GEAR TECHNOLOGY

JULY/AUGUST 2002

The Journal of Gear Manufacturing

www.geartechnology.com

IMTS PRE-SHOW ISSUE

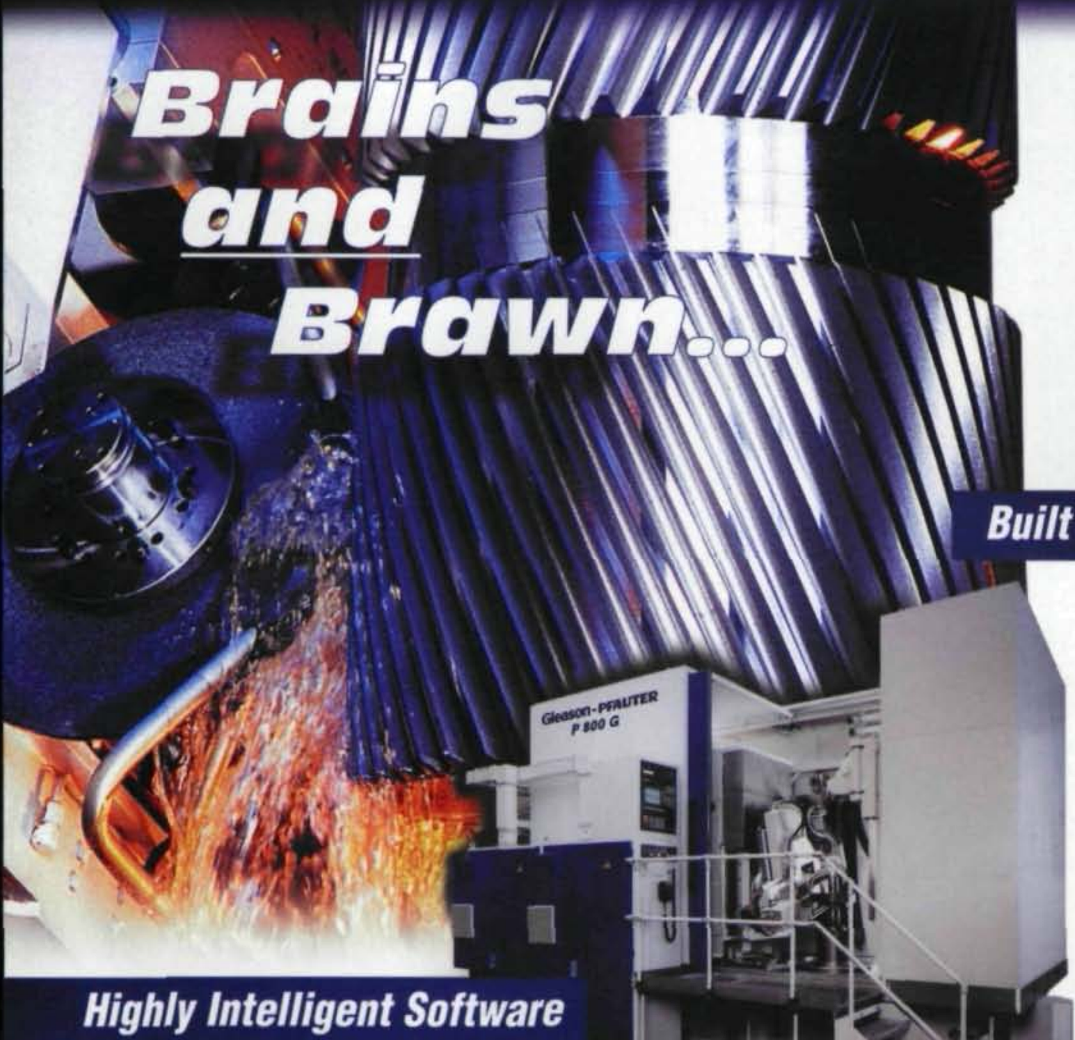
- Pre-Show Coverage
- Gear Surface Durability
- Hypoid Gear Measurement
- Minimizing In-Process Corrosion

ALSO IN THIS ISSUE:

- Publisher's Page: The E-volution of *Gear Technology*

THE GEAR INDUSTRY'S INFORMATION SOURCE

THE PERFECT COMBINATION FOR GRINDING GEARS



Built for Productivity

- On-machine dressing integrates the dressing unit with the grinding head to ensure the highest level of repeatability. Compensation for wheel wear between dresses is automatic.
- Designed with the flexibility to also grind internal and external gears with non-dressable Gleason high-precision vitrified or plated CBN wheels.
- On-machine inspection analyzes stock distribution, and compensates for heat treat distortion and part runout. The grinding cycle is optimized automatically.

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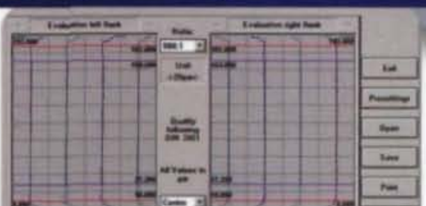

- Grinding technology database recommends and optimizes the "perfect production" methodology.
- K-Chart inspection allows specific input for both profile and lead modifications.
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The bigger the grinding application, the better we look. From 400 to 4,000 mm, Gleason-Pfauter Profile Grinders can take the time, cost and question marks out of your process, and put more profitability in.

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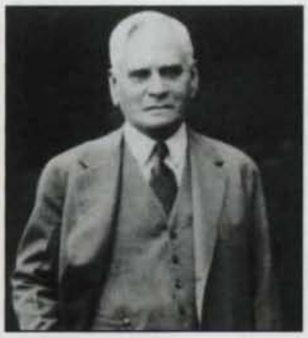
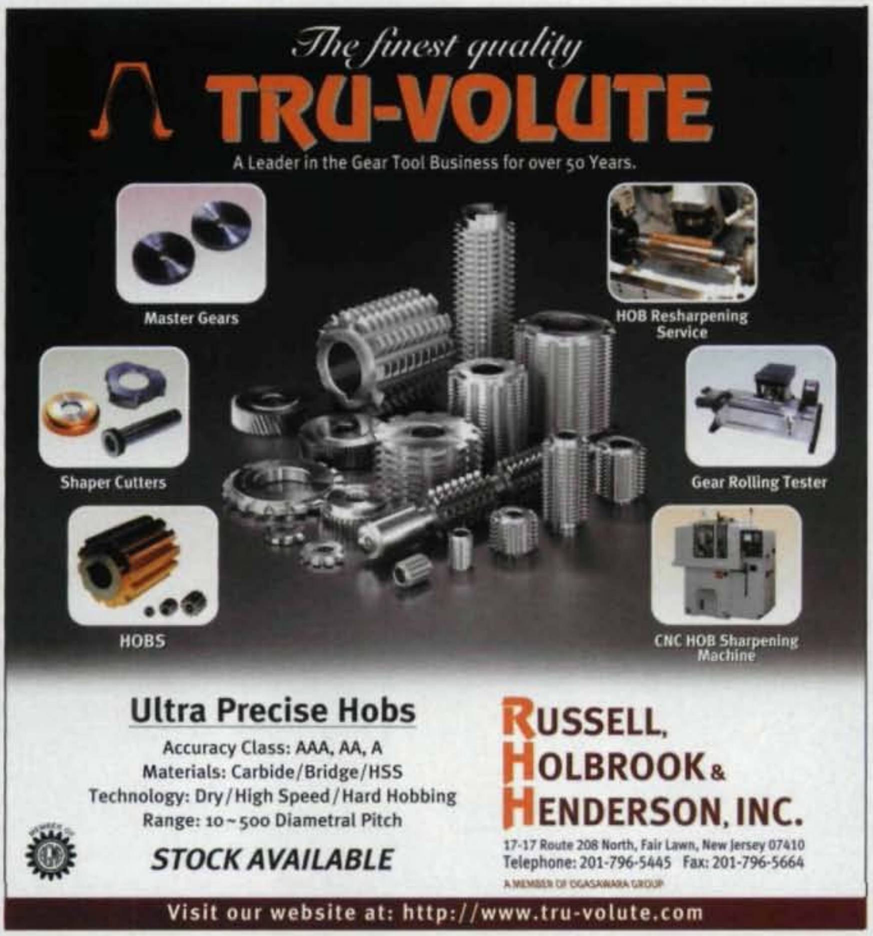
FEATURES

IMTS 2002 SPECIAL SECTION

DEPARTMENTS





GEAR TECHNOLOGY

The Journal of Gear Manufacturing

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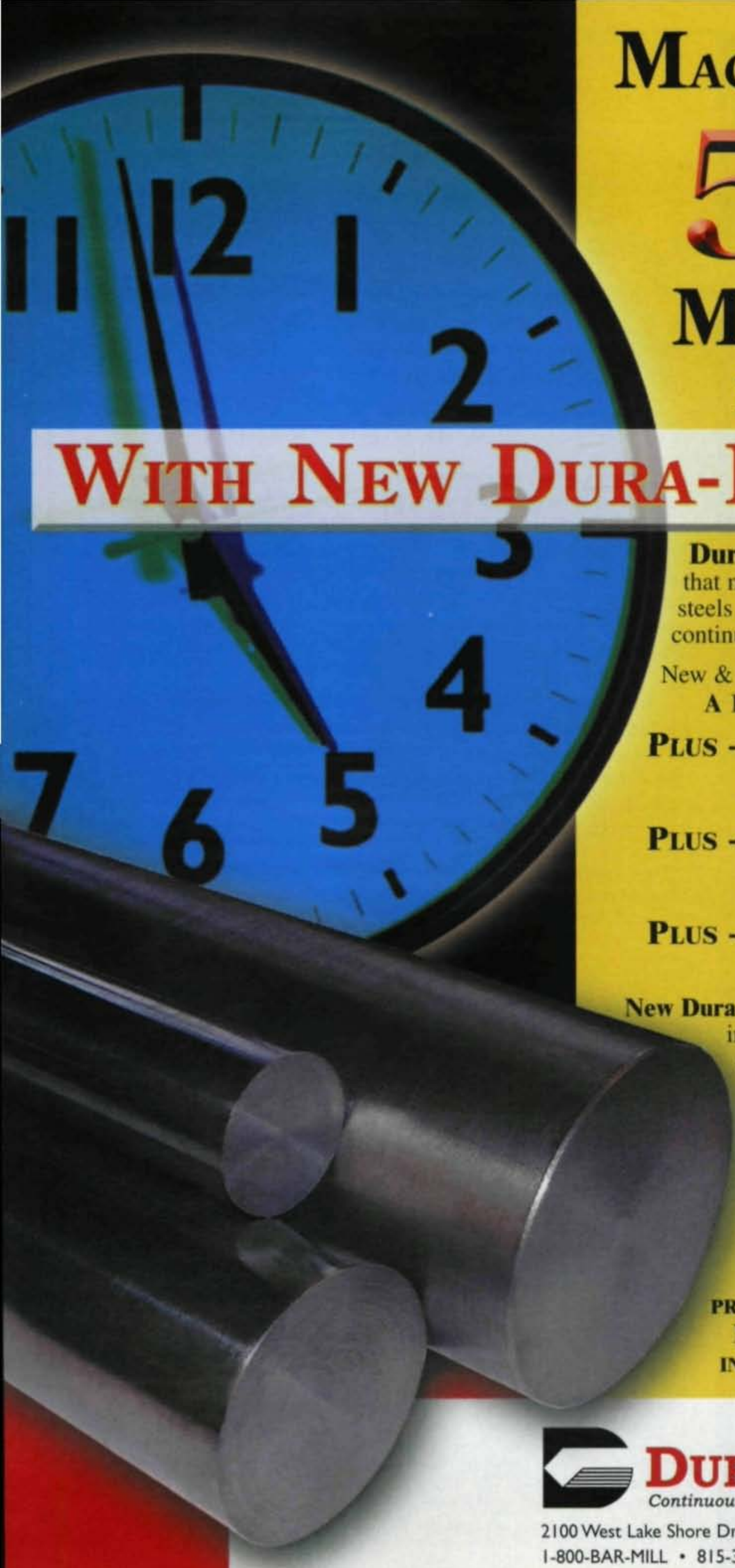


The E-volution of *Gear Technology*

Technology creates excitement. Just consider the natural buzz around IMTS, where manufacturers will go to explore ways they can increase productivity, improve quality, decrease costs or provide better service.

But technology is not just for manufacturers. At *Gear Technology*, we're creating a buzz of our own. That buzz is over *E-GT*, the next phase in our technological evolution. *E-GT* stands for *Electronic Gear Technology*. It's one of the biggest changes we've made in 18 years, and it's going to make access to *Gear Technology*'s information easier than ever before. Beginning with the January/February 2003 issue, the entire contents of the magazine will be available electronically. That includes all the articles, all the advertisements, all the figures and formulas, exactly as they appear in the print version.

Of course, we're not changing the printed magazine. The regular version of *Gear Technology* will continue to be available to all our qualified U.S. readers—for free—just as it always has. Also, people outside the United States will still be able to purchase subscriptions to the printed version.

Part of what makes *E-GT* exciting is that we're doing something that very few other magazines are able or willing to do. While we've always brought you information on leading edge technology related to gear manufacturing, *E-GT* keeps us on the leading edge ourselves. I'm proud of that capability. But what's really exciting about *E-GT* is how it will enable us to better serve our industry.

E-GT means that qualified subscribers will have access to an exact copy of our magazine (in PDF format) via ***The Gear Industry Home Page***™. You'll be able to retrieve an electronic version of the current issue whenever you want. You'll be able to store it on your hard drive to create an archive of issues for easy reference. And you'll be able to search through a particular issue for keywords or company names. You'll be able to receive *E-GT* when you're traveling. You'll be able to carry it on your laptop or burn it onto a CD.

Since we began publishing *Gear Technology* in 1984, our mission has been to serve the gear industry with the best possible technical and educational information related to the design, processing, manufacturing and inspection of gears. Today, our mission is the same. *E-GT* makes it easier for us to carry it out.

For example, with each passing year, the gear industry has become more global. Until now, we've had to charge subscribers outside the United States to offset the substantial costs of mailing the magazine. *E-GT* eliminates those costs. It will be available for free to qualified subscribers anywhere in the world.

Another benefit for subscribers outside the United States is that they'll no longer have to wait two or more weeks extra to receive their issues by mail. They'll have access to the content as soon as the issue is published and the electronic version is uploaded to our website.

To ensure that our magazine is reaching the right audience, our electronic subscribers will fill out a qualification card once per year, just as they do with our printed version. Part of that qualification card will include the subscriber's e-mail address. When each issue becomes available online, we'll e-mail the subscribers a notice to let them know they can download the issue at their convenience.

E-GT is a continuation of the process we began in 1996, with the launching of ***The Gear Industry Home Page***™, which remains the Internet's premier marketplace for the machinery, cutting tools and services related to gear manufacturing. In 1997, we launched ***powertransmission.com***™ to serve as a portal for manufacturers and buyers of gears, gear drives and other power transmission components. Today, those two websites deliver more than 200,000 page views and 50,000 user sessions per month. They've grown, evolved and taken on a life of their own, becoming an everyday part of the fabric of the industry. I expect *E-GT* to do the same.

Michael Goldstein,
Publisher & Editor-in-Chief

P.S. Those of you who are interested in becoming *E-GT* subscribers can now log on to *The Gear Industry Home Page*™ and fill out the simple qualification form. Visit *www.geartechnology.com* and look for the *E-GT* button. We're interested in your comments about how *E-GT* and our other products can make you more effective and successful. What ideas do you have that we haven't thought of yet? Let us hear from you at *people@geartechnology.com*.

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**.

Edwin R. Fellows: Shaping the Gear Industry

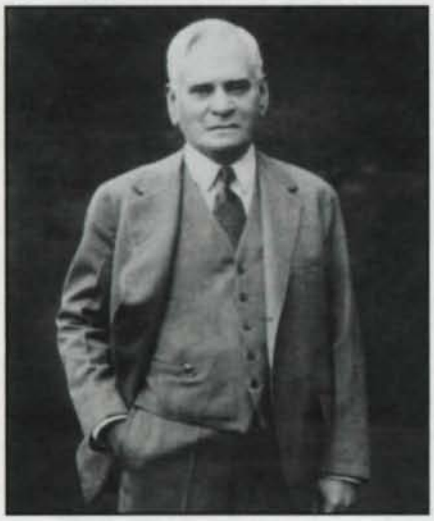
On July 13, 1896, a former window dresser received a $5,000 budget to start a company for making his far-reaching invention: the gear shaper machine.

The former window dresser was Edwin R. Fellows from Torrington, CT. The money was from subscribers (read: venture capitalists). And his invention was an idea he worked on while a draftsman at Jones & Lamson Machine Co. in Springfield, VT.

In 1916, the Fellows Gear Shaper Co. reached $1 million in machinery sales for the first time. The business that became Fellows Corp. was on its way. By then, Fellows was a director of his company.

In 1896, though, he was its 31-year-old manager, with a workforce of seven people. His first gear shaper machine was completed in 1897, though an experimental version had been built in 1896, at a machine shop in Fitchburg, MA.

Fellows' machine introduced a new type of gear-cutting tool. His shaper cutter was a hardened, ground gear with sharpened teeth.



Edwin R. Fellows: The former window dresser made good as the inventor of the gear shaper machine.

"At that time, no one else was making gear (shaper) cutters," says Don Whitney, a former manager of Fellows Corp.'s cutter-engineering department.

By 1905, Fellows' company was already having an impact on the automobile industry. That impact is reflected in *Precision Valley*, an account of the machine-tool industry that developed in the valley where Springfield is located.

The book lists automobile manufacturers that were Fellows customers in 1905. Those manufacturers included Buick Motor Co., Packard Motor Car Co., Olds Motor Works, Dodge Brothers, Cadillac Motor Car Co., and Pierce-Arrow Motor Car Co.

Before his company's start, though, Fellows got his start in Springfield with the help of a friend, James Hartness.

Hartness is remembered as a prominent Vermont industrialist and public figure. He is credited with 120 patents, ranging from the flat turret lathe to a safety razor. In 1900, he became president of Jones & Lamson. In 1921, he became Vermont's governor.

In 1889, though, Hartness was an employee at Jones & Lamson and was urging his Connecticut friend to join him. Fellows did so and became a Jones & Lamson employee in 1889.

The future industrialists knew each other through Fellows' mother.

Years earlier, Fellows' father had died while Fellows was in high school. Afterward, Fellows' mother took in boarders.

"Young Hartness was one of the boarders," Whitney says. "He and Edwin were good friends."

Whitney knows about Fellows and his company from work-related research and personal curiosity. For a time, Whitney taught a cutter design course at Fellows Corp., so he researched the company's history to create a preface for the booklet used in the course.

As for his personal curiosity, the 45-year employee of Fellows Corp. says: "I'm naturally interested in it because that was my life."

Fellows' invention received public recognition just a few years after his company's start.

In 1899, Fellows received the John Scott Award from the city of Philadelphia for his gear shaper machine and cutter. The award is given to men and women whose inventions contribute in outstanding ways to people's comfort, welfare and happiness. Other recipients of the award include Marie Curie, Thomas Edison, Jonas Salk and Orville and Wilbur Wright.

Fellows' machine made gears by simulating the meshing of two gears rotating around two parallel axes. A gear blank would be mounted on a vertical arbor. A complete gear, the cutter would then move up and down as it and the blank slowly revolved synchronously.

As Whitney explains, one cutter could produce spur and helical gears of any size, with any number of teeth—whether they were external or internal gears. L.T.C. Holt, though, notes a restriction in his book *A Short History of Machine Tools:* Fellows' cutter could make different-sized gears so long as their pitches were the same and the gears' teeth had the helix angle the cutter was made to create.

Whitney says that ability represented a significant advance in gear manufacturing.

Also, Fellows' gear shaper could make "shoulder gears," two different-sized gears on the same shaft with little clearance between them. That ability permitted more compact design of automobile transmissions.

In Holt's opinion, though, Fellows' cutter-grinding machine was more significant than his gear shaper machine. He explains that Fellows' precision grinding machine foreshadowed the grinding of hardened gears as a common step in production.

Fellows worked for his company for the rest of his life. He was president and director when he died May 21, 1945.

Fellows Corp. continued to serve gear manufacturers for another 57 years. It stopped operations Feb. 13, its parent company filing for bankruptcy.

On May 23, BF Acquisition won its bid for Fellows Corp. BF Acquisition is an affiliate of Park Corp., an Ohio-based company.

As reported in the *Rutland Herald* of Rutland, VT, BF Acquisition bid $3.72 million for the company.

BF Acquisition's purchase was expected to receive final approval May 28 from U.S. Bankruptcy Court in Delaware. Closing on the sale was expected to occur May 31.

A Two-Story Gear Unit

BHS-Cincinnati Getriebetechnik GmbH of Sonthofen, Germany, recently delivered what it says is the world's largest integral gear unit at more than 5 meters wide, more than 4.5 meters tall and weighing more than 42 tons. The gear unit was sold to MAN Turbomaschinen AG, GHH Borsig, of Berlin, a German compressor manufacturer.

MAN Turbomaschinen's customer, a Chinese chemical plant, plans to use this gear unit for manufacturing purefied terephthalic acid (PTA), a material used in polyester fiber production.

What's unique about these large integral gear units is that the compressor is not mounted in line with the gear drive but is directly mounted to the gear casing, says BHS engineering sales manager Stefan Burkart. With this arrangement, the efficiency rate can be significantly improved and the space requirement significantly reduced versus traditional stand-alone units.

Other companies make this kind of device, but this one is larger than most. However, similar sized integral gear units are sold by Flender Corp. of Bocholt, Germany, and SMS Demag AG of Düsseldorf, Germany.

The primary advantage of the integral gear unit is the compact installation it provides through the elimination of the coupling along with the capability of mounting the compressor housing directly to the gearbox, says Patrick Potter, sales engineer at BHS-Cincinnati. Even for single-pinion units, this is a significant advantage because the compressor housing can be overhung from the skid, which allows much more flexibility in piping arrangements for the compressor's process gas.

For multiple-pinion units, the ability to mount the compressor casings directly to the gearbox is a technical and cost advantage because multiple stages of

Standing tall at 4.5 meters and weighing in at 42 tons, this integral gear unit from BHS-Cincinnati Getriebetechnik GmbH of Sonthofen, Germany, is the result of work by a team of engineers and was sold to a Chinese chemical plant.

compression can all be handled by one gearbox, instead of requiring several separate stand-alone units, Potter says.

The space-efficiency of the integral gear unit is accompanied by operating efficiency—thrust collars eliminate the need for high speed thrust bearings, and power losses are typically lower than stand-alone units. Also, since the journal bearings for the compressor wheels are eliminated (the impellers are mounted on the pinions and the compressor uses gear unit bearings), a further reduction in system power loss is realized.

The freedom in selecting different pinion speeds allows an optimization of the aerodynamic efficiency in each stage of compression, Potter says. This explains why the overall power loss of an integral geared compressor is typically much lower than stand-alone units.

With the ability to drive up to 10 flange-mounted impellers, the units are equipped with thrust collars to eliminate the high speed thrust bearings. The collars transfer the thrust to the bull gear, where the axial load is taken by a low speed thrust bearing. The compressors' impellers are seated on extended pinion shafts, and the spiral housings are flange mounted onto the gear housing.

Featuring single-helical gearing with pinions of thrust collar design, the gearbox design holds upper and lower housing components for two- to four-stage applications. For five- to eight-stage designs, customers can use upper, middle and lower housing components.

To have nine- and 10-stage compressor applications, the customer has to install a fifth pinion below the bull gear. This pinion also can drive the bull gear and gearbox for turbine applications.

Regardless of the end use, Europeans are buying the integral gear units en masse. Since February, 50 units have been sold by BHS-Cincinnati, which is manufacturing them at a rate of about 100 units a year. A full 90 percent of these machines are sold in Europe for 100,000 to 1 million euros, or about $92,000 to $918,000 apiece. The rest of the sales are split between companies in America and Japan.

Tell Us What You Think . . .
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Or call (847) 437-6604 to talk to one of our editors!

2002 FAQs and Pavilion Info

Robin Wright

DATES AND LOCATION?

September 4–11, 2002
McCormick Place
2301 S. Lake Shore Drive, Chicago, IL 60616

IMTS REGISTRATION FEES?

$20 through August 4
$50 after August 4

EXHIBIT HOURS?

Lakeside Center (East) and North Building, Hall C: 9:00 a.m.–5 p.m.
South Building & North Building, Hall B: 10:00 a.m.–6:00 p.m.
Sunday, September 8 Only–All Buildings: 10:00 a.m.–4:00 p.m

FOR MORE INFORMATION

Contact The Association for Manufacturing Technology by telephone at (703) 893-4206 or visit *www.imtsnet.org* on the Internet.

IMTS PAVILIONS

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

This pavilion will feature cylindrical grinders; internal grinders; angular wheelside grinders; creep feed grinders; thrufeed grinders; centerless grinders; surface grinders; abrasive belt grinders; jig grinders; CNC tool and cutter grinders; universal grinders; cam grinders; bench, crankshaft and abrasive cutoff machines; band saws; circular saws; lapping machines; balancing machines; honing machines and polishing machines.

Controls and CAD-CAM—East Building, Hall D

This pavilion focuses on CIM/CAD/CAM systems, CNC controls, automation management systems, communications systems and LANs, software development systems and services, computers and software, instruments-controls and systems integration services.

EDM—East Building, Hall D

One of the largest gatherings of EDM manufacturers ever assembled, the pavilion features CNC wire EDM, EDM filtration system and supplies, ram-type EDM, metal disintegrators and die sinking machines.

Gear Generation—North Building, Hall B

Gear hobbers, gear shapers, gear cutters, gear shavers, broaching equipment, gear grinding equipment and gear measuring equipment are showcased in this pavilion.

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

Air purification equipment and services, safety guards, mats and equipment, filtration equipment, water and oil purification, air filtration, oil separation, sump cleaners, noise control equipment, dust removers, electrical equipment, way covers/tracks, storage systems, parts cleaners, parts washers, materials handling/storage systems, ball screws, bearings, spindles, conveyors, coatings, servo motors, pumps, degreasers, robotics, plant maintenance equipment, assembly/test equipment, motion control equipment and environmental management software are featured.

Metal Cutting—South Building, Hall A and North Building, Hall C

The Metal Cutting Pavilion includes machining centers, turning centers, assembly automation, milling machines and centers, boring machines, drilling machines, transfer machines, screw machines, broaching machines, burnishing machines, gun drilling machines, planer/mills, boring mills, multiple spindle drills and automatics, drill/mill/bore heads and slides, thread rolling, jig boring/milling machines and knurling machines, vertical turret lathes, bar feeds, automation systems, assembly machines, end finishers, machining cells, chuckers and CNC lathes.

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

All types of presses and the latest in laser production and technology are displayed here.

Quality Assurance—East Building, Hall D

Precision, laser and coordinate measuring machines; automated, precision and in-process gaging machines; tool condition monitoring equipment; measurement software; quality, control, testing and measuring equipment; comparators; metrology and vision systems will be on display.

Tooling & Workholding Systems—East Building, Hall E

This pavilion has special tooling, including boring bars, coolants, oils, ceramics, and composite cutting tools, gun drilling systems, jigs, reaming tools, and vises.

Business Services—North Building, Concourse Lobby

Here you will find industry-related publications, government organizations and other non-manufacturing organizations.

2002 SHOW INDICATES MINIMAL RECESSION DAMAGE

Despite the industry's economic hardship, projections for the IMTS 2002 Show indicate a relatively normal level of activity. Early figures from AMT reflect that attendance at this year's 75th anniversary show will be similar in number to the last show, held in 2000. Approximately 100,000 professionals have completed the preregistration procedure, which is close to the 110,000 attendees who turned out two years ago. Figures for the number of international registrants are about equal to that of those coming from overseas in 2000.

Organizers estimate that $804 million in sales will be transacted at this September's show, which would top the $800 million reached in 2000.

As far as floor space in the exhibit hall, there is a 4 percent reduction in the number of exhibits scheduled for September's show. However, more cancellations and additions of booths—as well as changes in the size of floor space per company—have taken place for this year's show, says John Krisko, exhibition marketing director.

"We've already made over 500 changes," Krisko says. "Where we've downsized someone, we've upsized someone else."

Additionally, Krisko anticipates a strong showing due to predictions about an upturn in the American economy.

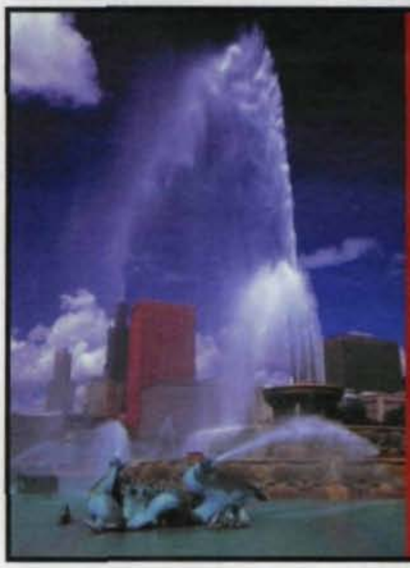
"We're fortunate that the timing is such that the show will take place at a time when the business cycle is picking up," he says. "The IMTS is the indusry's major machine tools show and will be at the leading edge of the economic recovery."

GETTING THERE

IMTS organizers are striving to find the lowest-priced travel accommodations in light of recent economic hardship. The Travel Technology Group is the show's official housing coordinator. United, Delta and Air Canada airlines are the official air carriers for IMTS 2002. A free shuttle will run between the official show-sponsored hotels and McCormick Place. To book a reservation or for more information on the 50 discounted hotels, contact TTG at (877) 727-2915 (domestic) or (312) 527-7300 (international) or on the Internet at *www.ttgonline.com/events.*

FOR EXHIBITS OF THE LATEST GEAR PRODUCTS, VISIT THESE COMPANIES...

A/W Systems Co., Hall B, Booth 7130
Bourn & Koch Machine Tool Co., Hall B, Booth 7048
D.C. Morrison Co., Hall B, Booth 6781
Darex Corp., Hall E, Booth 2200 and Hall B, Booth 7234
DE-STA-CO, Hall E, Booth 2080
Dura-Bar, Hall C, Booth 5067
Euro-Tech Corp., Hall E, Booth 2566
Flair Industry Accessory Co., Hall B, Booth 7140
Forst GmbH & Co. KG, Hall B, Booth 7126
Frenco GmbH, Hall E, Booth 2566
Frömag GmbH & Co. K.G., Hall B, Booth 7144
Gleason Corp., Hall B, Booth 6931
Gleason Cutting Tools Corp., Hall B, Booth 6931
Gold Star Coatings, Hall E, Booth 2701
Great Taiwan Gear Ltd., Hall B, Booth 7139
H.B. Carbide Co., Hall E, Booth 2702
Haug Verzahnungen GmbH, Hall B, Booth 6938
Ingersoll Cutting Tools, Hall E, Booth 2327
J. Schneeberger Corp., Hall B, Booth 7053
Kapp GmbH, Hall B, Booth 6962
Klingelnberg-Oerlikon, Hall B, Booth 7040
Koepfer America L.L.C., Hall B, Booth 6938
Leistritz Corp., Hall C, Booth 5315
Liebherr Gear Technology Co., Hall B, Booth 7040
LMT-Fette, Hall E, Booth 2889
M&M Precision Systems Corp., Hall B, Booth 7132
Mahr Federal, Hall D, Booth 4624
Melchiorre Officina Meccanica S.r.l., Hall B, Booth 7256
Micromatic Textron, Hall B, Booth 6686
Mitsubishi Heavy Industries, Hall A, Booth 8701
Mitts & Merrill L.P., Hall B, Booth 7144
Molemab Abrasives USA Inc., Hall B, Booth 7148
Monnier & Zahner AG, Hall B, Booth 6938
Nachi Machining Technology Co., Hall B, Booth 6953
Niles Werkzeugmaschinen GmbH, Hall B, Booth 6962
Noritake Co. Inc. (Abrasives Div.), Hall B, Booth 7056
Parker-Majestic Inc., Hall B, Booth 7258
Particle Industrial Co. Ltd., Hall B, Booth 7247
Reishauer Corp., Hall B, Booth 7033
Saazor-Walztechnik, Zorn GmbH & Co. KG, Hall B, Booth 6938
Star Cutter Co., Hall B, Booth 6950 and Hall E, Booth 2700
Star-SU Inc., Hall B, Booth 6950
SU America Inc., Hall B, Booth 6844
Ty-Miles Inc., Hall B, Booth 7241
Welduction Corp., Hall B, Booth 7245



OUTSIDE OF THE CONVENTION CENTER

After exiting McCormick Place, IMTS attendees have thousands of options besides going back to their hotels.

Most of Chicago's landmarks are a short cab ride away from the convention center and are within walking distance from many of the show-sponsored hotels.

For those seeking culture, Chicago is home to some famous museums, including The Field Museum of Natural History, The Art Institute of Chicago and The Museum of Science and Industry. Entrance fees are usually less than $10, with more expensive fees on weekends. During the week of the convention, The Field Museum is offering its Chocolate Exhibition, which features the creation and history of chocolate, and the Museum of Science and Industry is showcasing its Titanic exhibit.

A lighter alternative to museum-hopping is walking Chicago's famed Magnificent Mile. Water Tower Place is located in the center of this shopping district, which includes department stores like Nordstroms, Saks Fifth Avenue and Neiman Marcus. For leisure walking, there is Grant Park. The park includes Clarence Buckingham Memorial Fountain (pictured at left), built in 1927.

Also, the last of the summer festivals are taking place during the week of IMTS. The German American Fest will occur September 6–8 in Lincoln Square, and the Guinness Oyster Fest is scheduled for September 7 on the corner of Wells Street and North Avenue.

For more information, contact the Chicago Tourism Bureau by telephone at (312) 744-3315 or on the Internet at *www.chicago.il.org*.

IMTS OFFERS TECHNICAL CONFERENCE

In addition to walking the exhibit floor, IMTS attendees have the option of taking part in the 60+ conference sessions that focus on various manufacturing practices.

The categories offered for the IMTS 2002 Manufacturing Conference are:

Machining—includes emerging trends and high-speed machining,
Grinding & Abrasives—a focus on the latest technologies,
Toolings—sessions on design engineering and rapid tooling,
Quality—strategies and six sigma applications in manufacturing,
Job Shops—concentrating on the unique needs of contract and small manufacturing operators, and
Manufacturing Strategies—provides sessions on lean manufacturing practices, advances in manufacturing automation as well as supply chain and resource management and tools.

All of the sessions focus on issues like increasing productivity, strategies for reducing lead time, tools for assuring quality and the latest technical developments. SME organizers have scheduled speakers who include executives at companies such as Motorola Inc., Visteon Corp. and Lean Works Inc.

In addition to the speeches, attendees have the opportunity to network with other industry professionals during the technical conference. The intended audience consists of people with management, engineering, design, supervision, quality control, human resources, sales and marketing, purchasing, production operations and maintenance functions.

For those holding memberships in SME, the conference is free on September 9. For other cost information, visit the SME website at *www.sme.org/imts*.

For more information on the conference schedules for the six categories, visit the IMTS homepage at *www.imts.org* or e-mail the IMTS 2002 Manufacturing Conference team at *mfgconf@sme.org*.

STUDENT SUMMIT INTRODUCES NEXT GENERATION TO MANUFACTURING

The IMTS 2002 Show offers an opportunity for students, ranging from grade school to college, to take part in the exhibition.

This opportunity started at the 1998 show and attendance rose 11% by the time of IMTS 2000, according to the IMTS website.

Whether these students are college seniors ready to enter the engineering field or in elementary school, they will have the opportunity to visit the inside of the booths and speak to company representatives to better understand the technology. In the past, older students took advantage of this opportunity in greater number but all ages are invited, according to posted statistics on the IMTS website.

A goal of the student summit is to introduce the students to career opportunities and explain the future of the manufacturing technology industry.

Teachers and parents are also permitted to participate in the student summit. Show itineraries and assignments are available to teachers.

In 2000, a total of 3,923 students were chaperoned through the IMTS show by 605 teachers and parents. The students and their chaperones represented 35 states and 13 foreign countries.

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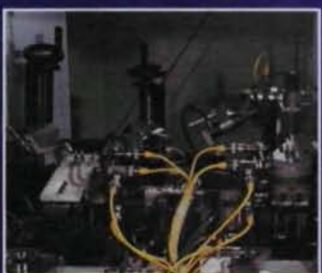

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Gear Surface Durability Development to Enhance Transmission Power Density

Joe Chen, John Flynn and Geoff Semrau

Introduction

Gear pitting is one of the primary failure modes of automotive transmission gear sets. Over the past years, many alternatives have been intended to improve their gear surface durability. However, due to the nature of new process development, it takes a length of time and joint efforts between the development team and suppliers to investigate and verify each new approach.

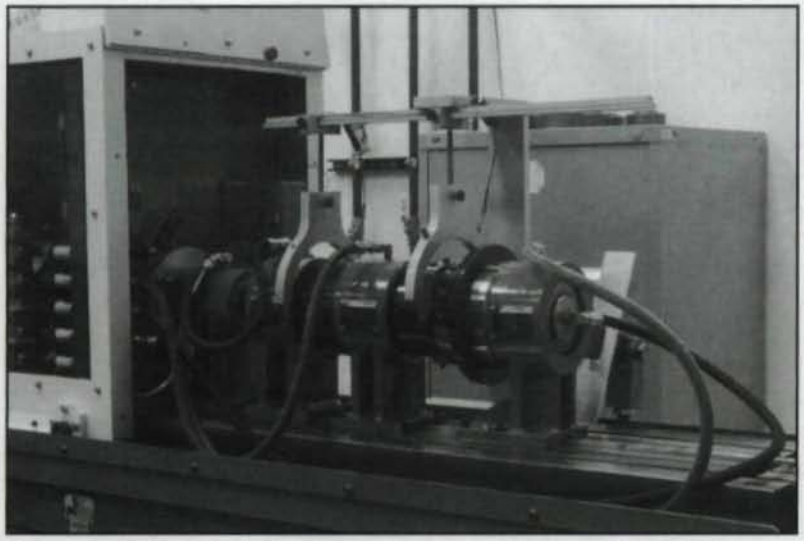

Figure 1—Back-to-back planetary gear component test machine and fixture.

Table 1—Test Matrix for Surface Durability Comparison

1. Baseline vs. Redesign						
2. Material Selection—Sun Gear Only, Use Standard Planets & Ring Gear for Testing						
Sun Gear Materials						
AISI/SAE (U.S.A.) Steels				European Steels		
4620M Baseline	8620	9310	5120	18CD4	25CD4	30CD4
X	X	X	X	X	X	X
3. Manufacturing Process—Use Standard Ring Gear for Testing						
Sun Gear Process						
Planets	Baseline	Honed	Coating	Dual Shot Peening	Isotropic 1	Isotropic 2
Prod. planet	X	X	X	X		
Without Shot Deburring	X					
Honed Planets	X	X				
Isotropic 1					X	
Isotropic 2						X

New and upgraded transmissions have required a higher input power capability to meet the customers' expectations. Increasing the power density in the transmission gear system was urgently demanded. To shorten the development time in this area, GM Powertrain's Advanced Gear Systems Group initiated a systematic approach to evaluate alternatives that had the potential to meet the needs. In addition to a single-tooth bending project for a gear bending fatigue study and joint projects with bearing suppliers to improve the durability of planetary bearings (Ref. 1), a comprehensive gear surface durability improvement project was established.

This study is a preliminary assessment of the effects of applying different design methodologies, material selections and manufacturing processes on gear surface durability. Based on this analysis, an in-depth study will follow to further understand the benefits of using different alternatives for future applications.

Objectives of the Study

- To evaluate and verify the effects of design, material selection and manufacturing process on power density of planetary transmission gear sets.
- To examine and interpret the effects of factors, such as surface roughness, residual stress, coating, material properties and geometry variations on gear surface durability.
- To understand benefit and risk factors of each variant for future applications.

Methodology

All tests were conducted at the GM Powertrain Gear Laboratory using a back-to-back planetary gear component test machine with a specially designed test fixture (Fig.1). An existing planetary gear set was chosen as the baseline because its surface durability characteristics were well known, and its design permitted easy inspection and maintenance.

The test matrix for the surface durability study is shown in Table 1. It consists of two different design approaches, seven material selections, and nine manufacturing processes.

Design specifications and stress calculations are shown in Table 2. The stresses are based on a torque of 1,500 N-m at the ring gear. Lead taper is not considered in the stress calculations.

The test samples were thoroughly inspected before the test. Relevant features of each test part were identified and recorded for future reference.

The gears were originally tested at a constant torque of 1,500 N-m at the reaction arm and a constant speed of 1,500 rpm at the input spindle. Under these conditions, however, the redesigned gear set did not pit in a reasonable period of time and displayed inconsistent failure modes. Increasing the torque to 2,000 N-m produced the desired results.

The test matrix was run in a random pattern to satisfy the statistical requirement for a small sample size. The random pattern is also helpful in detecting faults in the machine and fixture settings during testing.

Failure was achieved when any tooth flank developed a pit with an area of 1.0 mm^2 at a depth exceeding 1.5 mm. Pit size was measured by a computerized optical image device, and pit depth was assessed with a gear profile inspection machine.

A Weibull analysis (Ref. 2) was performed to establish life ranks.

A metallurgical failure analysis was performed on selected samples for a better understanding of the causes of the failure.

Test Results

Design Approach. The baseline planetary gear set was designed approximately 20 years ago and has been used in various transmissions since then. Recently, increased engine power and more stringent noise specifications caused this design to become obsolete. A new gear set, with enhanced capabilities but fitting in the same space, was then produced. The design approaches of these two gear systems are quite different. The original design used a relatively coarse pitch to enhance the tooth bending strength and adopted lead taper to reduce the gear force fluctuation.

The use of taper moderates vibration levels by preventing the sudden release of load at the tooth trailing end (Ref. 3). The redesign uses a finer pitch to increase both involute and helical contact ratios and incorporates profile modifications to optimize the load distribution. Based on 3-D FEA modeling, the new design has better load distribution and lower overall tooth compressive stress than the baseline gear set. Noise and vibration tests verified that the new design has a substantially lower gear mesh noise level (Fig. 2).

As was mentioned above, the two designs were tested under different loading conditions. Figure 3 shows the pitting life comparison between the baseline and redesigned gear sets. Figure 4 shows the corresponding Weibull analy-

Table 2—Design Comparison

	Design	
	Base Design	**Redesign**
Normal Module	1.630	1.439
Gear Ratio	3.33	3.29
Normal Pressure Angle	20.00	19.00
Helix Angle	18.00	20.00
Total Contact Ratio	2.69	3.63
Lead Modification	0–36 μm	0 +/– 18 μm
	Stress Comparison	
	Base Design	**Redesign**
Bending (MPa)	512	513
Compressive (MPa)	1,510	1,250

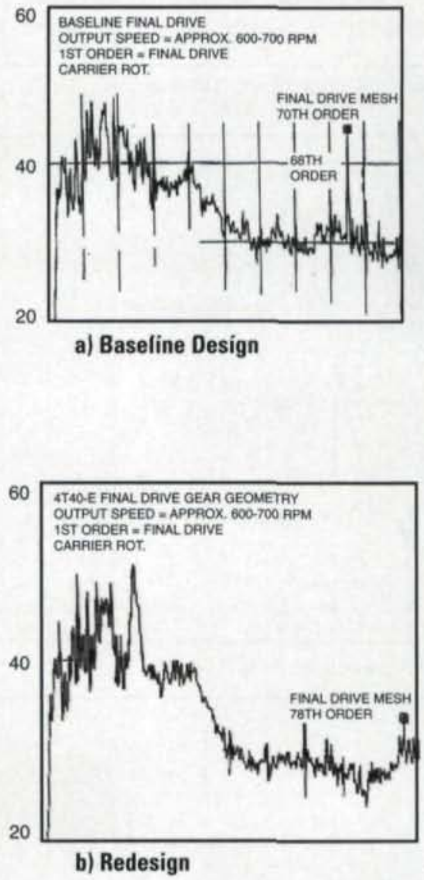

Figure 2—Gear noise and vibration level comparison.

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Geoff Semrau
is a senior project engineer with the GM Powertrain Base Transmission Group. He holds a master of science degree in mechanical engineering. He has been with GM Powertrain for 18 years, and he specializes in gear system development and analysis.

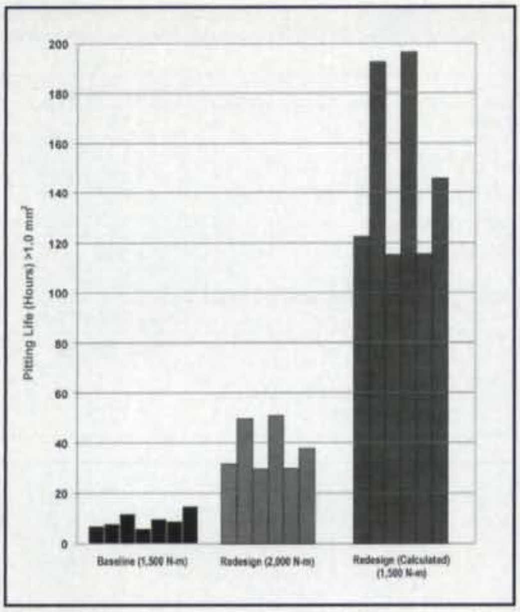

Figure 3—Sun gear pitting life comparison between designs.

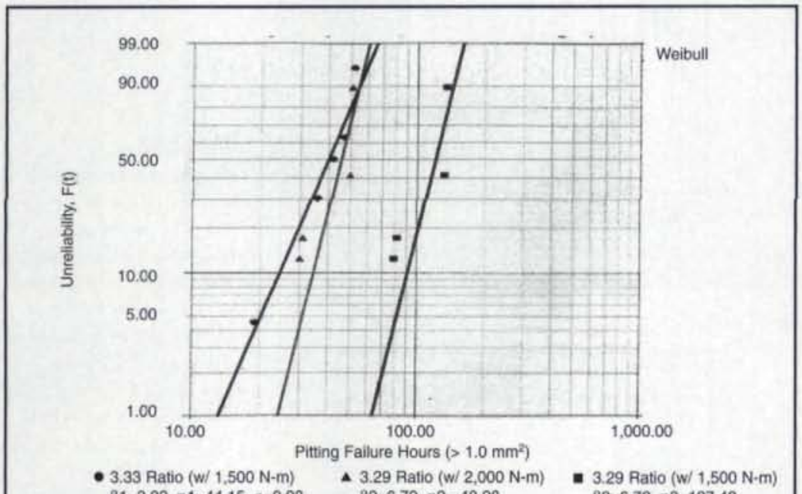

Figure 4—Weibull analysis for design comparison.

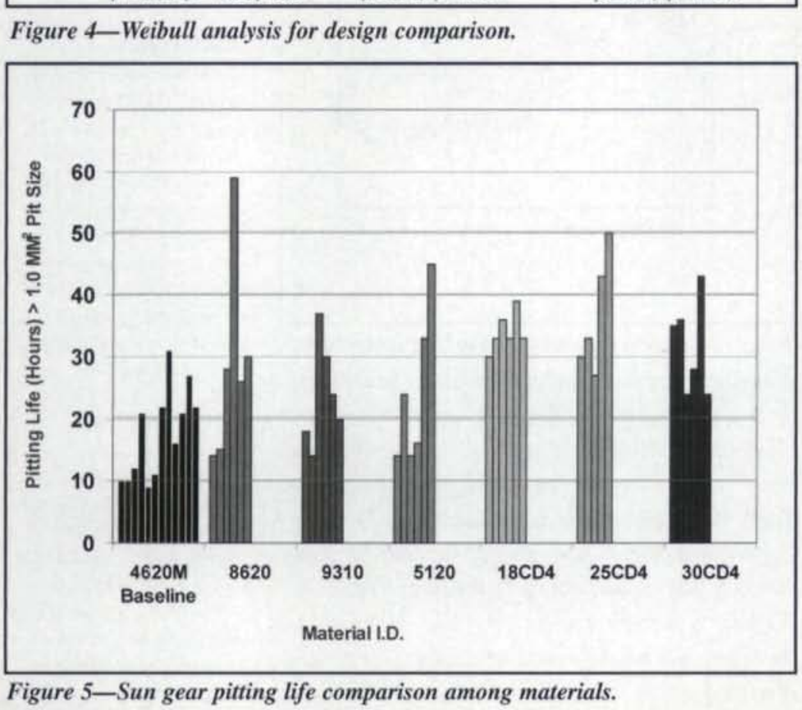

Figure 5—Sun gear pitting life comparison among materials.

sis result of these two design approaches. The analysis shows that the baseline coarser pitch sun gear has a B-50 pitting life of 40 hours. This compares to 46 hours at the higher load or 120 hours at the same load for the finer pitch gear set. The 120 hours is determined by extrapolation using an S/N curve with slope of 3.375. The data indicate that a significant improvement in pitting life has been achieved by the redesign.

Material Selection. Seven common gear steels were selected for surface durability testing. Figure 5 shows the surface durability test results, and Figure 6 shows the Weibull analysis. The sample gears were identical in design and manufacture. Several parameters possibly affecting surface durability were tabulated. Table 3 shows the chemical composition, retained austenite, case depth and hardness of each material. Table 4 shows a comparison of surface finishes.

Manufacturing Processes. Seven different manufacturing processes were evaluated. Both sun and pinion gears were fabricated using the various processes, and a total of nine combinations were tested (Table 1). Standard ring gears were used for all tests. To eliminate unwanted variations, the test gears—except those to be honed—were manufactured and heat treated as a single lot and later finished by the specific method. Figure 7 shows the durability life comparison of the manufacturing processes, and Figure 8 shows the Weibull analysis that ranks all the test variants.

The test results reveal that manufacturing processes can have a significant effect on the surface durability. While further investigation is needed, some general observations may be made:

The surface finish of the planet pinions has a great influence on the sun gear durability. This is illustrated as follows:

- Honed sun gears run with standard pinions have only one-third the life of standard sun gears run with honed pinions. The honed pinions have a better surface finish than the standard pinions.
- Honed sun gears run with standard pinions have approximately one-fourth the life of honed sun gears run with honed pinions.
- The shot deburring process, which is intended to remove gear edge burrs and heat-treatment scale, is detrimental to gear life if poorly controlled. Standard sun gears run with pinions that were not subjected to shot deburring have four times the life of the standard sun gears run with pinions that were shot deburred. The shot deburring process produces much rougher sur-

faces on the gear teeth and, if not under tight control, can cause severe surface damage. Figure 10 shows a comparison of gear teeth before and after a poorly controlled shot deburring operation.

Both isotropic surface finishing processes (Ref. 4) use a sequence of chemical and mechanical operations to smooth the gear surface by removing a few micrometers of material. One of these proprietary processes appears to have the potential of enhancing surface durability when both mating gears are treated.

Compressive residual stress near the tooth fillet has long been recognized as contributing to increased gear tooth bending life. The same theory can also be applied to gear surface durability (Ref. 5) with a certain degree of success. It is imperative, however, that the gear surface is not substantially damaged by the process used to impart that compressive residual stress. Figure 10 shows the comparison of the residual stress produced by the conventional and two secondary processes. The dual shot peening and the honing process, both completed after heat treatment, add compressive residual stress to the gear surface. These stresses will reduce surface crack progression and thus increase useful gear life. The dual shot peening requires two different shot sizes and intensities. The coarser shot provides deep penetration at the root, and the finer shot produces high compressive residual stress close to the surface. Similarly, the honing process provides high compressive residual stress close to the tooth surface.

All test variants except the honed parts were conventionally hobbed and shaved and then batch heat-treated. However, tooth profile distortion during heat treatment is not consistent from lot to lot or even part to part. Because the honing process is completed after heat-treating, better profile consistency can be achieved.

Table 5 shows a comparison of the profile control obtained by the conventional and honing processes. The much improved surface durability of the honed sun and planet result from the combination of benefits from consistent geometrical control and higher residual compressive stress.

Gear surface hardness is essential to sustain extended gear life. Non-metallic coatings can provide very high surface hardness (HRc 90) and lower friction coefficients. The non-coated samples in this study had conventional surface and core hardness. The mechanism by which

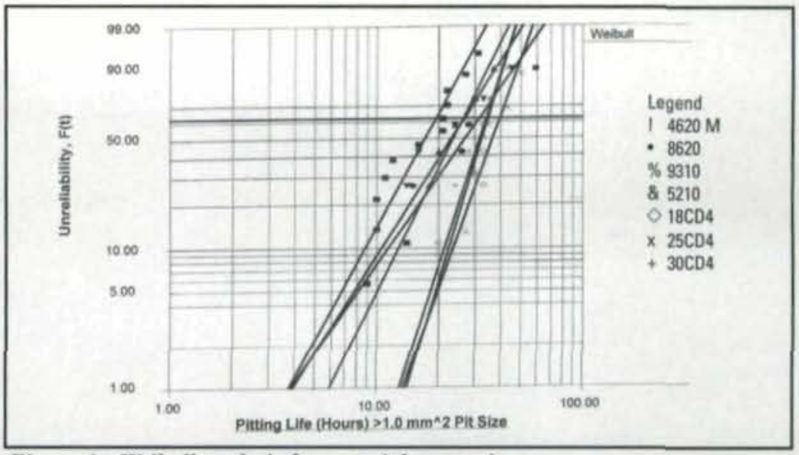

Figure 6—Weibull analysis for material comparison.

Table 3—Material Chemical Compositions and Metallurgical Analyses

Material	C	Si	Mn	P	S	Ni	Cr	Mo
AISI 4620	0.17/0.23	0.15/0.35	0.35/0.75	0.35 Max	0.35 Max	1.55/2.00	0.20 Max	0.20/0.30
AISI 4620M	0.17/0.23	0.15/0.35	0.35/0.75	0.35 Max	0.35 Max	1.55/2.00	0.20 Max	0.50/0.70
AISI 8620	0.17/0.24	0.15/0.35	0.60/0.95	0.35 Max	0.35 Max	0.35/0.75	0.35/0.65	0.15/0.25
AISI 5120	0.17/0.22	0.15/0.36	0.70/0.90	0.35 Max	0.40 Max	0.20 Max	0.70/0.90	0.03 Max
AISI 9310	0.07/0.13	0.15/0.30	0.40/0.70	0.35 Max	0.40 Max	2.95/3.55	1.00/1.45	0.08/0.15
AFNOR 18CD4*	0.15/0.22	0.10/0.40	0.60/0.90	0.35 Max	0.35 Max	0.20 Max	0.85/1.15	0.15/0.35
AFNOR 25CD4*	0.22/0.28	0.10/0.40	0.60/0.90	0.35 Max	0.35 Max	0.20 Max	0.90/1.20	0.15/0.25
AFNOR 30CD4*	0.27/0.33	0.10/0.40	0.60/0.90	0.35 Max	0.35 Max	0.20 Max	0.90/1.21	0.16/0.26

* European Material – similar to AISI 41XX family

Inspection	Spec.	4620M	9310	18CD4	5210	8620
Retained Austenite (%)		9	8	21	23	3
Surface Residual Stress (MPa)		–820	–634	–220	–110	–613
Total Case Depth (1/2 Height)	0.40–0.56	0.45	0.45	0.55	0.45	0.45
Total Case Depth (Root)		0.40	0.40	0.50	0.50	0.40
Effective Case Depth @ 1/2 Height		0.35	0.25	0.25	0.25	0.35
Effective Case Depth @ Root		0.40	0.25	0.25	0.25	0.35
Core Hardness (HRc)	32/44	43	38	36	33	41
Surface Hardness (HR30N) A-scale	75.5/79.0	77	76	76	76	76

Table 4—Surface Finish Comparison

Finish Term	4620M test side	5120 test side	18CD4 test side	25CD4 test side	30CD4 test side
Ra (µm)	0.238	0.245	0.202	0.254	0.213
Rsk	0.032	–2.187	–0.814	–2.334	–0.357
PV (µm)	8.198	8.179	2.315	5.947	3.345
Rms (µm)	0.310	0.350	0.270	0.190	0.740

Ra (µm) The average surface roughness
Rsk Skewness, a measure of symmetry of valleys; a positive skew indicates a "peaky" surface
PV (µm) Maximum peak-to-valley height over the sample
Rms (µm) The root-mean-square average of the measured height deviation taken within the evaluation area and measured from the mean surface

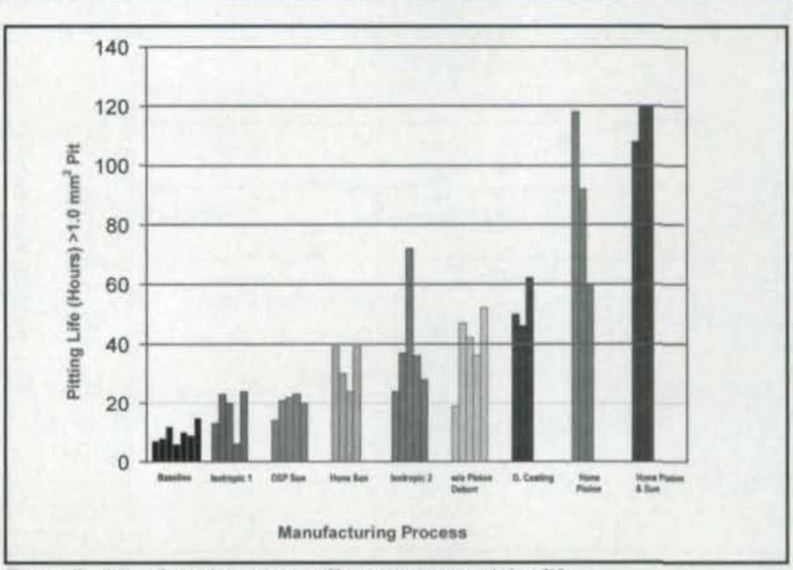

Figure 7—Manufacturing process effect on sun gear pitting life.

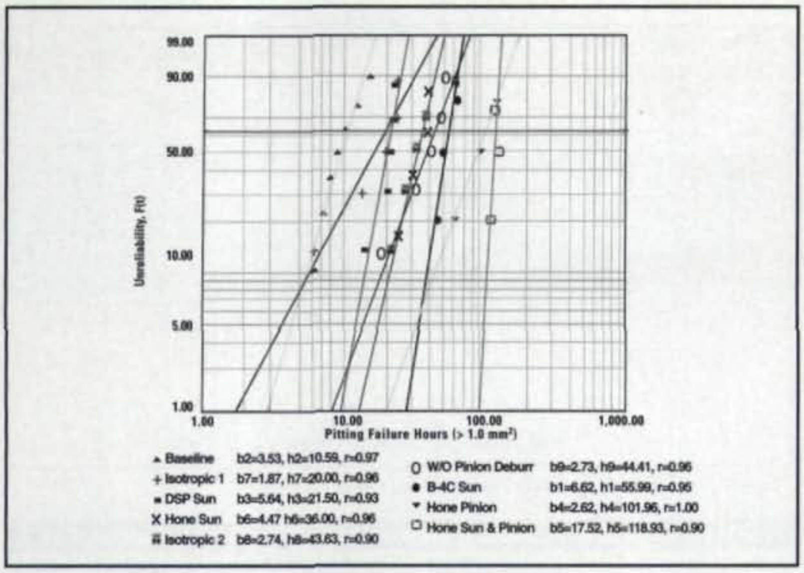

Figure 8—Weibull analysis for process comparison.

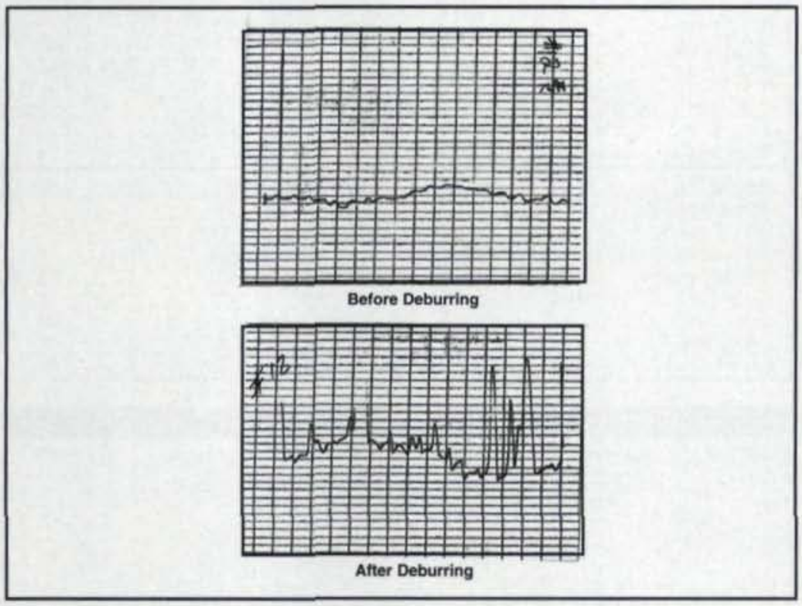

Figure 9—Planet surface roughness before and after shot deburring process.

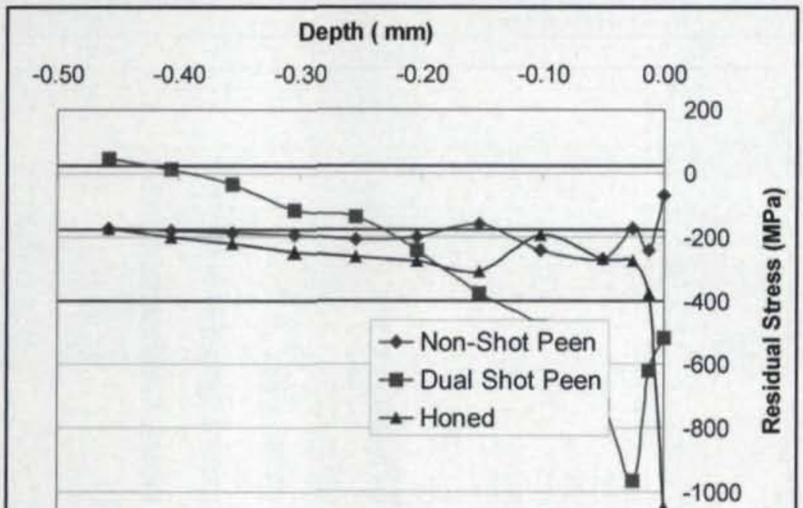

Figure 10—Residual stresses produced by different manufacturing processes.

coatings provide improved surface durability is not fully understood at this time and is the subject of continuing research.

Figure 11 shows typical microstructure photographs of tested samples. Failure analysis conducted by the GM Pow-ertrain Gear Laboratory revealed that most distress is surface-initiated fine grain pitting. Surface cracks initiating at inclusions were also found. The inclusions may have been non-metallic impurities in the steel or could have been caused by a manufacturing operation. There were also findings of intergranular oxidation (IGO), related to the high alloy content of the steel and improper environment control during heat treatment.

Conclusions

Two similar planetary gear sets with different design approaches were tested to compare surface endurance life. The redesigned finer pitch gear set has about three times the B-50 life of the baseline coarser pitch gear set.

Stress calculations show that the finer pitch gear set has about 21% lower compressive stresses and better load sharing than the baseline coarser pitch design. The redesigned gear set utilizes finer pitch to increase the involute and helical contact ratios and employs tooth profile modifications to prevent uneven load distribution along the line of tooth action.

Seven different gear steels were tested. All samples were manufactured and heat-treated by identical processes. Weibull B-50 lives for sun gears between the baseline and the best performing steel were spread from 18 hours to 37 hours respectively. The life ranks from the lowest to the highest are: 4620M (baseline), SAE-9310, SAE-5120, SAE-8620, 30CD4, 18CD4 and 25CD4. The last three steels are European products.

Although the chemical composition, surface finish, and microstructure of these materials were closely examined, no conclusive explanation of their varying surface durability can be made.

Nine different manufacturing processes were tested. Except for the honed gears, all test parts were identically manufactured and heat-treated. Secondary processes were then completed to enhance the power density capability. Weibull B-50 lives between the baseline and the best performing samples were spread from 9.5 hours to 115 hours. The gear surface lives among the test variants are ranked from lowest to highest as follows: baseline (standard) process (1), isotropic 1 (2), double shot-peened sun gear (3), honed sun gear with standard pinions (4), isotropic 2 (5), standard sun gears mated with pinions that were not shot deburred (6), non-metallic coated sun gear (7), standard sun gears with honed pinions (8), and sun gears and pinions both honed (9). Among the characteristics producing significant surface durability improvement are the surface finish, the residual stress pattern, the surface hardness, and superior tooth geometry control.

Planet tooth surface roughness appears to have a significant effect on the sun gear surface durability.

Acknowledgments

The accomplishment of this project occurred through the joint efforts of all the project team members, the manufacturing facility of GMPT-St. Catharine and GM Powertrain gear test and inspection laboratories. The authors would also like to express their appreciation to those who provided assistance and information to this project.

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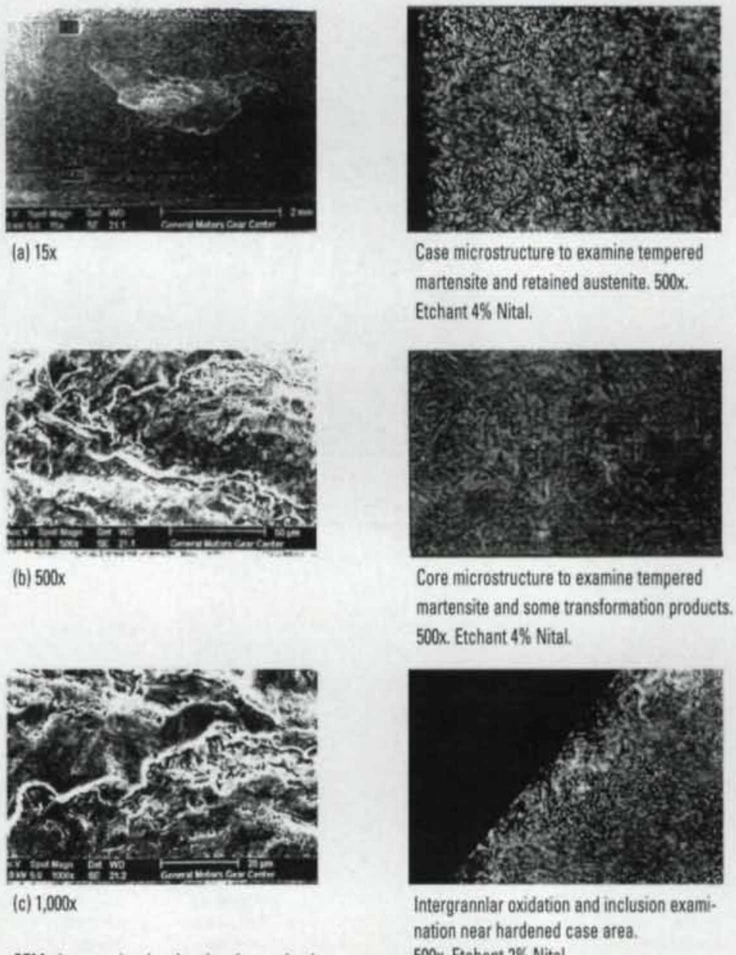
Table 5—Comparison of Geometry Control between Conventionally Manufactured Gears and Honed Gears

Units in Metric			[1]		[2]	
	Spec. Tolerance	Production		Honed By Nachi Machine		[2]/[1]
Sun Gear	for CP	6 Std. Deviation	CP	6 Std. Deviation	CP	%
Diameter over Balls	0.132	0.062	2.13	0.03	4.4	207%
Lead Average	0.036	0.026	1.38	0.006	6	433%
Lead Crown	0.01	0.009	1.11	0.004	2.63	237%
Lead Variation	0.038	0.036	1.06	0.019	2	189%
Involute Average	0.026	0.013	2	0.005	5.2	260%
Involute Crown	0.01	0.006	1.67	0.003	4	240%
Involute Variation	0.038	.018	2.11	0.012	3.17	150%
Total Pitch Runout	0.1	0.062	1.61	0.034	2.94	182%
	Spec. Tolerance	Production		Honed By Nachi Machine		[2]/[1]
Planet	for CP	6 Std. Deviation	CP	6 Std. Deviation	CP	%
Diameter over Balls	0.095	0.05	1.9	0.02	4.75	250%
Lead Average	0.036	0.037	0.97	0.004	10.29	1,057%
Lead Crown	0.01	0.013	0.77	0.002	6.67	867%
Lead Variation	0.038	0.05	0.76	0.015	2.53	333%
Involute Average	0.026	0.025	1.04	0.003	8.67	833%
Involute Crown	0.011	0.009	1.22	0.002	7.33	600%
Involute Variation	0.038	0.032	1.19	0.012	3.17	267%
Total Pitch Runout	0.038	0.042	0.9	0.019	2	221%



(a) 15x

Case microstructure to examine tempered martensite and retained austenite. 500x. Etchant 4% Nital.

(b) 500x

Core microstructure to examine tempered martensite and some transformation products. 500x. Etchant 4% Nital.

(c) 1,000x

Intergrannlar oxidation and inclusion examination near hardened case area. 500x. Etchant 2% Nital.

SEM photographs showing the pit examined.

Figure 11—Typical microstructure photograph of tested parts.

Performance Analysis of Hypoid Gears by Tooth Flank Form Measurement

Ryohei Takeda, Zhonghou Wang,
Aizoh Kubo, Soichiro Asano and Shogo Kato

This paper was presented at the JSME International Conference on Motion and Power Transmissions, MPT2001, in Fukuoka, Japan, in November 2001.

Introduction

The traditional way of controlling the quality of hypoid gears' tooth flank form is to check the tooth flank contact patterns. But it is not easy to exactly judge the tooth flank form quality by the contact pattern. In recent years, it has become possible to accurately measure the tooth flank form of hypoid gears by the point-to-point measuring method and the scanning measuring method. But the uses of measured data of the tooth flank form for hypoid gears have not yet been well developed in comparison with cylindrical involute gears. In this paper, the tooth flank form measurement of generated face-milled gears, face-hobbed gears and Formate®/generated gears are reported. The authors discuss the advantages and disadvantages of scanning and point-to-point measuring of 3-D tooth flank forms of hypoid gears and introduce some examples of uses of measured data for high-quality production and performance prediction.

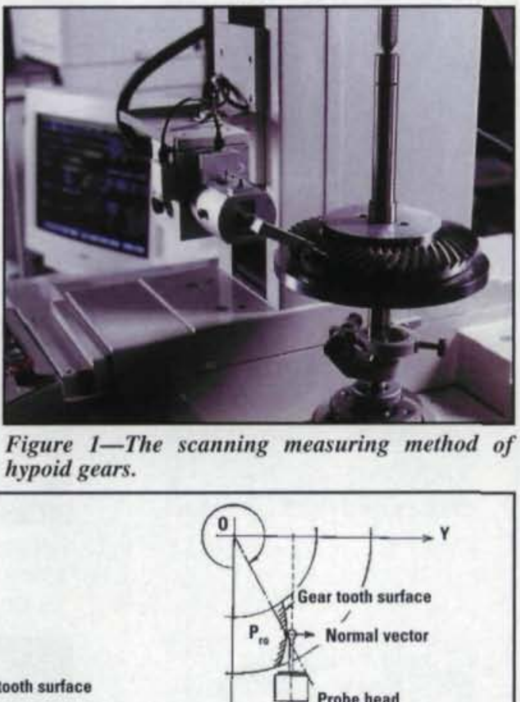


Figure 1—The scanning measuring method of hypoid gears.

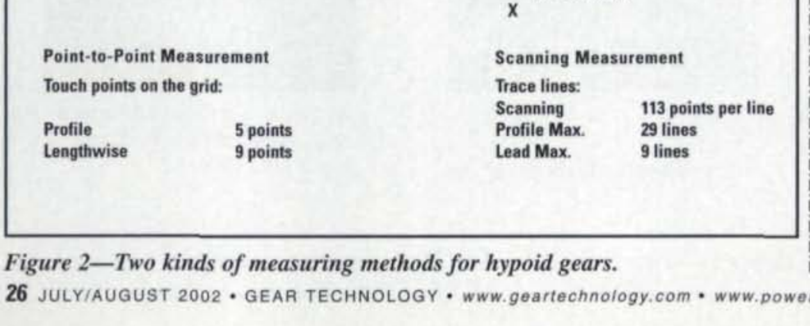


Figure 2—Two kinds of measuring methods for hypoid gears.

Point-To-Point or Scanning Measurement

The traditional measuring method for the tooth flank form of hypoid gears is carried out by point-to-point measurement using coordinate measuring machines (CMMs). That method is used to avoid the effect of friction between the 3-D sensor probe and tooth flank surface on the measured result.

Recently, a reliable measuring method by scanning the objective tooth flank has been realized. The scanning measuring machine, as shown in Figure 1, uses a 2-D sensor. The negative influence of tooth flank friction on the measured results is avoided by control of rotation of the z-axis and by parallel movement of the sensor head position considering the sensitivity direction of the sensor probe and the scanning direction of the tooth flank (Ref. 1).

Figure 2 shows how those two kinds of measurement are performed. A typical point-to-point measuring pattern is a 5 x 9 grid of the tooth flank. These measuring points usually exist well inside the tip and side edges of the objective tooth flank. Using the scanning measuring method, edge-to-edge measurement is possible. That measurement covers all of the tooth flank area, including the tooth tip and the area near the toe and heel. The scanning measuring machine that the authors have developed can incorporate various measuring patterns. For example, to simulate gear performance, a pattern of 29 lines of profile and one line of lead, or a pattern of three lines of profile and three lines of lead are usually incorporated. Each line has 113 measuring points.

Figure 3 compares data of a tooth flank form measured by both the scanning and point-to-point methods. The objective tooth flank form has some waviness (high-frequency components). That waviness was found to be the main cause of unpleasant gear noise. The scanning method can detect the detail of a tooth flank form, but the point-to-point method could not do so.

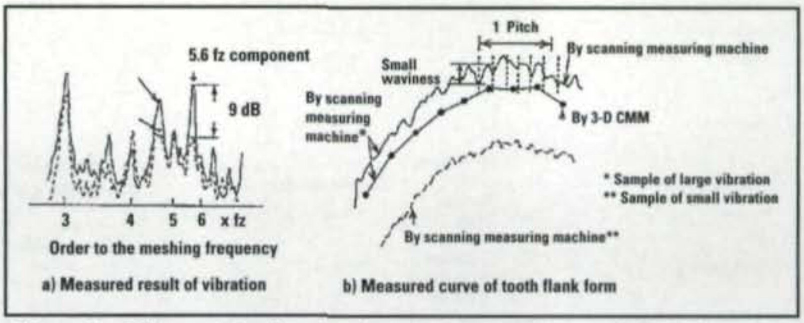


Figure 3—Difference in vibrational state of gears, when tooth flank form deviations have different high frequency components, and the comparison of tooth flank form measured by point-to-point and scanning methods for that case.

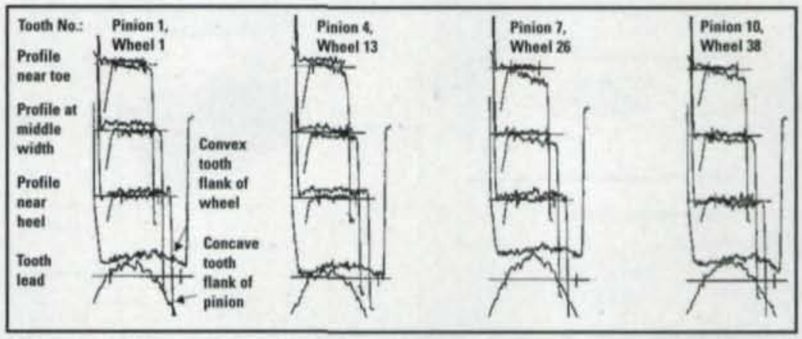


Figure 4—Measured tooth profile and lead form of Gleason face-milled, Formate®/generated gear set expressed in mating state.

Two Kinds of Methods to Define Reference Tooth Surface

Direct approach (Machine setting base). Existing CMMs normally incorporate the nominal surface calculated by cutting machine setting parameters and cutter geometry for both ring gear and pinion as the reference surface to define tooth flank form deviation. It is good in practice to check whether the tooth cutting is performed correctly or not. But hypoid gears are heat treated, usually case hardened, and then lapped. After heat treatment or lapping, tooth surfaces are distorted or deformed from that of the cutting stage. That means gears have lost their datum and it is therefore often not useful to measure the tooth flank form deviation of hypoid gears according to the reference based on the machine setting.

Conjugate approach. In the case of the scanning method, the reference tooth surface of ring gears is calculated by cutting machine setting parameters just like the former case. However, for the pinion, the conjugate surface to the ring gear surface is used. In this case, two reference surfaces can rotate theoretically without motion error.

The conjugate surface of the pinion is a virtual one. If the pinion and gear teeth are measured using such a conjugate approach, the measured values of the flank form deviation would show how far the form is from its true surface, which would realize conjugate motion. The same is true of cylindrical involute gears. That means we can use the experience of cylindrical involute gears for designing and manufacturing hypoid gears, and the measured data of the gear set can be used at any stage of designing or manufacturing.

Direct prediction of contact pattern from measured results. Figure 4 shows an example of the output forms of measured results from the conjugate approach for a Formate® hypoid gear set. Here, the ring gear's measured curve is shown by setting it to the position of contact corresponding to that of the measured pinion. Because the conjugate pinion tooth flank form is incorporated for reference in defining the tooth flank form deviation, every point on both curves corresponds to contact. From this presentation of measured results, we therefore can directly see the contact position of tooth flank of actual gears on the measured curves—that is, we can directly see the outline of the tooth flank contact pattern.

Measurement of Gears from Different Tooth Cutting Methods

The scanning method is capable of measuring tooth flank form deviation of hypoid gears being cut by different cutting methods. Figure 5(a) shows a sample of measured results from a generated face-milled gear set, and Figure 5(b) shows that of a face-hobbed spiral bevel gear set.

Tooth Contact Analysis Under No Load

Conventionally, tooth contact analysis (TCA) of hypoid gears is performed using tooth surface geometry calculated by the tooth cutting machine setting parameters for both ring gear and pinion. Figure 6(a) shows an example of tooth contact analysis of Gleason Helixform® hypoid gears (gear set 1 shown in Table 1) by direct approach (Gleason TCA). Using the concept of the conjugate tooth flank forms of mating gears and composite error surface (Ref. 2), a simulation program for predicting the gear performance was developed. Figure 6(b) is an example of the output of simulated results by conjugate approach for the same gears under the same conditions. The results of (a) and (b) agree well, when the same mounting position (V/H value) is given.

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Soichiro Asano
is president of Asano Gear Co. Ltd., of Osaka, Japan, which manufactures gears and gear units.

Dr. Shogo Kato
is senior researcher in Asano Gear's engineering department. In 1979, he developed principles for tooth profile measurement of hypoid gears.

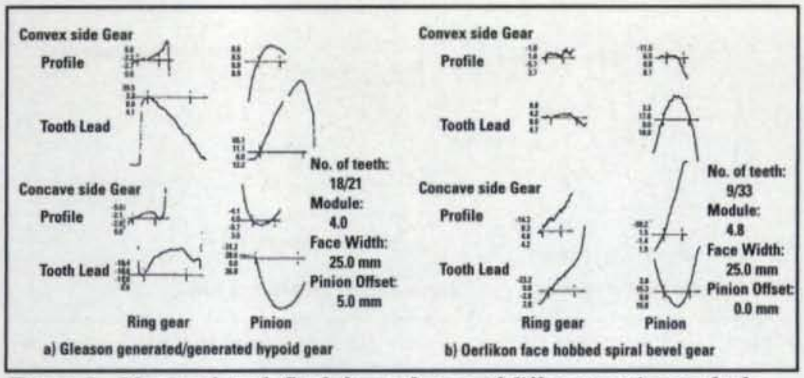

Figure 5—Measured tooth flank form of gears of different cutting methods.

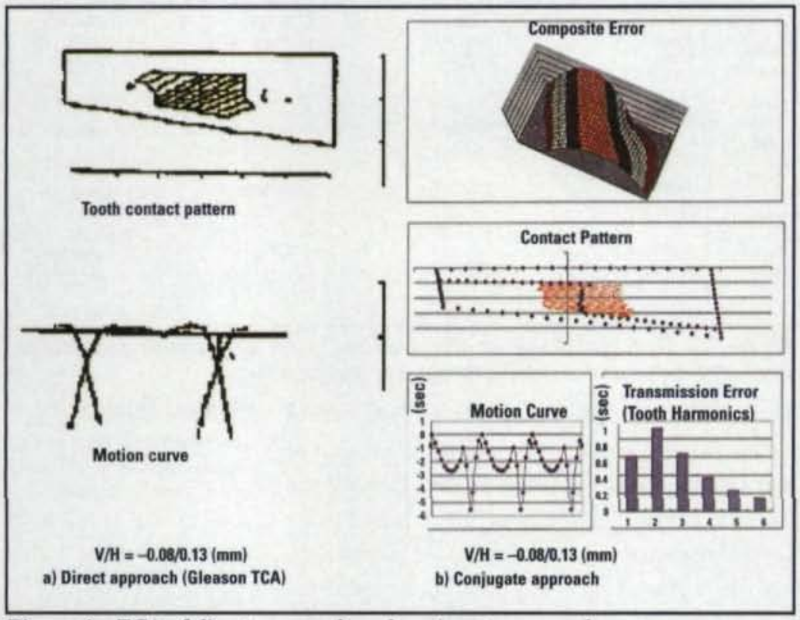

Figure 6—TCA of direct approach and conjugate approach.

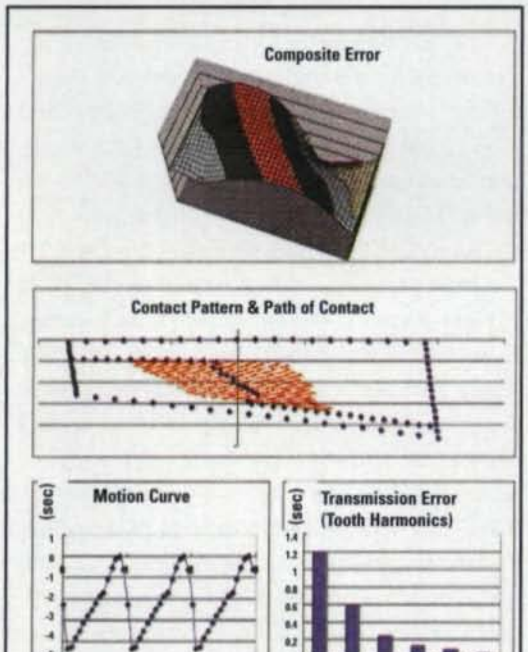

Figure 7—Simulation for pinion cutting change (conjugate approach).

At the first stage of hypoid gear development, cutting machines for pinion teeth are adjusted to get the optimum tooth contact pattern as seen in Figure 6(b). Figure 7 shows the simulated effect of a change in pinion cutting conditions. In this case, a 60' bias-in change is given according to the Gleason cutting sheet (Summary).

By this change, the path of contact (the trace of dots in the figure) is inclined and the contact pattern becomes longer, but the contact position is shifted in the toe direction. In this case, the mounting position should therefore be adjusted to get the contact pattern in the middle of the tooth flank.

Tooth Contact Analysis of Actual Gear

Using the conjugate approach, tooth contact analysis of actual hypoid gears based on the measured tooth flank form data becomes easy. An example of analysis of actual gears that had tooth wear problems in the field is discussed in the following sections.

No load analysis. The sample gear set used in Figures 8–10 is gear set 2 in Table 1. Figure 8(a) shows the composite error surface for the theoretical tooth flank form calculated from the machine setting parameters for ring gear and pinion. That surface is expressed by the form deviation curve on each contact line, neglecting its actual length.

The contact lines are set in the direction of the progress of gear mesh and the composite error values are plotted on these contact lines. The length of contact line near toe and heel of a tooth is stretched, which differs from the actual state. But by this expression, the contact point of tooth flanks can be more vividly recognized. The effect of toprem® is well recognized from the figure. Toprem® is a protuberance on the hypoid cutting blade that produces an undercut on the gear being cut.

From Figure 8(a), we can directly predict the contact pattern under no-load conditions to some extent. Figures 8(b) and 8(c) show the path-of-contact point and contact pattern expressed on the ring gear tooth flank under no load. Figure 8(d) shows the motion curve (transmission error) for this case.

This gear set has experienced trouble with tooth flank wear. Figure 9 shows the state of the initial tooth flank, i.e. of fresh gears just produced, in terms of measured composite error surface, observed no-load contact pattern obtained on the meshing frame (rolling tester) and the no-load contact pattern calculated by using the measured tooth flank form data (Ref. 4). The transmission error calculated for no-load conditions by using measured tooth flank forms is also shown. Figure 10 shows those aspects for the worn tooth flank of the troubled gears. Usually the mounting position of hypoid gears, normally expressed by (V, H) value, is different at lapping, at the tooth contact pattern checking on a rolling tester, and in an actual gearbox's assembled condition. This difference leads to the same kind of difficulty in carrying out the simulation using the measured data of tooth flank form deviation of hypoid gears. In the simulation, some adjustment of (V, H) values from those nominal mounting distances (V_n, H_n) at designing or on the rolling tester is usually necessary to obtain the nearest contact pattern between observed and simulated figures.

On load analysis. Figure 11 shows the comparison between the measured and simulated contact pattern under load, and the transmission error for that case. Figure 12 shows the distribution of normal load, flash temperature (a), and Hertzian stress on the tooth flank.

Flash temperature T_f (in degrees) is obtained as a function of the flash temperature index T_f^* by the following equation:

$$T_f = T_f^* \left(1.11\mu \sqrt{\pi \cdot rpm/30}\right) / \sqrt{\lambda \cdot \rho \cdot c},$$

where μ = functional coefficient of tooth flank; rpm = rotational speed of pinion; λ = normal conductivity; ρ = specific weight; and c = specific heat.

The sample gear set used in Figures 11 and 12 is gear set 3 in Table 1. Figure 13 compares the simulated, FEA calculated and measured tooth fillet stress (Ref. 6) for gear set 4 from Table 1. Figure 13(a) shows the changing state of tooth fillet stress with the progress of meshing at three longitudinal fillet positions along the tooth width, i.e. at 1/6 from toe, 1/2 from toe and 5/6 from toe.

Figure 13(b) arranges the same results in the form of fillet stress distribution along tooth width. These figures for tooth fillet stress show a good agreement among the FEA, measured and simulated results. Figure 14 shows a simulated frequency component of vibrational excitation for gear set 2 in Table 1, using measured tooth flank form deviation of the initial gear flanks shown in Figure 8. The vibrational excitation is calculated in terms of the tooth meshing frequency components. The actual frequency component in Hertz (1/s) of the vibrational excitation caused by the tooth meshing of these hypoid gears can be well predicted from these results and the driving speed of this gear set in operation. All of these quantities concerning the performance of gears are simulated-calculated at the same time. This is an extraordinarily big difference from conventional methods of hypoid gear designing and load carrying capacity calculation.

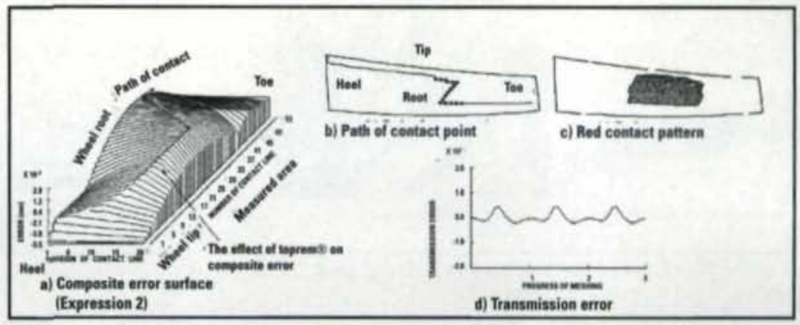

Figure 8—Composite error surface, path of contact point and red contact pattern expressed on the ring gear tooth flank (for gears cut by standard machine setting summary data, and V=0.00 mm, H=0.00 mm).

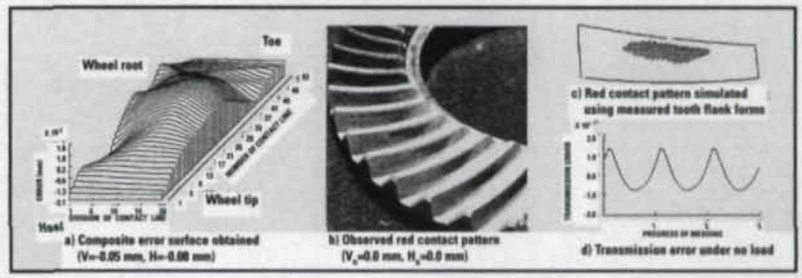

Figure 9—Composite error surface and red contact pattern for initial gear flank.

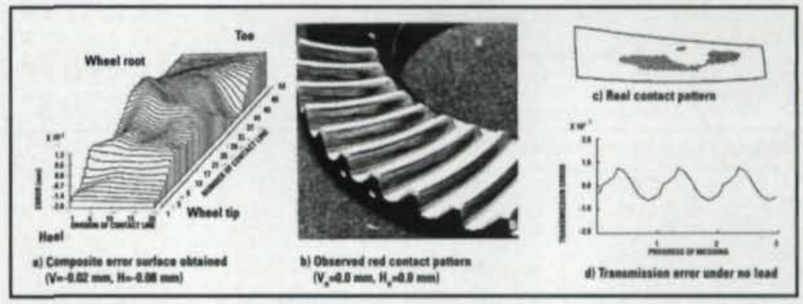

Figure 10—Composite error surface and red contact pattern for worn flank of troubled gears.

Using measured tooth flank form deviation and the performance simulation software, the performance of hypoid gears with actual tooth flank forms under certain gear alignment conditions can be well predicted at the designing stage and in the case of troubleshooting.

Taking an example of tooth flank wear trouble mentioned in the "No load analysis" section, the vibrational excitation is calculated with the progress of tooth flank wear as shown in Figure 15. We can predict how the vibrational excitation of hypoid gears changes with long-running usage (Ref. 5).

Conclusions

The merit of quality control of hypoid gears by measuring the tooth flank form is discussed. The scanning measuring method can realize tooth end-to-end measurement, which is very effective for knowing the detailed condition of the gear tooth. A performance simulation program of hypoid

Figure 11—Loaded contact pattern on ring gear flank and the transmission error (input torque = 30 N-m).

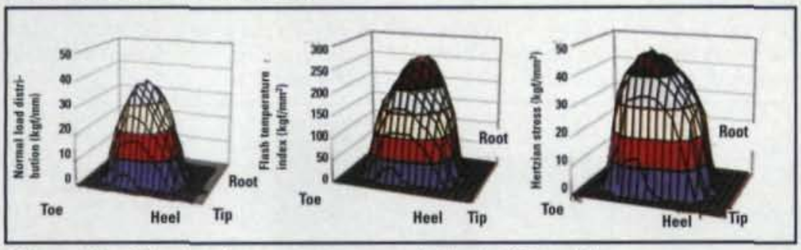

Figure 12—Simulated stress state on tooth flank of hypoid gears.

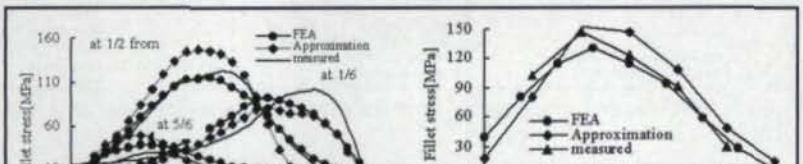

Figure 13—Ring gear tooth fillet stress (torque = 777 N-m).

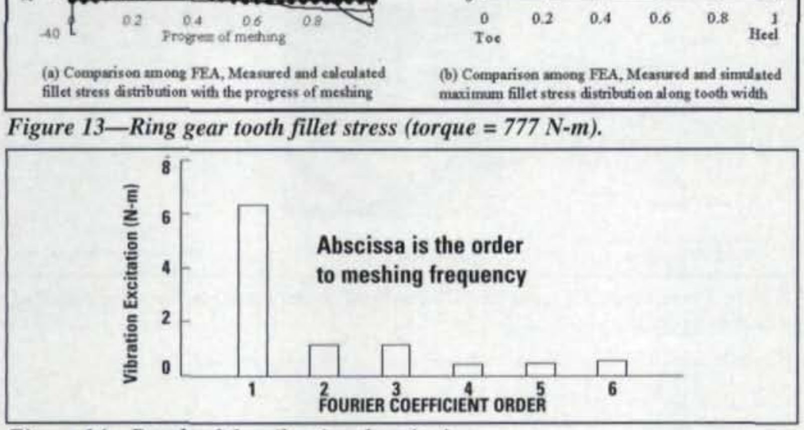

Figure 14—Result of the vibrational excitation.

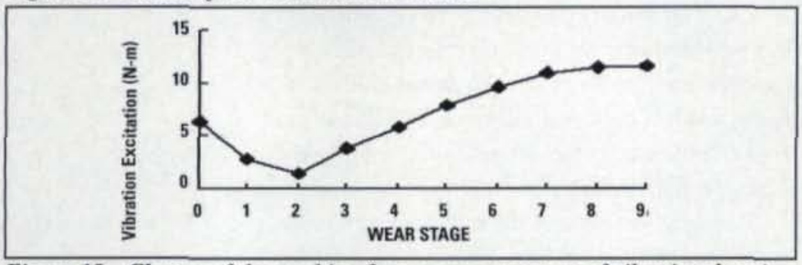

Figure 15—Change of the meshing frequency component of vibrational excitation with progress of tooth flank wear.

Table 1—The Dimensions of Hypoid Gear Sets.

Gear Set	1	2	3	4
Gear Type	Helixform®	Formate®	Formate®	Formate®
No. of Teeth	9/37	6/40	7/43	6/37
Module	4.11	3.90	4.186	8.243
Face Width	24.0 mm	27.0 mm	31.0 mm	40.0 mm
Pinion Offset	27.0 mm	22.0 mm	22.0 mm	31.75 mm
Figures in Which Gear Set Was Used	Fig. 6, Fig. 7	Fig. 8, Fig. 9, Fig. 10, Fig. 14 Fig. 15	Fig. 11, Fig. 12	Fig. 13

gears that can accept measured form deviation of real tooth flank form is developed. The gear performance—such as transmission error, contact pattern under load and no load, normal load distribution on tooth flank, contact stress, tooth fillet stress, flash temperature and vibrational excitation for actual production gears—can now be analyzed. Some simulated results are compared with actual results in the field and from experience. Also, the effectiveness of the measurement of tooth flank form accuracy of hypoid gears is discussed.

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Gleason Corp. Appoints Vice President and CFO

John J. Perrotti was named executive vice president and CFO of Rochester, NY-based Gleason Corp.

He has been with Gleason since 1986 in a variety of positions and has served on the board of directors since 2000.

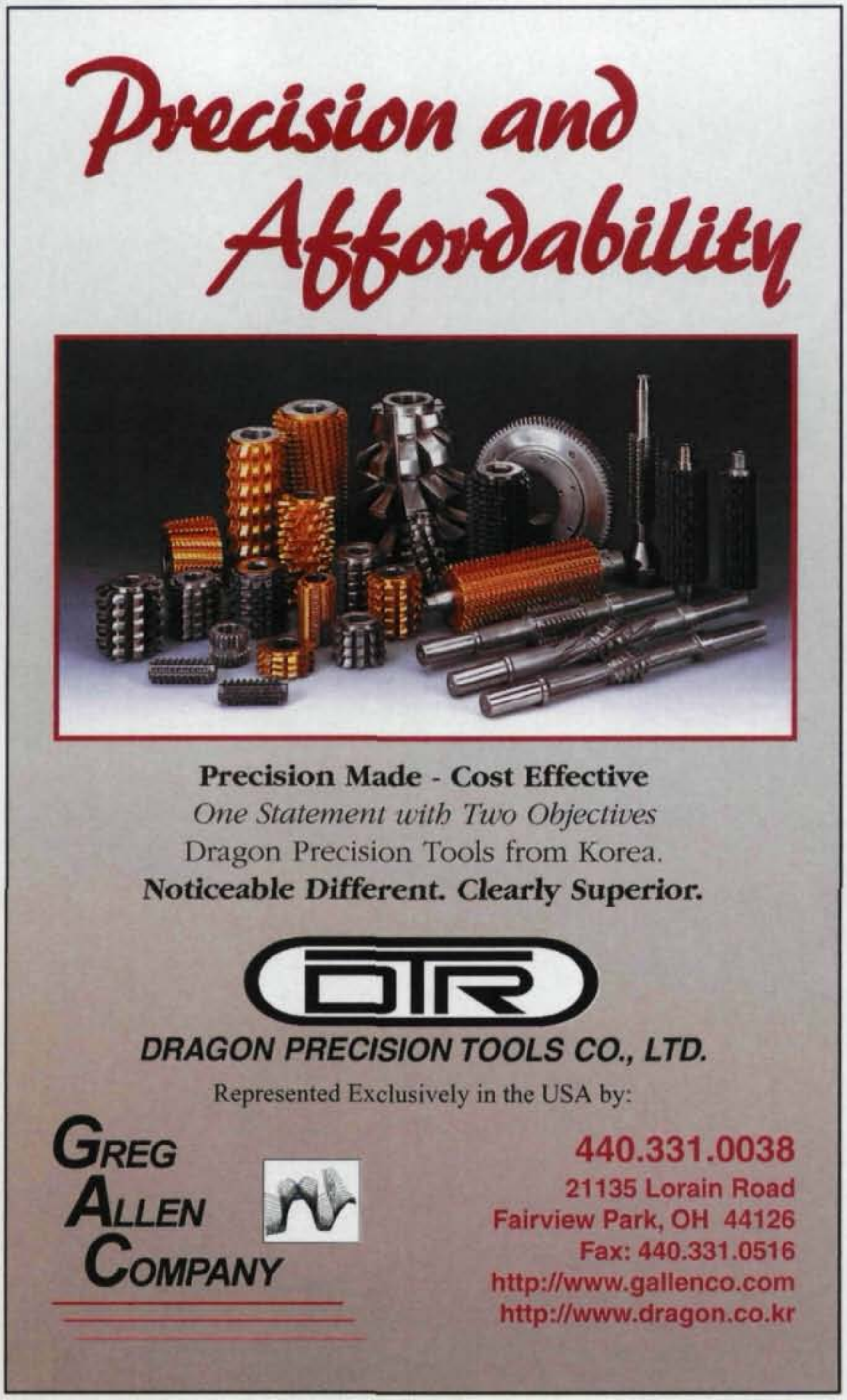
Perrotti holds memberships in several professional organizations, including the Association for Manufacturing Technology and the Financial Executives Institute. A CPA, he has degrees from the University of Rochester and Rochester Institute of Technology.

Mahr Federal Appoints New VP

Mahr Federal Inc., of Providence, RI, appointed Patrick Nugent as vice president of metrology systems.

Nugent most recently worked in the metrology systems customer solutions group for Mahr's parent company, Mahr GmbH of Göttingen, Germany. Prior to that, he served in numerous engineering capacities for Cummins Engine Co.

Among his new responsibilities are leading the systems' business development and furthering profitable growth in the North American marketplace.



Philadelphia Gear Hires New CFO


Stephen Verget

Philadelphia Gear Corp., of Norristown, PA, hired Stephen Verget as CFO.

Among his responsibilities will be leading all accounting, financial analysis and treasury functions for the company. He also will design Philadelphia Gear's evolving business model, which is focused on specialized gear aftermarket service and marine propulsion drives.

For the past 23 years, Verget has worked as a finance leader at E.I. DuPont de Nemours of Wilmington, DE, in a number of roles, including CFO positions in agricultural biotechnology and advanced materials.

New President and CEO Named at Caratron Industries


Paul D. Lefief

Paul D. Lefief was named president and CEO of Caratron Industries Inc., of Warren, MI, a manufacturer of aerospace gearbox assemblies, mechanical actuators, detail gearing and complex precision machined components for commercial and military aircraft systems.

Lefief has held numerous senior management positions for defense and commercial manufacturing companies, including DaimlerChrysler.

One of Lefief's goals will be to gain additional market share in the United States, Europe and Asia.

Caratron Industries Inc. has been a wholly-owned subsidiary of Belgium-based BMT nv. since 2000.

Bodycote's Lansing Plant Receives BorgWarner Certification

BorgWarner Automotive of Chicago, IL, selected Bodycote of Lansing, MI, for the Zero Defect Supplier Award for the second consecutive year. The award was presented at a recent ceremony in Chicago. Bodycote Lansing is an ISO 9000-, QS 9000- and Ford Q1-approved facility.

Bodycote Lansing specializes in batch atmospheric heat treating and salt pot processes. The facility also has an extensive vibratory cleaning capability. A focus at the plant is Bodycote's proprietary ferritic nitrocarburizing process, called Lindure™.

The Lansing plant is part of a five-plant network in Michigan. Bodycote North America Inc. is a subsidiary of Bodycote International plc, located in Macclesfield, England.

New Sales Manager for Greg Allen Co.

Janice Thomas

Janice Thomas was appointed sales and sourcing manager for the gear cutting tools product line of Greg Allen Co., located in Fairview Park, OH.

Her new responsibilities include managing and directing a nationwide network of sales representatives, and coordinating with global suppliers.

For the past 22 years, Thomas has worked in the global gear tool industry. Since 1994, she has been the U.S. sales engineer for David Brown Gear Tools of Huddersfield, U.K.

Birchmere Capital and Wilder-Deem Buy Miller Centrifugal Casting Co.

Miller Centrifugal Casting Co. (MCC), a foundry in Cecil, PA, was bought by Birchmere Capital L.P. of Pittsburgh, PA, and Wilder-Deem of New York, NY.

MCC manufactures finish-machined ferrous and non-ferrous centrifugal castings for equipment manufacturers and long product steel rolling facilities throughout North America. Additionally, it is a supplier of copper-based centrifugal castings, having patented the bimetallic casting process used in the worm gear business.

The Birchmere fund targets acquisitions in middle market manufacturing, distribution, service and financial companies. Wilder-Deem is a financial consulting and investment firm whose other steel-related holding is Damascus Steel Castings of New Brighton, PA.

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TECHNICAL CALENDAR

July 15–17—Powder Metallurgy Basic Short Course. Penn Stater Conference Center Hotel, State College, PA. This conference will focus on the history of P/M, different designs in compacting tools, the use of sintering in developing functional properties, injection molding of metal powder, MPIF standards, special tests for powders and the latest high-tech P/M technologies. $1,125 for APMI members and MPIF member company employees, $1,325 for nonmembers. For more information, contact the Metal Powder Industries Federation by telephone at (609) 452-7700 or by fax at (609) 987-8523.

July 15–19—Basic Gear Manufacturing Course. Daley College, Chicago, IL. Offering hands-on training in gearing and nomenclature, principles of inspection, gear manufacturing methods, and hobbing and shaping. Open to sales reps, technicians, executives, managers, machinists, quality managers and engineers. $650 for AGMA members, $775 for nonmembers. For more information, contact AGMA by telephone at (703) 684-0211 or by e-mail at *fentress@agma.org*.

September 4–11—International Manufacturing Technology Show. McCormick Place, Chicago, IL. Sponsored by AMT—The Association for Manufacturing Technology. See our coverage on pages 12–18 or visit *www.imtsnet.org*.

September 11–13—Basic Gear Noise Short Course. Ohio State University, Columbus, OH. Attendees will learn to design gears to minimize the major excitations of gear noise, transmission error, dynamic friction forces and shuttling forces. Extensive demonstrations of special gear analysis software will take place, in addition to showcasing of OSU gear test rigs. Participants are invited to discuss their specific gear and transmission noise concerns. $1,250. For more information, contact OSU by telephone at (614) 292-5860 or on the Internet at *www.gearlab.org*.

September 11–13—Fundamentals of Gear Design. University Center for Continuing Education, University of Wisconsin-Milwaukee, Milwaukee, WI. This course will provide attendees with a beginning knowledge of modern gear system design and analysis. A knowledge of geometry, trigonometry and elementary algebra is required. $1,095. For more information, contact the University Center for Continuing Education by telephone at (414) 227-3100 or visit the center's web pages via *www.uwm.edu*.

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LC 80

Minimization of In-Process Corrosion of Aerospace Gears

Son Nguyen, Ali Manesh, Jim Reeves and Danny Mahan

Factors	Level = "+"	Level = "-"
A Condition	Virgin	Reclaimed
B Alloy	Pyrowear 53	9310
C HT Condition	Carburized	Core Material
D Exposure Time	90 Minutes	30 Minutes
E Coolant Concentration	8%	1%
F Coolant Temperature	150°F	70°F
G Coolant Type	Synthetic	Soluble Oil

A	B	C	D	E	F	G	E*G	Hours to Initiation	
-1	1	1	1	1	1	-1	-1	1848	
-1	-1	-1	1	1	1	-1	-1	1848	
-1	1	1	-1	1	1	-1	-1	1847	
-1	-1	1	-1	1	1	-1	-1	1847	
-1	1	-1	-1	1	1	-1	-1	1847	
-1	-1	-1	-1	1	1	-1	-1	1847	
-1	1	1	-1	1	-1	-1	-1	1843	
-1	-1	1	-1	1	-1	-1	-1	1843	
-1	1	-1	-1	1	-1	-1	-1	1843	
-1	-1	-1	-1	1	-1	-1	-1	1843	
-1	-1	1	1	1	-1	-1	-1	1842	
-1	1	-1	1	1	-1	-1	-1	1842	
-1	1	1	1	1	-1	-1	-1	1801	
-1	-1	-1	1	1	-1	-1	-1	1801	
1	-1	-1	-1	1	-1	-1	-1	1395	
1	-1	1	1	1	-1	-1	-1	1394	
1	1	1	1	1	1	-1	-1	1392	
1	1	-1	1	1	1	-1	-1	1392	
1	-1	-1	1	1	1	-1	-1	1392	
1	1	1	-1	1	1	-1	-1	1392	
1	1	1	-1	1	1	-1	-1	1392	
1	1	-1	-1	1	1	-1	-1	1392	
1	-1	-1	-1	1	1	-1	-1	1392	
1	-1	1	1	1	1	-1	-1	1338	
-1	-1	1	1	-1	1	-1	1	1319	
-1	-1	-1	1	-1	1	-1	1	1319	
1	1	1	-1	1	-1	-1	-1	1224	Treatment Run Example
-1	-1	1	1	1	1	-1	-1	1220	
-1	-1	1	-1	-1	1	-1	1	1204	

Figure 1—Partial Experimental Matrix With Screening Analysis.

Introduction

Carbon steels have primarily been used to manufacture aerospace gears due to the steels' mechanical characteristics. An alloyed low carbon steel is easily case-hardened to obtain a hard wear surface while maintaining the ductile core characteristics. The microstructure achieved will accept the heavy loading, shocks, and elevated temperatures that gears typically experience in applications. The carbon steel machinability allows for general machining practices to be employed when producing aerospace gears versus the more advanced metal removal processes required by stainless and nickel-based alloys.

As a consequence of using non-stainless steel for gears, in-process corrosion (rust and chemical attack) of gears is possible during the manufacturing process. Surface corrosion of carbon steel gears and shafts can lead to unacceptable stress risers in the material if action is not taken to remove the surface pitting and neutralize the cause. Once the corrosion effect begins, it will continue to attack the grain boundaries of the material. The result is reduced mechanical properties of the alloy that can lead to component failure at performance levels well below typical operating conditions.

Prior to this project, the corrosion problem was minimized by the use of oil-based preservatives and rust-inhibiting machining coolants. However, as the negative effect on exposed production workers and the environment was better understood, and with disposal costs escalating, the gear manufacturing industry changed to water-based coolants and degreasing agents. This shift was immediately followed by an increase in rust. The result was more costly gears from increased rework, scrapped gears, increased preventative activities and manufacturing flow inefficiencies due to out-of-sequence processing. The replacement of corroded gears created additional delays. Corrosion of gears in the manufacturing environment continued to plague the entire gear industry; therefore an investigation to minimize the corrosive effect was warranted.

Objectives

The objectives of this project were to identify the root causes of the observed in-process corrosion of gears and to develop preventative practices to mitigate its occurrence during the manufacturing of gears.

Specifically, the objectives were:

- Utilize advanced manufacturing tools, such as statistically designed experiments, process flow charts, and failure modes and effect analysis (FMEA) to systematically study the potential causes of the in-process corrosion.
- Evaluate the impacts of chemical attack and residual coolant on corrosion, including the investigation of an adapted on-line Digi-Galv probe as a predictive tool.
- Identify and implement preventive practices to reduce in-process corrosion.

Approach, Scope, and Methodology

This project was conducted in two phases: Phase I was to identify root causes of in-process corrosion by conducting a comprehensive study, using manufacturing process bench marking, at two gear production facilities. The Phase I study was augmented by controlled laboratory experiments. The desired end product of Phase I was to understand the sources of corrosion on gears during the manufacturing process and to identify solutions to minimize the corrosion problem. Phase II was to implement the identified solutions to a restricted area of the manufacturing floor to test them in a production environment.

Phase I involved defining the boundaries of the gear making process, developing detailed process maps that describe all of the steps required to produce the gears, verifying the actual inputs at each process step, and performing the failure mode and effects analysis (FMEA) to assess priority of the process parameters. After the process conditions that could potentially be contributing to corrosion initiation were identified and prioritized, the design of experiments were planned and performed.

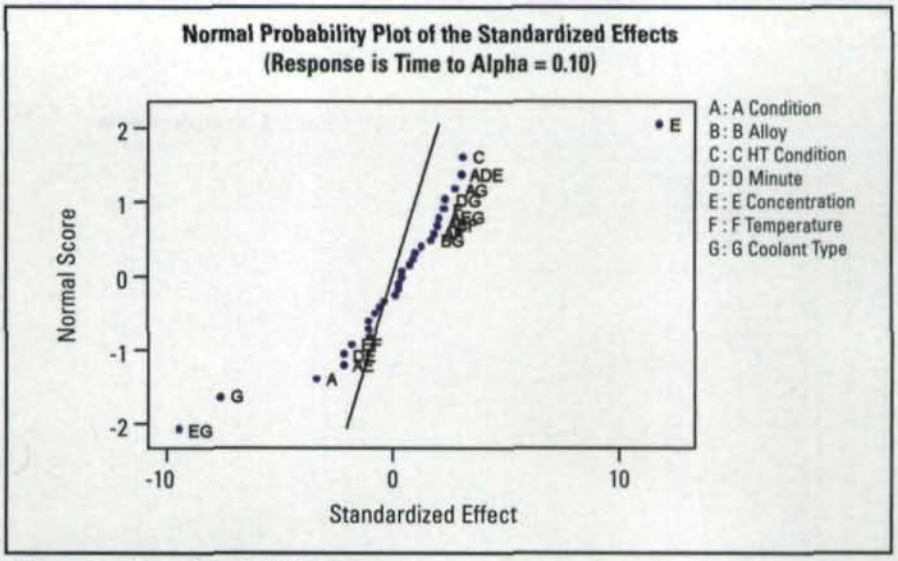

Figure 2—Normal Probability Plot.

For the process mapping, the boundary of the study was established from raw material handling through final inspection of the part. Typical manufacturing process steps for gears included turning, cutting, hobbing, deburring, grinding, heat treating (Cu plating, carburizing, stripping), lapping, shot peening and inspection. Three gear parts (spur, helical, and planetary pinion) were selected from two separate gear manufacturers as a result of the process mapping described above. These parts provided the basis for detailed evaluations of the significant manufacturing steps that were likely to initiate in-process corrosion. In addition, parts selected were made out of common base materials that are widely used in the aerospace industry to manufacture gears. The materials selected were 9310 (AMS6260, AMS6265) and Pyrowear X-53 (AMS6308) steels.

When the part selection and verification of the manufacturing steps were completed, the FMEA was used to evaluate the process inputs. The FMEAs allowed the team to prioritize process inputs that could contribute to corrosion initiation. Process control charts and the FMEA were used to identify and rank the suspect inputs to be tested.

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Danny Mahan

worked at the U.S. Army Aviation and Missile Command in Redstone Arsenal, AL, as a supervisor of manufacturing science and technology.

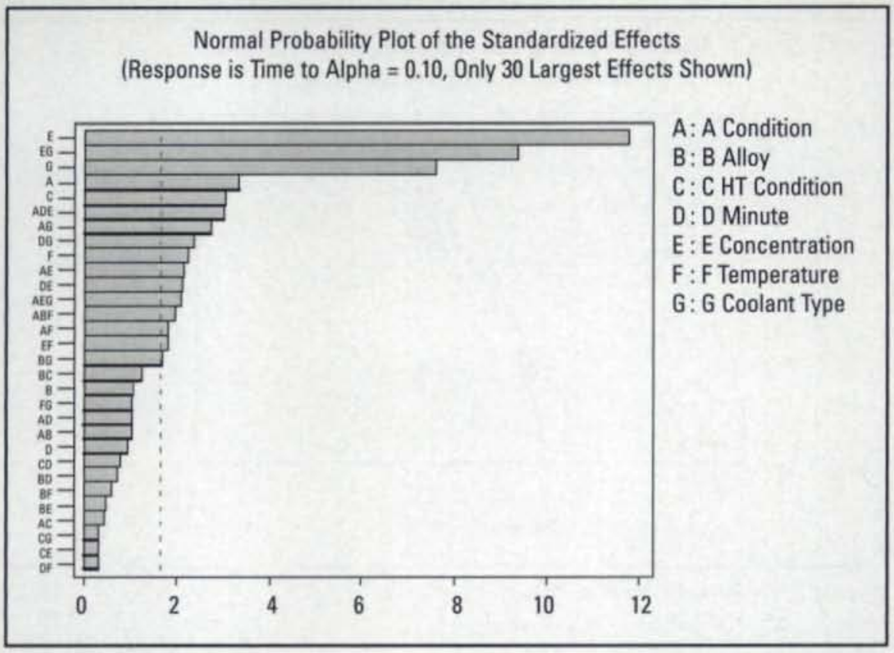

Figure 3—Pareto of Effects.

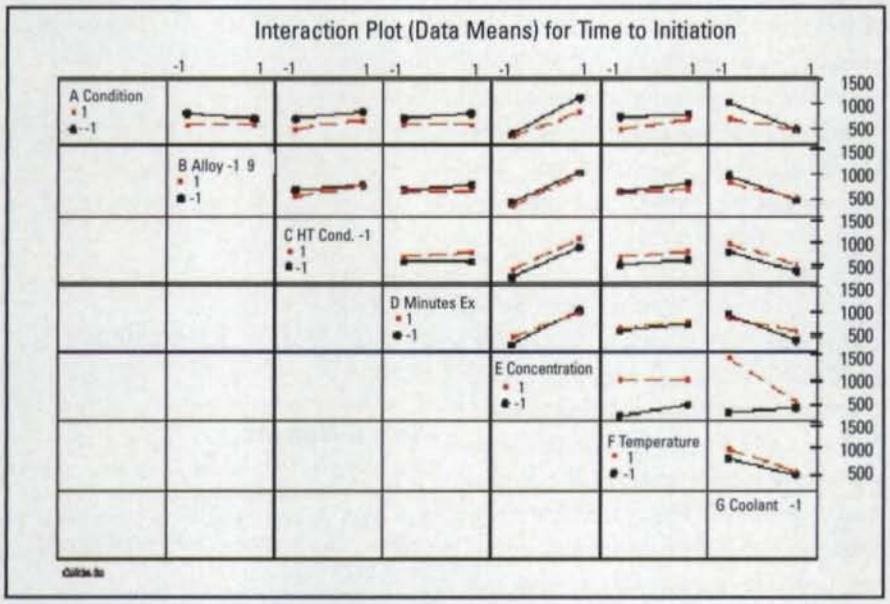

Figure 4—Interaction Plot.

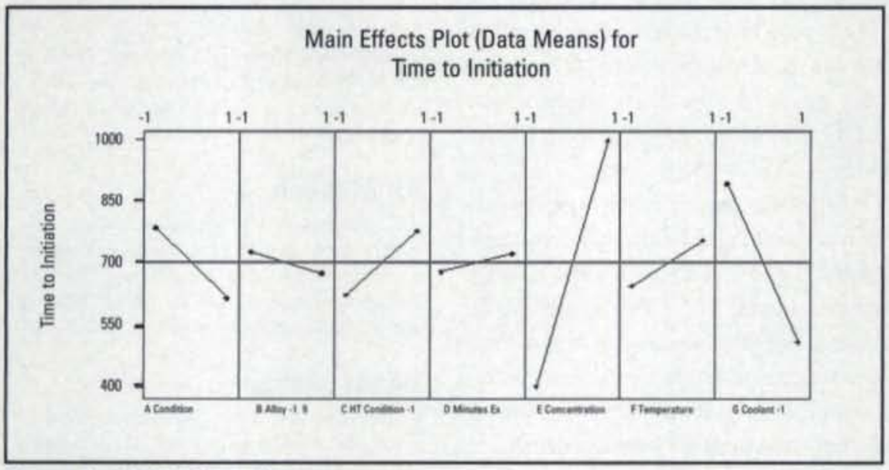

Figure 5—Main Effects Plot.

After a comprehensive investigation, the coolant was identified as one of the key process inputs that may be contributing to corrosion initiation. Multiple potential failure modes were identified for the coolant along with multiple possible interactions. Key factors identified after control chart and FMEA analyses were: coolant concentration, coolant temperature, exposure time, coolant type, coolant contamination and material heat treat condition.

Once the team had narrowed the list of potential corrosion initiation factors, the first DOE design strategy began. The strategies for the design and factor level settings are detailed in Figure 1. Factors selected for testing are: (A) coolant condition (virgin and reclaimed), (B) specimen alloy (Pyrowear X-53 and 9310), (C) specimen heat treat condition (carburized and uncarburized), (D) exposure time to coolant (90 and 30 minutes), (E) coolant concentration (8% and 1%), (F) coolant temperature (150° and 70°F), and (G) coolant type (synthetic and soluble oil). Refractometer readings were used as a measure of coolant concentration.

Phase II commenced in parallel with the DOEs as information became available from Phase I to speed up the verification of benefits resulting from implementation of the identified solutions. Examples of the success of this approach were the implementation of a new coolant in one gear facility and the resolution of the chemical attack problem noted on the gear line.

Discussion of Results

The DOEs were conducted at Honeywell Engines & Systems facility. The steel specimens were subjected to prescribed conditions identified in Figure 1. An example of a treatment run in the matrix was to soak a carburized Pyrowear X-53 specimen in an 8% concentration virgin soluble oil coolant at 70°F for 30 minutes. The specimens were then loaded into a humidity chamber that was set at 80°F and a relative humidity level of 70%. These samples were monitored twice daily for corrosion initiation. When corrosion initiation (response) occurred, the time (hours) to initiation was recorded and used for the experimental analysis.

Upon establishing the hours to corrosion initiation on the specimens, analyses of the experiment results were performed. A screening analysis was performed by sorting the hours to initiation in ascending order and evaluating the experiment matrix for any patterns. The visual pattern shown in Figure 1 that appeared to be significant is: coolant type, coolant condition, and an interaction between coolant concentration and coolant type. A statistical analysis was next performed. The normal probability plot and the Pareto of effects shown in Figure 2 and Figure 3 respectively, identified the same factors as being significant. Figure 4, the interaction plot, showed the coolant type by coolant concentration as the most significant interaction in the model. The main effects plot, Figure 5, indicated that coolant concentration and coolant type had the greatest effect. An analysis of variance (ANOVA) confirmed the results reported above as statistically significant. Based on the data, virgin and low concentration coolants are predicted to initiate corrosion more quickly than reclaimed and higher concentration coolants.

Heat treat condition also affected the initiation of corrosion in that high carbon (carburized) surfaces were more resistant to initiation as compared to core (uncarburized) surfaces. It was also synthesized from the data set that used/reclaimed coolants offered better corrosion resistance than the virgin mix in both synthetic and soluble oil coolants. The data also supported using the soluble oil coolant as the preferred cutting fluid. As a result of the experiment, the soluble oil, water-based coolant was implemented in the gear production area as part of Phase II work.

Based on the results of the first DOE, the strategy for the second experiment was developed. The factors selected for this experiment were: coolant concentration (3% and 6%), base material magnetism (0 gauss and 10 gauss), specimen surface finish (6 Ra and 36 Ra), iron particles in coolant (clean coolant and particles added), specimen raw material heat lot (heat lots 1 and 2), specimen heat treat condition (carburized and uncarburized), specimen alloy (9310 and Pyrowear X-53), degreasing solvent condition (virgin and used), and preservative oil application (four-minute soak application and spray application). At the suggestion of manufacturing personnel, the additional factor that was added to the DOE was the method of preservative oil application. Previous process mapping analysis revealed that a typical lot of gears could go through the preservative soak cycle 24 times. If the soak cycle could be replaced by a spray or quick immersion with the same result, significant savings in cycle time and cost could be realized.

With the factors and level settings established, the DOE was executed as described previously. However, there was no corrosion initiation observed on the samples after six months. The experiment indicated that the factors tested would not initiate corrosion, provided a coating of preservative oil was applied, regardless of

Run Order	Copper oz/gal	pH	Exposure (min.)	Attack
7	1	1	-1	1
1	-1	1	1	1
2	1	1	1	1
6	-1	1	-1	1
8	1	-1	-1	2
4	-1	-1	-1	2
5	1	-1	1	3
3	-1	-1	1	3

Factors	Level = "+"	Level = "-"
pH	10.3	8.6
Copper oz./gal.	9.9	6.3
Exposure time (min.)	90	45

Figure 6—Alkaline Strip Experiment Matrix.

Figure 7—PCI-Win Probe System.

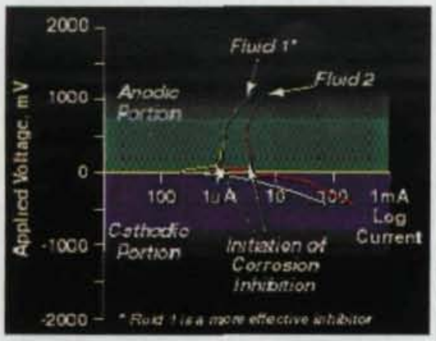

Figure 8—PCI-Win Sweep Output.

application method. Based on this result, the manufacturing specification was modified to only require a quick immersion in lieu of a four-minute soak. The practice was quickly implemented in Phase II.

Chemical Attack

During the project, a large quantity of gears were exhibiting a pitted condition at the machining operations in various areas. After metallurgical examination, it was determined that the pits were a result of chemical attack/corrosion. Since the machine cutting fluids, cleaning and preservation factors had been previously tested in Phase I, they were quickly dismissed as the root cause. This allowed the team to focus the investigation in the plating facility. The key factors were identified through a thought process mapping exercise. Possible initiators of the attack were alkaline pH, exposure time, and the ounces of copper in the alkaline strip solution. An experiment was designed to test these factors on 9310 steel specimens as shown in Figure 6. Analysis of the experiment identified pH as the factor with the highest significance. Data also indicated when the pH level was greater than 10, chemical attack did not occur.

For phase II implementation, the team installed a controller on the alkaline strip tanks to maintain the tank pH levels above 10.3, by automatically adding anhydrous ammonia when the pH level dropped below 10.3. It was noted that during the anhydrous ammonia addition, an exothermic reaction occurred, heating the solution to temperatures above 100°F. The problem identified with the elevated temperature was that when the alkaline stripping solution reached temperatures above 77°F, it became corrosive to carbon steels. The team installed a chilling unit in the stripping tanks to stabilize the solution temperature at 60°F. After installing the chiller and maintaining stable pH levels at 10.3–10.7, no chemical attack on an entire lot of gears has occurred due to pH imbalance as a root cause.

Residual Coolant

Early in the project, it was determined by extensive laboratory testing that water-based machining coolant was an effective corrosion inhibitor. Low carbon alloy gears coated with a film of in-process coolant did not corrode after two months in the high heat and humidity test chamber.

The results of this testing were:

- Used coolant is not a corrosion enabler.
- The coolant solution's ability to form a protective film barrier on the surface of the part determined its ability to inhibit corrosion. Whether this film came from virgin or in-process coolant was irrelevant.
- If a film was not left on the part by the coolant after the machining operation and it was not properly treated with a preservative oil, then corrosion was enabled. Such corrosion resulted in increased manufacturing costs and lead times.
- A corrosion-protective film could be formed after processing through either the coolant or preservative solution typically applied during the manufacturing process.

Test results indicated that residual coolant would leave a short-term corrosion inhibiting film on the gears similar to the ones resulting from immersion in an oil bath. This residual film could reduce the incidence of corrosion even if the preservative oil was not applied. If the proper fluid attributes could be measured and maintained, not only would costly corrosion initiation be greatly reduced, but the corrosion prevention steps (preservative baths) could also be decreased or eliminated.

On-line PCI-Win Probe

A significant barrier to relying on residual coolant as an effective short-term corrosion inhibitor is determining if the coolant has the proper attributes. Standard corrosion testing takes too long to give usable information in an on-going production environment. For example, this testing procedure would take approximately 48 hours to complete at added cost for coolant analysis. The team's goal was to find a tool to provide real time sump-site testing to predict the coolant's corrosion inhibiting properties.

After further research, the team decided on the use of an adapted Digi-Galv probing system, PCI-Win Probe, similar in operating principle to the ones used in the oil pipeline monitoring industry. The probe has the potential to provide quick indications of a coolant's corrosion-inhibiting capabilities.

The PCI-Win Probe system shown in Figure 7, consists of a small test cell (specimen housing and electrode), a digitally controlled dual range precision instrument unit, and a standard Pentium desktop PC with the AMPLICON PC30AT card and associated software installed. In addition, three accessories are added: a glass sleeve sample vessel, a constant temperature water bath with tubing to allow flow through the glass sleeve, and a pump to provide circulation of the sample. The accessories create a testing environment that simulates the actual conditions under which the coolants perform in the metalworking machines.

The PCI-Win Probe effectively measures the electrical resistance between the probe and metal specimen while both are submerged in the coolant being analyzed. The resistance represents the film formed by the coolant on the specimen. The higher the resistance, the more complete the coverage and the thicker the film. This resistance is measured and graphed by the PCI-Win Probe system, in the form of a "sweep" shown in Figure 8. The sweep consists of two parts, cathodic and anodic. The anodic portion (above the X-axis, or positive voltage values) of the sweep indicates the rust preventative (RP) packages of the fluid. The longer the curve remains in the vertical upswing, the better RP packages in the fluid. Also, the further to the left that the inflection point occurs, the better RP in the fluid. In general, an inflection point at or to the left of 10 µA indicates a fluid that is considered to be a good inhibitor of rust. As the RP package weakens, the sweep tends to trail off toward the right. If no inflection point occurs at all, and the sweep continues flatly toward the right, it demonstrates that the fluid's RP properties have depleted and are providing very little, if any, rust protection.

Using two common gear materials, laboratory testing of five water-based metalworking coolants and validation testing of two coolants were completed. Sample testing was done at Honeywell Engines and Systems. Ten machines were strategically selected to provide a broad range of machining processes and coolant conditions. In total, 10 weeks of tests were run with the two conditions for 9310 alloy and three weeks of tests were run with the two conditions for Pyrowear X-53 alloy. The purpose of the test was to validate previous results and to directly correlate the data gathered in the sweeps (location, initiation of inhibition) to the daily concentration, pH, bacteria, and total dissolved solids (TDS) levels.

The results obtained in the lab did agree with the Phase I results. In comparing the PCI-Win sweeps, it was evident that the FUCHS PT-97 soluble oil coolant was a better corrosion inhibitor than the ChemTool CT-757 synthetic coolant. Not only did the coolant type make a difference in sweep location and shape, the type of alloy was also a factor. For the Pyrowear X-53 alloy, the sweeps were shifted far to the right. In the DOE phase of this project, metal coupons made of Pyrowear X-53 and 9310 were placed in a humidity chamber and monitored for the initiation of corrosion. The Pyrowear X-53 coupons exhibited corrosion initiation before the 9310, which correlated to the PCI-Win findings. Additionally, it was clear that routine concentration, pH, bacteria, and TDS testing did not predict performance of rust inhibiting packages in coolants.

The PCI-Win Probe system did show an ability to differentiate between the two fluids' corrosion inhibiting performance. However, in its current form, the PCI-Win system is best suited for a laboratory environment. Additionally, because of several equipment stability issues, the team decided that it was not robust and precise enough to implement for production floor use. More testing and evaluation were required. As further research and development is conducted, it is expected that this technology could become a useful predictive tool for both lab and production environments

Conclusions

When corrosion occurs during the manufacturing of gears, production costs associated with scrapping or rework escalate, and product delivery delays are likely due to the disruption of work flow within the product lines. Based on this project, the key parameters and preventative practices to minimize corrosion during the manufacturing of aerospace gears have been identified as follows:

- Coolant condition, type, and coolant concentration are the major factors effecting the initiation of in-process corrosion. In this project, low concentration and virgin coolants will initiate in-process corrosion more rapidly than higher concentration and reclaimed coolants.
- With respect to inhibiting in-process corrosion, soluble oil coolant performed better than synthetic coolant.
- Carburized surfaces are more resistant to corrosion initiation than uncarburized surfaces.
- Corrosion protection results are similar, regardless of the preservative oil application method, quick immersion or several minutes' soak.
- The alkaline strip step in the plating process is a major source of chemical attack. Maintaining pH levels between 10.3–10.7 and fluid temperature at 60°F maximum in the alkaline strip tank will minimize the potential for chemical attack on gears.
- Residual coolant can be an effective short-term corrosion inhibitor, thereby eliminating the time-consuming and costly oil preservative steps during the manufacturing of gears. The key to implementing this practice is to have a reliable method of monitoring the coolant conditions.
- The PCI-Win Probe system has the potential of characterizing the corrosion inhibitor characteristics of a coolant.

Recommendations for Future Work

Additional work on developing the PCI-Win Probe system as an online coolant tester is recommended. Once the coolant's corrosion inhibitor property is ascertained through online testing, the possibility exists to eliminate the preservative oil altogether and rely solely on the residual coolant as an effective short-term corrosion inhibitor. Suggestions for improvements to the PCI-Win Probe system include the following:

- The calomel electrode should be manufactured to a tighter tolerance.
- A calibration method must be developed for the PCI-Win Probe system to improve accuracy.
- The probe assembly should be repackaged to be more rugged and portable.

Acknowledgment

This project was conducted by Honeywell Engines & Systems and administered by IIT Research Institute (IITRI) through the INFAC (Instrumented Factory for Gears) Program, which is funded by the U.S. Army Aviation and Missile Command (AMCOM). Process mapping was done both at Honeywell Engines & Systems and Bell Helicopter Textron Inc. Humidity chamber and coolant testing were conducted at Honeywell. Castrol Industrial developed the methodology for the PCI-Win Probe testing of the coolants. The authors would like to thank the staffs of AMCOM, IIT Research Institute, Honeywell Engines & Systems, Bell Helicopter Textron Inc. and Castrol Industrial for their help and support on this project.

Reference

INFAC, Corrosion of Aerospace Gears, INFAC Manufacturing Method Report number 00-001, Chicago, February 2000.

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New Polymer for Brake Actuator From Victrex USA

The Peek™ polymer was chosen as the material for the actuator unit of an electronically controlled parking brake because it allowed TRW of Koblenz, Germany, to develop a high efficiency gearing concept with a transmission ratio of 150:1 within a limited space.

According to Victrex's press release, the polymer provided lighter, quieter running parts than could be achieved with metal.

On this gear assembly, high torque was to be transmitted in a chemically aggressive environment within a limited space. The subassembly sits on the caliper in the rim, a result of which was that the construction space available for the gearing was only 2.08" in diameter and 1.2" in height.

Victrex USA is a manufacturer of high performance polyketones.

For more information, contact Victrex USA Inc. of Greenville, SC, by telephone at (864) 672-7335 or on the Internet at *www.victrex.com.*

New Gear Oil from Dow Corning

Molykote synthetic gear oils from Dow Corning Corp. can last three times longer than conventional mineral oils while reducing power consumption by as much as 17% in worm gearboxes, according to Dow Corning.

In its press release, the company said the oils' longer life is possible due to proprietary anti-oxidant additives and a manufacturing process that eliminates impurities which lead to oil degradation.

These gear oils are designed for use in worm, helical, spur, bevel, hypoid, and rack and pinion applications and meet most equipment OEM lubrication requirements.

For more information, contact Dow Corning of Midland, MI, by telephone at (800) 637-5377 or on the Internet at *www.molykote.com.*

Flaw Detectors from Agfa NDT

The USM 25 Series of portable flaw detectors from Agfa NDT weighs 3.5 lbs. and has a range of 0.020" in steel for optimum thin-range use.

According to the company's press release, curvature correction has been added to compensate for trigonometric flaw location calculations when performing angle beam inspection on piping and tubular goods. Two independent monitor gates, along with automatic A-Scan freeze for both gates, provides versatility and simplifies thickness measurements.

Multiple-curve DAC with two curves above and below the original recorded DAC curve enhances critical flaw sizing capabilities. An alphanumeric data logger option provides storage for 5,000 thickness readings and the ability to attach 500 A-Scans to thickness readings.

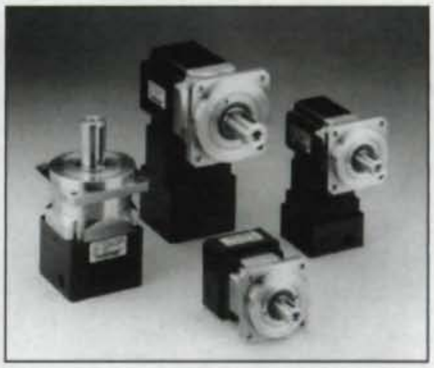
For more information, contact Agfa NDT of Lewistown, PA, by telephone at (717) 242-0327 or by e-mail at *infolink@agfandtinc.com*

New Gear Factory Software from Chris Watts Design

Chris Watts Design is offering a new software system for AutoCAD 2000, 2000I, 2002 and MDT users. The software, called Gear Factory, includes a dialog box that allows users to create standard or custom 3-D solid models, 2-D entities or 2-D isometric entities of standard involute gears.

According to the company's website, users can specify the pitch, pressure angle, number of teeth, width and insertion point of gears. The software is available for $79.95 per unit.

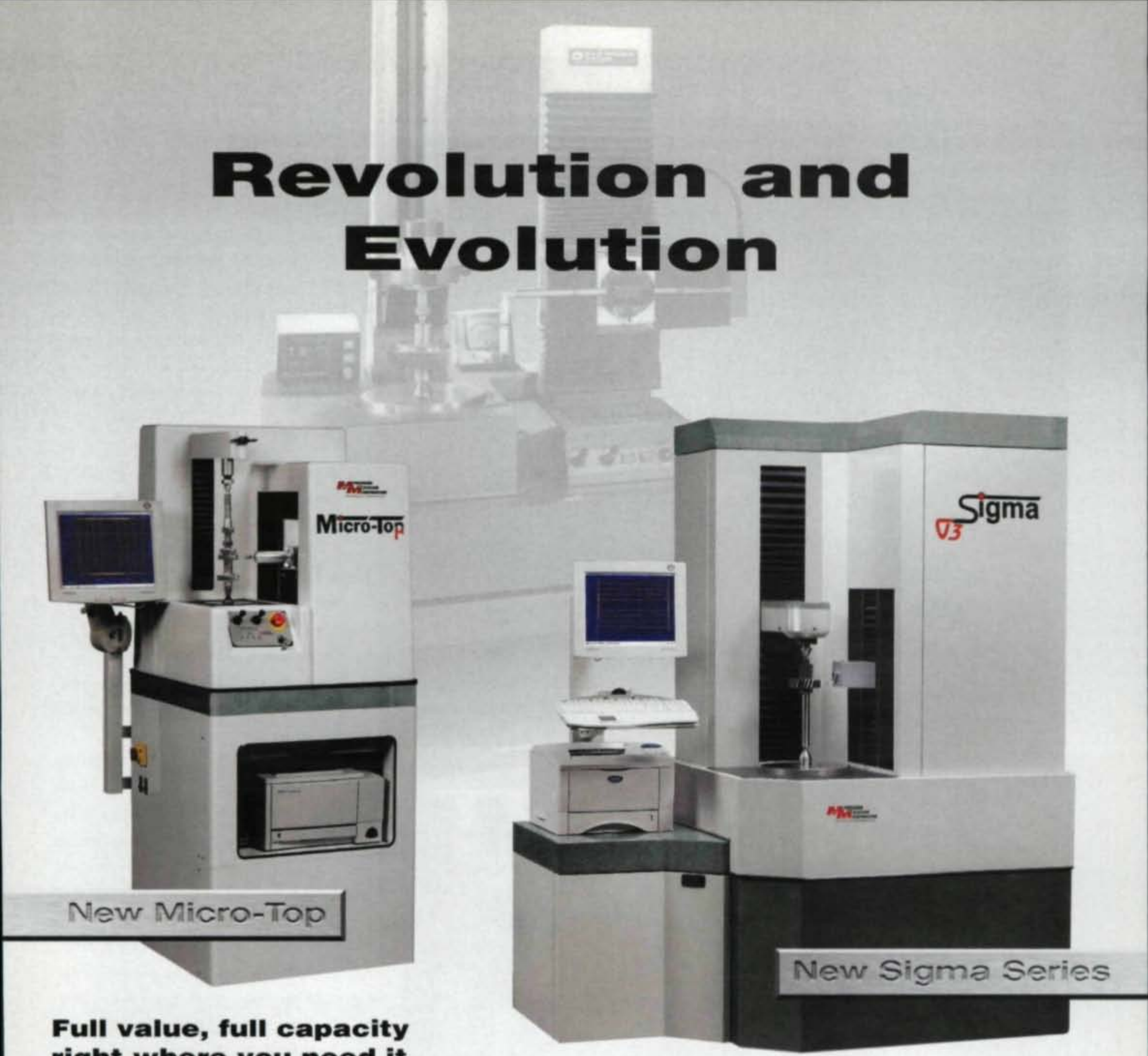
For more information, contact Chris Watts Design of Ojai, CA, by telephone at (805) 649-8038 or on the Internet at *www.cwattsdesign.com.*



New Sizes for Gearhead Series from Thomson Industries

Thomson Micron L.L.C. added 90 and 115 mm sizes of planetary gearheads. Available in both in-line and right angle models, these gearheads are suitable for applications like material handling, packaging, coil winding, pipe

Revolution and Evolution



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bending, machine tools, overhead gantry systems and injection molding machines.

With a standard four arc-minute backlash and crowned helical carburized steel gears that are hardened to HRC 60 minimum and flank-finished after heat treating, the gearheads are made to operate quietly. According to Thomson's press release, the gearheads' strength and torsional rigidity result from machining both the output housing and the helical internal gear from a single piece of high strength steel.

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

New Helical Shaft Mount Reducer

Emerson Power Transmission introduced a newly redesigned Browning helical shaft mount reducer.

The new shaft mount line incorporates a single tapered bushing mounting system and a barrier steel system.

The single tapered bushing mounting system is reversible and allows the bushing to mount from either side. It includes a tapered stabilizer ring that minimizes wobble and resists fretting corrosion. According to EPT's press release, this system reduces shaft binding found in two-bushing systems and can replace any competitive single- or double-bushing shaft mounts.

The barrier seal system combines a v-ring face seal, grease-filled labyrinth and rotating outer finger to provide triple protection against contamination and oil seal damage.

For more information, contact Emerson Power Transmission of Ithaca, NY, by telephone at (606) 564-2084 or online at *www.emerson-ept.com*.

New Generation of CNC Grinders

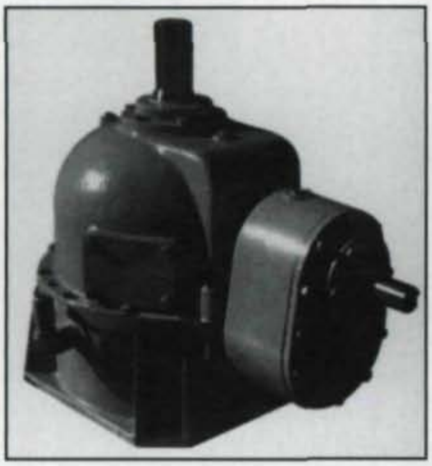
The Parker Majestic Division of Penn United Technology announced the development of a new generation of CNC cylindrical, rotary and profile shift grinders.

The Liberty Series are Siemens 810-powered machines with a 12" x 10" or a 14" x 30" capacity. Designed to simplify file management and programming, the series can be configured as an ID, OD or combination grinder. Additionally, it features a 5 hp OD motor and 1.5 hp ID motor.

The Revolution Series contains CNC rotary grinders with a 14" maximum diameter capacity chuck. These grinders can be configured with a vertical or horizontal grinding spindle and are switchable from one to the other. Grinders have the capacity to grind rings and spacers flat within 0.00001" and are menu driven.

The Freedom Series of CNC profile surface grinders is comprised of 3-axis Siemens 810- and 840D-powered machines with an 8" x 18" table capacity and an optional CNC over-the-wheel form dresser. These grinders can also be configured with a CNC rotating or indexing fixture.

For more information, contact Penn United Technology of Saxonburg, PA, by telephone at (866) 572-7537 or on the Internet at *www.parkermajestic.com.*



New Universal Cooling Tower Drive from Philadelphia Gear

A new universal cooling tower drive from Philadelphia Gear Corp. is designed to replace cooling tower drives and spare parts.

Available in two sizes, the universal cooling tower drive can be used instead of other drive models, with minimal modification. It contains spacer plates and change gears.

According to the company's press release, base plate space adapters make the drive modifiable to most other legacy cooling tower applications by adjusting the height of the output shaft. Also, the location of the change gears was designed so that spiral bevel gears within the main housing do not have to be modified to change ratios.

Numerous gear ratios can be achieved by using different sets of change gears external to the main housing. Therefore, the company says, the drive can be installed in 24 hours with only the smaller change gears needing to be installed when the unit is ordered.

For more information, contact Philadelphia Gear Corp. of Norristown, PA, by telephone at (800) 766-5120 or on the Internet at *www.philagear.com.*

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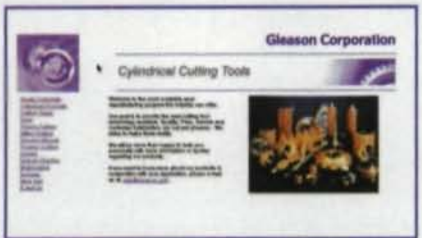

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A Gear with a Sweet Tooth

Gear manufacturers typically use plastic, steel or other metals to make their gears, but Andrew Shotts made his first gears out of sugar and chocolate.

These materials are more familiar to Shotts. As a pastry chef, he has worked in the kitchens of the Russian Tea Room, La Côte Basque and the ocean liner Queen Elizabeth 2. In 2001, he worked with two colleagues to create sugar and chocolate gears in that year's National Pastry Team Championship.

Considered the premier event of the pastry world, the annual pastry championship requires contestants to create a chocolate showpiece, a sugar showpiece, cakes, plated desserts, frozen desserts and petit fours surrounding a theme. International teams vie for a grand prize of $50,000.

While racking their brains for a vision of how to best illustrate the 2001 competition's Hollywood theme, the chefs on Team Shotts were inspired by 1930s actor Charlie Chaplin and decided to design an entry to honor his performance in the movie *Modern Times.*

Nothing symbolized the message of *Modern Times* better than a gear, says Shotts.

"It had to be a gear because, during (the) Depression, there was so much more an emphasis on the mechanical, rather than on humans," he says.

Shotts and his colleagues, Patrice Caillot and Rémy Fünfrock, constructed two gears. One gear was the team's sugar showpiece, the other was its chocolate showpiece.

"We were depicting an old movie reel with the sugar showpiece," says Shotts. "It's the same size film, 16 mm, that was used when the movie was shot. The white parts are supposed to be film wheels and the entire format of that gear is representative of that old over-and-under format of the 1936 movie camera."

The chocolate showpiece looks much like the sugar one, but there are some subtle differences between them. At the bottom of the chocolate showpiece, for example, are fanlike cutouts resembling a shutter. Both creations show gears curving on either side to illustrate the mechanical nature of factory work during the Depression.

Since the creators were trained in culinary arts rather than in manufacturing, their planning for the contest was extensive. They spent three months learning about machinery, designing a template and mixing the ingredients. Shotts, Fünfrock and Caillot began their creative process at the library, researching gears in periodicals and trade journals.

Once they became comfortable with the construction of a gear, they tried to devise the showpieces out of cardboard. They saved the cardboard template to a disk and sent it to an engineer in Atlanta, who then cut a mold to the exact specifications. Once they had this mold back from the engineer, they were able to pour the chocolate into it.

Each showpiece took *eight* hours to bake.

This year, Shotts and his partners are too busy with their day jobs to participate in the National Pastry Team Championship 2002 Contest. Shotts works in New York as a corporate pastry chef for Guittard Chocolate Co. and launches a new line of seasonal bonbons every three months.

Caillot works as executive pastry chef at New York's St. Regis Hotel, specializing in desserts, and Fünfrock explores new desserts in his role as executive pastry chef at Café Boulud in New York.

Though their gears were probably better tasting than those made in factories, the creators opted to throw out the showpieces after the competition.

More than three months of effort went into making this gear by an unusual coupling of culinary and engineering talent.

Vintage cinema inspired the creation of this gear, which is meant to represent the importance of machinery in 1930s American labor. This gear is reminiscent of gears used in an antique movie camera with 16 mm film.

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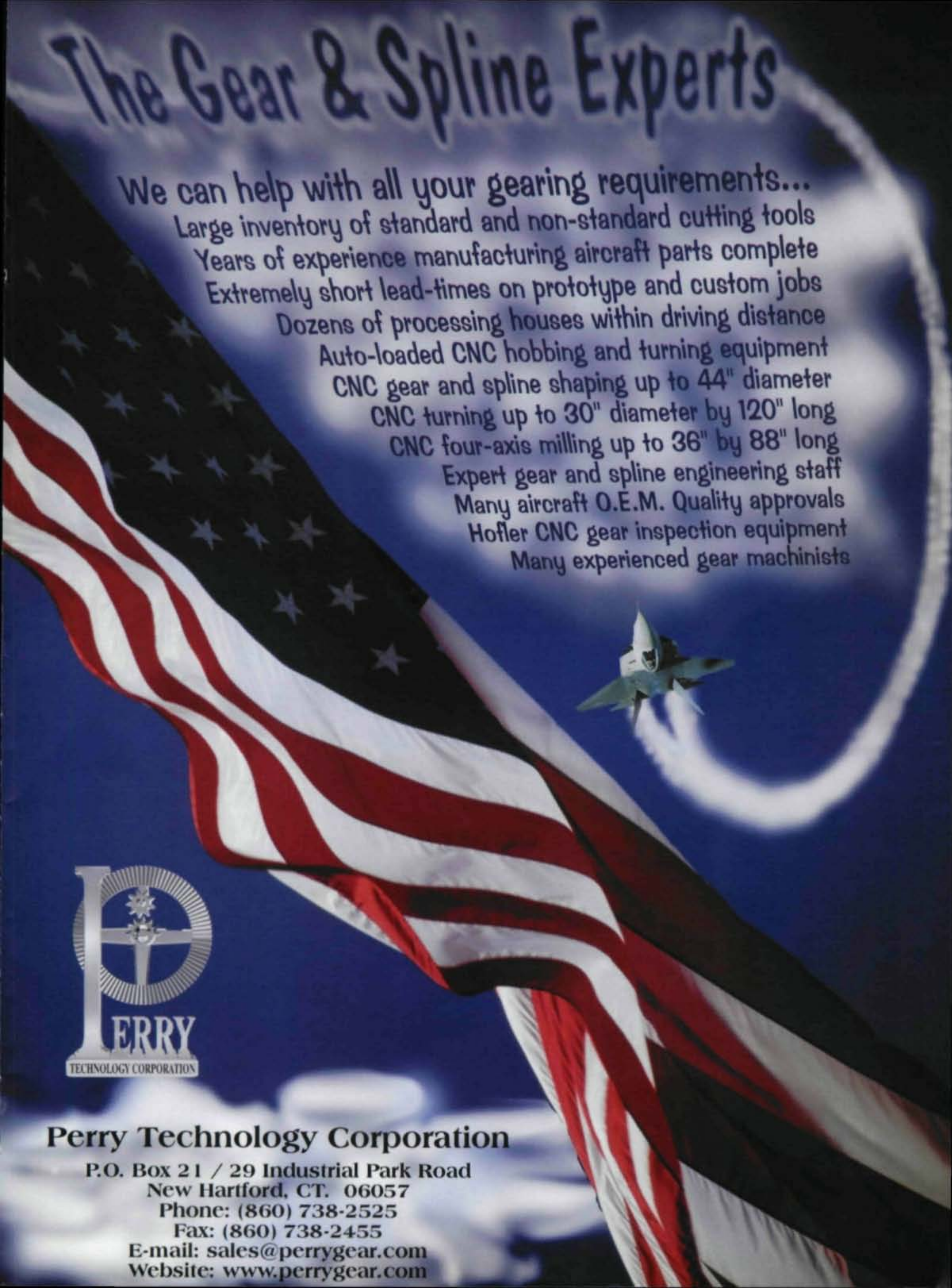
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