GEAR TECHNOLOGY

SEPTEMBER/OCTOBER 2003

The Journal of Gear Manufacturing

www.geartechnology.com

GEAR EXPO SHOW ISSUE

- Booth Listings & Map
- Columbus Entertainment Section
- Showstopper Advertising Section

FEATURES

- Company Profile: Horsburgh & Scott
- Solid Model Generation of Involute Cylindrical Gears
- Direct Gear Design: Bending Stress Minimization
- Gears in the Wind Energy Industry
- Local 3-D Flank Form Optimizations for Bevel Gears
- 10 Commandments of Gear Failure Analysis

THE GEAR INDUSTRY'S INFORMATION SOURCE

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SEPTEMBER/OCTOBER 2003

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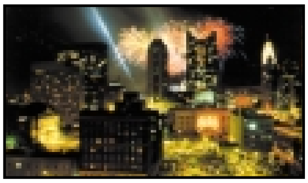


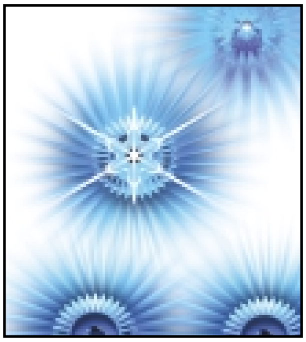
19

FEATURES

35

DEPARTMENTS

72



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Opportunity and Obligation

I was recently honored by the European Association of Machine Tool Merchants (EAMTM) at the organization's annual meeting this past June in Mallorca, Spain. The organization inducted me as a Fellow, EAMTM's highest honor, bestowed on members who have made significant contributions as volunteers serving the organization, which was originally founded in 1940. I felt especially honored, as I am only the 19th person and the second non-European to have been given this award.

In addition to being the publisher of *Gear Technology*, I am also the president of Cadillac Machinery Co., Inc., one of the world's largest dealers in used gear manufacturing equipment. Over the years, I've been an active volunteer in the associations of the used machinery business, including the Machinery Dealers National Association (MDNA). I served on MDNA's board of directors from 1976 to 1993 and on its executive committee from 1980 to 1993. I still serve as head of the investment committee for the MDNA's scholarship fund. I've been on the EAMTM board for more than 12 years and am now the second longest serving member.

Receiving this wonderful honor has caused me to reflect on my years of volunteer work in the associations, especially the opportunities that work has provided me, but also the obligation I feel we all have to help the industries which support us.

Working within a volunteer organization can provide great opportunities to learn and grow. For example, I got my start in publishing working as a volunteer for the MDNA, whose subsidiary, Machinery Information Systems (MIS), publishes a directory of used machine tools called the *Locator.* I sat on the board of trustees of MIS for 17 years, served as an officer for eight years and served as its president from 1981 to 1983.

When faced with major business decisions at MIS—buying a mainframe computer, buying a computerized typesetter, negotiating printers' contracts—it was we volunteers who had to do the job. Most viewed those tasks as chores, but I looked at them as opportunities to learn about computers, typesetting and printing.

As I learned about areas outside my normal business, I felt as though I was preparing for something, that the work I was doing on the *Locator* would be important down the road. I was right: After finishing my presidency at MIS in May 1983, I was able to launch *Gear Technology* the very next year. Without the knowledge and experience I had gained on the *Locator*, starting *Gear Technology* would have been more difficult, if not impossible.

In addition to gaining knowledge and experience, working as a volunteer provides many opportunities to improve your people skills. In a volunteer organization, you work with people who aren't beholden to you. Often, they're people with different agendas, and you have to get them to work together to solve problems.

Working in one of your industry's volunteer organizations exposes you to different people; some are your competitors, some end up being lifelong friends. By meeting and working with these people, you're exposed to different approaches, ideas and ways of doing things—not better, not worse, but different. These different viewpoints, approaches and perspectives can be useful when meeting your own business challenges. It also allows you a larger perspective of the industry and how and where your company fits in.

But the opportunities and personal satisfaction I've received from participating in these organizations aren't the only reasons I've given my time. I've always felt obligated to give something back to the industries that have been good to me. In one sense, that obligation comes from a respect for the work of the people who came before me. Two of those people were my father and grandfather, who were founding members of the MDNA in 1941, and seeing their contributions as volunteers was part of my training. In another sense, I feel obligated to contribute to the success of future generations.

The gear industry is affected by organizations that rely on volunteers. Hard work over the years has made this industry more organized and has made it run more smoothly. As a good example, can you imagine where we would be without industry standards? Over the years, AGMA's and other standards have been put together by many busy volunteers who took the time to get together and create them. The rest of us benefit from their work every day.

It's easy to sit back and reap the benefits of other people's hard work. But I feel we owe it to those volunteers, and to those who will follow us, to plant some seeds of our own. I volunteer in industry organizations so that when I'm done with my career, I'll be able to look back and see that I've made a contribution. When you look back on your own career, what will you see?

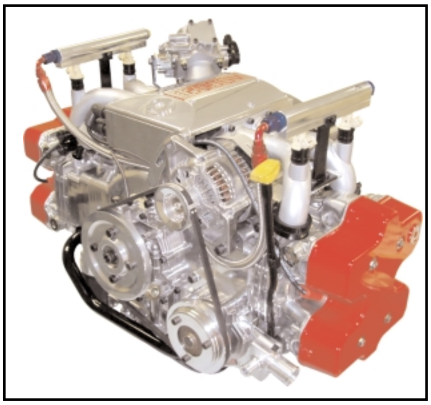
Michael Goldstein, Publisher & Editor-in-Chief

Australian Auto Engine Features Gears Inside Engine Block

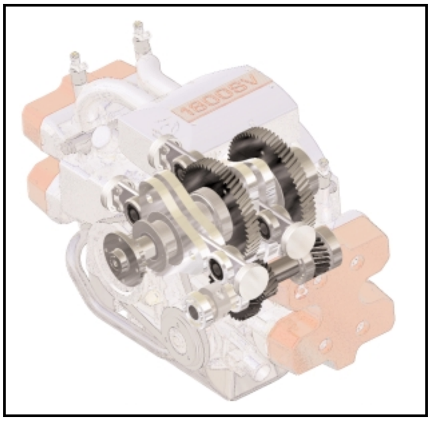
Seven years ago, an Australian mechanic decided to improve the internal combustion engine by ripping out its crankshaft, replacing it with a straight output shaft and transferring the pistons' power with cams instead of connecting rods.

Since then, the engine concept has been developed into three prototypes by Revetec Ltd., an R&D company in Sydney that designs engines. The development has taken place under the supervision of the engine's inventor, Bradley Howell-Smith, Revetec's managing director.

Today, the latest prototype engine, the CCE2003–01, is scheduled for factory production in a four-cylinder, four-stroke model for use in China's domestic cars. And in the heart of the engine, transmitting power to the output shaft, are five helical gears.



An Unusual Orientation—This Australian-built car engine features a horizontal piston assembly that uses cams, bearings and gears to transmit power to its "crankshaft"—a straight output shaft.



An Engine Block with Gears—Inside the engine block are five helical gears that transfer part of the engine's power to its output shaft.

With pistons driving cams, Revetec's engine has a much different shape than conventional internal combustion engines. Those engines have vertical or angled cylinders, Revetec's has horizontal ones. Each horizontal cylinder has an opposite on the other side of the engine, and their opposing pistons are attached to each other by a connecting rod. Two bearings are mounted on each end of each rod, and a three-lobed cam is mounted between each pair of opposing bearings. Thus piston action and engine power are re-created, but with a horizontal orientation.

The assembly lets Revetec replace the complicated, multi-offset crankshaft with a simple, straight output shaft. The assembly also splits power between its four cams. Two of those cams, the outer ones, rotate clockwise and are splined directly to the output shaft, which consequently rotates clockwise.

The two inner cams rotate counterclockwise, so their power has a counterclockwise motion. The motion doesn't interfere with the output shaft, though, because the inner cams ride on a sleeve on the shaft.

But Revetec doesn't want to waste that counter rotating power, so it uses five helical gears to reverse the power's rotation and add it to the output shaft. The first of those gears is mounted on the shaft's sleeve, between the inner cams.

That first gear, No. 1, is on the shaft's front end and turns counterclockwise. It meshes with gear No. 2, on the idler shaft. No. 2 meshes with No. 3, on a third shaft, the transfer shaft.

Via No. 2 and 3, motion is reversed to clockwise, then re-reversed to counterclockwise. Like No. 3, the transfer shaft also turns counterclockwise. But so does the shaft's other gear, No. 4. And No. 4 meshes with No. 5, the gear at the back end of the output shaft.

Thus motion is reversed one last time to clockwise and is added to the shaft.

According to Revetec, the redesigned engine has three main benefits: 1.) control of the torque and power curves, 2.) the ability of engine output to be tailored to an application and 3.) greater fuel efficiency. Revetec is working with organizations to verify its theoretical and practical data about the engine's capabilities.

The CCE2003–01 is a four-cylinder, 16-valve engine with sequential fuel injection and a swept volume of 1.8 liters. It can be either two- or four-stroke, gasoline or diesel, and natural or forced aspiration. The prototype is 280 mm deep, 650 mm wide and 500 mm high. In inches, that's 11 x 26 x 20.

Justin Stockl, a CAD engineer with Revetec, expects the prototype's production version to weigh 50–55 kg, or 110–121 lbs. Mark Newcombe, Revetec's marketing manager, adds the 2003–01 can be manufactured with common technology—no special machinery needed.

And its planned manufacture for China's cars is just a first step. "It's initial market entry," Newcombe says. He explains that Revetec sees its engine as benefiting the majority of applications for internal combustion engines, automotive and other.

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

"Our goal is to obtain penetration into these markets," Newcombe says. "That's the big picture goal."

Software That Keeps Helicopters Flying High

Most gear-related software aims to save money for a company, but the U.S. Navy-funded software project GearLife has a more altruistic goal—saving lives.

This gear prognostics module utilizes software from Impact Technologies of Rochester, NY, to create a multi-physics analysis environment that strives to create gear failure predictions in critical drive train applications. Impact Technologies received a Small Business Innovative Research Grant from the Navy to develop its software, which creates gear tooth models using proprietary gear-design software and analyzes them using the finite element analysis program ANSYS.

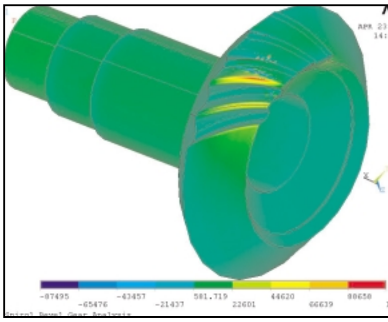
The lifesaving aspect comes from the fact that the module is designed for potential use in the gears of U.S. Navy helicopters. Ideally, GearLife will be able to detect when a helicopter's gears run the risk of not completing an intended mission.

Impact Technologies, the prime contractor for the Navy's assignment, collaborated with The Gleason Works to obtain the actual gear geometry and contact forces for spiral bevel and hypoid gears.

Lowell Wilcox, formerly a senior staff research engineer at The Gleason Works who has since retired, contributed a piece of commercial code software called T900 Windows Software for Finite Element Analysis of Bevel and Hypoid Gears as a contract assignment. He led a team in developing the code approximately 30 years ago and has updated it periodically ever since.

The software has the ability to convert gear geometry into finite element models of the tooth forms. A direct result of the procedure is that the nonlinear distribution of contact loads between the mating gear and pinion strength are solved as functions of the mating tooth form's flexibility and gear axle housing's support. Data transfer to GearLife from the Gleason Special Analysis files is automatic and seamless to the user.

According to Wilcox, the Gleason software has been used by 40 other cus-



tomers. Dana Corp., Caterpillar, Rolls Royce, and BMW have purchased the software (used by both Gleason and Impact Technologies) for applications where stresses are high.

Impact Technologies also contacted Fracture Analysis Consultants, of Ithaca, NY, to create a 3-D fracture simulation for predicting crack growth. Paul Wawrzynek, senior engineer for Fracture Analysis, says his company's software inserts the crack and locally remeshes. Then it performs an analysis of the cracked element, assigns a stress intensity factor around the crack and correlates it to test data.

"Our main function is to predict how fast the crack will grow," Wawrzynek says.

Avinash Sarlaskar, director of technology at Impact Technologies, explains his portion of the project.

There were three major parts to the analysis effort, he says. The first part entailed using the Gleason proprietary software for the accurate generation of gear geometry and contact forces on the gear, which led to the second part of calculating stresses in the critical fillet region, which is then analyzed using the Franc 3D commercial fracture analysis tool from Fracture Analysis.

"This is similar to predictions; for example, if you have a cholesterol level of X, there's a Y chance you may have a heart attack. This can tell you that, with the current condition of your gears, there's an 80% chance you can run this machine with certain level of risk for the next six months," explains Sarlaskar.

Sarlaskar says his predictions had very good accuracy. "In the world of high cycle fatigue (HCF), if your predictions come within a factor of two, then the results are considered to be very good."

To confirm this, the U.S. Navy conducted a series of tests where a helicopter transmission with seeded faults (insertion of intentional cracks/defects in gears) was tested. From time to time, the test was suspended and the seeded gear was inspected visually.

The analysis results were compared against these laboratory observations. The monitoring looked at correlating the vibration features, as well as other system parameters, with the size of the cracks. In summary, the size of the crack could be correlated reasonably well with the vibration features.

Though accurate, the module is not perfect. The technology is still not available to pinpoint exactly when gears will wear out because it's impossible to measure all factors, like pilots jamming gears.

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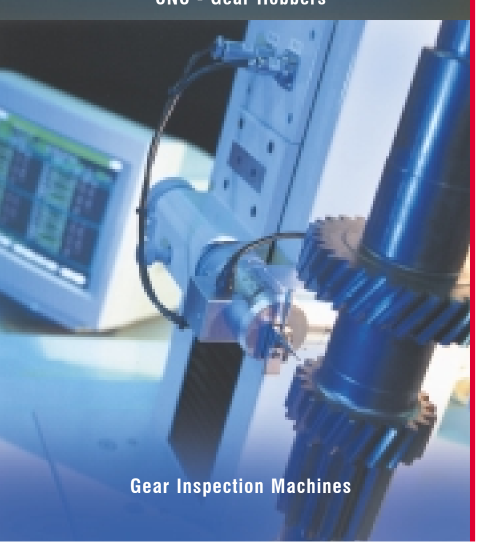

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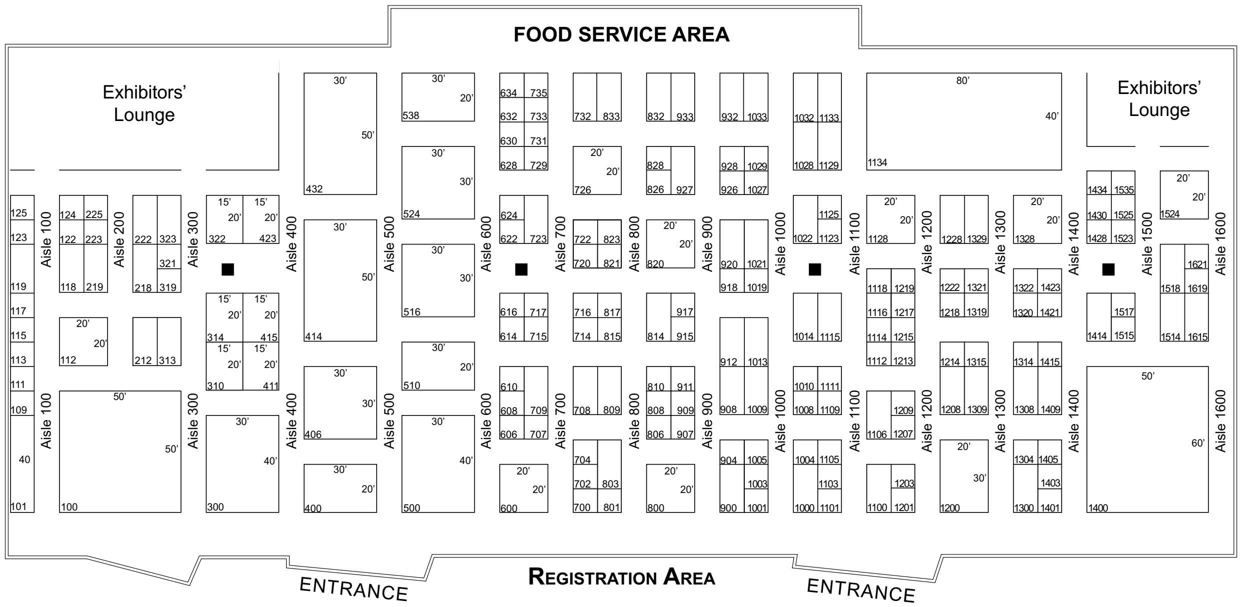

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A/W Systems Co.—Booth 111
Accu-Cut Diamond Tool Co., Inc.—Booth 1434
Accurate Specialties Inc.—Booth 1118
Acme Gear Co.—Booth 815
ADF Systems Ltd.—Booth 1022
ALD Thermal Treatment Co.—Booth 1203
All Horng Gear Industry Co. Ltd.—Booth 918
Allied Machine & Engineering Co.—Booth 1207
American Gear Manufacturers Association—Booth 800
American Metal Treating Co. —Booth 1209

Anca Inc. —Booth 310
Applied Process Inc.—Booth 926
Arrow Gear Co.—Booth 933
ATA Gears—Booth 920
B&R Machine & Gear Corp.—Booth 915
Balzers Inc.—Booth 900
Barit International Corp.—Booth 917
Bodine Electric Co.—Booth 717
Bodycote North America Co.—Booth 1414
Broach Masters/Universal Gear Co.—Booth 720
Broaching Machine Specialties Co.—Booth 700
Cadillac Machinery Co. Inc.—Booth 1033
Canmac Gears & Reducers Inc. —Booth 115
Capstan Atlantic—Booth 714
Chamfermatic Inc.—Booth 1125
The Cincinnati Steel Treating Co.—Booth 1028
Clifford-Jacobs Forging Co.—Booth 1004
Contour Hardening Inc. —Booth 928
Custom Gear & Machine Inc.—Booth 801
DuPont Engineered Polymers—Booth 908
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Euro-Tech Corp.—Booth 1329
Eurotrans—Booth 800
Extrude Hone Corp. —Booth 624
Fässler Corp.—Booth 400
Fhusa—Booth 411
G&G Manufacturing—Booth 1322
G&N Rubicon Gear Inc.—Booth 707
The Gear Industry Home Page—Booth 932
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Gold Star Coatings—Booth 319
Great Taiwan Gear Co. Ltd.—Booth 1001
Greg Allen Co. —Booth 732
Gupta Permold Corp.—Booth 702
Hamblen Gage Corp.—Booth 616
Hanik Corp.—Booth 907
Happy Forgings Limited—Booth 1219
Hawk Precision Components—Booth 1019
HobSource Inc.—Booth 1304
Hoffmann Filter Corp.—Booth 1515
Höfler Gear Grinding Machines—Booth 300
Hydra-Lock Corp. —Booth 1218

An expo exhibitor, Lambert & Wahli offer a variety of manufacturing equipment, including this gear hobbing machine.

Inductoheat—Booth 1109
Innovative Rack & Gear Co.—Booth 628
IonBond Inc. —Booth 1116
Ipsen International Inc.—Booth 716
Italian Trade Commission—Booth 1000
ITW Heartland—Booth 600
JRM International—Booth 538
Kapp Technologies—Booth 406
Koepfer America L.L.C.—Booth 516
Lambert & Wahli—Booth 832
Lapointe International Corp.—Booth 1328
LeCount Inc. —Booth 729
Leistritz Corp.—Booth 614
Liebherr Gear Technology Co.—Booth 1400
M&M Precision Systems Corp.—Booth 414
Machine Tool Builders Inc. —Booth 524
Marposs Corp. —Booth 1115
Metal Improvement Co.—Booth 1123
Metal Powder Products Co. —Booth 817
mG miniGears North America—Booth 1401
Microtect Diffusion Coating Technologies, Inc.—Booth 912
Midwest Thermal-Vac Inc.—Booth 1112
Mitsubishi Gear Technology Center—Booth 432

Russell, Holbrook & Henderson's ultra precise gear measuring machine certifies the accuracy of gears within 0.1–0.3 µm.

Nachi Machining Technology Co. —Booth 500
Nanjing Highspeed & Accurate Gear Co. —Booth 1320
Nanjing No. 2 Machine Tool Works—Booth 1027
National Peening—Booth 722
Neugart USA L.P.—Booth 606
Nissei Corp. of America—Booth 610
Nitrex Metal Inc.—Booth 1201

Nye Lubricants—Booth 809
Oak Ridge Gear Metrology Center—Booth 808
OEM Parts Co.—Booth 1314
The Ohio Broach & Machine Co. —Booth 1029
Ohio State University, Dept. of Mechanical Engineering—Booth 806
Okamoto Machinery Co.—Booth 904
On-Line Services—Booth 1114

Arrow Gear Co. will showcase precision manufacturing accessories for bevel, spur and helical gears from Booth 933.

Paulo Products Co.—Booth 814
Perry Technology Co.—Booth 1009
Precision Gage Co.—Booth 723
Preco Laser Systems L.L.C.—Booth 909
Presrite Corp.—Booth 820
Process Equipment Co.—Booth 726
Pyromaitre Inc.—Booth 1308
Quality Heat Technologies—Booth 1320
Rack & Pinion Inc.—Booth 622
Raycar Gear & Machine Co.—Booth 1309
Redin Corp.—Booth 510
Reishauer Corp. —Booth 1200
Reliance Gear Corp.—Booth 826
REM Chemicals—Booth 1111
Ribaut/Manoir—Booth 1014
Ronson Gears Pty. Ltd. —Booth 1214
Russell, Holbrook & Henderson—Booth 313
Samputensili—Booth 1134
Schafer Gear Works—Booth 708
Schütte TGM Ltd. —Booth 113
Scot Forge Co.—Booth 1213
Seco/Warwick Corp. —Booth 1128
Seitz Corp. —Booth 821
S.L. Munson—Booth 218
Solo World Partners—Booth 1208
Specialty Steel Treating—Booth 1133
Speedgrip Chuck Inc. —Booth 1105
Star Cutter Co. —Booth 1134
Star-SU Inc.—Booth 1134
SU America—Booth 1134
SW & Sons USA—Booth 1032
Ta Tung Gear Co. Ltd. —Booth 1106
Tech Induction—Booth 704
Testutor Systems—Booth 1008
Thermotech—Booth 1005
The Timken Co. —Booth 803
Toolink Engineering—Booth 1021
Trutec Industries—Booth 608
Tuson Corp. —Booth 1106
Ty Miles—Booth 1100
UFE Inc.—Booth 1013
Unigear Industries Inc.—Booth 1003
Viking Forge—Booth 715
Walker Forge Inc. —Booth 1010
Westerman Companies—Booth 1228
Western Pegasus Co.—Booth 823
Winterthur Corp. —Booth 212
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SME SEMINARS

October 6—Gear Processing and Manufacturing. Columbus Convention Center, Columbus, OH. Target audience includes process, manufacturing and design engineers, manufacturing managers, quality control engineers, shop supervisors, operators, job shop managers, and plant managers. Seven presenters will make 40-minute speeches. $395 for SME members, $495 for non-members. For more information, contact the SME by telephone at (313) 425-3098 or by e-mail at *lwalsh@sme.org.*

October 7—Design of Plastic and Powder Metal Gears. Columbus Convention Center, Columbus, OH. Taught by Ernie Reiter, president of Web Gear Services Ltd., this seminar focuses on identifying materials used in molding plastic gears, learning measurement techniques, specifiying gear tolerance and housing geometries. $395 for SME members, $495 for non-members. For more information, contact the SME by telephone at (313) 425-3098 or by e-mail at *lwalsh@sme.org.*

October 8—Gear Metrology. Columbus Convention Center, Columbus, OH. Session focuses on double-flank composite testing, tooth alignment, pitchline runout, standards overview, alternative testing methods, etc. Ed Lawson, chair of ANSI/AGMA's inspection handbook committee, is teaching this seminar. $395 for SME members, $495 for non-members. For more information, contact the SME by telephone at (313) 425-3098 or by e-mail at *lwalsh@sme.org.*

AGMA SEMINARS

October 6–8—AGMA Training School for Gear Manufacturing Basic Course. Greater Columbus Convention Center, Columbus, OH. Consists of the classroom training segment of the Gear Technology Training School held at Daley College in Chicago. $600 for AGMA members, $775 for non-members. For more information, contact the AGMA at (703) 684-0211 or by e-mail at *gearexpo@agma.org*.

Whatever your pleasure, Columbus is sure to have something to occupy those rare free hours you spend outside of Gear Expo.

For example, if your legs can still move after the show, Columbus is home to some fabulous golf courses. Bent Tree Golf Course, located at 360 Bent Tree Rd., in Sunbury, OH, is supposed to be very challenging, with water and tall trees located throughout the course. The gorgeous scenery and rolling fairways make this course one of the most famous in Columbus. Prices run from $48 on weekdays to $58 on weekends. For reservations, call (740) 965-5140.

More centrally located in Columbus is the Foxfire Golf Club at 10799 Route 104, which has both a beginner's and advanced course. The advanced course is considered to be the most challenging in central Ohio with the longest sand bunker in the Midwest. Costs for the Foxfire (beginner's course) are $11 for nine holes and $21 for 18 holes. Only the 18-hole option is available for the Player's Club, which is $32 on weekdays and $36 on weekends and holidays. For reservations, call (614) 224-3694.

If you can't possibly walk the greens after the show, you can still get in some

COLUMBUS HOT SPOTS

Events

- Gadgets Live! Center of Science and Industry (COSI), 280 E. Broad St., Experiments about potential and kinetic energy for children, including lessons on gear ratios.
- Kilroy Was Here Exhibit—Ohio Historical Society, 1982 Velma Ave., Ohio pop culture during the 1940s.
- Santa Maria Fall Tours, 90 W. Broad St. See one of the ships that made Christopher Columbus famous.
- Funny Bone Comedy Club, 145 Easton Town Center. Featuring petite Midwest comedienne Kathleen Madigan.
- October 11—Ohio State v. Michigan State football at Ohio State, time to be announced.

Live Music

Little Brothers, 1000 N. High St.
Amnesia Jazz Lounge and Nightclub, 384 W. Nationwide Blvd.
Barrister Hall Jazz Club, 560 Soyut

Breakfast

Chef-o-Nette, 2090 Tremont Ave.
First Watch, 496 High St.
Jack & Benny's, 2563 N. High St.

Coffee

Cup O'Joe, 627 S. 3rd St.
Coffee Table, 731 N. High St.
Stauf's, 1277 Grandview Ave.

Bookstores

Acorn Bookshop, 1464 5th Ave.
Book Loft of German Village, 631 S. 3rd St.
Half-Price Bookstore, 1375 Lane Ave.

Antiquing

Antiques and Art on Polar, 20 E. Lincoln
Fine Arts & Imports, 1356 Cherry Bottom Rd., Gahana
Echoes Art and Antiques, 24 E. Lincoln

Steak

Ruth's Chris Steakhouse, 7550 Highcross Blvd., (614) 885-2910
Hyde Park Grille, 1615 Old Henderson Rd., (614) 442-3310
Morton's of Chicago, 2 Nationwide Plaza, (614) 464-4442

Other Information Sources

www.columbusscene.com
www.columbuspages.com
www.columbusart.com
www.northmarket.com


Photo courtesy of Nationwide Insurance.

golf-related activity. The Jack Nicklaus Museum can be found at 2355 Olentangy River Rd. Inside, you'll find a traveling exhibit from the U.S. Golf Association's Museum Collection. The 50 framed photographs feature famous golfers as well as a few lucky ones who just happened to be standing around the cameras. The museum is open from 9–5 Monday–Saturday, and from 1–5 on Sunday. Admission is $9 for adults and $7 for seniors.

Not an athlete? There are more than enough museums to feed the cultural appetite of any Gear Expo attendee. The Columbus Museum of Art, 480 E. Broad St., (614) 221-6801, features works by Picasso, O'Keefe, Monet and Degas. It's open 10–5:30 Tuesday–Sunday, 10–8:30 Thursday. Admission is $6 for adults and $4 for seniors. The Center of Science and Industry (COSI), situated just down the street at 280 E. Broad St., (881) 819-2674, is open 10–5, Monday–Saturday and 12–6 Sunday. Admission is $12 for adults, $10 for seniors. The museum is broken up into seven "learning worlds." However, be careful of sitting too long at any computer—there's one that displays your face as it ages through the years!

Browsing may be the last thing you want to do after shopping at the expo all day. Or perhaps all that industrial purchasing you're going to do at the show will put you in a major shopping mood. Whatever the case, the Easton Town Center is at 4000 Worth Ave. and houses Nordstrom, Ann Taylor, Banana Republic and Pottery Barn.

Whether you've been shopping, golfing, museum hopping or just attending the expo, you'll certainly have worked up an appetite by the end of the day. Italian food is considered a local favorite, and Trattoria Roma, located at 1447 Grandview Ave., is supposed to have a phenomenal view of the city. If we're lucky enough to hit Indian summer, diners can sit outside. For reservations, call (614) 488-2104. Once you're stuffed, cleanse your palate at Martini Ristorante, 455 N. High St., (614) 224-8259, the place to see and be seen in Columbus. If you'd prefer a more laid-back atmosphere, High St. is home to plenty of bars centered on OSU sports. ⚙

Tell Us What You Think . . .
Send e-mail to *people@geartechnology.com* to
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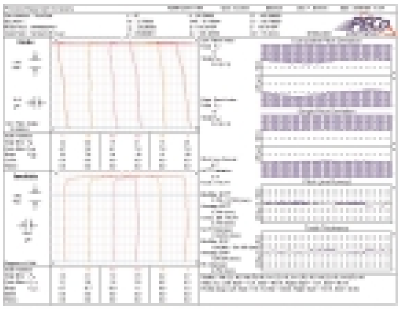
- **Contact the companies mentioned**
- **Make a suggestion**

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

Process Equipment Company

Booth Number: 726



Company Profile:

For over 50 years, Process Equipment Company (PECo) has been devoted to the design, manufacture and assembly of special machines for industry. Process Equipment has five plant locations, housing four business units, utilizing over 385,000 square feet of floor space. During the past five decades, PECo has built literally thousands of special systems including inspection machines, automated assembly equipment, laser welding and robotic systems.

Featured Product Lines:

• *ND430 Next Dimension®* Analytical Gear Measurement System
• Automatic Spline Inspection & Assembly utilizing the latest in robotic technology

Other Product Lines/Services:

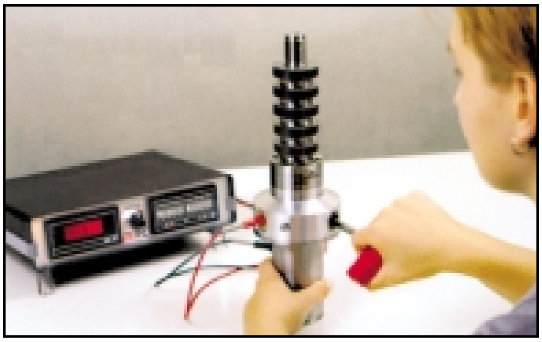
• Contract Gear Inspection
• Contract Manufacturing
• Automatic Laser Welding Systems
• High Speed Pulse Welding Systems
• Automation
• Robotic Accessories

Contact:

4191 US Rt. 40
Tipp City, OH 45371
Phone: 937-667-7105
Fax: 937-667-2591
E-mail: *pdgsales@processeq.com*
www.processeq.com

Euro-Tech Corporation

Booth Number: 1329



Product Line

MyTec GmbH, a hydraulic expansion clamping tool manufacturer located in Germany, is pleased to introduce the new "Power Control" system for highly repeatable clamping of gears or thin-wall parts. This system consists of an internal pressure transducer and a digital readout. While all MyTec hydraulic tools are rupture proof when expanded without a part, the addition of a "Power Control" unit assures extremely repeatable clamping of thin-wall parts without distortion. The system is extremely simple to use with the operator attaching 2 magnetic "paddles" to the arbor and actuating up to a pre-specified limit on the DRO. For more information, contact Euro-Tech Corporation at (262) 781-6777 or *www.eurotechcorp.com.*

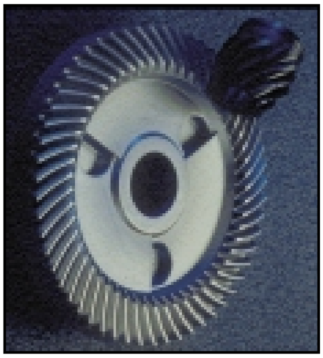
euro • tech

Contact:

N48 W14170 Hampton Ave.
Menomonee Falls, WI 53051
Phone: (262) 781-6777
Fax: (262) 781-2822
www.eurotechcorp.com

mG miniGears

Booth Number: 1401



Our extensive know-how, based on years of experience in motion transmission, our enduring reliability in flow systems engineering, as well as our mastery of diverse technologies, from the traditional machining of steel gears to the highly innovative metallurgical PM processes, make miniGears the ideal partner for designing, developing and manufacturing small and medium size customized mechanical components.

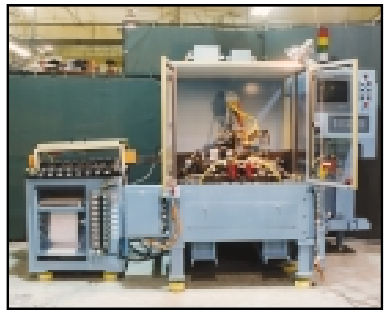
Our technical service and responsiveness in realizing our customers' design from concept to reliable mass production have made miniGears the premiere gear solution provider worldwide. Our continuously optimized mass-production processes and our highly competent supplier base assure our customers the value they demand, complete customer satisfaction being the key factor of mG's success and the foundation for its future.

Contact

mG
miniGears
North America

mG miniGears North-America
2505 International Parkway
Virginia Beach, VA 23452 - U.S.A.
Phone: 001-(757) 627-4554
Fax: 001-(757) 627-0944
E-mail: *mg_usa@minigears.com*
www.minigears.com

ITW Heartland



Proudly Manufactured in the USA

Booth Number: 600

Since 1936 ITW has provided the gear industry with functional gear inspection machines. Our gear profile burnishing equipment will enhance the quality of your gears. We offer complete turnkey solutions customized to your application (Burnisher + Washer + Inspection Equipment). Complete machine retrofits along with full technical support and service.

Put your trust in the people who invented the process.

- Functional Gear Inspection Equipment
- Gear Profile Burnishing Equipment
- Turnkey Systems
- Retrofits
- Full Technical Support
- On Site Service

Contact

ITW Heartland

1205 36th Avenue West
Alexandria, MN 56308
Telephone: (320)762-8782 • Fax: (320)762-5260
E-Mail: *itwgears@rea-alp.com* • Web: *www.itwgears.com*

Clifford-Jacobs Forging Company

Booth Number: 1004

Clifford-Jacobs Forging Company produces custom gear forgings up to 30 inches in diameter (from 10 to 650 pounds) up to 50 inches in length in carbon, alloy, stainless, and tool grades of materials. As a closed-die hammer shop, we offer the flexibility of low-to-medium production runs with a 25-piece minimum quantity on up to 1000 pieces per run. Complete die-shop on premises for quick-turnaround of new dies and tooling within weeks! Heat treat and rough-turning services available. A substantial inventory of raw material and warehousing of forgings guarantees 100% on-time delivery! Quick turnaround on inquiries normally within 2-3 days! ISO 9000 Certified. "Forging Partnerships of Value Since 1919."

See us at Booth 1004 at Gear Expo 2003!

Clifford-Jacobs Forging

Contact
Justin McCarthy
Clifford-Jacobs Forging Co., Inc.
P.O. Box 830, Champaign, IL 61824-0830
217-352-5172, fax- 217-352-4629
sales@clifford-jacobs.com* • *www.clifford-jacobs.com

Ipsen International, Inc.

Booth Number: 716

State-of-the-art Atmosphere Technology.
New to North America,
Proven to the rest of the world.

Technology benefits

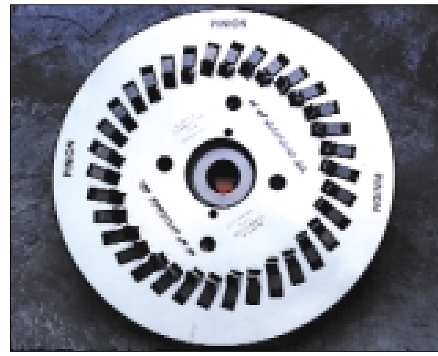
- Reduced labor cost
- Unsurpassed reliability
- Reproducible parts
- Energy efficient
- Cost effective
- Higher quality parts
- As automated as you like it

Ipsen®

Ipsen International
P.O.Box 6266 · Rockford, IL 61125-1266
Tel. 815.332.4941 · Fax 815.332.3074
www.ipsen-intl.com · e-mail: sales@abaripsen.com

A/W Systems

Booth Number: 111



Description:

A/W Systems manufactures a complete line of tooling for both straight and spiral bevel gearing. Most notable is our line of Face-Hob Cutter Bodies, which are available in all of the most common U.S. blade and size combinations (e.g. 11/64, 13/76, 17/88, 13/105, 19/105). Our In-House blade grinding capacity allows us to provide fully sharpened and coated stick blades, in M2 HSS, Rex 76, Ultra-fine grain Carbide, or any other customer desired substrate. Of course, a variety of coatings are also available.

Additionally, A/W Systems has entered into a partnership with Klingelnberg-Oerlikon Tech Center to provide state-of-the-art hypoid gear tooling technology and services to the U.S. gear manufacturing market.

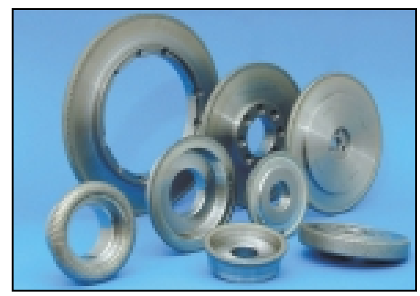
Our booth will display a wide variety of gear tooling, as well as provide technical materials.

Contact:

A/W Systems
612 E. Harrison
Royal Oak, MI 48067
Phone: (248) 544-3852
Fax: (248) 544-3922

Dr. Kaiser Diamond Dressing Tools

Booth Number: 218



Product Line

Dr. Kaiser Diamantwerkzeuge, located in Celle, Germany, specializes in the design and manufacture of precision rotary diamond dressers for the gear industry. ***Dr. Kaiser*** precision diamond products are unsurpassed in quality, accuracy, and innovative design.

Company Profile

Dr. Kaiser provides dressing solutions for continuous generating, single tooth, spiral, bevel, gear, and plunge grinding applications in both natural and polycrystalline diamond versions. ***Dr. Kaiser*** PCD reinforced dressers significantly extend dresser life when compared with standard non-reinforced direct plated dressers, especially in fine-pitch applications. ***Dr. Kaiser*** offers quick delivery and the highest accuracy at competitive prices. Relapping and replating services are available.

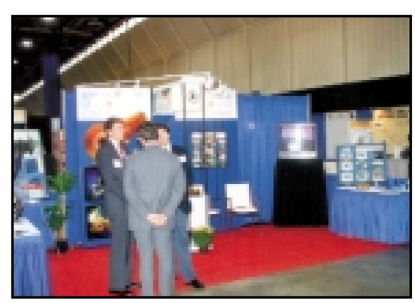
S.L. Munson & Company is the exclusive distributor for ***Dr. Kaiser*** products in North America.

Contact

S.L. Munson & Company
401 Huger Street
Columbia, SC 29201
Phone: 800-775-1390
Fax: 803-929-0507
E-mail: *info@drkaiser.com*

Arrow Gear Company

Booth Number: 933



Arrow Gear to Exhibit at Gear Expo

Arrow Gear Company of Downers Grove, Illinois will be an exhibitor at this year's Gear Expo.

Arrow's booth will contain several points of interest for visitors to the show. A variety of gold plated gears will be on display to illustrate the depth of the company's machining capabilities. To communicate the full scope of Arrow's operation, an orientation video will be presented. In addition, printed materials and interactive CD-ROM programs will be distributed.

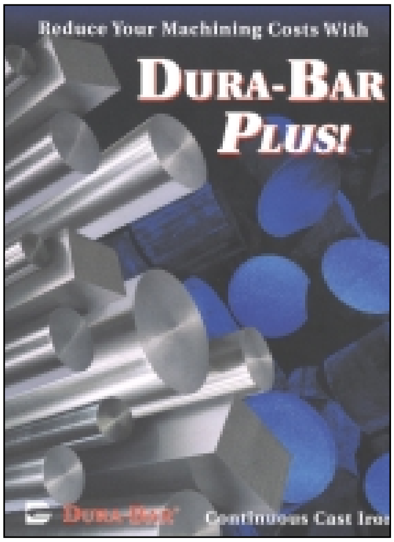
Arrow Gear produces high precision gears and gearboxes for aerospace and commercial markets. They have also introduced advanced computer techniques for the design and development of bevel gears.

Arrow Gear will be located at booth #933.

ARROW GEAR COMPANY

Dura-Bar

Booth Number: 927



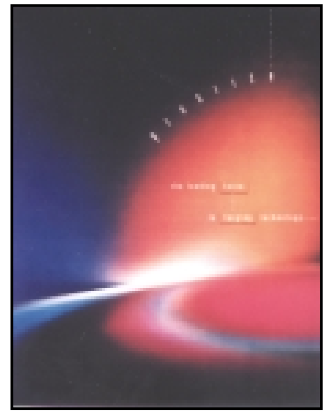
Product Line

Dura-Bar is the only manufacturer of continuous cast iron bar stock in North America, and is the largest in the world. Rounds, squares, rectangles, tubes and special shapes are supplied through a nationwide distribution network. Inherent properties include noise and vibration damping, machinability, strength, and wear resistance, making our bar stock an alternative to steel and other metals in fluid power, gear and other applications. New Dura-Bar *Plus* is an engineered iron that machines better than carbon and alloy steels and other grades of continuous cast iron. A material of uncompromising consistency, it allows metal component manufacturers to machine more parts per hour, thereby decreasing cycle time, increasing productivity, and boosting profitability.

Dura-Bar
1-800-BAR-MILL (227-6455)
www.dura-bar.com
sales@dura-bar.com

Presrite Corporation

Booth Number: 820



Product Line

Presrite Corporation's eight-page color brochure provides an overview of the company's forging capabilities, and information on its equipment and its three forging plants. It also identifies industries served and customer benefits. Presrite is equipped with a total of 16 forging presses, ranging in size from 1,300 tons to 6,000 tons. The company also has a state-of-the-art gear lab and sophisticated machining equipment. Presrite produces minimum-draft, net- and near-net-shape forgings up to 300 lbs. and 18 inches in diameter, and provides induction heating capacity for ferrous materials of 28,000 pounds per hour.

Presrite Corporation
3665 East 78th Street
Cleveland, OH 44105-2048
216.441.5990 FAX: 216.441.2644
E-Mail: info@presrite.com
Web Site: www.presrite.com

Chamfermatic Inc.

Booth Number: 1125

Company Profile

Chamfermatic Inc. was started in 1996 with the goal of building the best, easy-to-set-up gear deburring machines on the market. We have, by listening to our customers' needs, accomplished this goal.

Product Line

Chamfermatic Inc. offers a complete line of gear deburring machines with capacities up to 36 inches in diameter, from manual to fully automated systems. We also incorporate parts washing along with deburring operations to remove oil, lapping compound and chips from your parts, while adding a rust preventative. All of our equipment has as standard: automatic air-operated door, operator interface, P.L.C. and a filtration system. Also, they are all portable.

Our customer service response time is second to none. We also offer contract deburring of your gears, along with rebuilding all makes and models of gear deburring machines, making Chamfermatic a full-service supplier to the industry.

Contact

Chamfermatic Inc.

7842 Burden Road
Machesney Park, IL 61115
Mike Magee, President

Phone: (815) 636-5082
Fax: (815) 636-0075
E-mail: chamfer96@aol.com

Star-SU

Booth Number: 1134

Star-SU offers a comprehensive line of gear cutting tools of all types, including services for:

Hobs
Shaper cutters
Milling cutters
Rack cutters
Band saw cutters
Profile grinding wheels, electroplated CBN and diamond-plated
Shaving cutters
Chamfering and deburring tools
Chamfer-roller tools
Rolling and deburring tools for sprocket gears
Master gears
Screw compressor rotors

Resharpening and recoating of hobs, milling cutters and shaper cutters
Resharpening of shaving cutters
Stripping and replating of electroplated CBN and diamond-plated grinding wheels
Complete Commodity Management Services (CMS)
Pickup and delivery services are available in certain areas

Visit our website to download our complete program of products and find the match for your particular need.
www.star-su.com
sales@star-su.com
Phone: 847-649-1450
Fax: 847-649-0112

Our partners SU America, Star Cutter and Bourn & Koch offer a complete line of machine tools for gear roughing, finishing and tool sharpening applications.
www.suamerica.com
www.starcutter.com
www.bourn-koch.com

See us at AGMA Gear Expo 2003, Columbus, OH, in Booth 1134.

Barit International Corporation

Booth Number: 917

Company:

Barit International Corporation is a one-stop solution provider for all gear cutting tool needs, supplying the world's industries with top quality gear cutting tools since 1989. We excel in cost efficiency, quality and precision.

Product Line:

- Gear hobs
- Worm gear hobs
- Involute and parallel spline hobs
- Shaper cutters
- Broaches
- Form relieved milling cutters
- Shaving cutters
- Rack type cutters
- Straight bevel cutters

Please visit our booth for more details!

MEMBER OF AGMA

Contact

BARIT INTERNATIONAL CORPORATION
3384 Commercial Ave.
Northbrook, IL 60062 USA
Tel: 847-272-8128
Fax: 847-272-8210
Website: *www.barit.com*
E-mail: *people@barit.com*

Nachi Machining Technology Co.

Booth Number: 500

Nachi Machining Technology Co. represents global technical innovation and leadership in the machine building and tooling industry. Nachi supplies high technology machining solutions through the Nachi-Red Ring brand of machines and tools.

Nachi Machining Technology Co.'s. goal is to facilitate processes which optimize productivity while maintaining and improving quality.

The exhibit includes a display of tools, process examples, and video presentations. Broaching, Roll Forming, Hobbing and Shaving Machines/Tools are employed to demonstrate manufacturing processes for typical work pieces. Work pieces and manufacturing equipment will be available for inspection at the show.

Contact

NACHI RED RING
NACHI MACHINING TECHNOLOGY CO.
17500 Twenty-Three Mile Road, Macomb, MI 48044-1103
Phone: (586) 263-0100
Fax: (586) 263-4571
www.nachimtc.com

Great Lakes Gear Technologies

Booth Number: 400 (Fässler), 411 (Fhusa), 300 (Höfler)

Company Profile

Great Lakes Gear Technologies represents the finest lines of gear manufacturing equipment and gear tooling producers from around the globe. At Gear Expo 2003, we can be found in the booths of Fässler (#400), Fhusa (#411) and Höfler (#300).

Product Lines

Contact Great Lakes Gear Technologies for all your gear machinery and tooling needs:

- **Fässler** "MegaHone" Gear Honing and Diamond Hard Broaching Equipment.
- **GTS/Fhusa** Hobbing, Shaving, Shaping, Broaching & Chamfering Tools.
- **Escofier** "FCR" Gear Burnishing and Spline Rolling Equipment & Tooling.
- **Richardon** Heavy Duty Dry and Super Wet Hobbers and Rebuilding Services.
- **Höfler** Form and Generating Gear Grinders & Very Large Gear Hobbing Machines.
- **Ernst Grob** Coarse Pitch Spline Rolling Equipment.
- **Karats** High Speed CNC Gear and Spline Shapers.
- **Linnenbrink-Technik Warburg/Discom** Gear Noise and Dimensional Gear Checkers.

Contact

GREAT LAKES GEAR TECHNOLOGIES

8755 Ronda Drive, Canton Michigan 48187
Ph: 734-416-9300
Fx: 734-416-7088
www.greatlakesgeartech.com

Gleason Cutting Tools CORPORATION

BOOTH #100

Gleason Cutting Tools Corporation, Loves Park, Illinois operates one of the most modern facilities of its kind, producing hobs, shaper cutters, shaving cutters, bevel cutter stick blades, plated CBN wheels, plated diamond rolls, and form-relieved milling cutters.

Most recently, Gleason Cutting Tools has greatly expanded its production capacity for high precision CBN plated wheels. The new ultra-modern electrolytic and electroless nickel plating facility produces non-dressable grinding and dressing wheels manufactured with hardened steel bodies, precision ground profiles, plated with single layer CBN or diamond crystals.

A host of contract services are available as well, including tool resharpening, advanced coatings, heat treat, metallurgical lab analysis, workholding repairs, pickup and delivery and gear schools.

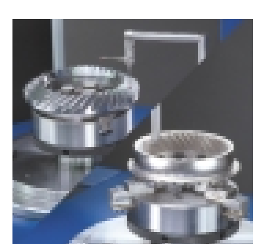
For more information, visit **www.gleason.com**

Gleason Corporation

BOOTH #100

Gleason will display several advanced new technologies at Gear Expo '03, designed to speed throughput and take cost out of bevel and cylindrical gear production. Significant among the new products on display will be:

- The 245TWG High Speed Threaded Wheel Grinder makes grinding in high volumes an economic alternative to shaving. The 245TWG delivers faster, more economical, high quality finish grinding of gears up to 245 mm (9.65") diameter, 3.25 module (7.815 NDP). DIN5/6 (AGMA 11/12) quality is achievable for most parameters, and lead and profile accuracy to 2.5 micron (0.0001").



- The Gleason-Mahr GMX 275 Gear Inspection Machine, designed from the ground up in a joint development effort between Gleason and Mahr delivers faster, more accurate, more complete and highly affordable elementary measurement of internal and external cylindrical gears, bevel gears and gear tools.

For more information, visit **www.gleason.com**

Russell, Holbrook & Henderson

Booth Number: 313

Product Line
As a leader in the fine-pitch gear tooling market, our line of TRU-VOLUTE hobs, shaper cutters and gear metrology products are recognized for the highest quality and precision in the industry.

Our products provide the superior quality and accuracy you demand. Our focus continues to be on the importance of quality tools, inspection methods and gear technologies, which are essential to first-class gear manufacturing.

Company Profile
Established in 1915, Russell, Holbrook & Henderson, Inc. has since been providing innovative products and solutions to the gear tooling industry.

Our parent company, Ogasawara Precision Laboratory Ltd., Japan, is a world leader in fine-pitch gear tool manufacturing and related products.

Contact
Russell, Holbrook & Henderson, Inc.

For the latest in our TRU-VOLUTE product updates, related articles and events calendar, please visit our online website at: http://www.tru-volute.com

Our sales and technical service can be reached at the following location:
Russell, Holbrook & Henderson, Inc.
A Member of Ogasawara Group
17-17 Route 208 North, Fair Lawn, NJ 07410
Telephone: (201) 796-5445
Fax: (201) 796-5664
http://www.tru-volute.com

"Gear Tool Solutions"

JRM International, Inc.

Booth Number: 538

Product Line
JRM International, Inc. has been a distributor of German and American machine tools and accessories since 1984. Burka-Kosmos supplies grinding wheels for all makes and models of thread-type, profile and generative gear grinders. James Engineering is a builder of gear deburring, chamfering and washing machines. Schrem hydraulic locknuts are designed for clamping all types of tools and workpieces. WEKO Gear Technology is a supplier of CNC inspection machines, machine service and rebuild/retrofit. You can also talk to the people from Kesel about their rack milling machines. Visit us at booth number 538.

JRM International, Inc.

JRM International, Inc.
5701 Industrial Avenue
Rockford, IL 61111
Phone: (815) 282-9330
Fax: (815) 282-9150
E-Mail: *jrmsales@jrminternational.com*
Web Site: *www.jrminternational.com*

Marposs Corp.

Booth Number: 1115

Need to Check Gears?
Looking for an easy, cost-effective way to check gears? The Marposs M62 bench gauge system with optional noise detection is accurate, easy to use and quickly re-toolable using ordinary hand tools. You'll save time and the cost of dedicated gauges. With the M62 you can measure:

- Radial composite deviation
- Radial runout
- Tooth to tooth radial composite deviation
- Tangential composite deviation
- Nicks
- Optional measurements include center distance, bore diameter and perpendicularity of bore to gear face.

All functional checks can be displayed on the rugged Marposs E9066 industrial PC system that offers a linear graphic display with full SPC functions.

Contact
MARPOSS

3300 Cross Creek Parkway
Auburn Hills, MI 48326-2758
1-888-627-7677 • 1-248-370-0404
Fax: 248-370-0621
E-mail: marposs@us.marposs.com
www.marposs.com

Nye® Synthetic Lubricants — **Booth Number: 809**

Add performance, life and value to gears

SmartGrease™

Synthetic lubricants designed for *your* product.

smartgrease.com

NISSEI GALAXY

NISSEI

Booth Number: 828

Company Profile

Established in 1939, Nissei is one of the world's leading manufacturers of form rolling machines. We provide valuable technology supporting the industry for the 21st century. We are confident that our technology matches your needs to solve existing problems.

Product Line

Nissei's form rolling machines in various models have already been used with Sintered Fe Alloy Gear Finishing for better accuracy and increased density only at the surface and with Ball Screw Class 3 or better. EPS screw manufacturers are looking into NISSEI's technologies with higher productivity and material saving from turning or grinding operation.

Contact us: Nissei Co.,Ltd. http://www.nisseiweb.co.jp/e_page/e_index.htm

2022Torisawa,Tomihama-cho,Otsuki-cityYamanashi,JAPAN 409-0502 T)81-554-26-5311 F)81-554-26-5313, mail@nisseiweb.co.jp

In USA: K K TECHNOLOGY INC./ Ken Kamimura 297 Kinderkamack Rd. Oradell, NJ 07649 T) 201-262-1470 F) 201-262-2187

Technical Seminar

Finishing Sintered Fe Alloy Gear

At: Hampton Inn & Suite
2F Clipper Room
10/6 and 10/7 5PM

REISHAUER

Booth Number: 1200

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Technical data:
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Number of teeth 6-150
Module/DP 1-3 / 25.4-8
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Workpiece weight maximum 3 kg / 6.6 lbs

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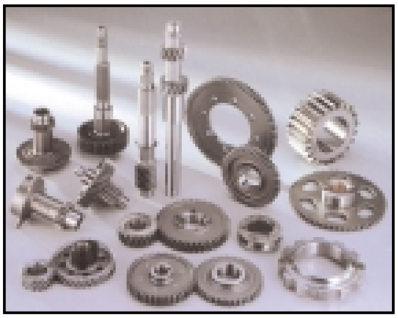

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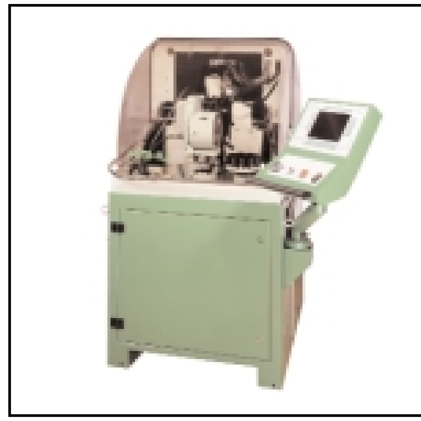

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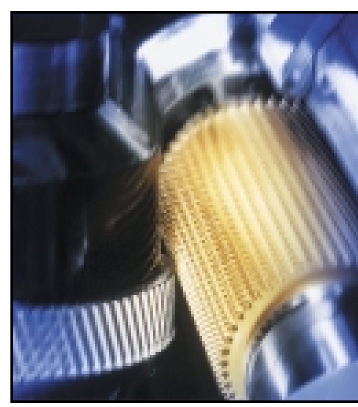

Company Profile

LMT-FETTE, North American importer of Liebherr's LORENZ shaping and shaving tools, is announcing the opening of its **new hob and shaper cutter resharpening center** in Libertyville, Illinois. We will be with LIEBHERR in booth 1400. Stop by and learn more about LMT-FETTE's high standards of quality, and how they will apply those standards to resharpening and deburring your hobs and shaper cutters.

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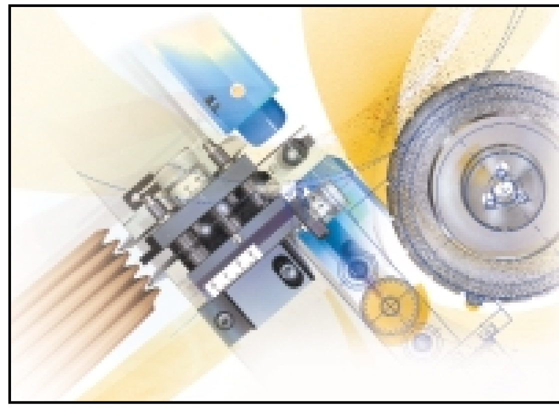

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Horsburgh & Scott: Heavy Duty Gear Expert

Big gears. They drive the machinery that rolls steel, grinds limestone, pulverizes coal, pumps mud, mixes rubber, raises bridges and does many other heavy-duty industrial jobs. For 117 years, big gears have also driven the business of Horsburgh & Scott of Cleveland, OH.

The company specializes in the design, manufacture, service, rebuilding and repairing of large industrial gears and gear drives. It serves industries including cement, chemical, mining, sugar cane, petroleum, steel, utilities and others.

Horsburgh & Scott built its reputation on manufacturing quality gears and gear drives for those industries, says president Dave Kraninger, and it's a reputation that they continue to foster. For example, Horsburgh & Scott offers a four-year warranty on their new gears and drives.

But over the past several years, the company has struggled to redefine itself in the face of a number of challenges, including corporate buyout, bankruptcy, overseas competition, manufacturing recession and a vastly shrunken steel industry, to which Horsburgh & Scott has long been closely tied.

The biggest change in Horsburgh & Scott's business, though, has been a shift from manufacturing original equipment toward serving the aftermarket.

Horsburgh & Scott takes pride in its ability to manufacture quality gears and drives for heavy industry. "We're going to keep our manufacturing base," Kraninger says proudly, indicating that much of the company's credibility stems from its reputation as a quality manufacturer. But Horsburgh & Scott spends much more of its time than previously in servicing, rebuilding, repairing and replacing drives already in the field.

Kraninger estimates that about 30% of the company's business is manufacturing original equipment, versus 20 years ago, when manufacturing new gears and drives made up 70% of the business.

Horsburgh & Scott Co.
Subsidiary of P&H Mining Equipment, a subsidiary of Joy Global Inc.
Established: 1886
No. of Employees: 190
Main Facility: 270,000 square feet
Heat Treat Facility: 30,000 square feet
Industries Served: Steel, Aluminum, Rubber, Plastics, Utilities, Movable Bridges, Petroleum, Mining, Paper, Sugar, Food Processing, Environmental Control and other industries where large gears and drives are used.
Major Products: Large industrial gears and drives, including spur, helical, internal, double helical, worms, Maag hard-cut, precision ground and herringbone gearing from 3 inches to 30 feet in diameter.
Specialty: Upgrade of existing gearing and gear units to provide increased horsepower in the same envelope.
Industry Affiliations: ASME, ASTM, ASM International, founding member of AGMA.
www.horsburgh-scott.com

Maag hard cutting is a specialty at Horsburgh & Scott. Using a CBN tool, the company cuts hardened gears "as accurate and smooth as a ground gear," says president Dave Kraninger.

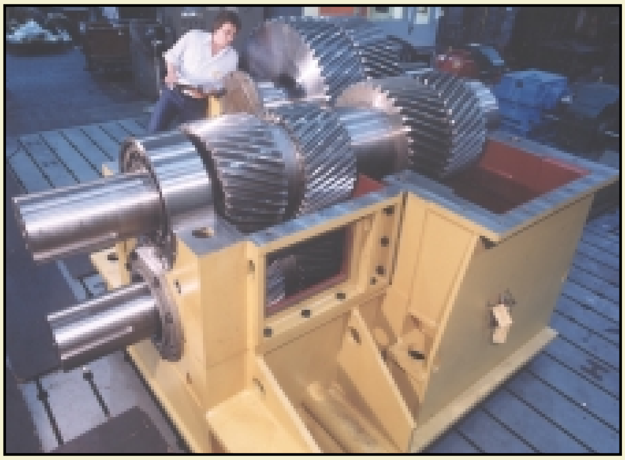
This shift in philosophy isn't original to Horsburgh & Scott, Kraninger says. Many of the gear companies serving the same industries are moving toward the aftermarket and service activities. One of the reasons is that many of the OEM companies that had built facilities for steel mills and other large plants are out of business. Also, as long as their specifications can be met, the remaining OEMs are most interested in buying gear drives at the lowest prices. Often, this means an overseas gear manufacturer will get the job. "The OEM business is diminishing for USA-based manufacturers," Kraninger says.

The change in focus means Horsburgh & Scott spends more time talking with

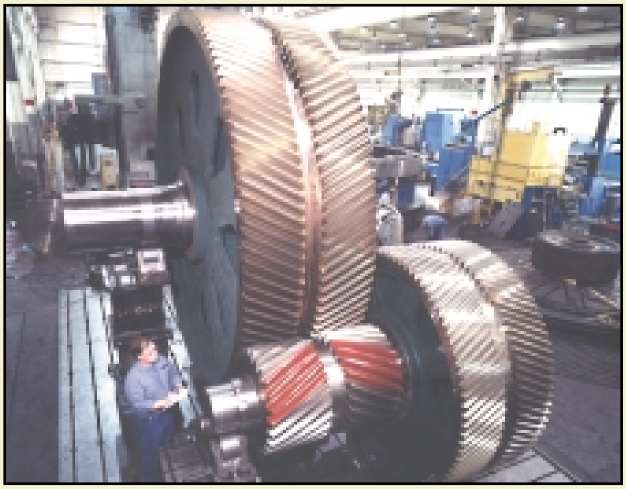
Horsburgh & Scott: The Aftermarket

One of Horsburgh & Scott's specialties has been the manufacture, service, rebuilding and repair of gears and gear drives for heavy industrial plants, such as steel mills, cane sugar processing, power plants and strip processing lines. Those facilities often use a variety of large, critical service gear drives. In many cases, the service lives of those drives are measured in decades, and keeping them running requires expertise.

A double-helical ring gear for an iron ore ball mill.



A cold mill combination speed increaser/pinion stand.



A double helical gear set for the main drive of a hot strip mill, undergoing final mesh test at Horsburgh & Scott.

Case 1

Recently, a Horsburgh & Scott customer in the steel industry needed help with some gear drives that had been upgraded about 20 years earlier. Gears in those drives were beginning to show signs of cracking.

"They really take a beating," says an engineer who works with the gear drives at the company.

In fact, the drives were being used to carry higher loads than they were originally designed for, so the company couldn't just buy new gears like the old ones. They needed engineering analysis of the parts. Also, manufacturing new parts isn't always the optimal choice, because of the expense and the amount of time needed for manufacture.

According to Dave Kraninger, president of Horsburgh & Scott, his company will be working on the project over the next couple of years, repairing gears where possible, replacing them and supplying spares when necessary.

Repairing cracks in large gears involves taking the gears back to Horsburgh & Scott's Cleveland manufacturing facility, where they undergo magnetic and ultrasonic inspection to completely map each gear and look for problems in the teeth, rim, hub and—in the case of fabricated gears—welds.

After inspection, cracks may be ground out or machined out using a large, horizontal boring mill with end mills. Parts are normally inspected a second time to be sure all the cracks have been removed. New material is welded in place, and the parts are thermally stress relieved in Horsburgh & Scott's in-house heat treat facility. Then the parts are "trued up," including recutting the teeth if necessary.

The whole process requires an integrated knowledge of gear design, manufacturing and heat treating, as well as expertise working with large gears, Kraninger says.

And his customer agrees. "There are a lot of companies that have the manufacturing capability," the customer says. "But they don't have the engineering or the heat treating. When you get into the highly technical, highly loaded gearing that we have, you need the expertise. These guys have it."

Case 2

Horsburgh & Scott recently completed a project for a cement company. The manufacturer had gear failure in a large enclosed drive, which is used to drive equipment for grinding limestone. One helix broke on the 10-foot-diameter, 40-inch-face, double-helical, composite-designed gear.

The original gear drive manufacturer, a Horsburgh & Scott competitor, recommended that the cement manufacturer purchase a new gear for this drive, but that would have taken months, Kraninger says. Instead, his company repaired the gear, replacing the broken helix in just under six weeks. The project involved buying a new forged rolled ring, turning, facing and mounting the ring, and finally, cutting the teeth.

The repaired gear is only intended to be a temporary replacement, though it may last several years. In the meantime, the cement manufacturer will have time to determine the best course of action regarding the long-term high-reliability requirement for the mill drive, while limiting its downtime.

end user customers, Kraninger says. The company needs to understand how customers are using their gear drives in order to provide solutions that best take advantage of Horsburgh & Scott's engineering, manufacturing, inspection, heat treating and rebuilding expertise. "We are really focused on improving the end user's gear reliability," Kraninger says.

Another significant challenge for Horsburgh & Scott has been the decline of the American steel industry.

According to Kraninger, the company has lost 34 steel industry customers to bankruptcy over the last five years, forcing management to face issues such as bad debt and where to find new business.

Despite that decline, the steel industry still makes up about 50% of Horsburgh & Scott's business, Kraninger says. But the company is working to expand in other markets, including cement, sugar, petroleum, mining and utilities. "We've had to work hard to establish ourselves in these industries," Kraninger says. But he adds: "We see ourselves having successes and being recognized by our customers."

Another challenge for the company has been the conversion from a family-owned business to a corporate-owned business. From 1886 until the mid-1990s, Horsburgh & Scott was owned and managed by members of the Horsburgh family. In 1998, Horsburgh & Scott was acquired by P&H Mining Equipment Co., a subsidiary of Harnischfeger Industries, Inc.

Horsburgh & Scott's carburizing furnaces can handle parts up to 75" in diameter and 180" long.

Shortly thereafter, in June 1999, Harnischfeger filed for Chapter 11 bankruptcy protection. Today, Horsburgh & Scott is still a subsidiary of P&H, now a subsidiary of Joy Global, Inc., the company that emerged from Harnischfeger's bankruptcy proceedings in 2001.

According to Kraninger, who took over as president in 2000, the bankruptcy of the parent company didn't affect Horsburgh & Scott terribly. As evidence, Kraninger points to the fact that after emerging from bankrupcy, both P&H and Horsburgh & Scott were able to repay all of their creditors 100% plus interest.

"Some peripheral customers may have looked at us with a jaundiced eye, and it probably cost us some business," Kraninger says.

Far worse than the effects of the bankruptcy has been the current manufacturing recession, which Kraninger likens more to a depression. "It's impacted us very dramatically," he says.

In the past few years, Horsburgh & Scott has had to undergo wage freezes, wage reductions and job force cuts. The company had about 230 employees when it was acquired by P&H in 1998. Today, it has about 190 employees. In 2002, the company closed its facility in Mentor, OH. That facility was a 70,000 square foot building used for Horsburgh & Scott's enclosed gear drive rebuild and service activities. Those activities have been moved to the company's main facility in Cleveland.

But today, although the market is still tough, Horsburgh & Scott is well positioned for the future, Kraninger says. "We're doing better, we're making money, we're weathering the storm."

He attributes the company's success to its unique blend of capabilities and its continued focus on the needs of its customers.

One of the capabilities that Kraninger feels sets his company apart is its experience with Maag hard gear cutting. "We're the missionaries on coarse-pitch hard gear tooth machining," he says. Maag hard cutting allows Horsburgh & Scott to cut carburized or high-through-hardened coarse pitch gears with a CBN cutting tool. The results are "as accurate and smooth as a ground gear," Kraninger says. The process also allows them to cut narrow-gap double-helical gears, which are common in many of the industries they serve.

In addition, Horsburgh & Scott boasts a large selection of both imperial and metric tooling, including hobs, shaper cutters, Maag tooling and generating tooth grinding tooling. All of that provides a lot of flexibility, Kraninger says.

Another aspect of their operation that sets the company apart is its engineering staff. "We have a few very unique engineers," Kraninger says, explaining that they allow the company to help solve customers' problems, instead of just manufacturing parts.

Also, Horsburgh & Scott has its own full-service heat treating facility and metallurgical lab. It has carburizing furnaces capable of handling parts up to 75" in diameter, 180" long and 60,000 lbs.

All of these capabilities add up to an ability to meet the needs of customers with big gears.

"Wherever there are big gears—low speed, high torque—and people have questions, we want to be the people they think of first," Kraninger says.

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Solid Model Generation of Involute Cylindrical Gears

Wang Lixin & Huang Wenliang

Nomenclature

R	Reference Radius
Ra	Tip Radius
Rf	Root Radius
Rb	Base Radius
m_n	Normal module
z	Number of teeth
x_n	Normal modification coefficient
h^*_{an}	Normal addendum coefficient
c^*_n	Normal bottom clearance coefficient
α_n	Normal pressure angle on reference circle
β	Helix angle on reference circle
s_n	Normal tooth thickness on reference circle

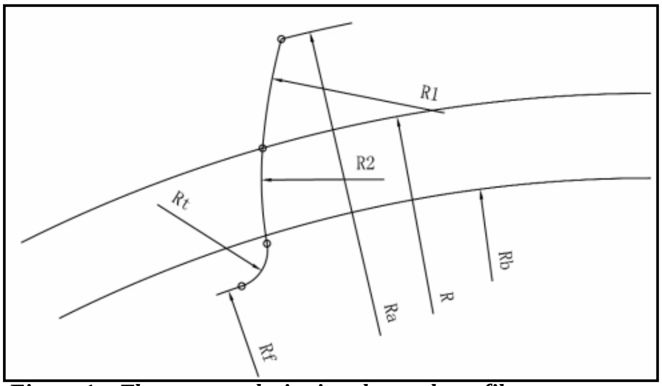

Figure 1—Three arcs substituting the tooth profile.

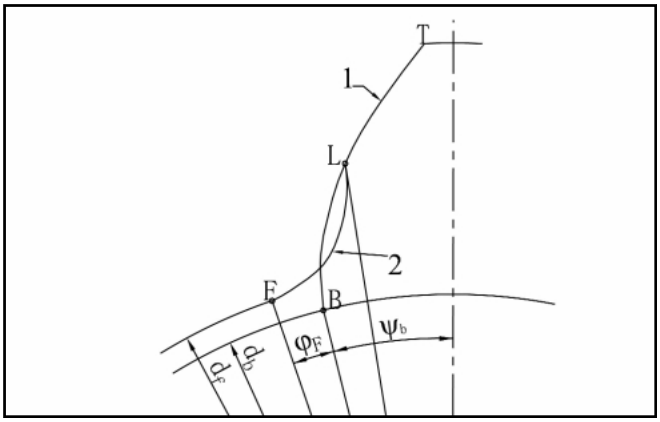

Figure 2—Tooth profile of involute gears.

This paper presents approximate and accurate methods to generate solid models of involute cylindrical gears using Autodesk Inventor 3-D CAD software.

Introduction

The key to gear solid model generating is getting the correct tooth profile. If the tooth profile is obtained, the solid modeling of cylindrical gears can be obtained easily through CAD software commands (extrusion, sweep, coil, circular pattern).

There are some resources to assist with this job. Sandeep Singal developed spur gears on Pro/E using involute equations without considering the undercut, and the root fillet is approximated with a circular curve joining the involute and root circle (Ref. 1). Deng Kai generated the accurate cylindrical gear tooth profile with the graphic solution. A cutting tool rack shape with a specific parameter needed to be drawn on the sketch status of 3-D CAD software (Autodesk Inventor) each time. Using the constraint feature, the rack was moved to simulate the real gear production procedure and the series trajectory was used to find the envelope as the gear tooth profile (Ref. 2). Another resource is the gear tooth profile included in the Autodesk Inventor's sample directory. The profile is approximately substituted by one or two arcs and a line joining the arc and root circle.

The two methods presented in this paper can generate a gear solid model directly by entering the conventional parameters of the gear only (m_n, z, α_n, β, x_n, h^*_{an}, c^*_n).

Approximate method

In many cases, gear tooth profile accuracy is not critical, such as a production demonstration, 3-D animation, etc. In those cases, we can use three arcs to substitute the involute tooth profile (Ref. 3).

In Figure 1, the gear tooth profile is formed with three tangent arcs (R1, R2, Rt).

$R = \frac{1}{2} m_n z / \cos\beta$

$Ra = R + m_n(h^*_{an} + x_n)$

$Rb = R\cos(\alpha_t)$

$Rf = R - m_n(h^*_{an} + c_n^* - x_n)$

$R1 = \rho' m_n$

$R2 = \rho'' m_n$

$$Rt = \frac{c^* m_n}{1 - \sin\alpha_n}$$

where: $$\rho' = \frac{z}{2}\sqrt{1 - \cos^2\alpha_n \frac{z-1}{z+1}} \qquad \rho'' = \frac{z^2 \sin^2\alpha_n}{4\rho'}$$

The centers of both arcs R1 and R2 are located on the base circle, and their tangent point is located on the reference circle. Arc Rt is tangent to the arc R2 and the root circle at the same time.

Accurate Method

The Combination of the tooth profile: The cutting tool and manufacturing method generate the shape of the gear tooth profile and affect the theoretical design result. The accuracy of the gear tooth profile comes from the cutting tool and the manufacturing method.

Two parts, Involute 1 and Root Fillet Curve 2, form the gear tooth profile (see Fig. 2). Involute 1 (from Point T to L) is generated by the linear (involute) part of the rack-shaped cutting tool (or gear-shaped cutting tool). There is a standard equation to describe it. Fillet Curve 2 (from point L to F) is formed by the tip of a cutting tool, and there is no standard equation to describe it. Point T is located on the tip circle. Point F, which is the intersection and tangent point between the root circle and root fillet curve, is located on the root circle. Point L is the intersection point of involute and root fillet curves.

Determining the Root Fillet Curve of Tooth Profile

Wu Jize pointed out that root fillet curve can be divided into three classes: offset of prolate involute, offset of epicycloids and arc (Ref. 4). I.A. Borotovskii analyzes the root fillet curve equation generated from different cutting tools in detail, evaluating both the rack- and gear-shaped cutting tools with tips filleted and chamfered.

In fact, the gear mentioned in the design phase and the virtual prototyping is the theoretical gear. The geometric parameters of gears can be calculated using a gear design handbook. An accurate tooth profile can be obtained by using the generating method. In the generating method, we use a standard rack cutting tool that corresponds to the helical gear being generated (m_n, z, α_n, β, x_n, h^*_{an}, c^*_n). The parameters of the cutting tool are α_t, s_n, h_a. When $\beta = 0$, the gear is a spur gear (Fig. 3).

Based on the gear parameters m_n, z, α_n, β, x_n, h^*_{an}, c^*_n, we have the following relation of the gear:

$s_n = (0.5\pi + 2x_n tg\,\alpha_n)m_n$; $tg\alpha_t = tg\alpha_n/\cos\beta$ $mt = m_n/\cos\beta$

$d = m_n z/\cos\beta$ $d_b = d\cos\alpha_t$ $tg\beta_b = tg\beta\cos\alpha_t$

$h_a = (h_{an}^* + x_n)m_n$ $h_f = (h_{an}^* + c_n^* - x_n)m_n$

The central angle between the involute start point B and the symmetrical line of the tooth is ψ_b: $\psi_b = \frac{s_n}{m_n z} + \text{inv}\alpha_t$.

The central angle between point B and F is φ_F (see Fig. 2)

$$\varphi_F = \frac{h_f \sin\alpha_n}{0.5 m_n z \cos\alpha_n} - \text{inv}\alpha_t$$

According to Figure 4, the point on the Fillet Curve 2 corresponds to the manufacturing instantaneous angle μ_w, and $\alpha_t < \mu_w < 0.5\pi$, so we have:

$$y = h_f \quad (1)$$

$$my = y/\sin\mu_w \quad (2)$$

$$l = my\cos\mu_w \quad (3)$$

$$\varphi_y = \varphi_F + 2l/d \quad (4)$$

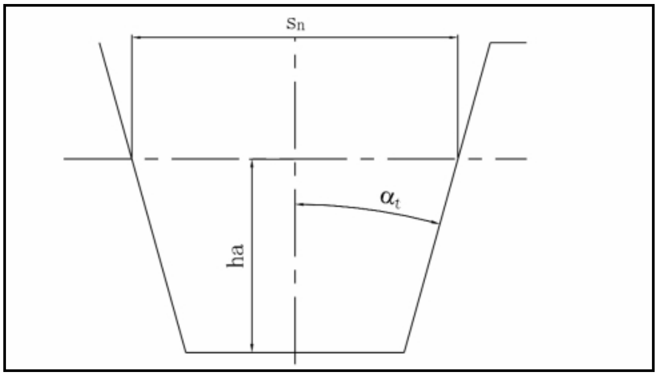

Figure 3—Template cutting tool rack.

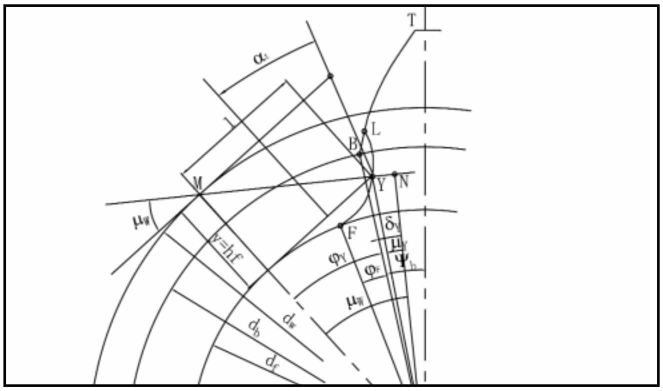

Figure 4—Determining the instantaneous mesh angle.

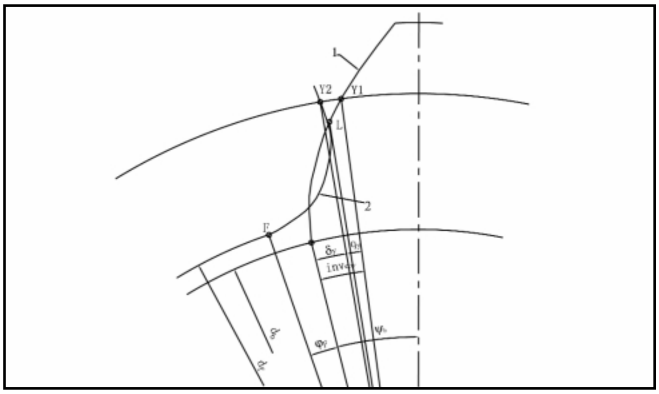

Figure 5—Determining the intersection between Involute 1 and Root Fillet Curve 2.

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Huang Wenliang
is a professor and Ph.D. supervisor in the School of Mechanical Engineering, Nanjing University of Science and Technology, located in Jiangsu Province, China. His specialties lie in the areas of dynamic characteristic analysis and malfunction diagnostics of mechanical systems and machinery vibrations.

$$tg\mu_y = tg\mu_w - \frac{2my}{d\cos\mu_w} \tag{5}$$

The polar angle and radius of Point Y is $\delta_y = \mu_w - \mu_y - \varphi_y$,

$$r_y = 0.5d\frac{\cos\mu_w}{\cos\mu_y}$$

The datum of δ_y is line BO. Point O, which is not shown in the figures, is the center of the gear. When the rotational direction is clockwise, the sign of δ_y is +; – stands for counter-clockwise. At point F: $\mu_y = \mu_w = 0.5\pi$; $my = y = 1$; $\delta_y = -\varphi_F$; $r_y = 0.5d_f$. Point F is the intersection of root circle and root fillet curve.

After getting the description of Root Fillet Curve 2 and knowing the equation of Involute 1, it is necessary to find the intersection Point L between Involute 1 and Root Fillet Curve 2.

Assuming an arbitrary μ_w, δ_y and r_y of point Y2 can be derived from the above formulas. The pressure angle of point Y1, located on the Involute 1, has the same radius r_y with Point Y2:

$$\cos\alpha_{ty} = 0.5d_b / r_y \tag{6}$$

Then, the central angle difference between Y1 and Y2 is: (see Fig. 5)

$$q_y = \text{inv}\alpha_{ty} - \delta_y \tag{7}$$

$q_y = 0$ is a nonlinear equation with variable μ_w. Finding the μ_w to satisfy the equation $q_y = 0$ means finding the intersection point (Y1 and Y2 are coincidental). In order to solve the equation, we introduce the Newton Iteration Numerical Method.

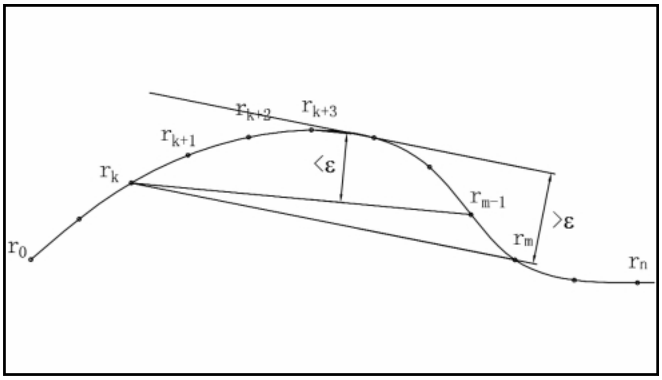

Figure 6—Equal tolerance fitting method using point choice.

Assume the initial value of μ_w is α_t, convergence criteria is $|q_y| < 0.0000005$. The derivative of q_y can be derived from Equations 1–7.

$$\frac{dmy}{d\mu_w} = -\frac{y}{tg\mu_w \sin\mu_w} \tag{8}$$

$$\frac{d\varphi_y}{d\mu_w} = \frac{2}{d}\left(\frac{dmy}{d\mu_w}\cos\mu_w - y\right) \tag{9}$$

$$\frac{d\mu_y}{d\mu_w} = \left(1 - \frac{2}{d}\left(y + \frac{dmy}{d\mu_w}\cos\mu_w\right)\right)\left(\frac{\cos\mu_y}{\cos\mu_w}\right)^2 \tag{10}$$

$$\frac{dq_y}{d\mu_w} = \left(\frac{d\mu_y}{d\mu_w}tg\mu_y - tg\mu_w\right)tg\alpha_{ty} + \frac{d\mu_y}{d\mu_w} + \frac{d\varphi_y}{d\mu_w} - 1 \tag{11}$$

$$\mu_w = \mu_w - \frac{q_y}{\dfrac{dq_y}{d\mu_w}} \tag{12}$$

In some cases, the root of the equation $q_y = 0$ cannot be found, for example, when z is large, $Rf > Rb$, etc. In those cases, let $\mu_w = \alpha_t$ as the intersection point.

Curve Fitting Method

The equation of tooth profile formed by Involute 1 and Root Fillet Curve 2 has already been proven. Using splines to fit the involute is feasible (Ref. 6). Some CAD software has the command to generate the spline from the equation, such as Pro/E, Unigraphics, etc. But other software does not provide this kind of function. In Autodesk Inventor, create a sketch spline using a series of suitable discrete points. In the field, the discretization method of complicated curves is discussed constantly. There are three kinds of methods—equal parameter, equal step and equal tolerance—that can be applied to the curve discretization (Ref. 7). Among them, the equal tolerance fitting method is most reasonable. To realize the equal tolerance fitting method, use the point choice method.

Method description. Use tiny steps to discretize the curve and estimate the tolerance of every segment, delete the unnec-

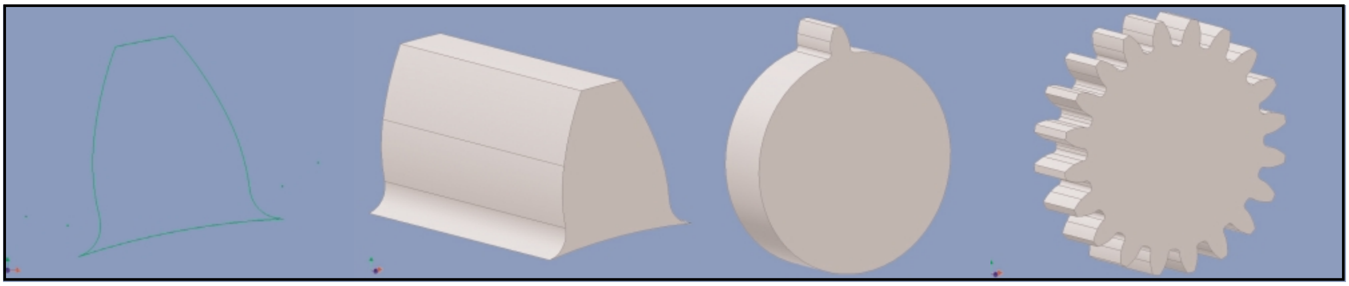

Figure 7—Step-by-step modeling procedure.

essary points, and the tolerance in the remaining segment is approximately equal (See Fig. 6). Points $r_0, \ldots, r_k, r_{k+1}, r_{k+2}, r_{k+3} \ldots\ldots, r_{m-1}, r_m, \ldots, r_n$ are the equal interval discrete points of a curve. ε is the fitting tolerance allowed.

The procedure in detail. For arbitrary initial point r_k (the first point is r_0), starting from r_{k+2} and being considered as a divided point r_m, find the distance d between every internal point r_i $(i = k + 1, \ldots, m - 1)$ and the line $r_k r_m$, if $d < \varepsilon$. Assuming r_{k+3} is a divided point until existing a point r_i, the distance d between r_i and the line $r_k r_m$ is $d > \varepsilon$, and here $r_k r_{m-1}$ is the longest distance segment to satisfy the fitting tolerance allowed. Point r_{m-1} is saved as a qualified point and all points between r_k and r_{m-1} are deleted. Let r_{m-1} as the r_k and repeat the above procedure. We can gain all the qualified points.

Generation of Involute Cylindrical Gear Solid Model in Autodesk Inventor

In Autodesk Inventor, use VBA programming to finish the solid modeling of the involute cylindrical gear. The step-by-step procedure is as follows (see Fig. 7):

Step 1: Create closed profile of the tooth profile.

Step 2: Extrude the profile to generate a tooth (Coil the profile to generate the spur gear).

Step 3: Extrude a root circle to generate the root cylinder and join it with the tooth just created.

Step 4: Circular pattern the tooth to finish the gear.

Step 5: Use the software commands to finish the rest of the modeling, such as the central hole.

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Direct Gear Design: Bending Stress Minimization

Alexander L. Kapelevich and Yuriy V. Shekhtman

Nomenclature

a_w	center distance
b	face width
C_{tt}	tooth thickness ratio
bl	operating backlash
d_a	outside circle diameter
d_r	root circle diameter
J	bending stress geometry factor
k_b	bending stress balance coefficient
K_f	stress concentration factor
ro	operating pitch diameter runout
S	bending stresses
S_w	operating pitch diameter tooth thickness
T	torque
α_w	operating pressure angle
δa_w	center distance variation
δ_S	balance tolerance
Δd_a	outside circle diameter tolerance
Δd_r	root circle diameter tolerance
ΔS_{wp}	tooth thickness tolerance

Subscript

1	pinion
2	gear

Introduction

Bending stress evaluation in modern gear design is generally based on the more-than-one-hundred-year-old Lewis equation. This equation, applied with the stress concentration factor K_f, defines the bending stress geometry factor J for traditionally designed standard or close-to-standard gears. The stress concentration factor K_f is defined from photoelastic experiments (Ref. 1) for rack-generated gears with standard tooth profile proportions.

The Direct Gear Design method (Ref. 2) is not constrained by a choice of gear tooth profiles based on standard tool parameters and uses nonstandard tooth shapes to provide required performance for a particular custom application. This makes finite element analysis (FEA) more preferable than the Lewis equation for bending stress definition. This paper does not describe the FEA application for comprehensive stress analysis of the gear teeth. It presents the engineering method for bending stress balance and minimization.

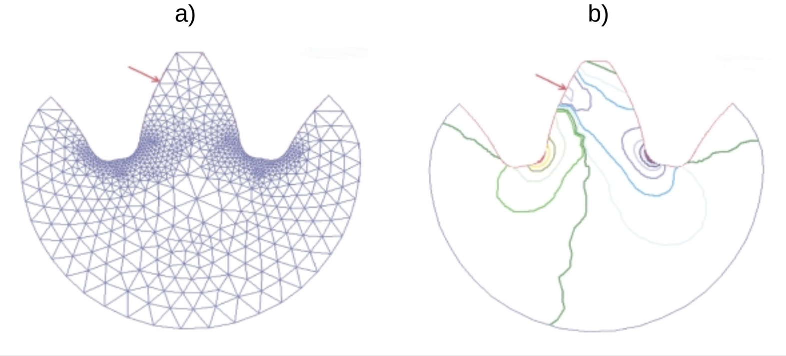

Fig. 1—The FEA gear tooth model: a) FEA mesh, b) stress isograms.

Tooth Modeling

The Direct Gear Design method defines parameters of the gear mesh to provide complete geometry of the involute profile of the teeth, including the base diameter, form diameter, outside diameter, tooth thickness, tip radii, etc. The fillet profile initially is defined as a trace of the tip of the mating gear tooth. This kind of fillet profile is used for plastic molded gears (Ref. 3).

The 2-D FEA model in Figure 1a presents a gear tooth profile that is limited from the sides and bottom by a constrained border with stationary nodes. All other nodes on the tooth profile and inside the tooth contour are movable. The fillet portion of the tooth profile (where maximum bending stress is expected) has equally spaced nodes with higher density (number of nodes per unit of profile length) than the rest of the tooth profile. The nodes on the involute profiles and the top land are located to have higher density close to the fillets and lower density in the top part of the tooth. The number of tooth profile nodes and the node density coefficient (ratio of the fillet profile node density to an average node density of the involute and top land profiles of the tooth) are selected. Fewer tooth profile nodes and lower node density coefficients yield less accurate stress calculations. Selection of larger numbers of tooth profile nodes and high node density coefficients provides a more accurate result, but increases calculation time. In most cases, 80–100 tooth profile nodes and node density coefficients of 1.75–2.5 were used.

The tooth load distribution problem is considered to define a value, a set of application point coordinates, and the direction of the force resulting in maximum bending stress. The friction effect at the contact point has been ignored. The load application point typically does not exactly match with a tooth profile node. It is replaced by a pair of forces that are applied to the two closest nodes above and below the load application point (Fig. 1a). The combined load value of those forces equals an initial load and distributed reversal proportional to the distances between the nodes and the load application point.

The automatically generated FEA mesh and bending stress isograms are shown in Figures 1a and 1b.

Bending Stress Balance

The pinion and the gear typically have different tooth shapes and face widths, and they could be made out of different materials or have different heat treatments, etc. In order to provide equally strong teeth of the pinion and the gear, their maximum bending stresses should be balanced. The balance condition providing equal bending safety factors for the pinion and the gear is

$$S_{\max1} - k_b \bullet S_{\max2} < \delta_s \quad (1)$$

where

$S_{\max1}$ and $S_{\max2}$ are maximum bending stresses in the fillet area of the pinion and the gear,

k_b is the bending stress balance coefficient reflecting the difference of material properties (allowable stresses) and the number of tooth load cycles for the pinion and the gear, and

δ_s is the permissible balance tolerance (typically less than 1%).

In order to satisfy the condition of Equation 1, the bending stress balance FEA program changes the tooth thickness ratio

$$C_{tt} = S_{w1}/S_{w2} \quad (2)$$

where

S_{w1} and S_{w2} are tooth thicknesses on operating pitch diameters (Fig. 2).

For gears that are designed using the traditional tool parameter approach, the tooth thicknesses S_{w1} and S_{w2} are changed by moving the tooling rack profile in or out of the center of the gears. Direct Gear Design changes the tooth thicknesses S_{w1} and S_{w2} while keeping certain conditions, such as the constant tooth top land thicknesses or the equal maximum specific sliding velocities for the pinion and the gear, etc. The fillet profiles, in this case, are still defined as traces of the tips of the mating gear teeth.

Sometimes the bending stress balance could be compromised to improve the performance parameters that have higher priority for particular gear applications (higher efficiency, lower noise, etc.).

Bending Stress Minimization

Bending stress minimization is the result of the definition of the fillet profile that provides minimum bending stress concentration and satisfies certain conditions (manufacturability, for example). There are different solutions to this problem. They are based on a curve fitting technique when the trochoid fillet profile, typical for the rack or mating gear generative method, is replaced by a parabola, ellipsis, chain line, or other curve reducing the bending stress. One of these solutions, using the fitted polynomial curve, is presented in U.S. Patent #6164880 (Ref. 4).

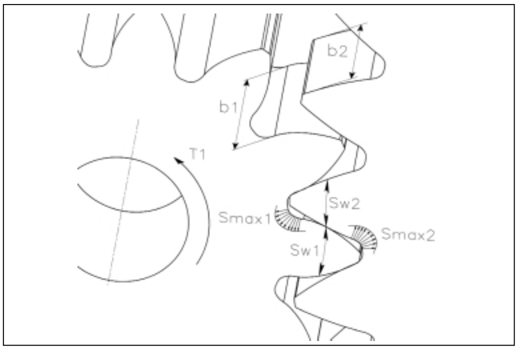

Fig. 2—Bending stress balancing.

This paper presents the fillet optimization that is based on three major components:

- random search method locating fillet points;
- trigonometric functions for fillet profile approximation;
- FEA for stress calculation.

An initial fillet profile is the trace of the mating gear tooth. This profile is the border limiting the optimization search area from the top to avoid interference with the mating gear. The first and the last fillet points lay on the form diameter circle and cannot be moved during an optimization process. The random search method is moving the fillet nodes (except first and last) along the beams that pass through the fillet center and the nodes of the initial fillet profile (see Fig. 3). The center of the fillet is the center of the best-fitted circle. The bending stresses are calculated for every new fillet point's combination. The program analyzes successful and unsuccessful steps, finding the direction of altering the fillet profile to reduce the maximum bending stress. The number of iteration steps (or optimization time) is limited. Extensive testing of this program allowed defining the set of random search parameters that provides satisfying solutions for all possible combinations of gear parameters. The random nature of this method does not repeatedly give absolutely identical results for the same set of gear parameters and number of iteration steps. The program was adjusted to provide the maximum bending stress difference for repeatable calculation not to

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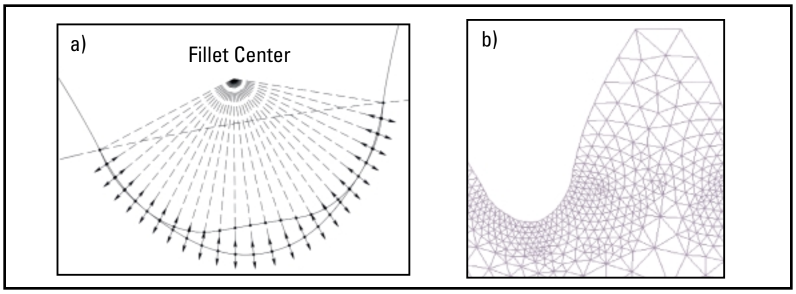

Fig. 3—Fillet profile optimization; a) random search node locating, b) FEA mesh around the optimized fillet.

Table 1—Fillet optimization of standard rack-generated gears.

Pressure angle, °		20		25		28	
Diametral Pitch, 1/in.		10		10		10	
Addendum, in.		0.1		0.1		0.09	
Whole depth, in.		0.22		0.22		0.198	
Tool tip radius, in.		0.03		0.03		0.0348	
Pinion Torque, in.-lb.		200		200		200	
		Pinion	Gear	Pinion	Gear	Pinion	Gear
Number of teeth		12	41	12	41	12	41
Tooth tip radius, in.		0.015	0.015	0.015	0.015	0.015	0.015
Face width, in.		0.5	0.5	0.5	0.5	0.5	0.5
Bending Stress (psi)	Standard	28,890	20,460	22,930	18,560	20,440	17,080
	Balanced	22,180	22,010	19,900	19,800	18,330	18,170
	Optimized	16,900	16,870	16,140	16,110	15,820	15,670

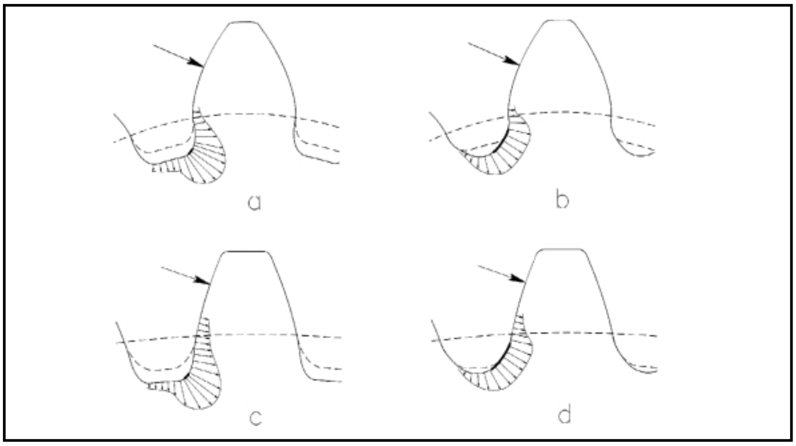

Fig. 4—Bending stress concentration for the balanced, traditionally designed (standard tool parameters) gear pair. Dashed line is the form circle; dotted line is the trajectory of the mating gear tooth; thick line is the stress concentration area; a and b are the 12-tooth pinion profiles before and after optimization, respectively; c and d are the 41-tooth gear profiles before and after optimization, respectively.

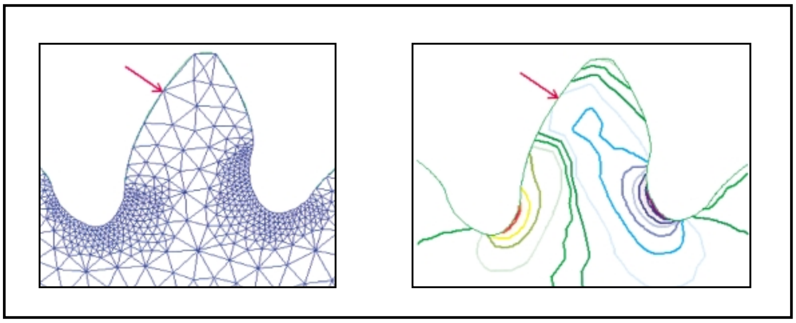

Fig. 5—FEA mesh and stress isograms for asymmetric tooth.

exceed 2%. The fillet shapes for these cases are also slightly different. Optimization of the pinion and the gear fillet profiles can result in bending stress differences exceeding the permissible balance tolerance δ_s. In this case, the tooth thickness ratio should be adjusted

$$C_{ttopt} = C_{tt} \bullet S_{\max 2}/S_{\max 1} \qquad (3)$$

and the optimization process should be repeated.

Table 1 shows the results of the fillet optimization of gears designed by the traditional standard rack generative method. The generating rack profiles with 25° and 28° pressure angles provide a much lower level of maximum bending stress compared to the standard 20° generating rack. As a result, the fillet optimization of the high-pressure-angle gear tooth profiles gives less significant relative bending stress reductions than for standard 20° gear teeth. Figure 4 shows the bending stress concentration before and after fillet profile optimization. The optimized fillet has a more even bending stress distribution along its profile compared to the fillet of the standard rack-generated gear.

Fillet optimization provides maximum bending stress reduction for gears with asymmetric teeth (Refs. 5 and 6) as well. Optimized asymmetric-tooth FEA mesh and stress isograms are shown in Figure 5.

Tolerancing

The bending stress balance and the fillet optimization are calculated for the pair of gears at the tooth profiles' maximum material condition and absolute minimum (counting on maximum gears' runouts and their misalignments) center distance in the zero backlash mesh.

The specified center distance is:

$$a_{w\min} = a_{wabs} + (ro_1 + ro_2)/2 + bl_{\min}/\cos(\alpha_{wabs}) + \delta a_w$$
$$a_{wnom} = a_{wabs} + \Delta a_w/2$$
$$a_{w\max} = a_{wnom} + \Delta a_w/2 \qquad (4)$$

where

a_{wabs} is the absolute minimum center distance that was used for bending stress balance and fillet optimization,

ro_1 and ro_2 are the operating pitch diameters' runouts of the pinion and the gear,

$bl_{\min}$ is minimum normal operating backlash,

α_{wabs} is the pressure angle that was used for bending stress balance and fillet optimization,

δa_w is the center distance variation related to other factors, like the maximum tooth alignment variation (including the shafts' misalignment), the bearing radial play, thermal expansion, etc.,

Δa_w is the total center distance tolerance.

The tooth parameters' tolerancing is shown in Figure 6.

The minimum material condition tooth thickness at the reference diameter is:

$$S_{w1,2\min} = S_{w1,2\max} - \Delta S_{wp1,2} \quad (5)$$

where

$S_{w1,2\max}$ are the maximum material condition tooth thickness of the pinion or of the gear at the reference diameter,

$\Delta S_{wp1,2}$ is the tooth thickness tolerance.

The minimum material condition root and outside diameters are:

$$d_{r1,2\min} = d_{r1,2\max} - \Delta d_{r1,2} \quad (6)$$

$$d_{a1,2\min} = d_{a1,2\max} - \Delta d_{a1,2} \quad (7)$$

where

$d_{r1,2\max}$ and $d_{a1,2\max}$ are the maximum material condition root and outside diameters,

$\Delta d_{r1,2}$ and $\Delta d_{a1,2}$ are the tolerances for root and outside diameters.

Tool Profile Definition

The gear manufacturing process drives the tool design first of all. The most common gear manufacturing processes are gear machining and gear forming.

The gear machining process uses the copying or generating methods.

The copying gear machining method is used for milling, fly-cutting, shear-speed cutting, broaching, and form grinding. The tool profile is identical or very close to the space profile between neighboring teeth (for milling and fly-cutting) or the space around all gear teeth (for shear-speed cutting and broaching). It allows using the tooth space profile including the optimized fillet as the tool profile.

The generating gear machining method is used for hobbing, shaper-cutting, and generative grinding. The tool profile is not identical to the tooth space profile and can be defined by the reversed "gear forms tool" generating method (Fig. 7). The gear teeth with optimized fillet profile are set in mesh with a generated tool rack (for hobbing and generative grinding) or with a generated tool gear (for shaper-cutting). The tool pressure angle is selected to provide desirable machining conditions.

The gear forming process is typical for powder metal gears, plastic and metal injection molded gears, forged and extruded gears. The tool cavity profile (Fig. 8) looks similar to the gear profile, but it is adjusted for shrinkage. Shrinkage adjustment depends on the manufacturing method, process parameters, gear shape and material, etc.

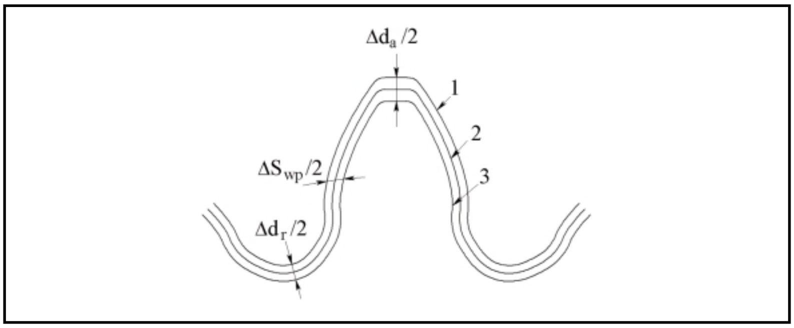

Fig. 6—Tooth parameters' tolerancing; 1, 2, and 3 are the tooth profiles at maximum, nominal, and minimum material conditions.

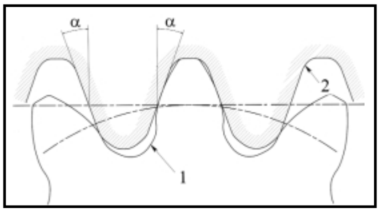

Fig. 7—Reversed "gear forms tool" rack-type tool profile generation; 1—the gear profile, 2— the tool profile.

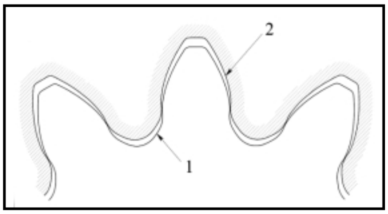

Fig. 8—Molding tool cavity profile definition; 1—the gear profile, 2—the cavity profile.

Summary

Direct Gear Design uses FEA for bending stress evaluation because the Lewis equation and its related coefficients do not provide a reliable solution to the wide variety of non-standard gear tooth profiles that could be considered.

Bending stress balance allows equalizing the tooth strength and durability for the pinion and the gear.

Optimization of the fillet profile allows reducing the maximum bending stress in the gear tooth root area by 10–30%. It works equally well for both symmetric and asymmetric gear tooth profiles. The bending stress reduction leads to:

- Size and weight reduction
- Longer life
- Higher load application
- Cost reduction (less expensive materials, heat treatment, etc.)
- Noise and vibration reduction, increased efficiency (finer pitch, more teeth will result in higher contact ratio for the given center distance).

The paper also describes an approach to the tooth parameters' tolerancing and tool profile definition.

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Gear Manufacturers Face Challenges in Growing Wind Energy Industry

Joseph L. Hazelton

East of San Francisco Bay, near the town of Rio Vista, 81 white towers stand 255 feet tall on rolling hills of dry grass harvesting a year-round crop: wind.

On each tower, blades 124 feet long rotate in the wind, transferring its energy to the gearbox inside the turbine nacelle. Sun and planet gears rotate around an internal ring gear, transmitting the energy to the nacelle generator, creating electricity. In total, the turbines generate 145 megawatts.

Installed this year, the wind farm represents an opportunity for the gear industry.

Wind energy is a growing international industry. The European Union added 4,493 megawatts of new capacity in ’01, then added another 5,871 in ’02. The United States installed 1,696 megawatts of new capacity in ’01 and 410 more in ’02.

A leading U.S. wind energy developer, FPL Energy alone is scheduled to install another 800 megawatts this year. Brent Reardon, the developer’s technical manager for wind, says the company’s goal is to install 750–1,000 megawatts each year for the foreseeable future.

More wind turbines means more wind turbine gears. Besides new manufacture, wind energy’s growth means more chances for work repairing the gears and overhauling them.

But wind energy is also a challenge to the gear industry.

The challenge starts with turbines in the 1.5–2.2 megawatt range. In that range and higher, wind turbines use planetary gear drives. Their sun and planet gears aren’t difficult to manufacture, but their internal ring gears are.

In that range, the internal ring gears have pitch diameters of 4- to 6-feet and quality levels of Q10–12 using AGMA standard 2000–A88.

Working with pitch diameters of more than 5 feet, manufacturers of wind turbine gears start to “bump up against” their machine limits, says Ed Hahlbeck, president of Powertrain Engineers, a consultancy based in Pewaukee, Wisconsin. Hahlbeck’s company specializes in large wind turbines, and Hahlbeck himself serves on the AGMA Wind Turbine Gear Committee.

The challenge of the internals is everyday, though, because turbines in 1.5–2.2 range are commonplace at utility-scale wind farms.

“With any new installation, you’re going to be working in that size range, with 1.5 as the lower limit,” says Frank C. Uherek, engineering manager for Flender Corp. and Winergy Drive Systems of Elgin, Illinois. “That’s where the market is sitting.”

The new wind farm near Rio Vista is an example. Each of its 81 wind turbines generates 1.8 megawatts.

But the market won’t be sitting in that range forever. Reardon expects the average wind turbine to be in the 1.5–3.0 range in the next two to three years, meaning gears’ sizes would become “tremendously bigger.”

Roland Ramberg, president of The Gear Works, estimates gears in 3.0 turbines would have to be about 30 percent larger than they are in 1.5 turbines.

Based in Seattle, Washington, Ramberg’s gear job shop specializes in high-accuracy industrial gears. In the wind energy industry, The Gear Works mainly provides repair-and-replacement service to users of wind turbines. Through bidding, though, it also manufactures gears for new wind turbines, primarily the internal ring gears for turbines generating up to 1.5 megawatts.

Wind energy’s market in the United States is growing, so wind turbines represent an opportunity for the gear industry.

His company wouldn’t have any trouble making the external gears for the 3.0 turbines, but it would have to buy the machinery for the larger internal ring gear.

“The internal would require a major investment,” Ramberg says. “It would be

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Tax Credit Promotes U.S. Wind Energy

"Unsteady"—Brian McNiff, president of wind energy consultancy McNiff Light Industry of Harborside, Maine.

"Very up and down"—Rick Walker, director of business development, wind energy developer AEP Wind Energy of Columbus, Ohio.

"On a roller coaster"—Mark Haller, vice president of technology, wind energy developer Zilkha Renewable Energy of Houston, Texas.

What are these wind energy people describing? Their industry's market in the United States.

U.S. wind energy was largely inactive during much of the 1990s. The industry started to revive five years ago, when installment of new capacity jumped from 11 megawatts in '97 to 233 in '98, then to 661 in '99.

But the U.S. revival has included very *large* fluctuations. After '99, installment of new capacity dropped to 53 megawatts in 2000, soared to 1,696 in '01, then dropped again to 410 in '02.

In contrast, the wind energy industry installed 4,493 megawatts of new capacity in the European Union in '01, the U.S. boom year. Wind energy followed up the next year with another 5,871 megawatts in the EU.

U.S. demand varies more than world demand because the U.S. government keeps letting its wind energy tax credit expire, says Christine Real de Azua, assistant communications director for the American Wind Energy Association, based in Washington, D.C.

The Federal Wind Energy Production Tax Credit is meant to help level the playing field between companies providing electricity from wind power and those providing it from other sources, like gas, coal, oil and nuclear. Specifically, it's a per-kilowatt-hour tax credit for wind-generated electricity during the first 10 years of operation. This year, the credit is 1.8 cents per kilowatt-hour.

The credit was part of the Energy Policy Act of 1992 and had an expiration date of June 30, 1999. But wind energy's U.S. market was largely dormant until '98.

In the late '90s, state requirements for renewable energy sources led to increased development of utility-scale wind farms. The farms showed that wind energy could compete with other energy sources.

By then, the federal credit was approaching its expiration date. On June 30, 1999, the credit expired. The U.S. government reinstated the credit in late '99, with a new expiration date, Dec. 31, 2001. The credit lapsed again at the end of '01, but was reinstated in March '02 and given its current expiration date, Dec. 31, 2003.

Wind energy's U.S. market was mainly inactive during much of the '90s, but started to revive in '98 and had a record year in '01, when 1,696 megawatts of new capacity were installed.

But the credit's short terms and lapses affect the wind energy industry. Installing a new utility-scale wind farm takes time. According to McNiff, wind farm projects will be suspended if turbines aren't being installed by Aug. 1 and the credit is set to expire Dec. 31 of that year. A member of AGMA's wind turbine gear committee, McNiff adds the projects won't resume until developers know the credit will be reinstated

"It tends to drive the production of wind turbines in a very cyclic manner," says Brent Reardon, technical manager for wind at FPL Energy, a leading U.S. wind energy developer based in Juno Beach, Florida.

In contrast, Europe's governments have long-term policies supporting development of wind energy and its countries steadily invest in wind energy, according to de Azua.

To make the U.S. market more stable, both Reardon and de Azua agree the federal credit should have a much longer life. For the AWEA, that life should be at least five years.

"It would help stabilize the wind industry for planning and development of future projects," Reardon says.

Internal ring gears for wind turbines generating 1.5–2.2 megawatts of electricity have 4- to 6-foot pitch diameters and AGMA quality levels of Q10–12.

millions."

Upgrading to manufacture 3.0 gears, a company might have to buy a larger CNC machining center for turning, milling and drilling; a larger gear-cutting machine—two if the company wanted to rough- and finish-cut separately; and a larger gear-grinding machine.

"Those would be the three major purchases," Ramberg says.

Such large machines could be bought from major machine tool manufacturers, but they'd be built to order.

"You're not going to go to the showroom and buy one off the showroom floor," Ramberg says. To indicate cost, he estimates the gear grinder alone would approach $2 million.

Equipping to manufacture larger internal ring gears is a problem for the future, though. Gear manufacturers are still dealing with a problem from the past: a general shift in wind energy from spur teeth to helical ones.

Ramberg noticed the shift several years ago, and both Hahlbeck and Uherek agree helicals are becoming more and more common.

Hahlbeck adds that cutting helicals on large internal gears is a special problem. He explains that the helicals are cut on shaping machines that generally aren't computer controlled, so the machines need special tooling, which increases manufacturing costs.

As wind energy grows, gear manufacturers face another challenge: higher volumes of production. To be more productive, they may have to replace their vitrified grinding wheels with CBN ones.

Describing the price difference as "huge," Hahlbeck says a set of roughing and finishing CBNs would cost several

New Wind Turbine Standard Is Ready for Growing Industry

The American Gear Manufacturers Association is preparing a 90-page standard on wind turbine gearboxes for its final reviews before publication.

After nine years of work, the AGMA Wind Turbine Gear Committee adopted the omnibus standard July 23. It will be the AGMA's first standard on wind turbine gearboxes.

The work started in January '94, with the committee's first official meeting. The original members were clear on the reason for organizing as a group.

"We were all seeing widespread failures in wind turbine gearboxes," says Jane Muller, an original member and the committee's vice chairwoman.

She's also a mechanical engineer with a gear consultancy, GEARTECH, located in Townsend, Montana.

"Wind turbines are a very demanding application for gears," says Brent Reardon, the committee's chairman. "They have to transmit very high and dynamic loads."

The committee started by creating an information sheet in conjunction with the American Wind Energy Association. The sheet, AGMA/AWEA 921-A97, provided recommendations for manufacturing wind turbine gearboxes and took effect in October '97. Since then, the committee has been expanding on the sheet to create a regular standard.

The standard is arriving at an opportune time. Mainly inactive for years, wind energy's U.S. market became more active in '98 and had a record year in '01, when 1,696 megawatts of new capacity were installed.

"It's a growing, fluid industry," Muller says.

As an example, she refers to the late '70s and early '80s. Back then, utility-scale wind farms used wind turbines that might generate 120 kilowatts. Today, new utility-scale wind farms commonly use turbines generating 1.5 megawatts. And more powerful turbines are commercially available.

"Just the basic design of the gearbox is changing quite rapidly," Reardon says.

As design and manufacture guidelines, the standard is the work of a committee that has expanded since it created its information sheet.

"We're up to 50 members attending every meeting. There are over 10 countries involved in this committee," Muller says. "It represents everyone involved in wind energy."

As a cross section, the committee includes several industry heavyweights. Reardon, its chairman, is from FPL Energy, a leading U.S. wind energy developer. Its members are from NEG Micon, Flender, MAAG Gear, Timken, SKF Industrial, Castrol Industrial, and Exxon Mobil.

Other members come from the U.S. National Renewable Energy Lab and Institut für Maschinenelemente Technische, connected to the Gear Research Centre at the Technical University of Munich, Germany.

In total, members' companies manufacture, purchase, operate and service wind turbines; manufacture the gears, bearings, lubricants and lubricant components used in them; provide monitoring equipment for them; and consult on their gears.

Many committee members are from companies in Europe, where wind energy is a larger industry than it is in America.

The AGMA is in the final stages of preparing for publication its first standard on wind turbine gearboxes.

According to Muller, they had commercial and general interests in contributing to the standard. American wind farms often use European wind turbines. Muller says the Europeans also contributed to do "the right thing" for the wind energy industry. She adds the standard benefited from the Europeans.

Reflecting the members' expertise, the standard includes a range of fields related to wind energy. It covers specifying, selecting, designing, manufacturing, procuring, operating and maintaining of wind turbine gearboxes. It also covers bearings, lubrication and condition monitoring of the boxes.

The standard has nine annexes, as well. They include wind turbine architecture, environmental considerations, wind turbine load description, quality assurance, operation and maintenance, minimum purchaser and gearbox manufacturer ordering data, lubrication selection and condition monitoring.

On Feb. 12, the committee approved the standard for a general ballot. The standard was then distributed to AGMA members for review and suggested changes.

Like other AGMA standards, this new standard will be voluntary. Its title is "Standard for Design and Specification of Gearboxes for Wind Turbines" and is designated AGMA/AWEA 6006-AXX. When published, the "XX" will be replaced by the publication year.

On July 23, the committee met in Big Sky, Montana, decided which suggested changes to include, and voted to submit the standard to the AGMA Technical Division Executive Committee.

The standard still has a ways to go before publication, though. After TDEC, the standard will be reviewed by the AGMA board of directors and then the standards council for the American National Standards Institute. After all three groups approve the standard, then the AGMA will publish it.

Manufacturers of wind turbine gears may have to push the limits of their machinery to create the internal ring gears needed by wind energy's larger turbines. Another manufacturing challenge is the general shift from spur teeth to helical ones.

thousand dollars, but the vitrifieds would cost only a few hundred.

However, Hahlbeck adds gear manufacturers tend to sell their wind turbine gearboxes to projects where the number of gears can be in the hundreds. In those cases, CBN wheels could be a cost advantage through higher productivity and greater consistency.

Uherek says serial production is key to CBN use: "If you're going to make 40 of something, CBN pays; if you're going to make one of something—forget it."

Serial production also takes advantage of CBN's longer life compared with vitrifieds, making the price difference more bearable.

Given these manufacturing challenges, it isn't surprising that Bernard Vuković of MAAG Gear uses "expensive" when describing gear manufacturers' involvement in the wind energy industry. Vuković is a gear engineer in the wind turbine gearbox division of MAAG, based in Winterthur, Switzerland.

Besides the high cost of the machines for manufacturing large wind turbines' gears and gearboxes, he mentions the expense of the cranes for removing malfunctioning gearboxes from erected turbines and the costs that can result from shipping the gearboxes back to manufacturing plants for repair.

So he advises gear manufacturers curious about entering the wind energy industry: "Unless you have really, really big pockets, then don't."

He also cautions companies interested in supplying just the sun, planet and parallel-axis gears, not the internal ring gears. He says an important question is: Who's responsible for what parts? That question becomes important when gearboxes malfunction and companies have to decide who's responsible for possibly expensive repairs.

"They can make or break somebody," Vuković says.

Photos courtesy of AEP Wind Energy, the American Wind Energy Association, FPL Energy and The Gear Works.

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Local 3-D Flank Form Optimizations for Bevel Gears

Hartmuth Müller

Abstract

Optimizing the running behavior of bevel and hypoid gears means improving both noise behavior and load carrying capacity. Since load deflections change the relative position of pinion and ring gear, the position of the contact pattern will depend on the torque. Different contact positions require local 3-D flank form optimizations for improving a gear set.

This paper presents methods on flank form modifications for spiral bevel or hypoid gears. Flank form modifications applied to generated gears are based on additional machining motions superimposed on the rolling motion. Additional motions are modified roll, helical motion, vertical motion, and horizontal motion. These motions are represented by a Taylor series approach. A Taylor series is a mathematical development of a function using polynomial functions: $f(x) = \sum_i a_i \cdot (x - x_0)^i$. The independent variable is the cradle angle.

In case of nongenerated gears, flank form modifications are performed by machining different plunging positions continuously. A plunging position is defined by cradle angle, radial distance, offset, machine root angle and sliding base. According to the approach used for generated gears, the motions are described as Taylor series depending on an imaginary strictly limited cradle movement.

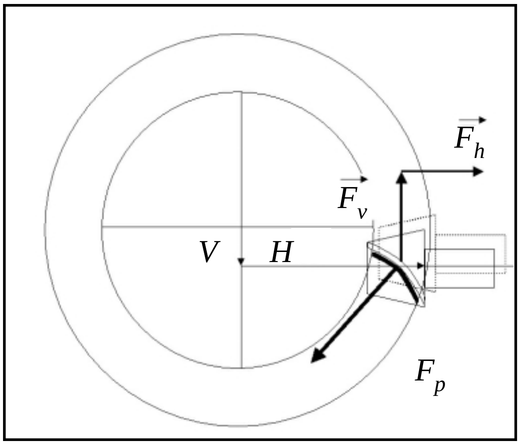

Figure 1—Tooth forces in a hypoid gear set.

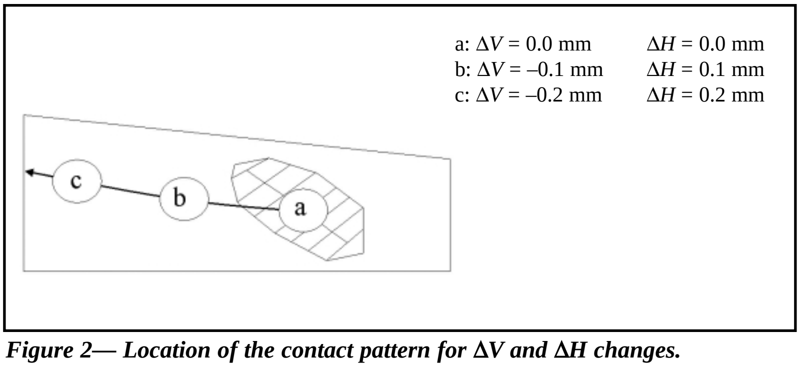

Figure 2— Location of the contact pattern for ΔV and ΔH changes.

Introduction

Designing spiral bevel and hypoid gears covers a lot of different aspects. In general, the aim is to minimize gear noise and gear volume as well as to maximize load carrying capacity. Minimizing gear volume and maximizing load carrying capacity are especially conflicted aims. Nevertheless it is important to design a well-balanced compromise within these aims.

For practical applications, it is necessary to keep the characteristics of the running behavior in a bandwidth defined by assembly tolerances.

Everything related to the running behavior of gears originates in the meshing operation of the teeth. Therefore a detailed look into the meshing operation with respect to influences of housing and bearings will be necessary.

Noise Behavior and Crownings

In the last few years, several approaches have been published dealing with noise optimizations (Refs. 1 and 2). The result of all these efforts concentrated on the transmission error and a reasonable pitch quality. If the transmission error exceeds a certain limit, the noise behavior will not be acceptable. The influence of the pitch quality is not very drastic. Gears with spacing better than DIN 5 will not show significant influences on the pitch error.

The influence of the shape of the transmission error is not yet fully clear. One possibility is to perform a Fourier transform in order to separate the first mesh harmonic from higher orders (Ref. 3).

A Fourier transform is any periodical function that can be expressed by a series of sinusoidal functions: $f(x) = a_0/2 + \sum_i[a_i \cdot \cos(i \cdot x) + b_i \cdot \sin(i \cdot x)]$. This principle performs a harmonic analysis. The coefficients a_i and b_i are called Fourier coefficients.

Since very small surface defects on the flanks of the gears have a great influence on higher orders of the Fourier transform, this area will be of great interest in the future (Ref. 3).

With a conjugate gear set, the unloaded contact area at each instant in time will be a line and the transmission error will be zero. As the gear pair rolls through mesh, these instantaneous line contacts result in a full contact pattern covering the whole active flank. Meshing conditions like this are ideal for minimum noise. However, even a small displacement of the pinion or ring gear will change the full contact pattern into a small line at the border of the teeth and would result in a noisy gear set.

Therefore every gear design requires reasonable crownings in profile and lengthwise direction of the teeth. The bigger the crownings are, the smaller the transmission error will change due to displacements, but the higher the transmission error will be. The smaller the crownings are, the smoother the gear will run, but the more sensitive it will be to displacements.

Gear Load and Displacements

In general, load applied to a bevel or hypoid gear set influences housings, bearings, gear bodies, shafts and teeth. For a better understanding, this paper separates two effects of the load. The first effect is a displacement of pinion and ring gear caused by tooth forces deflecting the pinion shaft and the ring gear according to the stiffness of bearings, housing and gear bodies. The second effect is the deflection of the flanks due to the load, resulting in surface stress and root bending stress.

Although this approach simplifies the real situation, it helps in understanding the effects of load. In Figure 1, a schematic view of a hypoid gear set is shown.

When the pinion rotates counterclockwise, the concave pinion flank will drive the convex ring gear flank. The force F_p of the pinion's flank will create an answering force $F_g = F_v + F_h$ of the ring gear. The vertical component F_v will decrease the hypoid offset V, and the horizontal component F_h will increase the mounting distance H. Increasing the mounting distance will push the pinion into the bearings. Therefore this direction of rotation is called the drive side.

The different locations of the contact pattern depending on ΔV and ΔH are shown in Figure 2. This figure schematically represents the characteristics for the drive side. The contact pattern in the ring gear is shown. The toe is on the right side, the heel on the left and the root on the bottom.

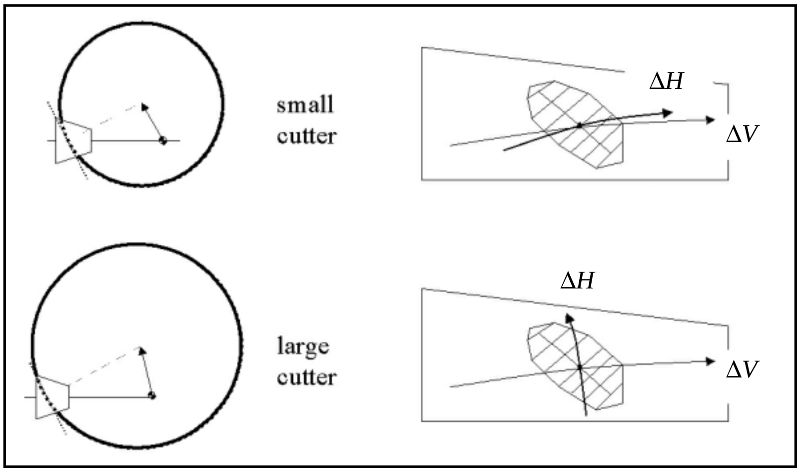

Figure 3—Contact pattern reactions to ΔV and ΔH changes.

This figure shows a bias-in condition, since the contact moves towards the tip-heel area of the tooth with $\Delta H = -\Delta V$. If the contact moved towards the root-heel area, the condition would be called bias-out.

The other direction of rotation is called the coast side and shows forces in the opposite direction. For the coast side, the tooth forces will increase the hypoid offset V and decrease the mounting distance H.

Macrogeometry Conditions

Even when the deflections are small numbers, the position of the contact pattern will change drastically. Depending on the diameter of the cutter, we get changes in the position of the contact pattern as shown in Figure 3.

The influence of the cutter diameter can be used to design a gear set insensitive to deflections. Since the tooth forces decrease the offset and increase the pinion mounting distance, an optimum for the cutter diameter is found when the trajectories for ΔV and ΔH are as close to the same as possible.

The optimal cutter diameter is given by $D_{cutter} = 2 \cdot R_m \cdot \sin(\beta_m)$, where R_m is the mean cone distance and β_m is the mean spiral angle.

Ease-Off Design

Besides the macrogeometry, the shape of the flanks is the most effective part optimizing a gear set. Noise optimization is done by reducing crownings for a smooth meshing operation. Load optimization needs to increase crownings in order to avoid edge contact and peaks in the root bending stress.

As shown earlier, the position of the contact pattern changes due to load deflections. Since the contact moves towards the heel area with increasing load, it is obvious that the unloaded contact

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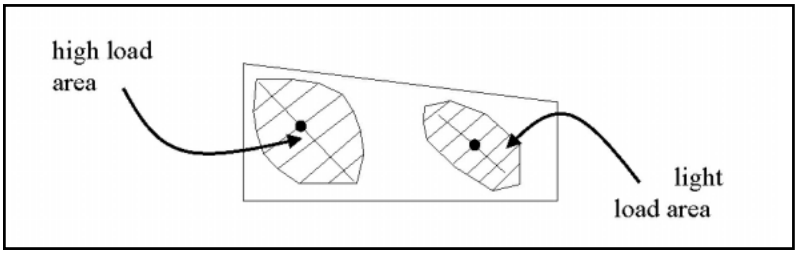

Figure 4—Load defined flank areas.

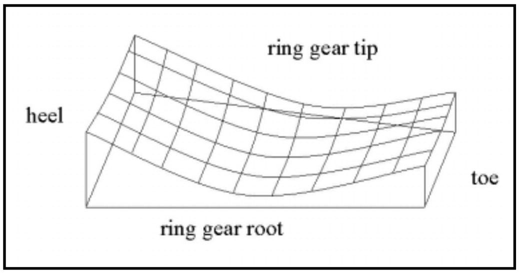

Figure 5—Standard ease-off.

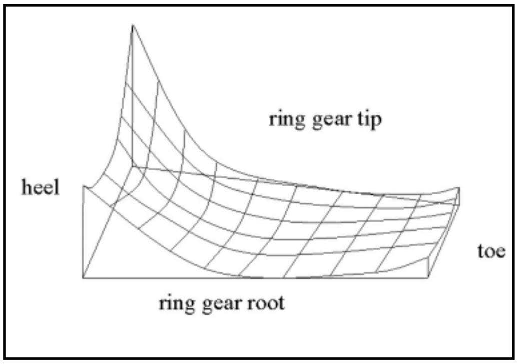

Figure 6—Optimized ease-off.

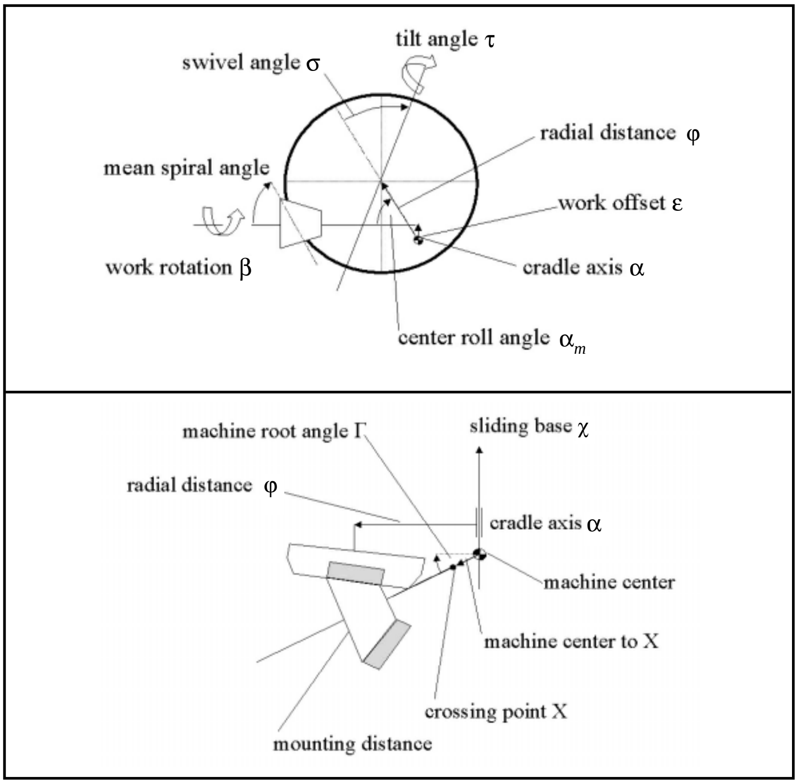

Figure 7—Machining parameters.

should be moved more toward the toe area. The phenomena of a load depending position of the contact pattern is used to define different load areas, shown in Figure 4.

The meshing topography is represented by the ease-off. The ease-off is the contact distance between two flanks meshing, ideally without transmission error. Figure 5 shows a typical standard ease-off. All other characteristics, like transmission error and size and location of the unloaded contact pattern, can be derived from the ease-off. A conjugated gear set has an ease-off which equals zero all over the flank.

Optimizing the noise behavior is more critical under light load conditions. The more load is applied, the more the surface of the flanks will be deflected resulting in a lower level of the transmission error. The lower the load is, the more important the flank's shape is for noise emission. Noise optimization will be achieved by introducing locally reduced crowning in the toe area. For practical use of this idea, the ease-off must guarantee a small unloaded transmission error within a pinion mounting distance variation of ±0.05 mm. This corresponds to practical tolerances for the assembly.

Optimizing the load carrying capacity can be achieved by introducing locally increased high crowning in the heel area (Figure 6). The load will deflect the meshing flanks. This can be seen by comparing the unloaded transmission with the loaded transmission, applying the same displacement to pinion and ring gear. The high crownings will help to avoid edge contact. Edge contact would result in peaks in the root bending stress and in peaks of the Hertzian pressure distribution.

Modified Motion

Modified motion is a principle of changing the flank's shape locally. It can be applied to pinions and generated ring gears. Plunged ring gears need a different approach, which is presented later. Since the principle of making all spiral bevel and hypoid gears is based on rolling a plane gear with a workpiece, it is completely sufficient to consider a virtual machine having a cradle. Modern 5- or 6-axis CNC machines just emulate a kinematically unlimited cradle-style machine.

The principle is to use small motions superimposed on the rolling motion. Figure 7 shows the principle of generating a pinion. The upper image is a front view in the direction of the cradle axis, the lower is a top view with the cradle axis in the drawing plane.

The standard rolling motion for a pinion or a generated ring gear is given by:

$\beta = \text{const} \cdot (\alpha - \alpha_m)$, $\Gamma = \text{const}$, $\tau = \text{const}$,
$\sigma = \text{const}$, $\varepsilon = \text{const}$, $\chi = \text{const} \cdot (\alpha - \alpha_m)$

Free form motions are introduced by developing a Taylor series of the sixth order around the center roll angle α_m. With this approach, the machining motion looks like:

Modified Roll:
$\beta = a_\beta + b_\beta(\alpha - \alpha_m) + c_\beta(\alpha - \alpha_m)^2 + \ldots + g_\beta(\alpha - \alpha_m)^6$

Angular Motion:
$\Gamma = a_\Gamma + b_\Gamma(\alpha - \alpha_m) + c_\Gamma(\alpha - \alpha_m)^2 + \ldots + g_\Gamma(\alpha - \alpha_m)^6$

Helical Motion:
$\chi = a_\chi + b_\chi(\alpha - \alpha_m) + c_\chi(\alpha - \alpha_m)^2 + \ldots + g_\chi(\alpha - \alpha_m)^6$

The principle of the superimposed additional movements is shown in Figure 8. The lines of contact between tool and flank are diagonal over the flanks. Each line has a corresponding cradle angle α.

When applying an additional movement by using a high order coefficient, we obtain a change of the flank's form along the line of rolling. In case of modified roll, the additional angular movement of the workpiece will affect both sides with opposite signs. This is shown in Figure 9 for the coefficients from the second order c_β up to the sixth order g_β. The upper left drawing shows the reference flank form without any modified roll coefficient.

For helical motion, the reaction on the flank depends on the flank angle of the tool. The bigger the tool's flank angle is, the more affected the flank form will be. Usual completing designs use a flank angle of about 30° on the inside blades and about 10° for the outside blades. This will result in nearly no effect on the concave side and big effects on the convex side. Using modified roll will affect both sides nearly the same. By combining modified roll and helical motion, the ease-off for the drive side and the ease-off for the coast side can be designed separately for completing designs. Figure 10 shows the effect of helical motion coefficients from the second order c_χ up to the sixth order g_χ. The tool's flank angle on the inside blades is 32°, the outside blade angle is 8° (Ref. 4).

Modified Crowning

All principles shown in the previous section need a rolling motion to allow flank form modifications. All these modifications work diagonally over the flank. Changing the ease-off values along

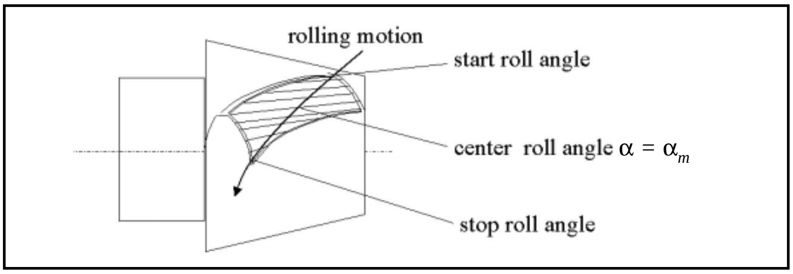

Figure 8—Rolling motion and lines of contact.

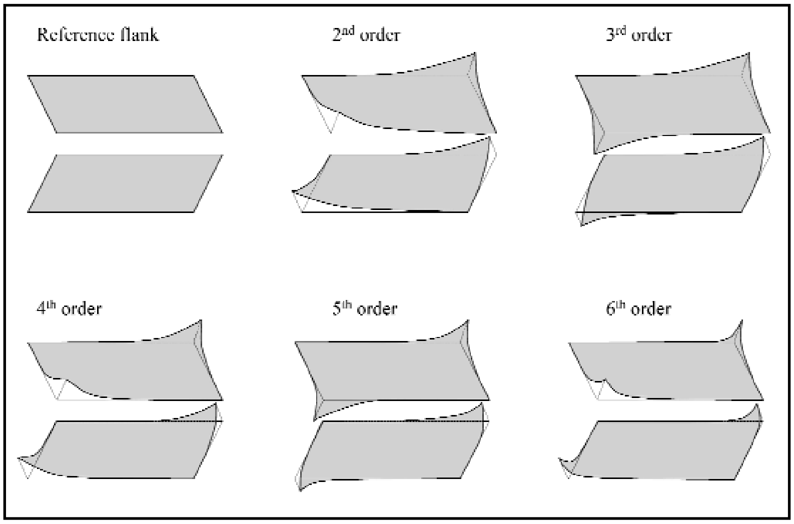

Figure 9—Flank form modifications using modified roll.

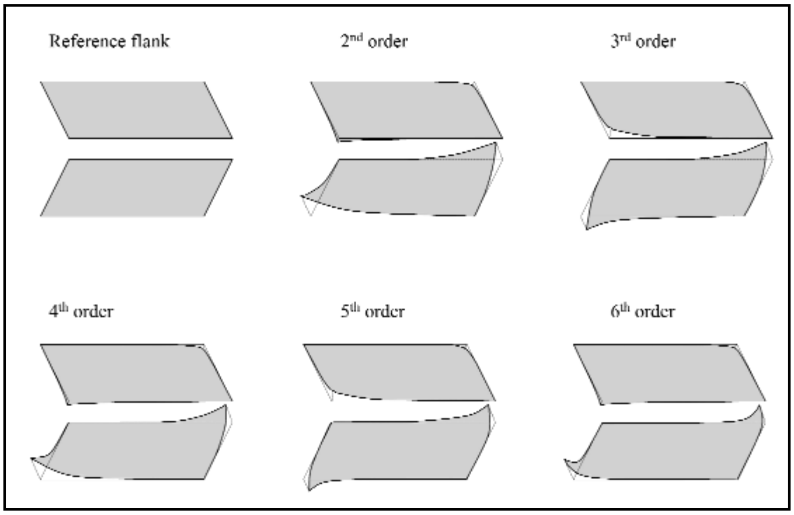

Figure 10—Flank form modifications using helical motion.

the other diagonal line can only be done by changing the tool's diameter.

If the gear ratio is high enough, the ring gears are usually made in a plunging operation. In this case, no rolling operation is performed. The shape of the gap corresponds to the shape of the tool. Changing the flank's form can be done using the Flared Cup® grinding principle (Ref. 5). The idea is to move a grinding wheel which has line contact to the gear flank along the face width. This movement permits defining of Taylor coefficients and superimposing of additional movements when

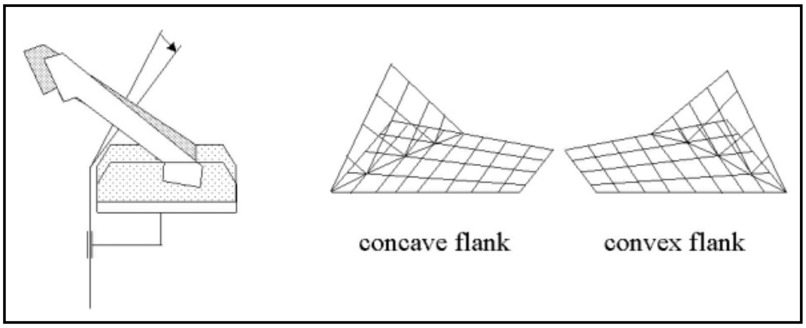

Figure 11—Machining a ring gear with two different plunging positions.

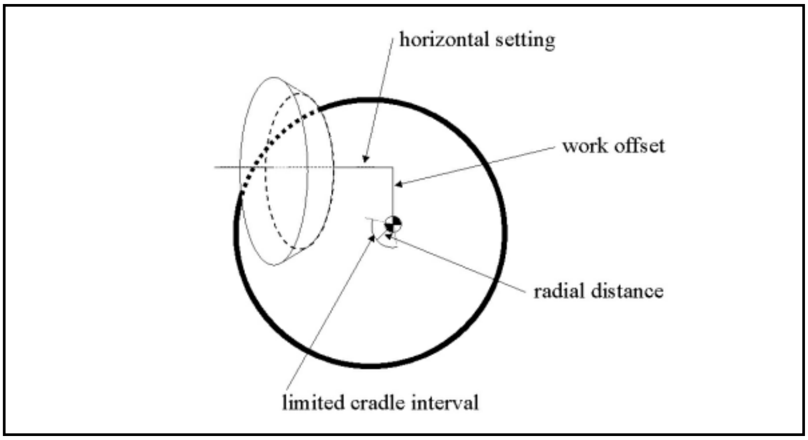

Figure 12—Machining parameters for modified crowning.

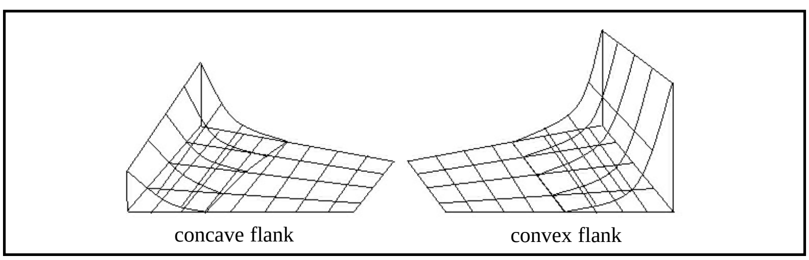

Figure 13—Flank form modifications using modified crowning.

going through the gap.

Another approach is modified crowning. The basic idea is to use different plunging positions to locally modify limited areas of the tooth. Figure 11 shows the effect of plunging a ring gear with two different machine root angles.

Machining a ring gear with the first setting will result in a flank form corresponding to a Formate® ring gear. In Figure 11, this is represented by the thin grid. When the second machine setting is applied to this ring gear, we will get a stock removal in the heel-tip area shown in Figure 11 with thick lines. When using a modification in the radial distance and the angular position of the workpiece, the triangular area of modification can become a square. Modifications in the toe area can be obtained by changing the machine root angle in the other direction.

Affecting both the heel and toe areas will be done by introducing three different plunging positions. For achieving a smooth transition between the two areas, it is sufficient to perform a smooth machining motion between the different plunging positions. Getting a well-conditioned numerical system, a small cradle movement with a very small radial distance is introduced, as shown in Figure 12.

With the principle of introducing a very small radial distance and a corresponding work offset and horizontal setting, we have the possibility of using the Taylor series approach known from generated gears. There is no generating process even if we introduced a limited cradle interval. Any cradle angle outside the limited interval will result in false ring gears.

Figure 13 shows the local flank form modification using two plunging positions for modifying the heel area on both flanks in a completing process (Ref. 6).

Conclusions

Noise optimization and load carrying capacity have been divergent aims. Compared to bevel gears, the contact conditions for spur and helical gears do not change drastically when load deflects the gearbox itself. The load-caused change in contact conditions for bevel gears needs to cover the displacement of ring gear and pinion as well as the deflection of the teeth themselves. When applying local 3-D flank form modifications to different areas of the gear's flank, we are able to improve both the load carrying capacity and the noise emission of a bevel or hypoid gear set.

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TECHNICAL CALENDAR

September 9–11—Midwest Machine Tool Show. Novi Expo Center, Novi, MI. This show's features include an industry summit, a technical forum called "Machining Strategies for Lean Manufacturing Operations" and technology sessions sponsored by SME. Registration is free. Contact SME by telephone at (313) 271-1500 or on the Internet at *www.sme.org*.

September 10–11, September 15–16—2003 Gear Noise Courses. Gear Dynamics and Gear Noise Laboratory, Ohio State University, Columbus, OH. The earlier session is the basics course and the advanced course is held September 15–16. Both courses aim to provide a better understanding of the mechanisms of gear noise generation, methods by which gear noise is measured and techniques in gear noise and vibration reduction. $2,100 for both courses, $1,300 for the basic course only, $900 for the advanced course only. Contact the university's department of mechanical engineering by telephone at (614) 292-5860 or on the Internet at *www.gearlab.org*.

September 15–16—UTS Metal Gear School. UTS facility, Rockford, IL. Topics include basic gear theory, minimum weight design strategies, gear size, geometry design, rating, producibility analysis, torsional analysis, gear noise, lubrication and profile analysis. $1,250. Contact UTS by telephone at (800) 435-7887 or on the Internet at *www.uts.com.*

September 15–19—AGMA Training School for Gear Manufacturing. Richard J. Daley College, Chicago, IL. Offers classroom and hands-on training in gearing and nomenclature, principles of inspection, gear manufacturing methods, and hobbing and shaping. Designed for employees with six months' experience in setup or machine operaton. $650 for AGMA members, $775 for non-members. Contact the AGMA by telephone at (703) 684-0211 or by e-mail at *fentress@agma.org.*

September 16–18—Accurate Diagnosis of Gear Problems. 49'er & Suites, Jackson Hole, WY. This course includes: How Each Cycle of Gearmesh Frequency is Generated; Gear Vibration Theory; Problems that Generate Harmonics of Gearmesh Frequency; Bent Shaft; Defective Teeth & Broken Gears, and more. $1,195 includes *The Gear Analysis Handbook* by James I. Taylor. Contact Vibration Consultants Inc. by telephone at (813) 839-2826 or on the Internet at *www.vibcons.com.*

Also see our coverage of Gear Expo 2003, pages 19–32, for information on technical events to be held at the show. Gear Expo will be held October 5–8 in Columbus, OH.

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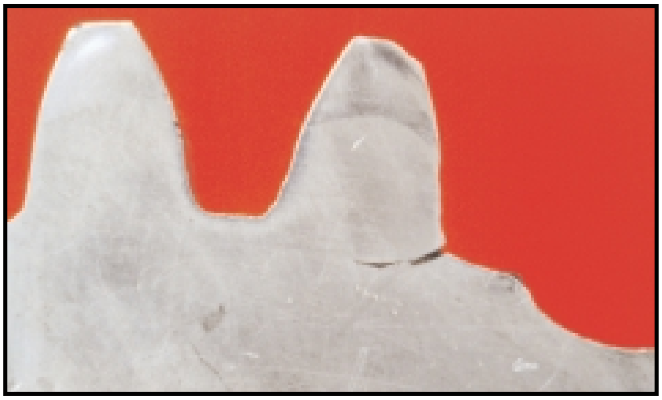
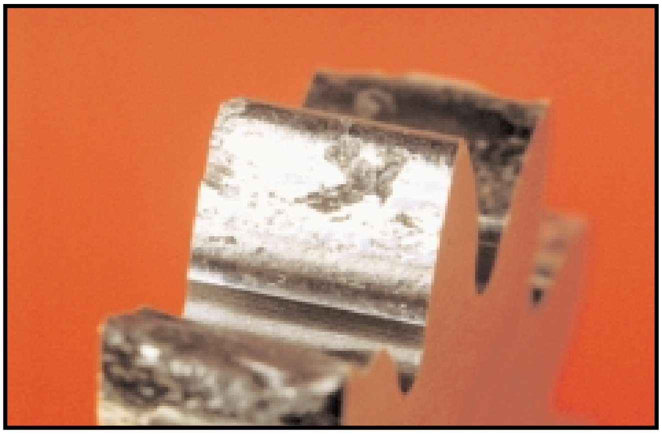
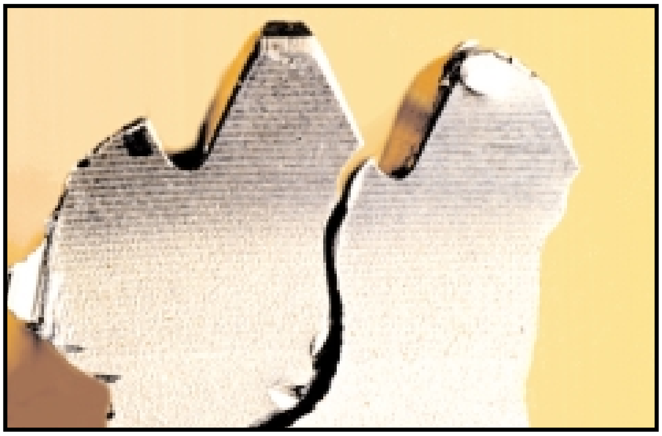
The Ten Commandments of Gear Failure Analysis

Robert Errichello







Robert Errichello
is founder and president of GEARTECH, located in Townsend, MT, and is a technical editor for Gear Technology *magazine. A gear consultant, he specializes in gear failure analysis, gear research and analysis, and gear design and production.*

I. Inspect failed components as soon as possible. If an early on-site inspection is not possible, someone at the site must preserve the evidence based on your instructions.

II. Make sure no work is done until you arrive. This means no disassembly, no cleaning (including exterior), or draining of oil. Verify that gearbox drawings, disassembly tools, and adequate facilities are available.

III. Devote at least two days for the inspection. After the first day, collect your thoughts and analyze the collected data. Often the first day's inspection discloses a need for other data, which you can gather on the second day.

IV. Concentrate on collecting evidence, not on determining the cause of failure. Regardless of how obvious the cause may appear, do not form conclusions until all evidence is considered.

V. Document what you see. List all observations, even if some seem insignificant or if you don't recognize the failure mode. Remember—there is a reason for everything you see, and it may become important later when you consider all the evidence.

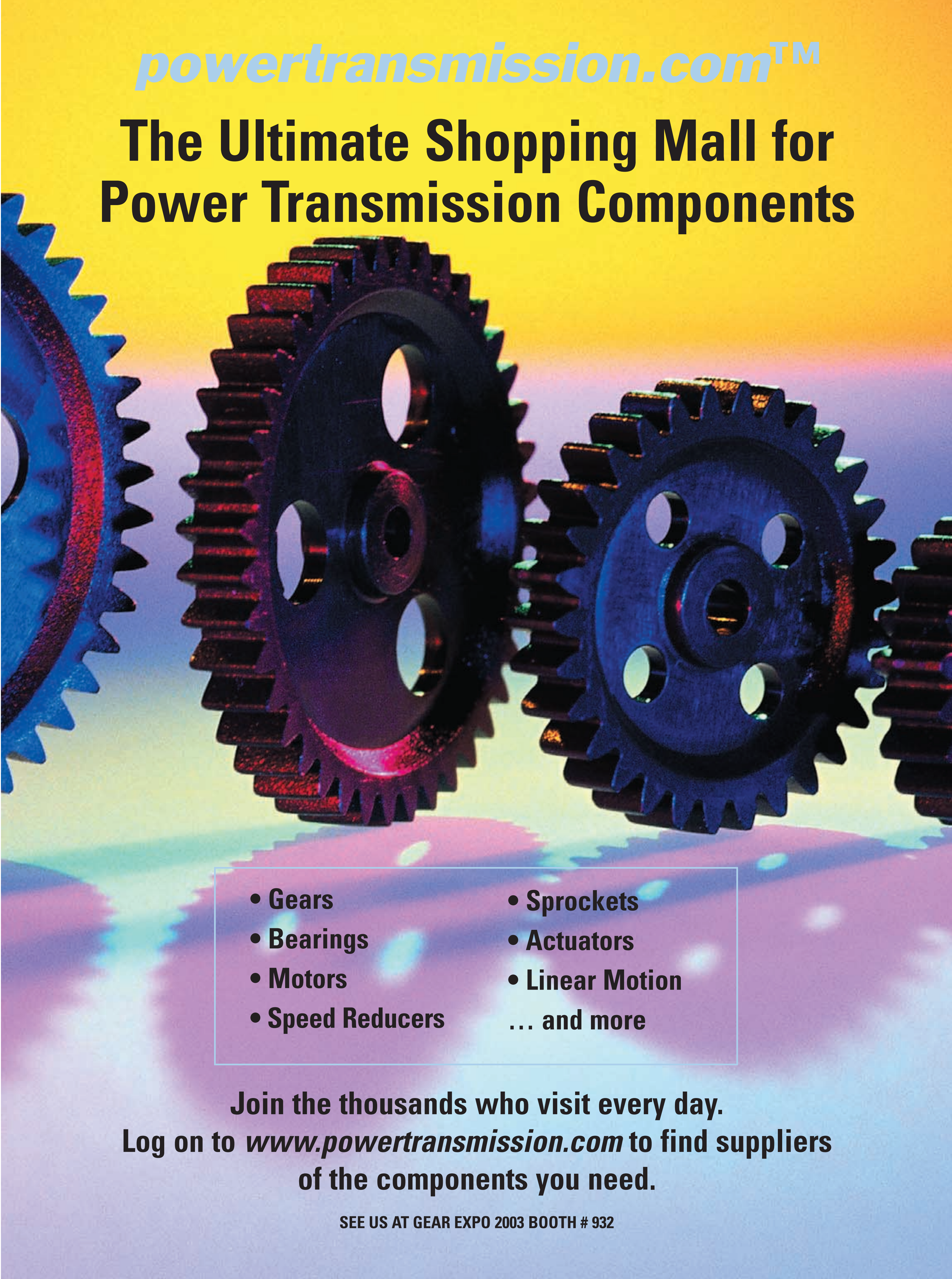
VI. Document what you don't see. This is helpful to eliminate certain failure modes and causes. For example, if there is no scuffing, you can conclude gear tooth contact temperature was less than the scuffing temperature of the lubricant.

VII. Search the bottom of the gearbox. Often this is where you find the best-preserved evidence, such as when a tooth fractures and falls free without secondary damage.

VIII. Use time efficiently. Be prepared for the inspection. Plan work carefully to obtain as much evidence as possible. Don't be distracted by anyone.

IX. Control the investigation. Watch every step of the disassembly. Don't let the technician get ahead of you. Disassembly should stop while you inspect and document the condition of a component, then proceed to the next component.

X. Insist on privacy. Do not let anyone distract you. If asked about your conclusions, answer that you do not form conclusions until your investigation is complete.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AGMA Opens Career Center

The American Gear Manufacturers Association added a new feature to its website for job seekers.

By signing up at *www.careers.agma.org*, job hunters can create multiple search agents to notify them by e-mail about prospects, apply for positions online and submit resumes to the database.

According to the association's press release, employers can maintain full control of their listings, retrieve applications by e-mail or online, save the search criteria for e-mail notification when potential candidates are posted to the database, and see data on how many times the listings were viewed as well as the number of online applications.

A 30-day posting costs $250 for AGMA members and $400 for non-members. Package pricing is available.

Gleason Wins AAM Award

Gleason Corp., of Rochester, NY, was one of seven American Axle & Manufacturing suppliers to receive its Supplier Recognition Award at AAM's 10th Annual Supplier Day, held at the company's Guanajuato Gear & Axle facility in Guanajuato, Mexico.

According to Gleason's press release, they were cited for this award due to the installation of Phoenix II 275HC gear cutting machines at various AAM facilities. Other criteria were Gleason's support of AAM on a global basis with its tool commodity management programs and technical support.

A team of AAM associates from procurement, engineering, quality assurance, manufacturing and materials management selected the winners.

Alfe Heat Treat Plant Receives Certification, Promotes Manager

Alfe Heat Treating's plant in Fort Wayne, IN, received quality assurance certification from the Gulfstream Aerospace Corp. of Savannah, GA.

According to Alfe's press release, the certification indicates that it utilizes the correct procedures to control product and service quality.

The company also announced the promotion of Matt Jones to general manager of the Saginaw division. Jones has been plant manager of that division since he started with the company in 2000. Prior to that, he was materials manager at Lear Corp.

With five plants in the Midwest and two additional ones under construction, Alfe serves the automotive, industrial and aerospace industries.

Gleason Cutting Tools Offers New Literature

Gleason Cutting Tools has produced a new brochure detailing its production capacity for high precision CBN-plated wheels used in external and internal, straight and helical, parallel and bevel gear grinding.

According to the company's press release, the plating facility houses an expandable electrolytic and electroless nickel plating capability that can produce up to 500 wheels per month.

Among the products it produces are non-dressable grinding and dressing wheels manufactured with hardened steel bodies, precision ground profiles and nickel-plated, single-layer CBN or diamond crystal. Sizes range from 30–500 mm outside diameters, up to 160 mm wide and can accommodate various mounting requirements.

Great Lakes Gear and Fhusa Form New Company

Great Lakes Gear Technologies of Canton, MI, and Fhusa S.A. of Barcelona, Spain, announced the formation of Gear Tooling Solutions L.L.C., which will market and provide technical support for Fhusa gear cutting tools in the North American market.

The new company will be exclusively represented by Great Lakes Gear Technologies from their new technical center in Canton, MI. According to Great Lakes Gear's press release, the new venture can take advantage of Fhusa's lower production costs and higher volumes. Fhusa and its partner companies manufacture tooling in Spain, South America, Europe and Asia.

Gear Tooling Solutions' Canton facility also plans to be the base for resharpening services in the Midwest market.

Great Lakes Gear Technologies represents worldwide gear equipment manufacturers for the hobbing, shaping, rolling, broaching, honing and grinding of gears.

Gleason Introduces Financing Option

The Gleason Works of Rochester, NY, has entered into an agreement with Captive Capital Corp. to help customers finance Gleason machinery.

Captive uses a web-based credit application process to select from competitive financing offers made by different lenders. According to Gleason's press release, customers benefit because their smaller out-of-pocket investment allows them to purchase more machinery.

In addition, a lower fixed-rate monthly payment hedges against future inflation. Users can deduct lease payments from their taxes as a business expense.

While the program is Internet-based, the entire procedure can be done off-line via fax. More information is available online at *www.gleason.vendorfinancial.com.*

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Products for the Gear Industry

Shaft Mounted Helical Gear Units from Renold

The SMXtra from Renold Gears features power ratings averaging 35% over previous models while optimized design features permit original frame sizes and dimensions, according to the company's press release.

A number of enhanced seal options are available for standard units, which can be installed to optimize protection from dust and moisture. By reversing one element of the standard design, the seal can provide the security to prevent the egress of oil into sensitive environments.

Other features include an improved single taper bush, motor mounting platform, and a compact torque restraint.

Available in single and double reduction units, the product offers gear ratios up to 25:1 with a power capacity range from 0.3–173 kW.

For more information, contact Renold Gears of Rochdale, U.K., by e-mail at *rgodson@gears.renold.com*.

Spindle Technology from Drake Manufacturing

Smart Spindle technology from Drake Manufacturing features an acoustic sensor that enables the grinding wheel to act as a precise probe and is available for both internal and external grinding machines.

According to the company's press release, the spindle reduces the chances of wheel damage and crashes. Other features include an integral touch sensor and devices that find part features and precut threads, as well as detect misloaded parts.

For more information, contact Drake Manufacturing Services Inc. of Warren, OH, by telephone at (330) 847-7291 or online at *www.drakemfg.com*.

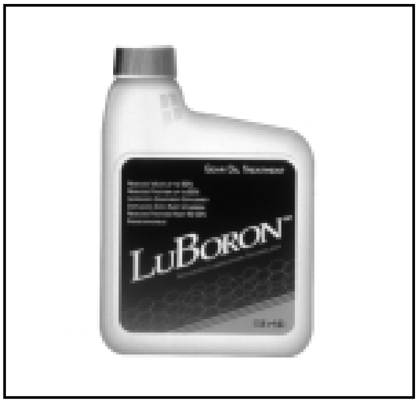
Broach Kits to Modify Sprockets and Gear Wheels from WDS

Broach kits from WDS enable users to cut keyways and splines in a drive wheel. Included in each kit is a series of high speed broaches, guides and shims, allowing engineers to modify one gear or small runs of gears in-house.

According to the company's press release, benefits of in-house production include the ability to produce prototypes, custom drive systems and products and to minimize downtime through the ability to immediately replace worn components.

Containing a series of metric or imperial-sized guides, high speed steel broaches and shims, the tools can cut four different key widths in various sized bores. Designed for use in conjunction with a manual press, kits enable customers to cut keyways in any type of drive, gear or pulley wheel made from a range of materials.

Contact WDS of Leeds, U.K., by e-mail at *pjeselton@wdsltd.co.uk*.



New Gear Oil Treatment from LuBoron

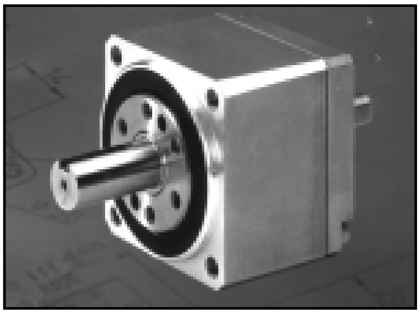
Boron CLB Bond gear oil from LuBoron is designed for use in manual transmissions, transaxles and final drives.

The oil features boron-based, advanced friction-reducing technology and requires a one-time only application.

According to the company's press release, the treatment provides high temperature stability, reduces varnish and gum buildup on gears and inhibits wear. As a result, gearbox life is extended.

This product forms a near-diamond hard micro layer of protection on bearings and gear surface parts with covalent and ionic bonds to metal surfaces, which provides a low friction surface impervious to most contaminants. In addition, the treatment helps reduce backlash tooth drag in differentials, allowing more horsepower to the wheels. Viscosity properties reduce loss of power caused by churning of the gear lubricant.

For more information, contact LuBoron Advanced Lubrication Technology of Charlottesville, VA, by telephone at (866) 582-6766 or by e-mail at *luboron@luboron.com*.



Miniature Gearhead from HD Systems

The CSF-1U size 8 gearhead from HD Systems delivers two arc-minute positional accuracy in a package size that is 30 mm^2 x 65 mm long.

According to the company's press release, the product has a rated torque of 21 in.-lbs. and a maximum torque of 80 in.-lbs. Also, the gearhead has both an input and output shaft for coupling configuration.

Size 8 gearheads are available in gear ratios of 30, 50 and 100:1.

For more information, contact HD Systems of Hauppauge, NY, by telephone at (800) 231-HDSI or by e-mail at *info@HDSI.net*.

Hydraulic Power Chuck from Logansport Matsumoto

The GHA6-8-66 hydraulic power chuck from Logansport Matsumoto permits machining at the high speeds and feeds required for cutting aluminum, according to the company's press release.

Designed for machining steel in hard turning applications, the big bore, 8", three-jaw chuck has a 66 mm through-hole. This allows the user to chuck larger parts or bar feed a larger diameter bar.

For more information, contact Logansport Matsumoto Co. of Logansport, IN, by telephone at (574) 735-0225 or by e-mail at *info@logan-mmk.com*.

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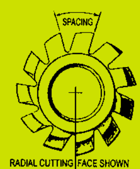

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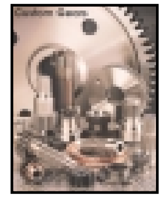

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Contour Hardening: Heat Treating Company, Indy Car Sponsor

Major sponsorship of an Indy car was working out well for racing fans Mike Chaplin and John Storm. On May 25, a warm, clear day, the co-founders of Contour Hardening watched from their racetrack suite as their car, a bullet on wheels, tore into sixth place at the Indy 500.

The black-and-white car, Contour's gear logo big on its nose and sides, was racing around the track at more than 200 miles per hour, until lap 62.

Driver Richie Hearn was coming out of a quarter-mile straightaway on the track's north end. But, coming out of the short chute, he was driving on the high side of the track and raced across a stretch of "marbles." Those are little bits of tire rubber that come off the cars during the race and are blown to the track's high side, near the outside wall.

Chaplin, Contour's vice president, says: "It's like walking on marbles." And what happens to the car? "It goes where it wants to."

The car went into the outside wall. Hearn wasn't hurt in the crash, but the car was too damaged to go on. Officially, he finished 28th, his starting position. As for Contour, its major sponsorship was a one-race deal for just the Indy 500.

It was also a deal put together at racing speed, in little more than a day. But, in a sense, it was a deal six years in the making.

Based in Indianapolis, Contour's ride to major sponsorship started May 16. Chaplin and Storm were at the Indianapolis Motor Speedway that Friday for practice day, when the track is open to drivers to practice with their cars.

They were also at the track because they wanted to become major sponsors of a car and driver, and they'd heard there were cars and drivers without major sponsors.

That day they found what they were looking for. The Sam Schmidt Motorsport team had a driver, but didn't have a car. Team Penske had a spare car, though, and owner Roger Penske was willing to loan it to Schmidt.

Still, Schmidt didn't have a major sponsor. Chaplin and Storm solved that problem in five minutes. Chaplin recalls their reaction to the chance: "We sort of looked at each other and said 'Let's go do it.'"

They were able to decide so quickly because they'd sponsored Indy cars for five years. From '97 through '01, Contour had been an associate sponsor, with small logos on its cars. Chaplin and Storm hadn't sponsored a car in '02, but they were still very familiar with Indy racing and sponsorship and could make a snap decision.

The two race fans finished the deal Saturday, May 17. Hearn and Contour's car qualified on the 18th and the next Sunday jumped off the starting line at the Indy 500. But 62 laps later, they were done.

"It could have been a winning car," Chaplin says. "It was just as quick as any of the front runners."

Despite the car's finish, there is business value in Contour's sponsorship. The value comes from the fans who know the Indy rules for sponsorship.

As Chaplin explains, under Indy rules, sponsors with certain products, like motor oil and gears, have to use their products in their cars. Consequently, the Indy cars sponsored by Contour have raced using gears manufactured by the company's subsidiary, Contour Performance Products, and heat treated by Contour itself.

Thus, on race day, after the green flag is waved, Contour's car becomes a demonstration model as it tears around the track. Fans aware of the rules will see Contour's gear logo and know the company's support goes deeper than a coat of paint.

And those fans who are current or potential Contour customers will leave the track with an idea of how much stress and strain Contour gears can endure. The idea may suggest to them how the gears might perform in their applications.

"It's a 230-mile-per-hour billboard," Chaplin says.

A Racing Billboard—The letters on the tires are blurs, but Contour Hardening's gear logo is clear on its car as it races at the 2003 Indianapolis 500. "It's a 230-mile-per-hour billboard," says Mike Chaplin, Contour's vice president.

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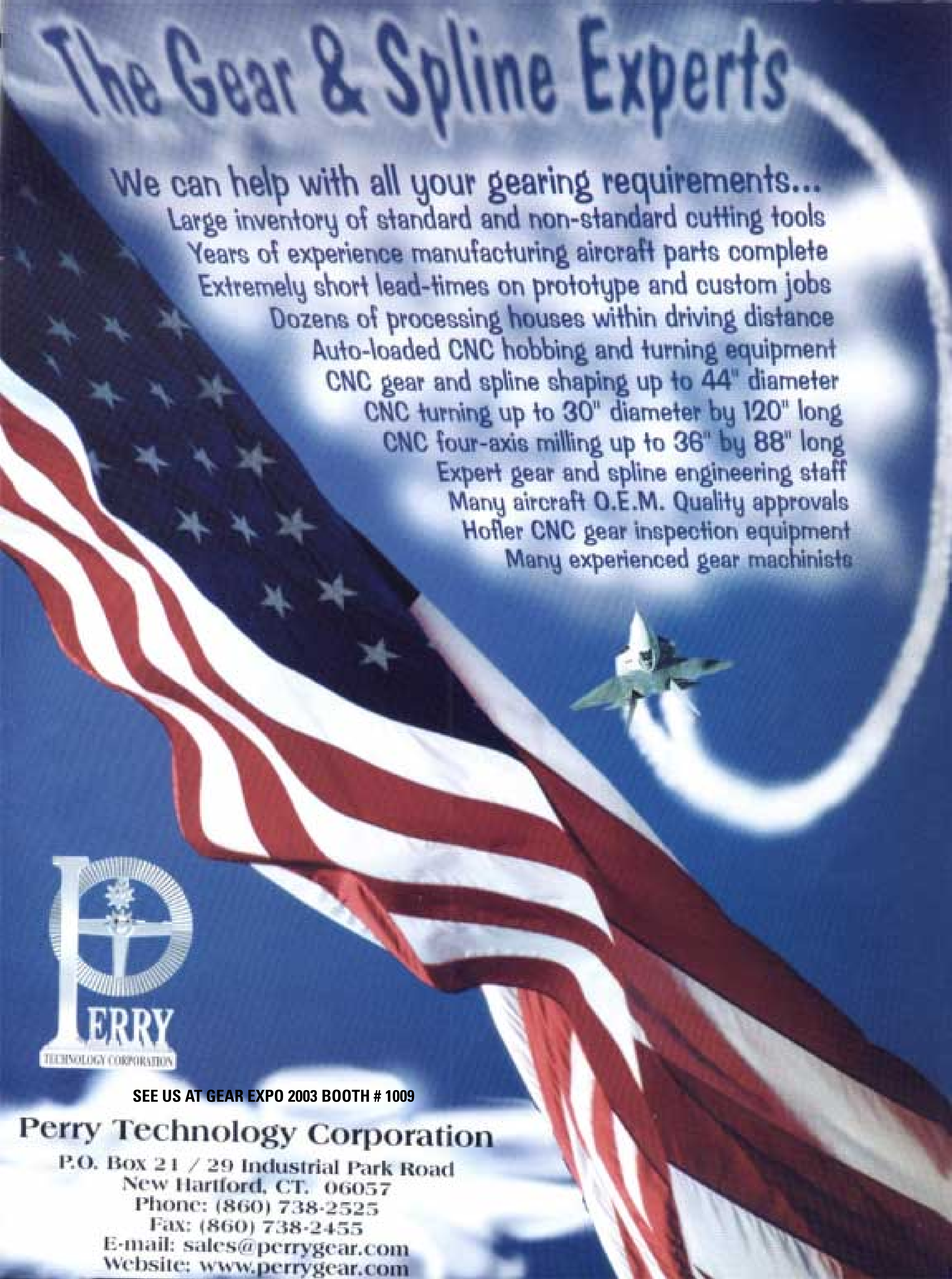

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