GEAR TECHNOLOGY

JULY/AUGUST 2000

The Journal of Gear Manufacturing

IMTS PRE-SHOW ISSUE

- PRE-SHOW COVERAGE
- MATH OF NONCIRCULAR GEARING
- PRECISION FINISH HOBBING

FOCUS ON INSPECTION

- MEASUREMENT TRACEABILITY & UNCERTAINTY
- Q&A: DETERMINING LEAD ERROR ON A CROWNED PINION
- ANALYTICAL GEAR INSPECTION
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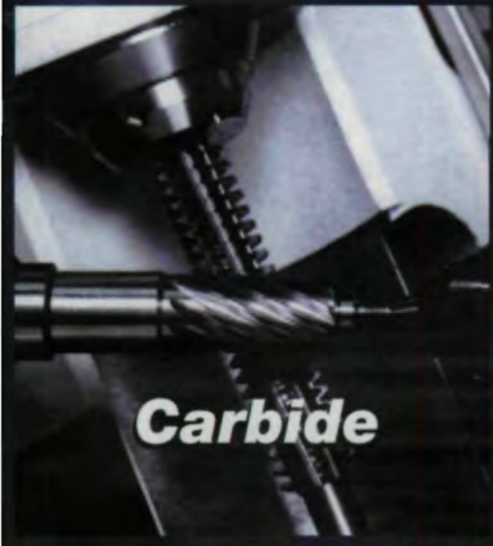

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JULY/AUGUST 2000

The Journal of Gear Manufacturing

FEATURES

INSPECTION FOCUS

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DEPARTMENTS

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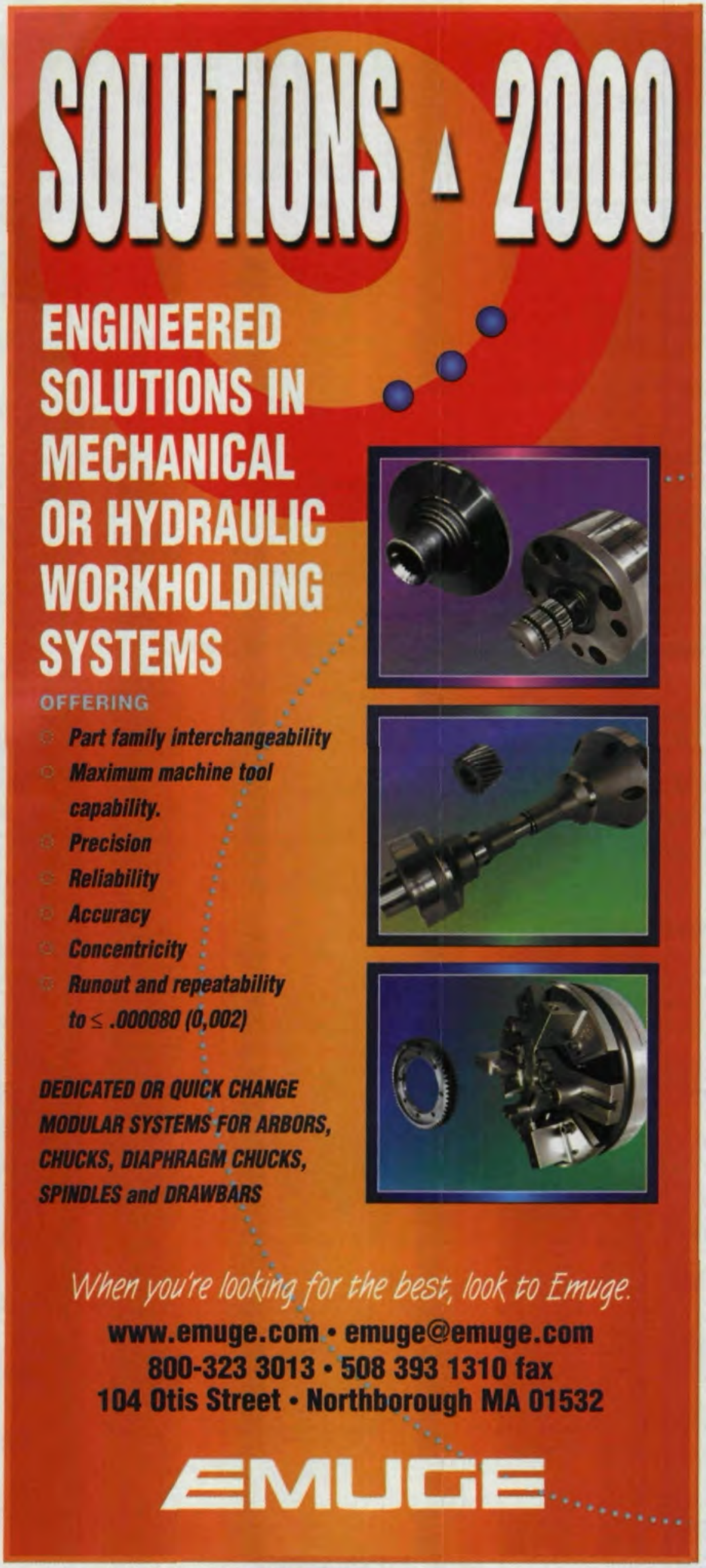
Cover photo courtesy of DSM Engineering Plastics, Reading, PA.



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CIRCLE 119

GEAR TECHNOLOGY

The Journal of Gear Manufacturing

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DON'T PANIC!

I'm a big believer in the value of IMTS as a marketplace where gear manufacturers can go and look at the latest machine tools and processes; compare hobbing machines, gear grinders and inspection equipment; see turning, milling or grinding machines in action; and ask questions of the various vendors all in one place. This year's IMTS promises to be the biggest ever, and I have no doubt that it will be a valuable experience to those who go there looking for ways to improve the way they manufacture products.

But there will be a new breed of exhibitor at this year's IMTS. They'll try to lure you to their booths with the candy of e-commerce and all it entails. They'll try to convince you that you need them and that you can't survive without them. These "dot-com" companies are ready to show you the wonders of the new economy, and they're waiting for you.

I'm sure you've run across them already. These guys are everywhere. Their promotions have infested my mailbox, my magazines, my computer—even the billboards I see on my way to work. Over the past couple of years, the dot-coms—along with their supporting cast of venture capitalists, programmers and ad agencies—have discovered the industrial marketplace. Lately, they've made so much noise that they've managed to create, in some areas, a sense of panic.

These companies say they can revolutionize the way you do business and that E-commerce is the future. They say their newest systems for online auctions, requests for quote, negotiating platforms, supply chain integration, or any of a thousand other buzzwords will put you ahead of your competition. The implicit threat, of course, is that if you don't take advantage of this new technology, you'll be left out of business and wondering what happened. My advice to you is: Ignore the hype and look at what is really going on.

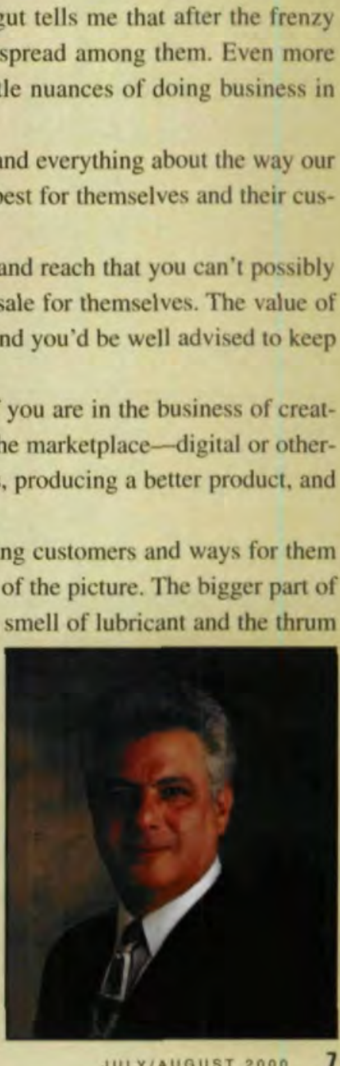
Many of the dot-coms make it sound as though they've invented new marketplaces, when, in reality, they're just tapping into markets that already exist. But they're not creating markets; they're feeding off of them. My gut tells me that after the frenzy dies down, most of these companies won't be around. There simply isn't enough business to spread among them. Even more important, many of these companies don't understand or address the normal rhythms and subtle nuances of doing business in the niches they're targeting.

Some of these dot-coms will not survive, but some of them will. While they may not understand everything about the way our businesses are conducted, and while they're still experimenting to find the model that will work best for themselves and their customers, these companies do have the potential of offering some value.

Whether you are looking to buy industrial goods or sell them, the Internet offers efficiencies and reach that you can't possibly get by phone, fax or travel. Most of the dot-coms will only slice off a small percentage of each sale for themselves. The value of finding new suppliers or customers, or the value of finding them faster, may be worth the price, and you'd be well advised to keep yourself informed about these companies and the possibilities they offer.

But it may be too easy to forget that there's more to see at IMTS than the dot-coms. Most of you are in the business of creating value for your customers. Even in the Internet Age, the things that will bring you success in the marketplace—digital or otherwise—are the same things that have always brought you success, such as serving your customers, producing a better product, and offering a fair price.

The advantages of the Internet boil down to faster and better communication, ways of reaching customers and ways for them to reach you and find you that didn't exist ten years ago. But the Internet is still only a small part of the picture. The bigger part of the picture is what you'll find at the *rest* of IMTS—you know, the part with the chips flying, the smell of lubricant and the thrum of the machine tools.



We can't forget that IMTS is the International *Manufacturing* Technology Show, and manufacturing is what it's all about. When you to go to the show, you might be lured into the booths of the dot-coms, and I encourage you to learn all you can while you're there. But don't let it take time away from the rest of the show. The focus should still be on the iron. Cutting chips (along with any number of other gear manufacturing operations) is where *you* create value for your customers.

Michael Goldstein, Publisher and Editor-in-Chief

Finally available:

The Truth

When it comes to gear grinding you will hardly find anybody who can tell which gear grinding machine or grinding method is the best for your job:

The profile form- or the profile generating method.

Self styled gear gurus claim in so called gear clinics to know it but are hardly able to calculate a realistic grinding time for your gears nor do they know different products available in the market. If you ask most machine tool makers or their friendly sales people for help, they will off course tell you their method is the best.

Don't believe it, ask for proof.

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CIRCLE 112

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.

Plastic Gears with Steel Cores

Applications requiring the self-lubrication, wear resistance and quiet operation of nylon gears, but which are too demanding for solid plastic, might benefit from the use of plastic gears with steel cores.

One company offering a solution in this area is DSM Engineering Plastics, which specializes in the manufacture of plastics suitable for machining. Their Nylasteel™ product is designed for manufacturers of gears, rollers, pulleys, wheels and sprockets. The composite stock shapes are available in standard configurations or with custom-designed steel cores. The steel core allows Nylasteel™ gears to be attached to a steel shaft the same way as steel gears are, including press-fit, bolt-circle or keyway.

Nylasteel™ billets come in diameters up to 10.5" and lengths up to 24", with steel core diameters from 1.5" to 4.5". The billets can be saw-cut and machined on a gear hobber.

DSM can also manufacture custom-designed hubs, including those that extend beyond the face width.

Nylasteel™ blanks and billets are available with several nylon varieties and either cold-rolled 1117 steel or stainless cores.

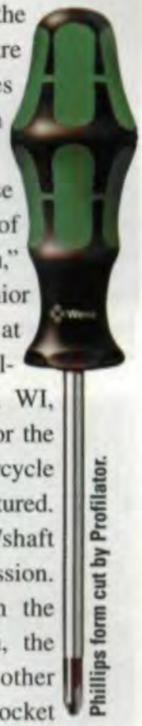
Circle 250

Profile Cutting

You wouldn't think that the technology used for making hand tools would be of much use to a gear manufacturer. But Wera Werk GmbH, a fifty-year-old German company that has developed an expertise in manufacturing screwdrivers, screwdriver bits and other geometrically profiled components, produces and sells a machine tool called the Profilator, which can be used to generate a variety of profiles, including involute tooth forms, face couplings and other forms that may be useful to gear manufacturers.

The Profilator uses electronically synchronized rotation of the workpiece and cutting tool to produce geometric forms ranging from front serrations, squares, hexagons and other polygonal shapes to hand-tool profiles such as Phillips or Torx®.

Harley-Davidson uses Profilator machines to produce the drive lugs on their motorcycles' transmission gears. The lugs are a coupling device similar to a Curvic® coupling, according to Jim Eaton, Vice President of Sales for American Wera, Inc., which handles sales of the Wera machines. The lugs are manufactured using carbide inserts in a generating process where the workpiece and cutter are positioned 180 degrees from each other, Eaton says.



Phillips form cut by Profilator.

"Of the 10 gears we use in a transmission, six of them have lugs on them," says Denny Digman, senior manufacturing engineer at Harley's Pilgrim Road facility in Menomonee Falls, WI, where the transmissions for the Cruiser and Touring motorcycle powertrains are manufactured. "There are two gear/shaft assemblies in a transmission. When the gears shift on the shaft of the transmission, the lugs engage either to other lugged gears or to a pocket gear."

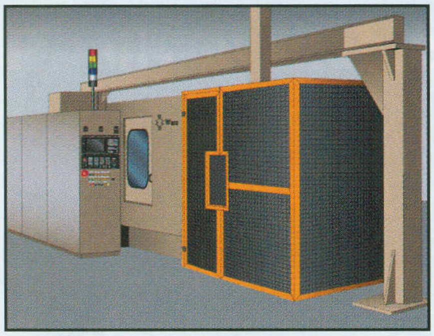
The Profilator machines at Harley-Davidson are all fully automated. The workpieces are picked up from a conveyor, machined, and dropped back on another conveyor, and double-sided parts are accommodated with an internal turnaround device.

Another example of these machines in action is at the Ford Motor Company's ZF-Batavia plant in Batavia, OH, where the company uses the machines to produce a 30-tooth involute spline for sport utility transmissions.

Normally, the manufacturer would employ blind spline broaching to manufacture this type of part, says Gerald Hounchell, division process engineer at the ZF-Batavia plant. "With blind spline,

Spline on differential case generated by Profilator.

Forms generated by Profilator.

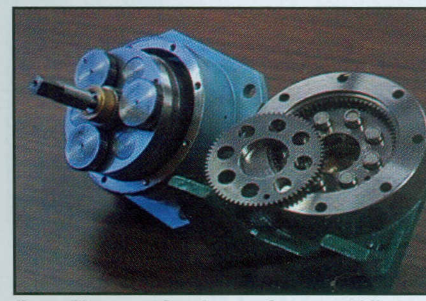


The Wera RM-140. Courtesy of American Wera.

you need an undercut," Hounchell says. "We found, however, that the undercut weakened the parts so much that they would snap off in the transmission under high torque conditions." The Profilator machine is able to cut the part without the undercut required by blind spline broaching. It also doesn't need coolant or other cutting fluids, and it doesn't require any costly finish grinding process.

The cutting process used by the Profilator machines at ZF-Batavia is similar to hobbing, except that the cutting tool is a fly cutter with rough and finish inserts. Multiple rows of inserts can be placed on each arbor, so that when one set wears down, you can shift down to another set on the same arbor. Instead of costly regrinding or resharpening of the cutting tool, the manufacturer just has to replace the inserts, says Eaton, resulting in savings on overall tooling costs.

Circle 251



Ikona Planetary Gearboxes. Courtesy of Ikona Gear Technology Inc.

The Ikona Gear: A New Planetary Gear System

In the ongoing battle to increase torque and efficiency while decreasing size, Ikona Gear Technology, Inc., of Vancouver, British Columbia, is offering a single-stage planetary speed reducer that company president Laith I. Nosh says is the first major invention of its type to be patented since the 1950s. "Most patents are for layouts using tooth forms that were invented years ago," says Nosh. Originally developed in Russia for the MI-2E helicopter, the Ikona tooth has a somewhat similar appearance to the traditional involute tooth. However, Ikona teeth are non-involute. The pinion teeth have convex profiles, while those of the internal gear are concave, making for favorable contact conditions. According to Nosh, the Ikona tooth form is new and offers important advantages in the areas of achievable ratios, zero backlash and rated torque.

Achievable Ratios. "An important advantage of the Ikona tooth form for internal gear pairs," says Nosh, "is the that the difference in the tooth numbers between the pinion and the internal gear

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can be as small as one without causing tip interference." Nosh explains when the Ikona tooth form is used in otherwise conventional planetary gear trains, the range of achievable ratios becomes enormous.

According to Nosh, a designer can use the Ikona tooth form to obtain any ratio between 9 and 5,000 with an error of less than 0.1%. "Ikona's single-stage layout means that for any specific ratio, we can design a reducer that is much more compact and efficient than a comparable multi-stage reducer." An example of this can be found in a job Ikona is doing for a steel producer. "We are now building two 100-HP units that need to fit into spaces for 10-HP units," said Nosh. "The existing 20-HP units had been failing on a continuing basis and they needed a more reliable planetary to fit into the same space."

Contact Ratios. Another advantage Nosh sees in the Ikona tooth form, and where he says it fares better than the involute form, is in the area of contact ratio. "With the involute tooth form, the contact ratio is approximately 1.8, producing a maximum torque that is limited by the highest tooth force which can be carried by a single tooth pair," said Nosh. Higher torque means large teeth and a large gear system. In the Ikona the contact ratio is larger—in many cases much larger—than the ratio for an involute gear, allowing for the transmission of large torque output as well as for the zero backlash qualities that Nosh says are inherent in the design.

Rated Torque. According to Nosh, the rating methods for spur gears published by the AGMA and the ISO are not appropriate to Ikona gears. However, practical experience can serve as a guide to the designer and could ultimately lead to such ratings. "To take advantage of the Ikona tooth form," said Nosh, "it is preferable to use a gear pair in which the contact ratio is as large as possible. Clearly, multiple tooth contacts will allow output torque that is considerably higher than that carried by involute teeth." Nosh also said, "Companies presently considering licensing the technology have spent a lot of money to develop new products, only to see them duplicated by others a year later. The Ikona Gear System will prevent this from happening since it is hard to reverse-engineer the Ikona tooth form. These companies also like the fact that no special equipment is needed to manufacture the Ikona gear." ✪

Circle 252

Tell Us What You Think . . .

If you found this column of interest and/or useful, please **circle 201.**

If you did not care for this column **circle 202.**

If you would like to respond to this or any other article in this edition of *Gear Technology*, please fax your response to the attention of Charles Cooper, senior editor, at 847-437-6618 or send an e-mail message to *Charles@geartechnology.com.*

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CIRCLE 130

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CIRCLE 158

The IMTS 2000 Primer

Charles M. Cooper

WHAT IS IMTS?

Founded in 1927 as the Machine Tool Show and held every two years, the International Manufacturing Technology Show (IMTS) has grown into the largest manufacturing trade show in both North and South America. The statistics for the 1998 show offer a glimpse of this magnitude. Over 1,440 exhibitors showed off 60 million pounds of machinery and went through 5 million pounds of display materials during the week long show. The show organizers themselves sent out 2,632,560 promotional pieces. Twenty-three foreign machine tool associations participated. It took 4,600 trucks to get everything to McCormick Place for the show. There were 450 journalists covering the event, which was attended by 121,764 people. There was $1,034,618,000 worth of business transacted on the show floor of IMTS 1998.

Because of the scope of the show—and this one promises to be even larger than the last one—everyone involved in manufacturing or in the purchase of manufacturing machines from the shop floor to the executive suite will benefit from a visit to IMTS 2000. This will be your best chance to see machines from 36 countries up and running and to talk to the people who build them.

In addition to the exhibits, IMTS 2000 will host technical conferences sponsored jointly by the Society of Manufacturing Engineers (SME) and the Association For Manufacturing Technology (AMT) covering a variety of industrial and manufacturing topics (see "Technical Conferences"). IMTS will also host The Student Summit, which offers students a chance to see what manufacturing is really all about as a viable career choice.

IMTS 2000 FAQs

WHAT ARE THE DATES AND LOCATION?
September 6-13, 2000
McCormick Place
2301 S. Lake Shore Drive, Chicago, Illinois, 60616 USA

WHAT ARE THE EXHIBIT HOURS?
9:00 am – 5:00 pm – Lakeside Center (East) & North Building Level C
10:00 am – 6:00 pm – South Building & North Building
*10:00 am – 4:00 pm – Sunday, September 10 Only-All Buildings

WHAT ARE THE IMTS 2000 REGISTRATION FEES?
$20 until August 4, 2000
$30 after August 4, 2000
After September 1, 2000, you must register on-site for $30.

WHERE DO I GET MORE INFORMATION?
Call the IMTS Trade Show at 1-800-828-SHOW (7469) or log onto their website at *www.imts.com.*

A show the size of IMTS requires a venue that can not only accommodate, but also complement, the show. McCormick Place, on Chicago's lakefront, is the largest convention space in the United States and the only one large enough to handle a show the size of IMTS. Taking care of travel and accommodations is the responsibility of Travel Technology Group, which has been appointed to coordinate and manage travel and hotel arrangements for exhibitors and attendees alike (see "Traveling to IMTS.").

THERE IS GOING TO BE A LOT GOING ON AT IMTS 2000. HERE IS A TASTE OF WHAT YOU CAN EXPECT.

TECHNICAL CONFERENCES

The Society of Manufacturing Engineers (SME) and The Association for Manufacturing Technology (AMT) have once again developed a comprehensive educational conference to run concurrently with IMTS. Called the IMTS 2000 Manufacturing Conference, it brings together experts from industry to give attendees the most useful and up-to-date technical information available. The big difference this year is the new format, which offers three new opportunities for you to benefit from the conference. They include keynote presentations from top industry professionals dealing with strategic manufacturing practices and the economy's effect on manufacturing. There will also be technology forums, presenting the latest in manufacturing technology from industry leaders, followed by Q & A style panel discussions as well as both full- and half-day conferences on a variety of topics. These include machining and grinding, forming, plastics, management practices, factory automation, design engineering, computer technology solutions, environmental issues and leadership development.

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TOUR THE PAVILIONS

To make finding the companies and products you want to see easier, IMTS 2000 is organized into various pavilions. They include: Abrasive Machining, Sawing and Finishing; Business Services, Controls & CAD-CAM, EDM, Gear Generation, Lasers & Laser Systems, Machine Components/Cleaning/Environmental, Metal Cutting, Metal Forming & Fabricating, Quality Assurance, and Tooling & Workholding Systems.

Abrasive Machining, Sawing and Finishing Pavilion (North Building—Hall B)

The Abrasive Machining section will include various types of grinders including cylindrical, internal, angular wheelside, creep feed, centerless, surface, abrasive belt, jig, tool and cutter, and universal grinders. The section will also feature abrasive cutoff machines. The Sawing area will feature band, circular and hack saws. Finishing equipment will include machines for buffing and polishing, vibratory finishing and lapping. Deburring and marking equipment will also be featured.

Business Services (North Building—Concourse Lobby)

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

Controls & CAD-CAM (East Building—Hall D)

Featured in the 2000 show are CIM/CAD/CAM systems, CNC controls, automation management systems, communications systems and LAN, software development services, computers and software, instruments, controls and systems integration services.

EDM (East Building—Hall D)

IMTS 2000 promises to be one of the largest gatherings of electrical discharge machinery and related equipment manufacturers under one roof. Products and technologies on display will include wire EDM, ram type EDM, EDM filtration systems and supplies, metal disintegrators and die sinking machines.

Gear Generation (North Building—Hall B)

Over 19,000 square feet of floor space will be occupied by exhibits from nearly every major company serving the gear industry. Manufacturers of gears and related equipment will find gear hobbing, shaping, shaving, skiving, rolling, grinding, lapping and measurement systems in this pavilion. See "Places to Visit" for a listing of gear industry vendors you do not want to miss.

Lasers & Laser Systems (North Building—Hall B)

World leaders in laser production and laser technology in manufacturing will feature a wide range of applications including metal cutting, marking, scribing, drilling, cladding, trimming, engraving, welding, heat treating and measurement.

Machine Components/Cleaning/Environmental (East Building—Hall D)

The Machine Components/Cleaning/Environmental Pavilion features the newest equipment, machine components, engineering services, environmental protection services and services for air, water and oil filtration and purification, safety guards, mats and equipment. Noise control equipment, electrical equipment, way covers/tracks, storage systems, parts cleaners, parts washers, materials handling/storage systems, ball screws, bearings, spindles, conveyors, AGVs, coatings, servo motors, pumps, degreasers, robotics, plant maintenance equipment, assembly and test equipment, motion control equipment and environmental management software will also be on display.

Metal Cutting (South Building – Hall A & North Building—Hall C)

This is the largest pavilion at IMTS 2000. It will feature over 600,000 square feet of machining centers, turning centers, milling machines, boring machines, drilling machines, transfer machines, screw machines, broaching machines, skiving/roller burnishing machines, gun drilling machines, plano/mills, boring mills, multiple spindle drills, drill/mill/bore heads and slides, thread rolling, jig boring/milling machines, and whirling machines.

Metal Forming & Fabricating (North Building—Hall B)

This pavilion features straight-side, OBI and hydraulic presses, water jet cutting equipment, CNC turret punch presses, tube and pipe benders, press brakes, roll benders, shears, welding and robotics welding equipment, hot and cold forming technology, spinning machines, wire forming, forming cells and systems, foundry/casting and investment casting equipment, plasma cutting, friction welding, stress relief equipment, coil and sheet handling equipment and plate benders.

Quality Assurance (East Building—Hall D)

Products and services here will include precision measuring machines, coordinate measuring machines, precision gaging, automated gaging, laser measurement, in-process gaging, tool condition monitoring equipment, measurement software, and quality and environmental management software.

Tooling & Workholding Systems (East Building—Hall E)

From angle brackets to z-axis fixturing and everything in between, the Tooling & Workholding Systems Pavilion at IMTS has it all including boring bars, cutters, drills, endmills, fixturing systems, gun drilling tools, hobs, inserts, jigs, keyseating tools, lapping tools, magnetic chucks, NC tables, over spindle adaptors, plates, quick change dies, reaming tools, screw thread inserts, tool storage equipment, universal fixturing, vises, and workholding systems.

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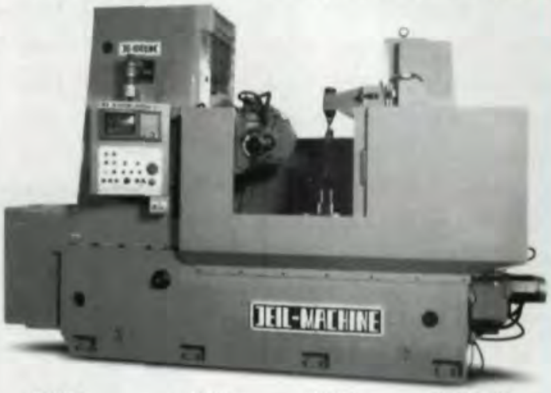

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The new Skyline Theatre at Chicago's Navy Pier hosts many outdoor concerts, theater productions and special events. (Photo: Willy Schmidt/City of Chicago.

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Travel and Technology Group (TTG), the official housing and air travel coordinators for IMTS 2000, has obtained special room blocks at numerous local hotels as well as special discounts on United Airlines and Delta Airlines. They have also worked out special rates with Avis and Alamo Car Rentals. To obtain IMTS hotel, airline and car rental rates, you must make your reservations through TTG by the July 16, 2000 deadline.

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PLACES TO VISIT

Listed below are some of the gear industry related companies you should visit on your way through IMTS 2000. Most of these booths are located in the Gear Generation Pavilion, North Building, Hall B. Those that are not are noted. Advertisers appear in boldface type—Please see page 17.

AWA, Booth 7244
Bourn & Koch Machine Tool Company, Booth 7056
Colonial Tool Group, Booth 5635 (North Building, Hall C, Metal Cutting Pavilion)
D. C. Morrison, Booth C-5650 (South Building, Hall A, Metal Cutting Pavilion)
Emuge Corp., Booth 2844 (Lakeside Center, Hall E-Level 1, Tooling and Workholding Systems Pavilion)
Forst GmbH & Co. KG, Booth 7126
Fromag GmbH & Co. KG, Booth 7144
Gleason*, Booth 6931
** This booth includes Gleason Corporation, Gleason-Hurth Maschinen und Werkzeug GmbH, Gleason Cutting Tools Corp., Gleason-Pfauter Maschinenfabrik GmbH, and The Gleason Works.*
Great Taiwan Gear Ltd./Luren, Booth 7139
Holroyd, Booth 6917 (North Building, Hall B, Abrasive Machining/Sawing/Finishing Pavilion)
Kapp GmbH Werkzeugmaschinenfabrik, Booth 6950
Kapp Sales and Service, Booth 6950
Kapp Tech, Booth 6950
KLF-ZVL, a.s. Kysucke Nove Mesto, Booth 7245
Koepfer America, L.L.C., Booth 6938
Leistritz Corp., Booth 5315 (North Building, Hall C, Metal Cutting Pavilion)
Liebherr Gear Technology Co., Booth 7040
Lorenz Cutting Tools, Booth 6953
Manufacturing Technology, Inc., Booth B-6005 (North Building, Hall B, Metal forming and fabricating Pavilion)
Mitsubishi Machine Tools, Booth 8260 (South Building, Hall A, Metal Cutting Pavilion)
Mitts & Merrill L.P., Booth 7144
M & M Precision Systems Corp., Booth 7132
National Broach & Machine Co., Booth 7048
NILES Werkzeugmaschinen GmbH, Booth 6950
Ohio Broach and Machine Co., Booth A-8675
Progress Promotion Ltd., Booth 7245
Reishauer Corporation, Booth 7033
Richardon, Booth 7033 (North Building, Hall B, Abrasive Machining/Sawing/Finishing Pavilion)
S. L. Munson, Booth B-6865 (North Building, Hall B, Abrasive Machining/Sawing/Finishing Pavilion)
Samputensili/SU America, Inc., Booth 7047
J. Schneeberger Corporation, Booth 7053
Star Cutter Company, Booth 6953 (Also at Booths E-2700 & E-2701)
Stieber Clamping Tools GmbH, Booth 6953
Suhner Manufacturing, Inc., Booth 2633 (Lake Center, Hall E, Level 1, Tooling & Workholding Systems Pavilion)
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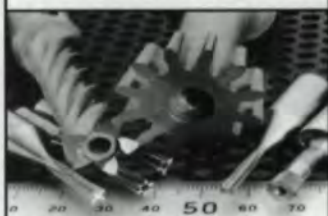

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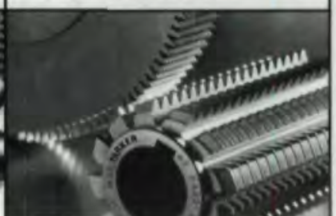

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CIRCLE 153

The Math of Noncircular Gearing

William C. Smith

GLOSSARY

TERMS

Pitch Point: The tangent point viewed in the transverse plane of the gear where the pitch curve rolls with the pitch curve of a rack or another gear. During mesh this point will move, but it will always lie on the line of centers.

Angle of obliquity: For two rolling pitch curves, the angle between the line of centers and the common normal through the pitch point.

Normal: As an adjective: being at right angles. As a noun: a straight line which meets a surface perpendicularly.

Array: The collection of coordinate points which describe a form. There may be, for example, an x array and a y array, but these may be spoken of collectively as the x,y array.

Index: Array elements are numbered starting at one. The index is a number which points to a particular element or coordinate in its array.

Slope angle: The angle from the positive X axis to a line which is tangent to a form at a given point.

Slope: The tangent of the slope angle.

Line-arc geometry: A form made up of a series of arcs and/or lines all connected end to end.

SYMBOLS

Gear pitch curve polar coordinates: rg, θg

Rack pitch curve rectangular coordinates: xrpl, yrpl

Gear tooth form rectangular coordinates: xgt, ygt

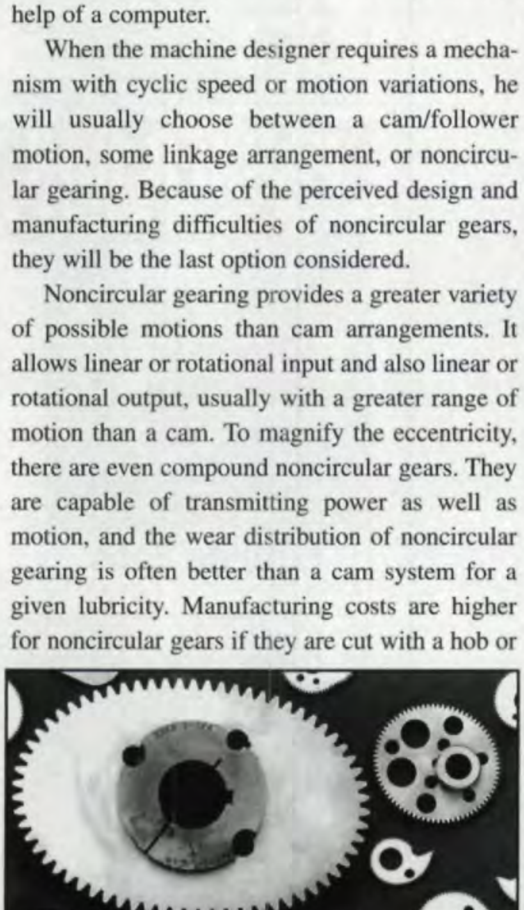
Rack tooth form rectangular coordinates: xrt, yrt

Slope at xrt,yrt: srt

Noncircular gearing is not new. There are well-documented articles covering standard and high order elliptical gears, sinusoidal gears, logarithmic spiral gears, and circular gears mounted eccentrically. What these designs have in common is a pitch curve defined by a mathematical function. This article will cover noncircular gearing with free-form pitch curves, which, of course, includes all the aforementioned functions. This article also goes into the generation of teeth on the pitch curve, which is not usually covered in the technical literature. Needless to say, all this is possible only with the help of a computer.

When the machine designer requires a mechanism with cyclic speed or motion variations, he will usually choose between a cam/follower motion, some linkage arrangement, or noncircular gearing. Because of the perceived design and manufacturing difficulties of noncircular gears, they will be the last option considered.

Noncircular gearing provides a greater variety of possible motions than cam arrangements. It allows linear or rotational input and also linear or rotational output, usually with a greater range of motion than a cam. To magnify the eccentricity, there are even compound noncircular gears. They are capable of transmitting power as well as motion, and the wear distribution of noncircular gearing is often better than a cam system for a given lubricity. Manufacturing costs are higher for noncircular gears if they are cut with a hob or shaper cutter, but for high-volume stamped, molded, broached, or extruded parts, the costs are comparable to cam systems. Prototypes are often cut by wire EDM.



Elliptical and other non circular gears. Courtesy of Cunningham Industries, Inc.

The design starts the same way you would design a cam, by knowing the required output displacement, velocities and accelerations, and calculating the pitch curves accordingly. The pitch curves may be closed for continuous motion, or open for motion limited to less than one revolution. This article starts with the assumption that you have done the preliminary work and know the pitch curve form. However, you may wish to use the math presented here for trial and error design work.

Noncircular gearing shares many characteristics with both ordinary gearing and cams. The pitch circles of ordinary gears roll together without slipping and are tangent at the line of centers. Similarly, the pitch curves of noncircular gears roll without slipping and are tangent at the line of centers. Noncircular gears may be external or internal. They can also be helical, although this adds greatly to the complexity of their manufacture. The universal law of gear tooth action applies to both ordinary gearing and noncircular gearing. This law states that the common normal through the contact point of two gear teeth in mesh must pass through the pitch point (the pitch point being the contact point of the two pitch curves). Applying this law determines the tooth profile of a mating gear, whatever arbitrary tooth profile may be chosen for the known gear. Also note that if the tooth profile is such that the normal at some point does not intersect its pitch curve, there is no solution for the mating tooth at that point.

Ordinary gears are always associated with a rack form whose pitch line rolls with the gear pitch circle. Similarly, noncircular gears are associated with a rack whose pitch curve rolls with the noncircular gear pitch curve. This rack association is important because two gears which mesh with the opposite sides of a rack profile, will mesh with each other. This implies that we only have to know the mathematical relation between a gear and a rack instead of having to know the relation between two gears.

Another aspect of the rack is that, if the rack teeth are straight-sided and all have the same pressure angle, the center distance mounting of the system is very forgiving—just like the mounting of ordinary involute gears. Unfortunately, most designs have too much rise to allow this, and the rack teeth pressure angles must vary to follow the pitch curve. Because each noncircular gear tooth is wedded to a particular mating gear or rack space, the teeth do not need to be all alike. There is no restraint on the thickness, height or pitch of the teeth as long as a contact ratio of at least one is maintained. Improved mesh may be achieved if the gear's dedendum can be reduced on parts of the pitch curve that are closest to the center of rotation. This relationship is very much the same as in ordinary gearing where a rule of thumb is that the ratio of the gear dedendum to the gear pitch radius should be less than 0.14 to avoid undercutting at the gear root.

Cams and noncircular gears also share a minimum size restraint in their design. For cams, it is a well-known fact that when the ratio of the total rise to the cam minor radius increases to a critical level, there will be a point where the pressure angle of the cam system becomes unacceptably large. Similarly, for a noncircular gear, when the ratio of the rise of the pitch curve to the pitch curve minimum radius increases to a critical level, there will be a point where the angle of obliquity becomes unacceptably large, 45 degrees being the usual limit. A large angle of obliquity also makes it difficult to design proper-meshing gear teeth.

The free-form definition of the pitch curve is usually made in terms of line-arc geometry, but it could also consist of one or more mathematical functions. To apply the math, the curve must be redefined as a closely spaced set of rectangular coordinates for the rack curve or polar coordinates for the gear curve. Typically the spacing will be about .0004 inches or .0005 radians. The calculations are surprisingly simple.

For our analysis, we will always use the gear center as the origin for both the gear form coordinates and the rack form coordinates. The polar coordinates for the gear pitch curve do not have the standard 'textbook' configuration—angles start at zero on the positive Y-axis and proceed clockwise. Figure 1 shows the axis system with a sample closed pitch curve consisting of three arcs

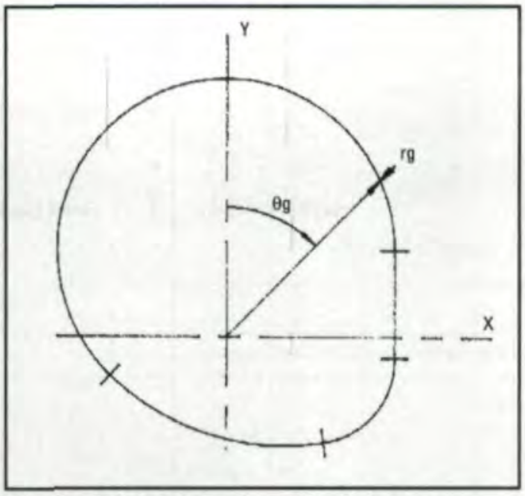


Fig. 1—Axis system and sample pitch curve.

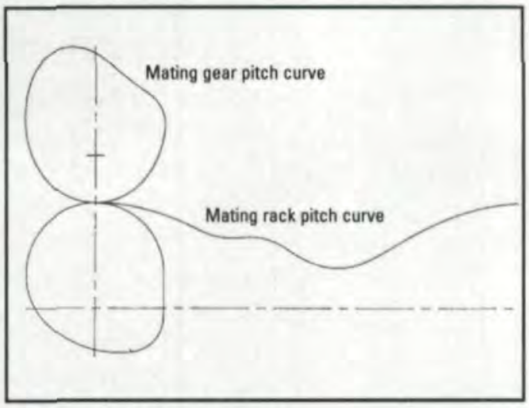


Fig. 2—Mating pitch curves.

and a line. The Glossary (See sidebar) defines the terms and symbols used in this article.

If the given pitch curve is for a gear, then the rack pitch curve is defined by the following algorithm:

1. Select the first point (rg, θg) on the gear pitch curve and set the first rack pitch curve coordinates: xrpl=0, yrpl=rg.
2. If θg equals zero then set XSHF=xrpl.
   Set XSAV=xrpl, YSAV=yrpl, ASAV=θg.

   If there are no more points to process then go to step 3.

   Select the next point (rg, θg) on the gear pitch curve and calculate the next rack pitch curve coordinates:

   xrpl=XSAV + YSAV • sine(θg-ASAV), yrpl=rg.

   Go to step 2.
3. Subtract XSHF from each xrpl coordinate.
   Exit the algorithm.

If the given pitch curve is for a rack, then the gear pitch curve is defined by the following algorithm:

1. Select the first point (xrpl,yrpl) on the rack pitch curve and set the first gear pitch curve coordinates: rg=yrpl , θg=0.
2. If xrpl equals zero then set ROT = θg.

   If there are no more points to process, then go to step 3.

William C. Smith

was employed as Principal Engineer/Scientist at Barber-Colman Company for many years and is now self-employed as a consultant and owner of Software Engineering Service. He has authored several articles on gear manufacturing and many computer programs in the area of gear cutting tool design and manufacture.

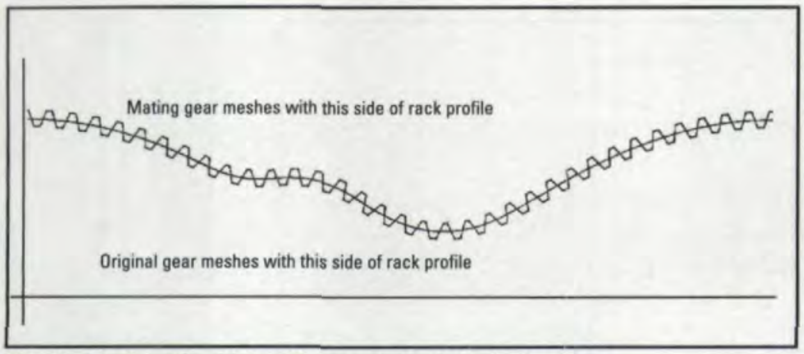


Fig. 3—Rack teeth which will generate teeth for both gears.

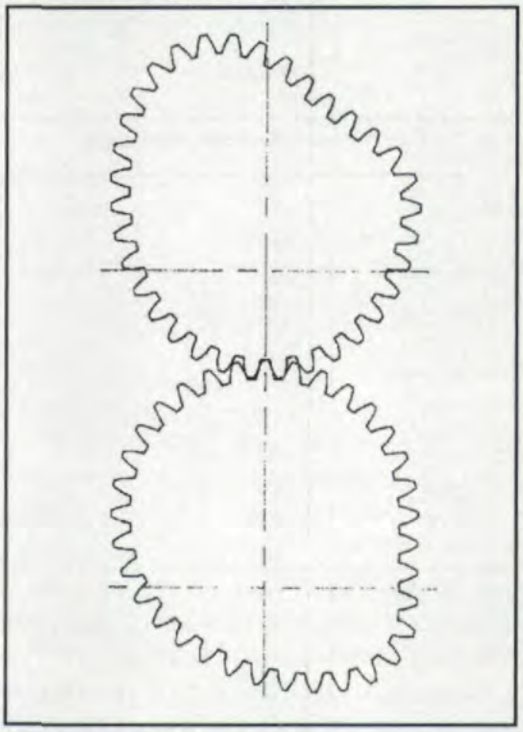


Fig. 4—Meshing noncircular gears.

Set RSAV=rg, ASAV=θg, XSAV=xrpl.

Select the next point (xrpl,yrpl) on the rack pitch curve.

Calculate the next gear pitch curve coordinates:

rg=yrpl, θg=ASAV + arcsin((xrpl-XSAV)/RSAV)

Go to step 2.

3. Subtract ROT from each θg coordinate.

Exit the algorithm.

Note that to simplify step 2 of both algorithms, we have assumed there will be a xrpl or a θg coordinate of exactly zero. Since this is not ordinarily the case unless you start at zero, you will need to prescan the (xrpl, yrpl) array or the (rg, θg) array and force a coordinate at zero using simple interpolation.

In both cases the resultant pitch curve coordinates should be converted to line-arc geometry using a curve-fitting utility and the length of the pitch curve calculated. If it is not equal to the length of the mating pitch curve within about .0001 inches, then the coordinate point spacing should be reduced and the algorithm applied again. These small increments simulate the calculus operation that would be applied to a pitch curve defined by a mathematical function. Double precision arithmetic should be used in the computer for these incremental summations in order to avoid loss by rounding.

Figure 2 shows the rack pitch curve developed from the sample in Figure 1 as well as the second mating gear pitch curve developed from the rack pitch curve. In order to maintain the same axis configuration, the rack pitch curve is inverted and shifted vertically to calculate the second mating gear pitch curve. Then the second gear is reinverted to put it in running position with the first gear.

Now we can position teeth along the rack pitch curve. This can be done in several ways. The preferred method is to use a program to scan through the (xrpl, yrpl) array—starting at a measurement that can represent the start of either a tooth or a space, and then continuing to measure through the array, alternately finding tooth and space positions at regular intervals. The measurement accumulates from point to point by calculating the straight-line distance between points, ignoring curvature. This usually requires interpolation between adjacent coordinate points to find an exact tooth position. The result is a table of X, Y coordinates along the rack pitch curve through which the rack teeth must pass. This table is then used in a CAD system to form the straight-sided rack teeth in line-arc geometry, or because of the simplicity of working with straight lines, a program could be written to calculate the rack teeth geometry. This rack tooth geometry should be continuous with root elements and tip elements connecting the flanks. If the corresponding mating gear pitch curve is closed, which signifies a complete revolution, there should be an integral number of teeth whose spacing can be calculated by dividing the length of the pitch curve by the desired number of teeth. The origin for the rack teeth geometry must be at the center of the gear. Figure 3 shows the rack teeth laid out on its pitch curve. The following data can now be used to calculate the mating teeth form:

1. The rack pitch curve form expressed in line arc format.
2. The rack teeth geometry expressed as an array of closely spaced (xrt, yrt) coordinates with slope srt. In practice, you don't need to generate this array at all. Using line-arc format for the rack tooth geometry, pick off one (xrt, yrt, srt) point at a time from the line-arc ele-

ments as the program loop is processed.

3. The xrpl array of rack pitch curve coordinates calculated earlier.
4. The θg array of gear pitch curve coordinates calculated earlier.

The combined (xrpl, θg) array represented by 3 and 4 above is a one-to-one correspondence of rack translation and gear rotation. Use the following algorithm to find the form of the mating teeth expressed as the (xgt, ygt) array:

1. Select a point (xrt, yrt, srt). If there are no more points then exit.
2. Calculate the slope of the normal through (xrt, yrt): sn=-1/srt. This now defines the normal as a line through (xrt, yrt) with slope sn.
3. Calculate the intersection point (xi, yi) where the normal intersects the rack pitch curve. (Use a routine that calculates the intersection point of either two lines or a line and circle. The pitch curve is operated on one segment at a time and checked to see whether the intersetion lies within the segment boundaries. If it does, the intersection has been found. The original array of (xrpl,yrpl) points could also be used to find the intersection instead of using its line-arc equivalent.)
4. Scan the xrpl array to find the index, IX, in the array where xrpl equals xi, which will most likely lie between two adjacent values in the xrpl array. Use linear interpolation to find the fractional position: FRACTION = (xi - xrpl(IX)) / (xrpl(IX+1) - xrpl(IX)).
5. Find the corresponding angle in the θg array: ANGLE = θg(IX) + FRACTION * (θg(IX+1) - θg(IX))
6. Calculate the gear tooth coordinates:
   xgt=(xrt-xi) • cosine(ANGLE) + yrt • sine(ANGLE)
   ygt=yrt • cosine(ANGLE) - (xrt-xi) • sine(ANGLE)
7. Go to step 1

In step 3 of the algorithm, we have simplified the process by assuming that there will be only one intersection point. You may need to consider the possibility of two or more intersections. If there is more than one intersection, only one of them will be correct. You will need to program an inner loop in which separate (xgt, ygt) pairs are calculated for each intersection and then the pair which is closest to the previous point is chosen. The best technique for searching the pitch curve for the intersection point is to start the scan on the pitch curve segment closest to the xrt value under consideration. Then alternately scan the segments left and right of the starting segment. This gives you the best chance of finding the correct intersection first.

There may be intersection points (xi,yi) missed because the rack pitch curve is not wide enough. If the curve corresponds exactly to a complete revolution of the mating gear, then a portion of the end of the rack pitch curve should be copied, horizontally shifted and appended to the beginning. A portion of the beginning should be copied, horizontally shifted and appended to the end. The shift value applied to the copied portions should be the exact X-extent of the pitch curve. Each portion should be long enough to contain about 3 teeth. The program needs to realize when it has found an intersection in the extended range so that, before searching for a match in the (xrpl, θg) array, xi will have the shift value added or subtracted. Only adjust xi for this search, not for calculations in step 6 of the algorithm.

The gear teeth array (xgt,ygt) is processed through a curve-fitting utility to provide line-arc geometry output and then through a smoothing utility to remove the loops which most often result from tooth generation. Figure 4 shows the two noncircular mating gears, each of which had their teeth generated by the rack teeth of Figure 3.

If you go through the effort of applying the math of this article to your own computer program, a good test of the system is to form a straight, horizontal line rack pitch curve with uniform straight-sided rack teeth. The resultant output should be an ordinary involute gear.

If you go through the effort of applying the math of this article to your own computer program, a good test of the system is to form a straight, horizontal line, rack pitch curve with uniform straight-sided rack teeth. The resultant output should be an ordinary involute gear.

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Precision Finish Hobbing

Yefim Kotlyar

Introduction

Nowadays, finish hobbing (which means that there is no post-hobbing gear finishing operation) is capable of producing higher quality gears and is growing in popularity.

This discussion addresses some of the challenges that gear makers experience when they attempt to finish hob or skive hob gears to a higher quality standard; a quality level that is higher than routinely expected in a production environment. Figure 1 shows the inspection charts of a gear with exceptional quality. One would expect such a level of quality to be the result of a secondary gear finishing operation, e.g. shaving, honing, rolling, or gear grinding. However, this gear was finished on a hobbing machine.

There are many legitimate reasons to specify a post-hobbing gear finishing operation—elimination of heat treat distortions and elevated surface finish requirements are just two. But there are also reasons that result from old paradigms, which may no longer be true.

Often, process engineers specify a post-hobbing gear finishing operation (shaving, for example) not necessarily because the gear's geometric quality and surface finish requirements are unachievable by the hobbing process, but rather because it is *difficult* to consistently achieve the desired quality. In statistical terms, the hobbing process has not been generally regarded as capable of producing AGMA quality 9 or higher (the process is considered capable when the process capability factor, Cp=Tolerance/(6Sigma), is greater than one). Another reason for specifying a post-hobbing gear finishing operation was the generative nature of the hobbing process, which creates a distinct tooth topology resulting from hob feed and enveloping marks (Fig. 2). A third reason for specifying a post-hobbing gear finishing operation was the possibility of productivity improvements during the rough hobbing. As compared to finish hobbing, the rough hobbing cycle times are usually much shorter since multi-start hobs and higher feed rates can be applied.

These paradigms can be challenged today. The continuous improvements in machine, workholding fixture, and hob quality combined with reliable QC procedures have steadily upgraded the statistical capability of the hobbing process. This, in turn, makes the finish precision hobbing process worthwhile to consider for a wider range of applications with greater precision requirements. Also, tooth surface variation due to generating marks can be minimized with the selection of an optimum hob feed rate and number of hob gashes. Tooth surface variation due to the generating marks can be so insignificant (millionths of an inch) as compared with other gear geometry errors that it may not be of concern for many gearing applications. While the visual effects of the hobbing generating marks can be dramatic, they should not be confused with the gear quality. In fact, the better the gear quality is, the more uniform the generative marks are and the greater the visual effects are. Finally, recent advancements in carbide (or comparable) cutting tool technology provide new opportunities for productivity improvements, as the increased cutting speed allowed by these tools can shorten the finish hobbing cycle time by a factor of two or three.

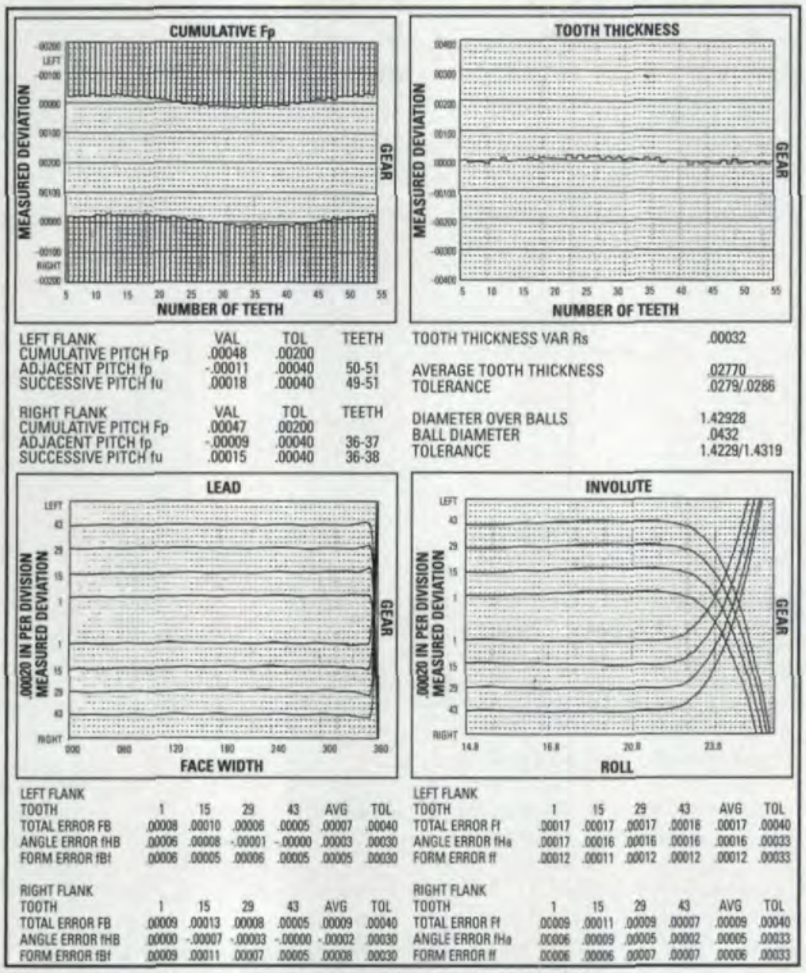

Fig. 1—Inspection charts of a gear with exceptional quality.

Effects of Hobbing Process Variables on Various Gear Characteristics

Various gear characteristics are important to overall gear quality. Some of the most common characteristics that are monitored during a gear manufacturing process are tooth lead, tooth profile, pitch variation, runout, and tooth thickness. Hobbing process quality is affected by the machine, fixture, blank, cutting tool, and cutting conditions. The hobbing machine is a very important, and certainly the most expensive, component of the hobbing process. Frequently, it is impossible to make a quality gear without a good machine. No wonder people pay the most attention to the machine. However, often the greatest contributors to gear quality are not the machine, but the fixture, the cutting tool, the blanks, the cutting conditions, or any combination thereof. These contributors affect lead, profile, pitch quality and other gear characteristics in different ways. Below is a review of some of the effects of these contributors on the quality of various gear characteristics. This review is not a comprehensive troubleshooting guide, but rather an attempt to create a checklist for gear makers who wish to consider the hobbing process for more precision gear finishing operations.

Gear Lead (Alignment) Quality. Hobbing methods can produce lead quality up to AGMA 11, 12 or even higher in a production environment. Here are some common factors that affect the gear lead quality:

- **Machine factor.** Machine rigidity is probably the most important factor. The machine must be mechanically and electronically "solid" to be able to withstand natural variation of cutting forces, especially in the beginning and the end of the cut. Today, few people (unless they use very old machines) have to deal with the notorious "break-in" and "break-out" phenomenon caused by the winding and unwinding of the machine gear train. Another flaw sometimes found in old machines is an excessive table drive backlash that can cause an irregular lead error. Most of the machine suppliers tackled both problems by creating a shorter gear train (or even a direct drive) and some kind of anti-backlash table drive. Today, many new gear hobbing machines can hob gears with a lead quality similar to that achieved by gear grinding. To be successful in attaining lead quality that approaches that of the grinding process, one must use a workholding fixture and gear blanks with qualities similar to those used during the grinding process.
- **Workholding fixture factor.** The workholding fixture is another frequent culprit that compromises the gear lead quality. Fixture geometric errors such as misalignments with the machine centerline and an inability to center the gear blank properly can increase lead wobble or lead taper. Figure 3 shows an example of lead error affected by a part's axial runout (or radial runout for high helix angle gears). Lack of fixture rigidity is another common factor skewing the gear lead away from perfection. For example, when cutting shafts, the beam between the machine table and the tailstock should be as short as possible to improve the system rigidity. In addition, the fixture should be dynamically stable and be able to absorb the cyclical variation of cutting and clamping forces.
- **Hob factor.** When gear makers are trying to achieve the best possible quality, they usually consider a one-start hob. If this is the case, neither the hob's mounting quality, the hob's inherent quality, nor the hob's sharpening quality have any direct effect on the lead characteristic. As much as the hob's geometric quality can affect a gear's profile, the geometry errors of a one-start hob have no influence on the lead quality. This is also true for multi-start hobbing with a non-hunting ratio combination (number of gear teeth is divisible by number of starts). Thus, as long as the hob cutting edges do not dramatically deteriorate, hob geometric qualities are irrelevant for achieving good gear lead characteristics. However, when a hob becomes dull, it can create an irregular surface finish, and it can have an indirect effect on the lead geometry

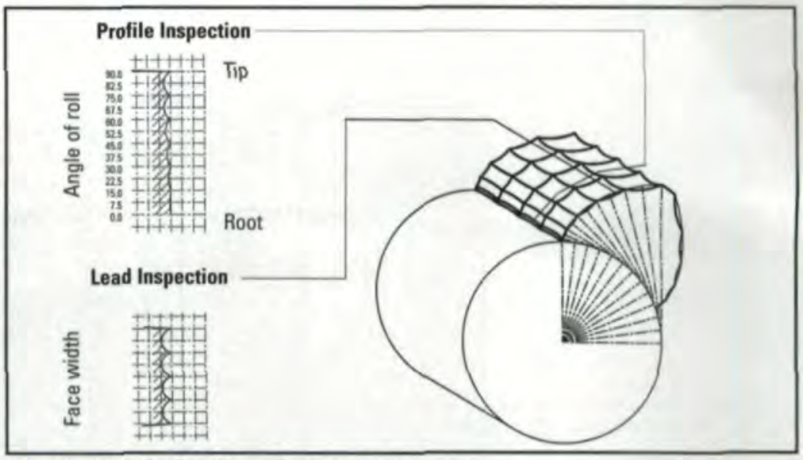

Fig. 2—Hob feed and enveloping marks.

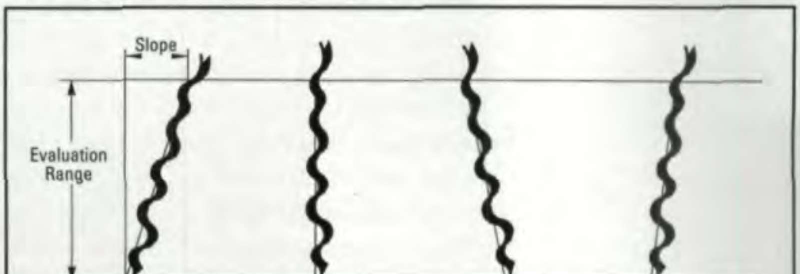

Fig. 3—Excessive slope variation can result from a fixture or blank runout.

Yefim Kotlyar
is the Gear Technology and Processing Manager at Bodine Electric Company, Chicago, IL. He is also the author of a number of articles on gear-related subjects.

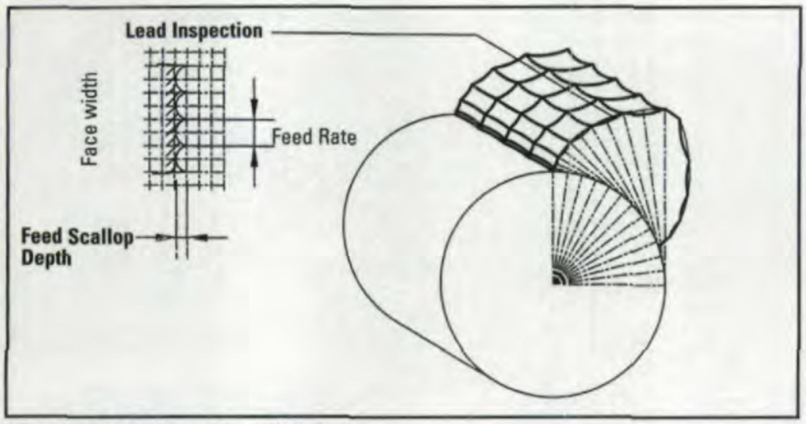

Fig. 4—Feed rate and scallop depth.

because the increased cutting forces can destabilize other factors such as fixture, blank, or machine rigidity. An irregular lead error could also be a result of a chip buildup on the hob cutting edges.

• **Gear blank factor.** Gear blank quality is another factor that can affect the lead variation. Gear mounting surfaces, i.e. bores and faces (for bore gears) or journals (for shaft gears), should be appropriately toleranced as those surfaces have a direct effect on lead quality. An inadequate blank geometry affects the slope component of the gear lead error. Figure 3 is also an example of the slope variation caused by a face-to-bore perpendicularity error. A similar error could result from excessive error in face-to-face parallelism.

• **Cutting conditions factor.** Aggressive cutting conditions can create excessive forces that may not be adequately absorbed by the fixture, thus negatively affecting lead quality. Also, as hob cutting edges wear, the cutting forces can climb considerably. In addition, oil contaminated with chips can create an irregular lead roughness. The hob feed rate also has a direct effect on tooth surface variation in the lead direction—feed scallop depth. Frequently, people who finish hob gears want the scallop depth not to exceed a certain value. The feed rate can be determined as a function of allowable feed scallop depth at the pitch circle. The effects of the feed rate on tooth surface are illustrated in Figure 4.

Hob feed rate = $\cos(\beta) \cdot \text{sqrt}\,(\delta \cdot 4 \cdot \text{HOBOD}/\sin(\alpha))$

Where:

Hob feed rate: Axial advance of hob per one work revolution, inch/rev.

β: Helix angle

δ: Allowable feed scallop depth at pitch dia., inch

α: Pressure angle

HOBOD: Hob outside diameter, inch

It is worth noting that the feed scallop depth is not constant within the entire tooth depth. It is greater at the tooth tip and smaller at the tooth root. Pitch circle is a convenient place to reference the limitation of feed scallop depth. If the gear lead is not inspected on the pitch circle, the amount of feed scallop depth shown could be different than what is expected.

• **Setup consistency factor.** There is no such thing as an identical setup. Every time the fixture is placed in the machine, there will be a different workpiece runout condition. Carl Eckberg, Vice President of Bourn & Koch, once paraphrased a joke about the three things important for real estate value: 1. Location, 2. Location, and 3. Location. He said that, likewise, there are three things that are important for hobbing quality: 1. Runout, 2. Runout, and 3. Runout. A tiny chip can contaminate a perfect fixture resulting in a dramatic lead variation. All mounting surfaces should be checked for proper runout. Consideration should be given to a fixture design that reduces the amount of possible mounting variations between setups. Also, a reliable, automatic system for removing chips from the fixture mounting surfaces, prior to loading the part, will facilitate a greater process capability.

Gear Profile (Involute) Quality. Improving gear lead and pitch characteristics is often easier than improving profile characteristics. In fact, it is not uncommon to see lead and pitch characteristics of hobbed gears at AGMA quality 11–12 and even better. However, when it comes to tooth profile quality, very few people can achieve quality higher than AGMA 9 on a consistent basis. Why such a discrepancy? One answer is that the gear profile quality is affected by a greater number of process variables. The profile quality depends on all contributors listed in the "Lead" section. However, the inherent hob geometry errors, i.e. lead; pressure angle; the sharpening quality of hob spacing, rake, and flute lead; and hob mounting quality are the additional and very significant contributors to gear profile quality.

• **Machine factor.** Worn bearings in the cutter spindle and outboard support, worn table drive, and dynamic instability of hob-worktable synchronization may create irregular profile errors.

• **Workholding fixture factor.** The fixture has a critical role for centering the part properly. An inadequate fixture can cause the workpiece to have a radial runout, or an axial runout, or a combination of both. Workpiece radial runout may dramatically affect the slope component of the profile error. For high helix angle gears, the workpiece axial runout can create a similar affect.

• **Hob factor.** This is probably the most frequent culprit causing profile errors. Unlike the gear lead, which is generated by the same hob cutting edge along the entire face width, the gear profile is generated by a large number of hob cutting edges. Every cutting edge, and its geometric relationship with adjacent cutting edges in the generating zone, affect the gear profile quality. Also, an inadequate hob mounting, with a radial or an axial runout, will simulate a condition of an inadequate hob index or lead quality. In the case of multi-start hobbing, there would be even greater numbers of quality contributors. That is why single-start hobbing is usually used when people are trying to achieve the best possible gear quality. The number of hob gashes is also important for precision gear manufacturing, especially for gears with a small number of teeth. The greater the number of gashes, the greater the number of profile generating cuts. Greater numbers of generating cuts reduce the inherent profile error (deviation from an ideal involute) created by the hobbing method. Figures 5 and 6 illustrate profile errors caused by a smaller and a larger number of gashes respectively. Profile deviation from the ideal involute caused by the enveloping cuts can be calculated. A greater number of hob gashes, which translates into a greater number of cutting edges, exponentially reduces the profile deviation (error) from the ideal involute.

$$\text{Profile deviation} = \pi^2 \cdot Zo \cdot \sin(\alpha) / (4 \cdot Z2 \cdot i^2 \cdot NDP)$$

Where:

Zo: Number of hob starts

α**:** Normal pressure angle

Z2: Number of gear teeth

i: Number of hob gashes

NDP: Normal Diametral Pitch of the gear

Profile deviation: Profile deviation from the idea involute curve, inch

• **Gear blank factor.** The gear bore quality is very important, as it can cause an inconsistent runout condition on the gear cutting vs. the gear inspection fixture. If the face of the blank is not square to the bore, a profile variation error can be observed. In the case of shafts, the journal that is used for the part clamping should be concentric with centers that might be used for locating the part during inspection. Blank errors will have a greater effect on gears with a small number of teeth, where the roll angle is very large, as well as on gears with a high helix angle.

• **Cutting conditions factor.** In case of a spur or a small helix angle gear, the tooth profile is not affected by the feed rate (Fig. 2). But in the case of gears with high helix angle, the tooth profile quality might be affected by excessive feed marks (Fig. 7). For high helix angle gears, the feed rate has to be kept under control, as it has an effect on both lead and profile form errors.

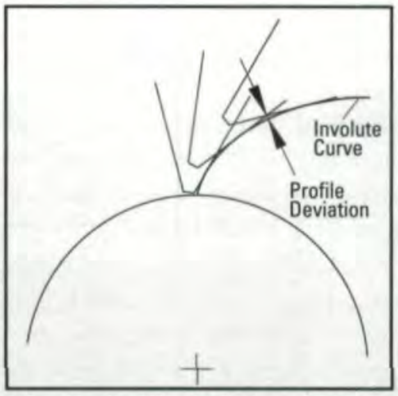

Fig. 5—Profile deviation from the ideal involute made by a hob with fewer gashes.

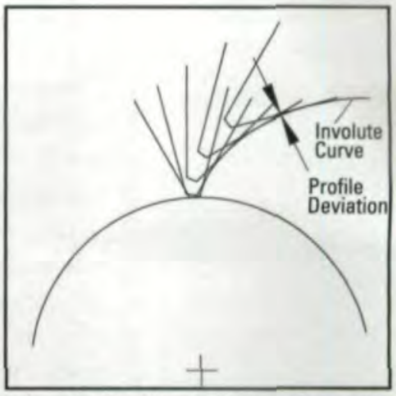

Fig. 6—Profile deviation from the ideal involute made by a hob with more gashes.

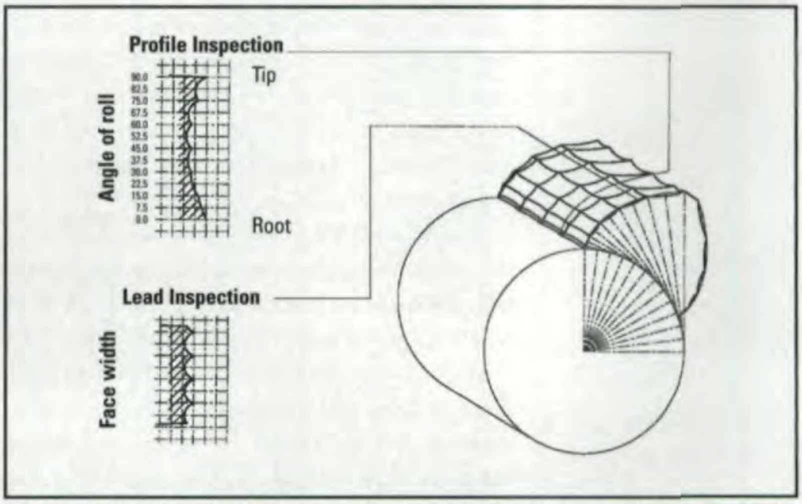

Fig. 7—Helical gear tooth topology. Excessive feed marks may affect gear profile.

• **Setup consistency factor.** A reliable hob mounting procedure, that includes a radial and axial runout inspection of proof journals on both sides of a hob, can help keep gear profile error under control. Everything listed in the relevant part of the lead section is also applicable here.

Pitch and Runout. The hobbing method can produce gears with pitch and runout quality up to AGMA 11, 12 or even higher.

• **Machine factor.** In the case of single-start hobbing, a tooth-to-tooth error is almost exclusively dependent on the hob spindle and machine table synchronization quality. Most reputable CNC hobbing machine suppliers build machines that are capable of making gears with a high degree of pitch accuracy.

• **Workholding fixture factor.** Workpiece radial runout caused by an inadequate fixture is the most frequent culprit contributing to accumulative pitch and runout errors.

• **Hob factor.** Similar to the lead characteristic, geometry errors of a one-start hob have no effect on either gear pitch quality or runout quality.

However, the thread-to-thread variation of a multi-start hob can have a dramatic effect on tooth-to-tooth errors.

• **Cutting conditions factor.** As long as the feed scallop depth is very small, which is usually the case for finish hobbing, cutting speed and feed have no effect on gear pitch and runout quality.

• **Gear blank factor.** Similar to the fixture effects, the geometric quality of the gear blank has a direct effect on the gear's accumulative pitch and runout errors. The greater the number of gear teeth, the lesser the effect of blank inaccuracy on the tooth-to-tooth error.

• **Setup consistency factor.** A reliable fixture mounting procedure, combined with runout inspection of all mounting surfaces, can help keep the gear pitch and runout errors under control. Proper care should be taken to remove burrs, and/or all other surface contaminants, prior the pitch and runout inspection.

Tooth Thickness. As opposed to rough hobbing, the finish hobbing process generally has a more stringent tooth thickness tolerance. The tooth thickness consistency mostly depends on the machine's thermal stability, the accuracy of hob shifting alignment, and the hob lead quality. It is important to note that the capability of the inspection technique can be a source of confusion. Dimension Over Pins (DOP) is probably the most popular method for indirect tooth thickness measurement. Generally, it is recommended to measure DOP in at least two places, 90 degrees apart. For other methods (span, center distance device with a master gear, base pitch device, or CMM), it is important to develop a procedure that provides the measurement of an average tooth thickness. As far as tooth thickness consistency is concerned, the finish hobbing process can approach the capability of a shaving or even a grinding process, assuming that the same inspection techniques and QC procedures are used.

• **Machine factor.** A machine's thermal instability is usually the greatest contributor to tooth thickness inconsistency. That is why many people study the machine's thermal behavior when they purchase a gear hobbing machine. Another possible contributor to tooth thickness inconsistency is workpiece/hob center distance variation caused by a hob shifting mechanism. Many new machines today are capable of producing parts with only .0002–.0003" tooth thickness variation. In fact, it is not uncommon to see a tooth thickness measuring technique that is less capable than the machine itself.

• **Workholding fixture factor.** Part runout induced by an inadequate fixture will make the gear teeth of the same part unequal. However, the fixture quality has no effect on the consistency of the average tooth thickness. Excessive part runout can create an illusion of a part-to-part tooth thickness inconsistency. That is why, prior to making tooth thickness adjustment on a hobbing machine, it is generally recommended to measure the gear tooth thickness twice, 90 degrees apart.

• **Hob factor.** Hob tooth thickness consistency along the whole face width is another important factor affecting tooth thickness variation from part to part. It is of even greater importance today since many gear makers are using longer hobs. A hob lead inspection can reveal a hob taper. A taper could also be created in the hob if it were sharpened with an excessive flute error. During hob shifting, a tapered hob could contribute to tooth thickness inconsistency.

• **Gear blank factor.** Similar to the fixture, a gear's blank quality has no effect on the part-to-part average tooth thickness variation.

• **Cutting conditions factor.** As long as the feed scallop depth and enveloping cut depth are very small, which is usually the case for finish hobbing, the cutting speed and feed have no effect on the tooth thickness variation.

• **Setup consistency factor.** The tooth thickness is established during the setup. That is why the tooth thickness consistency between setups depends on the reliability of QC procedures and the capability of the measuring technique.

Conclusion

Gear hobbing, as any other process, has certain inherent quality limitations. But, during the last 20 years, those limitations have changed, opening up new opportunities for quality improvements in traditional finish hobbing applications. In addition, opportunities have been created for the hobbing process to be used as a finishing operation in many more applications where a higher degree of precision is required.

As a result, the use of hobbing machines for gear finishing operations has grown in popularity. This popularity has been reinforced by skiving/rehobbing process advancements. The skiving/rehobbing process is a secondary gear finishing operation that can be done on a hobbing machine. The skiving/rehobbing process allows the manufacturer to eliminate heat treat distortions without having to resort to grinding or another expensive machining process.

Today, finishing gears on a hobbing machine is a viable alternative for a greater variety of gear applications, opening up cost reduction opportunities for gears with quality requirements in the transition area of AGMA Q9–11. ○

The author would like to express his gratitude to John Bodine and Paul Ruff for their editing help.

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CIRCLE 118

Fred Young Elected Chairman of AGMA Board

Frederick Young

Frederick Young, the owner and president of Forest City Gear, Roscoe, IL, was elected Chairman of the Board of the American Gear Manufacturers Association (AGMA) at AGMA's 84th Annual Meeting in Scottsdale, AZ. Young will preside over the board until March, 2001. "Fred Young is truly passionate about this business," said AGMA president Joe Franklin. "He is also an excellent model for successful entrepreneurs. Fred is always open to new information, he's naturally curious about how things get done. He is an internationalist and travels extensively around the world visiting gear manufacturers at virtually every stop. He is certainly one of the best known executives in the industry. As AGMA continues to grow and expand our services to companies outside of North America, Fred Young will be both an advocate for AGMA and a strong friend in court for members and potential members everywhere."

New President at Horsburgh and Scott

Dave Kraninger

Dave Kraninger has been named president of Horsburgh and Scott, a Cleveland, OH based manufacturer of custom enclosed drives and open gearing. A thirty-year veteran of the industrial gear market, Kraninger joined the company in 1984 and has most recently served as senior vice president.

Beavers Named CEO of Thomson Industries

Alex N. Beavers

Dr. Alex N. Beavers, Jr., has joined Thomson Industries, Inc., as Chief Executive Officer, succeeding John B. Thomson, Jr., who continues as chairman of the Board. Beavers comes to Thomson from PricewaterhouseCoopers, L.L.P. (PwC), where he was the managing partner of the Manufacturing and Supply Chain Management Consulting Practice for the Americas. In making the announcement, Thomson said, "Alex is eminently qualified to direct the company as we enter a new century and face the challenges of a global economy. He brings to Thomson the expertise necessary to build upon our strengths as the industry leader in linear motion and control technology. Fred's experience includes an in-depth working knowledge of manufacturing process improvement, supply chain management optimization, and e-business solutions to manufacturing companies in a variety of industries."

Bison Adds Argento to Executive Team

Jim Argento

Jim Argento has been named vice president for business development at Bison Gear and Engineering of St. Charles, IL. A 26-year veteran of Boston Gear, Argento will assume responsibility for policy and task deployment involved in Bison's growth initiatives, including the company's new product development process. He will also oversee Bison's management information systems.

Strategic Alliance Formed Between Gleason and Kashifuji

Gleason Corporation announced an agreement to form a strategic alliance to develop, manufacture, sell and service certain products with Kashifuji Works, Ltd., of Kyoto, Japan, a leading supplier of cylindrical gear machinery in the Asian market. The machines, cylindrical gear production machines, would be jointly designed by the two companies, manufactured by Kashifuji and sold in Japan and other Asian markets by OGA Corporation, Gleason's wholly-owned sales and service subsidiary in Japan and Taiwan.

According to David Burns, president and COO of Gleason, "We expect that this alliance will increase the access for both companies into certain markets. The collaboration of Gleason and Kashifuji, two leaders in the field of cylindrical gear machines, should produce an array of opportunities for both companies and mutually strengthen our global product offerings."

Schafer Acquires Patterson

Schafer Gear Works, Inc., of South Bend, IN, announced the acquisition of Patterson Gear and Machine, Inc., Rockford, IL, renaming it Schafer Gear Works Rockford, L.L.C. In the announcement, Schafer president Bipin Doshi, and executive vice president Stanley Blenke, said, "We are very pleased with this acquisition because it thoroughly complements our South Bend operations. Rockford adds capability for producing larger gears and for some precision gear grinding operations we have not offered before. The Rockford operation will result, long term, in the addition of work to both South Bend and Rockford plants."

miniGears Opens Branch Office in China

The Italian gear manufacturer m.G. miniGears S.p.A. opened of its first Chinese branch office, in Shanghai's Pudong Duty Free Zone. The office, supported by a distributing warehouse to supply China and the neighboring countries, has the task of providing design and technical-commercial support to both acquired and potential customers as well as keeping the headquarters in Italy up-to-date on trends and changes in the Asian market. Future plans call for the Shanghai branch office to become a production unit as well, specializing the manufacture of cut and powder metal gears.

New Powder Forging Standard

The Metal Powder Industries Federation (MPIF) has published a new standard for powder forged (P/F) steel parts covering carbon steel, copper steel, low alloy P/F-42XX steel and low alloy P/F-46XX steel. MPIF Standard 35, "Materials Standards for P/F Steel Parts" is a 24-page standard that gives chemical composition, physical and mechanical properties, hardenability and Jominy curves for 16 materials.

The physical and mechanical property data contained in the new standard were developed in a testing program conducted by Concurrent Technologies Corp., Johnstown, PA, with cooperation from the Center for Powder Metallurgy Technology and the standards committee of the Powder

Metallurgy Parts Association. The standard can be ordered from MPIF by calling the Federation at (609) 452-7700.

Changes at the Top for Cincinnati Machine's Advanced Systems and Services Business

Cincinnati Machine has announced the appointment of four new officers to its Advanced Systems and Services Business, which was formed to provide more effective service to OEMs in the aerospace, heavy equipment, fluid power and automotive markets.


Dan Janka


John Judge


Rich Curless


Dwaine Isenberg

Dan Janka was promoted to vice president and general manager, where he will be responsible for all sales, marketing, product management and service activities in North America.

John Judge has been appointed senior vice president for sales. Judge will oversee field sales and sales support activities in for the Americas' business, focusing on enhancing sales processes and channels.

Rich Curless is the new vice president for product and technology development, responsible for all product development and product management activities.

Dwaine Isenberg was promoted to vice president of quality and engineering, responsible for all quality systems and engineering design activities. He will focus on creating an engineering design process that achieves "right-the-first-time," six-sigma quality in Cincinnati Machine's products.

Odds and Ends

Nord Gear Corp. has opened a new sales and assembly facility in Corona, California. **William G. Rankin**, CEO of Unique Mobility, has been elected to the additional post of chairman of the board. **Nancy S. Berg** has been named executive director of the Society of Manufacturing Engineers (SME) in addition to her current position as SME's general manager. **J. Lee Juett**, president of the J. Lee Hackett Company of Farmington, MI, has been elected chairman of the American Machine Tool Distributors' Association for 2000–2001. **James S. Gleason**, chairman and CEO of Gleason Corp., was honored by the SME with their Eli Whitney Productivity Award for distinguished accomplishments within the broad concept of orderly production.

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VETERAN MACHINISTS & THE MILLENIUM OUTLOOK

The Millenium Outlook article in the January/February 2000 issue of Gear Technology *explored the prevailing attitudes of the gear industry as it stands on the brink of the new millenium through the thoughts and words of some of the industry's leaders. The article also placed the gear industry within the framework of 20th Century history. Joe Arvin, President of Arrow Gear, was interviewed for this article and requested an opportunity to elaborate on his published comments.*

I wish to provide further explanation regarding some of my statements, which appeared as part of the January/February 2000 *Gear Technology* Millenium Outlook, in order to provide clarification regarding the skills of our industry's workforce.

My comments regarding veteran machinists, such as myself, leaving the workforce, and their old-world craftsmanship not being essential for operating modern machine tools, should in no way suggest that the value of traditional machinist skills is diminishing. The reality, however, is that as the older machinists leave the workforce, they take with them the hands-on expertise that plays a valuable and essential role in the gear manufacturing environment.

This is not to imply that younger machinists are not highly skilled in their own right. While operating modern machine tools is somewhat less dependent on traditional machining concepts, today's machinist must possess a high degree of specialized expertise and computer knowledge.

The decline of old-world machining expertise does, however, present a real training challenge and should be considered carefully as the gear industry evolves and evaluates its future training initiatives.

Joseph L. Arvin
President, Arrow Gear Co.

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TECHNICAL CALENDAR

August 24. Gear Research Institute's Annual Meeting and Symposium. IIT Research Institute, Chicago, IL. Meetings and discussions covering the research and development activities of the Drivetrain Technology Center and the Gear Research Institute. Call the Gear Research Institute at (814) 863-9749 for more information.

September 6–8. Gear Noise: Short Course. Ohio State University, Columbus, OH. Learn how to design gears to minimize noise. Noise generation and measurement will be covered as well as gear rattle, transmission dynamics and housing acoustics. Contact Prof. Don Houser, OSU Dept. of Mechanical Engineering, at (614) 292-5860.

September 6–13. The International Manufacturing Technology Show (IMTS). McCormick Place, Chicago, IL. The 2000 show features two new pavilions, an expanded manufacturing conference and exhibits by companies from all over the world. See our coverage on page 13. For additional details log onto *www.imts.org* or call (703) 893-2900.

September 10–13. 8th International ASME Power Transmission and Gearing Conference. Omni Inner Harbor Hotel, Baltimore, MD. Top researchers present their latest work in the fields of gearing and power transmission Contact Neil Anderson, conference chairman, at (248) 688-2369 or log onto *www.enme.umd.edu/asme2000*.

September 11–15. AGMA Training School for Gear Manufacturing: Basic Course. Richard J. Daley College, Chicago, IL. Classroom and hands-on training in basic gearing, efficient machine set-up, gear inspection and gearing calculation. Call AGMA at (703) 684-0211 or visit *www.agma.org*.

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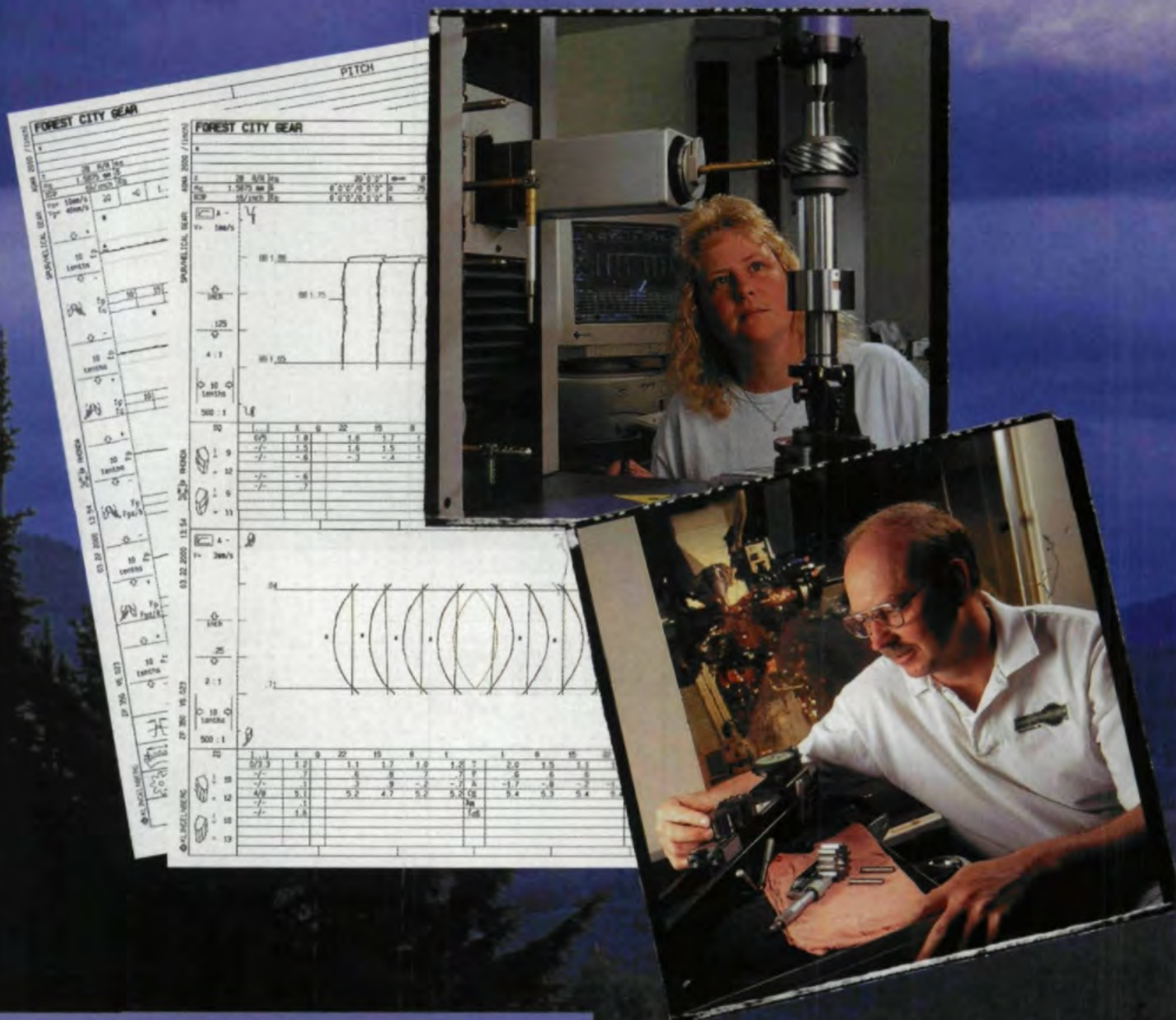
CIRCLE 137

If you inspect a gear in the Forest, does it make a sound? "No, we get a printout!" – The Quiet Gear Guys



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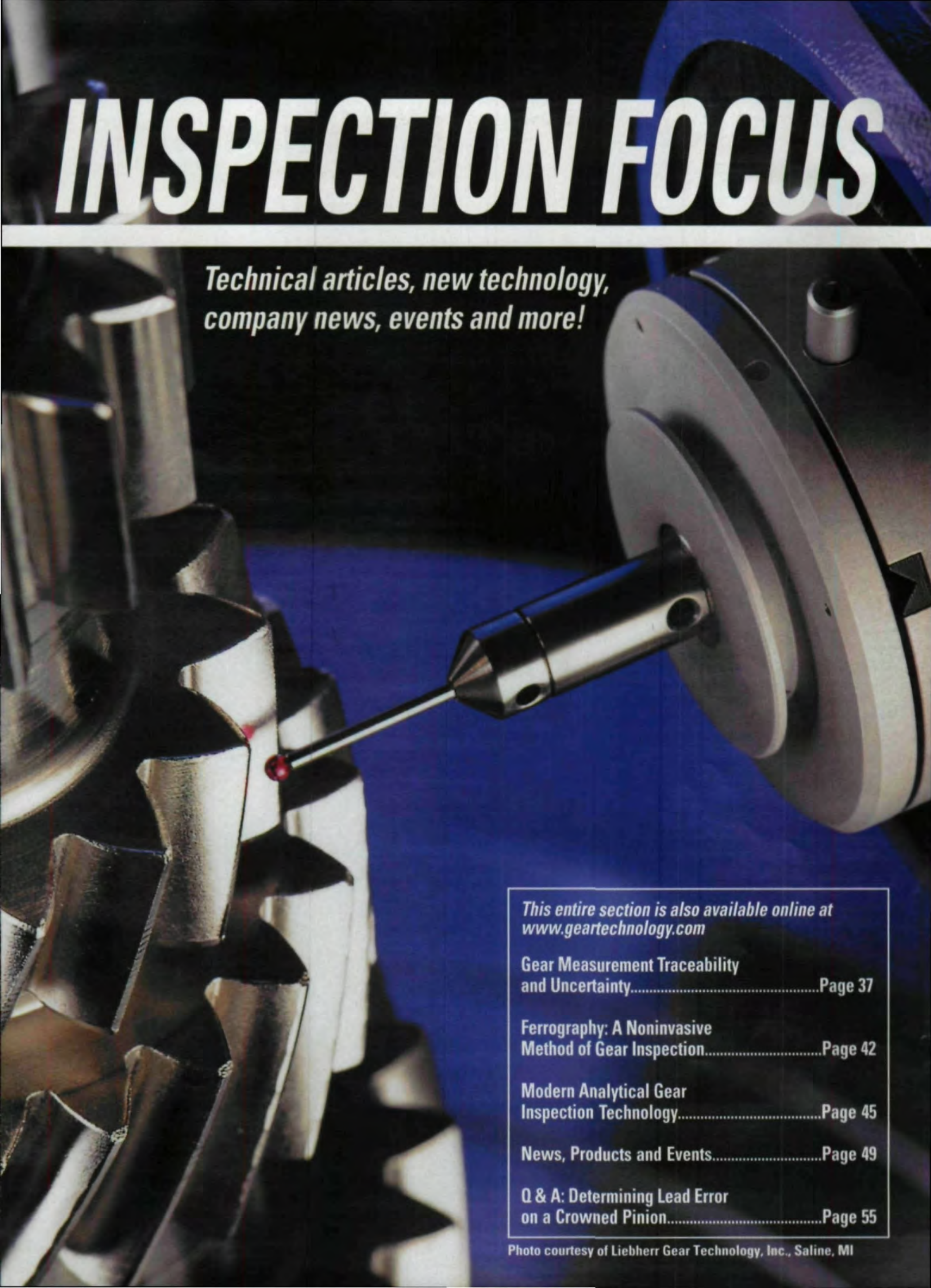

This entire section is also available online at www.geartechnology.com

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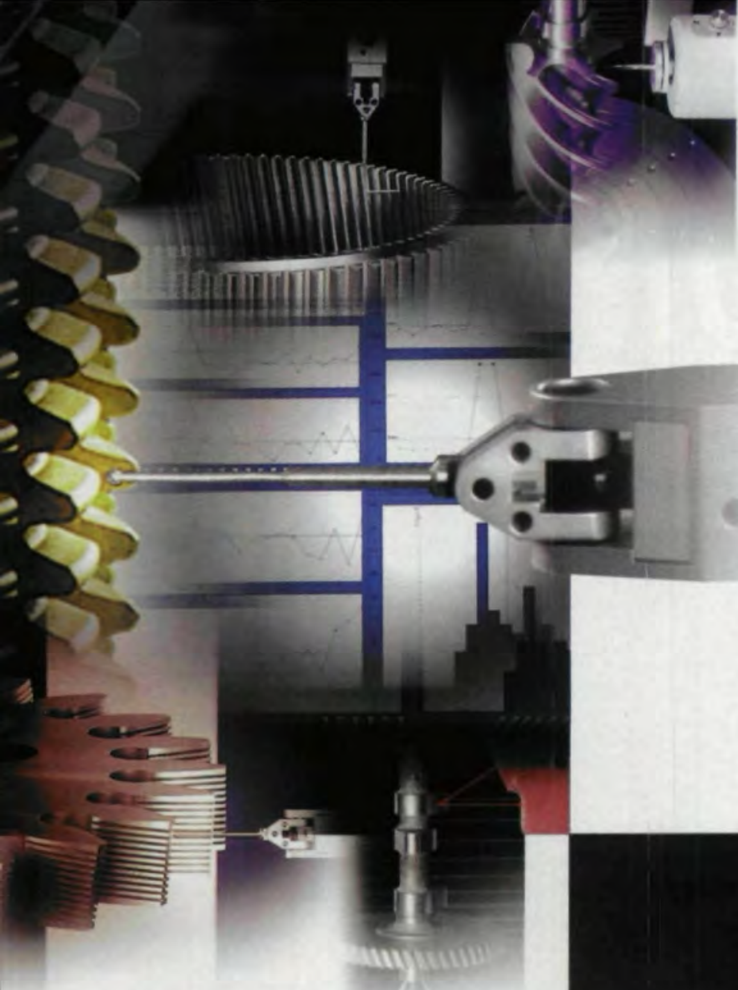

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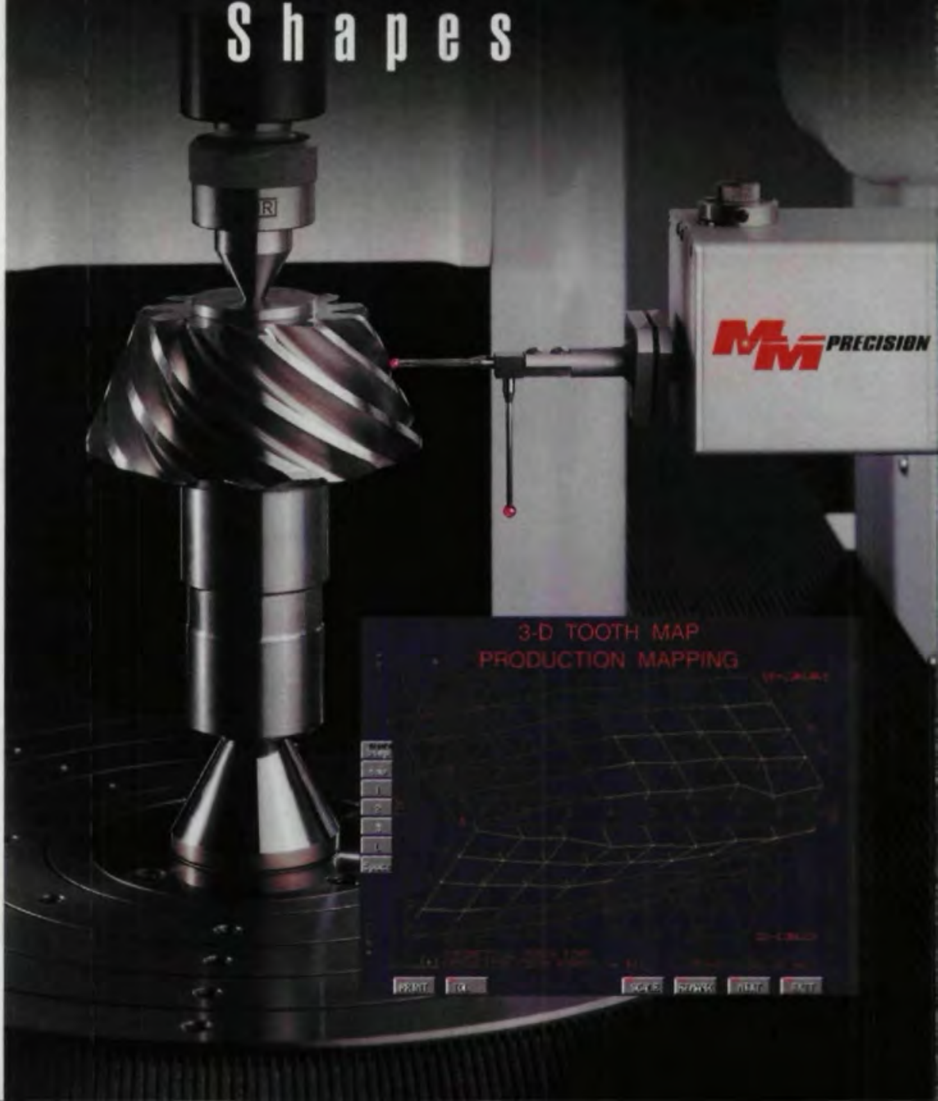

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CIRCLE 165

Gear Measurement Traceability and Uncertainty

Bruce L. Cox

Introduction

Until recently, there was a void in the quality control of gear manufacturing in this country (Ref. 1). Gear measurements were not traceable to the international standard of length through the National Institute of Standards and Technology (NIST). The U.S. military requirement for traceability was clearly specified in the military standard MIL-STD-45662A (Ref. 2). This standard has now been replaced by commercial sector standards including ISO 9001:1994 (Ref. 3), ISO/IEC Guide 25 (Ref. 4), and the U.S. equivalent of ISO/IEC Guide 25 - ANSI/NCSL Z540-2-1997 (Ref. 5). The draft replacement to ISO/IEC Guide 25 - ISO 17025 states that measurements must either be traceable to SI units or reference to a natural constant. The implications of traceability to the U.S. gear industry are significant. In order to meet the standards, gear manufacturers must either have calibrated artifacts or establish their own traceability to SI units.

Metrology and Traceability-Related Workshops. NIST hosted and co-sponsored two industrial workshops that addressed metrology issues in U.S. manufacturing. In August, 1992, NIST hosted "Metrological Issues in Precision Tolerance Manufacturing," in Gaithersburg, Maryland. This workshop revealed a concern among a wide cross-section of American industry that the quality control practices in the production of gears are not sufficiently traceable to NIST standards (Ref. 6).

In response to this finding, NIST teamed with the Department of Energy Oak Ridge Y-12 Plant in Oak Ridge, Tennessee, to conduct an "Advanced Gear Metrology Workshop" at the Y-12 Plant in April, 1993. Significant planning assistance for the workshop was also provided by the Defense Logistics Agency, which is responsible for the procurement of gears for U.S. military weapon systems. The most important findings from the workshops were that the gear industry most often uses involute or tooth alignment artifacts that were often not traceable to NIST; and that there were no nationally accepted standard artifacts or standard measurement systems to use in measurement comparisons.

Committee on Gear Metrology. As a result of the workshops, a partnership was formed between the American Gear Manufacturers Association (AGMA), the American Society of Mechanical Engineers (ASME), NIST, Pennsylvania State University, and the Y-12 Plant. ASME formed an industrial advisory committee known as the Committee on Gear Metrology (COGM). This committee was established to give industry's priorities on reestablishment of gear measurement traceability to NIST and the Y-12 Plant.

National Gear Metrology Center. In October 1994, a $3-million stipend was awarded through the Department of Defense's Technology Reinvestment Program. The first item on the agenda was the reestablishment of involute profile artifact calibration with a stated uncertainty and direct traceability to the SI unit of length through NIST. Next, a facility—the National Gear Metrology Center (NGMC)—was constructed at the Y-12 Plant. This facility was equipped with state-of-the-art coordinate measuring machines (CMMs) for the calibration of all types of gear artifacts. A computer controlled generative gear checking instrument was loaned to the Y-12 Plant for several years by M&M Precision Systems Corporation to help correlate data from the CMMs to the gear checking instrument.

Fig. 1—Involute profile artifact.

Gear Artifact Measurement Uncertainty

The measurement uncertainty method used at NIST and the Y-12 Plant is known as measurement decomposition. In this method, which was developed by Dr. Howard Harary at NIST, the complex measurement task is broken down into a series of simple subtasks, which can be represented with reference artifacts such as gage blocks, angle blocks, or spheres. The uncertainties of the reference artifacts and the repeatability of the measurements are combined to reach a final uncertainty for the gear artifact.

The measurement decomposition for involute profile artifacts consists of measuring the centers of two circles on spheres and calculating a line between the circle centers, translating a distance from the line using a gage block, and measuring a series of points in a direction normal to an involute curve on a sphere (see Fig. 1). A multiplier ($k=2$) is used to allow the uncertainty to

Bruce L. Cox
is an engineering specialist at the Oak Ridge Metrology Center, located at the Department of Energy Oak Ridge Y-12 Plant, which is managed by Lockheed Martin Energy Systems, Inc. He serves on the AGMA Inspection Handbook Committee and is the vice chairman of the AGMA Calibration Committee.

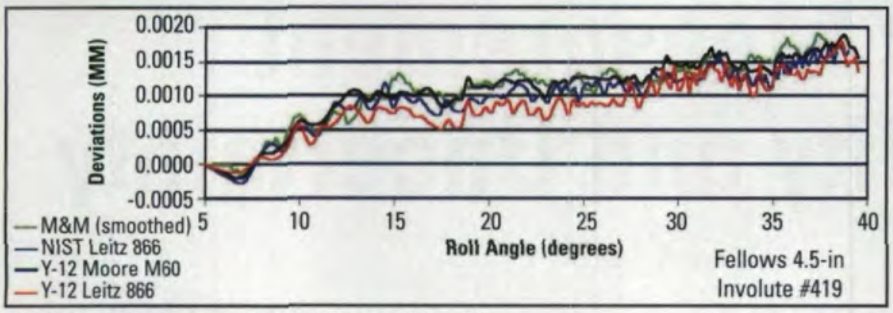

Fig. 2—Intercomparison of the involute profile artifact.

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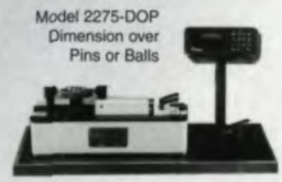
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represent approximately a 95% confidence level of uncertainty for involute profile artifacts of ±0.9 micrometers. To check the uncertainty, an intercomparison was done between NIST, Y-12, and M&M Precision Systems Corporation. The results are shown in Fig. 2.

The measurement decomposition for pin artifacts consists of measuring the centers of two circles on spheres and calculating a line between the circle centers, translating a distance from the line using a gage block, and measuring the diameter of a sphere (see Fig. 3). The stated uncertainty at approximately 95% confidence level for pin artifacts is ±0.7 micrometers for offset, ±0.5 micrometers for diameter, and ±0.3 micrometers for roundness.

The measurement decomposition for tooth alignment artifacts consists of measuring the centers of two circles on spheres and calculating a line between the circle centers, translating a distance from the line using a gage block, and measuring a series of points at an angle to the line using an angle block (see Fig. 4). The stated uncertainty at approximately 95% confidence level for tooth alignment artifacts is ±0.8 micrometers for infinite leads, ±0.9 micrometers for 100-inch leads, ±1.1 micrometers for 32-inch

Fig. 3—Pin artifact.

Fig. 4—Tooth alignment artifact.

leads, ±1.2 micrometers for 16-inch leads, and ±1.3 micrometers for 11-inch leads. Intercomparison data between NIST and Y-12 for tooth alignment artifacts is shown in Fig. 5.

The measurement decomposition for index artifacts utilizes a rotary table and the principle of circle closure to subtract rotary table errors. In circle closure, all angular measurements must add to 360°; therefore any error can be subtracted from the measurement (Ref. 7). The decomposition consists of measuring the radial and axial runout of the rotary table, the repeatability of measuring an angle between three spheres on the rotary table, and the repeatability of an index artifact on the rotary table (see Fig. 6). The stated uncertainty at approximately 95% confidence level for index artifacts is ±1.6 arcseconds or ±0.6 micrometers for index artifacts up to 6 inches in diameter. Intercomparison data between NIST, Y-12, and The Gleason Works is shown in Fig. 7.

In addition to the intercomparison measurements above, Y-12 has been involved in a round-robin of involute profile artifacts that is sponsored by the AGMA Calibration Committee and an international round-robin of gear artifacts that is sponsored by the University of Newcastle, UK. The results of the AGMA round-robin were published in the proceedings of the 1998 AGMA Fall Technical Meeting. The results of the international round-robin have not been published yet.

National Voluntary Laboratory Accreditation Program

The NGMC was accredited by the NIST National Voluntary Laboratory Accreditation Program (NVLAP) for measurement of involute profile artifacts, pin artifacts, and tooth alignment artifacts on July 8, 1999. This is the first laboratory accredited by NVLAP to calibrate gears.

Future Plans

During the 1999 AGMA Fall Technical Meeting, the COGM met to discuss the future of gear metrology. The committee decided that the NGMC should begin offering calibrations that meet the ISO 1328-1 and ISO 1328-2 standards, and their corresponding tech-

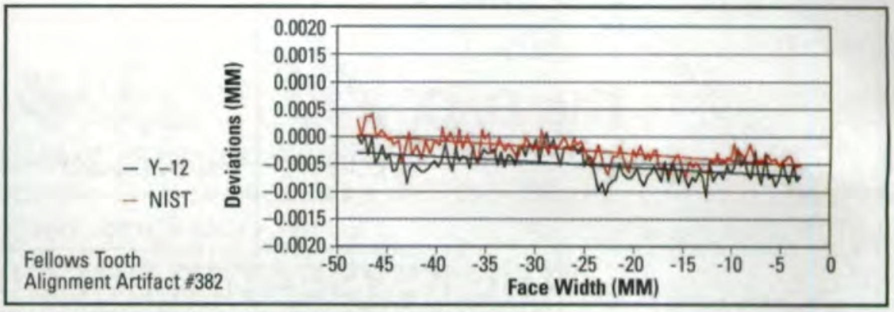

Fig. 5—Intercomparison of tooth alignment artifact.

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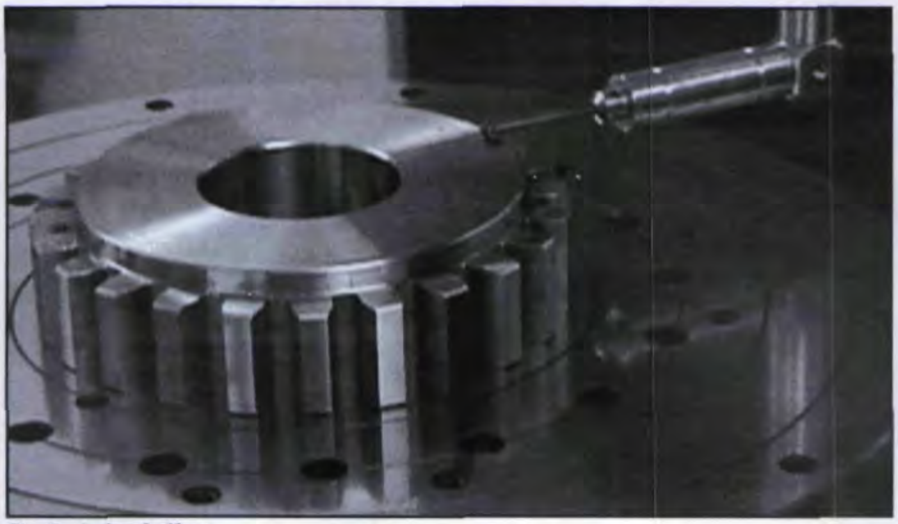

Fig. 6—Index Artifact.

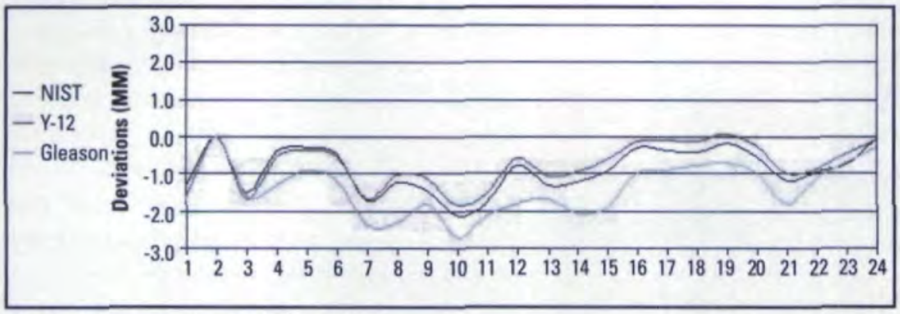

Fig. 7—Intercomparison of index artifact.

nical reports ISO/TR 10064-1 and ISO/TR 10064-2. Also discussed was what type of gear calibration would be needed next. It was generally agreed that bevel gears would need direct traceability and that runout should be calibrated on index and master gears. If you would like to have input in the next COGM meeting, contact Bill Bradley at AGMA by calling (703) 684-0211.

Acknowledgments

Thanks to all members of the AGMA Calibration and Inspection Handbook Committees for their guidance and support. Thanks to all members of the COGM, over the years, for providing direction for the NGMC. Thanks to Dr. Howard Harary at NIST for helping establish measurement uncertainty for gear artifacts and Bob Smith of R. E. Smith & Co., Inc. for providing the index artifact for the uncertainty measurements. Thanks to Gerry Gagnier of Fellows Corporation for providing calibration knowledge for the NGMC and M&M Precision Systems Corporation for supplying a gear checking instrument for correlation measurements. ⭘

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CIRCLE 198

Ferrography: A Noninvasive Method to Inspect Your Gears

Damaged cam bearings.

THE NEAR-DEATH EXPERIENCE OF A CHEVROLET

by Ms. Leslie Morovek, CAO Munroe Equipment Sciences, Inc.

In July of 1998 I leased a 1998 Chevrolet, 4 cylinder., 5 speed, Coupe. The car had 33 Kms on it when I took possession. As a part of Munroe Equipment Sciences Inc., I naturally put my car on a Ferrographic Analysis program.

Over a period of a year and a half, I saw my engine deteriorating. From the very first sample, water was a problem and bearing wear was noted. With no "valid" complaint, i.e. noises, excessive fuel consumption, etc., I really had no reason, other than the reports, to have my car looked at. Since this is a relatively new technology, I felt I would be met with considerable resistance if I were to take the car in for service without a physical complaint. Then GM Canada came to us as a customer. I naturally capitalized on the opportunity of having a warranty representative in our office, and told him the story of my car.

Shortly thereafter, I began to smell the fuel my car was leaking. Finally, a "valid" complaint. I called a Chevy dealership out of town because the local dealership I had been dealing with installed the oil filter too tightly, leaving the filter

Would you like to be able to see the condition of the gears in your transmissions without having to open the box and physically examine them? There is a way, and not too many people know about it. It's called Wear Particle Analysis, or ferrography, and it is just starting to get noticed.

Developed in the 1970s by the United States Navy, ferrography is the identification of wear particles suspended in the lubricating fluids of any oil-wetted machinery. It is not a form of used oil analysis, which monitors the state of the lubricant rather than that of the machinery being lubricated. According to Leslie Morovek, the chief administrative officer for Munroe Equipment Sciences Inc. (MES), a Winnipeg-based provider of ferrography services, "Ferrography provides a noninvasive look at not only current and historic conditions, but future conditions of a machine's lubricated components as well." Morovek adds that this is accomplished without the time and expense of a physical examination.

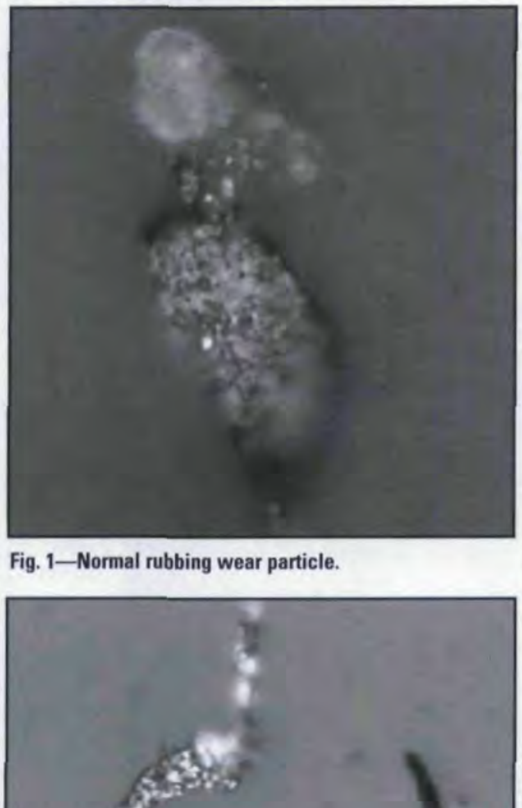

Fig. 1—Normal rubbing wear particle.

Fig. 2—Cutting wear particle.

Theory. Ferrography is based on the theory that once the size, shape, composition and concentration of wear particles has been determined by a trained analyst, these wear particles can then be associated with a specific component within the system. Once that association has been made, the condition of that component can be determined from a careful study of the wear particles.

Practice. According to Morovek, a glass substrate, or ferrogram analysis, is one common way to sort and identify wear particles. One method uses a combination of incline, chemical, thermal or mechanical sample preparation and a magnetic field, ensuring that all particles present in the oil sample are deposited on the substrate. This method also creates consistent ferrogram patterns or maps that provide a repeatable way to sort through the types and sizes of ferrous, nonferrous and contaminant (sand, dirt) particles. "Ferrous particles tend to form strings between the magnetic poles that are perpendicular to the flow of the sample," said Morovek. "The largest particles accumulate near the entry to the substrate and the smallest at the exit. Nonferrous particles often appear between these ferrous strings along with contaminants such as sand, dirt, fibers and friction polymers."

Once the particles have been identified as to composition and concentration, their wear pattern is examined. There are five major types of wear: abrasive, fatigue, corrosion, adhesion and lubricant breakdown. "Cumulatively, the particles in a sample carry with them the story of the internal workings of an individual piece of equipment," said Morovek. "The identification of these particles, and the wear mechanisms that generated them, can effectively demonstrate the equipment's operating history, its current state of performance, as well as generating alarms to future wear conditions."

Wear Particles. Some of the conditions that can be analyzed include normal rubbing wear (Figure 1), which is considered benign unless there are enough particles to affect lubricant quality; cutting wear (Figure 2), which includes a harder surface penetrating a softer surface as well as a softer surface becoming embedded with hard contaminant particles and cutting into a hard surface; and severe sliding wear (Figure 3), which is characterized by particles with sharp, fractured edges and parallel striations on their surfaces.

Gears and bearings have specific types of wear particles associated with them. Bearing wear includes bearing platelet wear particles (Figure 4), which are similar in shape to normal rubbing wear particles but denote abnormal wear patterns; and spheres (Figure 5), which are associated with roller bearing fatigue. According to Morovek, the presence of these dimpled, golf ball-like particles can signal impending wear damage long before spalling and failure actually occur (see "The Near Death Experience of a Cavalier").

Morovek describes gear wear (Figure 6) as a combination of rolling and sliding wear with irregularly shaped particles that have smooth, striated surfaces. "Gear wear is typically very large in comparison to other particles," said Morovek. "The composition of these particles may often be of greater significance than their size, as the progression from high carbon alloy steel to low carbon alloy steels is indicative of the severity of the wear."

The Human Factor

Unlike other methods, which employ a great deal of automation, ferrography still depends on a trained analyst to make the examination and interpret the results. "That is the technology's biggest liability and also its greatest advantage," said Mike Munroe, president of MES. "It's not a science like spectroscopy. Because of the need for a trained analyst, it is more of an art." This makes it slower and more expensive than used oil analysis, but according to Morovek, that time and expense is made-up for by lower maintenance and repair costs and less time spent with machinery off-line for overhaul or component replacement, reducing parts inventory and maximizing productivity for repair personnel. ○

Fig. 3—Severe sliding wear particle.

Fig. 4—Bearing platelet wear particle.

Fig. 5—Spheres.

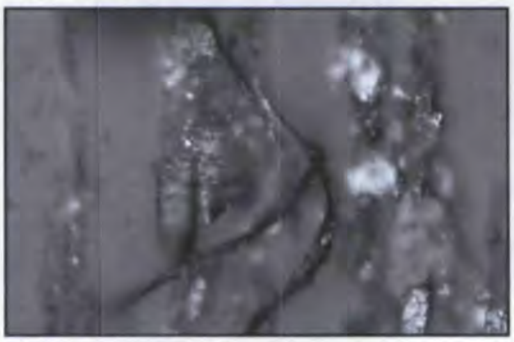

Fig. 6—Gear wear particle.

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media evenly distributed throughout the engine oil. As this happened almost immediately after installation, the next 5000 Kms the engine saw were essentially without an oil filter. This certainly did not help the already abnormal wear patterns.

As the dealership was unfamiliar with us, our technology and our reports (I provided copies), the shop manager contacted GM Canada and spoke with the very same GM official who had earlier been our customer. At this point, it was the opinion of the laboratory that the fuel dilution would cause a severe corrosive condition, furthering the abnormal bearing wear. At this point, the lab did not realize how significantly the presence of fuel had increased the rate of wear. We knew the bearings were in trouble, but didn't think a catastrophic event was at this point imminent.

Based on the analysis we provided, GM Canada gave the "go ahead" to replace the cam bearings. The whole process took about two weeks to complete. Although they were not able to find a direct cause of the fuel leak, all the seals and gaskets were replaced when the bearings were done, and so far, this seems to have fixed the problem.

I will be sampling it again in 2500 Kms to have a better look at the "after repair" condition. The corrosive condition actually "peeled" the surface off the bottom, inside of all five of the cam bearings, leaving the copper underlay exposed.

The long and the short of it is that our lab spotted a problem in the very first sample and GM Canada, without question, made all the necessary repairs. I am no longer driving around wondering if I will get where I'm going.

I'm still not sure which aspect of this experience pleases me more, the incredible level of customer service I received from GM Canada, or the fact that we (the lab) really do have the capability to accurately "predict" the future operating conditions of lubricated equipment. ○

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- ❑ Heat Exchangers
- ❑ Hobs
- ❑ Index Plates
- ❑ Injection Molds
- ❑ Keyseat Cutting Tools
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- ❑ Other __________

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Analytical Gear Inspection: *The Shape of Things to Come*

It used to be that gear manufacturers wanting to perform analytical gear inspection required at least three machines to do so: The lead measuring instrument, the tooth space comparator and the involute checking instrument. In the beginning, these machines were mechanically driven. Over the years, the manufacturers of analytical gear inspection equipment have combined these functions—and a host of others.

In addition to basic generative gear testing, today's analytical gear checker often comes with the ability to check other types of parts, including rotors, threads, splines, cams and gear cutting tools; the ability to test forms such as roundness or straightness; the ability to measure all types of gears, including spiral bevel gears and worms; and the ability perform limited 3D coordinate measuring.

Class 14 Ground Gear for a high speed compressor being inspected at Nixon Gear, Syracuse, NY.

The ability of these machines to measure a wide variety of parts has been of great value to the Waukesha Engine Division of Dresser Equipment Group, Waukesha, WI, according to lab inspector/programmer Matt Banski, who uses an M&M Model 3000 Gear Analyzer to inspect more than 300 different parts, including spur & helical gears, worms, worm wheels, straight bevel gears, gear blanks and other parts for their line of internal combustion engines.

Measuring Bevel Gears

Certain kinds of gears, particularly bevel gears, cannot be reasonably measured using traditional generative gear testing, says Ed Lawson, director of metrology for M&M. This has required gear inspection equipment manufacturers to greatly modify the way their machines work, both mechanically and through their software.

Lawson sees analytical gear measurement technologies as being on a spectrum, with traditional generative gear testing at one end, and coordinate measuring on the other. In order to accommodate the measurement of worm gears, bevel gears and other parts, the best of today's dedicated gear machines, he says, are somewhere in the middle.

Traditionally, bevel gears have been tested functionally, rather than analytically, by applying marking compound

WHAT IS ANALYTICAL GEAR INSPECTION?

The term gear inspection covers many different types of gages, instruments and machines, and what exactly gear inspection is depends on who you ask. Related terms, such as gear testing, gear checking and gear analysis only add to the confusion. But gear inspection can roughly be divided into two broad categories: functional and analytical.

Functional inspection tells the gear manufacturer whether a gear will work in a given application. In other words, will it function as required? Generally, this type of inspection is performed by roll testing a gear in mesh with a master gear, or in the case of a bevel gear, with its mating pinion.

Roll testers come in many varieties, from the simple, hand turned mechanical instrument to the very sophisticated, high speed, automatic version with computer controls, printouts and recording. They come from a large number of manufacturers, including Gleason, Klingelnberg, ITW Heartland, Siemens-Moore Products, Mahr Federal, David Brown, Fellows, M&M Precision Systems, Parker Industries and many others. These machines are used to measure and detect nicks, runout, and center distance variation including short term (tooth to tooth composite) and long term (total composite) parameters. Also, when used in conjunction with a properly designed and certified master gear, absolute center distance values can be provided that relate very well with effective tooth thickness.

Functional inspection is, by its nature, a composite measurement. You may have a gear that performs well, but only by accident. For example, errors in pressure angle and pitch may work to cancel each other out. But just because the end result is a functional gear, that doesn't mean you have your manufacturing processes under control.

Analytical gear inspection, also referred to as elemental gear inspection, is used to inspect individual elements of the gear's geometry, such as lead, profile, pitch and accumulated pitch. The key advantage of analytical gear inspection is that it allows the user to quickly and easily identify elements of the gear that measure out of tolerance—the key information needed to control the manufacturing process.

For example, analytical gear inspection can reveal the presence of hob mounting errors, cutting tool wear, heat treat distortion patterns, and many other problems.

Analytical gear inspection can be performed on stand-alone machines dedicated to specific measurements such as lead, profile or tooth space. However, today's CNC generative gear inspection machines generally combine these functions with many other measurements and calculations. Such machines are available from M&M Precision, Klingelnberg, David Brown, Roto-Technology and Mahr-Federal, among others.

ANALYTICAL INSPECTION IN THE FIELD

User: Jerry Moxley, Quality Engineer/Gear Lab Manager
Company: Dana Spicer Off-Highway Products Division
Product: Planetary Axles, Single Reduction Axles, Power Shift Transmissions, Electronic Controls, Torque Converters, Brakes and Specialty Suspensions.
Types of parts inspected: parallel axis gears, splines and spiral bevel gearing
Equipment: M&M 3525 with 3-D probe, approximately 1 year old; M&M 3040, approximately 5 years old; M&M 2025, approximately 11 years old.
How analytical gear inspection is used:
The machines are located in the gear lab. They're used for accepting/rejecting parts, part development, process control and quality proving.

User: Mike Ocasio, Quality Technician
Company: Nixon Gear, Syracuse, NY
Product: Precision ground gears.
Types of parts inspected: Internal and external gears, splined shafts.
Equipment: Höfler ZME 402 CNC Gear Measuring Center, 7 years old; Fellows 12H Lead & 12M Involute manual gear inspection units, approximately 35 years old.
How analytical gear inspection is used:
"Our Höfler is kept in a climate-controlled lab. It is used daily by both quality assurance and the machine operators. We use it for first piece accept/reject, part development and quality proving."

User: Richard Hayes, Quality Engineer
Company: Sumitomo Machinery Corp. of America, Chesapeake, VA
Product: Cycloidal speed reducers and gear motors.
Types of parts inspected: Cycloidal discs, planetary gears, helical gears, spur gears, shafts, and limited bevel gears.
Equipment: M&M Model 3000 Gear Analyzer, approximately 7 years old.
How analytical gear inspection is used:
"It is primarily used for final inspection of sampled parts from our manufacturing process or receiving inspection of parts manufactured by outside suppliers. In some cases, it's used to verify first-piece setup for machining process control and evaluation of gear components from returned defective units."

User: Geoffrey T. Grill, Gear Engineer
Company: Meritor Automotive, Oshkosh, WI
Product: Heavy vehicle axles for mining, logging and heavy construction equipment.
Types of parts inspected: sun gears, planetary gears, ring gears and splines.
Equipment: M&M 2000-4, 14 years old.
How analytical gear inspection is used:
Accept/reject product, either on first-piece setups or random sample of finished product.

User: Matt Banski, Lab Inspector/Programmer
Company: Waukesha Engine Division of Dresser Equipment Group
Product: Internal combustion engines for gas and air compression, prime and standby power generation, pump, chiller, blower, and other industrial applications.
Types of parts inspected: Inch and metric spur gears, helical gears, worms, worm wheels, bevel gears, gear blanks, shafts and non-gear parts inspected for runout, etc.
Equipment: M&M Model 3000 Gear Analyzer, approximately 2 1/2 years old.
How analytical gear inspection is used:
In-process inspection, final inspection, prove-out, part development and quality control.

User: Ricky L. Shinkle, Senior Engineering Lab Technician
Company: Delco-Remy America
Product: Gear Reduction Starters
Types of parts inspected: Plastic internal gears, armature sun gears, planetary gears, pinions, engine ring gears, motor drive shaft splines and clutch cam surfaces.
Equipment: M&M Model 2025, approximately 17 years old.
How analytical gear inspection is used:
Accept/reject parts, part development and process control.

User: Paul Bojanowski, gear quality control, and Dan Wolosian, quality process consultant
Company: Visteon Automotive Systems, Sterling, MI
Product: Rear axles and front axles for cars and light trucks.
Types of parts inspected: Ring and pinion gears of several sizes and ratios, rear axle differential and side gears, transmission gears, and NASCAR racing gears.
Equipment: Klingelnberg PNCs, approximately 2 years old; Gleason, Ono Sokki and Oerlikon single-flank testers, all approximately 5 years old; and Zeiss CMMs, approximately 5 years old.
How analytical gear inspection is used:
To establish process capability, perform Design of Experiment (DOE), monitor continuous improvement activities, and containment of reject material. The inspection equipment is also used to validate machine summaries and tool settings.

to pinion-gear pairs and running them together on a dedicated bevel gear testing machine. Roll testing machines don't incorporate the analytical approach, so they are used primarily on the shop floor to prove gear sets. An experienced operator listens for noise problems and nicks, checks for runout and views the tooth contact patterns. The operator would then have to make a judgment, comparing the new set with gear sets known to work well together.

Of course, today's functional bevel gear testers computerize much of this process, and they are often used in the lab as well. For example, the Gleason Phoenix HCT tester incorporates digital tooth contact imaging, structure-borne noise analysis and computerized high-speed, single flank testing.

But no matter how sophisticated they get, roll testing machines cannot reproduce the geometry of a spiral bevel gear. Some form of coordinate measuring is required, and machines such as the Phoenix tester, when used in the lab, are often used in conjunction with other machines. At one time, that required a coordinate measuring machine, but today's dedicated gear inspection machines can be equipped with CMM functions.

For example, the Klingelnberg series of analytical gear inspection equipment incorporates this kind of technology. Their P26 model, introduced at EMO 99, is a compact measuring machine for workpieces up to 260 mm in diameter. According to Klingelnberg marketing specialist Andreas Montag, "The tester is suitable for all measuring tasks in the gear technology and guarantees short measuring times with a high measuring accuracy." This includes all forms of spiral bevel gears manufactured by any of the major cutting processes.

The M&M machines also come with CMM-like capabilities. With the right software and probe, they can look at the gear tooth surface, compare it to either a theoretical or actually measured good gear, and mathematically recommend changes to the surface. The machines employ a sophisticated "virtual cutting" process simulation, which lets the operator see the effects of machine tool settings without having to cut another gear.

A relatively new machine on the market is the Primar, from Mahr Corporation. According to Mahr's marketing manager, Bruce Cowley, this machine is actually three machines in one. It combines the functions of a form tester for measuring roundness, straightness and other forms with those of a generative gear tester and a dedicated CMM. With the addition of a special software module, the Primar also has the ability to measure spiral bevel gears in 3D, Cowley says.

Advanced Computer Integration

Because of their ability to isolate the process parameters that cause parts to be out of tolerance, analytical gear inspection machines can be ideally suited for implementing a statistical process control program. All of the machines mentioned in this article come with computerized reporting and recording of inspection results. Software modules are available that allow for advanced statistical reporting.

In fact, the M&M and Klingelnberg machines can be used to generate corrective machine settings to directly control the manufacturing process. However, "a direct control of the manufacturing via statistical values is presently used only in a few companies," says Montag.

Versatility

Another advantage to analytical gear inspection systems is that they can be outfitted with the software to inspect gear cutting tools, including hobs, shaper cutters and broaches.

"The accuracy of gear cutting tools plays an important factor in producing quality gears," says Montag. "Klingelnberg has developed, in collaboration with important tool manufacturers and users, software modules for measuring hobs, shaping cutters and shaving cutters to monitor their quality and trace back problems caused by the geometry to the cutting tool."

M&M, Mahr and other manufacturers offer similar modules. M&M's software also includes measurement of broaching tools and racks, according to their product literature.

Today's analytical gear inspection machines are also called upon to measure tooth modifications such as crowning and tip relief. "Most of the gears which are used today are optimized," says Montag. "The flanks of the gears will be executed with clearly defined corrections, such as crowning, tip relief, root relief, etc. These clearly defined characteristics can only be manufactured and secured in connection with a suitable gear measuring machine." In today's competitive environment, it's important for the gear manufacturer to be able to prove these char-

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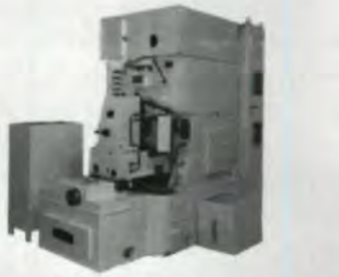

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acteristics to his customers, Montag says.

Inspection machines can also be outfitted with special analysis modules. For example, the M&M machines can perform inspections to pinpoint the effects of heat treat distortion. By measuring the part before and after heat treating, the manufacturer is better able to determine the ideal pre-hardening geometry.

Other machines may come with unique features. Mahr's Primar machine comes with a tilting table, which allows the machine to inspect parts based on their datum axes. In other words, the Primar can inspect gears as they will be mounted in their final application, rather than between centers, as most gear inspection is performed, says Cowley. The Primar performs two reference scans of the part prior to the inspection routine, adjusts the table to physically align the part, then performs the inspection. "Other machines on the market can do mathematical corrections, but cannot physically align the part," Cowley says.

Pushing Inspection to its Limits

Among the biggest challenges facing inspection equipment of all kinds today are the tighter and tighter tolerances demanded by manufacturing processes. "The increasing quality demands have led to the situation that in mass production, often tolerances smaller than 10 micrometers have to be secured," says Montag. "The old rule that the measuring uncertainty of a measuring system should be 10% of the tolerance to be checked cannot be kept. Today, measuring uncertainties of 20–30% are realistic."

While all the machine manufacturers are working to obtain ever-smaller uncertainties in their equipment, measurement accuracies are poorly understood by the end users, says Lawson, who adds that this understanding is increasingly important at a time when many manufacturing companies have either implemented or are planning to implement ISO 9000 or similar quality programs.

According to Lawson, most measuring machines, including CNC systems, aren't commonly being evaluated for accuracy. Instead, they're being evaluated for repeatability. Most companies employ a gage repeatability and reproducibility (GR&R) procedure, wherein some number of production parts are measured several different times by different operators, Lawson says. This allows them to statistically determine the repeatability of the measuring process. However, this observes only the consistency of the measurement, Lawson says, not the accuracy.

According to clause 4.11.1 of ISO 9001, "The supplier shall establish and maintain documented procedures to control, calibrate, and maintain inspection, measuring and test equipment (including test software) used by the supplier to demonstrate the conformance of product to the specified requirements. Inspection, measuring and test equipment shall be used in a manner which ensures that the measurement uncertainty is known and is consistent with the required measurement capability."

Further, Lawson reports that ISO Technical Committee 213 is developing new standards, which require manufacturers to subtract the measurement uncertainty from their manufacturing tolerances. This is logical, Lawson says, because our knowledge of a part's actual dimensions is limited by the uncertainty of the associated measurement process.

As has been the case with ISO 9000, implementation of this concept could be a stressful experience, Lawson says. However, ISO is becoming a powerful entity and many manufacturers are having to change their practices as customers begin to demand proof of quality at these levels. Today's inspection machines are powerful pieces of equipment, but if they're not calibrated, maintained, and used correctly, the validity of the measurement results will be adversely affected.

Today's dedicated gear inspection machine is a complex, multi-functional piece of equipment that can do work once requiring several machines, using sophisticated, on-board computer technology to record, transport and manipulate data in ways that were never before possible. ○

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CIRCLE 151

Inspection News Roundup

This section is dedicated to what's new and what's happening in the world of gear inspection and metrology. Here you will find news about products, companies and organizations, services and events affecting the gear inspection and metrology industry. For more information on any of the companies mentioned here, circle the appropriate reader service number.

FOCUS ON THE INDUSTRY

Mahr and Federal Merge

The merger of Carl Mahr Holding GmbH of Goettingen, Germany, and Federal Products Co., a subsidiary of Esterline Technologies (NYSE: ESL), into Mahr Federal Inc., has given the German metrology instrument maker a strategically important production site in the United States, located at the old Federal Products facility in Providence, RI. According to Mahr Federal president Joe Golemme, "By merging and expanding our product offerings, our goal is to double the size of the combined companies by 2005." According to Golemme, the integration will follow a five point plan:

- Merge and broaden the product lines.
- Create a series of resource centers across the United States and Mexico.
- Specialize the sales staff into two focused business units: Tools and Gages and Metrology Systems, hire additional sales personnel, regional managers and global key account managers.
- Broaden sales distribution to include e-commerce and high volume channels.
- Upgrade internal systems for improved order processing.

"Changing our production strategy is another important facet of our plan," said Golemme. "We will be consolidating each product's development and manufacturing at a single facility for marketing and distribution worldwide. The economies we gain from this 'Center of Excellence' concept will free up resources to develop new products and fuel additional growth."

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Carl Zeiss IMT Opens New Technical and Metrology Centers

Zeiss has opened two new facilities in the United States: a full service technical center in Lake Forest, CA, and a training and demonstration facility at J&H Machine Tools, the Zeiss distributor in Charlotte, NC.

The new, 4,000-square foot West Coast technical center will support regional customers, offer demonstrations and provide applications support and training services at a single location.

Zeiss' 2,500-square foot metrology center at J&H Machine Tools includes a demonstration area, a CMM training center and the latest in CNC machine tool and measuring technology.

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New Officers Elected to ASTM Board

The American Society for Testing and Materials (ASTM) has elected a new chairman, vice chairman and Finance and Audit Committee chairman to its 2000 Board of Directors.


Harvey P. Hack

Harvey P. Hack, an engineer at the Northrup Grumman Corporation, Annapolis, MD, will serve a one-year term as chairman. He joined in 1978, served as vice chairman from 1998 to 1999 and as chairman of the Committee on Standards from 1992 to 1994.


Richard J. Schulte

Richard J. Schulte, a founder and partner in the firm of Schulte Associates LLC, of Brecksville, OH, is the new vice chairman. He has been on the ASTM Board since 1996 and was chairman of the Finance and Audit Committee in 1999.


James Bover

James Bover, Ph.D., section head of Quality Assurance for Exxon Mobil Biomedical Sciences, Inc., of Annandale, NJ, is now chairman of the Finance and Audit Committee. A member since 1983, Bover joined the Committee on Standards, later chairing its Form and Style Subcommittee.

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National Conference of Standards Laboratories

From July 16, 2000, through July 20, 2000, the Westin Harbour Castle in Toronto, Ontario, Canada, will host the National Conference of Standards Laboratories: Annual Workshop and Symposium (NCSL). The event, cosponsored by the National Institute of Standards and Technology (NIST), will include papers, panel discussions, workshops and over 140 exhibits from the top companies in the metrology industry. According to the organizers, "The key conference provides a vital forum for the exchange of ideas, techniques and innovations among those who are proactively engaged in the exciting global Measurement Science Industry." For more information contact NCSL at (303) 440-3339 or log onto *www.ncsl-hq.org*.

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FOCUS ON TECHNOLOGY

Non-Invasive Testing for Gear Heat Treat Quality

Intex, Inc., has developed a non-invasive method to verify proper hardness on both case hardened and through hardened gears.

The TREC Model 421 utilizes pulsed eddy-current technology to perform non-invasive gear testing. Electromagnetic probes apply high-speed magnetic pulses to the gear under test and then detect the electromagnetic fields resulting from the transient eddy-currents induced deep within the gear (in excess of 6 mm in ferrous and 12.5 mm in nonferrous materials). Specific time-domain characteristics of those transient electromagnetic signals have been shown to be dependent upon the metallurgical properties of the gear, which, in turn, are dependent upon the heat treating process applied to the gear. Contact Intex at (800) 638-8937 or visit their website at *www.intexinc.net*.

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Low Cost Involute and Lead Measuring Machine from Basic

According to W.F. Wolf, CEO of Basic Machine Tools, the Model #16-ILM is "an economy involute and lead measuring machine, which is the alternative to high-cost machines that are beyond the reach of many gear shops."

The #16-ILM retains the features of single disk involute machines, but it also has certain universal characteristics such as measuring the involute profile error of any base circle diameter in common ranges, and utilizing only thirteen (13) base circle disks. For more details contact Basic Machine Tools at (323) 933-7191.

305

New Large Volume Portable CMM

Metronor Inc., announces the first portable coordinate measuring machine to handle volumes up to 45 cubic feet, exhibit 2-sigma sphere test accuracy of less than 0.002" and a 3D length accuracy (bias) of 0.004", and cost under $70,000 as a complete, turnkey system.

The SOLO machine uses a high-resolution charge-coupled device (CCD) sensor and Metronor's smart-LED Light Pen to make direct feature measurements throughout the sensor's field of view. SOLO is unique in having no moving mechanical parts, which offers excellent, long-term stability and reliability. "From the start, SOLO was designed to be rugged, reliable and easy to learn and use," said Dr. Alf Pettersen, vice president of Technology at Metronor. For more information, contact Metronor Inc., at (248) 353-3100.

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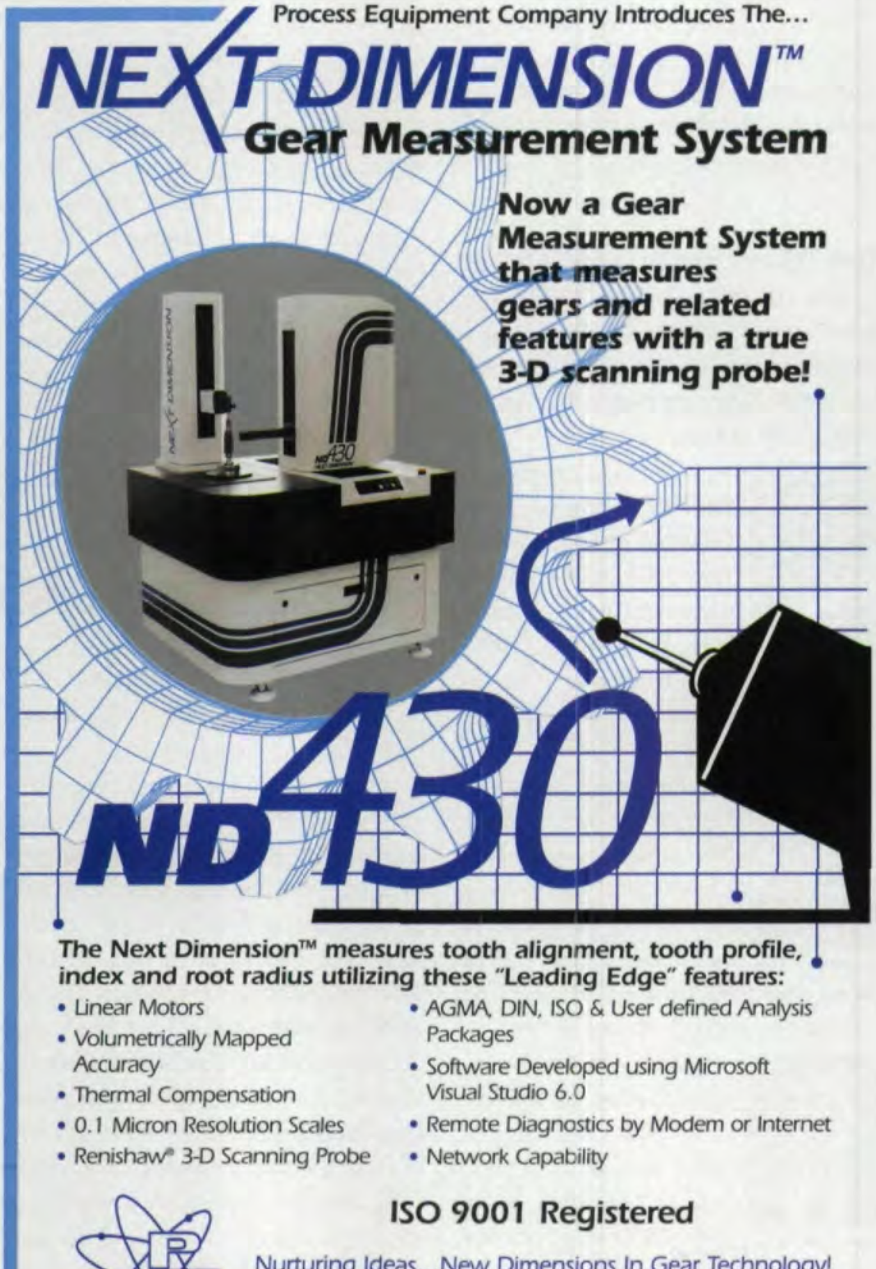

New Gear Inspection System from AST

American Stress Technologies, Inc. has introduced an off-line audit inspection system used to detect grinding damage, some heat treat qualities, and residual stress from manufacturing processes. The Gear Inspection System automatically scans the ground surface of the gear, sending test data to a Rollscan central unit where it is analyzed, displayed and stored. An operator can then examine the data and make process adjustments. For more information, contact American Stress Technologies, Inc. at (412) 963-0676 or by e-mail at *ast@sgi.net*.

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New CMM from Giddings & Lewis Controls

Giddings & Lewis Controls, Measurement and Sensing, have introduced the Endeavor Series coordinate measurement machines, which are designed to provide inspection lab precision (volumetric accuracy to 0.008 mm, 0.0025 mm repeatability) in a lower cost, shop floor machine.

The Endeavor features real-time temperature compensation to guarantee accuracy over a 5° C temperature range, a granite table for added thermal tolerance and a firm, vibration resistant foundation. Other design features include a brushless, linear motor direct drive system and a kinematic design featuring a rigid, lightweight moving structure supported by five optimally positioned bearing points to reduce stress on the drive system and enhance overall accuracy. For information contact Giddings & Lewis at (800) 348-9510 or log onto *www.giddings.com*.

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Sony launches New Non-contact 3D CMM

Sony Precision Technology America, Inc., has introduced its YP10 3D coordinate measuring machine for close tolerance parts applications. This system combines non-contact, auto-focusing optical/laser sensing technology and PC-based computer numerical control to provide 3-dimensional inspection, measurement and analysis of microscopic surface features on integrated circuits, printed circuit boards, computer hard disks and machined materials.

CNC movement within all axes is a closed loop controlled by the unit's 450 MHz Pentium II PC, which provides fast movement and reading response at all specified measuring points. Resolution in all three axes is 0.1 microns and Z-axis positioning repeatability is ±0.2 microns. For information on the YP10 3D CMM, call Sony at (949) 770-8400 or visit *www.sonypt.com*.

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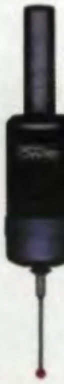

Fowler Offers CMM Probes

The Fred V. Fowler Co., Inc. announces a range of touch-trigger probes and associated equipment to meet a variety of probing applications on most coordinate measuring machines.

The P1-5A probe is a 5-axis CMM touch-trigger probe whose small size and rugged construction permit use for many applications, as does the P1-5BS probe with integrated body and shank. Both have 0.5 µm repeatability, employ a stylus force of 9 grams, are designed for operating 5 axes: ±X, ±Y, +Z, and travel over Z+5.0 mm. For further information, contact Fowler at (800) 788-2353 or visit their website at *www.fvfowler.com*.

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CIRCLE 129

Universal Testing Instruments from Shimadzu

Shimadzu Scientific Instruments has introduced the Autograph AG-1 Series of universal testing instruments. Available in seven load ranges from 1kN (200 lbf) to 250kN (50,000 lbf), the high precision AG-1 testers provide a full range of completely automated test functions. For maximum accuracy, Trapezium software for Windows 95/98 and NT 4.0 enables test data sampling at 1.25 ms intervals with a test force precision of ±0.5%. Test speeds from 0.00002 in/min to 40 in/min provide flexibility to accommodate a variety of testing needs.

For more information call Shimadzu Scientific Instruments, Inc., at (800) 477-1227 or visit their website at *www.shimadzu.com.*

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CIRCLE 183

New In-Line Rockwell Scale Hardness Tester

Newage Testing Instruments, Inc. has developed an automatic, in-line Rockwell testing machine, which can be customized to accommodate many types of parts. This tester, called the Versitron, can perform 500–600 tests per hour without any operator involvement.

The Versitron's hopper automatically fills a vibratory bowl, which orients and feeds the parts into a feed track. At the tester, pneumatic actuators move each part into the test fixture. The test cycle is initiated automatically and the part is pushed out of the fixture by another actuator. An escapement system drops out-of-tolerance test specimens into a separate box at the end of the line. Sensors verify proper part positioning and system operation. Touchpad controls provide an operator interface for running the system.

The Versitron senses and compensates for wear, dirt build-up and test specimen deflection under load. A nosepiece surrounding the indenter senses the surface of the test piece at the preload position. If the specimen deflects under load, the nosepiece compensates while maintaining a good reference point for the test measurement. For more information contact Newage Testing Instruments, Inc., at (215) 657-6040 or visit *www.newageinstruments.com.*

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New Hardness Testing Software from Krautkramer

Krautkramer's new UltraHARD software transfers files from Krautkramer's MIC 10 DL or DynaMIC DL portable hardness testers to a PC. UltraHARD simplifies the process of testing, documentation and statistical analysis for more efficient and thorough results with detailed analysis of the measurement data, linear display of measurement sets for hardness curves, and statistical evaluation of individual measurement sets or the total number of measurement readings over all the measurement sets. Simple data management is guaranteed by the integration into the Windows and MS-Office world. Contact Krautkramer at (717) 242-0327 or visit their website at *www.krautkramer.com*.

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New Range of Lenses for Optimet's Conoscope Probe and Systems

Optimet, a division of Ophir Optronics, announces a wide range of new interchangeable lenses for their Conoprobe 1000, Conoscan 2000 and Conoscan 3000 systems. No matter what Optimet probe or system is in use, the ability to quickly and easily change the lenses to create new measurements is now available. From microns to millimeters, a single sensor can now be used just by changing the objective lens. This flexibility eliminates the need to purchase separate sensors. For further information, contact Optimet at (800) 383-0814 or visit their website at *www.optimet.com*.

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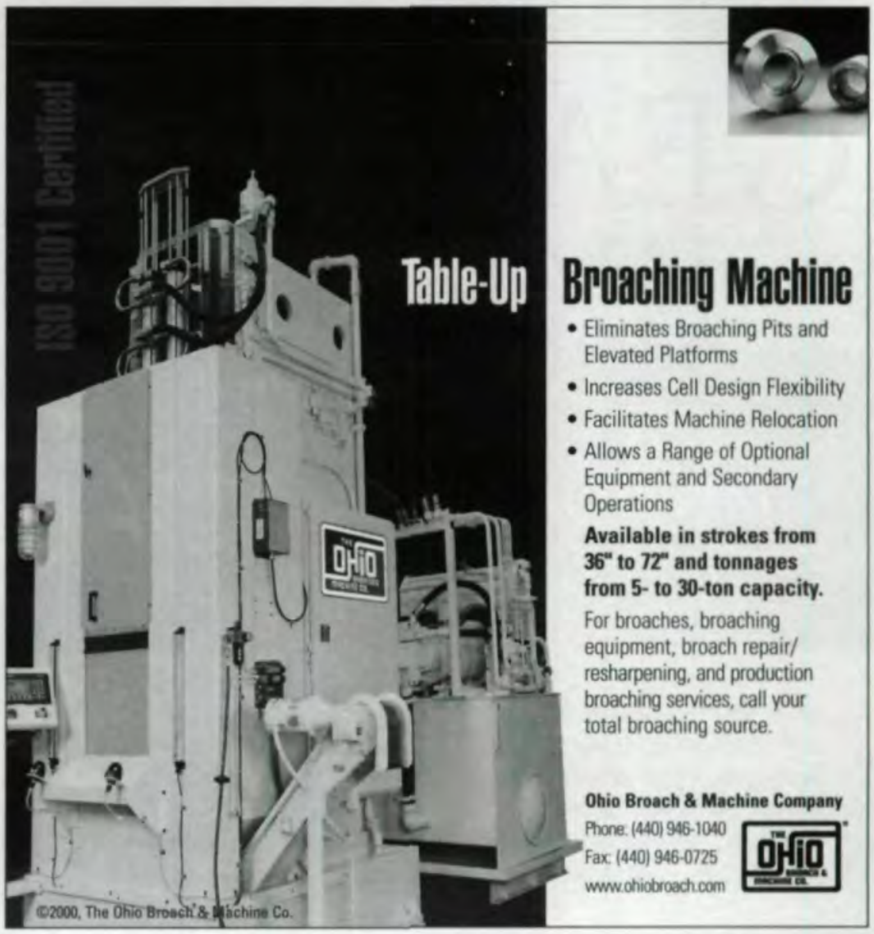
If you found this column of interest and/or useful, please **circle 227.**

If you did not care for this column, **circle 228.**

If you would like to respond to this or any other article in this edition of *Gear Technology*, please fax your response to the attention of Charles Cooper, senior editor, at 847-437-6618 or send e-mail messages to *Charles@geartechnology.com*.

CIRCLE 147



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Determining Lead Error on A Crowned Pinion

Q&A is your interactive gear forum. Send us your gear design, manufacturing, inspection or other related questions, and we'll put them before our panel of experts. Questions may be mailed to *Gear Technology*, P.O. Box 1426, Elk Grove Village, IL 60009, USA, faxed to (847) 437-6618 or sent electronically to *people@geartechnology.com*. An expanded version of Q&A is also available online at *The Gear Industry Home Page™*, *www.geartechnology.com*.

Question submitted by Daniel Braasch
Frisby P.M.C., Inc.
Elk Grove Village, IL

Q: How do you determine lead error on a crowned pinion when using analog gear checking equipment like a Höfler EFR630 ?

Answer submitted by Robert E. Smith
President, R.E. Smith & Co., Inc., Rochester, NY, and Technical Editor, Gear Technology *magazine.*

A: It is assumed that the EFR630 is not equipped with a computer for data analysis, and that all analysis is done manually. Also, how one analyzes the chart depends upon the accuracy system being used, such as AGMA, ISO, DIN, in house, etc. Each system has its own rules.

In the AGMA system, such as AGMA 2000-A88, "K" charts are used. The intention, in AGMA, is that the crown has to be evaluated in addition to the lead variation tolerance (the crown is not part of the lead or tooth alignment tolerance). Clause 9.5 in AGMA 2000-A88 discusses the "K" chart evaluation of unmodified gear teeth. Appendix C and Figure C-6 (Figure 1 in this article) attempt to show how crown is evaluated in addition to tooth alignment variation. However, it turns out to be confusing and doesn't clearly achieve the desired results. Note that the "functional face" is the face width minus any chamfer or rounding on the ends of the teeth.

In the author's opinion, DIN and ISO do a better job of evaluating crown and helix error. They both use a slope and form evaluation method. DIN 3960 says that the entire face width is used as the tooth trace test range, L_β. Common sense, however, says not to include any end chamfers, or rounding. DIN 3961 mentions reducing the face width by 10% at each end before evaluation. ISO 1328 Part 1 - 1995, uses the same methods of evaluation, but is more realistic in regard to the evaluation

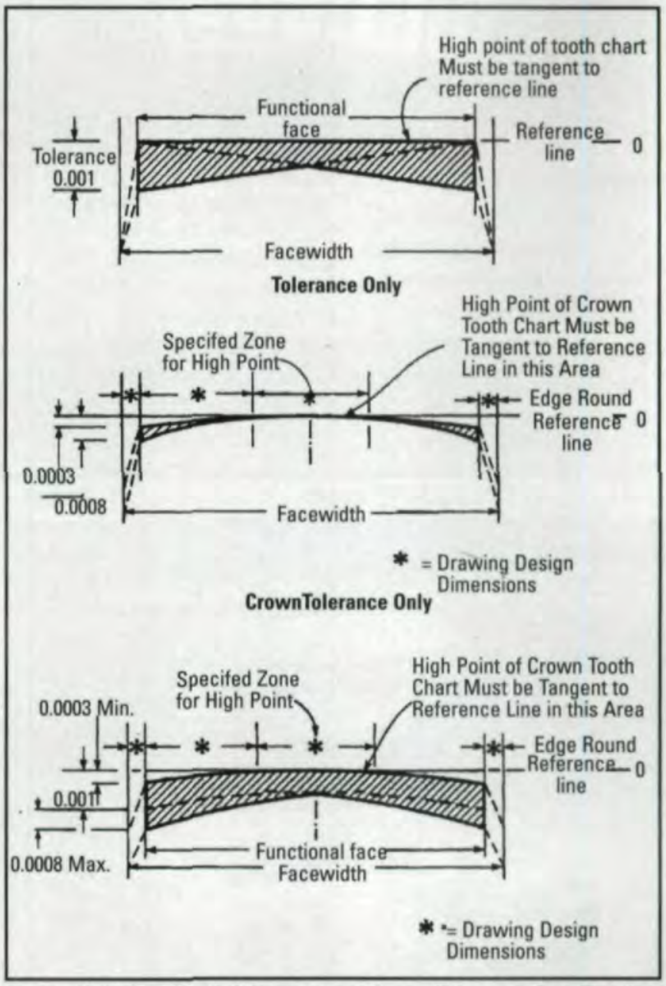

Fig. 1—(C-6) Total Tooth Alignment and Crown Tolerance Specification.

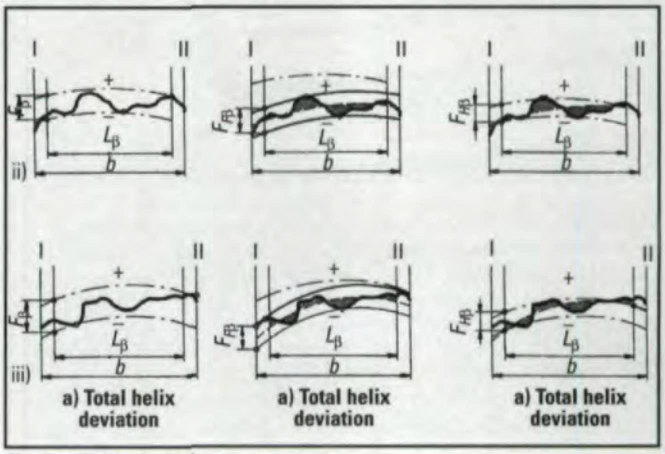

Fig. 2—Helix deviations.

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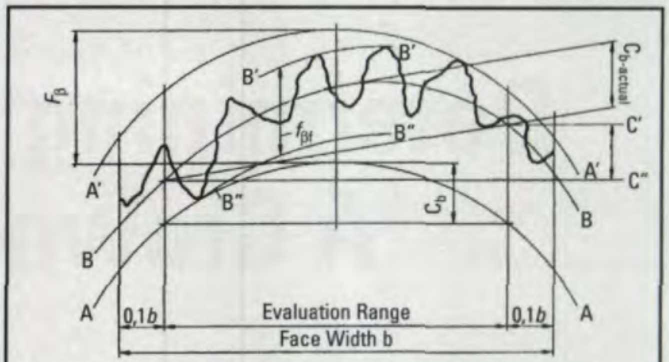

AA, A'A'	Corrected base lines bounding the test pattern within the evaluation range.
BB	Averaging actual tooth flank.
B'B', B"B"	Actual tooth traces bounding the test pattern within the evaluation range.
C'C', C"C"	Non-corrected nominal tooth traces through the points of intersection of the averaging actual tooth trace BB with the boundary lines of the evaluation range.
F_β	Tooth trace total deviation; results from the distance apart of the corrected base lines AA and A'A' as measured at right angles to the chart feed.
$f_{H\beta}$	Tooth trace angle deviation; results from the distance apart of the nominal tooth traces C'C' and C"C".
$f_{f\beta}$	Tooth trace form deviation; results from the distance apart of the actual tooth traces B'B' and B"B" as measured at right angles to the chart feed.
C_b	Nominal crowning
$C_{b\text{-actual}}$	Actual crowning

Fig. 3—Tooth trace test pattern for narrowed tooth trace test range.

range, L_β. In ISO 1328, the evaluation range is specified as the face width minus 5% or a length equal to one module, whichever is smaller, at each end.

When using a computer analysis system, the evaluation is automatic. ISO fits a "design" curve (that is the crown shape) to the trace and then evaluates form and slope errors relative to that (Figure 2). When using an analog recording system, the evaluation is done manually. DIN 3961, Figure 3, demonstrates a method of manually evaluating crown, form, and helix error separately, showing an exaggerated amount of waviness in the tooth trace. This is to illustrate the various parameters: crown, form, and helix error. To do a manual analysis, draw lines near the end of the trace that represent the evaluation length, L_β, then fit a curved line through the mean of the waviness that is superimposed on the crown curve. Form error is the bandwidth of the waviness (shown as $f_{\beta f}$ in the figure). Slope is the helix error (shown as $f_{H\beta}$ in the figure). Crown is $C_{b\text{-actual}}$ in the figure. This may not be as precise as computer analysis, but it can still be very accurate and useful. Certainly, it is much better than using a modified "K" chart.

Of course, crown should have minimum and maximum values specified, in addition to the lead or helix tolerance. ❍

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For more information about R.E. Smith & Co., Inc., **circle 231.**

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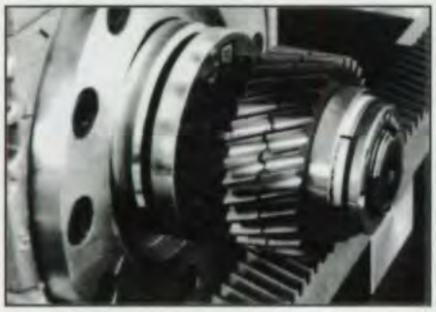
Welcome to our Product News page. Here we feature new products of interest to the gear and gear products markets. To get more information on these items, please circle the Reader Service Number shown.



New Preloaded Rack and Pinion Drive Systems from Andantex

Andantex has announced a line of preloaded rack and pinion drive systems for axis drive applications requiring high accuracy positioning. These systems effectively eliminate the backlash between the rack and pinion by using two pinions—one to drive the axis and one to preload the axis to eliminate the backlash. By eliminating the system backlash, accurate axis positioning is preserved during the transition period between acceleration/steady state and deceleration, where the rack and pinion flank contact and load reverses direction.

There are two types of preloaded rack and pinion systems: mechanically preloaded and electronically preloaded. Mechanical systems achieve preload by spring loading or torsionally winding one pinion against the other. These systems are typically driven by one motor and do not require a special motor controller. Electrical systems achieve their preload by electrically "braking" one pinion against the other. These systems require two motors/gearboxes and usually a special motor controller to handle the preload.

For additional information on preloaded rack and pinion drive systems, contact Andantex USA, Inc., at (800) 713-6170 or visit their website at *www.andantex.com.*

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New Harmonic Gear Drives from HD Systems

HD Systems, Inc., has introduced its new Size 11 and Size 14 harmonic gear drives. Each has a 30:1 gear ratio, the lowest ratio available for harmonic drive gearing. These systems offer 2 arc-min positional accuracy and smooth motion. With the new low ratio of 30:1, harmonic drive gearing may now be used in applications where planetary gears might have been used previously, resulting in a reduction in package size and weight while increasing positional accuracy and achieving zero backlash. The Size 11 (pictured) measures 40 mm in diameter and 26 mm in length. It has a maximum output speed of 460 rpm, rated torque of 19 in-lbs., and repeated peak torque of 40 in-lbs. The Size 14 has a diameter of 50 mm and a length of 29 mm. It also has a maximum output speed of 460 rpm, but its rated torque is 35 in-lbs. and its repeated peak torque is 80 in-lbs.

For information contact HD Systems, Inc., at (800) 231-4374 or visit *www.hdsystemsinc.com.*

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New Hobbers from Basic Machine Tools

Basic Machine Tools, national distributor of 75 models of Wolf gear machines, announces these new Wolf horizontal gear hobbing machine models: #GH3-2.5 and #GH5-5. Both machines, which are suitable for quantities ranging from single parts to mass production, can generate spur, helical and worm gears.

The GH3-2.5 can hob gears with a maximum diameter of 3.2", with a maximum tooth width of 2.5". The GH5-5 can handle gears with a maximum diameter of 4.9" with a 4.9" maximum tooth width. Options for the GH5-5 include a bevel gear hobbing attachment and a "tangential" worm wheel hobbing attachment. For more information contact Basic at (323) 933-7191 or log onto their website at *www.basicmachinetools.com.*

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Software for Parallel Axis Gear Analysis

Drive Systems Technology, Inc., and Eversolv Software have released PowerGear, a design and analysis tool for spur, single-helical and double-helical gears of either external or internal configuration. Originally developed by Ray Drago, president of Drive Systems Technology, for his *PC Applications in Parallel Axis Gear Design* seminar, which he teaches at the University of Wisconsin—Milwaukee, PowerGear is designed to be easy to use for both students and gear industry veterans alike.

From data entered by the operator, the program will calculate all required basic tooth geometry including tooth thickness, fillet geometry, contact ratios, etc.; as well as tool geometry, bending and contact stresses, flash temperature, strength and durability ratings in accordance with AGMA Standard 2001-C95. It will also calculate elastohydrodynamic film thickness for wear probability rating, frictional power loss, scoring hazard rating, tooth profile kinematics, subsurface shear stress/strength and much more. A number of output formats and methods are available including conventional printed format with analysis text notes, on-screen with real-time updates, graphical format, and CSV data files, which can be read by other programs (e.g. word processors, spreadsheets, etc.) for ready report and presentation preparation.

For more information about PowerGear, contact Eversolv at (513) 469-8400 or for a free, 30-day full demonstration version of PowerGear, log onto *www.eversolv.com.*

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New Gearheads from Thomson

Thomson Industries, Inc. has come out with two versions of its DuraTRUE 90 True Planetary right angle Gearhead, a hollow shaft design (pictured above) and a dual shaft design. Both units offer a backlash of 8 arc-minutes, a peak torque rating of 7,450 in-lbs., a peak radial load capacity of up to 1,798 lbs., and ratios ranging from 1:1 to 500:1.

The DuraTRUE 90 Hollow Shaft provides a direct coupling to multiple drives, making it ideal for tightly constrained designs. Also, it increases system reliability while decreasing cost by eliminating the need for separate couplings and reducing valuable real estate with a shorter installed length. It comes in 90 mm, 115 mm and 142 mm square frame sizes with bore sizes of 22 mm, 30 mm, and 38 mm. The DuraTRUE 90 dual shaft model gives

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CIRCLE 122

designers the option of operating 2 axes with a single servo motor, saving money by eliminating components. The unit is available in 60 mm, 90 mm, 115 mm and 142 mm square frame sizes.

For more information contact Thomson Industries, Inc., at (516) 883-8000 or log onto their website at *www.thomsonindustries.com.*

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For more information, contact General Magnaplate at (800) 852-3301 or visit the company's website at *www.magnaplate.com.*

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Send your new product releases to:
***Gear Technology*, 1401 Lunt Avenue, Elk Grove Village, IL 60007**
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New "Golden" Surface Enhancement from General Magnaplate

General Magnaplate Corporation has announced the release of its new, ultra-hard, micro-thin Goldenedge™ surface enhancement treatment for blades and other sharp edge cutting tools. The coating provides precise thickness control, giving razor-sharp edges a dramatically increased service life by as much as 20 times, while maintaining sharpness. Due to the fine-grain structure, surface tension is reduced, which in turn decreases cutting resistance while improving equipment operational speeds.

The new coating creates a dense, smooth golden surface with increased hardness up to Rockwell C 85. A thin, uniform coating ranges in thickness from 0.00004" to 0.00006" or 1.0 to 1.5 microns. The non-stick surface meets USDA/FDA codes for food and drug contact, cleans easily with water and resists most chemicals and solders. The service temperature ranges from –300°F (184°C) to +1000°F (538°C), and the process temperature is from +450° F (232°C) to +932° F (500°C). Applications include die cutting, flaking, forming, filleting, gutting, grinding, pulverizing, scaling and sawing.

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www.gleason.com

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Visit the Liebherr Gear Technology site for links to specifications on the Sigma Pool range of CNC gear processing machines – hobbing, shaving, shaping, bevel gear generating machines and measuring machines. North American service for Sigma Pool is located in Saline, Michigan, telephone (734) 429-7225.

www.lvt.liebherr.de

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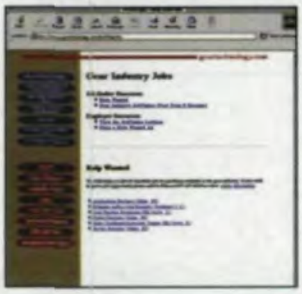

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A BARD OF SCIENCE

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

Oliver E. Saari was an engineer with two great professional loves in his life—writing and gear design, and he was devoted to each in their turn. The same original thinking that informed his fiction, giving life to tales of space exploration, the evolution of man, and many other topics, led him to become one of the great pioneers in gear design.

Oliver Saari: Gear Designer

Oliver E. Saari was born in Helsinki, Finland, on March 22, 1918. His family immigrated to the United States in 1927. After graduating from high school in 1935, Saari went to work for the Civilian Conservation Corps and attended a vocational school where he learned tool and die making. After that, he entered the University of Minnesota to study mechanical engineering. He graduated in 1943 and went to work for the Buick Motor Division of General Motors, where his interest in gears developed. According to Saari, gear design was the most mathematical field in mechanical engineering. "He once told me that he might have been a physicist," said Heidi Leeson, Saari's daughter, "but engineering seemed a safer bet when it came time to get a job."

In 1945, he went to work for Illinois Tool Works (ITW) and earned a master's degree in mechanics from the Illinois Institute of Technology. Saari's career at the Illinois Tool Works was one of prolific invention and innovation, including Spiracon Roller Screws, Planoid Gears, Endicon, Helicon, Concurve and Spiroid Gears, all of which are trademarks of Illinois Tool Works. According to Dr. Faydor Litvin, Director of the Gear Research Laboratory at the University of Illinois at Chicago, "Saari's inventions bear the features of an unorthodox way of thinking, which resulted in original ideas that have already been applied in industry and will be widely used in the future."

Oliver Saari: Writer

Poul Anderson, a close friend of Saari's, described the relationship between science fiction writers and science eloquently when he said, "Our writers are bards of science."

Saari was such a bard, a voice in a choir of friends and role models that included Poul Anderson, Robert Heinlein, C.D. Simak, Gordy Dickson, Arthur C. Clarke and others who speculated on the future, the universe, and the role of science in human endeavor.

Saari's stories deal with artificial intelligence, electromagnetism, astronomy and flight, nuclear energy and space travel. He saw space stations launching missions to other worlds ("The Space Man," 1952), reliable nuclear power ("Stellar Exodus," 1936), artificial intelligence ("Dog," 1950), and the mutative effects of radiation on life ("Two Sane Men," 1937).

Saari's work first saw print in *Astounding Science Fiction*. The story, "*Stellar Exodus*," sold for $35.00.

After "Stellar Exodus," his by-line was seen again in *Astounding Science Fiction*, as well as in *Startling Stories* and *The Magazine of Fantasy and Science Fiction* among others. Out of 30 stories written between 1935 and 1953, when he quit writing and turned his attention entirely to gear design, Saari saw 19 of his stories in print.

As for why Saari quit writing, the evidence points to Saari making a choice between writing and gear design, between what he felt he could do well and what he felt he could do brilliantly. "I think he got a charge out of having his stories published and actually getting paid money for them, but there is no question that his engineering work meant more to him," said Leeson. "He knew he could write and even bragged about getting stories back with no editorial changes whatsoever, but felt his own lack of skill in character development. From the early 1950s on, he poured all his creativity into his [gear design] work."

Oliver E. Saari, Science Fiction Writer.

Saari's Last Chapter

Oliver Saari died on January 25, 2000, at the age of 81. Unlike many who don't live to see the future they write about, Saari was able to see that many of the things he and his contemporaries wrote about decades ago were, indeed, becoming real. This, perhaps, speaks less about his longevity than it does about the influence science fiction has over science fact. What will the lives of our descendants be like? We must listen to the bards of science as they sing and remember that once upon a time, they sang about us. O

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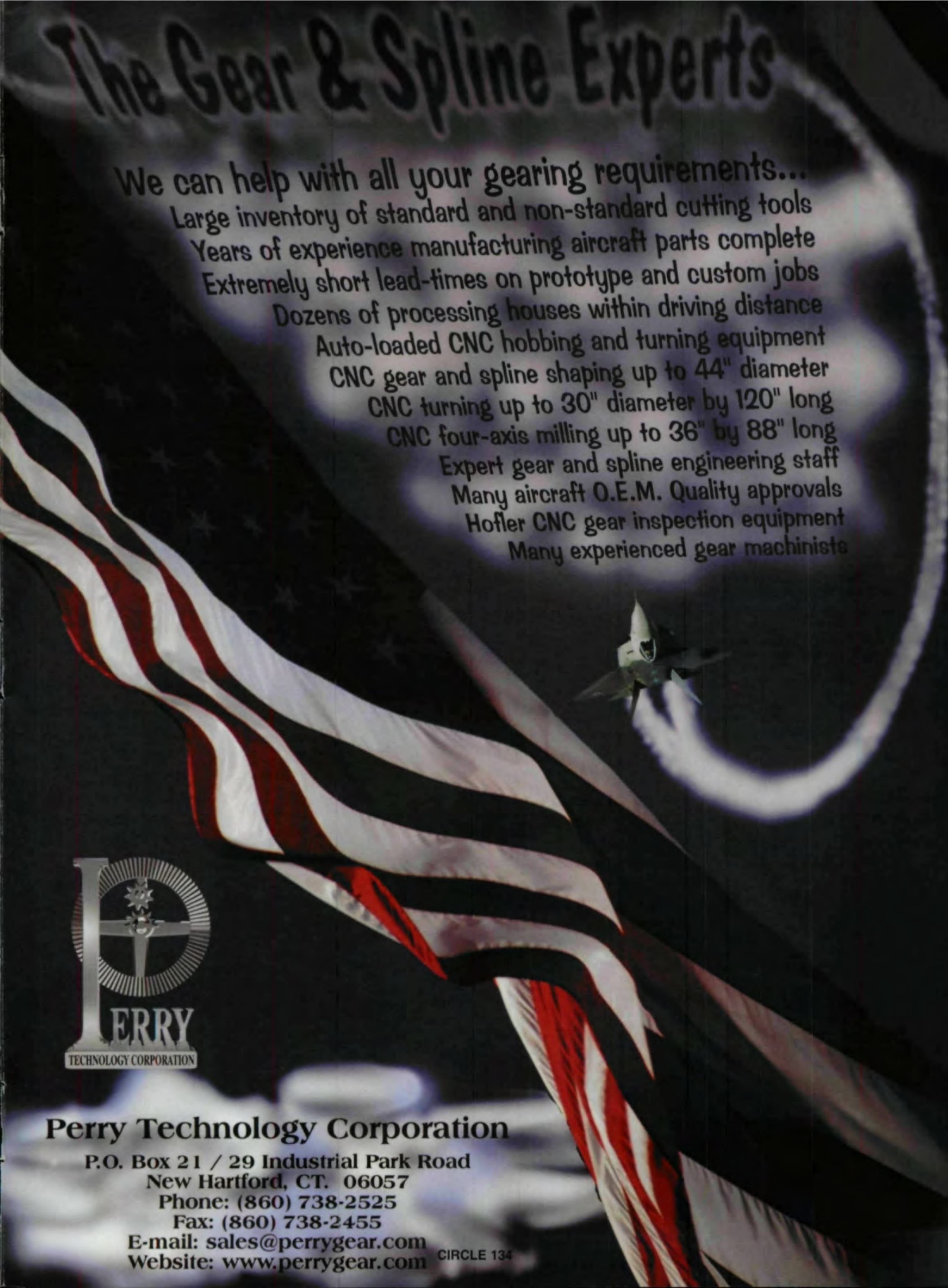
If you would like to respond to this or any other article in this edition of *Gear Technology*, please fax your response to the attention of Charles Cooper, senior editor, at 847-437-6618 or send e-mail messages to *Charles@geartechnology.com.*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