GEAR TECHNOLOGY

JULY/AUGUST 1999
The Journal of Gear Manufacturing

GEAR EXPO PRE-SHOW ISSUE

- PLAN YOUR TRIP TO NASHVILLE
- Y2K AND THE GEAR INDUSTRY
- MYTHS AND MIRACLES OF GEAR COATINGS
- VECTORS IN GEAR DESIGN

Plus • Book Review: Litvin's *Theory of Gearing* • Addendum: Ancient Gears

THE GEAR INDUSTRY'S INFORMATION SOURCE

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JULY/AUGUST 1999

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FEATURES

17

DEPARTMENTS

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CIRCLE 163

CIRCLE 166

GEAR TECHNOLOGY

The Journal of Gear Manufacturing

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KICKING TIRES

For the first time in probably 15 years, I've attended an auto show. Although I haven't been purposely avoiding them, over the past decade or so, the auto industry hasn't given me a compelling reason to go.

It used to be that you could tell the make, model and year of a car just by looking at it. But the recent cookie-cutter models seem to be stamped from the same set of dies, year to year and manufacturer to manufacturer. The automobile enthusiast has had only bits and pieces to get excited about.

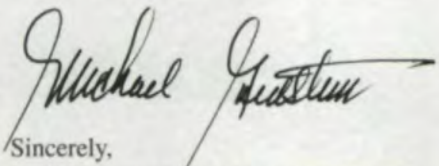
But a rejuvenation in automotive design appears to be underway. Current and concept models on display at the 1999 Chicago Auto Show, held in February at Chicago's McCormick Place, focus as much on selling adrenaline, adventure and mystique as they do on transportation.

Some of the best examples include the recent work of Chrysler, whose Vipers and Prowlers are now among the most recognizable cars on the road. Chrysler also showed their new PT Cruiser, a model that takes its styling cues from classic cars of the 1930s. It looks like nothing else on the road. With its high fenders, distinctive grille and a shape that defies industry-standard classification, it's part car, part minivan and part sport utility. It seems like the people at Chrysler are having an awful lot of fun designing unique and specialized vehicles—and it's going to Europe. Americana, here we come!

Ford has also reached for some nostalgia with its concept for the rebirth of the Thunderbird. The prototype is reminiscent of the original 50s models, and it looks as good in metal as it does in print. Ford is planning to sell 20,000 of these per year, but frankly, I don't know why they can't sell twice that number. This car is going to put the "boom" back in Baby Boomers.

The American designers aren't the only ones who seem to have been rejuvenated. For example, the new Jaguar Type-S has all the styling cues that have made Jaguar famous, unique and highly identifiable. The Mercedes S Class used to be a big, blocky automobile, but I was impressed by its svelte new look. Even Volvo has broken out of its styling box with its S80 sedan. The Audi TT is a tightly styled coupe, and the Volkswagen Beetle, with its familiar design and cartoonish colors, is absolutely the cutest thing around. Although I didn't own one the first time around, I sure remember how they were all over the place.

The 1999 Chicago Auto Show has renewed my interest in current-model vehicles. The industry seems to be interested in serving more than just our transportation needs. This move toward niche marketing is going to make automobiles fun again. Perhaps I'll become an Auto Show regular again.



Sincerely,
Michael Goldstein, Publisher-in-Chief

THE AMERICAN DESIGNERS AREN'T THE ONLY ONES WHO SEEM TO HAVE BEEN REJUVENATED. FOR EXAMPLE, THE NEW JAGUAR TYPE-S HAS ALL THE STYLING CUES THAT HAVE MADE JAGUAR FAMOUS, UNIQUE AND HIGHLY IDENTIFIABLE. THE MERCEDES S CLASS USED TO BE A BIG, BLOCKY AUTOMOBILE, BUT I WAS IMPRESSED BY ITS SVELTE NEW LOOK.

New Name for the NASA Lewis Research Center

The place was built in 1941 as a research facility working on aircraft engine design. At that time, the governing authority was the National Advisory Committee for Aeronautics (NACA) and the facility was called the Aircraft Engine Research Laboratory. In 1947, the Cleveland, Ohio, facility was renamed the Flight Propulsion Research Laboratory to mark the expansion of its research activities into flight propulsion. A year later, in September, 1948, the facility was again renamed. This time it became the Lewis Flight Propulsion Laboratory in honor of George W. Lewis, the late director of aeronautical research for the NACA. When NACA was dissolved in 1958, the center was taken over by NASA and renamed the NASA Lewis Research Center. Now, forty-one years later, this historic laboratory has changed its name again. The Cleveland, Ohio facility is now the John H. Glenn Research Center at Lewis Field.

"We are honored that the center will now bear the name of two great men, John Glenn and George Lewis," says center director Donald Campbell. "The blending of names reflects the pioneering research in aerospace technology that employees have performed throughout the center's history, and will continue to perform in the future." Some of that pioneering research is directed toward questions of gear design and manufacture with both military and civilian applications.

"I cannot think of a better way to pay tribute to two of Ohio's famous names—one an aeronautical researcher and the other an astronaut legend and lawmaker—than by naming a NASA research center after them."

—NASA administrator Daniel S. Goldin.

There is a great deal of analytical and experimental gear research being conducted in the areas of gear tooth shape, geometry, material, thermal behavior, lubrication, noise and vibration, and manufacturing techniques. This work, which primarily addresses the needs of both the U.S. Army and NASA, emphasizes aeronautical applications such as helicopter transmissions, and is geared toward reducing weight, noise and vibration while maintaining high mechanical efficiency. Some of the research projects at Glenn include investigations into gear crack propagation, studies of gear dynamic forces, and face gear technology for aerospace power transmission.

The name change was the idea of U.S. Senator Mike DeWine (R-OH), who proposed it in the FY 1999 VA-HUD Appropriations Bill last October in recognition of Glenn's contributions to science, space and the State of Ohio.

Glenn was the first American to orbit the Earth, piloting his Mercury-Atlas 6 "Friendship 7" spacecraft through three orbits on February 20, 1962. Part of Glenn's training for that mission took place at Lewis in the Multiple Axis Space Test Inertia Facility (MASTIF), also known as the Gimbal Rig. This was used to teach astronauts how to bring a capsule, tumbling through space, under control. Thirty-six years later, on October 29, 1998, Glenn became the oldest astronaut in history when he returned to space as part of the crew of the space shuttle Discovery (STS-95). During the mission he participated in experiments on the effects of space flight and the aging process.

The designation of the historic site upon which the Center is built as Lewis Field celebrates the legacy of accomplishment and innovation left to us by George W. Lewis (1882-1948). Among a multitude of accomplishments in the fields of aviation and engineering, Lewis became the NACA's first executive officer in 1919. Five years later, in 1924, Lewis was named the NACA's director of aeronautical research, a post he held until 1947.

"I cannot think of a better way to pay tribute to two of Ohio's famous names—one an aeronautical researcher and the other an astronaut legend and lawmaker—than by naming a NASA research center after them," says Daniel S. Goldin, the NASA administrator who made the name change official.

Circle 251

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 circle the appropriate number on the Reader Service Card.

John Glenn in his space shuttle space suit.

Wormgear Predictions by Computer

Imagine sitting down at your PC and being able to predict the contact patterns and other details vital to the design and manufacture of wormgears quickly and easily. Dr. Michael Fish, formerly of the Department of Mechanical Engineering at Huddersfield University and now a research engineer with Holroyd, created such a program as an offshoot of his research into wormgear transmissions. Holroyd, a subsidiary of Renold PLC and one of the largest manufacturers of screw machined products and precision gearing, is now using Fish's software for analyzing wormgear contact.

Known design parameters and manufacturing settings are fed into the computer. The program then calculates the clearance between engaging tooth flanks and the positioning accuracy (or transmission error) resulting from the given specifications. The analysis can also include influences that will result from the manufacturing process as well as from how the set will be used in its application. Factors such as machining quality, alignment of components and deformation of the contacting surfaces under load can also be taken into account.

The software then generates accurate representations of the final off-load contact conditions that will be achieved using the given parameters. An exact contact-marking pattern illustrating this information can, therefore, be generated beforehand.

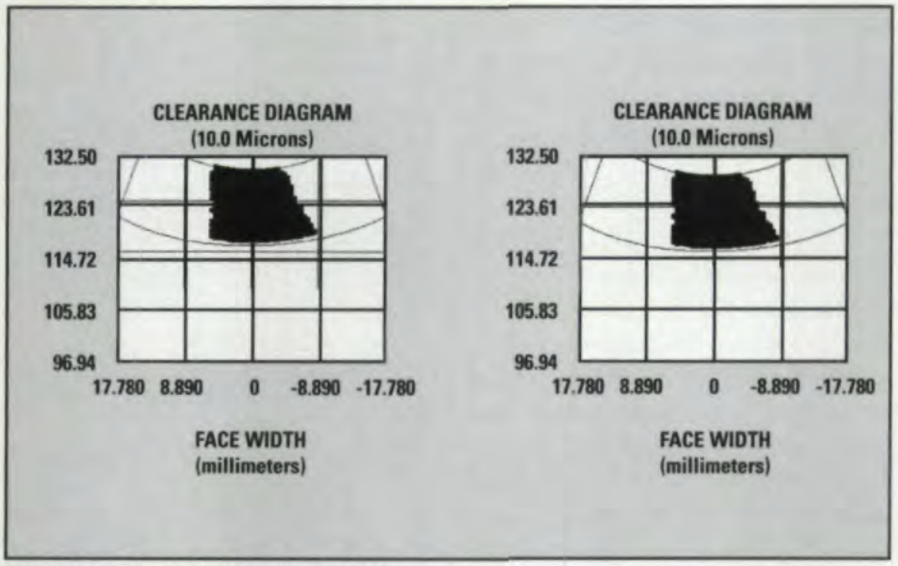


Figure 1 — Theoretical marking pattern.

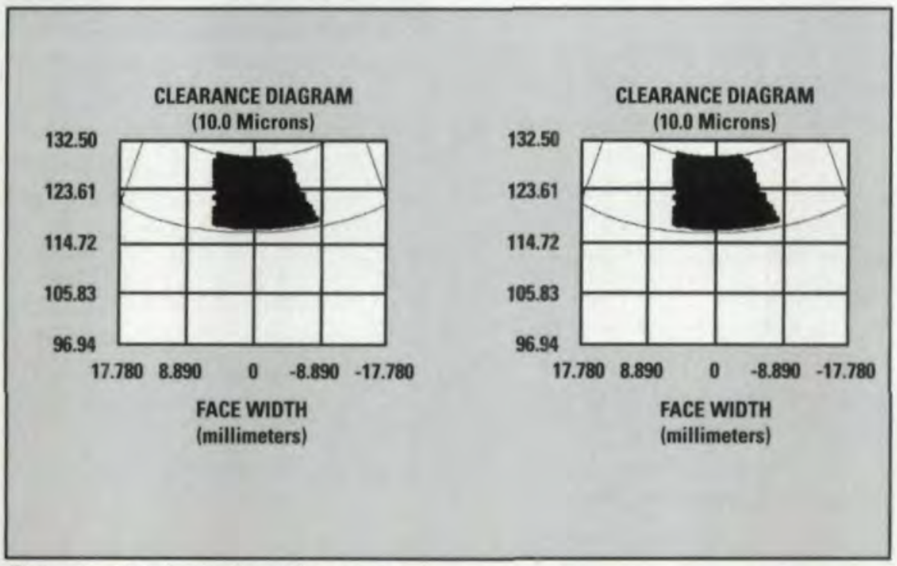


Figure 2 — Synthesized marking pattern.

"We have learned that the dynamic behavior of worms is not as unpredictable as was once believed," says Fish. "Provided that sufficient accurate data is known about the manufacturing process, it is possible to simulate contact to a high degree of accuracy. The new software is enabling Holroyd to identify critical factors in the design and manufacturing process and therefore impose closer controls on the quality of the final product."

This simulated contact pattern for a sample gear set is seen in Figures 1 and 2, which show the theoretical marking pattern for two gear designs and then the synthesized contact pattern generated by the computer, which includes error sources found during the manufacturing process defined as deviations from the theoretical conditions.

The new system enables the required contact conditions to be achieved more quickly than with existing iterative processes, which involve cutting then marking the worm and wheel set, followed by inspection and assessment. Used as an integral part of manufacturing and servicing processes, the software can allow the operator to:

- Give fast analysis of theoretical designs to find the optimum contact conditions.
- Compensate for the effects of manufacturing tolerances on theoretical contact.
- Assess the tolerance of a design to operating conditions.

According to Fish, "The software has the capability of simulating potential sources of variation in contact, which may occur in manufacturing or operation. Such sources include worm thread and wheel tooth surface generation, tooth pitch spacing, axis eccentricity, axis alignment, and component deformation. Adding these elements to theoretical contact conditions can significantly improve the accuracy of the synthesized contact predictions. This is a significant result, as the ability to accurately control quality and performance is critical in most modern customer specifications."

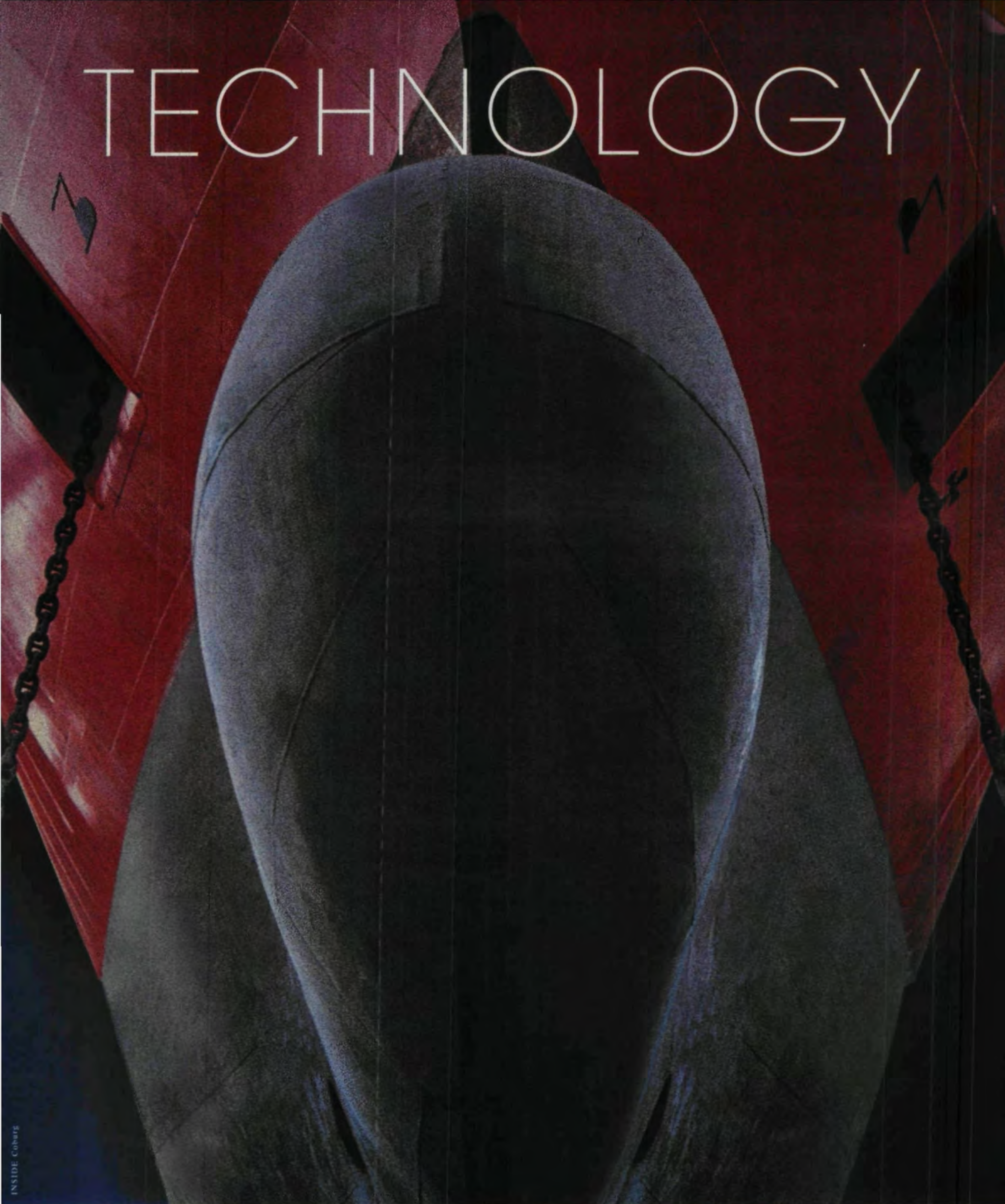
The software also has a troubleshooting role. It can model the changes in linear and angular shaft alignments, which happen during assembly, or which sometimes take the form of slight deflections under load in operating conditions. The gear set design can be modified to compensate for this effect as a result. This gives the option of investigating and removing sources of unacceptable operating errors in existing sets.

Holroyd believes that this new program has far reaching implications for the gear industry in that it represents a significant tool with which to quickly release the expertise held within the company. The operator can draw on existing working design and manufacturing knowledge, which recognizes criteria necessary for any intended application, and then apply this through the software to produce an optimum design.

When asked if Holroyd would be marketing this software, Fish said, "There are no plans to market the software, as it is essentially a tool to be used by a qualified worm gear designer. Output data can only be utilized through experience, and the knowledge of what represents a satisfactory result is still dependent upon the operator. Since there are so many factors that determine suitability, it is essential to keep the human element when entering design data."

Holroyd sees the development of this program, as well as its overall software development efforts, as essential parts of the company's drive toward higher quality products produced more efficiently and cost-effectively. According to Fish, "A better understanding of contact will enable maximum product suitability for any given application. Proven applied knowledge for customer benefit and reduced delivery times will consequently increase demand." ⚙

Tell Us What You Think . . .
If you found these Revolutions of interest and/or useful, please circle **200**.


TECHNOLOGY
INSIDE Coburg


BY NILES

Development of Gear Technology and Theory of Gearing

Ray Drago, P.E.

FAYDOR L. LITVIN

Dr. Faydor. L. Litvin is director of the Gear Research Laboratory at the University of Illinois at Chicago. His research interests include the theory of gearing, application methods for the generation of gear tooth surfaces, the computerized simulation of meshing and bearing contact, the generation and design of new types of gears, and the computer controlled generation of surfaces.

Dr. Litvin's current research emphasizes the computerized design, generation and simulation of meshing and contact of aligned and misaligned gear drives. The primary goal of this work is the localization and stabilization of bearing contact as well as the reduction of transmission errors.

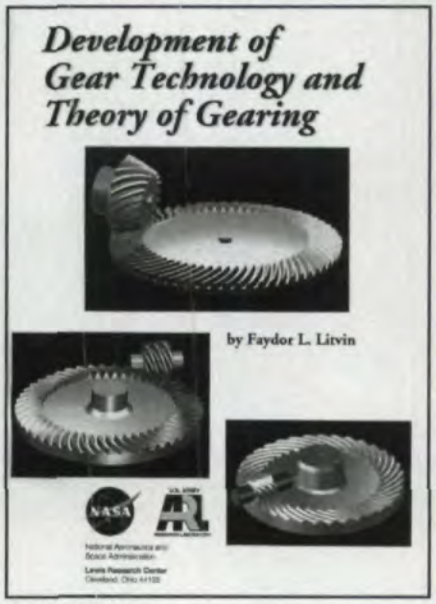
In a recent letter to *Gear Technology*, Dr. Litvin expressed his great appreciation for our review of his work. "The author is very gtrateful to the reviewers who have found time to read the book and introduce it to the readers of *Gear Technology*. The review is a keenly insightful piece that captures precisely what inspired the book's author to pay tribute to the Gear Pioneers.

"The author understands that due to the barrier caused by difficulties of the theory of gearing, differential geometry and kinematics, the audience for his book is limited. However, even difficult topics can be transferred to an engineering audience, if they are represented and discussed conceptually. Such a goal is the next one for the author, and he hopes to fulfill it in the near future."

EDITOR'S NOTE: *Gear Technology* is working with Dr. Litvin to develop an article that presents the theory of gearing from a conceptual standpoint. We hope to present the readers with a demonstration of some of the practical applications of the research in an upcoming issue.

I must admit that after thumbing through the pages of this relatively compact volume (113 pages, 8.5x11 format), I read its three chapters (theory of gearing, geometry and technology, and biographical history) from rear to front. It will become obvious later in this discussion why I encourage most gear engineers to adopt this same reading sequence!

While the main text (Chapters 1 and 2) provides an excellent summary of recent (and some not so recent) developments in gear tooth geometry and geometry modification, I found the last thirty pages (Chapter 3) most compelling. Here the author, through material gathered from first hand sources, presents an excellent biographical summary of the people, machines, and theories from all over the world that have influenced and, in many cases defined, the development of gear technology over the last 120 years.



Faydor L. Litvin,
NASA Reference Publication 1406,
Glenn Research Center, Cleveland OH 44135

As a gear engineer with more than a passing interest in the history of the subject, I found this treatment original in many aspects and thoroughly enjoyable to read. I found the author's own historical observations especially fascinating, some of which were, I would imagine, based on his own experience.

In one chilling example, the closure of the author's discussion of C. F. Ketov (a Russian professor of engineering who taught and wrote in the former Soviet Union during the early 1900s) reads "... as dean of the College of Mechanics and Machines, he was accused of resisting the policy of 'selection of personnel,' making his dismissal, if not his sudden death, inevitable. An ironic coincidence darkened the last day of his life when his request that a talented student be granted a position was declined because of the selection policy." After reading every word of the historical section, I found myself wishing for a more complete treatment, but one must recognize the space limitations of a book whose subject is gear technology and theory. Still, Chapter 3 puts the modern gear engineer's daily battles of budget, time, and research priorities in perspective. This section, alone, makes this book worth a read.

Chapter 1 begins with a review of basic principles of gear kinematics. Although highly mathematical in orientation, this section is well presented and interesting. While most practicing gear design engineers would seldom have the need for these fundamental underlying principles, they are valuable to both researchers and students. It is my belief, obviously shared by Dr. Litvin, that all gear engineers should be schooled in these basic principles to better understand the daily design tasks which form the bulk of their work. This presentation provides an excellent summary, which should be required reading for all aspiring, young gear engineers.

A detailed study of Chapter 1 certainly requires a thorough understanding of not only vectors but differential geometry as well. While the material is well presented, it will challenge all but the most mathematically oriented gear engineers. Still, this material can be very valuable and enlightening, even without a full understanding of the detailed mathematics involved. By following the general development of the equations, the interested reader can obtain a good appreciation for the nature of gear tooth contact and, more importantly, a better appreciation for the inherent complexity of gear mesh theory.

Chapter 2 is much more readable than Chapter 1. It is also of generally more interest and certainly more pertinence to the daily activities of most gear engineers. This treatment starts with a simple development of the theory of involute gearing and then moves rapidly to other gear tooth forms including face gears, cycloidal tooth forms, and worm gears.

The discussion of these various tooth forms also includes some detail related to the manufacturing methods and motions required to generate each. Unfortunately, a disproportionate amount of this detail is devoted to noninvolute forms, while needed emphasis on the various modifications frequently used for involute forms is treated somewhat superficially.

Overall, this volume has something to offer to most serious gear engineers. It has earned a place in my personal library of both current and historical gear literature. ○

The entire publication is available for free download at ftp://ftp-letrs.lerc.nasa.gov/LeTRS/reports/1997/RP-1406.pdf (Adobe Acrobat format).

Ray Drago
lives a dual life. He is a Senior Technical Fellow of the Boeing Company specializing in gear technology, and he is also Chief Engineer of Drive Systems Technology, Inc., a gear engineering consulting company which he founded in 1976.

Tell Us What You Think . . .
If you found this article of interest and/or useful, please circle **201**.

BIGGER AND BETTER THAN EVER

Still trying to decide whether to go to Gear Expo this year? Here's what you need to know so you won't end up singing the blues

Charles M. Cooper

Gear Expo 99, AGMA's biennial showcase for the gear industry, has left the Rust Belt this year and landed in Music City U.S.A., Nashville, Tennessee. The event, with exhibitors from around the globe showing off the latest in gear manufacturing as well as metalworking processes, will be held at the Nashville Convention Center, October 24–27, 1999. According to Kurt Medert, AGMA vice president and Gear Expo show manager, "In choosing Nashville, AGMA's Trade Show Advisory Council found a city that is an excellent trade show site. It has the right mix of convention center, nearby hotels, and a clean downtown area with entertainment readily available for the exhibitors and visitors alike. Nashville is in the heart of southern industry, which we see as a focus of growth for the gear industry and its customers."

This year's Gear Expo promises to be the biggest ever. "Gear Expo has grown dramatically since its inception in 1986 as a small tabletop exhibition," says Medert. "The diversity of products and services presented has now made this a must-see show for anyone in the gearing industry. We increase the space available for each show, but we can barely keep up with demand. This year we have the entire Nashville Convention Center and we're running out of room." With 45,000 square feet of exhibit space already earmarked for 145 exhibitors, Gear Expo 99 has already surpassed Gear Expo 97 in terms of exhibition space and is well on its way to becoming the largest Gear Expo ever. With several months to go and only 5,000 square feet of exhibit hall floor space available, show management is confident that

GEAR EXPO 99 SHOW BASICS

Who? Everyone involved or interested in gears and gear manufacturing.

What? AGMA's Gear Expo 99—Their biggest show yet.

Where? The Nashville Convention Center, Nashville, Tennessee.

When? October 24–27, 1999.

Why? To view the latest that the gear industry has to offer at the only international trade show dedicated to buying, specifying and manufacturing gears.

How? Contact AGMA at (703) 684-0211.

For more information about the show, visit ***The Gear Industry Home Page™*** at *www.geartechnology.com.* While you are there, come and take a look at *Show Central,* the world's first online 3D virtual metalworking show and *Gear Technology*'s electronic look at Gear Expo 99.

Inside the Nashville Convention Center. Courtesy of the Nashville Convention and Visitor's Bureau.

PLACES TO STAY

AGMA has blocked rooms at three hotels near the Nashville Convention Center for the convenience of Gear Expo registrants and exhibitors. When making your reservations, please use the phone and fax numbers listed here and mention the American Gear Manufacturers Association to receive the special AGMA rates. Please note that these rates do not include taxes. These hotels will be holding blocks of rooms and suites until September 19, 1999. After that, the AGMA room blocks and the special AGMA reduced rates in these hotels will no longer be available.

Renaissance Nashville Hotel

611 Commerce Street
Nashville, TN 37203
Telephone: (615) 255-8400 or (800) 327-6618
Fax: (615) 255-8163
Rates: Single = $139.00/Double = $149.00

The Renaissance Nashville Hotel is considered the headquarters hotel for the show and is structurally connected to the Nashville Convention Center, the site of Gear Expo 99 and all related seminars and official AGMA meetings. It has upscale amenities and is especially suited for exhibitors because of its proximity to the exposition hall. It has a total of 673 rooms, including 24 suites.

Doubletree Hotel Nashville

315 4th Avenue North
Nashville, TN 37219
Telephone: (615) 244-8200
Fax: (615) 747-4894
Rates: Single/Double = $119.00

The Doubletree Hotel Nashville is located three blocks from the Nashville Convention Center and two blocks from the popular and historic 2nd Avenue "Entertainment District." Recently renovated, the hotel features well-appointed guest rooms and amenities that include an indoor pool, business center, restaurant and lounge. It has a total of 337 rooms, including 10 suites.

Clubhouse Inn and Conference Center

920 Broadway
Nashville, TN 37203
Telephone: (615) 244-0150
Fax: (615) 244-0445
Rates: Single = $86.00/Double = $96.00

The Clubhouse Inn is located four blocks from the Nashville Convention Center. The hotel's restaurant offers a complimentary buffet breakfast to all guests, as well as full service lunch and dinner menus. It has a generous package of amenities that includes free parking and daily complimentary cocktails during the evening's Manager's Reception. It has 285 rooms, including 12 suites.

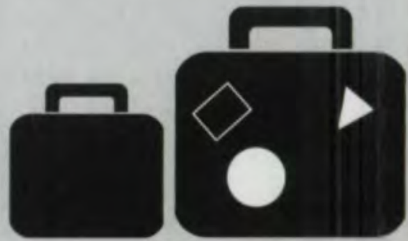


exhibit space will be sold out well in advance.

Helping to generate this growth is the expanded Gear Expo 99 promotion and advertising program, which is being conducted under the guidance of the AGMA Trade Show Advisory Council. The program specifically targets the customers of gear manufacturers, a very important segment of the total audience AGMA is hoping to draw, through direct mail and advertising in a mix of customer magazines. This special promotional activity, done in concert with the traditional direct mail and advertising placed in major industry periodicals, is designed to ensure reaching the largest audience possible for both exhibitors and visitors alike.

Increased attendance, corresponding with the increase in both exhibitors and promotional activity, is also expected for the 1999 show. Each Gear Expo has seen a steady rise in the number of visitors from all over the world. Gear Expo 97 saw 4,148 registered attendees, guests and ex-hibitors. This year that number is expected to top 4,500 and could possibly reach 4,800.

Don't imagine that product and service exhibits are all that Gear Expo 99 will offer. The show also boasts new educational opportunities for attendees. AGMA has joined forces with the Society of Manufacturing Engineers (SME) to hold three seminars dedicated to unique issues within the gear manufacturing and processing industry. The scheduled topics include "Heat Treat and Hardening of Gears," "Gear Metrology," and "Gear Processing and Manufacturing." The gear seminars will take place on October 25, 26 and 27 respectively and are expected to enhance the overall appeal of the show and attract a larger audience in light of the dual promotional efforts of AGMA and SME.

Continuing education for engineers isn't the only opportunity for learning taking place at Gear Expo 99. This year, AGMA's Education Council has developed a program for students that not only includes a video tape promoting careers in the gear industry for use in high schools and technical schools, but also involves Gear Expo 99. AGMA will invite local trade schools and high schools within a 50-mile radius of Nashville to bring groups of students to the show. They will be given group tours of the show hall led by the Education Council members—starting with cutting processes and ending with finishing processes—using the exhibitors' booths as demonstration modules. The tours will end at the AGMA Foundation booth where the students will view the 14-minute video on careers in the gear industry.

Exhibits of the latest and greatest the gear industry has to offer, continuing education seminars and a look at the gear industry for the next generation are all ready to go this October in Nashville. Are you? If not, contact AGMA at (703) 684-0211 for more information. ❍

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If you found this article interesting and/or useful, please **circle 202.**

July 19–22. Gleason Pfauter Hurth Basic Fundamentals. Loves Park, IL. This four-day program is designed for those new to gear making who are seeking a basic understanding of gear geometry, nomenclature, manufacturing and inspection. Also runs **August 16–19, September 20–23, October 11–14, November 15–18** and **December 6–9**. For more information call (815) 877-8900 or visit *www.pfauter.com*.

September 8–10. The Ohio State University Basic Gear Noise Seminar. Ohio State University, Columbus, OH. This seminar covers gear design to minimize transmission error, the fundamentals of noise generation and measurement, transmission dynamics, acoustics, and more. For more information contact Prof. Donald R. Houser at (614) 292-5860.

September 13–17. AGMA's Training School for Gear Manufacturing—Basic Course. Richard J. Daley College, Chicago, IL. This course is designed primarily for employees with at least six months of experience in setup or machine operation. The five-day course includes basic gearing, efficient machine tool setup techniques, accurate gear inspection and gearing calculation. Also runs **November 8–12**. For more information, contact AGMA at (703) 684-0211.

September 14–16. AGMA's Training School for Gear Manufacturing—Gear Inspection Course. Richard J. Daley College, Chicago, IL. The gear inspection and troubleshooting workshop is designed to cover analytical and functional inspection, setup, qualifying and operation of manual lead, involute and spacing checking machines. Students will also learn to troubleshoot lead and involute errors. For more information, contact AGMA at (703) 684-0211.

September 28–30. Wisconsin Manufacturing and Tool Expo (WMTE). Wisconsin State Fair Park, West Allis, WI. One of the five largest metalworking shows in the United States, WMTE will be of interest to companies that market metal cutting equipment, metal forming equipment, tooling and accessories, CAD/CAM, quality control and measurement equipment. There will also be free technical seminars and workshops. For more information contact Expo Productions at (414) 367-5500.

October 10–12. AGMA 83rd Annual Fall Technical Meeting. Denver, CO. The Fall Technical Meeting draws knowledgeable gearing professionals from all over the world to hear an international array of experts present the latest research and information on all aspects of gear manufacturing. For more information contact AGMA at (703) 684-0211. ○

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AGMA Elects New Board Chairman

Mr. Bipin Doshi

Bipin Doshi was elected chairman of the board of the American Gear Manufacturers Association at AGMA's 83rd Annual Meeting in Palm Springs, CA. Doshi will preside through March of the year 2000.

"As AGMA moves into the next century," commented Joe Franklin, CAE, president of AGMA, "we are fortunate to have Bipin Doshi as our chairman. Bipin is truly multidimensional—he owns a small business, yet his professional background was at a multinational; he's a general manager, but, by education, he's a scientist; he lives in the heartland of America, but he was born in India. Every constituency in AGMA has an advocate in Bipin—international members as well as those in North America; businessmen and engineers; small companies and large."

Doshi is president and CEO of Schafer Gear Works, Inc., located in South Bend, Indiana. Schafer Gear Works is a custom manufacturer of gear and machined components for the general industrial and automotive markets.

Gleason Names David Burns President and COO

The board of directors of Gleason Corporation (NYSE—GLE) has elected David J. Burns president and chief operating officer of the company. James S. Gleason will remain chairman and chief executive officer of the company.

Burns, 44, has been executive vice president of the corporation since 1995 and previously served as vice president of the Machine Products Group. According to Gleason, "Dave Burns is an invaluable member of our management team. He has more than 20 years of in-depth experience in all aspects of the company's operations and he understands the importance of all the company's key stakeholders including shareholders, customers, employees and suppliers. We are very proud to promote him to the position of president and COO, and look forward to his continued contributions to the company."

Burns is currently chairman of the board of trustees of the American Gear Manufacturers Association Foundation. He is also a member of the Government Relations Committee of the Association for Manufacturing Technology and a director of the West Irondequoit Foundation. He holds an MBA from the William E. Simon Graduate School of Business Administration at the University of Rochester and completed his undergraduate degree at St. John Fisher College.

The Gleason Works Achieves QS 9000-TE

The Gleason Works, a Rochester, NY, subsidiary of Gleason Corporation, has earned ISO 9001/QS 9000-TE supplement (tooling and equipment) registration. The Gleason Works is one of the first machinery suppliers to achieve the QS 9000-TE supplement registration.

The TE supplement to the QS-9000 standard is an automotive industry quality system standard designed specifically for manufacturers of machine tooling and equipment and their non-production materials. The standard was designed to provide for continuous improvement for automotive suppliers, emphasizing defect prevention and the reduction of variation. TE was developed by the Big Three U.S. automakers and was just approved in the fall of 1998. To date, only DaimlerChrysler has required that their suppliers be certified with the TE supplement by the year 2000.

The Gleason Works began work on implementing the QS 9000-TE quality system in March 1998. All of the other major operating units of Gleason Corporation are currently ISO 9001 certified and are working toward upgrading to the QS 9000-TE over the next 12–18 months.

1999 Machine Tool Consumption Levels Off

February U.S. machine tool consumption totaled an estimated $341 million, according to the Association for Manufacturing Technology (AMT) and the American Machine Tool Distributors' Association (AMTDA). This was down 2% compared to the revised estimate of $348 million for January, and down 51% compared to the estimated $696 million total for February 1998. With the year-to-date total computed at $688.6 million, 1999 is down 48% compared to 1998. These statistics are computed from reports submitted by companies participating in the United States Machine Tool Consumption (USMTC) report. "January and February orders are down, which is consistent with what forecasters had projected for the beginning of 1999," said Don Carlson, AMT president. "The market appears to be strengthening in line with the second half forecast as demonstrated by the WESTEC show in Los Angeles."

Boeing and Derlan To Make Split-Torque Transmission

The Boeing Company and Derlan Aerospace of Canada have announced an agreement to jointly develop a "split-torque" face gear transmission for the Boeing-manufactured AH-64D Apache Longbow helicopter.

The face gears will be manufactured by Derlan using a patented continuous grinding process that has been developed by Boeing over the last several years. The resulting transmission is expected to weigh less and be capable of transferring more horsepower than the current designs. Initial testing of the transmissions is scheduled to begin within three years.

Goodfellow Resigns from Gleason Corporation

David Goodfellow has resigned his position as president and CEO of Gleason Pfauter Hurth Cutting Tools, formerly Pfauter Maag Cutting Tools. Goodfellow has also resigned his position as senior vice president of Gleason Pfauter Hurth Worldwide Sales. No further details were available at the time of publication. ○

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Vectors in Gear Design

Clifford M. Denny

Terms

- D_j journal diameter
- F force vector
- M module
- m tooth loading force displacement
- R moment arm vector
- r_f journal friction radius
- ε efficiency
- μ coefficient of friction
- ϕ_n normal profile angle
- ϕ_o operating pressure angle
- ω angular velocity

Appendix

This article presupposes a knowledge of vector equations. An appendix will be posted at *www.geartechnology.com/vectors.htm.* This appendix contains a more basic introduction to the equations used in this article with explanations of their origins and supporting figures.

Introduction

Friction weighs heavily on loads that the supporting journals of gear trains must withstand. Not only does mesh friction, especially in worm gear drives, affect journal loading, but also the friction within the journal reflects back on the loads required of the mesh itself.

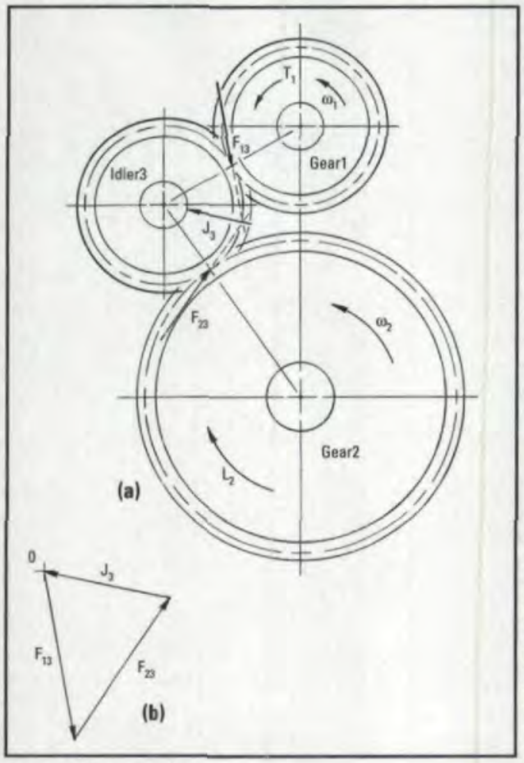

Fig. 1 – Idler to the left.

Several simple problems using principles of elementary mechanics that illustrate these concerns are provided. These examples present the designer with analytic and graphical methods that focus on problems that could arise in a design. The designer can then work around and eliminate such problems before they are magnified many times in reality.

Two- and three-dimensional problems are included. These involve spur, helical, and worm gears.

Two-Dimensional Problems

These problems can be solved with vectors alone in the same way that one may draw using a CAD program or drawing board. Most simply, this can be illustrated in the frictionless case:

Problem 1

***Idler placement*[2].** Depending on the direction of power flow, Figure 1 shows Gear 1 driving Gear 2 through Idler 3. Gear 1 rotates in the positive direction (anti-clockwise). The torque T_1 that drives Gear 1 is also positive (anti-clockwise). The equilibrating load torque L_2 restraining Gear 2 will be negative (clockwise).

Tooth loading vectors will lie on the individual lines of action of the specific meshes involved. Considering the idler in Figure 1a, its journal reaction force passes through the journal's center and the point of intersection of the two tooth-loading forces acting on this idler. The magnitudes of tooth loading forces are known from the gear geometries and applied torque. As the idler is in equilibrium, the three forces acting upon it must add vectorially to zero, as shown in the force vector diagram in Figure 1b. J3's magnitude is thereby found. J3 is the journal load on Idler 3; F13 is the tooth load of Gear 1 on Idler 3; F23 is the tooth load of Gear 2 on Idler 3.

Figure 2a shows Idler 4 in mesh on the opposite side of the gear train. Following the same procedures just discussed, the direction of Idler 4's journal load P4 is found. Vector addition determines its magnitude shown in Figure 2b.

For the conditions of this example, it is apparent that the location of Idler 3 is decidedly superior.

Problem 2

Idler with Friction. Figure 3a is a 2:1 reduction drive through an idler. The driver and idler

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have 20 teeth each. The driven gear has 40. These are module 1.0, 20° pressure angle gears. They operate on standard centers. The idler's journal is 6 mm in diameter. Friction in both the mesh and the pivot are considered, and the idler's own throughput efficiency is found. The coefficient of friction μ is 0.4. The displacements m, due to mesh friction, of the resultant driving forces are[2]:

$$m = [\pi M \cos(\phi_n) / (2 \cos(\phi_o))]\, \mu$$

$$m = [\pi M / 2]\, \mu = [\pi \cdot 1.0 / 2] \cdot 0.4 = 0.63 \text{ mm}$$

The displacement m is along the line of centers <u>into</u> the driven gear from the pitch point. The journal friction radius r_f is[1]:

$$r_f = (D_j / 2) \sin[\operatorname{atan} \mu]$$

$$r_f = 3 \cdot \sin[\operatorname{atan} 0.4] = 1.1 \text{ mm}$$

The resultant vector of the mesh forces lies tangent to the friction circle on the side that opposes motion.

Here, the force vector of Gear 1 on Idler 3 is known in both magnitude (*applied torque is known—here it's 1.0*) and direction (*gear train geometry is known*). As friction is included, only the placement and direction of the restraining force of Gear 2 on Idler 3 is known here. Idler 3's rotation determines the placement of the journal loading vector; the intersection of the two tooth loading vectors determines its direction.

Of these three vectors, only one is known in both magnitude and direction; the other two are known only in their direction. This is enough to find their magnitudes vectorially as shown in Figure 3b.

The journal force's direction depends on the friction considered. Direction 'a' is for no friction, 'b' is for journal friction alone, 'c' is for mesh friction alone, and 'd' is for both. For each journal force direction, a different idler's output force magnitude is found.

Friction then reduces the magnitude of the idler's output force below that of the input force driving it. The idler's throughput efficiency is 100 times the ratio of these two forces.

The efficiency $\varepsilon = (F_{23} / F_{13}) \cdot 100$.

The table below shows the effect of friction in its various combinations on the throughput efficiency of this idler. μ_m is the coefficient of sliding friction in the tooth mesh; μ_j is that of the journal.

Case	μ_m	μ_j	ε
a	0.0	0.0	100
b	0.0	0.4	91
c	0.4	0.0	87
d	0.4	0.4	79

Problem 3

Speed increasing and decreasing drives. In figure 4, the small gear has 18 teeth; the larger

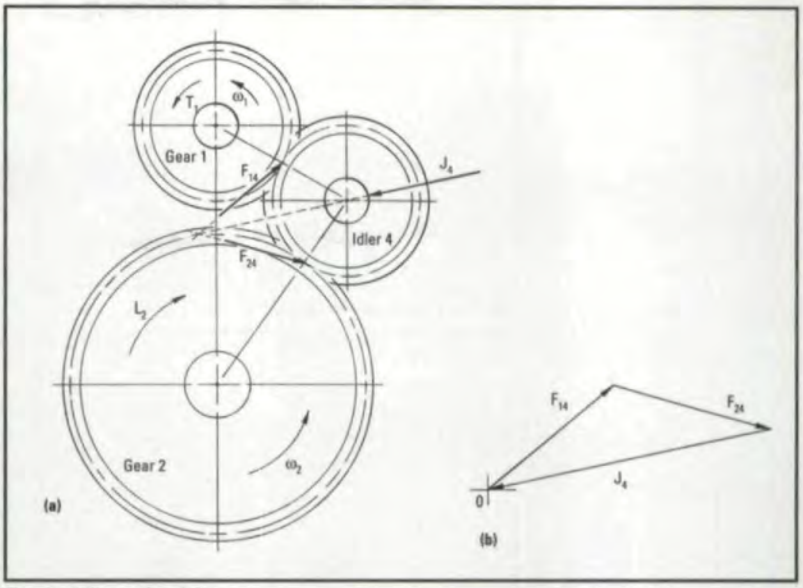

Fig. 2 – Idler to the right.

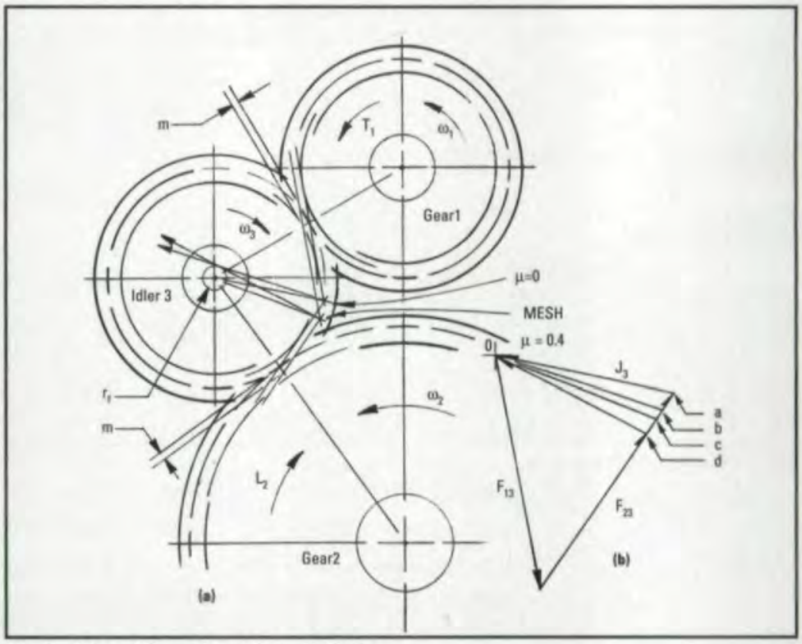

Fig. 3 – Idler with mesh and journal friction.

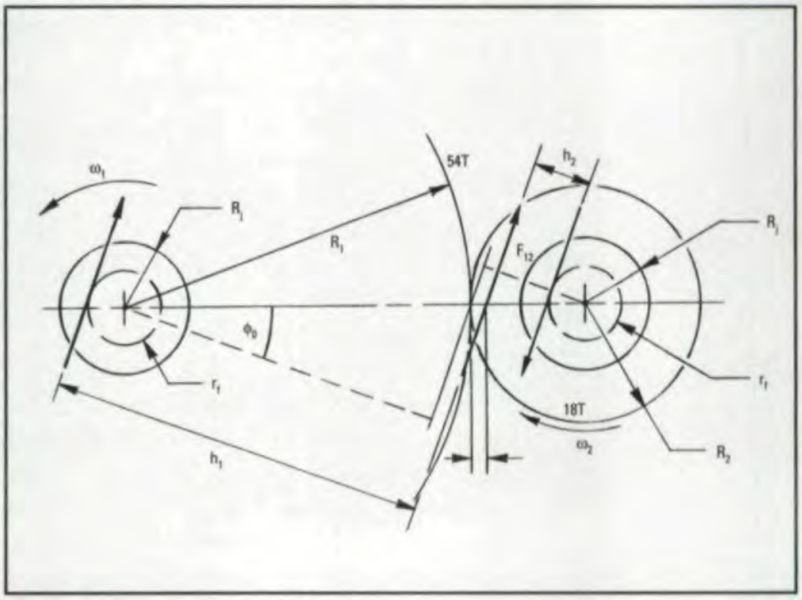

Fig. 4 – Speed increasing drive.

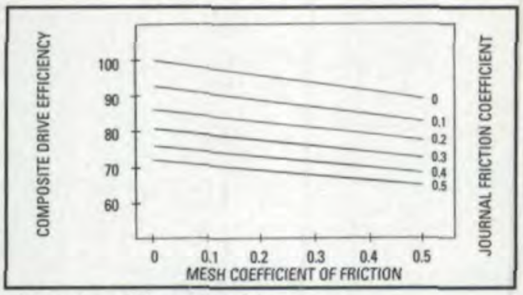

Fig. 5 – Speed decreasing drive.

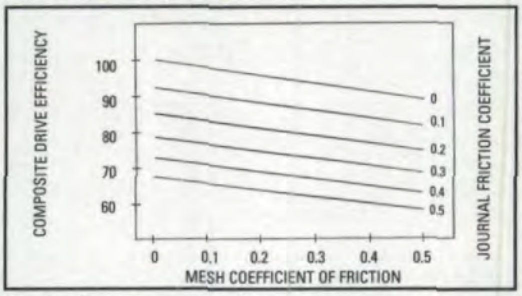

Fig. 6 – Speed increasing drive.

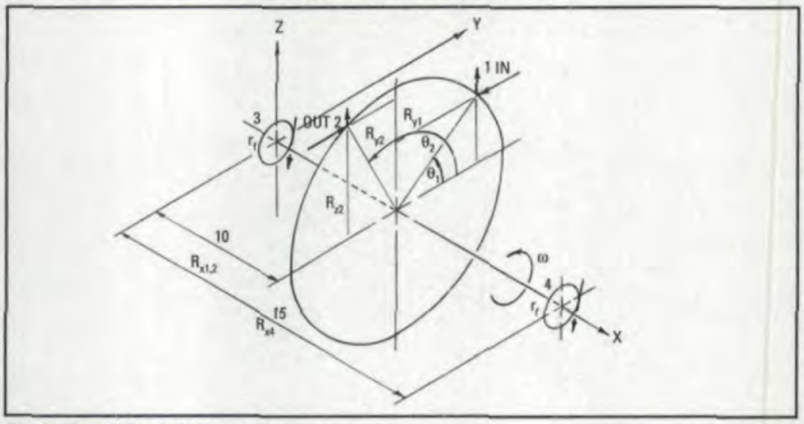

Fig. 7 – Spur idler with journals.

one has 54. These are 1.0 module, 20° pressure angle gears operating on standard centers. To simplify matters for illustrative purposes, both the motivating source and the load are pure torque. Therefore all vector directions will be parallel to the line of action in the mesh.

Both journal diameters are 10 mm. For Gear 1 driving Gear 2,

$$h_1 = (R_1 + m)\cos\phi_o + r_{f1}$$
$$h_2 = (R_2 - m)\cos\phi_o - r_{f2}$$

The efficiency equation becomes:

$$\varepsilon = [(h_2 R_1)/(h_1 R_2)] \cdot 100.$$

For Gear 2 driving Gear 1,

$$h_1 = (R_1 - m)\cos\phi_o - r_{f1}$$
$$h_2 = (R_2 + m)\cos\phi_o + r_{f2}$$

The efficiency equation becomes:

$$\varepsilon = [(h_1 R_2)/(h_2 R_1)] \cdot 100.$$

Figures 5 and 6 show that the speed decreasing drive has greater efficiency than the speed increasing drive. Full ranges of friction coefficients are shown from 0 to 0.5. Journal friction here just happens to have a more severe effect on the efficiency than does the mesh friction. This is not true in all cases.

Three-Dimensional Problems

Equilibrium conditions are observed in three dimensions just as they were in two dimensions. Simply stated, the summation of moments is zero, and the summation of forces is zero. In solutions to these problems, all moments and all forces are resolved into their orthogonal 'x', 'y' and 'z' components and handled mathematically.

The appendix[4] shows the use of 3x3 determinants to find the vector components of moment or torque[3]. Also, the equations for the vector components of force are given. These all could have been used in the solution of the two-dimensional problems as well.

Problem 4

Spur Idler on a Shaft. Figure 7 shows an idler gear integral to a shaft supported by two bearings. The operating pitch circle radius is 30 mm. The operating pressure angle is 20°. The input pitch point p_1 is at 35° from the positive x-y plane. The output pitch point p_2 is at 115° from this x-y plane. The gear's pitch points are at x = 10 mm. Bearing B_3 is at x = 0 mm; bearing B_4 is at x = 15 mm. The input torque is + 400 Nmm.

Spur gear sets have no x components of force here. Using the equations set forth in the appendix,

$F_{y1} = -\{400/[(30-m)\cos 20°]\}\sin(35°+20°) = -11.62$

$F_{z1} = \{400/[(30-m)\cos 20°]\}\cos(35°+20°) = +8.14$

The sign of m here is negative, as this is the point of power input. The sign of m would be positive at points of power output. As mesh friction is ignored in the example, m = 0.

Input point:

$R_{x1} = 10\text{mm}$
$R_{y1} = (30-m)\cos 35° = 24.57\text{mm}$
$R_{z1} = (30-m)\sin 35° = 17.21\text{mm}$

Output point:

$R_{x2} = 10\text{mm}$
$R_{y2} = (30+m)\cos 115° = -12.68\text{mm}$
$R_{z2} = (30+m)\sin 115° = 27.19\text{mm}$

Using 3x3 determinants, the resultant torques from forces at the various points are:

$$\begin{vmatrix} i & j & k \\ 10.0 & 24.57 & 17.21 \\ 0.0 & -11.62 & 8.14 \end{vmatrix} = T_1$$

$$\begin{vmatrix} i & j & k \\ 10.0 & -12.68 & 27.19 \\ 0.0 & F_{y2} & F_{z2} \end{vmatrix} = T_2$$

$$\begin{vmatrix} i & j & k \\ 0.0 & 0.0 & 0.0 \\ 0.0 & F_{y3} & F_{z3} \end{vmatrix} = T_3$$

$$\begin{vmatrix} i & j & k \\ 15.0 & 0.0 & 0.0 \\ 0.0 & F_{y4} & F_{z4} \end{vmatrix} = T_4$$

Solve the determinants:

i	j	k
400	–81.38	–116.23
$-12.68F_{z2} - 27.19F_{y2}$	$-10\,F_{z2}$	$10\,F_{y2}$
0	0	0
0	$-15\,F_{z4}$	$15\,F_{y4}$

Sum the components:

$$\text{i:}\quad 400 \quad -27.19\,F_{y2} \quad -12.68\,F_{z2} = 0$$
$$\text{j:}\quad -81.38 \quad -10\,F_{z2} \quad -15\,F_{z4} = 0$$
$$\text{k:}\quad -116.23 \quad +10\,F_{y2} \quad +15\,F_{y4} = 0$$

Also, F_{y2} and F_{z2} are related by virtue of their position at 115°. Furthermore, as this is the output point on the gear, these forces produce a net negative torque to counteract the driving positive 400-Nmm torque. Hence, the 20° pressure angle here takes on the negative sign.

$$F_{y2}\cos[115-20°] + F_{z2}\sin[115°-20°] = 0$$
$$-0.087\,F_{y2} + 0.996F_{z2} = 0$$

Furthermore, the summation of forces in the several directions are zero:

$$-11.62 + F_{y2} + F_{y3} + F_{y4} = 0$$
$$8.14 + F_{z2} + F_{z3} + F_{z4} = 0$$

The final simultaneous equation matrix becomes:

$$\begin{vmatrix} 27.19 & 12.68 & 0 & 0 & 0 & 0 \\ 0 & 10 & 0 & 0 & 0 & 15 \\ 10 & 0 & 0 & 0 & 15 & 0 \\ -0.087 & 0.996 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \end{vmatrix} \begin{vmatrix} F_{y2} \\ F_{z2} \\ F_{y3} \\ F_{z3} \\ F_{y4} \\ F_{Z4} \end{vmatrix} = \begin{vmatrix} 400 \\ -81.38 \\ 116.23 \\ 0 \\ 11.62 \\ -8.14 \end{vmatrix}$$

The resultant forces then become:

$F_{y2} = 14.14$ N $\quad F_{z2} = 1.23$ N

$F_{y3} = -0.84$ N $\quad F_{z3} = -3.13$ N $\quad F_3 = 3.24$ N

$F_{y4} = -1.67$ N $\quad F_{z4} = -6.25$ N $\quad F_4 = 6.47$ N

Problem 5

Spur Idler on a Shaft with Journal Friction Alone. If the journal diameters are 12 mm, and if the coefficient of friction is 0.4, the bearing friction radius is $r_f = 6.0 \sin(\text{atan } 0.4) = 2.22$ mm. Refer to Figure 7.

Now, there will be y and z components of the bearing moment arms to include. These are related to the bearing load components as $|R_y F_y| = |R_z F_z|$.

The frictional moment arm directions in the journals depend on the shaft rotational direction and directions of the journals' load components as follows:

$$\text{sign}(R_z) = \text{sign}(\omega) \bullet \text{sign}(F_x)$$
$$\text{sign}(R_y) = -\text{sign}(\omega) \bullet \text{sign}(F_z)$$

The resultant torques from forces at the various points now may be written:

$$\begin{vmatrix} i & j & k \\ 10.0 & 24.57 & 17.21 \\ 0.0 & -11.62 & 8.14 \end{vmatrix} = T_1$$

$$\begin{vmatrix} i & j & k \\ 10.0 & -12.68 & 27.19 \\ 0.0 & F_{y2} & F_{z2} \end{vmatrix} = T_2$$

$$\begin{vmatrix} i & j & k \\ 0.0 & R_{y3} & R_{z3} \\ 0.0 & F_{y3} & F_{z3} \end{vmatrix} = T_3$$

$$\begin{vmatrix} i & j & k \\ 15.0 & R_{y4} & R_{z4} \\ 0.0 & F_{y4} & F_{z4} \end{vmatrix} = T_4$$

Sum the component torques:

i	j	k
400	–81.38	–116.23
$-12.68F_{z2} - 27.19F_{y2}$	$-10\,F_{z2}$	$10\,F_{y2}$
$R_{y3}F_{z3} - R_{z3}F_{y3}$	0	0
$R_{y4}F_{z4} - R_{z4}F_{y4}$	$-15\,F_{z4}$	$15\,F_{y4}$

The simultaneous equation matrix becomes:

$$\begin{vmatrix} 27.19 & 12.68 & R_{z3} & -R_{y3} & R_{z4} & -R_{y4} \\ 0 & 10 & 0 & 0 & 0 & 15 \\ 10 & 0 & 0 & 0 & 15 & 0 \\ -0.087 & 0.996 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \end{vmatrix} \begin{vmatrix} F_{y2} \\ F_{z2} \\ F_{y3} \\ F_{z3} \\ F_{y4} \\ F_{z4} \end{vmatrix} = \begin{vmatrix} 400 \\ -81.38 \\ 116.23 \\ 0 \\ 11.62 \\ -8.14 \end{vmatrix}$$

Solve by iteration:

1. Set the R values to zero, and solve for the F's.
2. Based on the F values, solve for the R's according the following equations and include in the second iteration. Continue until the R and F values converge.

The signs of the bearing reaction force components and the direction of rotation determine those of the friction radius as previously explained. Subsequent equations for these latter components accommodate their signs and magnitudes.

$$R_{y3}^2 + R_{z3}^2 = r_f^2$$
$$R_{y4}^2 + R_{z4}^2 = r_f^2$$
$$R_{y3} = -(|\omega F_{z3}|/\omega F_{z3})\, r_f \sqrt{[F_{z3}^2/(F_{y3}^2 + F_{z3}^2)]}$$
$$R_{z3} = +(|\omega F_{y3}|/\omega F_{y3})\, r_f \sqrt{[F_{y3}^2/(F_{y3}^2 + F_{z3}^2)]}$$
$$R_{y4} = -(|\omega F_{z4}|/\omega F_{z4})\, r_f \sqrt{[F_{z4}^2/(F_{y4}^2 + F_{z4}^2)]}$$
$$R_{z4} = +(|\omega F_{y4}|/\omega F_{y4})\, r_f \sqrt{[F_{y4}^2/(F_{y4}^2 + F_{z4}^2)]}$$

The resultant force and moment arm component magnitudes converge on the 4th iteration and become:

$F_{y2} = 13.39$ N $\quad F_{z2} = 1.17$ N $\quad T_{out} = -379$ Nmm

$F_{y3} = -0.59$ N $\quad F_{z3} = -3.10$ N $\quad F_3 = 3.16$ N

$F_{y4} = -1.18$ N $\quad F_{z4} = -6.21$ N $\quad F_4 = 6.32$ N

$R_{y3} = 2.18$ mm $\quad R_{z3} = -0.42$ mm $\quad r_f = 2.22$ mm

$R_{y4} = 2.18$ mm $\quad R_{z4} = -0.41$ mm $\quad r_f = 2.22$ mm

The ratio of output to input torque is 379/400 = 0.95. Journal friction alone reduced the efficiency of this idler to 95%. With mesh friction, it would be lower.

Problem 6

Helical Idler on a Shaft. Figure 8 shows the gear's orientation. Input point p_1 is 35° from the positive x-y plane; output point p_2 is 205° from this plane. The gears each have 20° operating pressure angles, and 25° left hand operating helix angles. The operating pitch radius of the input gear is 60 mm; that of the output gear is 20 mm. The input torque is 500 Nmm. Journal and mesh friction are ignored here for simplicity. Friction journal radii r_f and mesh force vector displacements m are zero.

$F_{x1} = +(500/60)\tan 25° = 3.886$ N

$F_{y1} = -[500/(60\cos 20°)][\sin(35°+20°)] = -7.264$ N

$F_{z1} = +[500/(60\cos 20°)][\cos(35°+20°)] = 5.087$ N

Also,

$F_{x2}\sin(205° - 20°) + F_{y2}\cos(20°)\tan(25°) = 0$

$F_{z2}\sin(205° - 20°) + F_{y2}\cos(205° - 20°) = 0$

So,

$$F_{x2} - 5.028\,F_{y2} = 0$$
$$F_{z2} + 11.430\,F_{y2} = 0$$

The moment arms are:

$R_{x1} = 20.0$ $\quad R_{y1} = 49.149$ $\quad R_{z1} = 34.415$

$R_{x2} = 30.0$ $\quad R_{y2} = -18.126$ $\quad R_{z2} = -8.452$

$R_{x3} = 0.0$ $\quad R_{y3} = 0.0$ $\quad R_{z3} = 0.0$

$R_{x4} = 40.0$ $\quad R_{y4} = 0.0$ $\quad R_{z4} = 0.0$

The torque determinants become:

$$\begin{vmatrix} i & j & k \\ 20.0 & 49.15 & 34.42 \\ 3.89 & -7.26 & 5.09 \end{vmatrix} = T_1$$

$$\begin{vmatrix} i & j & k \\ 30.0 & -18.13 & -8.45 \\ F_{x2} & F_{y2} & F_{z2} \end{vmatrix} = T_2$$

$$\begin{vmatrix} i & j & k \\ 0.0 & 0.0 & 0.0 \\ F_{x3} & F_{y3} & F_{z3} \end{vmatrix} = T_3$$

$$\begin{vmatrix} i & j & k \\ 40.0 & 0.0 & 0.0 \\ F_{x4} & F_{y4} & F_{z4} \end{vmatrix} = T_4$$

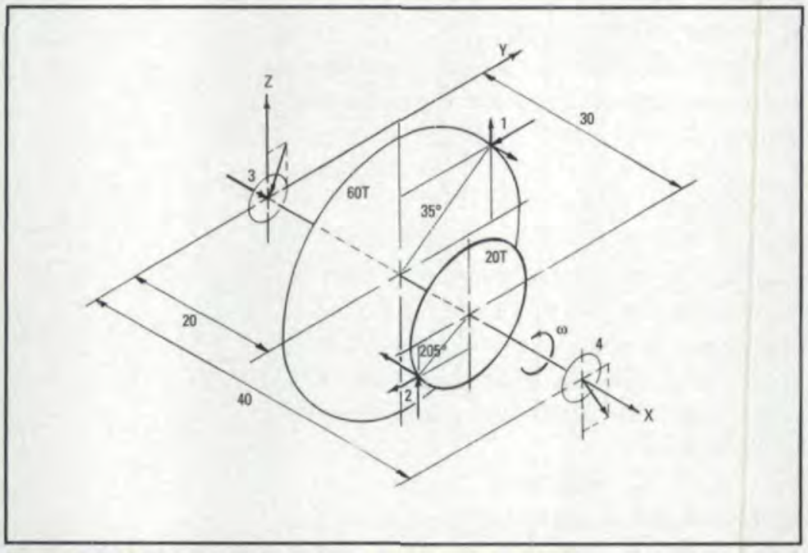

Fig. 8 – Helical idler on a shaft.

The final simultaneous equation matrix becomes:

$$\begin{vmatrix} 0 & -8.452 & 18.126 & 0 & 0 & 0 & 0 & 0 \\ 8.452 & 0 & 30 & 0 & 0 & 0 & 0 & 40 \\ 18.126 & 30 & 0 & 0 & 0 & 0 & 40 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 11.430 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & -5.028 & 0 & 0 & 0 & 0 & 0 & 0 \end{vmatrix} \begin{vmatrix} F_{x2} \\ F_{y2} \\ F_{z2} \\ F_{x3} \\ F_{y3} \\ F_{z3} \\ F_{y4} \\ F_{z4} \end{vmatrix} = \begin{vmatrix} 500 \\ 32 \\ 336.27 \\ -3.886 \\ 7.264 \\ -5.087 \\ 0 \\ 0 \end{vmatrix}$$

The forces become:

$F_{x2} = -11.66$ N $\quad F_{y2} = -2.32$ N $\quad F_{z2} = 26.50$ N

$F_{x3} = 7.77$ N $\quad F_{y3} = -5.85$ N $\quad F_{z3} = -14.98$N

$F_{yz3} = 16.077$ N $\quad F_{x4} = 0$ N $\quad F_{y4} = 15.43$ N

$F_{z4} = -16.62$ N $\quad F_{yz4} = 22.673$ N

Problem 7

Worm Gear Drive. Figure 9 shows a worm and gear arrangement. Only the worm's cross-sliding tooth friction will be included in the mesh, as it has a large effect in reducing the efficiency of such drives. The resultant tooth mesh force will pass through the single point of contact between the two pitch cylinders. The driven worm wheel, supporting the journals and thrust bearings with their frictional losses, is the only object under consideration here. The wheel's driven load is pure torque in this example.

The worm lead angle is 10°, which is also the operating helix angle of the gear in this 90° drive. The worm has one tooth (one start) and is left handed. The gear pitch is one module with 64 teeth at a pressure angle of 20°. Therefore, the gear's pitch radius is 32.4936 mm; the worm's pitch cylinder radius is 2.879 mm. The torque transmitted to the gear after losses is 500 Nmm. (The worm's input torque will be greater, but is outside this problem's concern.)

Were friction zero, F_N would be 16.628 N, and its components would be:

$F_x = 2.713$ N $\quad F_y = -15.388$ N $\quad F_z = -5.687$ N

The following mesh forces on the gear for input torque = 500 Nmm are derived with $\mu = 0.4$.

The normal tooth load: $F_N = 17.977$ N

The sliding friction load: $\mathcal{F} = 7.191$ N

$\mathcal{F}$ is perpendicular to F_N and parallel to the x-y plane. Components of both $\mathcal{F}$ and F_N combine to produce the net resultant force acting through the pitch point of the mesh. Its components are:

$$F_x = 10.015 \text{ N}$$
$$F_y = -15.388 \text{ N}$$
$$F_z = -6.149 \text{ N}$$

The journals are 12 mm on each side of the gear's pitch circle, and 12 mm in diameter. Journal friction is $\mu = 0.4$. There is a thrust frictional loss acting on a radius $R_t = 9$ mm. The journal friction radii $r_f = 2.228$ mm.

The torque determinants become:

$$\begin{vmatrix} i & j & k \\ 0.0 & 0.0 & 32.494 \\ 10.015 & -15.388 & -6.149 \end{vmatrix} = T_1$$

$$\begin{vmatrix} i & j & k \\ 0.0 & -0.5 & 0.0 \\ 0.0 & 0.0 & F_{za2} \end{vmatrix} = T_{2a}$$

$$\begin{vmatrix} i & j & k \\ 0.0 & 0.5 & 0.0 \\ 0.0 & 0.0 & F_{zb2} \end{vmatrix} = T_{2b}$$

$$\begin{vmatrix} i & j & k \\ -12.00 & R_{y3} & R_{z3} \\ 0.0 & F_{y3} & F_{z3} \end{vmatrix} = T_3$$

$$\begin{vmatrix} i & j & k \\ 12.00 & R_{y4} & R_{z4} \\ 0.0 & F_{y4} & F_{z4} \end{vmatrix} = T_4$$

$$\begin{vmatrix} i & j & k \\ 0.0 & -0.5 & 0.0 \\ 0.0 & 0.0 & F_{za5} \end{vmatrix} = T_{5a}$$

$$\begin{vmatrix} i & j & k \\ 0.0 & 0.5 & 0.0 \\ 0.0 & 0.0 & F_{zb5} \end{vmatrix} = T_{5b}$$

The final simultaneous matrix equilibrium equation becomes:

$$\begin{vmatrix} 0.5 & -0.5 & R_{z3} & -R_{y3} & R_{z4} & -R_{y4} & 0.5 & -0.5 & 0 \\ 0 & 0 & 0 & -12 & 0 & 12 & 0 & 0 & 0 \\ 0 & 0 & 12 & 0 & -12 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & \mu R_t \end{vmatrix} \begin{vmatrix} F_{z2a} \\ F_{z2b} \\ F_{y3} \\ F_{z3} \\ F_{y4} \\ F_{z4} \\ F_{z5a} \\ F_{z5b} \\ F_{x6} \end{vmatrix} = \begin{vmatrix} 500 \\ 325.427 \\ 0 \\ 10.015 \\ 15.388 \\ 6.149 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The magnitudes and directions of the journal frictional moment arm components are:

$$R_{y3} = -\left(|\omega F_{z3}| / \omega F_{z3}\right) r_f \sqrt{[F_{z3}^2 / (F_{y3}^2 + F_{z3}^2)]}$$

$$R_{z3} = +\left(|\omega F_{y3}| / \omega F_{y3}\right) r_f \sqrt{[F_{y3}^2 / (F_{y3}^2 + F_{z3}^2)]}$$

$$R_{y4} = -\left(|\omega F_{z4}| / \omega F_{z4}\right) r_f \sqrt{[F_{z4}^2 / (F_{y4}^2 + F_{z4}^2)]}$$

$$R_{z4} = +\left(|\omega F_{y4}| / \omega F_{y4}\right) r_f \sqrt{[F_{y4}^2 / (F_{y4}^2 + F_{z4}^2)]}$$

These insure that the respective journal loading vectors are tangent to the journals' friction circles on the side that inhibits motion.

As the driven load is pure torque here, and since the thrust frictional load is treated as a pure torque, these were treated as couples in the free body. Frictional loads here do not alter the components of the journal loading, so no iteration is required.

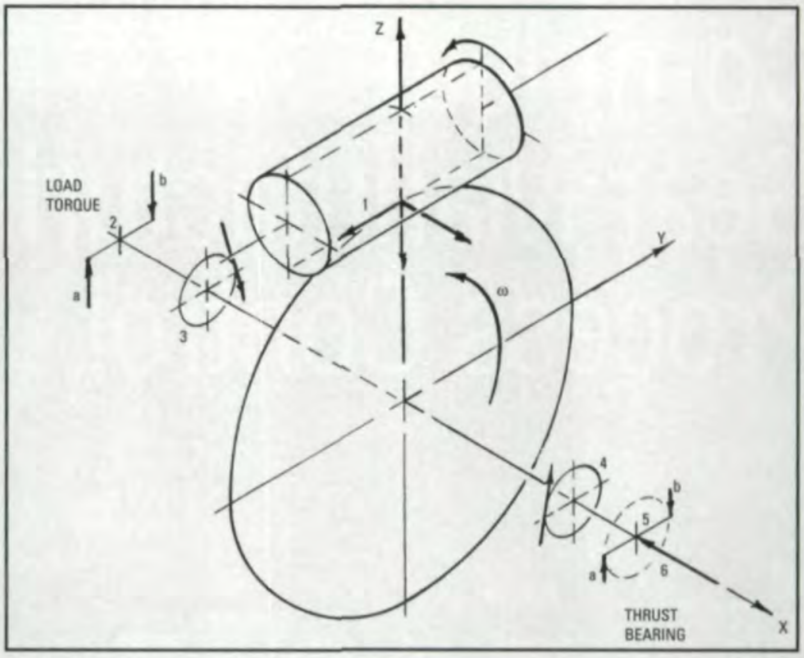

Fig. 9 – Worm gear drive with friction.

Given 500 Nmm torque input to the gear, the journal loading forces with tooth and journal friction are:

$F_{y3} = 7.7$ N $\quad F_{z3} = -10.5$ N $\quad F_3 = 13.0$ N

$F_{y4} = 7.7$ N $\quad F_{z4} = 16.6$ N $\quad F_4 = 18.3$ N

Output torque delivered and bearing losses under various conditions follow:

Results for no friction:

$$T_{out} = -500 \text{ N mm}$$
$$T_{thrust} = 0 \text{ N mm}$$
$$T_{journal} = 0 \text{ N mm}$$

Results for mesh and thrust friction only:

$$T_{out} = -464 \text{ N mm}$$
$$T_{thrust} = -36 \text{ N mm}$$
$$T_{journal} = 0 \text{ N mm}$$

Results for mesh, thrust and journal friction:

$$T_{out} = -394 \text{ N mm}$$
$$T_{thrust} = -36 \text{ N mm}$$
$$T_{journal} = -70 \text{ N mm}$$

References

1. Holowenko, A. R. *Dynamics of Machinery*, Wiley, 1955.
2. Holowenko, A. R. class notes, ME566, Purdue University, 1960.
3. Shigley, J. E. *Kinematic Analysis of Mechanisms*, McGraw Hill College Div., June, 1969.
4. Visit *www.geartechnology.com/vectors.htm* to see the Appendix.

This article is based on materials that were presented at the SAE Plastic Gears for Power Applications TOPTEC held August 26–27, 1998 Dayton, OH.

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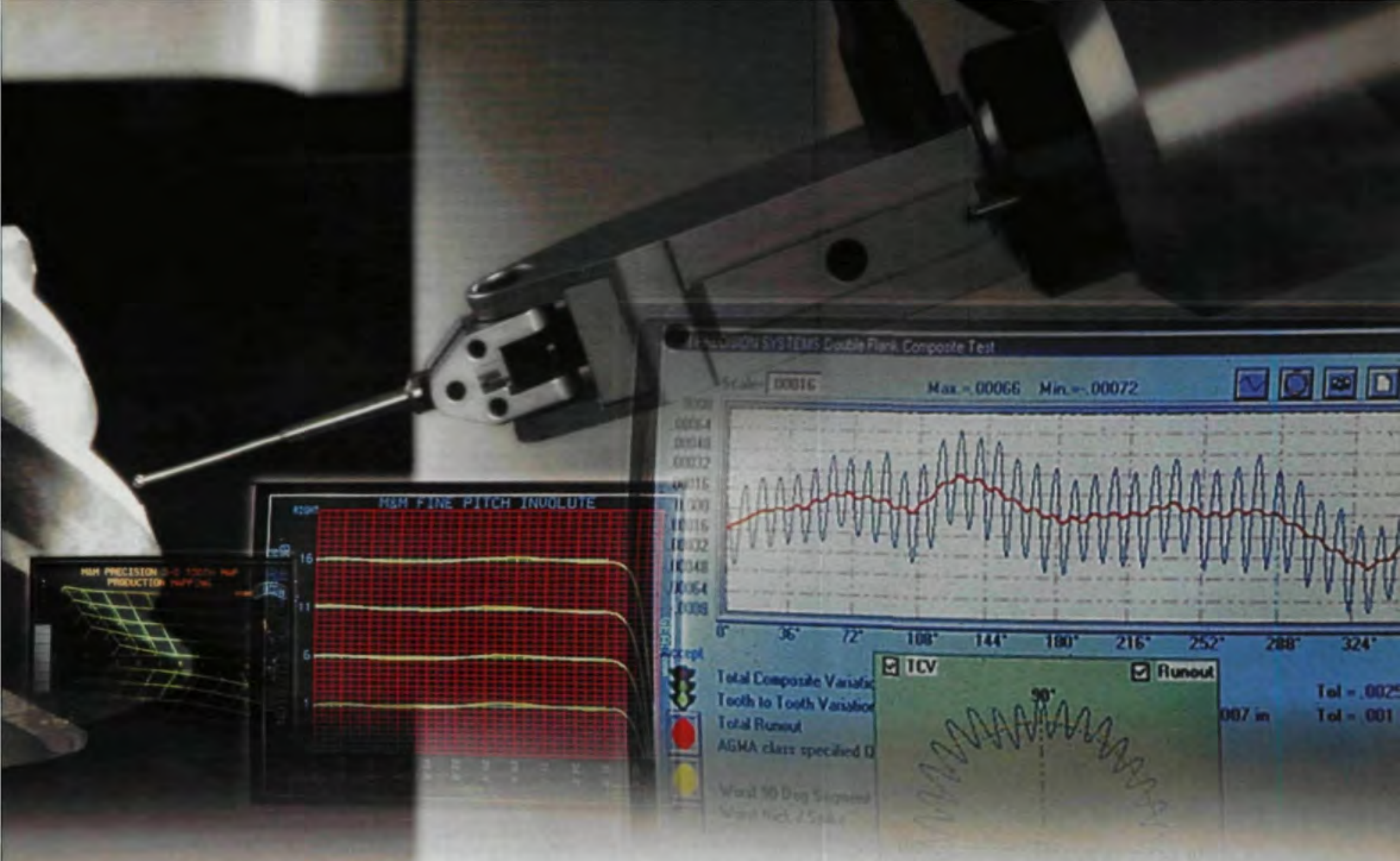

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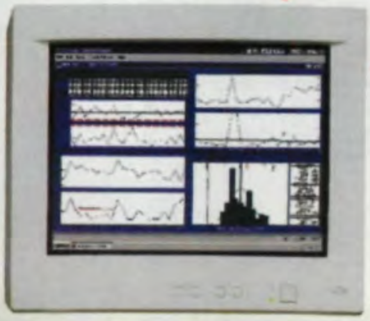

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Myths and Miracles of Gear Coatings

William R. Stott

Three years ago, coated gears seemed to be the perfect solution for the Micro Marine Corporation. The early designs for the gear drive of their MicroCAT human-powered boat used a combination of thin-film dry gear coatings with lubrication and wear-resistance properties. These coatings simplified their design, provided corrosion resistance, made the gear drive environmentally safe and eliminated the need for gear drive lubrication and maintenance. It was a success story in the making.

However, the MicroCAT of today doesn't use coated gears. Instead, the gear drive employs stainless steel gears and a semifluid grease lubricant."It's not that the coating didn't work," says Micro Marine president Bill Hulbig. The company had found that relatively small amounts of water seeping past the seals of the underwater drive were causing corrosion in the bearings. By using stainless steel gears and filling the gear case with grease, they were able to avoid the problem.

Micro Marine's story isn't exactly one of gear coatings failure, but it isn't exactly one of resounding success either.

An Industry of Contradictions

The preponderance of evidence suggests that gear coatings work. But even when they do work, as in the case of Micro Marine, companies don't always continue to use them. Also, coatings have been used for decades on gears in a wide variety of applications, yet there are no standards or specifications written specifically for gear coatings. Nearly every coatings manufacturer or vendor claims to have gear customers, yet few manufacturers of geared products are willing to talk about their use of coatings. The automotive industry has spent huge amounts of time, money and effort researching and developing coatings for their transmissions, and they seem to work, yet few transmissions have ever used coatings in production. The subject of coatings for gears seems to be filled with contradictions, and the lack of available information complicates the issue for the average gear designer.

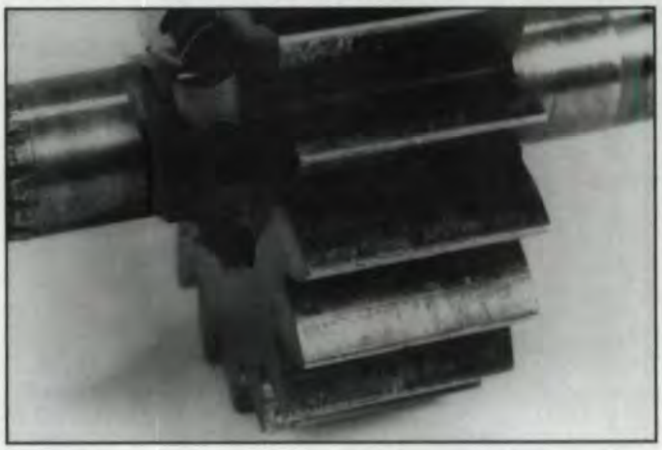
If They Work, Why Not Use Them?

Gear coatings have been available for decades. They offer lubricity, hardness, corrosion protection or some combination of these properties (see the accompanying article, "Types of Coatings for Gears"). Coated gears have been used and proven in a variety of niche and specialty applications, and they have been written into military, federal and contractor standards for many different types of products as well.

However, there seems to be an industry-wide prejudice against the use of coatings. To the average gear designer or manufacturer, most examples of gear coatings are academic. They may be used in aerospace applications, says the voice of conventional wisdom, but not mine.

"Coatings are typically viewed as a failure mode waiting to happen," says Joseph Rogers, product and business development manager for Diamonex Performance Products, a maker of diamond-like carbon coatings. "Few gear manufacturers want this

Gears coated with Hi-T-Lube® by General Magnaplate Corp.



Spur gear treated with Hi-T-Lube® by General Magnaplate Corp.

as their first choice for improving gears."

If coatings are improperly applied, or if the wrong coating is selected for a given application, the gearbox will definitely have problems, says Richard Hickey, president of Microfin, providers of thin-film coatings and platings. "With gears, if the coating starts to flake, pieces will break off, and you'll tear the living bejeezus out of the gears," he says.

In addition to this reluctance among designers to introduce another possible failure mode, there is also a general lack of information available to gear designers about coatings. In fact, in spite of the long history of the use of coatings for gear applications, the American Gear Manufacturers Association has no written standards or publications that address the issue, and no committee is currently considering the topic, according to AGMA technical vice president William A. Bradley III.

This lack of information may be the biggest reason why more gears aren't coated. "If there isn't information available, what do you do?" says Hickey. "There isn't a resource that's readily available for designers regarding gear coatings."

Successful coatings stories are hard to come by. One big reason is that most manufacturers are unwilling to talk about the coatings they use because they don't want their competitors to know how they achieve their performance levels. One good example is Richard Mellentine, the gear transmission manager for a major North Carolina auto racing team, who has been using a Balzers tungsten carbide coating on racing gears. "It's such a hard coating that it extends the life of the gear greatly," Mellentine says. "It keeps polishing the gear, and there's no wear." Mellentine asked that his team name not be mentioned, because he doesn't want other racing teams to know about this advantage.

Other companies are unwilling to let their competitors and customers know that they're using coatings at all, because it might suggest that the product has been having pitting or wear problems, says Balzers marketing director Frederick Teeters.

Another big issue is the cost consideration. Many times, the improvements gained by coatings aren't

The Diamond Black process is able to handle large volumes of automotive gears.

NOTICE

The article "Specifying Custom Gears" in the May/June 1999 issue of *Gear Technology* contained a number of errors. We apologize to the co-author, Mr. C. Kent Reece, and our readers for the inconvenience.

We recommend that you avoid using the formulas in the article, because of accidental errors including the inadvertent switching of some metric and English symbols. Please consult a qualified gear engineer and/or the appropriate standards for any questions regarding gear design or specification.

Gear Technology is committed to providing you with the best possible technical information on gears, and we're increasing our efforts to have technical material reviewed by qualified personnel. This includes our panel of technical editors, who didn't have the opportunity to review "Specifying Custom Gears" before it was published. You can count on finding in our pages the highest possible quality and credibility in technical articles.

Michael Goldstein, Publisher & Editor-in-Chief
William R. Stott, Managing Editor
Charles M. Cooper, Senior Editor

worth the additional expense to a manufacturer. Sometimes, improvements in a gear can be achieved in other ways, such as by grinding or peening, which may be easier or cheaper to implement.

Why So Much Interest?

Even though it's hard to get solid information about coatings, there remains a tremendous interest among gear manufacturers.

Robert Zajac is supervisor of the development lab at Peerless Winsmith, one of the leading worm gear drive manufacturers. "If somebody came in and presented a coating that looked interesting, we wouldn't hesitate to look at it," Zajac says.

In fact, Peerless Winsmith has experimented with coatings on their steel worms on at least a couple of occasions. They tried a titanium nitride coating but never had any success with it. "For some reason, it turned out to be abrasive," Zajac says. They've also tried a vendor-supplied coating. "It didn't hurt us, but it didn't help us either," Zajac says.

Despite the lack of success so far, Zajac says the company would be interested in trying coatings again. "We'd like to find something that works," he says. "Because worm gears tend to run hot, we're always trying to reduce friction and increase efficiency."

The biggest reason for gear manufacturers' interest may be the ability of coatings to increase the power density of existing gear drives. Some of these coatings are twice as hard as steel, and most offer a lower coefficient of friction. Manufacturers of geared products are always faced with demands for more power in less space. Continually producing new models to meet higher torque demands and longer life requirements can be expensive. For an operation on the scale of a major auto manufacturer, retooling for a completely redesigned transmission might cost hundreds of millions of dollars, according to some estimates.

Gary Doll is a former staff scientist at the physics department of the General Motors Research Center. "The holy grail out there is coming up with some sort of coating, or a systematic design of coating and product, to effectively improve power density," says Doll.

Chasing the Holy Grail

Although Doll is now a senior research specialist with the material science department of Timken Research, and although he now spends most of his time working with the power density of bearings, he may know as much as anyone about the development and use of hard coatings for automotive gear applications.

In 1993, Doll and his associates at GM authored a paper on the use of boron carbide (B_4C) coatings on sun gears and pinions (Ref. 1). In the paper, they stated that the coatings "greatly reduce wear and increase the life of the transmission several times."

Since that initial research, both General Motors and Ford Motor Co. have had production models of transmissions coated with boron carbide by Diamond Black Technologies, Inc. of Conover, NC. According to company president Gene Robinson, Diamond Black has coated more than a million transmission gears for the major auto makers, and

TYPES OF COATINGS FOR GEARS

Coatings for gears can be either very inexpensive or cost-prohibitive. Their uses range from cosmetic to doubling the life of a gear set. They include technologies that are just emerging as well as some that are more than 50 years old. Some are very precise, while others are useful for only the lowest-precision, lightest-load gearing. The following breakdown should help sort out some of the options available for steel gears.

Black Oxide. A conversion coating formed by a chemical reaction with the iron in ferrous alloys to form magnetite (Fe_3O_4). The finish is usually sealed with rust preventatives or oil post-treatment and may require follow-up maintenance to keep the surface oiled. Black oxiding alone does little more than enhance the aesthetic appeal of the part, and often requires combination with other processes or coatings to provide any real corrosion protection, says Richard Hickey, president of Microfin Corporation.

Boron Carbide (B_4C). A very hard, amorphous ceramic material applied using the PVD process of magnetron sputtering. The Diamond Black version has been used in production models of automotive transmissions by Ford and General Motors. It continues to be an area of intense research and development for gears. See main article for more information.

Conversion Coatings. See Black Oxide, Electroless Nickel and Phosphate Coating.

Diamondlike Carbon (DLC). An amorphous form of carbon with diamond-like bonds. This material has much promise as a gear coating and has been the subject of intense research among automotive and other manufacturers. Multi-Arc, Inc. and Diamonex are two suppliers working with gear manufactures. Applied using CVD or PVD processes. See main article for more information.

Electroless Nickel. A chemical process that takes place in an aqueous solution without electric current. Plating rate and thickness are uniform, so application to gear teeth will not change dimensions. Offers corrosion protection, wear resistance, lubricity and appearance benefits. Many formulations exist for different wear or lubricity requirements. Special additives, such as diamond particles, PTFE or light-emitting substances, can provide additional benefits, says Michael Feldstein, president of Surface Technology, Inc. of Trenton, NJ. See the article "Composite Electroless Nickel Coatings for the Gear Industry" in the January/February 1997 issue of *Gear Technology* for more information.

Electroplating. A metallic coating is applied by electrodeposition. Most plating materials and processes are not suitable for most gear teeth, as they generally alter the dimensions of the gears. Because of this, electroplating is typically reserved to coating the gear blank before teeth are cut. Chrome and nickel plating are common for corrosion protection. Some aerospace applications use gold, silver, lead or other heavy metal platings to prevent galling.

Molybdenum Disulfide. This substance has become the workhorse of dry-film lubrication for gears. It combines a low coefficient of friction with high load carrying capacity, and it works well in a vacuum. For lower precision gears, it can be used in powder form or applied using techniques such as spraying or dipping, followed by curing in an oven. It can also be applied by PVD sputtering, which allows much tighter tolerances and thinner films.

Phosphate Coating. Similar to black oxiding, phosphate coating is essentially the controlled corrosion of a part. A mildly acidic solution removes metal from the part and produces tiny reservoirs that improve the adhesion of dry-film lubricants or oil.

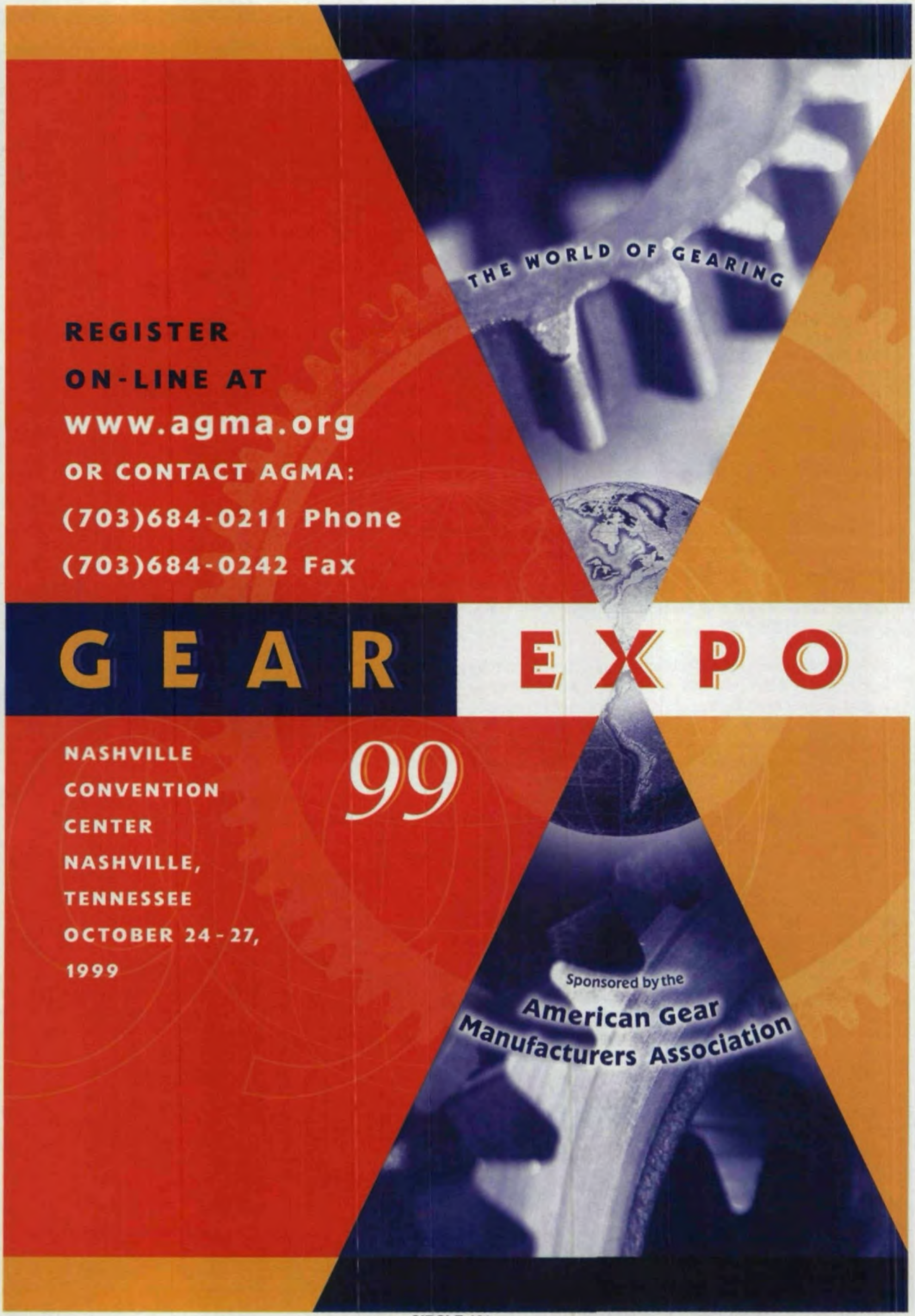
Polymer Coatings. One of the best examples of polymer coatings is polytetrafluoroethylene, or PTFE, which is marketed under a variety of trade names, the most familiar being DuPont's Teflon®. PTFE provides tremendous lubricity and chemical resistance. Although DuPont doesn't recommend Teflon® for use on gears because of its low wear resistance, some manufacturers have experimented with it. PTFE and other polymers are often used as additives in other coatings.

Proprietary Coatings. Many companies specializing in coatings offer special formulations of products to combine lubrication, wear, and other characteristics depending on the application. Microfin's Microlube® and Lubralloy® coatings and General Magnaplate's Hi-T-Lube® are some examples.

Thin-Film Lubricants. Many formulas exist, including a variety of proprietary coatings and application methods. Most are applied by spraying, dipping or painting, followed by curing in an oven. Depending on the material and the process, curing temperatures may not be suitable for all substrates. See also Molybdenum Disulfide.

Tungsten Carbide (WC/C). One of the most promising areas of research for automotive transmission manufacturers. This PVD sputtered coating has been used successfully on a number of production gear applications under the Balzers Balinit® C trade name.

Gears from a racing motorcycle removed after an oil leak occurred during a race. The WC/C coated gear (on the left) shows very little wear, while the uncoated gears show severe adhesive wear. Courtesy of Balzers.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they currently coat gears for the GM-manufactured transmissions of the Volvo S80 Turbo and the BMW Diesel Turbo.

The Diamond Black coating is essentially the same material written about by Doll and associates in 1993. It is boron carbide applied through the physical vapor deposition (PVD) process known as "magnetron sputtering," in which single atoms are liberated from a bulk target of boron carbide and impinged on a substrate to form a coating with a thickness of about 2–3 microns. The coating has a theoretical hardness of 95 Rc with added properties of lubricity and toughness, says Robinson. Perhaps most importantly, the magnetron sputtering process takes place at less than 250° F, which means that the substrate material is not metallurgically altered by the application of the coating.

Even though Diamond Black's boron carbide is the best example of a coating that has been successfully used on an automotive production basis, several other materials have been successfully tested.

One promising area of research looks into the use of diamond-like carbon coatings (DLCs), which are applied using low-temperature chemical vapor or ion beam (PVD) deposition. The coating is a hard (Vickers 1000-3000), low-friction coating of an amorphous form of carbon with diamond bonds. Like Diamond Black's process, DLC deposition temperatures are low enough not to affect most gear steels.

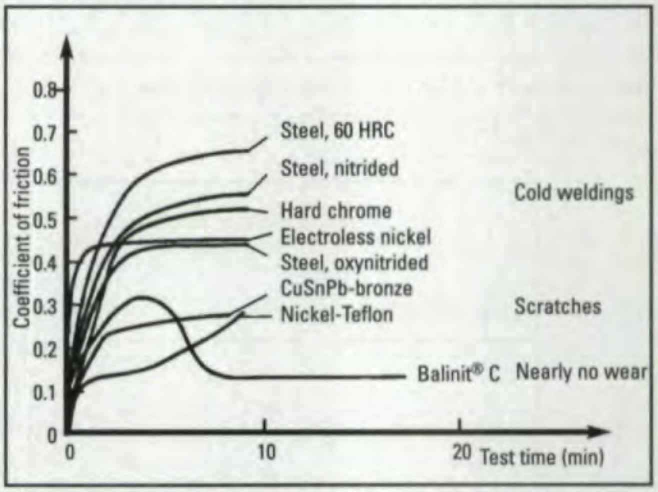
Diamonex Performance Products is one of the companies working in this area, and they are involved in tests with a variety of automotive components, including gears, says DLC product manager Joseph Rogers. Diamonex recently signed an agreement with a major automotive supplier of fuel injection components to supply vacuum DLC coatings on a production basis, Rogers says. Although no one has yet committed to using DLC coatings on transmission gears, proving the technology on other parts may be an important first step, Rogers says.

Multi-Arc, Inc. also has been working with automotive manufacturers to develop amorphous DLC coatings for transmission gears, says marketing director Mark Pellman. The coating definitely works, Pellman says, but that doesn't necessarily make it the right solution. "Even though this technique solves the problem, there are cheaper ways to increase power density, including peening," Pellman says. However, he doesn't rule out future possibilities, as the cost of producing these coatings will drop as the technology improves. In fact, for some applications, the process is already being used by Multi-Arc on a production basis. One example is a chemical pump application, which uses precision gears coated with DLC, Pellman says.

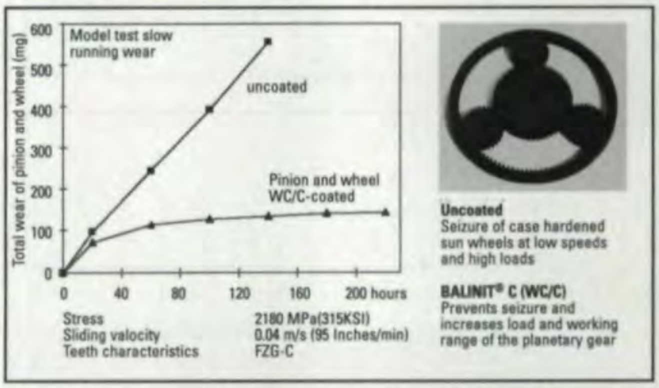
The other big contender for automotive transmission gear coating is an amorphous tungsten carbide (WC/C) such as the Balinit® C coating provided by Balzers. This coating is applied using a PVD ion bombardment technique similar to that used to apply the DLC and Diamond Black coatings.

Balzers has used its Balinit C coating on spur gears for

Examples of gears coated with Hi-T-Lube® by General Magnaplate Corp.



Dry running properties of materials, including the Balinit® C (WC/C) coating from Balzers.

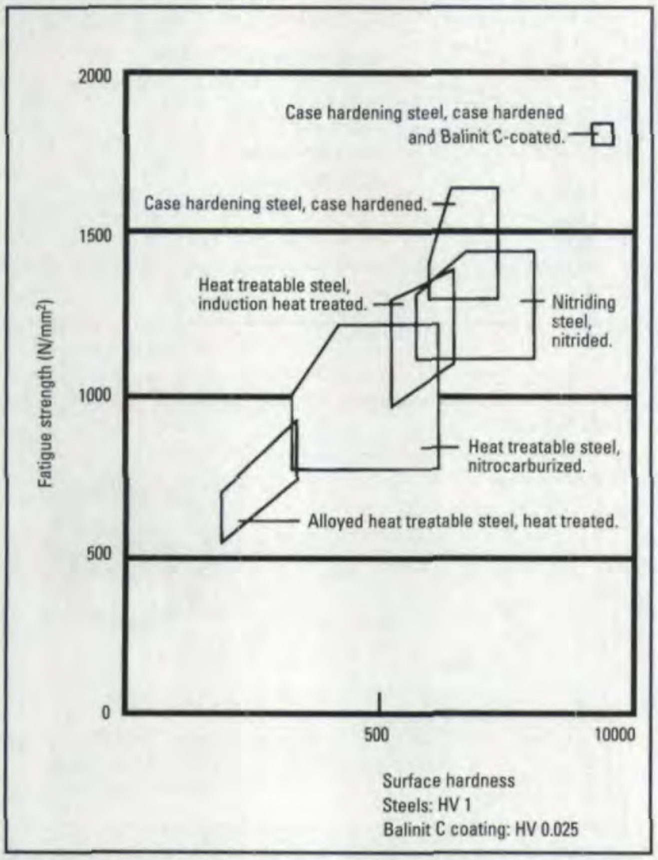


The Balinit® C coating from Balzers has been used to prevent seizure and increase the load and working range of the planetary gear set used in a concrete mixer.

racing motorcycles, highly loaded planetary gears for concrete mixers and precision worm gears, among other applications, and they are aggressively pursuing all gear markets, including the automotive market, says marketing director Frederick Teeters.

The general consensus is that all of these coatings can provide significant benefits for automotive transmission gears. "These coatings work," says Doll. "In some cases, they work rather spectacularly."

Gears coated with Hi-T-Lube® by General Magnaplate Corp.



Relative pitting fatigue strength and hardness of steels with different heat treatments. Note the Balinit® C (WC/C) coating in the upper right corner.

But this doesn't mean that we'll see coated gears on every auto transmission any time soon. "It's probably never going to be high volume," Doll says. "I don't think the industry is ready to put a coating on every gear. I don't see it happening."

Pushing the Envelope

Dr. Dong Zhu, principal engineer and program manager with Eaton Corporation, has been investigating the possibilities of using coatings on medium- and heavy-duty truck transmissions for the past five years. The task is more daunting than that of the consumer automobile manufacturers, because the typical truck transmission faces much higher life and load requirements, Zhu says.

"We've tested virtually every available coating from all manufacturers on both test rigs and actual transmissions," Zhu says. "I have to say that so far our success is quite limited."

According to Zhu, there are still some technical problems to be resolved. "As you know, gears are very similar to hobs in geometry. However, the materials are completely different. When we deposit a PVD coating on the heat treated, very rough and dirty surface of a cheap, carbon steel gear, we have a lot more problems than they have when coating hobs."

Zhu says that Eaton is working in collaboration with the coatings manufacturers and major university research labs on issues such as part cleaning, coating adhesion, coating uniformity and quality consistency. They'll have to overcome these problems before we see any real production examples of coated gears in truck transmissions.

However, Zhu is optimistic that these coatings will be used in the near future. "I think we understand the problems better than most," Zhu says. He estimates that another three years will be necessary before the technology is perfected.

Another possible heavy-duty application for coatings is in off-road equipment. Larry Seitzman is team leader for engineered surfaces at the advanced materials technology division of Caterpillar, Inc., where they are exploring the same kinds of carbon-based PVD coatings technologies being examined at Eaton, Ford, GM and elsewhere.

"The experience of gears, not just at Caterpillar, but in a lot of industries, is that designers are pushing steels right to their limits," says Seitzman. "Coatings are one of the tools that can push you beyond those limits."

Although trade secrecy prevents Seitzman from discussing how gear coatings have been used in production applications, he's extremely postitive about the potential for coated gears, especially considering the rapidly advancing technology.

Seitzman and his colleagues at Caterpillar are working to identify the necessary tools and requirements to make the thin-film process economically viable. "The biggest obstacle is having a manufacturable, reliable process for putting the coatings on the parts," he says.

What About the Rest of Us?

The coatings being examined by the likes of General Motors, Ford, Eaton and Caterpillar might have huge implications for the rest of the gear industry, but for the most part, these technologies are still in the proving stage. They represent the cutting edge of coatings technology, and they may provide the gains in power density everyone is looking for, but only if the cost of the process becomes low enough for mainstream use.

Meanwhile, there are many coatings of a less high-tech nature that are applied to gears in diverse applications every day. Joseph Bregi Jr., president of Doppler Gear Co., Minneapolis, MN, has estimated that somewhere between 5% and 10% of the gears his firm manufactures receive some kind of finish coating or plating. Many of his gears are used in lawn and garden equipment, and the coatings, are often decorative, Bregi says.

> **"The experience of gears, not just at Caterpillar, but in a lot of industries, is that designers are pushing steels right to their limits. Coatings are one of the tools that can push you beyond those limits."**
> **–Larry Seitzman of Caterpillar, Inc.**

Doppler Gear is also the manufacture of splined power take-off shafts that receive a yellow zinc coating for corrosion protection, Bregi says, as well as gears that are coated with a dry-film lubricant.

Despite the fact that gear coatings are common on products manufactured at Doppler Gear, Bregi will be the first to admit that he knows little about the gear coatings themselves. "If a customer specifies it on the blueprint, we just send it out to a local plater," Bregi says.

Coatings and Gear Design

Because the subject of coatings is little understood by most gear designers and manufacturers, and because gears are little understood by most platers and coaters, the use of coatings on gears has often been under less than ideal conditions. All too often, they are brought in after a product has been designed to certain specifications. They're used to fix problems, or they're used to increase life or power density on an existing gearbox. But this is probably not the best approach, say coating and gear industry experts.

The possibility of using a gear coating should be explored in the earliest design phase, says Microfin president Richard Hickey. "It's never too early. Once the designer knows what he wants to accomplish with the gear, that's the time to investigate. Maybe he can use a less expensive material and coat it."

Gary Doll of Timken agrees that designing gears for coatings might be the best approach, but there aren't enough people who understand both gears and coatings for this to be practical. "Nobody really understands how to effectively design in a coating," Doll says. The standards that exist for coatings are material standards that don't necessarily consider the special requirements of gears. "With gears, you have adhesive wear, fatigue wear, corrosive wear, and a whole gamut of things to deal with," Doll says.

The combination of special knowledge regarding gears and coatings is crucial in the design phase, which means that gear specialists and coating specialists have to work together, says Hickey. Microfin corporation provided coatings for a manufacturer of computer component transfer equipment. "They were trying to use very soft gears, with no heat treating, and they had higher load requirements than we realized. Ultimately, the loads crushed the gears," Hickey says.

Ready or Not, Here they Come

Developing the industry standardization and familiarity with the specifications and capabilities of coatings may be just a matter of time. Although some coatings have been around for a long time, the ones that seem to have the most potential benefit for the most applications are just now being developed.

"The thin-film industry is really in its infancy," says Caterpillar's Seitzman. Both in the U.S. and Europe, there are standardization efforts underway, although none of them are specific to gears, Seitzman says.

However, nearly every coatings material and process supplier sees the gear industry as a ripe fruit ready for plucking. "There's not a major gear manufacturer who hasn't approached us to explore coating their gears," says Frederick Teeters of Balzers. "The gear coating market someday may be bigger than the cutting tool market."

It's obvious from our exploration of various industries that manufacturers share that point of view. "In the next 10 years, almost all new designs that are pushing the limits of gears are going to use coatings," Seitzman says. This optimism extends not just to heavy equipment, but across all disciplines involving gears. "And I strongly suspect it will be sooner." ○

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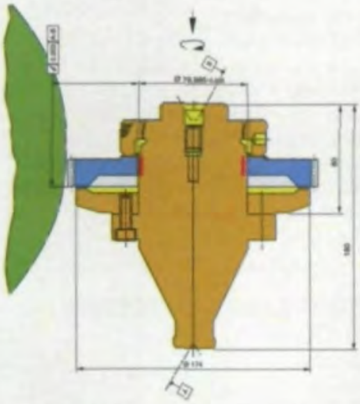

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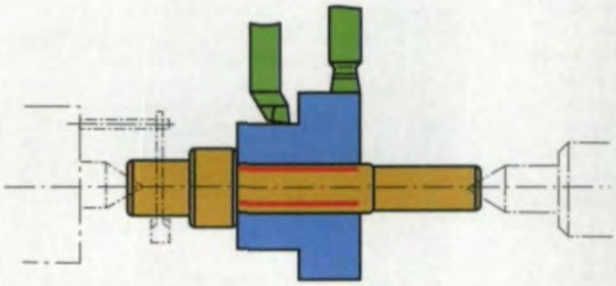

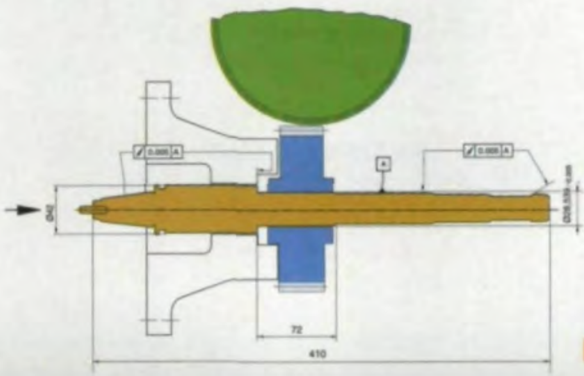

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The Gear Industry and Y2K

Charles M. Cooper

If you think Y2K will mean the end of the world, forget it. General Vladimir Dvorkin recently said, "I'd like to apologize beforehand if I fail to realize someone's hopes for the Apocalypse." The general was, of course, discussing Russian nuclear missiles, making the point that they are not going to launch or detonate when the calendar rolls over to January 1, 2000. General Dvorkin's American counterparts are similarly optimistic. While all that is a relief, it raises the question: will Y2K be as kind to the rest of society? And more specifically, will it be as kind to the gear industry? According to AGMA's president, Joe Franklin, the answer is a resounding "yes." According to Franklin, the AGMA Board considers Y2K a non-issue within an industry that is well ahead of others in its preparedness for January 1, 2000. But is it really? Does the gear industry understand the problem any better than other sectors of society? It's a relief to know that the nuclear bombs are not likely to fall within the first moments of the year 2000, but how about the computers and machines that keep the worldwide economy together?

The Y2K Problem

The Origin of Y2K. As anyone who has had his PC's memory upgraded can tell you, computer memory costs money. We pay tens of dollars per megabyte today—the lowest cost in history. Fifty years ago, when computers filled whole rooms and worked on thousands of vacuum tubes, and then later on still-clumsy solid-state technology, the cost of memory for these machines was orders of magnitude higher than it is today.

Because of that, and other costs, computer engineers had to cut corners wherever they could, and one place they did it

was in the way computers handle dates. This, of course, has created a problem.

Computers that were built to this standard didn't understand the concept of a century since they deal only with two-digit years—lower numbers for the past, higher numbers for the future. Therefore, they will not understand that with "00" they will be in a new century. When the dates roll over to 00, these machines will consider the year to be 1900. The computer designers understood this, and over the years computer experts have raised the issue from time to time, but the problem was always seen as something that would happen sometime in the future, not

> **"Foreign countries trail the United States in addressing Y2K problems by at least several months, and in many cases much longer. Y2K remediation is underfunded in most countries."**
> **– Lawrence Gershwin, National Intelligence Council**

something to supercede current issues. It has simply never been a priority until now.

The Panic Industry. Today, if you watch TV or listen to talk radio, and take what they are offering on the subject of Y2K to heart, you might be tempted to buy a little house in the mountains and then equip it with a generator, lots of bottled water, canned goods and enough beef jerky to reshingle your roof. A whole industry has sprung up catering to the fears surrounding Y2K—the power grid will go out, financial institutions will go under and take our money with them, airplanes will fall out of the sky, ships will sink, the list goes on and on. There will be problems with Y2K, you can be assured. But, as Gen. Dvorkin implied, it will certainly not be the end of the world.

General Worldwide Preparedness. Most experts agree that Americans will greet the year 2000 without noticing much of a change. Some small businesses that do not have the funds are considered to be at risk, but the government, the financial sector, transportation, major industry—in fact, the overwhelming majority of the U.S. economy—will go on. The United States, Canada and the Netherlands are the most prepared for the coming century. Close behind are a number of industrialized nations including Great Britain, Ireland, Canada, Denmark and Israel. Other nations lag behind to a greater or lesser degree.

According to Lawrence Gershwin, the national intelligence officer for science and technology for the National Intelligence Council, in a January 20, 1999 report to the Government Management, Information and Technology Subcommittee of the House Government Reform and Oversight Committee, *"Foreign countries trail the United States* in addressing Y2K problems by at least several months, and in many cases much longer. Y2K remediation is underfunded in most countries."

The problem this poses for American business is one of linkage. On a strictly local level, things should go fairly smoothly. But in broader areas such as telecommunications, financial systems, air transportation, the international manufacturing supply chain, oil supplies and trade, all of which are global, we will see Y2K problems. This means that no country in the world, no matter how well prepared it is domestically, will be immune.

The American Gear Industry and Y2K

"The Y2K issue has been discussed by the AGMA Board of Directors. The directors see it as a non-issue because all the companies in the industry are so well positioned," says Franklin.

And so far, we haven't found anyone here in the United States to disagree with him. According to John Zukowski, the engineering manager for Perry Technology Corp., "As for the whole Y2K problem, it has been blown out of proportion, especially for many smaller manufacturers. Huge companies, like Gleason, with older systems and custom, often "in-house" software will have a more significant problem tracking down the bugs than a small company that can rely more on its computer providers."

Still, even if small firms are ahead of the game in terms of remediation, the national trend in terms of Y2K preparation favors large firms with greater resources and, more importantly, awareness as to the extent of the problem. Speaking of small business at a press conference held with his Mexican and Canadian counterparts, John Koskinen, White House chief Y2K coordinator said: "Our problem thus far is not that small companies seem to lack resources. Our real problem in terms of the information we have is small companies have decided they're just going to wait, see what breaks, and then try to fix it. We would feel better if we had more small companies saying 'we need the resources' or 'we need the technical support, can you help us?'...What we have is a lot of people deciding they're going to wait and see. And we're trying to advise them that that's a very high-risk strategy—that if they wait until it breaks and then try to fix it, they may be with a large group of people in a long line waiting for these fixes, and that's a high risk."

In spite of the government analysis that spells trouble for small businesses counting on fixing the problem after the fact, the belief that larger companies will have a harder time seems to be conventional wisdom in the gear industry. Bourn & Koch Machine Tool Co.'s vice president and general manager, Tim Helle, says, "Smaller companies will have the advantage in fixing these problems. They tend to have simpler systems and more alternatives. Large companies have complex systems that will be difficult to fix in time." When asked if customers will see problems on January 1, 2000, both Helle and Zukowski believe that they will not.

"Most customers will not notice a problem," says Helle.

Internal Problems. According to Helle: "It is likely that if a problem should arise it will be in the scheduling area. That is a key area we are concentrating on and one that all companies should look at closely."

Scheduling is not the only internal area that companies should look at. According to Bob Fowler, materials manager for Reef Gear Manufacturing, "The greatest impact on the gear industry will come from problems with business operating systems, especially in accounting and inventory control." Problems in these areas could adversely affect the company's ability to process and fulfill customer orders and should be addressed before they break down. However, simply addressing the internal problems may not be enough for a company doing business in today's global marketplace.

External Problems. Imagine that you are 100% Y2K compliant. Each and every one of your computer systems is up to date and capable of handling the change to January 1, 2000. Does this mean you are immune to the sting of the Y2K bug? It does not, not in the least.

Industry does not exist in a vacuum. There are suppliers to be considered as well as shippers and the customers themselves. These three, very broad external segments are key areas of concern when confronting the Y2K bug.

Most of the larger firms and many smaller ones have audited (or at least communicated with) those companies that supply them. This is especially true in the automotive industry. "We have surveyed our suppliers and are satisfied with their preparations," says Fowler, "especially those that also directly supply the auto industry—they are the most advanced." Checking on customers' Y2K readiness is also taking place. According to Helle, "We see that many of our customers have already been upgrading their systems. Our critical suppliers are almost 100% compliant."

On the local, and even national levels, this is all good news. The industry seems to be ready. But what about transportation, financial systems, oil supplies and trade—all factors that affect the U.S. gear industry to a greater or lesser extent? Because these sectors of the economy are globally linked, they must be taken into account when determining the true effect the Y2K bug will have on the American gear industry.

Y2K Across the Globe

As mentioned above, the rest of the world gets somewhat mixed reviews when it comes to Y2K preparation and remediation. Generally, the industrialized countries of Western Europe are more prepared than most, with Russia, Asia, the Middle East and Latin America lagging behind to greater or lesser degrees. According to the National Intelligence Council's Gershwin, the troubles these countries face can be broken down into five areas.

1. Time and resource constraints limit the ability of most countries to respond adequately by 2000.

2. Governments in many countries have begun to plan seriously for Y2K remediation only within the last year, some only in the last few months, and some continue to significantly underestimate the cost and time requirements for remediation and, importantly, testing. Because many countries are way behind, testing of fixes will come late, and unanticipated problems typically arise in this phase.

3. The largest institutions, particularly those in the financial sectors, are the most advanced in Y2K remediation. Small and medium sized entities trail in every sector worldwide.

4. Most countries have failed to address aggressively the issue of embedded processors. While recent understanding is that failures here will be less than previously estimated, it is nevertheless the case that failure to address this issue will still cause some highly dependent sectors with complex sensor and processing systems to have problems, centered right on the January 1 date.

5. The lowest level of Y2K preparedness is evident in Eastern Europe, Russia, Latin America, the Middle East, Africa, and several Asian countries including China.

For American industry, including gear manufacturers, that means that foreign suppliers, customers and shippers could easily have problems that their American counterparts have managed to avoid. If your suppliers or major customers are in any of the countries that are lagging significantly in Y2K preparedness, you could be in for problems. China, Japan, Poland, Russia, South Africa, Venezuela and Yugoslavia are some of the major players falling behind in their Y2K preparation, but there are a number of others (see sidebar) identified as showing significant shortcomings or being highly vulnerable to disruptions.

John Koskinen, White House chief Y2K coordinator, said: "Our problem thus far is not that small companies seem to lack resources. Our real problem in terms of the information we have is small companies have decided they're just going to wait, see what breaks, and then try to fix it."

This means that the doom-and-gloom predictions made for the United States, which are not likely to come true here, are very likely to come true in many of these other countries. Companies in these countries doing business with American firms are probably going to have major difficulties within their businesses and with the surrounding infrastructure. For example, it won't do any good for a gear shop in Shanghai to be Y2K compliant when the Shanghai electrical grid shuts down because it isn't also Y2K compliant. With no power to run its hobbers, the shop is out of business, and if it is one of your suppliers, then you have a problem.

The problems in these countries do not stop there. Areas that are already experiencing economic hardships such as Russia and the countries of the former Soviet Union, as well as those countries troubled by the Asian economic crisis, will be even harder hit by the effects of the Y2K bug. According to Gershwin: "The coincidence of widespread Y2K-related failures in the winter of 1999-2000 in Russia and the Ukraine, with continuing economic problems, food shortages, and already difficult conditions for the population, could have major humanitarian consequences for these countries." As for Asia, Gershwin states: "The Asian economic crisis has hampered the Y2K remediation efforts of all of the Asia-Pacific countries except Australia. While the lines of authority for China's Y2K effort have been established, its late start in addressing Y2K issues suggests Beijing will fail to solve many of its Y2K problems in the limited time remaining, and will probably experience failures in key sectors such as telecommunications, electric power and banking." Neither of these analyses bode well for companies that do business in these areas of the world, and they are highly indicative of problems in other countries as well.

Shipping. The question of foreign suppliers and customers may be moot, however, in the face of the problems with ocean shipping and foreign ports—a vital issue for machine tool manufacturers who sell and ship overseas. Gershwin reports that the U.S. National Intelligence Council has flagged both ocean shipping and foreign ports as being among the least prepared for the Y2K bug. Given just the number of embedded microprocessors on a modern cargo ship, not to mention the on-board computer systems and software, the remediation of a country's cargo fleet becomes a daunting task. According to Lloyds of London, the International Maritime Safety Agency notified governments all over the world about the dangers Y2K poses to maritime shipping in 1997. However, work on the embedded chip issue has only recently begun.

These embedded chips, which are the key to automation, are critical on modern ships in that they control so many shipboard operations—from the engine room to the bridge communications, navigation, control and alarm systems. In port, these chips also control various aspects of cargo handling operations, elevators, security and other vital systems. Failure of these embedded processors could leave a ship adrift or without navigation, or it could shut down the operations at a port.

In a marine guidance note entitled "Marine Electronic Systems and the Year 2000 Problem," the British Maritime and Coastguard Agency states: "There has been considerable publicity about the potential failure of computer systems, which are unable to process the changes in year date from 1999 to 2000. This publicity has often focused on systems, which are recognizable as computers (e.g. a 'PC' or mainframe). However, the prob-

Y2K Compliance, Progress and Readiness

GartnerGroup, an information technology research and publishing corporation headquartered in Stamford, CT, has defined a scale called COMPARE (COMpliance Progress And REadiness) that enterprises can use to judge their own or their partners' efforts for year 2000 compliance. The COMPARE scale features the following levels:

- **Level I: Begin.** This is the stage at which all enterprises begin preliminary activity.
- **Level II: Problem Determination.** This level indicates that a complete inventory of technology and business processes has been taken, and preliminary costs and resources have been determined.
- **Level III: Plan Complete and Resources Committed.** Achieving this level indicates that mission-critical systems have been identified and needed resources have been committed for that technology.
- **Level IV: Operational Sustainability.** At this level, mission-critical technology has been remediated from year 2000 risk.
- **Level V: Fully Compliant.** At this level, all technology within the enterprise and within business partners has been made compliant.

GartnerGroup presents COMPARE level status by industry (Figure 1) and by geographic area (Figure 2). On each status bar showing the COMPARE level status, on average, the 25 percent of the bar farthest to the right represents large enterprises, the 25 percent farthest to the left represents small enterprises, and the middle 50 percent represents midsize enterprises. Figure 3 is a Compliance vs. Risk chart detailing where various countries and economic sectors are in terms of the probability of mission-critical system failure.

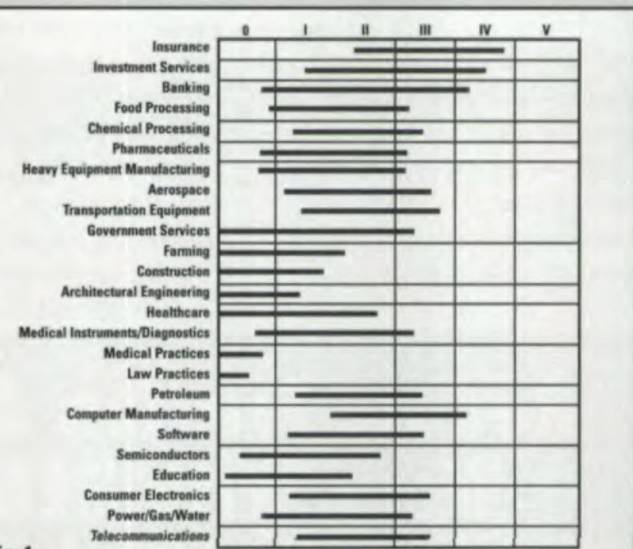

Fig. 1

Fig. 2

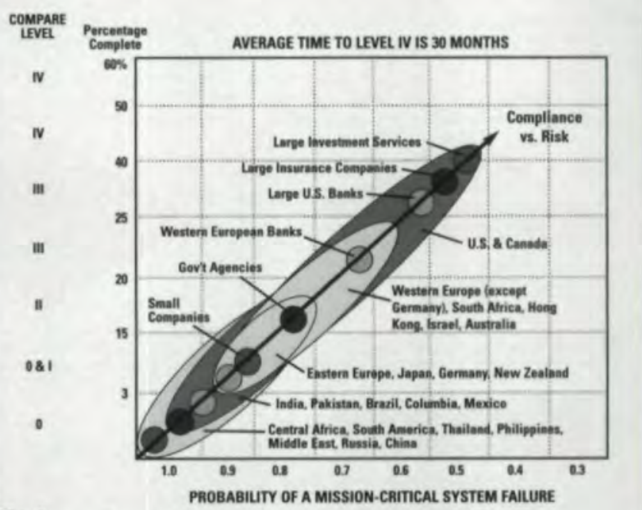

Fig. 3

Fig. 1—Status by Industry—Worldwide
In the United States, as of late 1998, large enterprises (i.e. those with more than 20,000 employees) are between 20% and 40% complete with their year 2000 compliance efforts. GartnerGroup's analysis yields a mission-critical failure probability of less than 15% (the same probability as for enterprises in "leading" industries, such as financial). Midsize enterprises (i.e. those with 2,000 to 20,000 employees) are 10% to 20% complete and have a 0.6 probability of a mission-critical failure. Small enterprises (i.e. those with fewer than 2,000 employees) are 0% to 10% done and have a 0.8 probability of a mission-critical failure.

Strategic Planning Assumption: Through the end of the first quarter of 2000, between one-third and one-half of all enterprises will experience mission-critical business process interruptions due to the year 2000 problem (0.7 probability).

Fig. 2—Status by Geographic Area—Worldwide
Australia, Belgium, Canada, the Netherlands, Sweden and the United States are leaders. Asia, Eastern Europe, India, Pakistan, Russia, Southeastern Japan, most of South America and Latin America, most of the Middle East, and Central Africa all lag behind the United States by more than 12 months.

Although regions such as the Middle East and Russia are further behind than Germany and Japan, GartnerGroup expects the disruption to be greater in Germany and Japan because of their tight supply chains and their greater dependence on IT systems.

Fig. 3—Year 2000 Compliance vs. Risk—Worldwide

Source: GartnerGroup, "Y2K Risk Assessment and Planning of Individuals," October 1998—Reprinted with Permission.

lem will also occur with some of the 'embedded systems,' which are used in machinery control, monitoring and automation equipment. Owners and operators (of ships) are urged to take steps to identify all systems which may prejudice standards of safety or pollution prevention by failure to process a date change, and to take corrective action in good time."

Many ship owners have followed this advice, which has been echoed by maritime agencies all over the world, by upgrading their ship's systems. The experience of Shell International Trading and Shipping Co. is an example of a shipping company (in this case oil tankers) confronting the Y2K bug.

After the original equipment manufacturers told Shell that 10% of the embedded systems would be Y2K noncompliant, an audit of their tanker fleet showed that of the dozens of embedded processors on their largest and most automated ships, 20% were non-compliant and another 10% were suspect. Shell hired an outside firm, Real-Time Engineering, to perform the test, which found problems in the navigation and communication systems, engine room, cargo monitoring and control systems, LANs, PCs, and other equipment and application systems. Shell proceeded to reprogram or replace the affected systems. Depending on the system, this meant either a cheap, straightforward reprogramming job or a complete system replacement.

However, like most industries, Y2K compliance is linked with the size of the company and the amount of preparation that company's particular country has given the Y2K issue. The example above cited a large corporation in Great Britain, one of the countries near the top of the preparedness list. Shell can be seen as a kind of ideal in this case. The company began work on the problem in the mid-1990s, dedicating the time and the resources to, as Shell UK director of corporate affairs John Mills stated, "get it right."

What Can You Do?

The answer to that question depends on where your company is along the Y2K preparedness curve. Some of you are just starting to address the issue, others have their own house in order and are now looking at their suppliers and customers, and a few are waiting to see what will break, assuming that whatever does break will be easy to fix. Wherever you fall along this line, the following advice from the Small Business Administration and a look at what Gleason Corporation is doing about the problem can help take much of the sting out of the Y2K bug.

Gleason's Efforts. Like other major corporations, gear industry giant Gleason Corporation has developed a plan of action to deal with the Y2K bug. According to its plan, which can be found on Gleason Corporation's Web site (*www.gleasoncorp.com*), The project includes the following phases: inventory identification, impact analysis, risk evaluation, remediation, acceptance testing and implementation. Risk assessments are being performed to identify the systems that are most likely to be affected by the year 2000 in order to prioritize and schedule the readiness of such systems. Gleason believes that it has budgeted sufficient resources to address the year 2000 issues associated with such systems. Year 2000 readiness for such systems will be addressed in one of three ways: elimination, replacement, or conversion. In addition, the company is contacting its major suppliers in order to determine the year 2000 readiness of these entities.

Get your house in order. If you have not prepared for Y2K yet, now is the time to start. The U.S. Small Business Administration has developed a simple five-step plan for Y2K preparedness that is similar in many ways to the plan developed by Gleason.

Awareness. Educate and involve all levels of your organization in solving the problem. Create a communication strategy to make sure that everyone is informed and that management has the data it needs to make proper decisions. This can include seminars or meetings, even outside speakers to educate employees. It is also important to develop a standard for readiness. The United States Federal Reserve uses the following definition: "Systems are defined as ready if they can demonstrate correct management and manipulation of data involving dates, including single century and multi-century formulas, without causing an abnormally ended scenario within the system or generating incorrect values involving such dates."

Remember, the awareness phase never ends. As people move to other jobs, and new people are hired, they must be educated. Also, there is an ongoing need to keep your staff and business partners informed.

Inventory. Create a checklist identifying all the different computer-based systems, components, service providers and hardware containing microchips that support your business.

Each entry on this list should be ranked by how critical it is to your business. For each entry, indicate what kind of component it is, the area it supports (e.g. telecommunications), the name of the vendor and the release number. Also, some systems will fail before the January 1 date. This is due to the system performing forecasting or future processing and it is called "time horizon to failure." The "time horizon to failure" should be listed in the inventory.

Assessment. Examine how severe and widespread the problem is in your business and determine what needs to be fixed. Beginning with your most critical systems and those on the verge of "time horizon to failure," determine which ones are date sensitive. Date sensitive systems are defined as systems that manipulate or work with dates in some way, or a system that operates differently based on the date.

Test these systems to gage their Y2K compatibility. This testing can be done by following the logic of the program's code or by running the system as if it were already January 1, 2000. The former method may be unavailable if the system was purchased from an outside vendor. If that is the case, have the vendor perform the tests. As for changing the date to January 1, 2000, there are risks that need to be taken into account before this kind of test is performed. If possible, your staff should work with the vendor to perform these tests, especially if the system involves building or manufacturing control, or has embedded processors. Once the tests have been made and the systems in need of remediation identified, you have three options: repair, replace or retire.

Repair. There are two possible repair strategies: windowing or date expansion. Windowing involves programming that interprets year fields to determine what century the year falls into before the date field is used in comparisons, calculations or sorting. Date expansion, as the name implies, involves expanding all 2-digit year fields in your system's data files and in the programs that process those files so they can hold the century as well as the 2-digit year. Businesses often use a combination of the two methods to meet their specific needs.

"The survival of key suppliers and customers throughout and beyond the year 2000 is of critical importance." John Mills, Shell UK

Replace. Here, you have several choices. You may rebuild the system in-house, purchase a replacement system from a vendor, or you can outsource that particular area to a service bureau or some other outside service provider. Timing is important with a replacement strategy because if the replacement can't be installed prior to the "time horizon to failure," then you could be forced into a repair strategy.

Retire. This is an opportunity to look at your systems and decide which need to be upgraded for more than just Y2K and which need to be eliminated. This was recently done at Perry Technology when they needed a general upgrade for their computer systems. "Perry has just installed a new system some 18 months ago—new software, workstations, server, that is all Y2K compliant," said Zukowski. "We only have a couple of stand alone machines in non-critical areas that will have to be upgraded, but all the essential accounting, inventory and business operations systems are already compliant."

Bridges. Regardless of which strategy you adopt, during this phase pay special attention to the interfaces that exist between your systems. If possible, develop a chart that shows the systems that have such interfaces, what they are and when they occur. Since different systems will have different schedules for assessment, correction and implementation, it may be necessary to write (or have written) programs that "bridge" the Y2K gap between compliant systems and those in need to upgrade. These bridges take data and modify it so that it works correctly with the system being interfaced. This requires careful and detailed planning to properly execute.

Correction and Testing. Implement the readiness strategy you have chosen and test the fix. Testing is one of the most critical phases in the process of Y2K readiness. It verifies whether the repaired or replaced system operates properly and that existing business functions such as accounting or inventory control continue to operate as expected. It also verifies that interfacing systems operate correctly together. Remember, this is not confined to computer software. All computer-related systems need to undergo this process.

The best way to perform the test is to take the system off-line (if possible) on a Y2K compliant platform and see if the system operates correctly when you change the date to January 1, 2000. You should also check to see if the system recognizes that 2000 is a leap year and that the date goes from 2/28/2000 to 2/29/2000 and then to 3/1/2000. If it does not, now is the time to fix it. If your system does end-of-week, end-of-month, end-of-quarter or end-of-year processing, you will want to test these functions as well. You should also test whether the system will forecast and retrieve historical data properly.

Implementation. Move your repaired or replaced system into your production environment. If possible, run the new system next to the old one for a short period of time. Develop an installation plan for your upgraded system that includes all programs and files that need to be moved into production as well as a contingency plan should problems arise. Make backups of the production files from the old systems and run this data on the new system in tandem with the old in order to compare results.

The Small Business Administration has a great deal of useful information regarding Y2K available on its Web site at *www.sba.gov*. It is also going beyond providing information in order to assist small businesses to handle the problem. According to Debra Silimeo, Associate Administrator for SBA's Office of Communications and Public Liaison, "We are about to launch a new Y2K Action Loan program to assist small businesses that need money to make Y2K-related repairs."

Other Things to Think About

Testing the interfaces between your various systems is important, but it is not enough. How does your company interface with its customers, suppliers and shippers? Assess the Y2K compliance of each company you do business with, and if they are not compliant, try to help them along in order to avoid supply chain and fulfillment difficulties caused by problems you have no control over. If you have the time and the resources, try to make sure that the companies your suppliers and shippers depend on are also Y2K compliant since if they are depending on these companies, so are you. If you have international dealings, look at the countries where you do business and make contingency plans for any sort of disruptions that may take place in those countries. According to John Mills, Shell UK's approach to this question is that "the survival of key suppliers and customers throughout and beyond the year 2000 is of critical importance. Again, initiatives are already in place to encourage companies to tackle this problem seriously. Suppliers are being assessed on their criticality to our business and on the availability of alternative sources of supply. All key suppliers are being asked to provide us with a statement of their approach to year 2000 compliance."

Ultimately, no one really knows the extent of the problems that Y2K will cause. We can look at the preparations various companies and countries are making and guess at the levels of severity each will experience. We can also take heart in the fact that the United States is the leader in terms of Y2K preparedness and so will probably experience the least difficulties. But, in the end, all we can do is prepare ourselves and our companies as best we can and wait. Will AGMA's confidence be justified? We'll find out on January 1st, 2000.

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Welcome to our Product News page. Here we feature new products of interest to the gear and gear products markets. To get more information on these items please circle the Reader Service Number shown.

New Wear Tester for Plastic Gears

LNP Engineering Plastics has announced the release of its new wear tester, designed to specifically measure the wear performance of engineering thermoplastic materials used for injection molded gears under controlled conditions. According to Ed Williams, lead applications development engineer for LNP, "The tester enables us to characterize the wear performance of thermoplastic materials under typical gear application conditions in order to give gear designers more applicable data to utilize in material selection."

LNP plans to first characterize the wear performance of some of the more common thermoplastic gear materials, like acetals and nylons, and then move on to internally lubricated and reinforced materials which may be needed for more demanding applications. "There is a growing demand for injection molded gear materials, which will carry greater loads at higher speeds and temperatures," says Williams.

LNP contracted the final wear tester design and construction to Kleiss Engineering. It consists of two computer controlled DC servo motors capable of 60 in-lb. continuous torque (120 in-lbs. intermittent) and 4000 rpm. Each motor has a 2000-count optical angle encoder that can measure the change in gear backlash as the gears run. "Since we were most concerned with measuring the wear performance of the materials in the gears, we decided that recording the increase in backlash as the gears ran was an appropriate measurement," says Williams. The tester has an adjustable center distance and can be used with a variety of gears. "This will enable us to not only evaluate our test gears, but also look at gears supplied by our customers," adds Williams. For more information contact Mark Stokes at (610) 363-4500.

Circle 300

New Products from BNA

BNA Bonfiglioli North America has introduced a series of worm gears that provide the broadest combination of size range and mounting versatility. To meet the user's specific requirements, special configurations can be designed. They include reducers fitted with limit switches for control of linear travel, clutches for overload applications and many others.

BNA has also introduced a new series of in-line helical gearing that promises greater efficiency and noise-free operation in a power dense coaxial design. Maintenance costs are reduced, because of the increased two-stage reduction, as much as double that of competing products. Torque ranges from 260 in-lbs. to 10,600 in-lbs. with ratios between 2.6:1 and 287:1. The units are available with foot, flange or universal mountings.

BNA offers one of the world's most extensive ranges of gearmotors, speed reducers and planetary drives from Italy's largest drive manufacturer. Headquartered at its newly expanded facilities in Concord, Ontario, the company maintains an extensive inventory of drives and components, along with complete technical assistance and sales support. Bonfiglioli drives are in operation in more than 50 countries worldwide. For more information contact Joel Camunias, BNA Technical Sales, at (905) 738-4466 or contact him via e-mail at *sales@bnagear.com.*

Circle 301

Thomson Micron Introduces Clean Room Planetary Gearheads

Thomson Micron LLC has just developed and released a clean room and vacuum compliant UltraTrue True Planetary gearhead that delivers both high torque and quiet operation with all metal construction and no plastic seals or internal components. Ultra precise (4 arc-minutes of backlash) and compact, it is ideal for wafer polishing, CMP (chemical mechanical planarization) equipment, Chemical or Plasma Deposition equipment and wafer cleaning equipment.

The UltraTrue True Planetary gearhead is offered in either in-line or right angle construction. Both configurations are available in 5 frame sizes with ratios from 1:1 to 100:1. It provides up to 31,000 in-lbs of torque, the highest torque capacity gearhead offered by Thomson Micron, and it boasts an efficiency of 92%. Lubricated for the life of the gearhead, UltraTrue True Planetary gearheads are maintenance-free. When replacing older spur gearheads, True Planetary gearheads provide higher torque, lower backlash and longer life in a compact, low inertia package. Call 516-467-8000 for further information or send e-mail to *gearheads@thomsonmail.com.*

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STS Proshield Corrosion Inhibitor forms a long-lasting, thick, waxy coating that protects metal parts and equipment during shipment and indoor or outdoor storage for up to two years. It seals out moisture, air, salt spray, corrosive fumes, dust and particulates. It contains no 1,1,1-trichloroethane, CFCs or other ozone depleting solvents.

Available in 10- and 16-ounce aerosol cans with invertible spray valves, as well as 1-, 5-, and 55-gallon containers, Proshield protects steel, iron, cast iron, brass, aluminum and other specialty metals. It stops exfoliation or filiform corrosion, and as an industrial lubricant it protects gears, chains, wire rope and other moving parts that require heavy-duty lubrication and high levels of corrosion resistance. Proshield also protects and lubricates airbrake release springs, motors, shafts, pistons, machined parts, forklifts, elevators, vehicle doors, and raw and unfinished stock.

For additional information call (800) 807-3761, fax (806) 372-1102 or go online and visit the STS Web site at *http://www.stsnow.com.*

Circle 303

New Alloy from Carpenter Offers Improved Machinability

Substantially improved machinability is offered by Project 7000 stainless Type 416, the latest in the line of Project 7000 stainless alloys developed by Carpenter Technology Corporation of Reading, PA.

Depending on the application, Carpenter estimates that the new stainless steel gives fabricators the capability to improve productivity from 25% to 50% over what's possible with generic stainless Type 416. It also offers a good productivity advantage over the company's companion Project 70 stainless Type 416, which has been well known for its free-machining characteristics. The expected gain may be measured in terms of any one or more of several key variables—faster speeds, higher feeds, longer tool life, less downtime, better finishes, or the ability to machine difficult parts that were previously unmanageable.

Project 7000 stainless Type 416 is the first martensitic stainless grade in Carpenter's Project 7000 stainless series. It is a hardenable, straight-chrome alloy that can be hardened like conventional Type 416 stainless.

Arrangements to obtain Project 7000 stainless Type 416 for trial purposes may be made by calling any Carpenter service center or sales representative. For a preliminary technical data sheet, call Norm Schmidt at (610) 208-2551.

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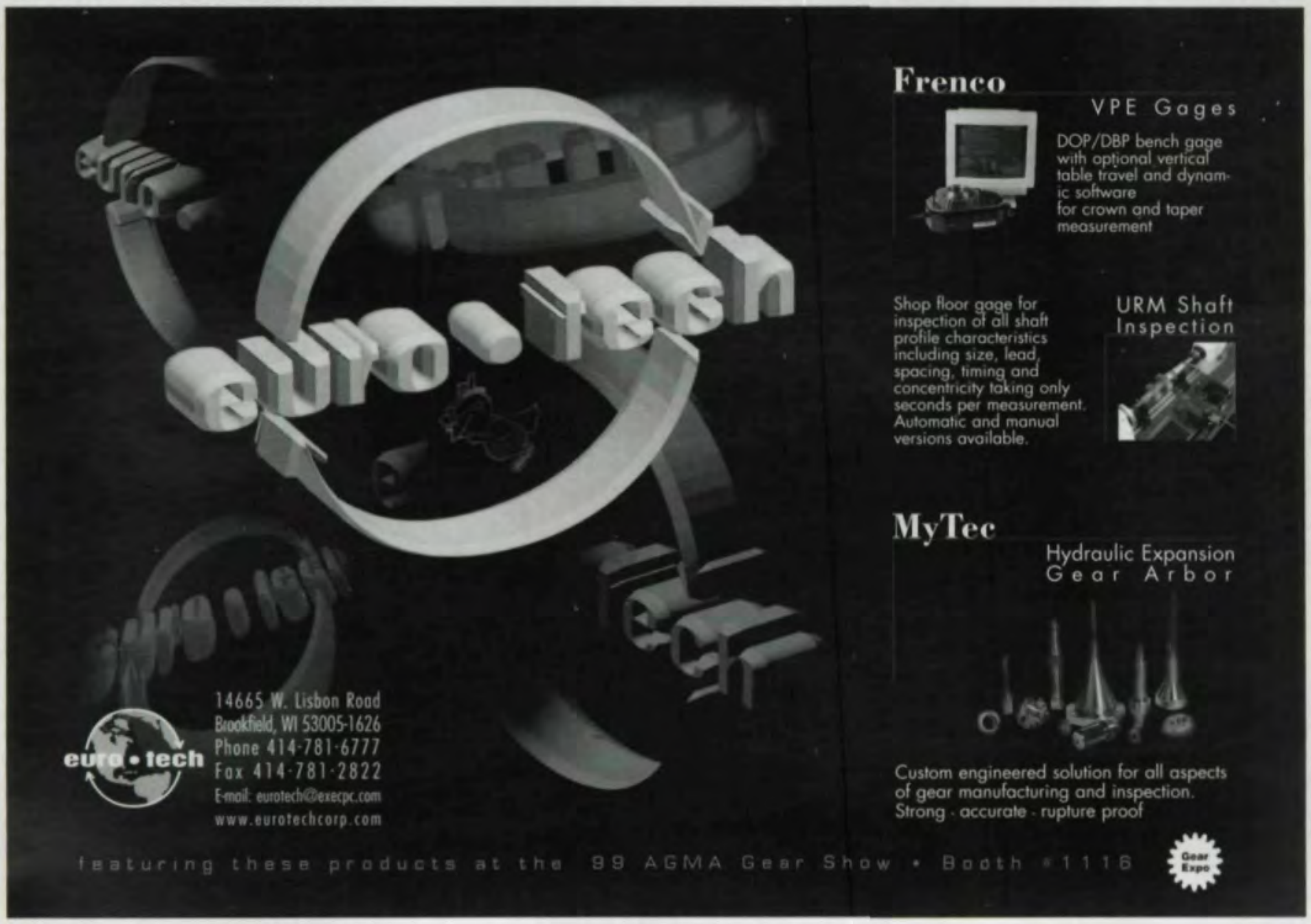

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CIRCLE 122

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www.geartechnology.com/copage/ajax.htm

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www.starcutter.com

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www.samputensili.com

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LeTourneau, Inc. a large OEM manufacturer of mining, forestry and intermodal equipment in Longview, Texas, is currently screening candidates for the position of Industrial/Manufacturing Engineer with gear manufacturing concentration. Desired candidate must possess a minimum of ten years experience in gear manufacturing product development, knowledge of proven processes to achieve quality parts at competitive costs, record keeping, traceability and quality procedures (DNV). Must be familiar with gear cutting equipment, gear case hardening methods and tooling methods. A degree in Engineering is preferred. Position may require limited travel.

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A Brief History of Gears

Gear Technology's bimonthly aberration — gear trivia, humor, weirdness and oddments for the edification and amusement of our readers. Contributions are welcome.

No one is quite sure when gears were invented. It's universally agreed, however, that they've been transmitting motion in one form or another for quite a long time.

The earliest accounts of gears come from ancient Chinese and Greek literature. However, many of these references are vague and unreliable. With some of these texts, it's difficult to say where history begins and mythology leaves off. To make matters worse, the literature very often contains descriptions of devices that may or may not have included gears.

Most of the hard evidence we have of ancient gear development comes from the Eastern Mediterranean. For example, a work called *Mechanical Problems* came out of Aristotle's school around 280 B.C. It describes parallel wheels in mesh, although it doesn't specifically mention toothed wheels of any kind, and these might have been friction disks rather than gears.

Another classical inventor who may have contributed to gear science was Ctesibios of Alexandria (circa 300 B.C.), who was a barber by trade and whose inventions included an incredibly accurate water clock. The clock included an early form of rack and pinion gearing, according to accounts written by Vitruvius nearly three centuries later (circa 25 B.C.).

The clearest early evidence of the practical use of gears comes from Archimedes (circa 250 B.C.), whose screwed devices were the precursors of modern worm gearing. His designs for war machines included many gear components. Archimedes may also have been one of the early developers of astronomical clockworks.

By the time of Heron of Alexandria (circa 60 A.D.), it's clear that gearing had been developed and was widely considered as an acceptable means for transmitting motion and solving mechanical problems. Heron describes the use of parallel gear trains to raise a very heavy load with little effort. He also incorporated Archimedes-type screw drives in his hodometer (odometer), a device for measuring distances travelled by a cart.

Judging from the history books is one thing. Finding hard evidence of actual gears is another. The biggest problem in finding archaeological evidence of gears is that early gear materials were not built to last. Gears made during the classical era were probably made of bronze. When bronze tools and mechanical pieces broke, they were simply melted down and refashioned into something else.

The oldest surviving geared mechanism is the Antikythera device, a precision mechanism that was probably crafted around 80 B.C. The device lay undisturbed for centuries off the tiny Mediterranean island of Antikythera, among a shipwreck filled with marble and bronze statues and other treasures. Although the device received early attention as some type of astrolabe or celestial calculator, its complexity was not fully understood until it was studied by the late Derek de Solla Price, a Yale professor of science history. He wrote the definitive work on the subject, *Gears from the Greeks—The Antikythera Mechanism, A Calendar Computer from ca. 80 B.C.* Although the book was published in 1974, it remains one of the best studies of early gearing.

Gears from the Greeks describes a device that included more than simple gears. In fact, the Antikythera device contains more than thirty gears arranged in a complex differential gear train. It was used to mechanically calculate the position of the sun and moon. Archaeologists date its manufacture to around 80 B.C., but this astronomical device's complexity is far greater than anything previously ascribed to that time period, and the gear train is certainly more sophisticated than anything described in the literature of the period.

Dr. Price concluded that the Antikythera gears must either have been the stroke of individual genius or that they had been under continuous developed since the time of Archimedes. Either way, the sophistication of the Antikythera device is remarkable ⚙

References:

1 Price, Derek de Solla. *Gears from the Greeks: The Antikythera Mechanism, a Calendar Computer from ca. 80 B.C.* Science History Publications, a div. of Neale Watson Academic Publications, Inc., New York, NY, 1974.

2 Price, Derek de Solla. "An Ancient Greek Computer." *Scientific American*, June 1959, p. 60-67.

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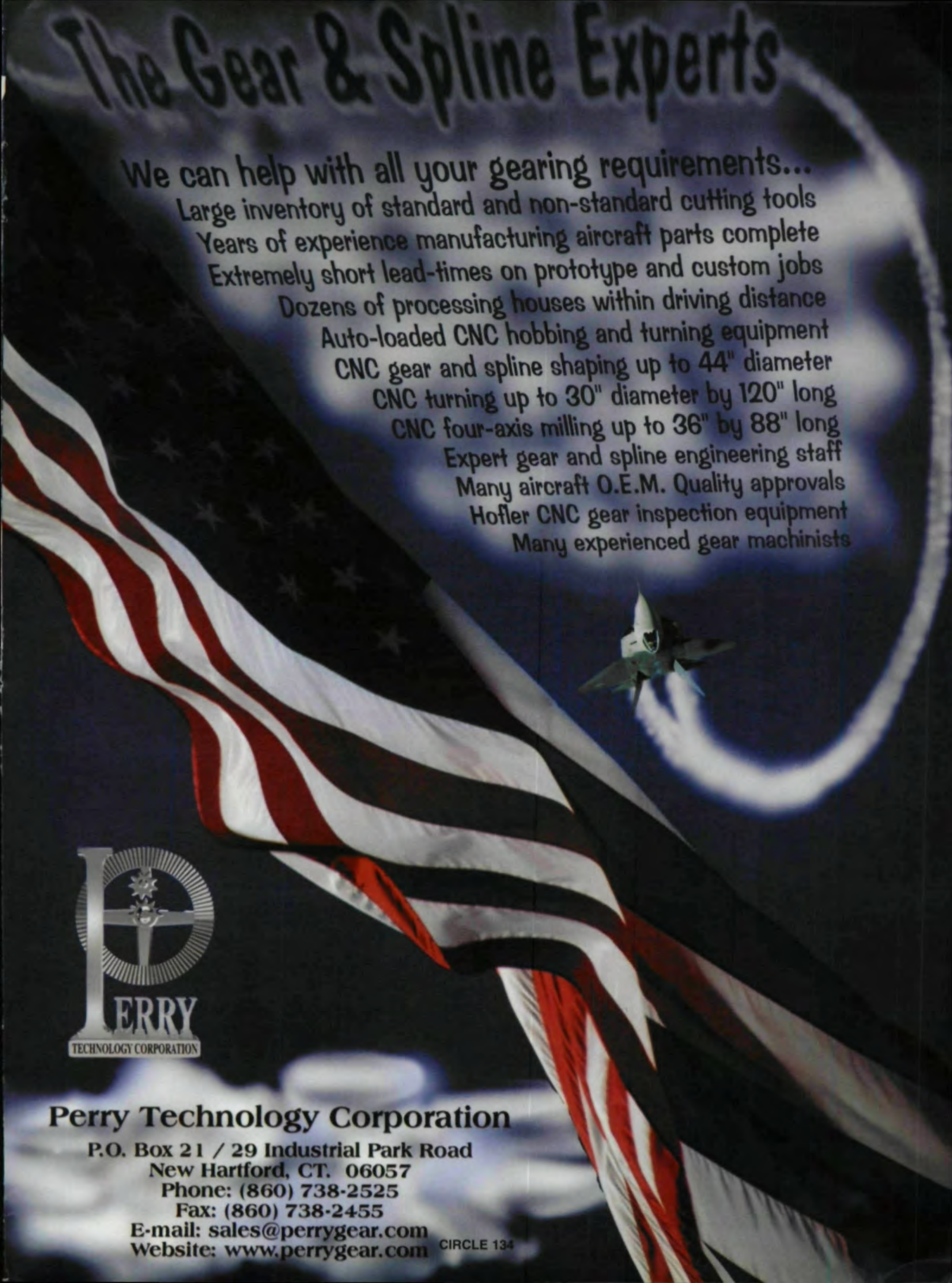
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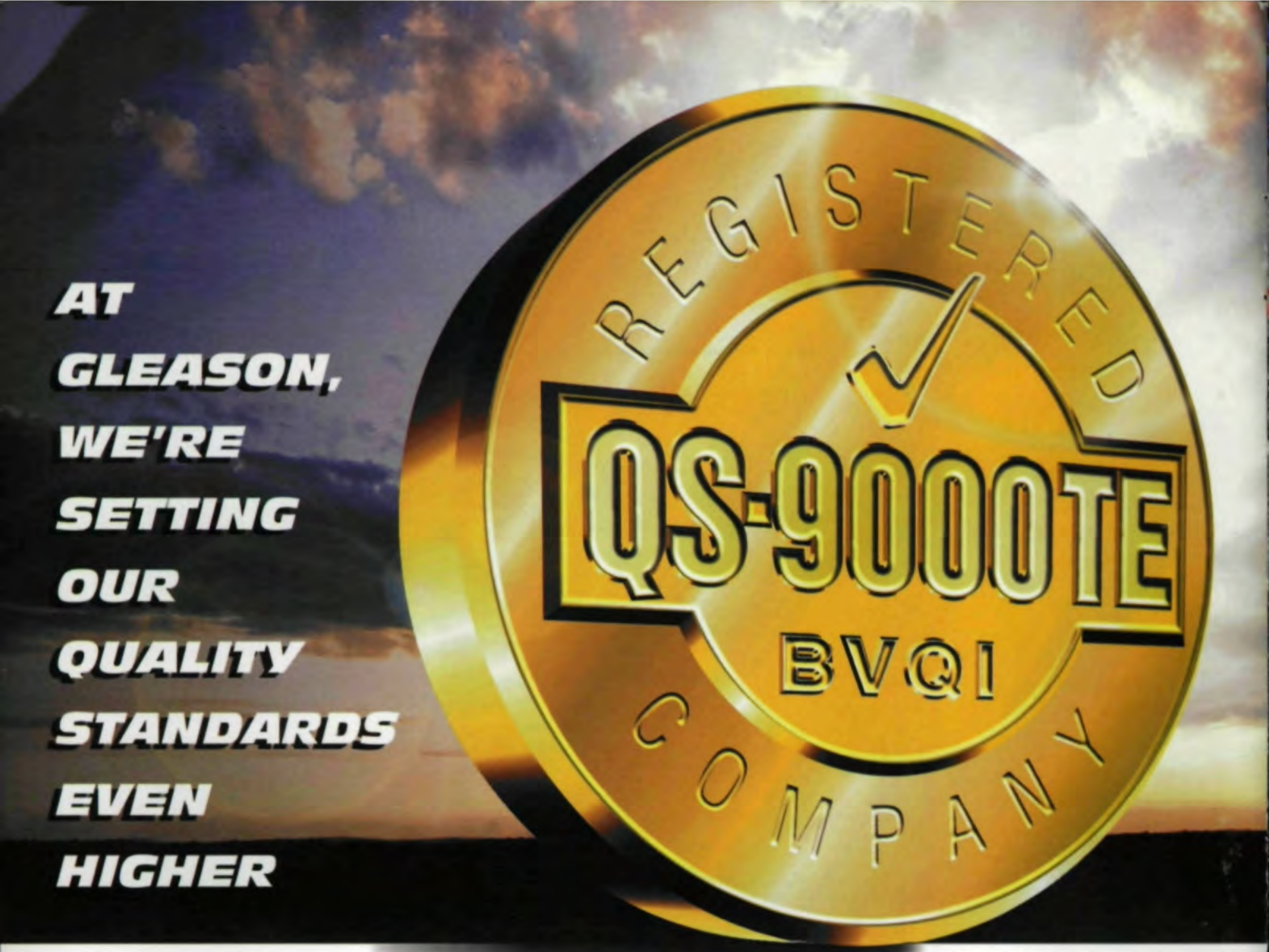

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