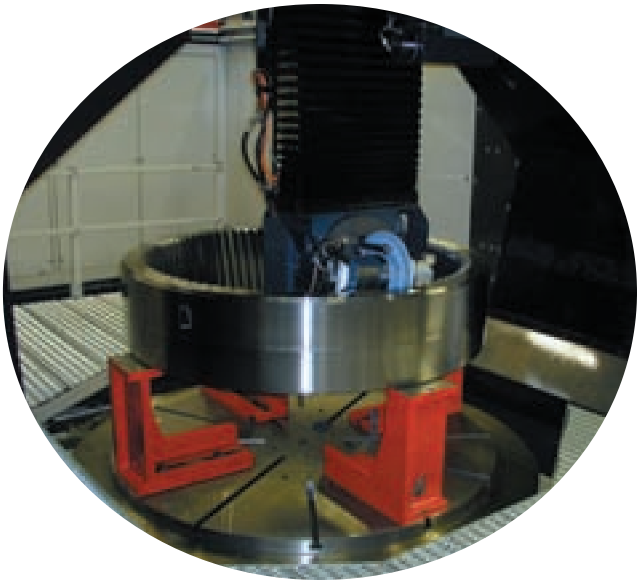
We replaced the expensive worm and worm gear drives in machine tables with much better and more accurate direct drives. We standardized components to use them in many different machine sizes, and so on.

Believe it or not, today, a 48" grinder costs about half what it cost only three to four years ago. And it is a lot better and more universal-to-use machine.

With these new machines being more than five times faster, labor cost all of a sudden was no longer an issue. Our customers were back in business.

The problems for our customers were solved, but only for those who invested in new equipment. All others continue to compete with their slow, outdated equipment, battling rising labor costs—in my opinion, without a future. These machines might earn the salaries of the operators but will not contribute a single dollar for new equipment.

In the meantime, the equipment that former Eastern Bloc competitors brought into the market is now more than 15 years old and ready to be replaced, if the funding is available. Mostly, it is not. Their wages are rising faster than ours. Soon, the difference will be insignificant. The danger is over.



But many of us now are concerned with new foreign competitors, not just in our own backyards, but around the world.

China: Opportunity and Threat

I have visited China and Korea on a regular basis since 1974—30 years—on average three times a year. After my first visits to China, I was largely convinced, especially with its communist regime, that China would need a long, long time to become an industrialized nation, being too far behind to keep up with our technology. I've had to change my mind in the last three to five years. One can witness almost daily how fast things happen.

Last year, I visited a brand new company built and getting ready to compete with the biggest German gearmotor manufacturer. A 140,000-square-foot manufacturing building under one roof was waiting to be furnished with modern machine tools. Some of them had already arrived and were being installed. The office building was extremely representative, made from granite and marble, and it was equipped with modern furniture and electronic communicating systems. Once fully operative, the company will employ more than 500 workers, with a minimum of research and development, marketing and labor costs.

The company pays wages amounting to $160–$180 per month, which is roughly $1 per hour. This is about one-twentieth of what we have to pay our workers in Germany even before all the social and tax costs.

With one-twentieth of the cost per worker, guess who will make more money, the original or the Chinese copy?

This is hard to beat. The original has only one choice if it wants to stay in business in Asia: Go there and start a business, too, which the company did.

Because of their expected limited quality, those copied motor drives will—in the beginning—probably be sold in Asia only.

They surely won't come to Europe. But they ruin the market in Asia for the original. A well-known company, with an already existing export market, may want to live with this competition or go into the lion's cage as well, to beat the competition with their best weapon—the wages. And indeed, fact is, more and more companies go to Asia to produce there, to participate in the incredibly fast growing market. And there is nothing wrong with it. Our automobile companies, for instance, have done the same for a long time already without selling one car fewer made in their homelands.

But who of us can go to China?

The answer is very, very few.

And we cannot produce gears in China and tell our German customers they are made in Germany.

We cannot buy open gearing there and only put them together here. What if those gears are not of the expected quality? Would you want to discuss warranty questions in Mandarin with your Chinese supplier, over thousands of miles?

Would you like to go to court with a Chinese company in case they delivered substandard gears? How about liability?

Would you want to check thoroughly the gears you receive and maybe have to rework them? Your calculated profit would be gone.

No, this is no solution for us.

I am strongly convinced that Chinese companies start looking for business in their own neighborhood, in Asia. This market is much bigger than we expected, and it's developing extremely fast. They will try to enter our markets only if the quality of their products is comparable with ours.

If this happens, we've done something wrong.

If we continue to struggle month after month to work for the paycheck only, instead of planning ahead, and to line up and strengthen our corporations to meet new competitors, we will have the same problem I had with my company 15 years ago. I woke up surrounded by enemies, and it was almost too late. The day they knock on our door and ask to come in will come sooner than we expect, so get prepared.

But couldn't that happen at home as well, with our next-door competitor?

European Perspective?

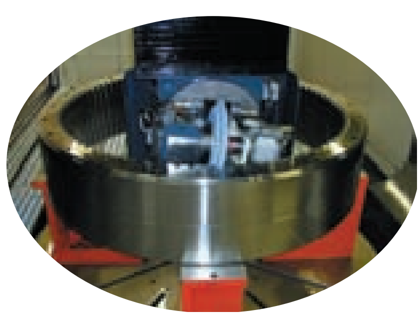
Although I don't believe Europeans have different strategies than Americans—we all want to survive and prosper—I do believe there is a remarkable difference between our industry in Europe, especially Germany, and the gear industry in the U.S.

We live much closer together. If you think you know all the German companies, you start learning about the Italian, Spanish, British and others. Every year, more nations join the European Community with all the advantages this huge market has to offer. And they all compete against each other. We communicate in so many different languages that we need to be very flexible. Try to sell a Frenchman a gear using the English language. Not only does he not understand, he simply does not want to understand. You have to talk to him in French. We export and import all the time and know foreign currencies as a very normal thing. I, for instance, live 10 miles from France and 120 miles from Switzerland.

We go to other countries for shopping, even for lunch and dinner. I grew up calculating exchange rates.

I believe Europeans have an advantage over the average American when it comes to international trade. If you are living so close to each other, you cannot survive not knowing your neighbor, not knowing your competitor. Knowing what he does is of substantial importance. But you do not want to copy; you want to differentiate, develop your own profile. You constantly have to be more inventive and you have to sell it harder with very good and proven facts. It is simply a matter of survival.

In this very competitive environment, profit margins are thin, unless you have something new to offer. Inventions, however, come seldom in the gear industry. We can state that gears have already been invented, just like the fork, knife or spoon. Everybody can make gears—if we speak about the normal gear. But, if we all use the same equipment, pay comparable wages, taxes, etc., and pay the same prices for steel, bearings and castings, where is the difference between one and the other company? Why do some do very well and others not?



There must be a difference. Or do some have better sales guys? I doubt it. It has to have something to do with the methods we use to make these gears and the grade of specialization some companies have developed.

Specialization

During the last 10–15 years, I have noticed in Germany a very strong trend towards specialization.

All the bigger companies reduced the number of their product lines and their activities. As an example, there is a big gear manufacturer where you once could order a single gear or a tailor-made gearbox. No longer. The organization has become so specialized, it cannot handle small orders anymore. By the time you would get a quote, a smaller company would already have shipped the product, and time is money.

Instead, the company now concentrates on making large numbers of wind power gearboxes in all sizes, especially big ones. Because this business is highly fluctuating, only 50% of the company's gears are made in-house. The rest is subcontracted, but only to those who can cope with the specs—and these are tight. In doing so, the company keeps its own equipment loaded over three shifts, and the risk of fluctuation is with the small suppliers, who can handle fluctuations much better.

These wind power gearboxes become bigger and bigger. Small companies cannot jump on this business because of the high investment cost for big production machines. Internal gear cutters and grinders, machining centers for planetary gear housings, test stands and so on are just too much for a smaller company. Today, the wind power manufacturers are highly specialized; they are a closed society. You will find this trend all over. Specialization warrants the optimum use of the equipment and perfects the product.

Wind Power

Often declared dead, wind power is as alive as ever. Being the second biggest steel consumer after the automobile industry, wind power has created numerous new jobs in all areas. The German gear industry, like no other, invested very early in the research and development of this technology. Fortunately the companies were able to start with small units in the beginning, gradually increasing the size to ever-higher kilowatt output. Five years ago, a 650-kilowatt unit was standard. Today we are building gearboxes for up to 5 megawatts of power. Internal, helical planetary ring gears with 100" in diameter are in sight.

Often erected close to housing areas, wind towers, which can be more than 300' high, have to run quietly and reliably. Correspondingly, the requirements for these gearboxes are high. Every manufacturer advertises his product with the argument of having quiet running gears. His secret is the know-how to get there. But one property they all have in common: The normal, unmodified gear tooth is history. Totally new tooth geometries were developed and optimized in practical tests. And good for us machine tool builders; they cannot be produced on old machines. Sub-suppliers to the wind power industry are accepted only if they have the know-how to grind all kinds of modifications without distortion. Also, after grinding, the gears must be nital etched for tooth burning—100%.

The Need for Education

For this very demanding new technology, we must realize how important it is to educate people on topics like gear noise, tooth load, surface finish and lubrication, just to name a few. And in this point I believe there is another difference between Europe—especially Germany—and the United States.

By tradition, German technical universities educate a high number of graduated mechanical engineers in a very practical way.

The industry offers apprentice training over a period of 3.5 years, normally for approximately 5% of the total number employed. This training might be complemented by further education up to various grades, including access to university studies. University and apprenticeship are cost-free to the student. The apprentice even gets a remarkable monthly payment. Unfortunately, it's still not enough.

The Outlook for Gear Manufacturing

In my opinion, there will always be gears—at least for a long, long time.

We will continue to increase their efficiency and life and try to produce perfect gear reducers needing as little maintenance as possible. Some gear applications will certainly be substituted by electrical or other alternative drives. Other applications will come into being (example: wind power).

The future of our gear industry, whether in Europe or the United States, also depends on our ability to comply with the ever-growing requirements and to accept new technologies. This won't be cheap. In fact, it will be almost impossible for the smaller companies. Education and science are prerequisite for our success. Furthermore, it will be necessary for companies to position themselves to use their best know-how, to specialize and find a niche where each one can run a profitable business.

This could be as a specialist in large series production or as a repair business with close customer contact. It does not matter what we do as long as we specialize instead of trying to dance at every party.

In any case, we need to be prepared for meeting new competitors. The good news is, new markets are also offering new opportunities for us. Three billion people who one day want to live like we do have all kinds of needs and desires. Great things can be achieved in the building of power plants and transport systems, the providing of health care and supplying of water. However, they will be able to pay for it only if they are allowed to sell their services to us. Headline: Global trade. In the beginning they pay for it with cheap labor, with manpower. Later on they will want to supply cheap mass products, including, possibly, gears.

Therefore many of our companies must get prepared for this new situation, and, if necessary, must change their manufacturing programs.

We cannot resist this pressure. We cannot withstand the attraction of low-cost products for a long time. Changes don't come easy. They are like big ships: You turn the steering wheel and nothing happens. The ship goes on straight. Only slowly will it change its direction. Therefore, if we accept what's happening, let's turn the wheel early enough to avoid any collision that could ruin our industry.

An earlier version of this article was presented at the 2004 AGMA Annual Meeting in Tucson, Arizona.

Opportunities for Gear Grinders—

Insights from the Machinery Front

Tom Lang, Vice President, Kapp Technologies

Tom Lang

Economic times have definitely turned the corner in our industry. Interest in gear-related products is soaring again. However, many large companies aren't as eager to spend their own capital on new machines as they once were. Our largest corporate customers are still purchasing equipment, but they are not buying enough equipment to manufacture 100 percent of their requirements. Instead, they are turning to smaller companies to do the work for them.

Outsourcing can be successful for several reasons. Many smaller companies have wanted to get into hard finishing gears, but with the uncertainty of sufficient business to justify large investments, they stayed out of the market. The current trend is allowing these companies to enter those markets previously unavailable to them. Outsourcing allows everyone to have a share in the profits with a reduced risk of investment.

Figure 1—Automation is no longer just for the automakers. Even the smaller shops have significant opportunities to reduce labor costs and production times by integrating automation.

As an example, a longtime customer of ours had been manufacturing low- to medium-lot quantities of high precision gearing for many years. Recently, this customer was awarded a long-term contract to provide thousands of parts per month from a large manufacturer that normally produced all of its gears in-house.

In another case, we recently delivered a machine to a new customer that landed its first contract for hard finishing gears from another, larger corporation. Again, our customer was able to justify the machine purchase based on the larger company's outsourcing program.

Along with the move towards outsourcing, quite a few of the smaller companies have implemented automation technology to meet their increased production needs. American manufacturers have traditionally been very labor intensive, but in order to compete in the global market, we have had to find ways to minimize our labor content. In years past, one way to minimize labor was to build cells or groups of machines with one operator loading two to four machines. However, with many current cycle times running at 60 seconds or less, it is impossible for one man to load and unload any more than one machine at a time. One way to solve this challenge is by using efficient and affordable automation systems.

Automated systems aren't new. They were invented and first installed by the automotive industry years ago. Today, many small machine shops are adopting similar technology to improve their efficiency and consequently increase their competitiveness. Overall, the process is simple. A machine is set up to automatically run enough parts on a carousel or in a magazine for one or two hours, or for an entire eight-hour shift. Therefore, the operator can still run multiple machines, and labor expenses can be once again reduced dramatically.

Not only does automation effectively reduce labor costs, it increases machine productivity. It's not hundreds of thousands of parts that are being run on these machines, it's the few hundreds to low thousands—this is an entirely different level of automation.

Even though automation technology has been around for a decade, 10 years ago it was very expensive, and five years ago, no one was in an economic position to utilize it. All of that has now changed. Quite a number of companies are now seriously looking at automating their processes. Not surprisingly, many of these companies have relatively few employees for their output. They look first at how the process can be automated with the goal of "0" labor content. These are the companies that will prosper in tomorrow's market.

The fact is that when you have six or seven major U.S. automotive projects going on at one time, you know that the economy is on the upswing. What is different than in previous times is that only about half of these programs are slated to be manufactured by the automakers themselves. The others will be outsourced.

At Kapp-Niles, we continue to invest in new technology, and our engineers are challenged to produce new and innovative products for our industry. For example, we have recently introduced a new machine series with integrated automation. It's all about being competitive in the world market.

The Kapp KX 300P is offered with complete automation packages.

For More Information:
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Superfinishing Gears

THE STATE OF THE ART, PART II

Gary J. Sroka and Lane Winkelmann

Management Summary

Chemically accelerated vibratory finishing of gears using high density, non-abrasive ceramic media has generated much interest among gear designers and users. Increasingly, this gear superfinishing technology is being used to solve real-world problems. However, implementing of this technology has been hindered by several misconceptions.

In a previous *Gear Technology* article, the authors identified and discredited two misconceptions surrounding this gear superfinishing process.

In this article, they discuss three more misconceptions. Their discussion includes evidence supporting that the performance benefits of superfinished gears are real, that the process can reduce gear noise/vibration/harshness, and that superfinishing doesn't distort gear geometry.

Gary J. Sroka *is research & development manager for REM Research Group Inc., located in Brenham, TX. He holds a doctorate in physical chemistry. His research interests include development of new products and processes for superfinishing gear and bearing alloys using chemically accelerated vibratory finishing.*

Lane Winkelmann *is a senior research associate at REM Research Group. He has developed proprietary products and processes for the superfinishing of stainless steels, brass, and carbon steel alloys and has published several gear-related technical articles.*

Introduction

More than eight years ago, chemically accelerated vibratory finishing using high density, non-abrasive ceramic media first appeared in the gear industry.

As with any new technology, well-intentioned opposition is usually present before there is widespread acceptance. Chemically accelerated vibratory finishing—superfinishing—has often faced such opposition because of several misconceptions.

In *Gear Technology*'s November/December 2003 issue, we identified and discredited two misconceptions surrounding this gear superfinishing process. The first of these was the notion that gear teeth with mirrorlike surfaces would not exhibit adequate lubrication properties because residual machine lines or a dimpled surface were required to facilitate oil retention.

The second misconception was that the relationship between surface roughness parameters and component functionality was not well understood, and required advanced mathematics and sophisticated software to master, leaving no simple method of determining which surface would exhibit the desired performance.

In our prior article, we showed that superfinishing gears using high density, non-abrasive ceramic media did in fact produce an isotropic micro-texture on the surface that facilitated lubrication. The superfinished surface was free of stress raisers, distressed metal, and peak asperities—all of which would reduce the life of a gear.

Also, laboratory and field tests supported the conclusion that monitoring of only average roughness (R_a) was necessary during the process in order to attain the best surface. It was shown that an R_a of < 3.0 μin. (0.08 μm) ensured optimum performance benefits (Ref. 1).

In addition to those two misconceptions, there are three more that need to be addressed:

3.) Superfinishing has no supporting theory, so its performance benefits must be looked upon with suspicion.

4.) Superfinishing doesn't reduce noise/vibration/harshness.

5.) Superfinishing distorts gear geometry.

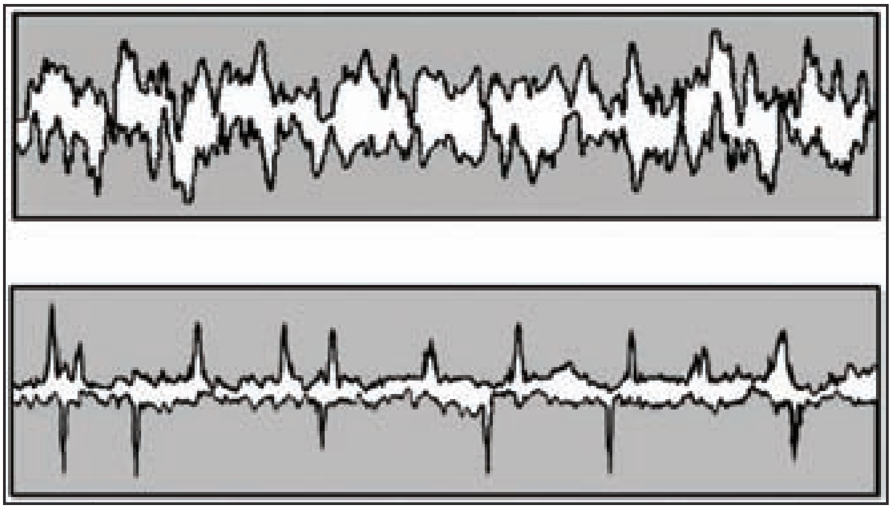

Figure 1—Graphic showing the interaction between surfaces with the same nominal R_a. The upper graphic illustrates random surfaces brought into contact. The bottom graphic shows two planarized surfaces brought into contact. The film thickness required to separate the planarized surfaces is much less than that required to separate the random surfaces.

Misconceptions

Misconception No. 3. Superfinishing has no supporting theory, so its performance benefits must be looked upon with suspicion.

Gears, like many inventions now taken for granted, were used for centuries with great success before the advent of modern analytical tools and methods. Many parameters have since been created to fully characterize the properties of a surface, and tribologists continue in their work for a theoretical correlation between gear performance and these surface properties.

Moreover, existing theories may not take full account of the unique surface properties imparted by chemically accelerated vibratory finishing. For example, in a mated pair, superfinished surfaces, each with an R_a of 8.0 μin. (0.20 μm), will interact much differently than a mated pair in which each surface has been finely honed to an R_a of 8.0 μin. (0.20 μm) (see Figure 1). The difference is due to superfinishing's creation of planarized surfaces. These surfaces are essentially free of peaks that can penetrate the lubricating film.

Misconception No. 4. Superfinishing doesn't reduce noise/vibration/harshness.

Since gears have a sliding component, superfinishing reduces noise/vibration/harshness in the majority of cases because it lowers friction and facilitates lubrication.

Spiral bevel gear sets, having high sliding ratios, especially benefit from superfinishing. The process not only reduces noise/vibration (Refs. 2–3), but also improves fuel economy in automotive applications (Ref. 4).

Although new gears may be very quiet initially, they often become noisier with usage. Wear, scuffing and micropitting usually lead to unacceptable gear geometry distortions. Such changes in geometry increase transmission error with a concomitant increase in noise/vibration/harshness. Superfinishing, however, reduces wear, scuffing, and micropitting, thereby slowing noise growth (Ref. 5).

Moreover, noise can also result from surface undulations introduced during a gear's machining/grinding stage. In superfinishing, the media is large enough to bridge the crests of the undulations, reducing their amplitude.

Superfinishing has reduced noise/vibration/harshness in a number of gear applications. For example, Sikorsky Aircraft Corp. uses the process on its S-76C+ helicopter gearboxes, reducing noise from the second-stage bevel gears by 3.7 dB and from the bull gear's first harmonic by 7 dB (Ref. 2).

Misconception No. 5. Superfinishing distorts gear geometry.

Superfinishing gears requires skill to avoid unwanted results. Skill is needed because the process has an inherent characteristic: It will remove more stock from the tip of a gear tooth than from the root area. The reason is simple. Since the proccess is chemical/mechanical, the tip will have greater contact frequency with the media and therefore be subjected to more mechanical rubbing than the root fillet area. The amount of bias depends on gear size and diametral pitch, media size and shape, and processing parameters.

Is this inherent characteristic a major obstacle? Not necessarily. A skilled technician can develop a process whereby the amount of bias is negligible.

Aerospace gears, for example, are typically final ground to an R_a of 12–16 μin. (0.30—0.41 μm). Therefore, only a small amount of stock must be removed to achieve an R_a of < 4.0 μin. (0.10 μm). Consequently, when superfinishing, potential geometry distortion is easier to control in aerospace gears—and high-end auto-racing gears—than in other lower quality gears.

In fact, several years ago, aerospace AGMA Q13 spiral bevel gears with a starting R_a of 12 μin. (0.30 μm) were superfinished to an R_a of < 3.0 μin. (0.08 μm), and still complied with the AGMA Q13 tolerance specifications (Ref. 6). Since that time, the success of this project has been repeated with a large number of aerospace gears having a wide assortment of geometries.

On the other hand, for automotive applications, the starting average roughness (R_a) typically ranges from 60–80 µin. (1.5–2.0 µm) with a mean peak-to-valley height (R_z) of approximately 300 µin. (7.6 µm). The R_z indicates that about 300–400 µin. (7.6–10.2 µm) of stock must be removed to achieve a surface that is free of asperities. For ring-and-pinion gear sets, which are usually lapped after carburization and kept as pairs, a much more uniform stock removal process is required to avoid altering the contact pattern and/or increasing the transmission error.

In one case, a DANA 44 lapped ring-and-pinion gear set was superfinished to a 3.0 µin. (0.08 µm) R_a after optimizing the media and process. The amount of stock removed from tip to root and across the spiral was extremely uniform. The contact pattern was maintained and transmission error did not increase over baseline. A paper presented at the 2004 AGMA Fall Technical Meeting reported the results of this study (Ref. 7).

On rare occasions, however, one comes across cases that are problematic. For example, initial attempts to superfinish a much finer-pitched internal gear for the Global Hawk UAV resulted in the inadvertent removal of more stock near the tip than at the root. Fortuitously, the company was pleased with the outcome because the biased removal provided needed tip relief.

When no bias is desired or can be tolerated, another approach is possible. The gear designer can compensate by leaving more stock at the tip than at the root. Recently, Sikorsky Aircraft used this approach. The company decided it wanted to use this superfinishing technology to take advantage of its performance benefits, so it designed its gears to fit the process (Ref. 8).

Although skill is needed to select the optimum superfinishing parameters, during the last several years, there have been advances in the areas of media, chemicals and techniques that simplify the task. As a result, a reasonably competent technician working under commercial conditions can now successfully superfinish gears ranging in weight from just a few grams to more than 4,000 pounds (1,814 kg).

Also, once optimal superfinishing conditions have been established, subsequent processing is virtually guaranteed to be successful because the process itself is extremely robust and requires little skill.

Summary

In the past several years, superfinishing of gears—that is, chemically accelerated vibratory finishing using high density, non-abrasive ceramic media—has been increasingly accepted by the gear industry. To date, there is no tribological theory to explain the gear performance imparted by this basis-metal surface engineering. Nonetheless, this process removes peak asperities, stress raisers and the layer of distressed surface metal from gears and gives them an isotropic micro-texture that facilitates lubrication.

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A Study on Reducing Gear Tooth Profile Error by Finish Roll Forming

Seizo Uematsu, Donald R. Houser, Sung-Ki Lyu, Long Lu, Ju-Suck Lim

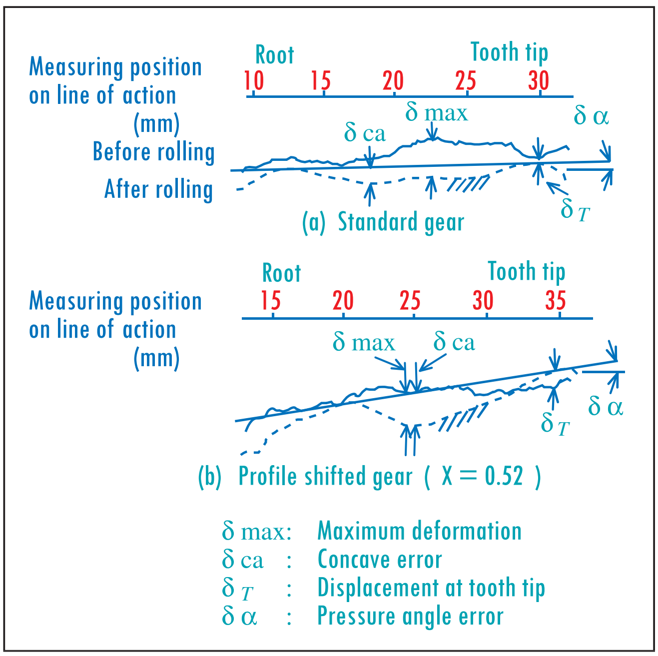

Figure 1—Plastic deformation on tooth profile.

Management Summary

In recent years, the gear industry is increasingly applying non-cutting forming methods to the production of toothed workpieces. Of these, finish roll forming seems to have the widest range of application. Finish roll forming is a manufacturing technology that improves the tooth profile accuracy, pitch accuracy and surface roughness of a hobbed gear. In this technique, a hobbed gear having a finish roll stock allowance contacts under high load with a tool having a high accuracy profile. The high load plastically deforms the surfaces of the teeth, smoothing them and making them more accurate. This concept was proposed by Ford Motor Co. for the finishing of automotive pinions (Ref. 1).

Based on the proposed concept, automotive gear manufacturers attempted finish rolling larger gears, but could not obtain adequate quality. A great deal of research and development work has been carried out by many companies and researchers to see if roll forming can be more widely applied to larger gears with coarser pitches (Refs. 2–6). However, these investigators could not develop a mechanism to generate high quality profiles.

In this study, the authors have developed a rack-type rolling process in which a rack tool is used to roll gear teeth. The results of the experiment and analysis show that the proposed method reduces errors.

Introduction

This paper deals with the tooth profile error of spur gears that have been finished by roll forming. First, we present experimental data that confirms that the tooth profile error is a synthesis of a concave error and a pressure angle error (Refs. 7–8). Since various types of tooth profile errors appear in the experiments, evaluation parameters are introduced for rolling gears so that profile quality may be objectively evaluated. Using these evaluation parameters, the relationships among the tooth profile error, the addendum modification factor (A.M. factor) and the tool loading force are verified.

The character of concave error, pressure angle error and tool loading force of finish roll forming by using a forced displacement method are verified. This study makes clear that the tool loading force of finish roll forming is a very important factor that affects involute tooth profile error.

Evaluation Parameters for Roll Forming

Figure 1 shows the evaluation parameters for gear rolling. The parameters are maximum deformation δ_{max}, concave deformation δ_{ca}, deformation at tooth tip δ_T and pressure angle error δ_α. The solid and broken lines in the figure indicate the tooth profile curves before and after rolling, respectively. δ_{max} is the

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Dr. Sung-Ki Lyu *is director of the Regional Consortium Center, located at Gyeongsang National University in Jinju, South Korea. The center performs industrial research sponsored by 20 participating companies. Lyu is also a professor in the university's mechanical & aerospace engineering department. He teaches and researches in the area of gear design.*

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Ju-Suck Lim *is a graduate student at Gyeongsang National studying finish roll forming of gears.*

value of deformation at the position of maximum deformation when the tooth profile curves are compared before and after rolling a gear. δ_{ca} is the value of deformation at the position of the maximum distance from the tangent line to the profile where a tangent is drawn through the tooth tip and tooth root on the profile.

A positive value of δ_{ca} indicates a concave shape on the tooth profile, whereas a negative value indicates a convex shape. δ_T is the amount of deformation at tooth tip. A positive value of δ_T is the form in which the tooth tip is lower before rolling and a negative value is the opposite form. δ_α is the pressure angle error.

Test Gear and Experimental Method

The experiment was conducted on module 5 spur gears as follows: A rack was used for the tool and was driven at a speed of 4.5 mm/min. (0.08 mm/sec.). The number of teeth on the gear was 22 and the A.M. factor was 0.52.

The specifications of the roll forming tool and the test gears are shown in Table 1. The shape of the test gears is shown in Figure 2 and in Photo 1. The gear on the left side of the photo is a standard gear, and the gear on the right is one of the roll formed gears made in this study. The rolling was performed

Table 1—Specification of Roll Forming Tool and Test Gears.

	Tool	Test gear
Module (m)	5	
Number of teeth (z)	11	22
Pressure angle (deg)	20°	
Tooth width (mm)	17.5	10
Coefficient of profile shift		0.52
External diameter (mm)		125
Material	SK5	S45C
Hardness	HRC 63	HRB 80
Individual pitch (μm)	1.0	7
Cumulative pitch (μm)	1.0	20

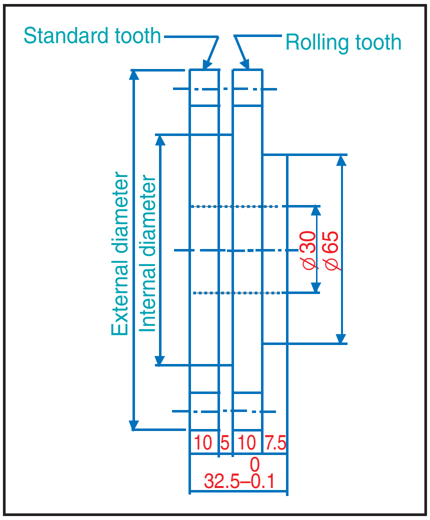

Figure 2—Shape of test gear.

Photo 1—Test gear.

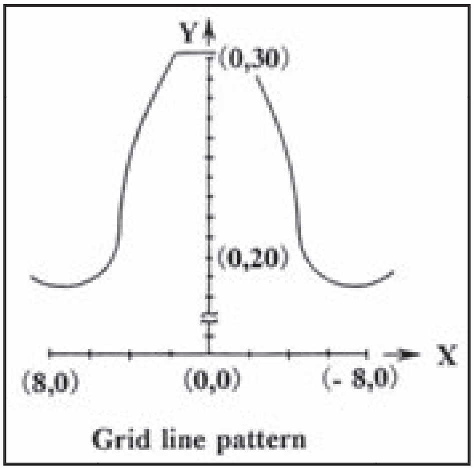

Figure 3—Method of tooth deflection measurement.

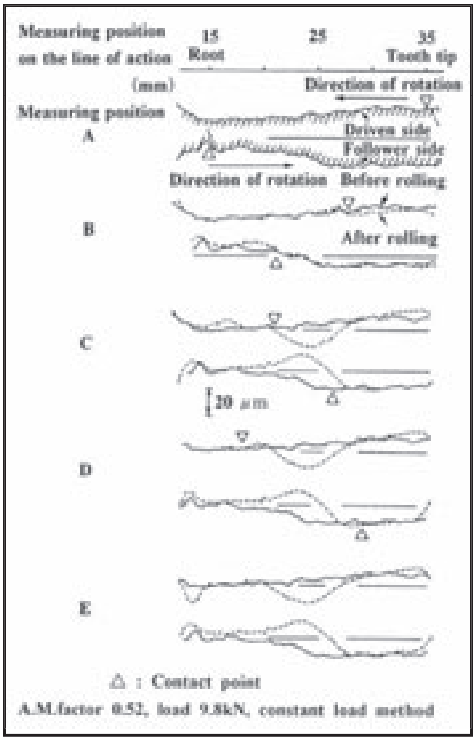

Figure 4—Variation of tooth profile in rolling process.

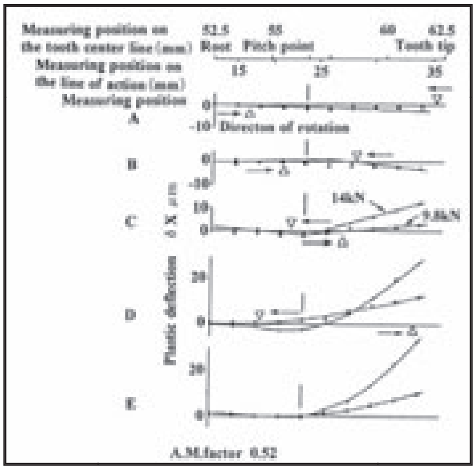

Figure 5—Plastic deflection of tooth.

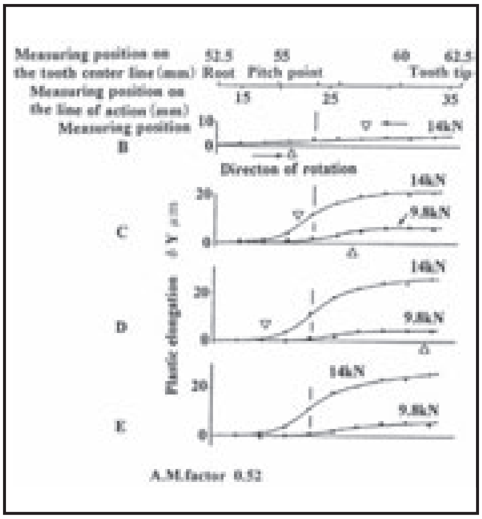

Figure 6—Plastic elongation on the tooth center line.

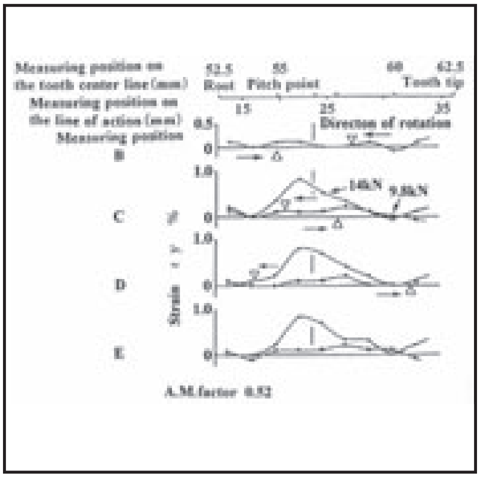

Figure 7—Strain distribution on the tooth center line.

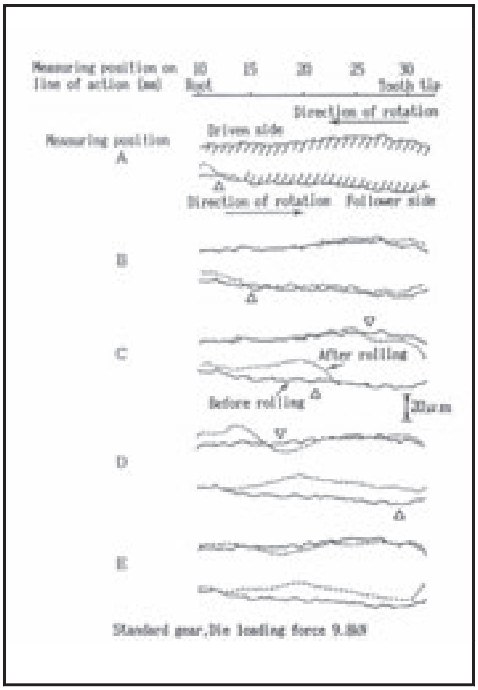

Figure 8—Variation of tooth profile in rolling process.

over several teeth and was repeated several times on the same teeth. The tooth profile and tooth trace curves were measured after each rolling cycle. After rolling, the evaluation parameters were compared to those of the standard tooth.

Deformation Mechanism

If the amount of deformation becomes partially negative on a tooth profile, this phenomenon cannot be explained by analytical methods based on the amount of deformation. Therefore, the teeth seem to bend plastically during rolling. The formation mechanism of the pressure angle error was studied as follows: Since a large portion of the roll stock plastic deformation occurs during the first rolling pass, the remainder of the discussion will focus on results after the first rolling pass.

For verification, the profile of mating tooth and the displacements of lattice point drawn on the side of the tooth were measured at several positions on the line of action. Therefore, we stopped the mating gear at several positions on the line of action. During rolling, each measuring position on the line of action was judged by comparing the output from the strain gage at the tool's tooth root and the analytical mating diagram. Since the tool driving speed is 0.08 mm/sec., the tool can be stopped near a target position.

Figure 3 shows the lattice points drawn on the tooth side. The lattice points are arranged on the mirror-finished side of the tooth using the micro Vickers tester. In the coordinate system on the tooth side, the Y-axis is positioned on the centerline of the tooth side and the origin is positioned 30.5 mm from the tooth tip on the centerline. The X-axis is the direction perpendicular to the centerline. The lattice point interval Δ is set to 1 mm. The components of the displacement of the lattice point are δ_X, δ_Y in each axis. The plastic strain ε_y between lattice points on the centerline direction was defined as follows:

$$\varepsilon_{yi} = (\delta_{yi} - \delta_{yi-1})/\Delta \qquad (1)$$

where index *i* indicates the position of a lattice point from the origin on the centerline.

Figure 4 shows how a gear having an A.M. factor of 0.52 is deformed during rolling. The sign ∇ indicates a contact point on the tooth profile. The contact point on the tooth begins from the driven side at tooth tip and ends at the follower side at the tooth root. The load is 9.8 kN. At points A and B, the amount of deformation on the tooth profile contacted with the tool is positive. At point C, the gear rotates slightly from point B and a concave shape of the tooth appears at the pitch point on the tooth profile. Here, it is observed that the deformation of the driven side changes from positive to negative. The tooth profiles at points D and E show very little difference from the profile at point C.

Figure 5 shows the plastic deflection δ_X. When the load is 9.8 kN, and the gear rotates from point A to point B, the plastic deflection is very small.

At point C, the plastic deflection grows large at the dedendum. The deflection of the dedendum at point C is unlike at point B and is inverted from positive to negative.

While the gear rotates from point B to point C, the heights of contact point on the driven side and the follower side are inverted near the pitch point. Here, the change in the direction of the dedendum corresponds to the tooth profile at point C in Figure 4. When the gear rotates from point C to point E in Figure 5, the tooth profiles at points D and E show very little difference from that at point C.

Figure 6 shows the radial elongation δ_Y. The tooth shows no elongation at point A. The tooth is slightly elongated at point B and is elongated more on the dedendum at point C. The elongation does not change when the mating progresses further.

Figure 7 shows the plastic strain ε_y calculated from the results shown in Figure 6. The strain is nearly zero at points A and B and becomes very large at point C. The maximum strains are 0.2% and 0.9% when the loads are 9.8 kN and 14 kN, respectively. These results indicate that the plastic area reaches the center of the tooth near the pitch point where the heights of the contact point on the driven side and the follower sides are inverted. When the gear rotates from point D to point E, the strain at these points is nearly zero.

Figure 8 shows the deformation process in which the A.M. factor is zero. Results would likely be similar for values of A.M. factor up to about 0.4 based on the results of Uematsu (Ref. 7). In positions A and B, the tooth profile of the follower side contacts the tool, and the amount of deformation on the rolled part is in the positive direction. In position B, the tooth profile of the driven side has not yet come in contact with the tool. However,

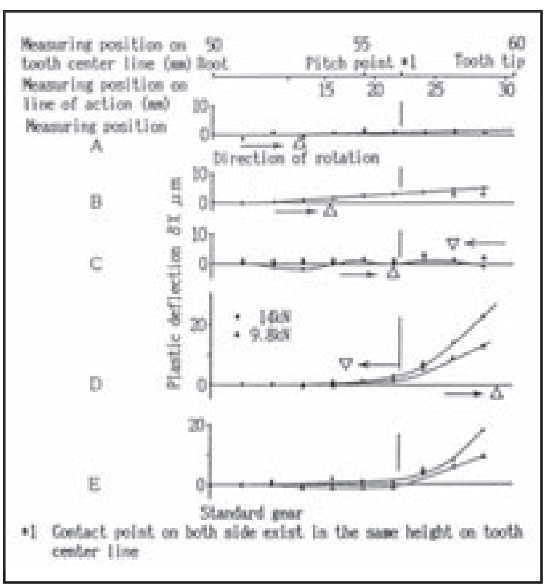

Figure 9—Plastic deflection of tooth.

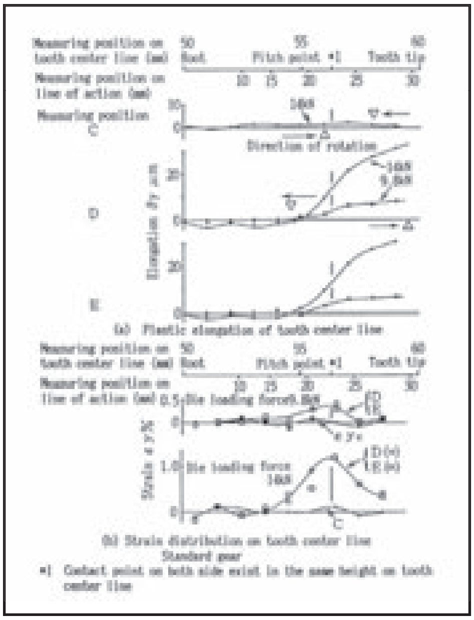

Figure 10—Plastic elongation on tooth center line.

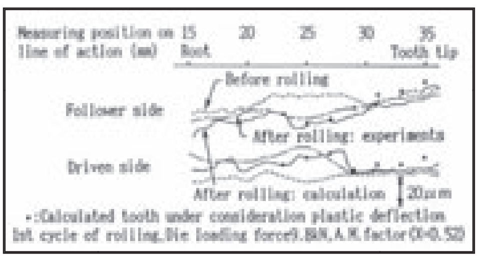

Figure 11—Calculated tooth's plastic deflection based on experimental results.

the tooth profile has been deformed in the negative direction before the tooth comes in contact with the rolling tool.

At position C, the tooth profile of the driven side begins to contact with the tool, and the negative deformation that appeared in position B is disappearing. The tooth profiles on both sides also contact with the tool, and the amounts of deformation on the driven side have a positive direction.

In position D, the amount of deformation on the driven side decreases and this tooth profile has been deformed more negatively than before rolling. In position E, the tooth contact has finished on both sides. The amount of deformation on the follower side that appeared in position D again decreases.

Figure 9 shows the plastic deflection of the tooth in rolling. The change of the plasticity deflection corresponds well to the tooth profile shown in Figure 8. When the tooth contact occurs on the tooth profile of one side as shown in positions A and B, the plastic deflection appears on the tooth root, and the elongation in the interval is small. When the tooth contact crosses near the pitch point as shown in positions C and D, the deflection in the addendum becomes bigger.

Figure 10 shows the elongation, and the plastic strain between points C and D are shown in Figure 9. When the tooth contact crosses near the pitch point as shown in positions C and D, the elongation in the addendum becomes bigger. When the load is 9.8 kN, the strain becomes more than 0.2%. When it's 14 kN, the strain becomes 1.2%. As a result, the plastic region spreads near the pitch point on the central part of the tooth.

Formation Mechanism of Pressure Angle Error.

Plastic deflection and elongation in finish rolling were confirmed by the experimental result described above. Plastic deflection that appears in the addendum is affected by the transfer direction of the contact point on the tooth. The transfer direction of the contact point is decided by the direction of rotation. Therefore, as the tooth bends to the driven side, the amount of deformation on the tooth profile decreases on the driven side and increases on the follower side. The elongation appearing on the addendum decreases the amount of deformation on both tooth sides.

The amount of deformation on the tooth profile consists of the components: δP_d, δP_f, $\delta_X \cos\theta$, $\delta_Y \sin\theta$ where δP_d, δP_f is the amount of deformation, $\delta_X \cos\theta$ is the plastic deflection, $\delta_Y \sin\theta$ is the plastic elongation, and θ is the pressure angle. The total amount of deformation Y_d of the driven side and Y_f of the follower side will consist as following:

$$Y_d = \delta P_d - \delta_X \cos\theta - \delta_Y \sin\theta$$
$$Y_f = \delta P_f + \delta_X \cos\theta - \delta_Y \sin\theta \qquad (2)$$

Then, the result of the calculation based on Equation 2 is added to the tooth profile in which the deformation was calculated, and the pressure angle error is examined.

Figure 11 shows the result. The tooth profiles represented by the broken, dashed and solid lines are respectively the tooth profile before rolling, the experimental tooth and the calculated tooth.

The deformation correction value calculated by Equation 2 is shown by the black circles. The corrected tooth profile and the rolled tooth form agree to an accuracy of 1–2 μm.

Therefore, the convex shape on the addendum of the driven side of the rolled tooth was not verified by the calculation with only the mean deformation being predicted by Equation 2. Similarly, the amount of deformation difference on the driven side and follower side is verified by the calculations using the same equation.

When the plastic region reaches the central part of the tooth, the pressure angle error is based on the second and third terms of Equation 2.

Tooth Profile Error at Low Load

In the above, the load was set to 9.8 kN, so that the deformation may easily appear in the tooth, and the mechanism in which the pressure angle error arose was examined. However, the conclusion obtained in this experiment may not always apply to the case in which the load is set at a lower value.

Figure 12 shows the results with a 5 kN load. The other experimental conditions are the pitch-line velocity of 8.5 m/min., and the number of total rolling cycles is 30. The plastic deflection and plastic strain ε_y on the center line is shown in Figure 12(a). This deflection is about 3 μm near the pitch point and becomes about 12 μm at the tooth tip. The strain remains at roughly 0.2% from the pitch point to the tooth tip. There is a maximum compressive strain of 0.2% on the dedendum, and the plastic region spreads to the central part of the tooth.

The profile of both sides of the rolled tooth is shown in Figure 12(b). The rolled tooth deformed almost uniformly along the hobbed tooth shape; the amount of plastic deformation ranges from 2–8 μm. On the follower side, the concave shape at the pitch point has amplitude of about 30 μm.

Conclusion

In this paper, we have defined an evaluation method for tooth rolling and have established the formation mechanism of the pressure angle error. Analysis reveals two causes of the tooth profile error:

1.) When the tool approaches the work with a constant load, the number of mating teeth on the line of action varies, the normal load on the tooth changes with the number of mating teeth, and the concave type error occurs at the pitch point.

2.) When the tooth contact stress is very high near the pitch point, the plastic deformation extends inside the center of the tooth and the addendum deflects to the driven side.

Additional results of this study are as follows:

1.) The pressure angle error that appears in the addendum is the sum between plastic deflection on the addendum and the elongation in the same region and results in the concave shape at the pitch point.

2.) The deflection in the addendum decreases the deformation on the driven side and increases the deformation in the follower side (reverse effects).

3.) The elongation in the addendum decreases the amount of deformation in both teeth.

4.) This deflection and elongation arise when the contact point crosses near the pitch point on the right and left tooth profiles.

5.) The direction of deflection is decided according to the transfer direction of the contact point on the tooth surface, and the tooth deflects to the driven side regardless of the number of teeth and the addendum modification coefficient.

Acknowledgments

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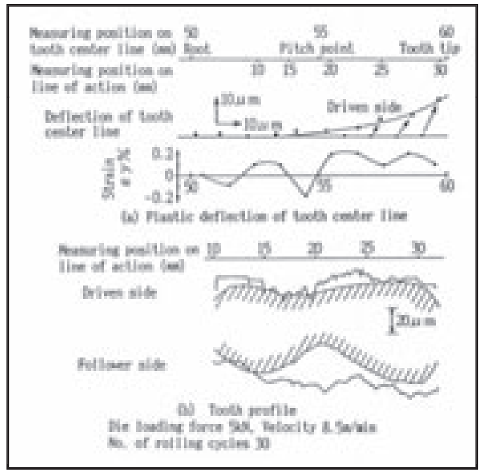

Figure 12—Tooth profile error and plastic deflection under low load rolling.

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Systematic Investigations on the Influence of Case Depth on the Pitting and Bending Strength of Case Carburized Gears

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Dr.-Ing. Peter Oster
Prof. Dr.-Ing. Bernd-Robert Höhn

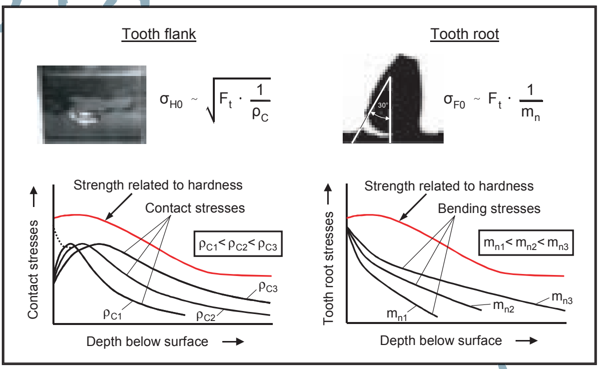

Figure 1—Basic principles of tooth flank and tooth root stresses (schematically).

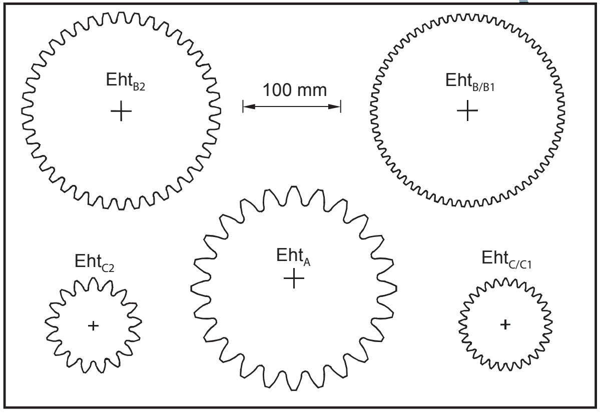

Figure 2—Gear types (pinion) of the test program.

Management Summary

High power transmitting gears are nowadays nearly always case carburized and hardened. The value of case depth is one important parameter that has to be specified by the gear designer for the heat treatment process. On the one hand, the available gear load capacity can be reduced with a case depth that is too small. On the other hand, unfavorable influences on the material properties and possible increased distortion by hardening and increased requirements for grinding may result from a case depth that is too large. In times of modern and increasingly optimized gear manufacturing, there is a fundamental need for the gear designer to know how to determine an appropriate case depth for his actual gear application in order to guarantee the required load capacity and taking into consideration the different basic principles in the nature of contact and bending stresses that are most relevant for gear load capacity.

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Introduction

In modern gear manufacturing, power-transmitting gears are nearly always made of case carburized steels, which are particularly suitable for withstanding high local stresses without sustaining damage. The heat treatment process of case carburizing is an exceedingly demanding process, requiring a high level of technical knowledge and experience.

Gears are case carburized to increase surface hardness, improve wear resistance and achieve high contact and bending strength. The hardness distribution in general is described by the characteristic parameters of surface hardness, case depth (*Eht*) and core hardness, and is usually seen as an approach for the strength distribution in the case hardened layer. While surface and core hardness are restricted to narrow limitations, case depth can be varied in a wide range. Thus the value of case depth decisively influences the hardness (strength) profile in the case carburized layer.

Failure modes of pitting and tooth root breakage are affected by the value of case depth. Whereas the pitting load capacity is a function of Hertzian contact stresses, depending on the square root of applied load and reciprocal of equivalent radius of flank curvature, the tooth root strength is related to bending stresses and directly to the applied load and gear module.

These differences in the nature of contact and bending stresses result in different requirements regarding the strength profile for tooth root and tooth flanks of a gear and have to be taken into consideration when choosing an appropriate case depth (see Fig. 1).

Since the costs of a case carburized gear are influenced significantly by the value of case depth, experimentally verified and easily applicable rating formulas are required to evaluate the influence of case depth in order to guarantee required load capacity regarding pitting resistance and tooth root bending strength of a gear.

For this purpose, the pitting and the bending strength of case carburized gears were investigated (Ref. 14). Gears of different sizes and different gear geometry were included in the test program in order to determine the basic principles for the influence of case depth on the gear load capacity. Residual stress and further characteristics of the case hardened layer that are also influenced by the value of case depth were examined.

Test Programs and Test Gears

The investigations have been carried out on several gear types, different in gear size and gear geometry. Figure 2 shows the test pinions of the gear types.

From each gear type, several test series of gears having the same geometry but different case depth were investigated. Table 1 shows the complete test program.

Test series	1	2	3	4	5
	Case depth in mm (drawing specification)				
Eht_A	0.3	0.6	0.9	1.4	2.0
$Eht_{B/B1}$	0.2*	0.4	0.7*	1.1	1.6*
Eht_{B2}	0.2**	-	0.7**	-	1.6**
$Eht_{C/C1}$	0.2*	0.4	0.7*	1.1	1.6*
Eht_{C2}	0.2**	-	0.7**		1.6**

* only bending fatigue tests ** only pitting fatigue tests

Table 1—Test Program: Influence of Case Depth on Pitting and Bending Strength.

Nomenclature	
Eht	Case depth at Vickers hardness 550HV1
Eht_{Fopt}	Optimum case depth for maximum bending strength
Eht_{Hopt}	Optimum case depth for maximum pitting resistance
F_t	Nominal tangential load
S_F	Safety factor—bending
S_H	Safety factor—pitting
Y_{Eht}	Case depth factor—bending strength
Y...	Influence factor—bending, according to DIN 3990 (Ref. 4)
Z_{Eht}	Case depth factor—pitting resistance
Z...	Influence factor—pitting, according to DIN 3990 (Ref. 4)
a	Center distance
m_n	Normal module
z	Number of teeth
ρ_c	Relative radius of flank curvature at pitch point
σ_F	Bending stress number
σ_{Flim}	Allowable bending stress number
σ_H	Contact stress number
σ_{Hlim}	Allowable contact stress number
*Further symbols according to DIN 3990/ISO 6336 (Refs. 4, 9).	

Tooth root bending strength was investigated on gear types Eht_A, Eht_B and Eht_C. Essential data for the bending gears are listed in Table 2.

Pitting resistance was investigated on test series of all gear types but with special focus on test series with center distance of 200 mm. The design parameters for the pitting gears are given in Table 3.

All test gears were made from one batch of 16MnCr5 steel, comparable to SAE 5115. The chemical composition of the gear material is shown in Table 4.

All gears were hobbed, carburized and hardened with the carburizing process, which was varied in order to obtain the desired different case depth values. After heat treatment, the test gears were mechanically (shot) cleaned. The flanks of the pitting gears were additionally finished by grinding (MAAG–0°) to surface roughnesses of R_a = 0.2–0.4 µm (*a* = 91.5 mm) and R_a = 0.3–0.5 µm (*a* = 200 mm), respectively, and a gearing accuracy of 4–6, according to ISO 1328 (Ref. 8). The peak-to-valley roughness R_z in the unground tooth root of the bending gears is $R_z \approx 5$ µm.

Test gears were manufactured according to industrial practice and fulfill the requirements for case carburized gears of quality MQ according to DIN 3990/ISO 6336 (Refs. 4, 9).

Parameter		Unit	Eht_A	Eht_B	Eht_C
Normal module	m_n	mm	8	3	3
Number of teeth	z	-	24	67	29
Pressure angle	α	°	20	20	20
Helix angle	ß	°	0	0	0
Face width	b	mm	30	30	20
Add. mod. factor	x	-	0.27	-0.60	0.56
Tip diameter	d_a	mm	212.3	201.0	96.3

Table 2—Gear Data of Bending Test Gears.

Parameter		Unit	Eht_A	Eht_{B1}	Eht_{B2}	Eht_{C1}	Eht_{C2}
Center distance	a	mm	200	200	200	91.5	91.5
Normal module	m_n	mm	8	3	5	3	5
Number of teeth	z_1 z_2	- -	24 25	67 69	40 41	29 30	17 18
Face width	b	mm	18	18	18	12	14
Pressure angle	α	°	20	20	20	20	20
Helix angle	ß	°	0	0	0	0	0
Contact ratio	ε_α	-	1.50	1.50	1.50	1.51	1.38
Relative radius of flank curvature	ρ_C	mm	19.5	14.3	15.4	9.5	10.0

Table 3—Gear Data of Pitting Test Gears.

Element composition wt%									
C	Si	Mn	P	S	Cr	Al	Ni	Mo	Cu
0.17	0.37	1.20	0.02	0.03	1.17	0.04	0.15	0.04	0.15

Table 4—Chemical Composition of 16MnCr5 Steel.

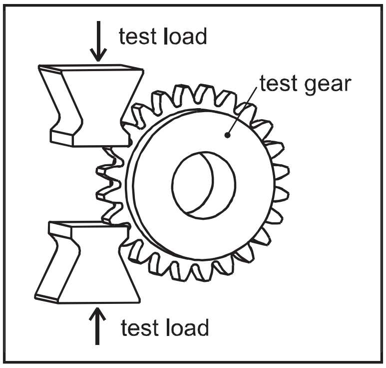

Figure 3—Clamping of test gear.

Test Conditions

Each test series repeated single stage tests in the range of endurance limit and low- and high-cycle fatigue.

Bending fatigue tests were carried out in pulsator test rigs of 100 and 250 kN capacity. The frequency was about 110–120 Hz. The gear teeth were clamped between two contact jaws as shown in Figure 3 and loaded in such a way that the load direction was tangential to the base circle. The endurance limit was assumed to be 6 x10^6 stress cycles without breakage. The endurance strength in bending was calculated according to the method in DIN 3990/ISO 6336 (Ref. 9).

Pitting fatigue tests were performed on FZG gear test rigs (see Fig. 4). The gear center distances were 200 mm and 91.5 mm, respectively. A detailed description of the test rig is given in Reference 5. The gears were spray lubricated with refined mineral oil ISO VG100 (viscosity v = 100 mm²/s at 40°C) with a 4% sulfur-phosphate additive. Oil injection temperature was 60°C. All tests were performed at rotational speed of 3,000 rpm at the pinion of the driving gear. The gears were loaded to various Hertzian stress limits until failure occurred. An endurance limit was considered to be reached when the test pinion ran for 100 x 10^6 cycles without damage. Test gears were deemed to have failed when 4% of the active working flank area of a single tooth was damaged by pitting. The applied contact pressure and Hertzian stresses were calculated according to the method of DIN 3990/ISO 6336.

Test Results—Bending Strength

Figure 5 shows the hardness distribution of bending gears type Eht_C. Surface hardness and core hardness of the different test series are comparable. The case depth values are clearly different.

Surface hardness of all test gears type Eht_A and type Eht_B is also in the same range, 720 +/– 50 HV1.

Core hardness of test gears type Eht_A is about 350 HV10 and, due to the larger size, is somewhat less than core hardness of gear types Eht_B and Eht_C.

Figure 6 shows test results for the influence of case depth on the bending strength of all test series. Each point represents the tooth root endurance limit of one test series as determined by the S-N curve and is related to the maximum bending strength of each investigated gear type. Results of some former investigations (Ref. 2) are shown.

Maximum bending strength was achieved for a case depth of 0.1...0.2 · m_n. In the range of case depth < 0.1 · m_n, bending strength strongly decreases with reduced case depth. In the range of case depth > 0.2 · m_n, the bending strength decreases with increasing case depth but was more moderate compared to the range of too small a case depth. The actual results are in good agreement with those from former investigations.

Test results clearly demonstrate that the bending strength of case carburized gears is influenced significantly by the ratio of case depth to gear module. This corresponds with the basic principles for tooth root bending stresses, as a module of a gear is a relevant parameter for the dimension of the critical cross-section in the tooth root area. Increasing the module causes a decreasing stress gradient over the material depth. With the same maximum tooth root bending stresses at the surface, a larger gear will therefore have higher stresses at a given distance below the surface than a smaller gear (see Fig. 1).

Compared to DIN 3990/ISO 6336 standards for case carburized gears, all test series with a case depth of 0.1...0.2 · m_n show a bending fatigue strength equal to or even higher than specified by the DIN/ISO field for allowable stress number σ_{Flim} of quality MQ case carburized gears.

Investigations of material properties, on the one hand, gave no indication of a relevant influence of carbon content (C approximately 0.65–0.85%) or residual austenite content (< 5–20%) on the test results for the investigated gears. On the other hand, material investigations showed that with increasing case depth and thus also increasing duration of the carburizing process, intergranular oxidation as well as grain size of the former austenite increased (see Fig. 7).

Residual stress distribution in the case carburized layer was determined by X-ray diffraction.

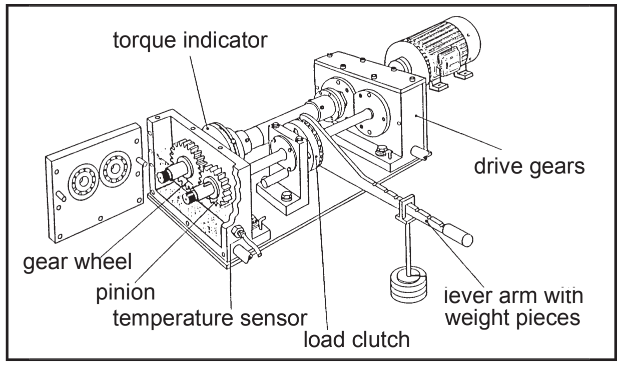

Figure 4—FZG gear test rig for pitting endurance tests.

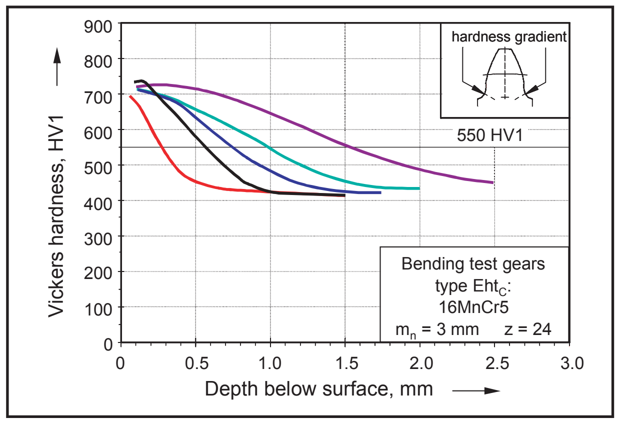

Figure 5—Hardness distribution of bending test series, gear type *Eht$_C$*.

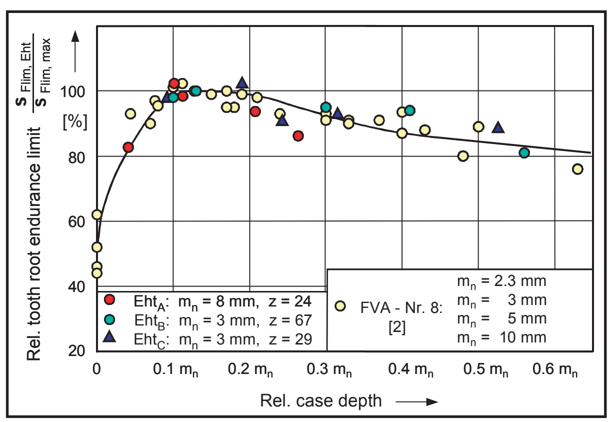

Figure 6—Test results for the influence of case depth on the tooth root bending strength (endurance limit).

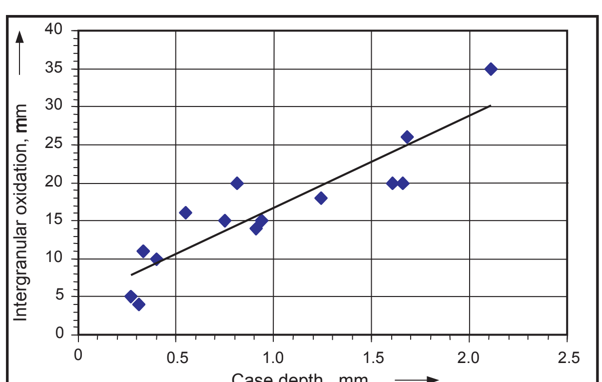

Figure 7—Case depth and intergranular oxidation of bending test gear types *Eht$_A$*, *Eht$_B$*, *Eht$_C$*.

Figure 8 shows the residual stress distribution for different test series of gear type Eht_C. Residual stress distribution has the typical form known for case carburized and shot cleaned gears. Residual compressive stresses at the surface and in the near surface area, especially maximum values, are smaller for test series with higher case depths and longer carburizing times than for gears with smaller case depths.

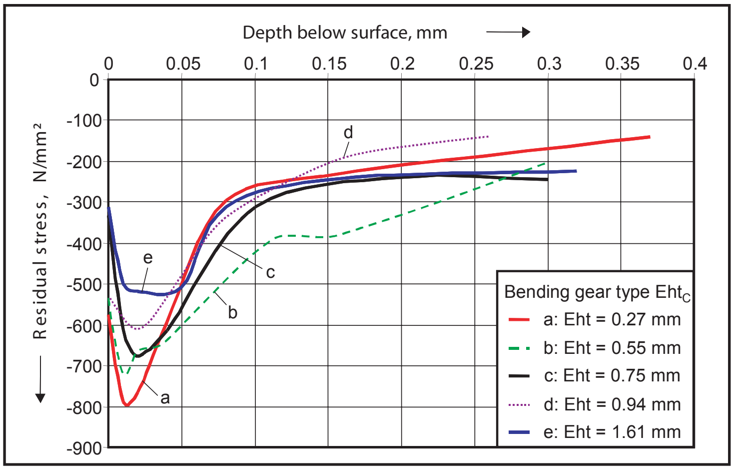

Figure 8—Residual stress distribution for test gears with different case depth (bending gear type *Eht_C*).

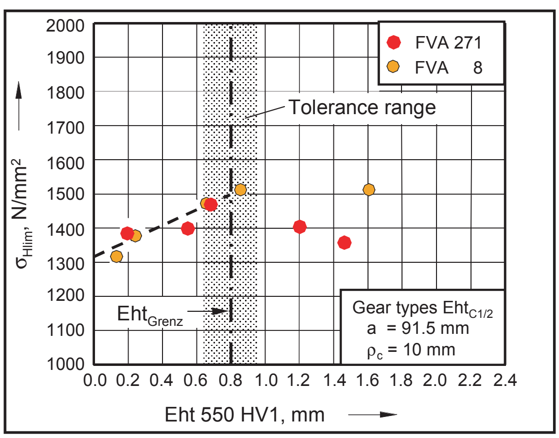

Figure 9—Test results for the influence of case depth on the pitting resistance (gear size ρ_C = 10 mm).

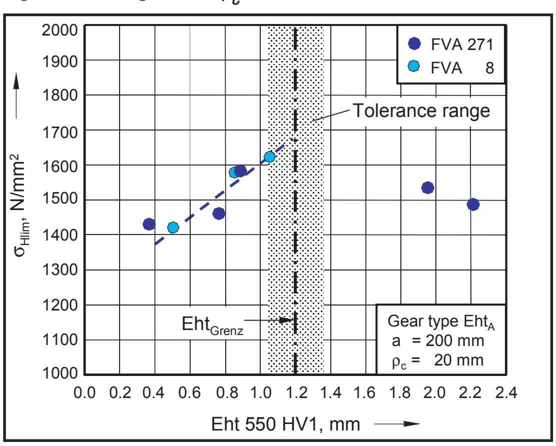

Figure 10—Test results for the influence of case depth on the pitting resistance (gear size ρ_C = 20 mm).

It is well known that these influences—higher intergranular oxidation, larger grain size, smaller residual compressive stresses in the tooth root area of a case carburized gear—may result in reduced bending strength (Refs. 1, 3 and 6). As all test gears were made of the same batch of steel and manufactured under equivalent mechanical conditions, results are related to case depth carburizing time and not separated into individual influence parameters.

Test Results—Pitting Resistance

In former investigations on the influence of case depth on the pitting resistance of case carburized gears (Refs. 2, 11), an optimum case depth to ensure the maximum allowable contact stress number has been established as:

$$Eht_{Grenz} = \frac{\rho_C + 10}{25} \pm 0.15 \text{ mm} \qquad (1)$$

The test results are mainly based on smaller gears. In Figure 9, results of investigations on the influence of case depth on pitting resistance (Ref. 14) are compared with the results from other investigations (Ref. 2). Results are given as allowable stress numbers, which are derived from the pitting fatigue limit of S-N curves for the investigated test series of gear types Eht_{C1} and Eht_{C2}. The highest fatigue limit was achieved for test series with case depth in the range of optimum case depth Eht_{Grenz}. Test series with smaller or larger case depth than the optimum depth (Eht_{Grenz}) achieved lower fatigue limits. Results in Figure 10 are based on larger gears (gear type Eht_A) from other investigations (Refs. 11, 14). Tendencies for the influence of case depth on the pitting resistance are the same as for smaller gears. However, the highest fatigue limit was achieved for larger optimum case depth. These findings are also confirmed by the results of the investigations on the test series of gear type Eht_{B2}.

Figure 11 summarizes the experimental results on the influence of case depth on the pitting resistance for test series of different gear types. The achieved contact fatigue limit (surface pitting) of each test series is related to maximum fatigue limit of the relevant gear type for $Eht \approx Eht_{Grenz}$.

Figure 11 shows that all gear types achieved maximum pitting resistance if case depth was in the range of optimum case depth Eht_{Grenz} as defined in References 2, 10 and 11. An approximately linear decrease of pitting resistance with the difference of actual and optimum case depth was found.

Several guidelines given in literature (Refs. 12, 13) recommended case depth as a function of module. Comparing test results of gear types Eht_{B2} and Eht_{C2}, both with the same module but different radii of flank curvature, indicates that the gear module may not be sufficient for choosing appropriate case depth regarding contact fatigue life. Especially for gears with small ratios of m_n/ρ_C, often used in high speed gears, discrepancy will arise if choosing case depth as a function of relative radius of flank curvature or if choosing case depth based on module.

Compared to DIN 3990/ISO 6336 standards for case carburized gears, test series with case depth in the range of Eht_{Grenz} achieve allowable contact stress numbers as specified in DIN/ISO standards for quality MQ case carburized gears. Fatigue limits (pitting) of other test series, in particular with smaller case depth, fell mostly below the upper limit of the DIN/ISO allowable field for material quality MQ.

Thus, the results indicate that optimum case depth for maximum pitting resistance is a function of the relative radius of flank curvature as described by Equation 1.

Accompanying investigations on the material properties indicated for most gear types a slight increase of surface carbon content and consequently higher content of residual austenite with increasing case depth. On the other hand, the investigations showed no relevant—and from the value of case depth—independent influence of these specific parameters on the achieved pitting resistance (see Fig. 12). Only two test series of gear type Eht_A with a large case depth showed a relatively high surface carbon content, but also showed case depth to be the dominant influence on the achieved fatigue limits.

Residual stress distribution was measured using X-ray diffraction. Figure 13 shows measurement results for a different test series of gear type Eht_{B2}. For test series with smaller case depth, relatively high compressive residual stresses were measured in the near-surface region. Larger case depth, especially on test gears with higher surface carbon and higher residual austenite content, caused mostly a reduction of compressive residual stress in the case hardened layer. In some cases, test series with larger case depth and high surface carbon content

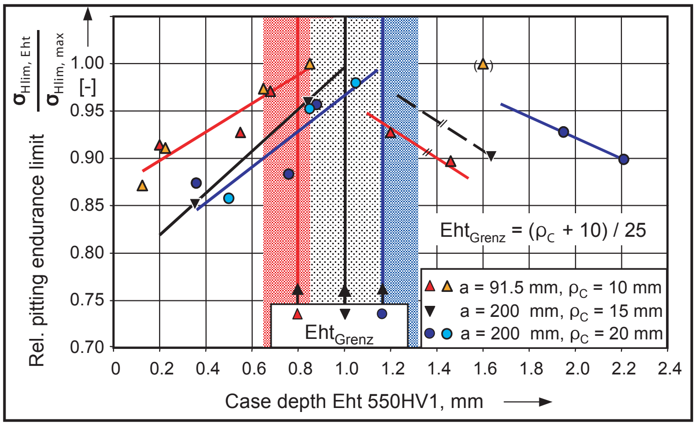

Figure 11—Comparison of test results for the influence of case depth on pitting resistance for different gear sizes.

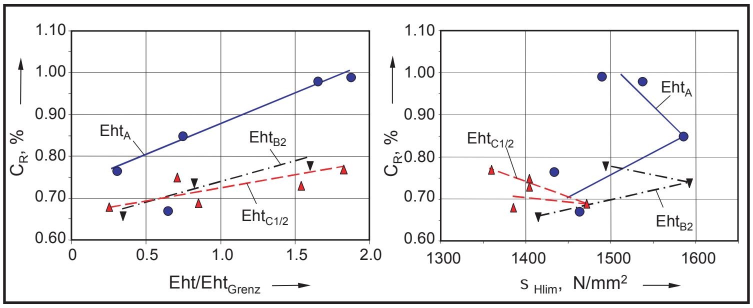

Figure 12—Case depth (*Eht*), surface carbon content (C_R) and achieved pitting fatigue limit (σ_{Hlim}) of investigated test series.

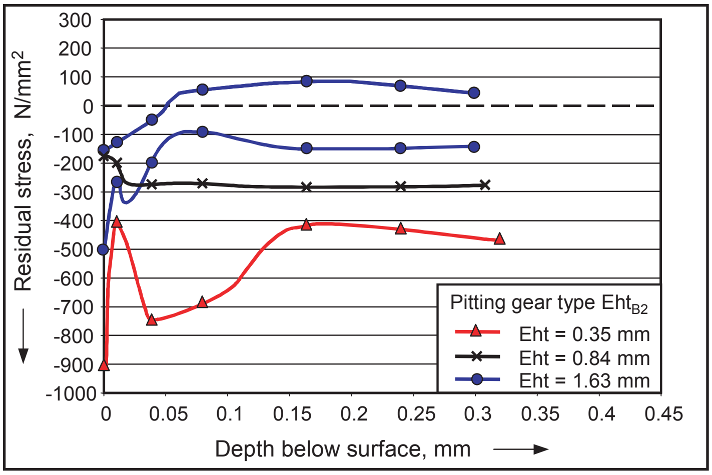

Figure 13—Residual stress distribution for test gears with different case depth (pitting gear type Eht_{B2}).

showed even small tensile residual stresses below the surface.

The results presented in Figures 9–11 are based on typical pitting failures. Analysis of the damaged gear flanks showed that these failures originated at the surface or at least in the near-surface region. The given stress values therefore have to be regarded as surface contact fatigue limits.

Test series of gear type Eht_{B1}, and in some cases also test gears of gear type Eht_{B2}, failed due to a special type of tooth breakage where the fracture occurred above the tooth root, frequently halfway down the tooth tip (see Fig. 14). Analysis of the fractured surfaces showed that the fracture was starting at a small inclusion in the material, generally at the transition between the case hardened layer and the softer core material.

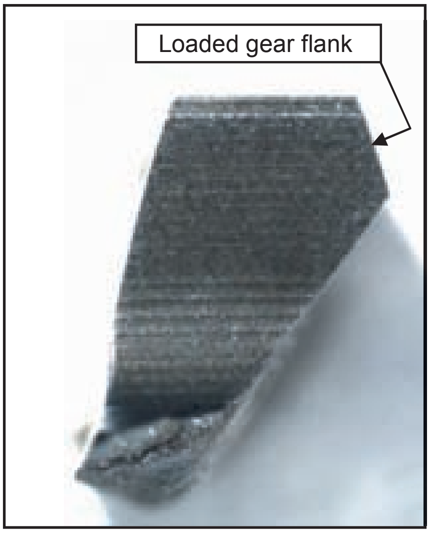

Figure 14—Special tooth breakage on test gear type Eht_{B1}.

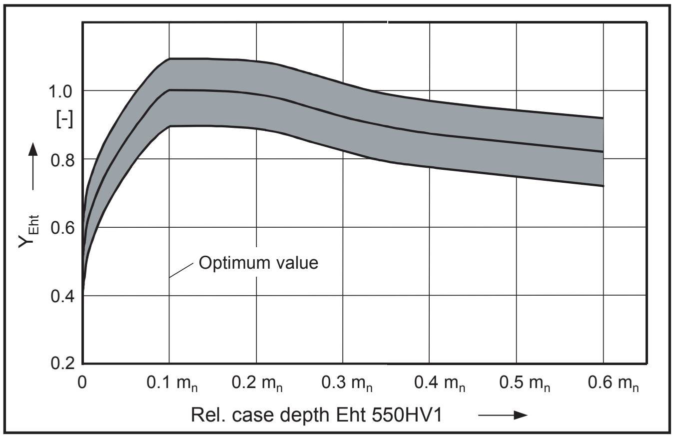

Figure 15—Influence factor Y_{Eht} for the influence of case depth on tooth root bending (endurance) strength.

These tooth breakages appeared suddenly, often after a high number of load cycles and without any indication of previous surface (pitting) damage. Gear type Eht_{B2} and especially gear type Eht_{B1} are characterized by a relatively small module but a high number of teeth (high relative radius of tooth curvature). Tooth breakage appeared on each of the two test series of gear type Eht_{B1} with case depths of 0.5 mm and 1.3 mm, respectively. As the nature and the mechanisms of this special type of tooth fracture are not fully understood, results of gear type Eht_{B1} were not taken into consideration in results on the influence of case depth on the surface contact (pitting) fatigue.

Results of the influence of case depth on the load capacity of the tooth flank agree with the accompanying investigations. These theoretical studies show that the variation of case depth influences the stress as well as the strength distribution over material depth, especially if residual stresses connected with the value of case depth are taken into consideration. Computations demonstrate that adequate case depth, depending on the relative radius of flank curvature and applied load, leads to a peak value of stress/strength ratio at or near the surface so that pitting will be initiated in this area. Smaller values of case depth or unfavorable residual stresses due to large case depth can result in a higher stress/strength ratio, or a lower load capacity. It may also lead, especially for gears with small ratios of m_n/ρ_C to a relocation of the maximum value of stress/strength ratio to a greater distance below the surface. This relocation may lead to gear damage that is initiated below the surface. Results of the theoretical studies have been published in detail (Refs. 7, 15).

Application of the Test Results on the Influence of Case Depth on Gear Load Capacity

Influence factor Y_{Eht} for tooth root bending strength. Test results indicate tooth root bending strength is influenced by the ratio of case depth to gear module. Optimum case depth for maximum tooth root bending strength (Eht_{Fopt}) is evaluated as

$$Eht_{Fopt} = 0.1...0.2 \cdot m_n$$

Gears with case depth in the range of optimum case depth Eht_{Fopt} should certainly achieve the allowable stress number according to standards for material quality (MQ).

For case depth values different from the optimum ($Eht \neq Eht_{Fopt}$), achievable tooth root bending strength is reduced. When evaluating the influence of case depth on tooth root bending strength, the influence factor Y_{Eht}, as defined in Figure 15, depends on the ratio of the case depth to the gear module. All test results fall into the given tolerance field. Y_{Eht} may be integrated in the standardization calculation method for rating gears according to DIN 3990/ISO 6336, shown in Equation 3 (Refs. 4, 9).

$$S_F = \frac{\sigma_{Flim} \cdot Y_{ST} \cdot Y_{\delta relT} \cdot Y_{RrelT} \cdot Y_X \cdot Y_{Eht}}{\sigma_F} \quad (3)$$

Influence factor Z_{Eht} for surface contact (pitting) fatigue strength. Test results show that pitting resistance is influenced by case depth. Optimum case depth regarding the maximum pitting resistance of the tooth flank (Eht_{Hopt}) is a function of relative radius of flank curvature according to Equation 4.

$$Eht_{Hopt} = Eht_{Grenz} = \frac{\rho_c + 10}{25} \pm 0.15 \text{ mm} \quad (4)$$

Gears with case depth in the range of Eht_{Hopt} should achieve the allowable stress number for case carburized gears of material quality MQ according to DIN 3990/ISO 6336 (Refs. 4, 9).

Smaller or larger case depth values than the optimum lead to a decrease of pitting resistance. Influence of case depth on allowable contact stress number (pitting) is described by the influence factor Z_{Eht}. Z_{Eht} is established as a function of the optimum case depth regarding maximum pitting resistance Eht_{Grenz}—that depends on the gear geometry, described by ρ_c—and the relevant case depth of the actual gear application. Z_{Eht} may be approximated from Figure 16.

According to DIN/ISO, the influence of case depth on pitting load capacity can be taken into consideration by introducing factor Z_{Eht} into Equation 5.

$$S_H = \frac{\sigma_{Hlim} \cdot Z_w \cdot Z_L \cdot Z_v \cdot Z_R \cdot Z_X \cdot Z_{Eht}}{\sigma_H} \quad (5)$$

Optimized case depth regarding maximum pitting and bending strength. Equations 2 and 4 and influence factors Y_{Eht} and Z_{Eht} may be used to calculate optimum case depth for maximum load capacity of tooth root or tooth flank as well as to determine adequate case depth for actual gear application if geometry, relevant stresses and minimum required safety factors are known. Consequently, lightly loaded gears will tolerate less case depth. On the other hand, safety factors S_H and S_F for a gear with a given case depth may be calculated by using Y_{Eht} and Z_{Eht}.

Especially for critical gear applications and special gear geometries, an optimized load capacity may be evaluated by using

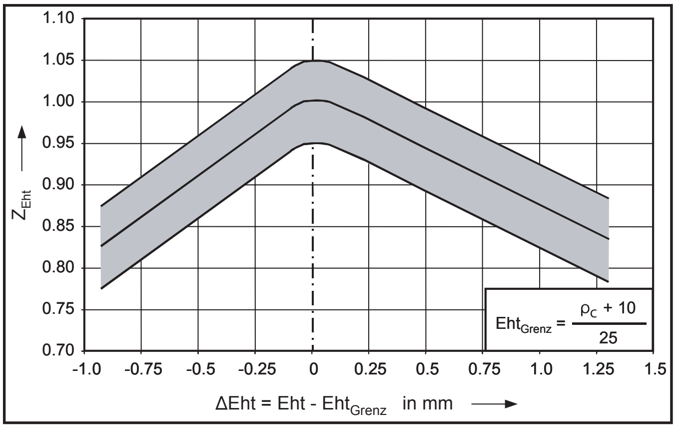

Figure 16—Influence factor Z_{Eht} for the influence of case depth on the pitting resistance (endurance strength).

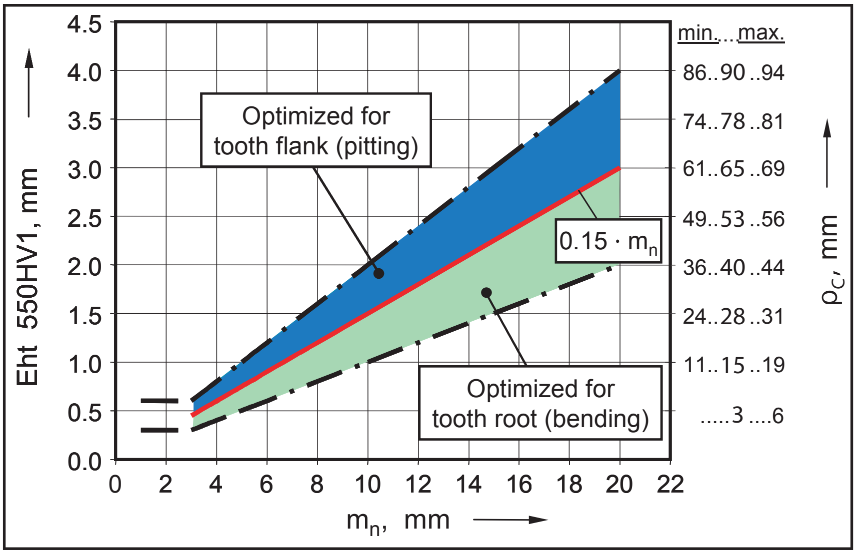

Figure 17—Basic recommendation for simplified determination of "optimized" case depth regarding maximum load capacity for tooth flank (pitting) and tooth root (bending) of case carburized gears with usual ratio of m_n/ρ_C.

defined influence factors.

For practical use, easily applicable guidelines are required. As tooth root and tooth flank of a gear cannot be loaded independently from each other, an adequate case depth for a gear has to consider requirements for surface contact fatigue (pitting) as well as for tooth root bending strength. Often, simple empirical methods that are based on long practical experience—mostly case depth as a function of gear module—are used (Refs. 12, 13). For a wide range of standard gears, these recommendations also agree with the results of the presented investigations. Figure 17 shows a simplified guideline for practical use in order to determine optimized case depth for a gear regarding maximum load capacity for tooth flank and tooth root. Given values are based on test results and with special regard to fatigue limits as stated in the standards (Refs. 4, 9).

Choosing case depth according to Figure 17 requires that module and relative radius of flank curvature of a gear be within the limits of the specified range. For other gear geometries as well as critical gearing, it is recommended to evaluate an optimized case depth with regard to the defined influence factors Y_{Eht} and Z_{Eht}. In case of a given gear geometry and a case depth outside the specification, a decrease of the gear load capacity is expected.

Conclusions

The influence of case depth on the bending strength and pitting resistance of case carburized gears was systematically investigated in a number of test series with different gear sizes and geometries.

Test results show that the case depth influences both bending and surface (contact) load capacity but in different ways. Maximum load capacity is achieved for an optimum value of case depth, but optimum values for maximum tooth root bending strength and pitting resistance of a gear need not necessarily be the same. An unfavorable case depth, smaller or larger than the optimum, leads to a decrease of achievable load capacity.

Based on the results, rating formulas were derived which can be used to calculate optimum case depth for maximum load capacity of tooth root and tooth flank of a gear as well as to determine adequate case depth in order to guarantee required load capacity.

By introducing the defined influence factors into the standardized calculation method, the influence of case depth on bending and surface (contact) load capacity can be taken into consideration if rating a gear according to DIN/ISO.

For practical use, a basic recommendation for choosing optimized case depth regarding maximum gear load capacity is given, applicable for a wide range of standard gears.

Acknowledgment

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ADVANCES FROM AACHEN

WZL AND GRC CONTRIBUTE TO GEAR MANUFACTURING

The WZL Gear Department Staff—Projects sponsored by the Gear Research Circle are performed by the WZL gear department's staff. Klaus Peiffer, Gleason Corp.'s representative in the GRC, describes the staff as "a source of very well educated specialists for the gear industry."

Borg Warner, Dana, General Motors, Gleason, Klingelnberg, and ZF. These companies are heavyweights in the gear industry. They're international operations with thousands of employees in offices and factories around the world—Argentina, Australia, China, England, Germany, India, Japan, South Africa, and the United States.

But even these companies don't always have the time and resources to spare for long-term research & development projects to advance gear manufacturing. So they and many other companies, including Caterpillar, DaimlerChrysler, Samputensili and Saint-Gobain Abrasives, come together in a consortium: the Gear Research Circle.

Founded in 1956, the GRC consists of 70+ companies in the gear industry that jointly sponsor R&D projects. And while GRC companies have international operations, their joint R&D is done in one building in Aachen, Germany. The city is home to a well-known technical institute, RWTH Aachen University, which houses the Laboratory for Machine Tools and Production Engineering, probably best known by its German acronym: WZL.

The lab includes the chair for manufacturing technology, which is headed by professor Fritz Klocke, and the chair of machine tools, which is headed by professor Christian Brecher. The two chairs share the WZL gear department. GRC work is done by professors, scientists working toward doctorates, technicians and undergraduates in that department.

The research furthers the art of gear manufacturing for GRC members. The advances show up in the form of better machines, tools and other technologies, which benefit the gear industry.

"Many of the technologies that we currently use on our machines have been developed at the GRC," says Klaus Peiffer, vice president–product development & technology for Gleason Corp.

Peiffer, Gleason's representative in the GRC, can easily think of four GRC contributions to gear manufacturing:

1.) better understanding of hobbing, shaping and bevel cutting through simulations;

2.) development of processes for dry cutting gears with high speed steel tools;

3.) improvement of skiving through study of its tool systems, tool materials, cutting geometry and operating data, like speeds and feed rates; and

A Well-Equipped Gear Department

Research work is done with modern gear manufacturing and measuring machines, including:

- a Gleason-Pfauter P 300 hobber, installed in 2000;
- a Kapp VAS 55 P gear profile grinder, in 1996;
- a Liebherr LC 122 hobber, in 1997;
- a Liebherr LFS 182 gear shaper, in 2003; and
- a Sampuntensili K 250 HSC bevel gear cutter, in 2003.

Besides machine tools, the department has numerous test rigs:

- a power train test rig,
- a bevel gear power-circulating (PC) test rig,
- 24 back-to-back test rigs,
- 11 twin-disk test rigs,
- four pulsator test rigs,
- a Klingelnberg T20 bevel gear tester, and
- two spur and bevel gear noise test rigs for single-flanks tests.

The gear department also has several metrology machines, such as:

- two Zeiss CMMs,
- a Klingelnberg P40 gear measuring machine,
- a Stresstech X 3000 X-ray analyzer
- a Seifert XRD 2000 X-ray analyzer,
- a Stresstech Rollscan 300 Barkhausen-noise analyzer, and
- a scanning electron microscope.

Modern Gear Machinery—The WZL gear department includes several modern gear machines on loan from GRC companies. The department uses the machines to conduct its 25+ research projects, both GRC and non-GRC.

4.) better understanding of profile grinding, so grinding burn can be prevented.

Peiffer adds that the profile grinding research is recent, even ongoing, with its results only now being introduced into industry application.

Dividing Up the Work

The department's research covers gear design, gear manufacture and running behavior. Design is handled by the gear calculation team. The gear manufacturing team works on hobbing, shaping, shaving, grinding, honing and other manufacturing processes. Studies of load carrying capacity and running, stress and noise behaviors of gears are performed by the gear investigation team.

Together, the three teams include some 16 scientists. These mechanical engineers hold diplomas equal to master's degrees in the United States, and most are working toward doctorates.

Undergraduate assistants help perform and evaluate trials. Manufacturing engineering students, they work on the teams for 11–19 hours a week—in addition to their regular studies.

GRC companies provide equipment and funding for the department to do its work. The money comes from two sources: a one-time admission fee for new GRC members and an annual membership fee. Each fee ranges from 3,500€–14,500€ (about $4,200–$17,500). GRC annual fees alone make up about 30% of the WZL gear department's budget.

Both admission and annual fees, however, vary depending on a company's size and what it manufactures.

GRC money supports two types of research: common and applied. Common research is funded by groups of companies, and applied research is sponsored by one or very few companies. The third type, pure research, is funded by public organizations. Of the department's 25+ projects, only some of them are GRC projects.

Membership Has Advantages

GRC research results are restricted to members, so the companies gain a competitive advantage over nonmembers. GRC companies also receive the results of the department's German and European publicly funded projects.

The department presents the research results of 16–18 technical papers to GRC members during its annual spring gear conference, which is held at Eurogress, Aachen's convention center.

This August 17–18, the department will give a shorter version of its conference at The Gleason Works in Rochester, NY. This version will consist of the best presentations from the '05 conference—held in April—and will be for the benefit of U.S.-based member-companies who didn't attend the Aachen meeting.

Members can send employees to either conference. Each attendee receives a copy of the spring conference's proceedings, including a detailed report of each presentation and a list of all other literature published by members of the WZL gear department.

Another advantage of membership in the GRC is that members participate in many segments of the gear industry, including machine tools, metrology, cutting tools, abrasives and coatings. Many R&D partnerships are possible.

"It's all these partnerships that make a total system work," Gleason's Peiffer says. "In the GRC, we can find any kind of partner in this business."

Coming Up with Ideas

Thinking of research projects for 70+ companies is a research project in itself.

"It's hard to find topics that are of interest to all of them," Klocke says. "However, we continuously ask them for ideas and their opinions about future challenges, and we consider them in our proposals for new projects.

"We have to make sure that larger groups of member-companies can take advantage of the research results."

Results

Klocke sees the long-term research work as the starting

A New Home, A New Test Rig—WZL is expanding its research work to include aspects of the system behavior of transmissions and has taken steps to prepare for this work. WZL's new building, though still being constructed, already houses a universal gear test rig in its basement.

point for advances in gear manufacturing. From the WZL building in Aachen, the research results are taken by GRC companies and used in their factories around the world, enhancing techniques for designing and manufacturing gears or becoming improvements or innovations in gear machine tools, cutting tools and materials.

"It's up to the technology suppliers to develop a technology to industrial relevance," Klocke says. "Our job is mainly to show the potential."

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The WZL gear department is working on more than 25 projects.

The following isn't a complete list of them, but it shows projects undertaken by each WZL gear team, both for the GRC and for other organizations:

Gear Manufacturing Team

Discontinuous Form Grinding

- Potential of new dressable grinding wheels. The goal: Learn the behavior and potentials of modern grinding wheels in relation to grinding burn. Sponsor: GRC
- Determination of characteristic values to avoid grinding burn. The goal: Find a systematic way to predict grinding burn in discontinuous profile grinding. Sponsor: German Federation of Industrial Cooperative Research Associations (AiF)

Gear Honing

- Potential of ceramic tools. The goal: Study the performance of different types of honing tools in the cutting process and in the dressing process. Sponsor: GRC
- Process simulation by means of FEA. Honing is a grinding process with very low cutting speeds. The goal: Obtain fundamental information about grinding processes with very low cutting speeds. Sponsor: German Research Foundation (DFG)

Hobbing

- Potential of cermet cutting tools in hobbing. The goal: Study types of new cermet materials to determine their potential in hobbing. Sponsor: Research Association for Machine Tools and Manufacturing Technology (FWF)
- Reconditioning of carbide hobs. The goal: Learn why carbide hobs in industrial applications do not show reliable wear behavior and find the solution to this problem. Sponsor: Research Association for Machine Tools and Manufacturing Technology (FWF)

Bevel Gear Cutting

- High speed cutting of bevel gears. The goal: Study the effect of process parameters, cutting materials, coatings and other influence factors on the wear behavior in bevel gear cutting. Sponsor: German Federation of Industrial Cooperative Research Associations (AiF)

Gear Shaving

- Process Simulation by Means of FEA. The goal: Determine loads on tools under specific conditions of the gear shaving process, a very complex process geometrically and technologically. Sponsor: German Research Foundation (DFG)

Gear Calculation Team

Tooth Root Geometries

- Optimization and generation of arbitrary tooth root geometries in gear manufacturing processes. The goal: Find a way to determine tool geometry based on a given tooth root geometry. Sponsor: GRC

Tooth Contact Analysis

- Influence of gear errors on noise emission of gears. The goal: Find critical and less critical gear geometry errors in terms of noise emission. Sponsor: GRC
- Design of function-oriented, acceptable manufacturing errors for bevel gears. The goal: Determine the effect of different gear geometry errors on excitation of and contact patterns for bevel gears. Sponsor: Industrial Research Foundation (Stiftung Industrieforschung)

Process Simulation

- Development of SPARTApro. The goal: Help manufacturing engineers optimize the hobbing tool and its process. The software is available only to GRC member-companies. Sponsor: GRC
- Modeling and calculation of chip creation parameters in bevel gear cutting. The goal: Create a bevel gear version of SPARTApro. Sponsor: German Research Foundation (DFG)

Gear Investigation Team

Noise Behavior

- Noise analysis of a real gearbox. The goal: Learn the influence of bearings and housings on noise emission of a real gearbox in addition to noise emission of the gears. Sponsor: German Research Foundation (DFG)

Load Carrying Capacity

- Potentials of PVD coated gears. The goal: Determine the potential of PVD coatings on gear flanks to replace toxic additives in the oil. Sponsor: German Research Foundation (DFG)

The Machine Tool World, All in One Place

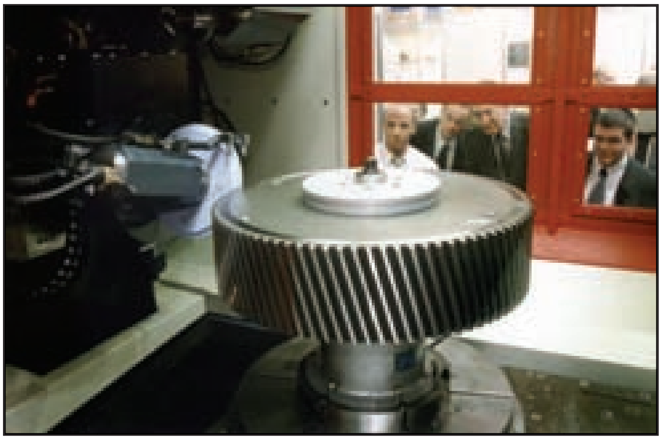


Photo: Deutsche Messe AG, Hannover

Soon, machine tool users will again be able to visit the machine tool world by going to one place: Fairgrounds Hannover in Germany.

EMO Hannover 2005: The World of Machine Tools will open on the fairgrounds Sept. 14 and continue through Sept. 21.

One of the world's largest trade shows, EMO is a chance for machine tool users to see a wide range of machinery, with more than 14 buildings featuring equipment, including milling machines, lathes, forming machines, machining centers, grinding machines, and gear cutting machines.

Attendees from the gear industry should find interesting products in the exhibits on cutting, splitting and milling machines; precision tools, diamond tools, and measuring tools; coolants and lubricants; surface finishing technology and thin-film processes; and robotics and automation.

Admission prices vary. A day ticket costs 25€, a season ticket 45€, and a student ticket 10€.

Additional information can be obtained via *www.emo-hannover.de.*

A symposium, "Cutting Edge Machine Tools for Tomorrow's Production," will be held Sept. 15–16.

The discussion will be divided into five themes: "The Future of the Machine Tool," "Micro and Precision Machining," "Simulation and Optimization," "Modularization" and "Automation." The information is based on research projects funded by Germany's Federal Ministry for Education and Research (BMBF) and is being held by The German Machine Tool Builders' Association (VDW) and the Research Centre Karlsruhe's production and manufacturing technologies division (PFT).

The symposium costs 95€ for admission for one day, 150€ for both days. Its languages will be German and English.

EMO Hannover 2005: The World of Machine Tools

Dates: September 14–21, 2005
Hours: 9 a.m.–6 p.m.
Site: Fairgrounds Hannover, Germany
Organizer: The German Machine Tool Builders' Association (VDW)
Web: *www.emo-hannover.de*

Admission Fee

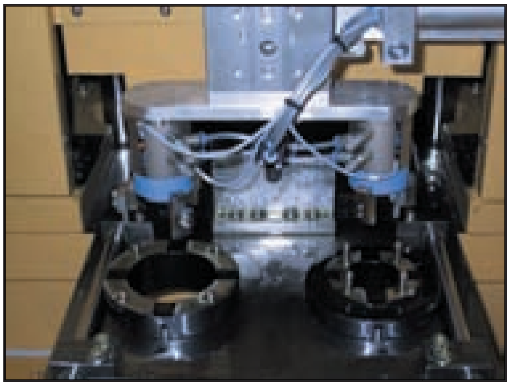
Day ticket	25€
Season ticket	45€
Student ticket	10€

Hall 2 hosts many gear machine tool exhibitors, including:

• Doimak	A57
• Fässler	A36
• Frenco	A73
• Gleason	A56
• Höfler	A58
• Kapp	B56
• Klingelnberg	C42
• Koepfer	C43
• Lambert	A59
• Liebherr	C42
• Reishauer	A72
• Samputensili	D40
• Wera Werk	B59

EMO Hannover 2005 will have exhibits on:

- Machine tools for cutting, splitting and milling
- Precision tools, diamond tools, measuring tools
- Coolants, lubricants
- Welding, cutting, hardening, heating
- Surface finishing technology, thin-film processes
- CAD/CAM
- Instrumentation and control technology
- Robotics and automation
- Mechanical, hydraulic, electrical and electronic accessories for manufacturing technology
- Industrial electronics, sensor and diagnostic technology
- Sheet metal, wire and tube working machines, metal forming machine tools
- Machine tools for thermal, electrochemical and other processes
- Software for entire manufacturing technology area
- Control systems
- Components for flexible automation
- Quality management systems
- Material flow and storage technology
- Metal forming machine tools
- Machines and systems for tool and mold construction, rapid prototyping, model construction



Attendees of the free "New Technology Broaching Seminar" will learn about technologies for making parts like these better, faster and cheaper.

Broaching Seminar to Attract Leading Experts

Manufacturers can learn about the latest technologies in broaching by attending the free "New Technology Broaching Seminar" being held by Broachman LLC in Dearborn, MI, on October 11.

"The seminar will provide attendees with the basics of broaching as well as educate them on the newest technologies that will result in broaching parts faster, better and at a lower cost per piece broached," says Ken Nemec, president of Broachman.

The seminar will include presentations from people at a wide variety of broaching industry companies, including Stenhøj Hydraulik, Broachman LLC, Triple E Manufacturing, Parma Broach, Katexim Broach and Berghaus Broach.

In addition, many related technologies will be covered by presenters from companies that are involved with materials, coatings, lubrication, inspection and deburring, including Bohler Uddeholm Specialty Metals, Gold Star Coatings, Master Chemical, Balzers, Process Equipment Co. and On-Line Services.

"Sharing technologies will be a key to the success of our seminar," Nemec says. "Our focus will be sharing ideas and innovation to reduce costs and improve quality and the bottom line."

The seminar, which includes lunch, will be held at the Holiday Inn Fairlane-Dearborn in Detroit, and the organizers are expecting as many as 300 attendees. The format will be 10–15 minute mini-presentations until lunch, followed by several break-out meetings including question-and-answer sessions.

Registration is available online at *www.broachman.com.*

For more information:
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Website: *www.broachman.com*

EVENTS

Making Bevels and Hypoids Right Requires Training

Machine tools, cutting tools and other needed supplies—that's the easier part of making bevel and hypoid gears. With settings from well designed gears and gear blanks of the right tolerances, the machine tools will do their jobs.

The harder part is creating the good designs and figuring the right tolerances. That requires understanding from gear engineers, and understanding requires training.

Gleason Corp., however, offers that training via two courses on designing and manufacturing bevels and hypoids.

The first course, "Fundamentals of Bevel Gear Design," is recommended for people currently designing and engineering gears. It emphasizes design elements of bevels and hypoids, with lectures on gear theory, terminology, selection of gear size, tooth design parameters and cutting methods.

Students calculate a gear dimension sheet using Gleason computer programs and evaluate the resulting stress data. They also learn about gear lubrication, gear mountings, types of failures, gear blank dimensions, gear blank tolerances, and calculating gear life.

The course includes machine and process demonstrations on Gleason's latest equipment and software.

"At the end of the course, the student will have learned enough of the basics to be able to design a gear set," says Richard Jaworski, application engineer, customer support–Asia/Pacific. Jaworski is the main teacher for both bevel/hypoid courses.

The first course should be taken after attending Gleason's more general course on gear process theory. Likewise, people should take the fundamentals course before the second bevel/hypoid course, "Applied Gear Engineering."

"The applied gear engineering course is an extension of the fundamentals course," Jaworski says.

Attendees of the applied course should be designers of bevel and hypoid gears or be responsible for creating cutting or grinding summaries.

According to Jaworski, the applied course promises to provide students with a working knowledge of the theory of tooth contact pattern development and the use of Gleason computer programs for tooth contact analysis—TCA, undercut checks and machine summary settings.

Like in the first course, instructors teach via lectures, discussions and hands-on workshops with Gleason computer programs.

Also, students learn about product application testing, software for loaded tooth contact analysis (LTCA) and finite element analysis (FEA), and methods of hard finishing bevels and hypoids.

Each 12-student course is taught in the same classroom, which features 12 computer work stations with wireless connections to Gleason's local training network.

In both courses, students can bring specific design problems to discuss with instructors. The problems can be reviewed either in class as a group or individually after class depending on the nature of the problem and the design's confidentiality.

"We take the time to work with the individuals after class on their designs if they wish," Jaworski says.

In the fundamentals course, students bringing problems should make sure their data include horsepower, speed, ratio and torque loads.

In the applied course, they should bring the following for their existing or future applications: horsepower, speed, torque loads and size restrictions.

In both courses, attendees should bring electronic calculators.

The remaining sessions for the fundamentals course are Aug. 22–26 and Nov. 7–11, and for the applied course Aug. 29–Sept. 2 and Nov. 14–18. Attendees must submit their registration forms so Gleason receives them 30 days or more before the starting date of the first course.

"Usually these classes book within 30–60 days before start of class," says George Baldwin, manager of Gleason's customer/dealer training department.

The courses are taught at The Gleason Works in Rochester, NY. Attendees can stay at any of nine hotels in the Rochester area. Gleason can reserve hotel rooms for students, or they can make their own reservations. When making them, attendees should ask for the Gleason corporate room rate. Hotel information, including rates and distances to The Gleason Works, is available on Gleason's website.

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Corrections

In the May/June issue, on page 19, two equations and a number of in-text variables didn't appear as they should have in the leftmost column. Equation 1 should have appeared as it does below. Also, the arrows somewhat above Equation 2 should have been just above its *x* and *x′* variables. Likewise, the arrows elsewhere in the column's text should have appeared just above their nearby *x*, *x′* and x_0 variables.

$$\sum_i \left(|\vec{x}_i - \vec{x}_0| - d_i\right)^2 \longrightarrow \text{Min} \quad (1)$$

In the May/June Industry News section, *Gear Technology* reported that Star SU consolidated sales with Bourn & Koch and Winco. In the case of the Winco consolidation, the sales of each company's tool product line will be affected, not their *gear* tool product lines.

We apologize for these inconveniences.
—The Editors

EVENTS

September 6–9—9th International Conference on Shot Peening. UMLV, Copernic Building, Paris, France. Focuses on shot peening, deep rolling, laser peening, ultrasonic peening, combined and cold work processes. 750€. Fees are reduced to 700€ for members of universities. For more information, contact IIIT International by e-mail at *nikulari@iiit.com* or on the Internet at *www.icsp9.iiit.com*.

September 13–14—Advances in P/M Gear Technology Seminar. Crowne Plaza at Detroit Metro Airport, Romulus, MI. Presents a future outlook for P/M gearing as well as the automotive industry's changing requirements. Also covers P/M heat treating, gear design, material selection, tooling, manufacturing inspection and applications. For registration before Aug. 12, $825 for MPIF members, $925 for members of APMI and $1,025 for non-members of either organization. For registration after Aug. 13, $925 for MPIF members, $1,025 for APMI members and $1,150 for non-members of either. For more information, contact MPIF by telephone at (609) 987-8523 or on the Internet at *www.mpif.org*.

September 13–15—Basic Gear Noise Short Course. Department of Mechanical Engineering, Ohio State University, Columbus, OH. Aimed at gear designers and noise specialists who encounter noise and transmission problems. $1,390. For more information, contact the Gear Lab by telephone at (614) 292-5860 or on the Internet at *www.gearlab.org*.

September 14–16—International Conference on Gears. Technical University of Munich, Garching, Germany. Keynote addresses and presentations for manufacturers, developers, engineers, designers, researchers, users and suppliers of all types of gears, gear components and gear materials from throughout the world. The official language of the conference is English, although some presentations will be in German. Conference fee is 980€ and is reduced to 882€ for VDI members or members of sponsoring organizations. For more information, contact the conference headquarters on the Internet at *www.vdi-wissens-forum.de*.

September 19–20—14th Annual Gear Failure Analysis Seminar. Big Sky Resort, Big Sky, MT. Sponsored by AGMA, this seminar explores various types of gear failure, such as macropitting, micropitting, scuffing, tooth wear and breakage. Handouts include a 272-page manual, which has copies of seminar presentations, reference technical papers and an atlas of 36 photographs showing and explaining all failure modes. $625 for AGMA members, $845 for non-members. Class size is limited to 30 participants. For more information, contact AGMA by telephone at (703) 684-0211 or by e-mail at *tech@agma.org*.

September 27–29—Wisconsin Manufacturing & Tool Expo. Wisconsin Expo Center at Wisconsin State Fair Park, Milwaukee, WI. Seminars concentrate on metalworking technology for both large and small job shops as well as business management practices. New product areas include plastics manufacturing and production. $10 for all three days. For more information, contact Expo Productions by telephone at (800) 367-5520 or on the Internet at *www.expoproductions.com.*

October 10–13—Gear School 2005. Gleason facility, Rockford, IL. A blend of shop time, classroom study and lectures covering fundamentals, high speed steels and coatings, gear cutting and inspection. $895. For more information, contact Gleason Cutting Tools at (815) 877-8900 or on the Internet at *www.gleason.com.*

October 18–20—Expo Metalmecanica 2005. Expo Guadalajara Center, Guadalajara, Mexico. Part of International Manufacturing Week of Mexico. Product categories consist of machinery and supplies; robotics and automation; metal joining and assembly; material handling and storage; quality control, calibration and testing; software and systems; surface finishing tools and supplies; engineering and maintenance; and plant safety and environmental protection. Registration is free through the pre-registration period, which ends Oct. 11. For more information, contact Roc Exhibitions by telephone at (630) 271-8210 or by e-mail at *info@rocexhibitions.com*.

October 18–20—Mid-Atlantic Machine Tool Show. Fort Washington Expo Center, Fort Washington, PA. Attendees evaluate machining centers, metalworking equipment, robotics, metal cutting tools, quality control and inspection, among other technologies. Attendance is free. For more information, contact the American Machine Tool Distributors' Association by telephone at (800) 878-2683 or on the Internet at *www.amtda.org*.

John J. Perrotti

Gleason Acquires M&M Precision Systems

Gleason Corp. acquired M&M Precision Systems Corp. on June 24.

According to the company's press release, Gleason will retain M&M's existing management team. Main operations will remain in the Dayton, OH, area. Under Gleason's ownership, M&M will be renamed Gleason M&M Precision Systems Corp. Sales and distribution channels will be integrated with Gleason's existing sales offices and representatives in most markets.

John J. Perrotti, Gleason's president and CEO, said in a press release, "M&M brings complementary products that further strengthen our ability to serve our global markets. By leveraging Gleason's leadership in gear technology and our global reach, we believe great opportunities exist to expand sales of M&M's products."

Knoy Joins American Wera

Scott Knoy was hired as vice president of sales by American Wera.

Among his responsibilities will be sales and customer service for WERA profilators, tooth rounding and pointing equipment as well as PRAEWEMA honing machinery.

Prior to this position, he was employed as a regional sales manager for Gleason Corp. Knoy has worked in the gear industry for the past 12 years.

EMAG Buys Jos. Koepfer & Sohne GmbH

EMAG has acquired majority interest in Jos. Koepfer & Sohne GmbH.

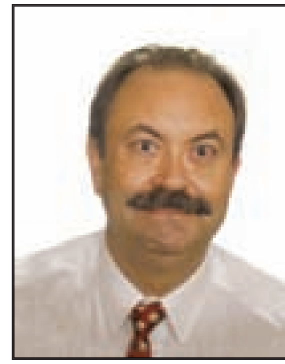
Present product lines and personnel will remain, according to the company's press release. In North America, EMAG of Farmington Hills, MI, will continue to service customers with EMAG Production Centers and related machines.

Within the new EMAG group, Koepfer will act as the gear technology center. In total, the Koepfer group comprises three enterprises for the development and building of high precision gears, cutting tools and high precision parts. Its consolidated sales figures for 2004 were 60 million euros.

EMAG specializes in manufacturing high production turning and multifunction production centers. Its consolidated sales for 2004 were 350 million euros.

During EMO 2005, the company will display its first development. The VSC250DUO WF is a multifunctional production machine that integrates double-spindle turning, hobbing and deburring in a single cycle.

Philadelphia Gear Appoints Sales Rep for Latin America

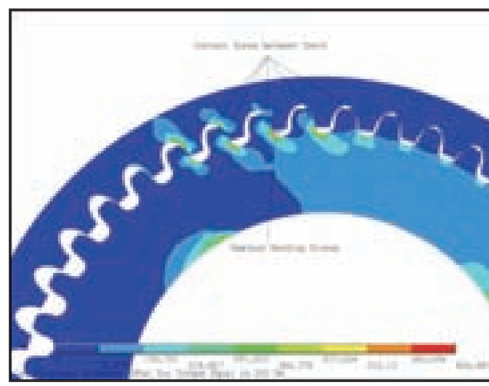


Jorge J. Flores

Philadelphia Gear Corp. hired Jorge J. Flores as direct sales representative for Latin America.

According to the company's press release, Flores will be responsible for increasing and developing business with energy-related companies from Mexico to Argentina. Overall, it requires Flores to maintain a solid and constant presence in the market of the Latin American countries.

Prior to joining Philadelphia Gear, Flores founded "Power Transmission Elements," a training course for maintenance personnel covering the history and basics of power transmission.



Ikona Launches New Gearing Technology Services Division

Ikona Gear launched a services division that enables clients to leverage advanced finite element analysis services for evaluating and improving custom gearing solutions.

Finite element analysis (FEA) is a technique for modeling complex structures used in situations that are difficult to model with standard engineering techniques.

FEA helps Ikona Gear verify whether a proposed design will be able to perform to the client's specifications prior to manufacturing or construction.

According to the company's press release, United Gear & Machine Works just utilized the new division to evaluate high-end planetary gears purchased from third-party suppliers.

Laith Nosh, Ikona's president and CEO, says, "As an industrial gear manufacturer, United Gear requires all gears from third party suppliers to be of the highest quality and able to perform under exceptional conditions. By leveraging FEA services, the company was able to quickly and accurately evaluate its planetary gears, make recommended alterations to improve performance, reduce risk of failure and satisfy the end user's requirements."

Gleason Appoints New Sales Management

Gleason Corp. has appointed John M. Terranova and Kelvin T. Harbun as vice presidents of sales.

Terranova is vice president of American sales and responsible for the sales and marketing of Gleason products, including those from the Gleason technical support centers in Novi, MI, and Queretaro, Mexico. He has worked at Gleason in a number of technical, sales and manufacturing positions, most recently as head of the implementation team for lean processes at The Gleason Works in Rochester, NY.

As vice president of Asia-Pacific sales, Harbun will be responsible for the sales and marketing of Gleason products in Japan, China, Korea, India, Australia and Thailand. Most recently, he worked in Ludwigsburg, Germany, in association with Gleason-Pfauter and Gleason European sales.

In Memoriam: Gear Manufacturer Joseph M. Garfien: 1909–2005

Joseph M. Garfien, co-founder of United States Gear Corp., died May 5 from an infection. He was 95 years old.


Joseph M. Garfien

Mr. Garfien had more than 70 years of experience in the gear industry, starting as a machine operator in the late 1920s, when he was newly arrived in America, and including work for the U.S. and Israeli governments.

An Austrian immigrant, Mr. Garfien's journey to the United States started with several soccer games in the United Kingdom. In 1928, he was a teenaged player with the Austrian national team and traveled with it to Great Britain. After the games, he continued westward, an uncle in Chicago sponsoring his immigration.

"There wasn't very much opportunity in Austria at the time," Mark Garfien explains about his father's decision.

But, arriving in Chicago, Mr. Garfien had no job, no money, no English. He dealt with his first two problems by joining Perfection Gear, beginning as a machine operator. He also drew a second income from playing soccer. As for English, the Polish-speaking Mr. Garfien learned that over time.

At Perfection, he became a practical, hands-on gear engineer with an intuitive grasp of gear geometry and manufacturing, a grasp that he made good use of and became known for. By 1941, Mr. Garfien was consulting with the U.S. Army to deal with the poor performance of some of its trucks. In '53, though, he left Perfection to become his own boss, co-founding International Gear. He left that business 10 years later to co-found a second company, U.S. Gear, with his son and son-in-law, Don Garfield. Today, U.S. Gear employs 300 people in Chicago and is still owned and operated by the Garfien family.

In the late '60s, Mr. Garfien worked with the Israeli government on gear-related projects. In 1967, he helped it reverse engineer the gears of Soviet-made tanks and trucks captured during the Six Day War. Through reverse engineering, the government could judge the state of Soviet gear manufacturing and, by extension, estimate the state of Soviet heavy industry. Also, Mr. Garfien helped set up the Israeli gear manufacturer Ashot Ashkelon. A souvenir of his Israeli work hangs on a wall at U.S. Gear: a photo of himself shaking hands with Golda Meir.

Mark Guggenheim, a 17-year employee, describes Mr. Garfien as a likable fellow, a firm boss, but one who cared about his employees and was willing to listen to them.

"Joe had a lot of longtime employees," says Guggenheim, U.S. Gear's vice president of manufacturing and engineering. "He treated his people with respect. He was loyal to them."

Outside the Garfien family, several U.S. Gear employees are the children of past employees. Mark Garfien thinks this says something about his father as U.S. Gear's leader: "He could be trusted."

By the late '90s, Mr. Garfien had ceded day-to-day administration of U.S. Gear to his son, the company's president, and his son-in-law, its vice president of sales. Still, he came in every workday, except for his last four months, when he cut back to three days.

"He wanted to get here every day, bright and early, just to be here," Guggenheim says.

Mark Garfien recalls his father's love of his family and love of his country.

Mr. Garfien is survived by his son; two daughters, Barbara Garfien and Charlene Garfield; nine grandchildren; and three great-grandchildren.

Guggenheim, invited a number of times to Mr. Garfien's home, says the gear manufacturer loved to show off his gardens, would buy flats and flats of flowers at the beginning of the season. At his funeral, Mr. Garfien's family provided baskets of flower seeds for mourners, asking them to plant the seeds in memory to him.

After he died, a grandson discovered in a desk drawer in Mr. Garfien's home a tape player with a cassette recording of "God Bless America."

Michael Goldstein, a 40-year friend and associate, learned about the recording at Mr. Garfien's memorial service and thought: "God did bless America, He sent us Joe Garfien."

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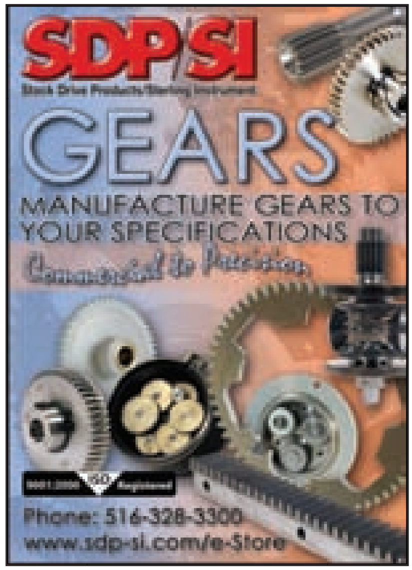

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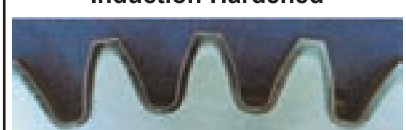

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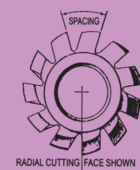

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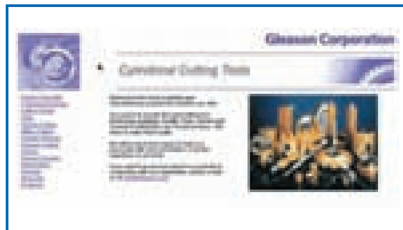

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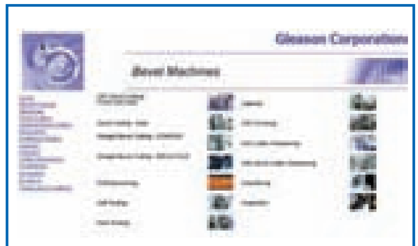

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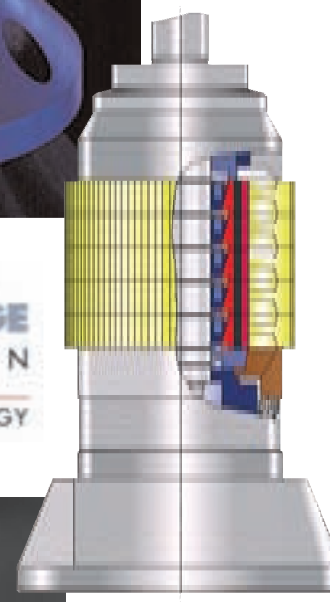

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