September 2011

GEAR TECHNOLOGY

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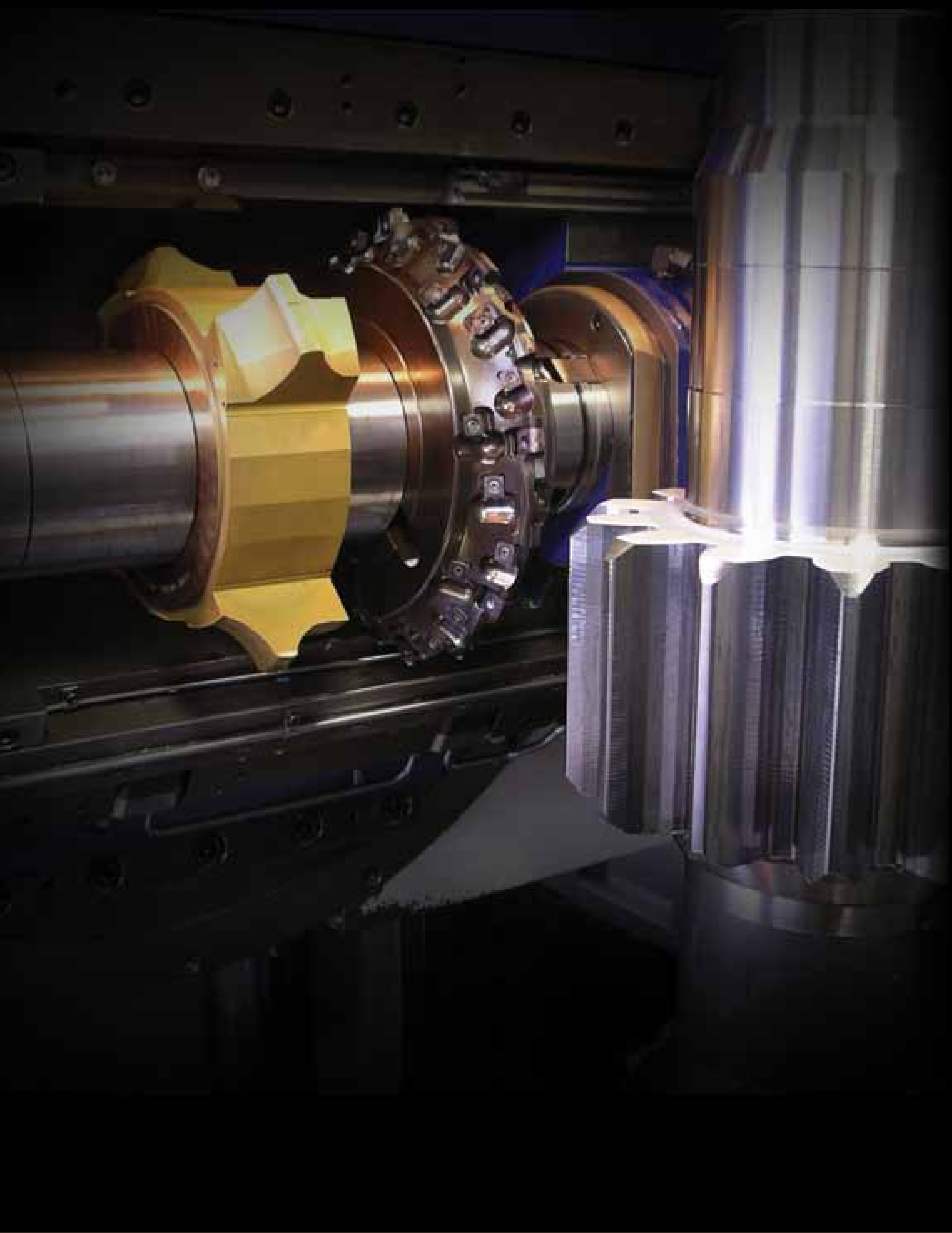
The Journal of Gear Manufacturing



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GEAR TECHNOLOGY

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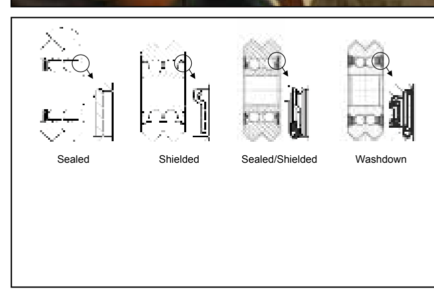

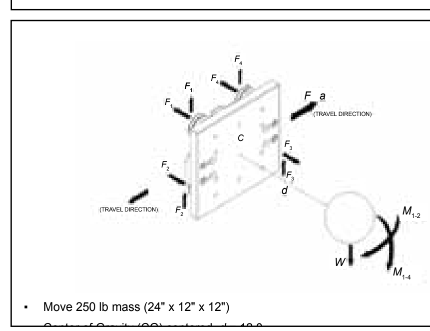

Vol. 28, No. 6 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, July and December by Randall Publications LLC, 1840 Jarvis Avenue, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). Randall Publications makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1840 Jarvis Avenue, Elk Grove Village, IL, 60007.

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VOL. 28, NO. 6

Randall Publications LLC
1840 Jarvis Avenue
Elk Grove Village, IL 60007

Phone: (847) 437-6604
Fax: (847) 437-6618

EDITORIAL

Publisher & Editor-in-Chief	Michael Goldstein ***publisher@geartechnology.com***
Managing Editor	William R. Stott ***wrs@geartechnology.com***
Senior Editor	Jack McGuinn ***jmcguinn@geartechnology.com***
Associate Editor	Matthew Jaster ***mjaster@geartechnology.com***
Editorial Consultant	Paul R. Goldstein
Technical Editors	William (Bill) Bradley Robert Errichello Octave Labath, P.E. Joseph Mihelick Charles D. Schultz, P.E. Robert E. Smith Dan Thurman

ART

Art Director	Kathleen O'Hara ***kathyohara@geartechnology.com***

ADVERTISING

Advertising Sales Manager	Dave Friedman ***dave@geartechnology.com***
Materials Coordinator	Dorothy Fiandaca ***dee@randallpublications.com***

CIRCULATION

Circulation Manager	Carol Tratar ***subscribe@geartechnology.com***

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EVERYONE'S A CRITIC

A small group of editors is seeking participants for an open-ended focus group to be held at the upcoming Gear Expo. To qualify, you must have been a reader of ***Gear Technology*** or ***Power Transmission Engineering*** magazines, you must have subscribed to one of their e-mail newsletters, or have visited and used either ***www.geartechnology.com*** or ***www.powertransmission.com***. Let us know how we're doing, what types of articles you'd like to see more of, and how else we can serve you and the industry.

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Not All Good Ideas are Brand New

by Dr.-Ing. Carsten Hünecke,
Head of Mathematic Technical Department Klingelnberg

In the March/April issue of *Gear Technology*, the article "Gear Measuring Machine by NDG Method for Gears Ranging from Miniature to Super-Large" was published. The article describes the so-called "Normal Direction Generate Method (NDG)" as a new method for involute tooth profile measurement.

The basic idea is to move the probe not only in the X-axis direction of a measuring machine synchronously with the gear rotation angle, but also the Y-axis direction in a way that the probe moves along the line of action. This reduces the movement in X-axis direction required for the measurement.

This statement is right, but the idea is not new. There is an old patent in the United States and in Germany from Professor Willy Höfler which describes this idea. The patents were filed in 1988 (U.S. patent No. 4,852,402) and in 1987 (German Patent DE 37 17 166 C2) and later owned by Klingelnberg. As described in the article, the probe is moved along the line of action, which is tangential to the base circle. A measuring device using the patented method was the TPF.

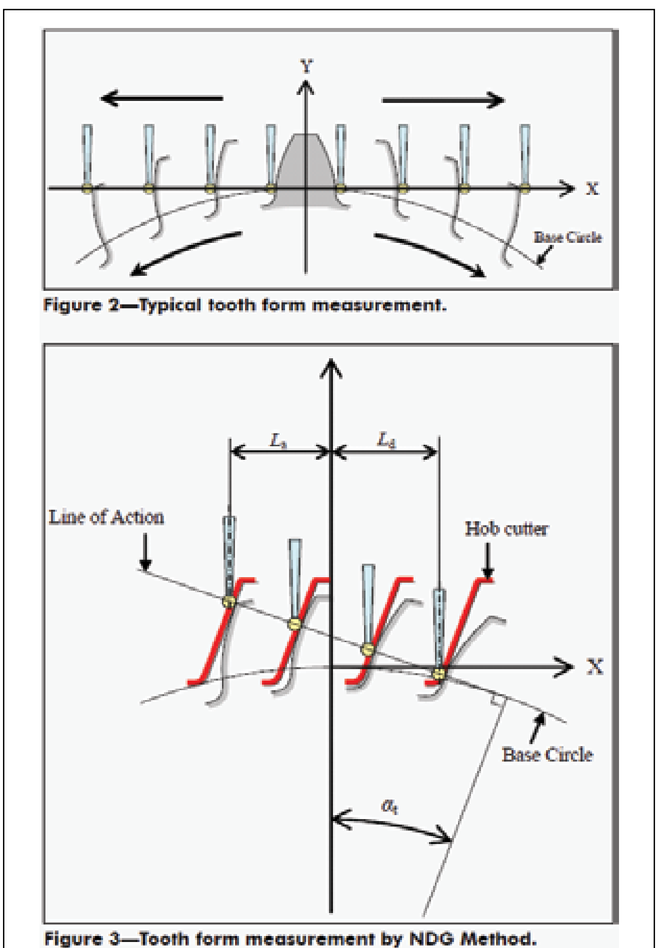


Figure 1—Figures 2 and 3 from the March/April 2011 *Gear Technology* article, "Gear Measuring Machine by NDG Method for Gears Ranging from Miniature to Super-Large."

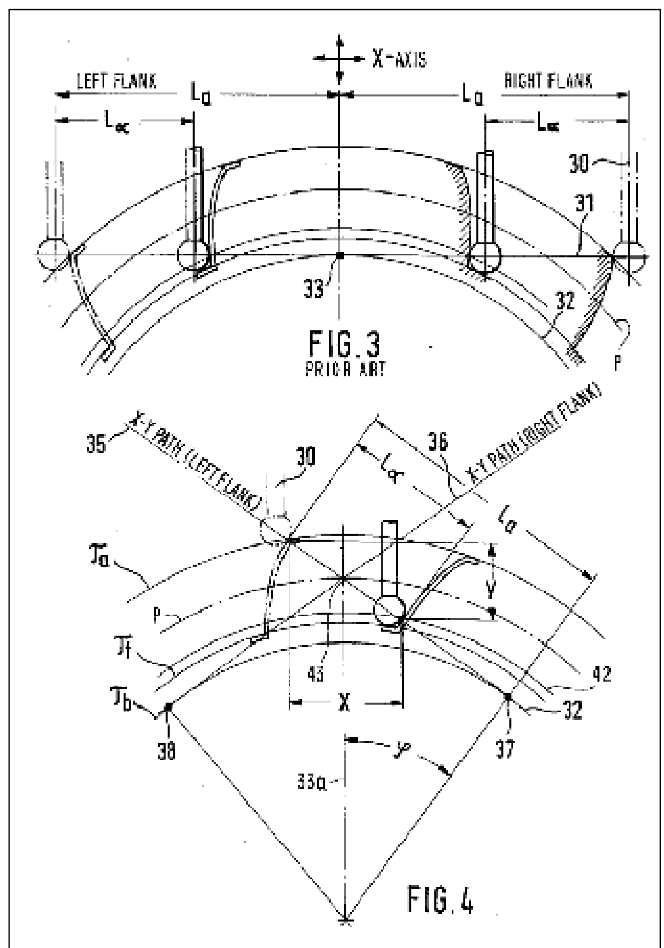


Figure 2—Figures 3 and 4 of the U.S. Patent No. 4,852,402, "Method and Apparatus for Checking or Testing the Profile of Gear Flanks, Particularly of Involute Gears."

Reliable and Efficient Skiving

Klingelnberg's New Tool and Machine Concept allows for Precise Production

The new stick blade tool system uses carbide technology which has long been used for bevel gears (All photos courtesy of Klingelnberg).

Klingelnberg AG presents its latest innovation, skiving. This newly developed tool system can be used on bevel gear milling machines and allows for a productive, stable and precise production process, particularly for internal gears. Despite high productivity and system-inherent accuracy, the breakthrough of skiving has been denied due to the tool problem. The chip formation process in skiving is very complex whereby large negative rake angles and only very small clearance angles arise during the process. The current tools, mostly cylindrical or conical solid carbide cutting wheels, have no degree of freedom for the necessary optimization. In addition to high machining forces, negative cutting angles also consistently lead to excessive wear of the tools meaning that the tool costs per component largely surpass the proportional machine costs. Klingelnberg's newly developed software shows the exact chipping conditions and therefore allows for a targeted optimization of the cutting geometry and the production movement.

The new stick blade tool system uses carbide technology which has long been used for bevel gears. "Skiving itself is in fact an ancient concept. The key innovation hereby lies in the use of stick blades and the resulting design possibilities for the cutting edge—a breakthrough in cutting technology," says Dr. Hartmuth Müller, chief technical officer of Klingelnberg. The stick blade has the distinct advantage of offering optimal cutting geometry through grinding. This is a necessary condition for the optimization of the chip formation process and therefore forms the basis for the breakthrough of skiving. A stick blade tool system also offers a wide range of further advantages including flexibility, optimized cutting geometry and minimal use of carbide metal.

Using the known Oerlikon stick blade grinding machine, the user can cost-effectively produce the tool for their own application within the shortest lead time and guarantees longer tool life than those of a shaping cutter or a skiving tool. In a stick blade tool, carbide is only used for the cutter which therefore ensures a highly efficient use of resources.

The entire process is highly energy-efficient, productive and flexible. In addition to the free design of the tool, tooth flank modifications can also be applied by superimposing additional movements during the skiving process. These advantages in comparison to gear hobbing, gear shaping or broaching are of particular importance for the production of internal gears. A simple comparison of shaping and skiving productivity shows that skiving is up to ten times quicker and offers a significantly longer tool life.

Although skiving is a machining process using a defined cutting edge, the surface qualities achieved are outstanding. Due to the very high fre-

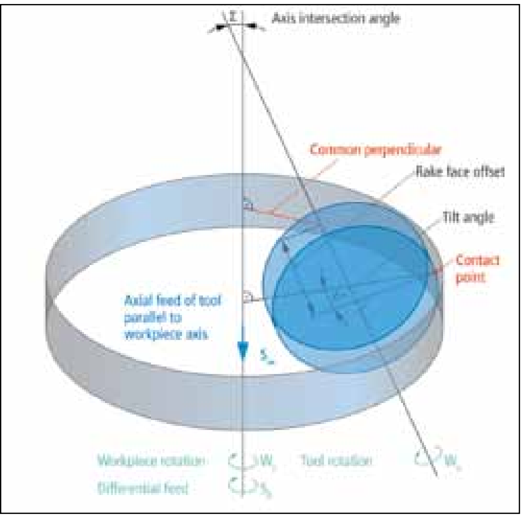
continued

quency with which the cutting edges move across the tooth flanks to be produced, a completely different surface texture is achieved than, for example, that of gear hobbing or shaping. In the image, the movements of two successive cutters in the tooth space are displayed as blue tracks. The distance of these tracks is determined by the axial feed rate with which the tool is moved along the face width of the gear to be produced. The cutting frequency is up to ten times higher than that of gear hobbing. As a result, a finer surface texture is achieved without the hollows created by gear hobbing or the grooves created by shaping and caused by tool wear.

Skiving can be executed on the Oerlikon C29 and C50 bevel gear milling machines. These machines ensure a highly-precise coupling of all movements which are necessary for skiving.

The incorporation of all these steps along the process chain to form a continuous data network guarantees stable and secure manufacturing processes. For Klingelnberg this is a trusted and globally approved approach within the scope of the closed loop concept. In order that the user is able to benefit from the same process security for skiving as that for bevel gearing, Klingelnberg has developed the closed loop for skiving which also incorporates tool preparation operations.

Skiving can be executed on the Oerlikon C29 and C50 bevel gear milling machines. These machines ensure a highly-precise coupling of all movements which are necessary for skiving. The highly dynamic process also requires a rigid machine design. The vertical arrangement of the tool and workpiece spindle offers particularly favorable conditions for chip removal. The C29 and C50 machine series meets all conditions required for skiving.



Skiving is a machining process in order to create periodic structures on rotationally-symmetric parts.

Skiving is a machining process in order to create periodic structures on rotationally-symmetric parts, for example, involute and non-involute gear teeth and splines for both internal and external components. The periodic structures are created through a generating process. The kinematic basis for this is the crossed axis helical gear. The skiving principle was developed at the beginning of the twentieth century and patented in 1910 by the company Pittler. Based on the target component geometry, a meshing tool is designed having a crossed axis with that of the work piece at a predefined angle. The cutting movement arises from the sliding component in direction of the face width of the teeth of the tool and the gap to be machined. This component is determined by the angle between the crossed axis, the size of the tool and the rotation speed of the producing gear transmission.

For more information:

Klingelnberg
1465 Woodland Drive
Saline, MI 48176
Phone: (734) 429-7225
www.klingelnberg.com

The Ever-Expanding Spiral Bevel Platform

Expanding market share in the spiral bevel gear segment poses many challenges, particularly in quality requirements and new equipment investment. If a manufacturer has any hope to succeed, emphasis in these areas is necessary. Companies like

continued

Vancouver Gear Works Ltd., Iwasa Tech (Japan) and ATA Gears (Finland) are committed to this market segment and are all preparing for increasing demand in spiral bevel applications.

VanGear Collaborates with Iwasa Tech. Vancouver Gear is a provider of specialty gear manufacturing services in Western Canada. Originally founded to provide aftermarket replacement parts for the flourishing coastal marine industry, the company has since branched out to other industries (oil and gas, forestry and mining) and has continued to develop into a specialty jobbing facility. Iwasa Tech began sending large bevel gear sets milled by CNC machining centers in 2009. In November 2010, the company opened Iwasa Tech USA Inc. in Chicago and started its worldwide sales and service by spring of 2011 as an associate member of AGMA.

Jim Mantei, vice president of business development at Vancouver Gear.

For both companies, the biggest challenge in 2011 will be to expand the market share for large spiral bevel gears above 1,200 mm PCD in the worldwide market, according to Yoshikazu Abe, president at Iwasa Tech and chairman of the Japan Gear Manufacturers Association (JGMA).

"We are in a position to supply five-axis CNC hard finished milled tooth profiles to very high quality levels, and we're strategically aligning ourselves with VanGear to penetrate this market segment. In the meantime, our sales office in Chicago is expected to develop overseas sales of a variety of gears in the worldwide market," Abe says.

Both Iwasa Tech and Vancouver Gear have invested heavily in ISO-certified quality management systems since spiral bevel gears are used in applications with these stringent high-quality requirements (Iwasa Tech currently can manufacture to a DIN 2–3 class or AGMA Q 14–15).

Yoshikazu Abe, president at Iwasa Tech.

Another

area of focus is to minimize distortion during the carburizing heat treating process to provide consistent and proper effective case depths. The tooth finishing is done by five-axis CNC milling, and extensive research utilizing the most suitable tooling and optimized cutting gives the ability to hard finish to a very high quality and surface finish level.

Iwasa Tech has been manufacturing spiral bevel gears the traditional way on a Klingelnberg spiral bevel gear generator for many years. More recently, the company invested heavily in five-axis CNC machining technology for both spiral pinion shafts and gears.

"Both Vancouver Gear and Iwasa Tech are committed to continued investment in new equipment to enhance our capabilities to provide great customer service by reducing lead times and providing customers with viable options to the traditional method of manufacturing spiral bevel gears. We've had good success in Asia and now want to offer this technology to North America," Abe says.

Pulverizers and cement crushers for the power generation industry and thrusters for the marine industry have contributed to an increase in Iwasa's spiral bevel gear business in the past few years, but the forecast for the marine industry is a bit of a downward trend, as demand for new marine vessels is slowing at the moment but expected to rebound sharply next year. In general, business is good. "We've been growing at a rate of about five percent per year over the past five years and we expect this to continue for the next few years," Abe says.

Iwasa Tech and VanGear will be exhibiting at Gear Expo 2011 with an emphasis on its spiral bevel product line.

ATA Gears Preps for Spiral Bevel Growth. ATA specializes in the design, production and sale of customized spiral bevel gears for the vehicle, heavy engineering and marine industries. The company's main emphasis is the continuous training of ATA employees to meet the ever increasing quality requirements found in the spiral bevel market. Currently, ATA offers high-quality ground or skived spiral bevel gears in the range of 2–120 inches.

"We work closely with leading universities and research institutes so that we always have the latest knowledge and know-how in the spiral bevel field," says Heikki Stranius, sales director at ATA Gears. "Manufacturing methods in gear cutting have developed dramati-

continued

cally. The new five-axis machines offer interesting possibilities to bevel gear manufacturers."

ATA Gears has always been in the high end of spiral bevel gear business where requirements and tolerances are traditionally very tight, according to Stranius. "Today, we pay a lot of attention to the topography and heat treatment of large size spiral bevel gears. We invest an average of 10–15 percent of our turnover every year in new machinery."

ATA Gears opened a brand new factory location in 2009, offering additional space of 50,000 square feet with

an investment plan to purchase $15 million in new equipment to increase capacity (equipment includes gear generators, CNC machining centers, CMM checkers, etc.).

The company quickly recovered from the recent economic slowdown and is currently seeing improvements in all business sectors. "We see increasing demand in the market for high quality spiral bevel gears. With the help of our latest and future investments, ATA is prepared for even more growth in the next two to three years," Stranius adds. "Price competition is one of the big challenges in the global market. ATA Gears is striving hard to meet price competition. We also see that delivery performance must improve in the future. We see growth in all segments such as marine applications and other heavy-duty gear applications."

Though the company will attend two to three trade shows in Europe and Asia this year, they have not decided yet if they will be attending AGMA's Gear Expo.

For more information:

ATA Gears
P.O. BOX 120
FI-33101 Tampere, Finland
Phone: +(358) 3 2870 111
www.atagears.fi

Iwasa Tech
5-4 Shinkiba 4-Chome Koto-ku
Tokyo, Japan 136-0082
Phone: +(81) 3-3521-0103
www.iwasa-tech.com

Vancouver Gear Works, Ltd.
14551 Burrows Road
Richmond, B.C. V6V 1K9
Canada
Phone: (604) 278-31111
www.vangear.com

Gleason

INVESTS IN COARSE-PITCH HOB PRODUCTION CELL

In response to unprecedented global demand for large cylindrical gears, Gleason Cutting Tools Corporation has invested in an advanced coarse-pitch hob production cell to reduce delivery time to as little as six weeks on a full range of large roughing and finishing hobs. The new hob cell, in combination with lean manufacturing methods, speeds production of coarse-pitch hobs complete from barstock including on-site final inspection of all critical hob features. The hob cell has also enabled Gleason to expand its product range to include hobs as large as 450 mm in diameter, 530 mm in length, and up to 40 module. This product offering includes Gleason's

continued

popular E-Z Cut hob, which features a unique flute design that adds extra cutting edges and delivers rough cutting feed rates up to 70 percent faster than conventional hobs. In addition, the hob cell gives Gleason the ability to produce the finishing hobs, ground to AGMA Class AA classification and with any desired profile or special involute modification.

For more information:
Gleason Corporation
1000 University Avenue
Rochester, NY 14692
Phone: (585) 473-1000
www.gleason.com

Romer

LAUNCHES NON-CONTACT LASER SCANNER

Romer Inc., a brand of Hexagon Metrology Inc, has announced the launch of the CMS108, a high-precision, non-contact laser scanner available for their portable coordinate measuring machines. The newest option in Romer's laser scanning portfolio, the CMS108, is the most adaptable and adept at scanning a wide range of materials with enhanced sensitivity to color and surface finishes. Its improved accuracy makes it attractive for inspection and reverse engineering applications where laser scanners have been unable to meet tight tolerances. The CMS108 mounts with a kinematic joint to the seven-axis Romer portable CMMs, which include the Absolute Arm SE and the Infinite

2.0 SC Arm. The CMS108 is the most precise laser scanner offered by Romer, with an accuracy of 20 micronsthat is a 16 percent gain in accuracy over previous scanning solutions. In addition, the device was engineered for applications with a wide variety of color and surface finishes. Flying dot technology allows the laser scanner to rapidly detect changes in color and surfaces via their reflectivity. An operator can scan traditionally difficult finishes, including shiny and mirrored surfaces, without making manual exposure adjustments. The laser scanner can transition from matte to shiny features without additional calibration. With three different line widths and differing point densities, the CMS108 is able to perform inspection routines on small intricate parts and large surfaces.

"The CMS108 is the perfect addition to our portable scanning portfolio," states Eric Hollenbeck, Hexagon Metrology's product manager for portable products. "With versatility and an exceptional data collection rate, we now offer an incredibly accurate scanner capable of inspecting different consecutive surfaces on the fly with no adjustments. The CMS108 system integrates our industry-leading Scanning System Specification which specifies and calibrates the arm and scanner as a single unit. Although any organization with portable metrology requirements could potentially benefit from this technology, typical users include those in the automotive, aerospace, medical, rail and energy production industries. The addition of the CMS108 to our lineup demonstrates Hexagon Metrology's commitment to offering the customer unrivaled choice in portable metrology."

The CMS108 is currently available for the seven-axis Absolute Arm SE with measuring ranges of 2, 2.5, 3, 3.5, 4 and 4.5 meters. The sensor can also be added as an upgrade to the seven-axis Infinite 2.0 SC Arm.

continued

Both products are produced in the new, state-of-the-art facility in Oceanside, California.

For more information:
Hexagon Metrology, Inc.
North Kingstown, RI 02852
Phone: (800) 274-9433
www.hexagonmetrology.com

C & B Machinery System

DOES THE WORK OF THREE MACHINES

C & B Machinery of Livonia, Michigan has improved productivity and flexibility of their double-disc non-coplanar connecting rod grinding system, first introduced in 2009 for the Chevrolet Volt 1.4 L auxiliary engine. The first grinding system produced a stepped connecting rod from a parallel (or coplanar) rod. The 1.4 L Chevy Volt connecting rod has a 1.2 mm symmetrically smaller crankshaft end width, and both the pin and crank ends of the rod are ground in one sequence. At the time, the system was considered the most advanced double-disc grinder ever produced by C & B.

This latest system, recently shipped to Eston Manufacturing Division of Linamar Corporation, is grinding a 1.8 L connecting rod with a symmetrical reduction of the pin end of 3.8 mm. As before, the challenge was to produce this part from a coplanar connecting rod in one operation. Stock removal from the pin end of the connecting rod is 5 mm and stock removal from the crank end is 1 mm. Previously, this connecting rod required three grinding operations to complete and the crank and pin end were ground on two separate machines.

C & B's application engineers took the challenge to develop a special tooling package and unique two-stage grinding cycle, which first rough grinds the pin end to a stock condition equal to the crank end. It then finish grinds the crank and pin ends of the connecting rod simultaneously. Grinding the crank and pin ends at the same time produces much better symmetry between the two. Additionally, the grinder easily exceeds Eston's 1.67 Ppk requirements for size, parallelism and flatness. The grinding system also includes a post process gaging system with automatic feedback to the grinding wheel infeed servos, providing automatic compensation for wheel wear. The gage also inspects step relationship between the crank and pin end faces.

The C & B model DG-2H-30/SA Connecting Rod grinding system has the ability to grind parallel parts, noncoplanar parts, pin end only or crank end only configurations with very simple changeover. This bodes well for meeting today's manufacturing requirements—lower production rates, better flexibility and a never-ending demand for lower machining costs per piece. With models utilizing up to 42" diameter grinding wheels, large diesel connecting rods can also be produced in this manner.

For more information:
C & B Machinery
12001 Globe Street
Livonia, Michigan 48150
Phone: (734) 462-0600
www.cbmachinery.com

Mahr Federal's MarForm Series

GETS UPGRADES

Mahr Federal will be featuring the new version of their successful MMQ 400 series, the MarForm MMQ 400-2, at Quality Expo 2011, September 20–22, 2011, at McCormick Place North, Chicago, Illinois. Mahr Federal will occupy booth # 600. The MarForm MMQ 400-2 integrates a new controller which allows the measurement of surface finish parameters according to ISO, ASME and JIS standards. With dramatically increased speed and resolution, the MMQ400-2 samples data with spacing as tight as 0.005 microns. Benefits include reduced set-up and cycle times, and cost savings from using a single system for both form and surface measurements.

The MarForm MMQ 400-2 Formtester was a ground up redesign which delivers a machine that is more robust, less sensitive to environmental influences, faster, more flexible and more accurate than comparable systems. The MMQ 400-2 offers an impressive array of features, including extremely solid construction with a generously dimensioned, reinforced steel base. High-precision mechanical bearings for the rotary table eliminate the need for an air supply, and all motors and electronic components have been thermally isolated to enhance stability. Wherever possible, homogeneous materials have been used in construction to minimize the effects of thermal expansion.

The skidded probe roughness package for the MMQ 400-2 utilizes the same diamond- tipped PHT stylus, as is used on Mahr Federal's popular PS1 and M300 surface finish machines, and the same *MarWin*-based surface finish software as the MarSurf XR 20. The stylus is mounted opposite the ruby-tipped form probe on the MMQ 400-2's motorized T7W probe head. The MMQ 400-2 automatically swivels the probe to apply the diamond stylus, and changes from horizontal to vertical measurement as needed, utilizing standard surface finish parameter cut-off lengths. A skidless probe measuring option is also available utilizing diamond-tipped styli that are directly mounted to the T7W probe head.

Several versions of the MMQ 400-2 Formtester are available. Options include: manual or motorized center and tilt tables; vertical Z-axis length of 350 mm, 500 mm or 900 mm for long shafts; and horizontal X-axis of 180 mm or 280 mm. All measuring axes are fully motorized. A selection of available probes—including the T7W 360 degrees motorized bi-directional probe and the manual T20W probe—further enhances measuring flexibility.

Also on display at Mahr Federal's Quality Expo booth # 600 will be the new MarCheck measuring and evaluation unit for Mahr's high-precision Linear 100 universal length measuring instrument, the new generation of MarCal digital calipers and the new Digimar 816 CL Height Gage, along with a full range of other Mahr Federal handheld gages and other dimensional metrology products.

For more information:

Mahr Federal Inc.
1144 Eddy Street
Providence, RI 02905
Phone: (401) 784-3100
www.mahr.com

Seco Tools Inserts

DEBUT AT CANADIAN MANUFACTURING SHOW

Seco Tools will introduce new turning insert grades and chipbreaker inserts within its exclusive Duratomic coating product line at the 2011 Canadian Manufacturing Technology Show. The company will occupy booth # 2726 at the event, which takes place October 17–20 at the Direct Energy Centre in Toronto.

Two new insert grades appearing at the show are TK1001 and TK2001. These are the latest additions to Seco's Duratomic family of turning and milling insert grades. Additionally, there will be a large offering of geometries and chipbreakers designed for the ISO K10-K20 range of cast materials, such as grey and ductile irons.

For more information:

Seco Tools
2805 Bellingham Drive
Troy, MI 48083
Phone: (248) 528-5444
www.secotools.com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Chuck Ayersman, Gleason Cutting Tools Corp.'s production manager, is a solid champion of lean and lean OJT, where all shop personnel are cross-trained so that no critical/constraint-area machines ever go unmanned or lose production time (all photos courtesy Gleason Cutting Tools Corp).

Real-World Job Training the Lean Way—

AND *LOVING* IT

Jack Mc Guinn, Senior Editor

Make no mistake—lean manufacturing is here to stay. And no wonder. As a fiercely competitive global economy continues to alter companies' "Main Street" thinking, that relatively new dynamic is spurring the need for "I-need-it-yesterday" production output. And for increasingly more industries—big or small—that means getting as lean as you can, as fast as you can.

continued

But did you ever wonder what other benefits beyond better throughput lean might afford companies? Here's a simple equation: better-trained workers = better production = better profits. Yes, the posited equation is simple. But the solution?—much less so. Anyone who runs a gear shop, reads this magazine or a daily newspaper is well aware of the growing lack of highly trained workers to run their machines and do their quality inspections, for example. So it is logical to assume that improving on-the-job-training (OJT) is a top priority.

Enter lean—and with a vengeance—to not only make a company more productive and cost-effective, but to provide a solid workforce as well. Not just, for example, to train a worker on how to organize his tool pegboard. But to also train a new hire—or a veteran employee—on how best to run his or her multi-axis machining center or hobbing machine. *Gear Technology* conducted an admittedly limited—but rewarding—exploration of the concept. We talked to the folks at Gleason Cutting Tools Corp. in Loves Park, Illinois, where lean is the way of the world, if you will—and more. Specifically, we queried Gleason's production manager, Chuck Ayersman, regarding the demonstrable success they've enjoyed since implementing lean. But we also went a step further—we questioned some of the Gleason shop floor personnel—the people who do the training and do the work—as to how lean has affected their OJT methods.

Brodie Goza, referencing an OPS (operational process standard) to aid in the training of a new employee. OPSs are used to ensure "standard (quality) work" and that everyone performs processes the same way.

Three happy campers on the Gleason lean team are (from left) Dane Mead, Brodie Goza and Larry Smuck.

Last, we talked with Shaun Browne, president of Canadian-based Digital Mentor Group Inc. (*digitalmentorgroup.com*) for a relative outsider's input regarding lean-inspired, gear-related OJT. His firm strives to build high-performance workplaces that enable clients to, as he says, "capture, document and transfer organizational best-practices to production employees."

To do that, Browne developed WHYSEEQ—a standard-work instruction development process; and One Way/Right Way and Every Buddy a Trainer—two OJT systems specifically designed for the manufacturing, processing and construction industries, among others. His latest book, *Re-Inventing OJT*, based on his STARRRS process for supporting training in the workplace, will be published later this year.

First up, Gleason's Chuck Ayersman.

(GT). Can you quantify to what extent lean principles have been incorporated into your location's OJT program?

(**CA**). One hundred percent shop-wide manufacturing, direct and non-direct departments; heat treat, coating and shipping operations.

GT. What metric(s), bench-mark(s) do you use to measure the efficacy of the lean-influenced OJT?

CA. We measure our performance in reduction of lead times; labor cost to shipments; non-conforming quality cost improvements; and reduction of safety incidents through risk assessment. Customer satisfaction, personnel turnover, number of implemented cost saving ideas per employee and increased profitability are also considered.

GT. Do you actually have tradition-based, in-house training staff onsite, or does lean render that need unnecessary?

CA. We have experienced technical people within all departments that are now very competent in lean principles to help expedite (OJT) in all phases.

GT. With lean-inspired OJT methods, are more—or less—personnel needed to do the job?

CA. Yes and no. All personnel are crossed-trained so that no critical/constraint-area machines ever go unmanned or lose production time. What we call "support operators"—those that are not in constraint areas—can efficiently operate constraint processes without adding additional people. We will add additional people only in a case of a constraint process that needs to create weekend shifts for 24/7 operations.

GT. Is there a cost difference in using lean-inspired OJT methods for training production workers?

CA. Cost difference gains are realized by continuing to improve operating procedure standards (OPS); best-practice processes—which decreases training time; and less non-conforming product and injuries through continuous ideas/kaizen events.

GT. How about time differential?

CA. All people learn at different levels, and training is an ongoing process. We have total confidence as people are trained that they have a better understanding; we don't waste valuable time for retraining as we did in traditional training.

GT. Who trains the trainers?

CA. Trainers are continually evolved from our lean environment. This is a result of continued education of manufacturing processes as well as total knowledge of the business. This education is then applied to how it affects the employees, the community and the environment. Standardization of OPS for processes and ISO environmental and quality documentation assure training is ongoing and current to the latest standards.

GT. Is there a lean "bible" or other publications you use to augment OJT?

CA. Each and every process has a best-practice OPS, and the group is empowered through documented processes and procedures via team-approved changes and kaizen events.

GT. How does lean-related OJT affect traditional "mentoring" by veteran employees of their newer counterparts?

CA. Veteran operators welcome the opportunity to train newer employees through documented training procedures (that) transfer as much knowledge as possible. Everyone is aware that the more efficient newer employees become, the easier their own jobs become; and we all win as a team. With traditional training, operators would be less than willing to give all (their) knowledge to newer people, thinking they may become a threat to their position and earning power.

GT. How does lean OJT impact upon "remedial training"?

CA. It takes people through disciplined, step-by-step procedures designed to improve skills and knowledge with trainers' and supervisors' involvement to monitor, assist and improve performance.

The following responses are from Gleason personnel—Larry Smuck (LS) (contract services sharpening machinist), Dayne Mead (DM) (hard jobs machinist) and Brodie Goza (BG) (bevel/EDM lead operator). As their answers indicate, they are not simply drinking the lean Kool-Aid. They are all-hands-on-deck for lean thinking and lean OJT.

GT. Since lean has been implemented at your plant, have you received any training—or re-training—relevant to the things you do, especially a new machine that you were previously unfamiliar with?

DM. Yes—by having kaizen events. Specifically, on

continued

reducing set-up times, which in turn made me have to re-evaluate how I was trained and how I train future operators. We have also been provided lean books from the company library.

BG. Machine operation training starts on Day 1—and never ends. There is always something to be learned about a machine (new or old) today that we didn't know yesterday, regardless of an individual's total experience. If we think we know it all, we just closed the door to new ideas and future development.

GT. Were you trained by a fellow employee, someone in management or by a professional trainer? And could you please briefly explain how that worked?

DM. After the commitment was made to do lean, middle-management was instructed on how to be lean coaches. And then outside consultants were brought in for continued supplemental training.

BG. We read lean culture books, were coached by managers, taught each other and were provided with professional training by a consultant. Kaizen events with a consultant involved real-life examples, working through daily problems. This direct involvement helped to jump-start our culture.

GT. Keeping in mind lean-inspired principles used for OJT, what is your definition of "doing a good job"?

DM. By understanding who is your next customer, you can better focus on their needs. And by concentrating on eliminating waste. (Both make you) a greater benefit to your company.

BG. Meeting expectations regarding performance and production goals is doing a "fair" job. Doing a "good" job also entails having a culture that is effective, improvement-based and team-oriented.

LS. Understanding the proper product flow, meeting the customer's requirements and continuing to learn and perform lean principles.

GT. Since lean was implemented, have you provided any OJT for a new hire? If so, how would you compare that experience with how it was done in the past, pre-lean?

DM. Yes (I have), and I definitely have a lot more awareness when I am training—use of major goals of reducing waste and working more efficiently.

BG. New-hire OJT is much easier now. This is mainly because we now have operational process standards located at each machine that define each setup. These comprehensive procedures are full of step-by-step pictures that help a new person quickly understand what is being done. It also standardizes the process so everyone performs each task the same way.

LS. In the past, new hires were taught how to simply keep the machines running, producing parts. Now, the training is more complex because they are educated on how their performance impacts the whole process.

GT. Has using lean-related principles for OJT made the responsibility for training someone easier and more effective for you?

DM. Yes, because it helps you to get people to buy in to what everyone is trying to accomplish with lean manufacturing. Documented best-practice procedures have been established, so all are doing the tasks the same way—every time.

LS. Yes, because we have documented processes that can be given to new hires. They can read and see the process step-by-step, which supplements the "hands-on" approach.

GT. How about remedial training—i.e., using lean-inspired practices to retrain a veteran co-worker?

DM. Yes, the continued positive results sell themselves to the veteran co-workers—that working more efficiently will make their job easier—they are more open to retraining and new ways of thinking.

BG. This can be very difficult. Long-term employees are the most difficult to re-train, but you can teach an old dog new tricks! The best lean-inspired practice is—involvement. Get them involved, they see the resulting benefit, and they buy in.

LS. Open-minded employees who wanted to improve and be a part of what we're doing accepted the ongoing change. Those that didn't moved on to other professions.

GT. Is OJT at your plant easier or more complex using lean?

DM. Easier, because once the culture has changed and attitudes are changed there is a lot more support with on-the-job training.

BG. Easier, again because of the Operational Process Standards.

LS. Easier because training requirements are documented, as it makes follow-through much simpler.

GT. Is there now a "set-in-stone" procedure for OJT?

DM. No; we are more flexible to the needs of each individual operator. All individuals require different specifics while being trained to reach the common goal

BG. There are no set-in-stone procedures. OJT will always need to be "molded to fit" a trainee's learning style; everyone learns differently. As trainers, we still need to adapt to fit the learning style.

GT. Is providing or receiving lean-inspired OJT a more rewarding experience as opposed to doing it "the old way"?

DM. Yes co-workers that are more open-minded are easier to work with.

BG. Absolutely; new employees are "part of the team" from Day 1. We value their input and want them to succeed. A trainee's new ideas matter. This is rewarding for both the

continued

trainer and trainee because being involved gives everyone a sense of respect.

GT. Do you believe lean OJT is a more "real-world" type of instruction in that it is perhaps much more application-specific than previously?

DM. Yes, especially with all the competition in business. Everyone knows how their specific tasks tie directly to the big picture, whereas in the past, they only knew their specific tasks and nothing more.

BG. Yes. Previously, we would teach a person the basics on how to run a machine and then throw work at them. Now we apply real applications during the training. Knowledge is open, nothing held back. Difficult applications are part of the training.

LS. Now training doesn't end with simply producing a part. There are direct interactions with the end users and how it fits into their needs on a daily basis.

GT. Is it your perception that Lean OJT is better accepted by new hires?

BG. Jump in, sink or swim—the old way—that is hard to accept. Now we build a boat and row together. Lean OJT is not just about teaching someone how to do the job. It is about teaching them a culture that is effective, improvement-based, team-oriented and, ultimately, makes us better today than we were yesterday.

Which brings us to Shaun Browne to close things up. You'll note some of the questions mirror those asked of Gleason's Ayersman.

GT. Once lean is established, can you quantify to what extent lean OJT principles are typically incorporated into a gear industry manufacturer's OJT program? And what metric(s) are used to measure the efficacy of lean-influenced job training?

SB. The issue of metrics is an interesting one, as there is often a disconnect between how Operations and Human Resources track training and performance improvement. Traditionally, HR has tracked training using softer elements such as completion results, reporting on numbers of attendees and workshops offered. To be fair, they often lack the ability to track training implementation. While there are tracking systems, like "Friday 5s," these systems rely on the workshop participants to self-report on skill usage and knowledge application after training.

Operations, on the other hand, tracks everything related to the production process. These are usually "hard" numbers. Examples might include elements such as product quality, process compliance, tolerances, change-over statistics, etc. As HR becomes more involved in job skills training, they will need to adopt harder measurements more akin to what Operations is already using.

GT. Do companies typically use in-house trainers?

SB. This is one of the biggest issues confronting lean manufacturing, in my opinion. While there is a lot of lean training—and by that I mean training on how to do a lean project—there must also be a strong emphasis on lean implementation and application. Lean processes have to transition to (OJT) if the lean project is to be fully successful. It is essential that effective, practical job-skills training follows the lean process. That training can be done in simulation or in production, but it has to be done. In-house trainers can be a good choice, but we've also had great success using occasional trainers—production employees who take on training duties for a short period of time—as they are very familiar with the operation of the equipment. The key to this is planning for implementation as diligently as you plan for the lean project itself.

GT. Lean OJT method: more—or less—personnel needed?

SB. We believe that more trainers are required during lean implementation, but they don't have to be training professionals. We've worked hard to de-mystify and de-professionalize the training process by building a training-delivery template that embeds adult learning principles, evaluation and activities so that the occasional trainer is able to deliver "good enough" (OJT) without having to waste time learning all the theories.

GT. Is there a cost difference in using lean-inspired OJT?

SB. Actually, it can be less expensive. While the training process may take more time—due to including adequate practice to embed the new or revised process—the "time-to-competence" is reduced. The issue is how long it takes the employee to return to productive performance. Using a traditional job-shadowing technique, the time-to-competence is usually much longer than when using a more structured approach.

GT. How about time differential?

SB. Using a more structured approach might take a few hours instead of a few minutes of (traditional) job shadowing. Yet the pay-off—the return on investment—comes in producing a safer employee who generates less re-work and scrap and who produces a quality product that meets design standards and customer expectations.

GT. Who trains the trainers?

SB. If you are using a straightforward job-skills training system, then training can be done inline or in small workshops that might last a day, including sufficient practice time to develop trainer competence and proficiency.

GT. How does lean-related OJT affect traditional mentoring by veteran employees of their newer counterparts?

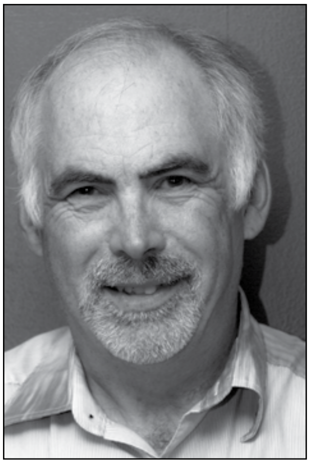
SB. I don't think there is much of an impact at all. The reality is that about 80 percent of training in most manufacturing firms is informal. That means it's training that is not sanctioned by management, not tracked by HR and doesn't use standard work instructions to ensure consistency. That informal training will continue in spite of the desires of the organization. If, however, you can provide all employees with a training process or template, at least you can control the delivery process.

GT. How does lean OJT impact upon remedial training?

SB. Remedial training—training to "fix" an employee

continued

and return him or her to an approved level of process compliance—requires that management already knows what a "good job" is. The problem is that it is difficult to get an agreement on the good job definition. If you want to check this out, pick a production task in your manufacturing area and ask the supervisor what constitutes a good job for that operation. They might answer "safety" and "maintain line speed." Then ask the Quality department the same question; they might respond by quoting design specifications, maintaining build tolerances and meeting the customer's expectations...(dependent upon who is being asked), all the answers are different. Yet, the real answer is "all of the above." Remedial training has to include safety, line speed, maintaining specifications and achieving improved productivity while providing the employee with the skills, knowledge and experience necessary to work with the least-wasted movement and highest productivity.



Shaun Browne, author, OJT implementer and Digital Mentor Group president.

For more information:

Chuck Ayersman
Production Manager
Gleason Cutting Tools Corp.
1351 Windsor Rd.
Loves Park, Illinois 61111
Phone: (815) 877-8900
Fax: (815) 877-0264
www.gleason.com

Shaun Browne
Principal
Digital Mentor Group, Inc.
203-24 Queens square
Cambridge, Ontario, Canada
N1S 1H6
Phone: (519) 624-5835
digitalmentorgroup.com

Size and Material Influence on the Tooth Root, Pitting, Scuffing and Wear Load-Carrying Capacity of Fine-Module Gears

Prof. Dr.-Ing. Bernd-Robert Höhn, Dr.-Ing. Peter Oster and Dr.-Ing. Christo Braykoff

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Management Summary

A definite trend exists towards the miniaturization of actuators in the field of drivetrain engineering. Therefore, gears with smaller module size ($m_n \leq 1$ mm) are increasingly in demand.

But since neither results of load-carrying-capacity tests or specific calculation methods of tooth-root bending, pitting and scuffing load-carrying capacity for this gear size are given, the general calculation methods according to DIN 3990/ISO 3663 (Refs. 2–3) have been used. In this study, limiting values for the load-carrying-capacity of fine-module gears within the module range 0.3–1.0 mm were determined and evaluated by comprehensive, experimental investigations that employed technical, manufacturing and material influence parameters. These limiting values exceed the load-carrying-capacity values—as expected—according to DIN 3990/ISO 3663 (Refs. 2–3) gear material quality MQ (maximum quality).

Introduction

The scope of fine-module gears has been constantly increasing in recent years; Figure 1 summarizes some of the most important applications of miniaturized actuators.

The existing calculation standards—according to DIN/ISO (Refs. 2–3)—do not limit their validity for small-size gears and are therefore also used to calculate the load-carrying-capacity of fine-module gears. The experimental coverage of these calculation methods is based primarily on the module range between 2–20 mm; the reference gear of DIN/ISO has a module of 5 mm. Most durability tests are conducted on gears within the module range 3–5 mm.

The use of these standards for small-size gears has been validated on a limited number of experiments and is based mainly on the general-size influence according to materials strength. Although there are no limitations for use of DIN/ISO in the module range smaller than 1 mm, their usage may be problematic and risky without reliable verification.

As miniaturized drives are increasingly used in space technology, robotics and medicine, a comprehensive, experimental study for proving the load-carrying-capacity of fine-module gears is urgently needed. The aim of this work is to prove the usability of DIN/ISO on smaller gears and to expand the experimental coverage (Fig. 2)—thus providing a reliable dimensioning of small-size gears.

Theoretical Study

The following chapter presents some basic relations regarding the size influence based on an example of geometrically similar gears—i.e., a gear with the same number of teeth and same addendum modification coefficient. The face width changes proportionally to the module. Furthermore, a symmetrically mounted shaft is assumed, and bearing clearance and bearing deformations are ignored. All values mentioned in Figures 3 and 4 refer to the test gear designed for this work.

Relations Based on Gear Load-Carrying Capacity

Tooth root-carrying capacity. Potential load peaks notwithstanding, the nominal tooth root stress can be calculated according to DIN/ISO as:

$$\sigma_{F0} = \frac{F_t}{b \cdot m_n} \cdot Y_{FS} \cdot Y_\beta \cdot Y_\varepsilon \leq \sigma_{FP} \qquad (1)$$

$$\text{i.e.: } \sigma_{FP} \sim \frac{F_{tP}}{b \cdot m_n}$$

as Y_{FS}, Y_β and Y_ε are dimensionless and independent from the size.

Assuming an equal, allowable tooth root stress for all gear sizes, the maximum allowable/permissible (index *P*) load-per-face-width depends on the module as:

$$\left(\frac{F_t}{b}\right)_P \sim m_n \qquad (2)$$

With $b \sim m_n$, the allowable tooth load depends quadratically on the module—i.e., gear size:

$$F_{tP} \sim m_n^2 \qquad (3)$$

The relationship between the maximum allowable torque and the gear size can be derived:

$$T_p = F_{tp} \bullet d$$

Because $d = z \bullet m_n$, it follows that:

$$T_P \sim m_n^3 \qquad (4)$$

Pitting durability. Absent any possible load peaks, the occurring contact stress can be calculated according to DIN/ISO (Refs. 2–3) as:

$$\sigma_{H0} = \sqrt{\frac{F_t}{b \cdot d_1} \cdot \frac{u+1}{u}} \cdot Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \leq \sigma_{HP}$$

$$\text{i.e.: } \sigma_{H0P} \sim \sqrt{\frac{F_{tP}}{b \cdot d_1}} \qquad (5)$$

as Z_H, Z_ε and Z_β are dimensionless and—including Z_E—are independent of the gear size. Assuming an equally allowable contact stress for all gear sizes, the maximum allowable load per face width depends on the module also as:

$$\left(\frac{F_t}{b}\right)_P \sim \sigma_{HP}^2 \cdot d_1 \quad \text{with} \quad d_1 = z_1 \cdot m_n \quad \Rightarrow \quad \left(\frac{F_t}{b}\right)_P \sim m_n \qquad (6)$$

Consequently, the allowable load-per-face-width and the allowable torque for tooth root and pitting-carrying-capacity have an equal dependence on the gear size. Figure 3 illustrates the dependence of the gear size for fixed, nominal tooth root stress σ_{F0} and nominal contact stress σ_{H0}.

Dynamic performance of spur gears. The related rotational speed of a gear can be calculated as follows:

$$N = \frac{n_1}{n_{E1}} = \frac{n_1 \cdot \pi \cdot z_1}{30000} \cdot \sqrt{\frac{m_{red}}{c_{\gamma\alpha} \cdot b}} \qquad (7)$$

With $c_{\gamma\alpha}$ = const., $m_{red} \sim m_n^3$ and $b \sim m_n$, it follows that:

$$\Rightarrow \; N \sim m_n \cdot n_1 \qquad (8)$$

so that…

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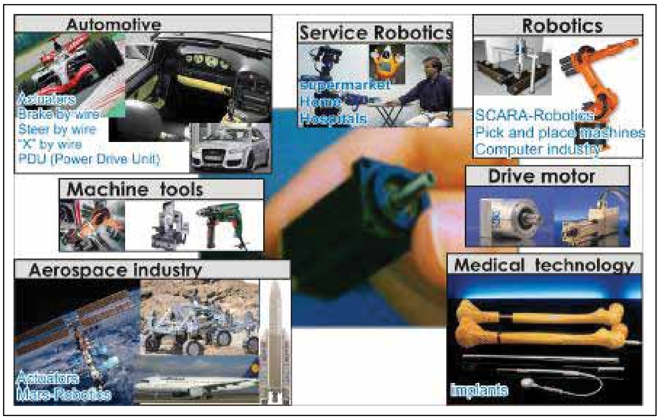

Figure 1—Applications of fine-module gears (*Source: Alpha Getriebebau GmbH and own elaboration*).

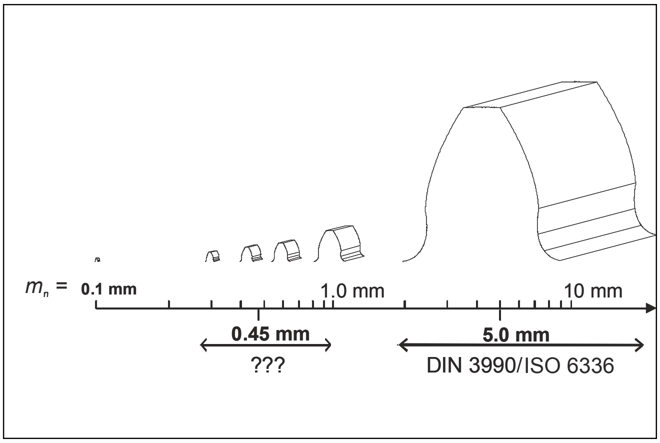

Figure 2—Research area of the present work in comparison to DIN 3990/ISO 6336.

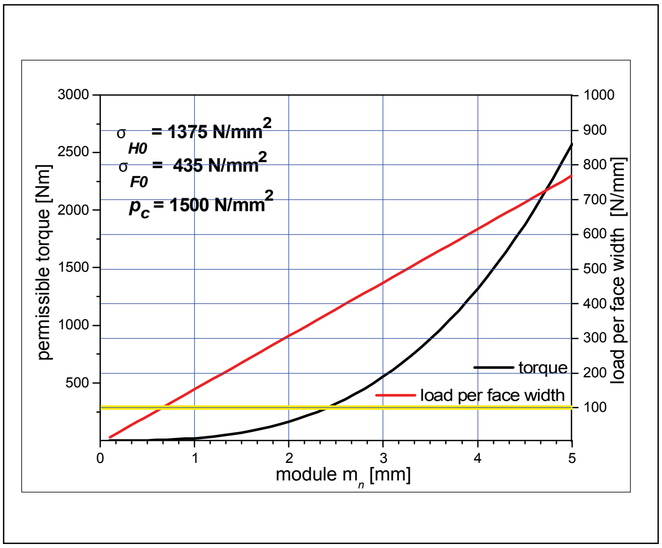

Figure 3—Influence of gear size on allowable load per face width and torque concerning pitting and tooth root bending for b/m_n = 15.

$$\text{So that} \quad n_1 \sim \frac{N}{m_n} \quad \text{for a given } N. \qquad (9)$$

Figure 4 shows clearly the dependence of the related rotational speed on the gear size for resonance and pre-resonance (N = 1/2, 1/3, 1/4) ratio. According to these relationships it can be summarized that reducing the gear size increases the speed range under the resonance ratio. It therefore follows that by decreasing the gear size, and for a constant N, higher rotational speeds are acceptable.

Influence of size on notch sensitivity. By calculating the load-carrying capacity according to the general theory of

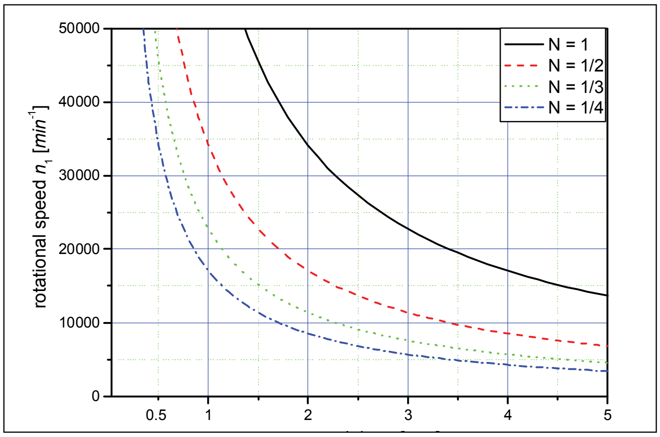

Figure 4—Dependence of related rotational speed on gear size.

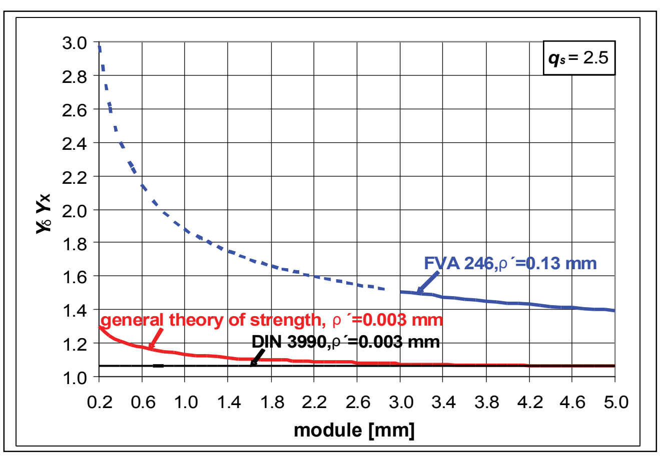

Figure 5—Dependence of gear size on the supporting effect of materials according to DIN 3990/ISO6336, the general theory of strength and FVA Research Project 246.

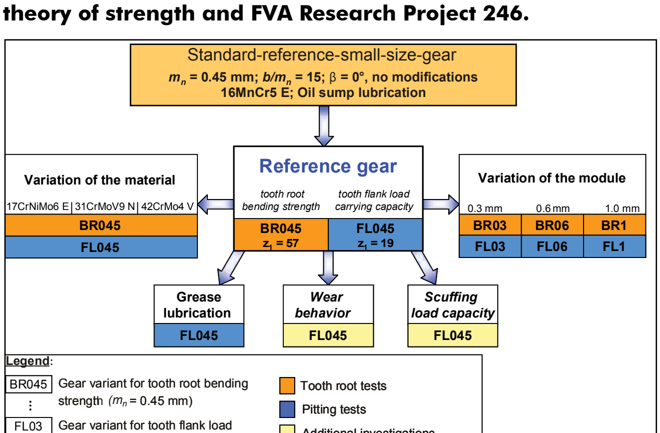

Figure 6—Research program.

material strength (Ref. 5), the notch sensitivity factor β_K is a measure of the supporting effect of the material; it is determined from the ratio of notch-stress-concentration factor α_K and notch-sensitivity nx. At the same time, for the geometrically similar gear, the stress concentration factor depends only on the notch geometry.

Related to the approaches of Petersen (Ref. 6), Siebel (Ref. 8) and Neuber (Ref. 4), the notch sensitivity can be calculated as a function of one constant dependent on the material and the stress gradient on the notch with maximum stress:

$$n_\chi = 1 + \sqrt{\rho' \cdot \chi^*} \qquad (10)$$

As a function of the material, the slip-layer thickness is independent of the size. In contrast the relative stress gradient (Ref. 8) depends on the gear size:

$$\chi^* = \frac{1}{\sigma_{max}} \cdot \left(\frac{d\sigma}{dy}\right) \sim \frac{1}{m_n} \qquad (11)$$

The supporting effect of material—DIN 3990/ISO 6336 (Refs. 2–3)—is included in the relative-notch-sensitivity factor $Y_{\delta\ rel\ T} = f(q_s)$ and the size factor Y_X. The relative-notch-sensitivity factor $Y_{\delta\ rel\ T}$ is the quotient of the notch-sensitivity factor of the calculated gear Y_δ divided by the standard test gear factor $Y_{\delta\ T}$. From this purely geometrical dependence can be concluded that the relative-notch-sensitivity factor is independent of the size. It enables only the influence of the notch sensitivity of the material to be taken into account.

The size effect on the stress gradient is taken into account in the size factor Y_X. If the module of the gear is smaller or equal to 5 mm, the size factor—DIN/ISO—amounts to 1.0. Therefore an increasing, supporting effect of material—thereby increasing load-carrying-capacity for a geometrically similar gear (m_n < 5 mm)—is not implied in this factor (Fig. 5).

The notch-sensitivity of gears with variable tooth root geometry was an important topic of FVA Research Project No. 246 (Ref. 7). As a result of many extensive experiments during the project, a size influence for gears smaller than 5 mm was found—resulting in a slip-layer thickness ρ´ for case-hardened gears amounting to 0.13 being used.

In comparing the three discussed calculation methods (Fig. 5), there is no increase of the load-carrying capacity by decreasing the size from m_n = 5 mm to m_n = 0.45 mm (DIN/ISO). Otherwise—according to the general theory of material strength—there is a load-capacity increase of 15%. By appropriate extrapolation of the results of FVA Research Project 246, a 60% load-carrying capacity increase is expected.

Similar to the calculation method of the tooth root load-carrying capacity, there is also no increase expected for the pitting-carrying capacity (DIN/ISO) by reducing the gear size. For gears smaller than m_n = 10 mm, the size factor Z_X amounts to 1.0; for much smaller gears (m_n << 10 mm) there is no increased support effect implied.

Research Program: Test Gearing and Test Rig

Test gearing. The performed research program (Fig.

6) included experimental investigations of the influence of gear size upon the gear load-carrying capacity of case-hardened spur gears within a module range of 0.3–1.0 mm. Furthermore, additional investigations of the material influence—case-hardened, nitrided and through-hardened steels—on the load-carrying capacity and random tests to appraise scuffing-load capacity and wear behavior of the reference small gear were done; a variation with a grease lubricant was also provided.

To investigate different kinds of damage in the same test rig, two different, standard-reference gears were defined, allowing a systematic investigation of the tooth root bending strength (BR) and the tooth flank load-carrying capacity (FL).

The standard reference spur gear has a module m_n = 0.45 mm with a ratio between tooth width and module of b/m_n = 15; it is case-hardened (16MnCr5) (Table 1).

For the module variation, no dimensionless, geometric gear parameters have been changed. Center distance, tip diameter and face width vary proportionally with the module. After heat treatment all tooth flanks were ground; the gears had no flank modifications. During this study adequate test conditions and adapted methods for load-carrying capacity investigations of small-size gears were defined.

When establishing the test conditions, attention was paid to a good transferability of the results to the standard gear size with module ≈ 5 mm. The tests and evaluation of the results are also based on the experience of earlier studies on the standard DIN reference gears.

Test rigs. A suitable test rig was developed for the needs of this study, taking into account the special circumstances of small gears. Figure 7 shows the FZG small-gear test rig that was especially developed for testing gears with a center distance between 7.5–65 mm. The test rig has a speed range of 50 rpm–10,000 rpm and a range-of-test torque of 0.5 Nm–200 Nm. These rig parameters allow the testing of gears in the module range between 0.3–2 mm.

Inspection of the test gears is possible without disassembling the test gear box (Fig. 7); this saves time and capacity during the testing. The memory function of the test rig also enables the parallel testing of three different test gearboxes without losing time for inspection and documentation of the test gears.

The studies on tooth bending strength were carried out mainly in a high-frequency resonance pulsator with the wheel of the gearing z_1/z_2 = 19/29. In order to confirm the results of the pulsator rig, additional gear-running tests on the FZG small-size test rig for each of the test variants were performed.

Experimental Results

Regarding the aim of this study, it is important to mention here that the investigations had been made on real gears produced according to the current state of technology. The test gears were milled, hardened and grind-finished. As such, the milling, grinding and heat treatment process achieve the technical limits of realization with decreasing gear size.

continued

Figure 7—FZG small-size gear test rig.

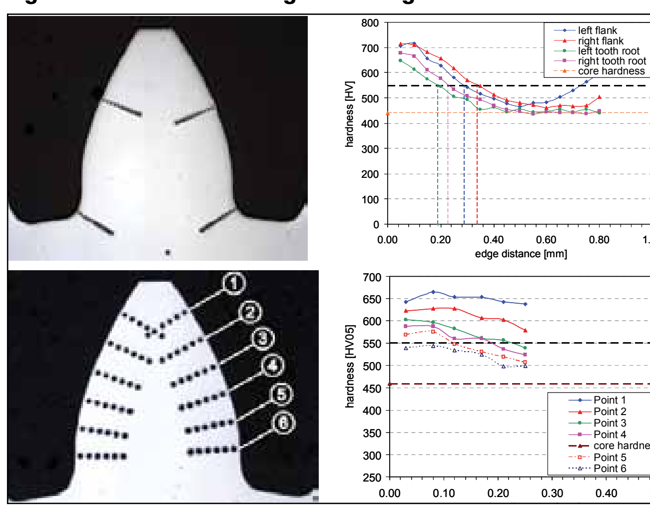

Figure 8—Measurement of the case depth of flank variant test gear (FL06: *z* = 19, above) and reference gear (FL045: *z* = 19, below) along tooth profile. Case depth graphic of FL045 is an example of one right flank.

Table 1—Basic geometry parameters of the reference test gears.							
Description		FL045	BR045	Description		FL045	BR045
module	m_n [mm]	0.45	0.45	number of teeth	z	19/29	57/58
normal pressure angle	α_n	20˚	20˚	addendum modification coefficient	x_1	0.450	0.903
pressure angle at the pitch cylinder	α_{wt}	20˚	20˚		x_2	0.689	0.500
helix angle	β	0˚	0˚	transverse contact ratio	ε_α	1.40	1.23
center distance	a[mm]	7.50	26.46	tooth width	b[mm]	6.75	6.75

All test gears were measured for geometry and hardness. Up to the gear size m_n = 0.6 mm, the test gears had no noticeable metallographic problems (Fig. 8). In contrast, the case depth profile of the gear series module m_n = 0.45 mm (Fig. 8) was not constant along the tooth profile. The case depth near the tooth root fillet was smaller than the case depth at the tooth tip. This fact can be explained by the limits of heat treatment for small gears.

As a consequence, the gear series m_n = 0.3 mm was manufactured in a different way. These gears were ground into the hardened material; these heat treatment results and manufacturing conditions have to be considered for the evaluation of the load-carrying capacity of the test gears m_n = 0.45 mm and m_n = 0.3 mm.

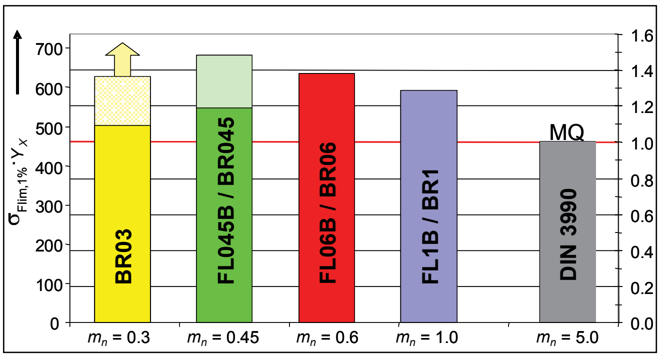

Figure 9—Results for the tooth root load-carrying capacity of different gear sizes.

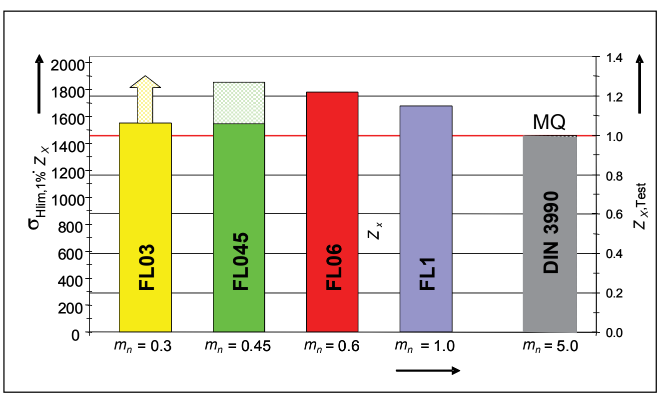

Figure 10—Results for the pitting load-carrying capacity of the different gear sizes.

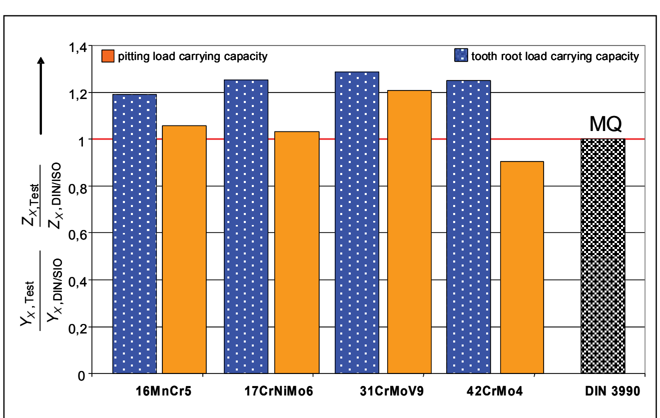

Figure 11—Material influence on the pitting and tooth root load-carrying capacity determined on the reference gear (m_n = 0.45 mm).

Influence of module (gear size) and tooth root load-carrying capacity. Figure 9 compares the experimentally determined load-carrying capacity values with those values derived from the DIN 3990/ISO 6336 (Refs. 2–3). The size factor according to DIN/ISO is already taken into account. The chart shows that if we pay attention to the existing gear quality in the tooth root area, we will find a proven relationship between the theoretical study and the experiments. The tooth root load-carrying capacity for m_n = 0.6 mm is 40% higher than what is documented by DIN/ISO. Yet despite the technical limits, the tooth root load-carrying capacity for m_n = 0.45 mm is 20% higher compared to DIN/ISO—with a greater potential of approximately 50%. The potential can be estimated with the approach that the strength profile over the material depth is a function of the local hardness profile $\sigma_{permissable}(y) \approx c \bullet HV(y)$ with $c = const.$

Metallographic examination of the wheel BR03 reveals no existing case depth in its tooth root area. This gear size was manufactured differently from those of the other test gear series; therefore, this variant cannot be directly compared to the other gear sizes. And yet, there are some load-carrying capacity reserves visible.

Pitting load-carrying capacity. The right ordinate axis of Figure 10 illustrates the evaluated allowable stress number $\sigma_{Hlim'Test1\%}$ by the tests related to the allowable stress number σ_{Hlim} (DIN 3990/ISO 6336) (Refs. 2–3). This corresponds to an experimentally determined size factor $Z_{X,\ Test.}$ It is clear that the pitting load-carrying capacity increases up to module 0.6 mm for approximately 20% when compared to the reference value in DIN/ISO. The values of the reference gear m_n = 0.45 mm are 5% higher than the values in DIN/ISO (the dark bar). If the reference gears are manufactured with equivalence to the experience with higher-module gears, there is an additional load-carrying potential—approximately 20% higher permissible contact stress than the existing experimental results (bright bar).

The experiments with a gear size m_n = 0.3 mm were prepared by a different manufacturing process and cannot be directly compared. All gears of this size have failed because of a broken tooth from the tooth flank. If these gears were to be manufactured like higher-module gears, there is also an additional load-carrying capacity potential; additional research is needed in this area.

Influence of material**: **The evaluated material influence related to the existing values of the materials specified in DIN 3990/ISO 6336 (Fig. 11). It is obvious that there is no clear difference between the case-hardened gear materials. The case-hardened steel 17CrNiMo6 (*Note: since publication of DIN EN 10084, the case-hardened steel 17CrNiMo6 was substituted with 18CrNiMo7–6*) has a slightly higher root-carrying capacity than 16MnCr5; both materials possess equal pitting load-carrying capacity values.

The through-hardened gears also show a higher tooth root-carrying capacity than the values contained in DIN/ISO.

The *load-carrying capacity increase* of the nitrided gear series 31CrMoV9 must be emphasized. This result is explained by the fact that, for smaller gear sizes, the nitrided depth profile appears similar to that of the case depth profile of the case-hardened gears.

This means that because of the obviously better-managed heat treatment, the nitriding process may become much more important for smaller gears.

Additional Investigations

Scuffing load-carrying capacity. By calculating the safety factors against scuffing for the reference gear series (m_n = 0.45 mm) under the defined test conditions, both calculating methods in DIN 3990/ISO 6336 obtain different results (Table 2).

Although using FVA No. 2 oil without EP additives, no scuffing damage had been found during the tests. In using the integral-temperature method (DIN 3990) safety factors $S_{int\ S}$, safety factors smaller than 1 are allowed if the flash temperature method yields safety factors larger than 1.4. The calculation results show that the usage of the calculation methods included in DIN/ISO is safely and reliably applicable to small-size gears.

Wear behavior. Figure 12 describes via (inventor and metallurgist John T.) Plewes diagram the experimentally determined wear coefficient of the reference gear series—investigated at different speed and temperature conditions, and constant torque.

The linear wear coefficients obtained by the tests on small-size gears with FVA oil No. 2 are significantly below the reference values for mineral oils without EP additives. The wear behavior remains nearly constant for the same oil temperature and different peripheral speed.

By increasing the temperature, the linear wear coefficient is changing to areas with greater wear.

Comparison of Test Results with State-of-the-Art Standard

Figure 13 shows a comparison between the experimentally determined size factors $Y_{X,\ Test}$ (tooth root bending) for the case-hardened gears (Fig. 9) and the size factor according to DIN 3990/ISO 6336. Also described are experimentally determined size factors that were evaluated in other research projects at the FZG Gear Research Center on gear modules m_n = 1.75 mm; m_n = 3.0 mm; m_n = 5.0 mm; m_n = 8.0 mm; m_n = 10.0 mm; m_n = 16.0 mm; and m_n = 20.0 mm. A clear trend towards increasing size factor for gears smaller than 5 mm is noted.

The trend line illustrates the experimentally evaluated size factor $Y_{X,\ Test}$ for the case-hardened steel 16MnCr5. Because of its better hardenability, steels like 17CrNiMo6 and 17NiCrMo14 are generally used for larger-module-size gears. Test results with these steels are also included in Figure 13; one can see that DIN 3990/ISO 6336 (Refs. 2–3) easily covers the size factor for these steels in the module

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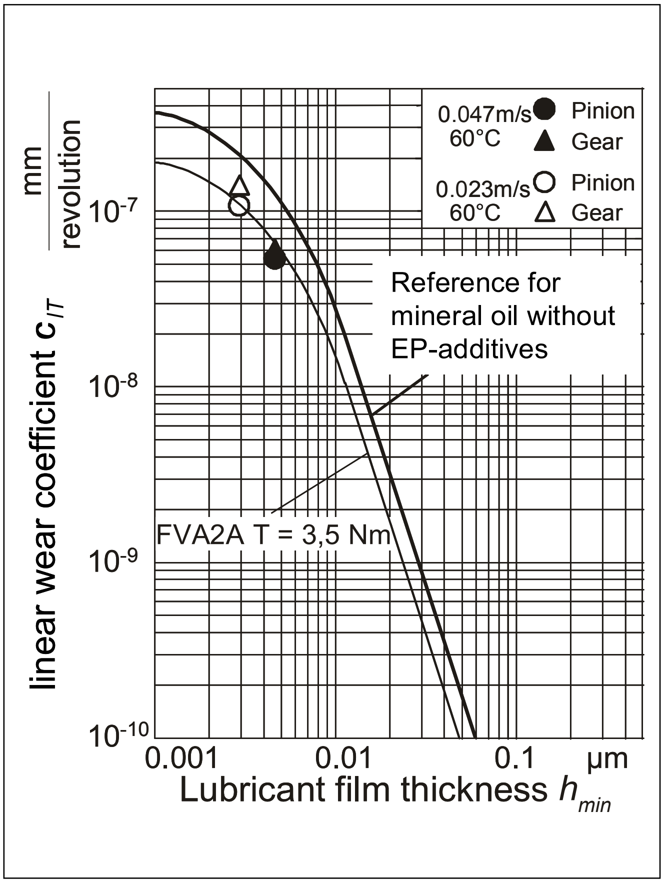

Figure 12—Wear coefficients obtained on FL045 for T_1 = 2.85 Nm.

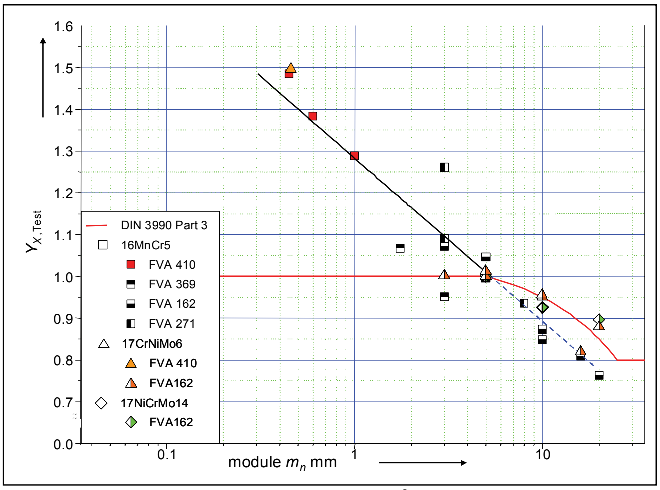

Figure 13—Experiment-derived size factors $Y_{X,\ Test}$ against $Y_{X,\ DIN/ISO}$ (tooth root bending) for case-hardened steel.

Table 2—Calculated safety factors against scuffing for the reference gear (FL45) Refs 2-3.					
T_1 [N_m]	$\theta_{Start\ S}$ [˚C]	$\theta_{int\ S}$ [˚C]	$S_{int\ S}$ [-]	$\theta_{B\ max}$ [C]	S_B [-]
3.5	60˚	120.9	0.96	127.9	2.53
3.5	90˚	168.4	0.69	177.0	1.63
4.2	60˚	130.6	0.89	139.0	2.18
4.2	90˚	180.4	0.64	190.8	1.41

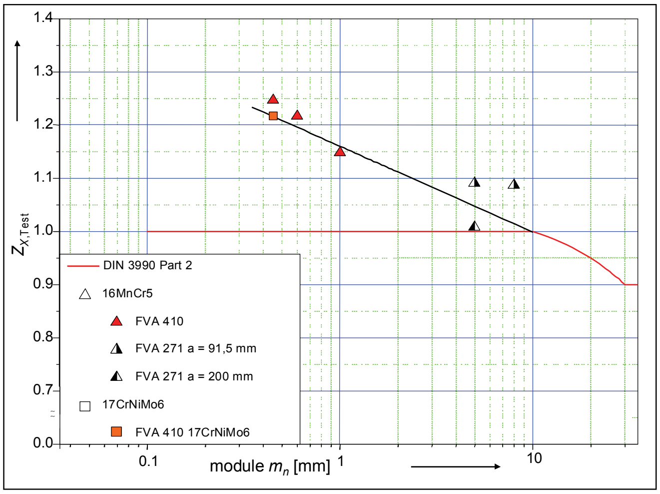

Figure 14—Experiment-derived size factors $Z_{X,\ Test}$ against $Z_{X,\ DIN/ISO}$ (pitting) for case-hardened steel.

range over 10 mm.

Analogous to Figure 13, Figure 14 includes a comparison between the experimentally determined size factors $Z_{X\ Test}$ (pitting) for the case-hardened gears (Fig. 10) and the size factor according to DIN 3990/ISO 6336. Experimental results (Ref. 9) for modules m_n = 5.0 mm and m_n = 8.0 mm (similar number of teeth) are also attached. The trend line illustrates the experimentally evaluated size factor $Z_{X,\ Test}$ for the case-hardened 16MnCr5 steel. Here one can also recognize a trend towards increasing size factor for modules smaller than 5 mm. It should be noted that there are few experimental results known within the module range 1 mm < m_n < 3 mm. Consequently, further investigation of this module range is needed.

Summary

This work presents fundamentals in the load-carrying capacity research field of small-size gears and provides for reliable dimensioning of gears within the module range 0.3–1.0 mm. The results for the tooth root and pitting load capacity show that with a decreasing gear size, the load capacity related to the torque load increases up to 1.5 times of the DIN reference gear, i.e.:

(module 5 mm); i.e., Y_X (m_n = 0.45 mm) ≈ 1.5 respectively: Z_X (m_n = 0.45 mm) ≈ 1.5.

The variation of material for small-size gears shows no disadvantages in using 17CrNiMo6 steel when compared to 16MnCr5. The performance of the nitrided gears in this gear-size range is emphasized.

The definition of adequate test conditions and methods—as well as the design and successful operation of a specific test rig for small-size gears during this work—provide the groundwork and basic knowledge for further scientific investigation in the research of small-size gears.

Acknowledgment. *The research project "Load-Carrying Capacity of Small-Size Gears" is the basis of this paper and was financed by the German Research Association for Power Transmission (*Forschungsvereinigung Antriebstechnik, FVA*) with the support of the Federation of Industrial Cooperative Research Associations (Arbeitsgemeinschaft Industrieller Forschungsvereinigungen, AiF).*

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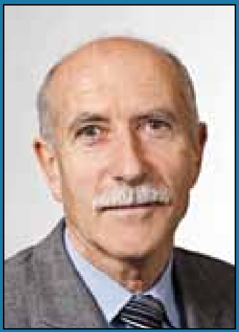
Dr. Christo Braykoff *received his degree in mechanical engineering from the Technical University of Sofia and the Technical University of Karlsruhe in 2001. From 2001–2007, he worked at the Gear Research Centre (FZG) and obtained his PhD on the topic, Load-Carrying Capacity of Fine-Module Gears. He has worked since 2007 at MAN Truck & Bus AG as a design engineer and is responsible for the development of driven rear axles and transfer cases of trucks and buses. Dr. Braykoff is an active member of the FVA working groups "Bevel Gears" and "Spur Gears" and has since 2008 been a member of the FVA scientific advisory board as MAN representative.*

Dr. Bernd-Robert Höhn *studied mechanical engineering at the Technical University Darmstadt (1965-1970) and served as an assistant lecturer (1970-1973) at the Institute for Machine Elements and Gears at the Technical University Darmstadt prior to becoming an assistant professor at the university (1973-1979); in 1978, he received his PhD (Dr. Ing.) in mechanical engineering. In early April, 1979 Höhn worked as a technical designer in the department for gear development of the Audi, and by 1982 was head of the department for gear research and design for the automaker. In 1986 Audi named Höhn department head for both gear research and testing of automotive transmissions, until his departure in 1989 to become head of both the Institute of Machine Elements at the Technical University and of the Gear Research Centre (FZG). Höhn has served since 2004 as vice president for VDI for research and development and since 1996 has led the working group 6 and 15 for ISO TC 60—calculation of gears.*



Dr.-Ing. Peter Oster *is a chief engineer at the Gear Research Center specializing in tribology and load capacity of gears. As a research group leader, he guided the studies presented in this article.*

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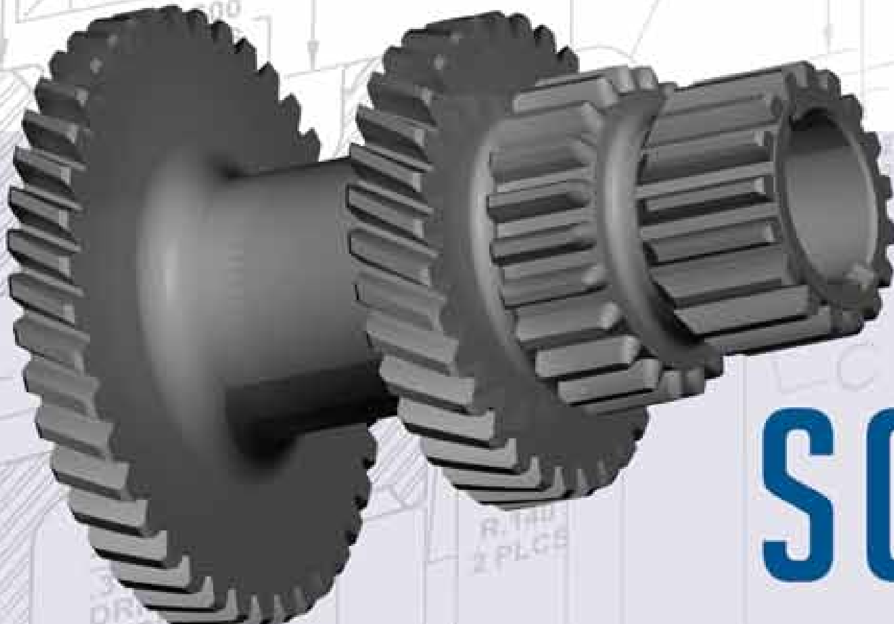

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Analysis of Load Distribution in Planet Gear Bearings

Louis Mignot, Loic Bonnard and Vincent Abousleiman

Management Summary

In epicyclic gear sets designed for aeronautical applications, planet gears are generally supported by spherical roller bearings with the bearing outer race integral to the gear hub. This article presents a new method to compute roller load distribution in such bearings where the outer ring can't be considered rigid. Based on the well-known Harris method, a modified formulation enables accounting for the centrifugal effects due to planet carrier rotation and the assessment of roller loads at any position throughout the rotation cycle. New model load distribution predictions show discrepancies with results presented by Harris, but are well-correlated with 1-D and 3-D finite element models (FEMs). These results validate the use of simplified, analytical models to assess the roller load distribution, rather than the more time-consuming FEMs. The results of centrifugal effects due to planet carrier rotation on roller loads are also analyzed. Finally, the impact of the positions of the rollers relative to the gear mesh forces on the load distribution is shown.

Introduction

Epicyclic gear sets are power transmission systems that provide high capacity, power density and efficiency. As such, they are widely used in various aeronautical applications, including helicopter main gearboxes and turboprop-power gearboxes, where weight is a critical performance criterion. In planetary and epicyclic gearboxes, high loads are transmitted via the planet carrier, which could result in misaligned contacts on gear meshes or planet bearings. Conventional gearbox designs thus include spherical roller bearings to support the planets on the planet carrier axles. These bearings can cope with misalignment angles up to 1.5° (Ref. 1) while providing good radial load-carrying capacity. A past study (Ref. 2) shows that bearings are a major source of failure in epicyclic gear sets. The authors also demonstrated that the optimization of planet bearings design can provide significant weight reduction, since the saving obtained on one planet is multiplied by the number of planets, which is generally greater than four. At the early gearbox design phase, it is thus essential to perform parametric studies in order to find the most optimized design for the planet bearings. Spherical roller bearings in aeronautical, epicyclic gear sets are characterized by two main features:

1. For weight-saving reasons, the outer ring of these spherical roller bearings is usually integral to the planet gear hub, which is, in addition, made as thin as possible. The gear mesh forces induced by the sun planet and the ring planet meshes are thus applied directly to the outer ring at localized points. The conventional assumption of rigid bearing outer ring submitted to a concentrated load is not valid in this instance. The outer ring must be considered deformable to determine the roller load distribution.

2. In epicyclic gear sets, the carrier is rotating while the ring is stationary (Fig. 1). This renders the planet bearings' kinematics rather complex, with the inner ring rotating around the gearbox main axis while the outer ring is rotating around the inner ring (planet carrier axle). The effect of the centrifugal loads induced by the outer ring weight could influence the roller load distribution, since the ratio of centrifugal loads to accumulated radial gear loads can be as high as 20% for typical turboprop applications.

In this regard, several studies have been conducted to determine the influence of a deformable outer ring on the bearing loading. An analytical approach was proposed in 1963 by Jones and Harris (Ref. 3) and also described in Harris (Ref. 4). The results showed that the outer race distortion modifies significantly the roller load distribution, compared with rigid outer race assumption; i.e., the number of loaded rollers increases and the most loaded roller is no longer located along the gear tangential direction but close to mesh force application. Effects of the bearing's diametral and out-of-round clearance were also obtained with the same model by Harris et al. (Ref. 5). For this model, however, no finite element (FE) validation exists that could provide a reasonable approximation of the performance of the model.

Liu and Chiu (Ref. 6) proposed a model that accounts for inertial effects induced by planet carrier rotation and roller centrifugal forces. The main results showed the influence of the bearing diametric clearance on roller load distribution and fatigue life. Some discrepancies were also observed by the authors, as compared to the Jones/Harris study (Ref. 3). Other authors have proposed an FEM approach as well; Drago et al. (Ref. 7) studied the effect of planet bearing outer race deformation on gear stresses using a 3-D FEM. The authors demonstrated that the optimization of roller loads can adversely affect gear stresses and that the planet bearing can't be designed without accounting for them.

The model presented in this article is based on the Jones/Harris approach (Ref. 3).

Initially, an example of the Jones/Harris model will be offered. A comparison of predicted loads and deformations with 1-D and 3-D FEMs will show discrepancies that can be explained by the assumptions made in the Jones/Harris equations.

Next, a new model is proposed that can solve non-symmetric problems to account for centrifugal effects due to planet carrier rotation. The results analyze the effects of centrifugal forces. The influence of roller positions with respect to mesh loads is also studied.

Analysis of State-of-the-Art Model

Jones/Harris analytical model description. In the Jones/Harris approach, the outer ring flexibility is modeled as a thin elastic ring with a mean radius R and a section moment of inertia I (Fig. 1). The effect of gear teeth on ring stiffness is ignored. The loads acting on the bearing outer ring are simplified as two equal and diametrically opposed loads representing, respectively, sun planet and ring gear planet meshes (Fig. 2). The mesh loads are assumed to act along the line of action and on the pitch radius R_P.

These loads can be decomposed into elementary radial (F_s) and tangential (F_t) forces, and a moment (M) acting on the elastic ring mean radius R. The rollers are assumed to be equally spaced around the outer ring, with the first roller located along the O-x axis defined in Figure 3. The position of the roller number j is characterized by an angle ψ_i and the reaction force of this roller on the outer ring is noted Q_i. In summary, the planet gear outer ring is submitted to mesh forces F_s, F_t, M and roller contact loads Q_i.

The system studied is thus symmetric around the O-x axis. This makes it impossible to study the influence of centrifugal effects that introduce an asymmetric force acting along the O-y axis, or to study the load distribution with arbitrary roller positions. The radial elastic ring deflection at point i—due to a load P—is expressed by means of influence coefficients C_i^P for which detailed expressions are not given in this paper but can be found in References 3–4.

$$u_i^P = C_i^P P \qquad (1)$$

It is worth noting that the elastic ring deflection only takes into account the bending in the ring—excluding the tension or shear. The validity of this approximation for rings such as the planet gears will be illustrated later in this paper. The total radial displacement at any location i is thus obtained by combining the effects of all elementary loads which yields:

$$u_i = u_0 \cos(\psi_i) + C_i^{Fs} F_s + C_i^M M + \sum_j \left| C_{ij}^{Qj} \right| \left\{ Q_j \right\} \qquad (2)$$

continued

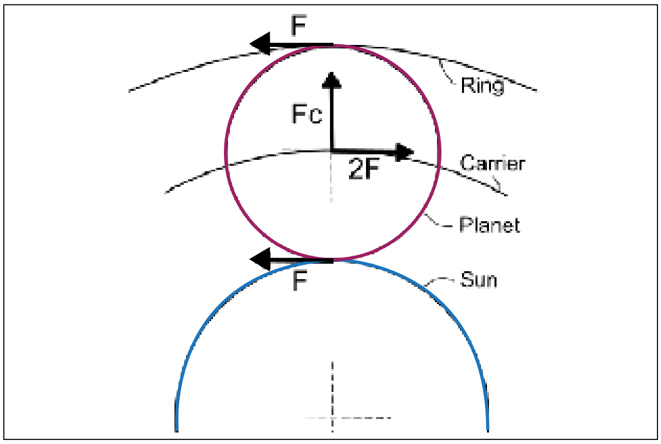

Figure 1—Loads acting on a planet.

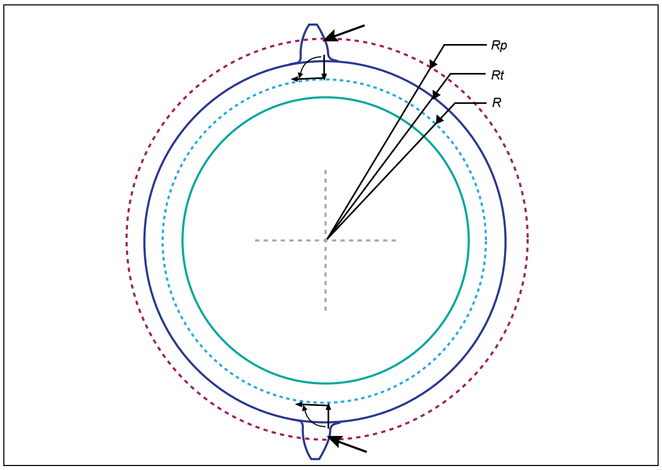

Figure 2—Simplification of mesh loads.

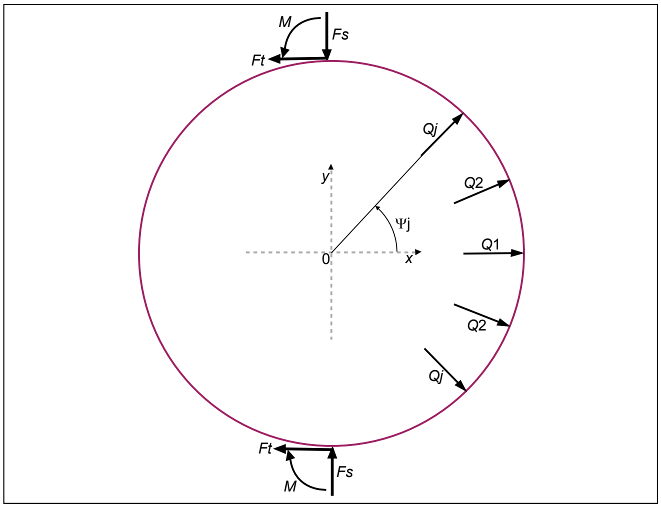

Figure 3—Forces acting on the planet gear outer ring.

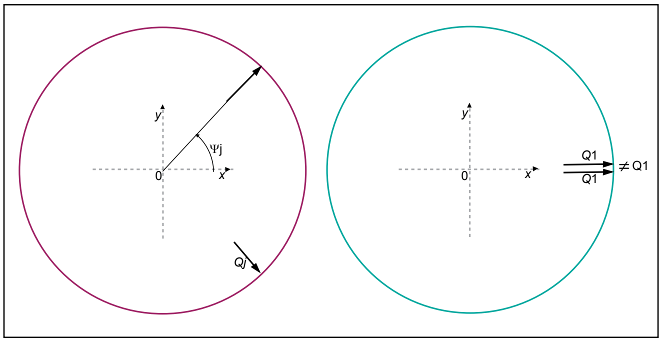

Figure 4—Jones/Harris model assumption of symmetric roller loads.

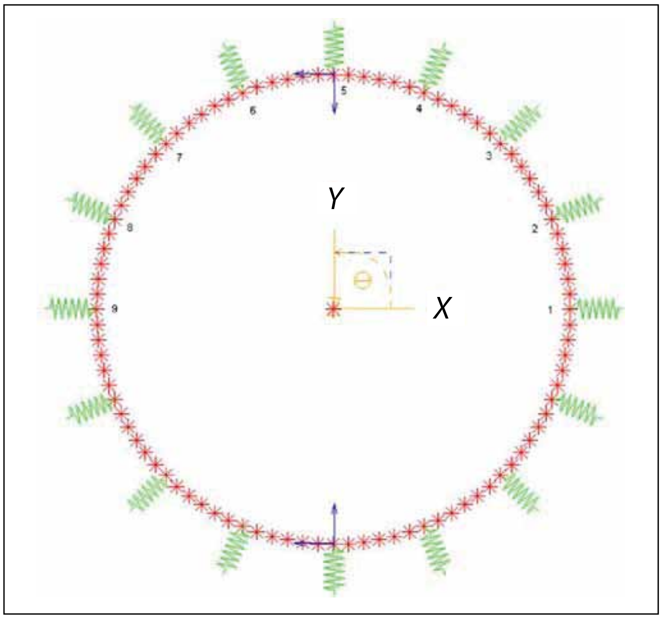

Figure 5—Example of 1-D-beam FEM.

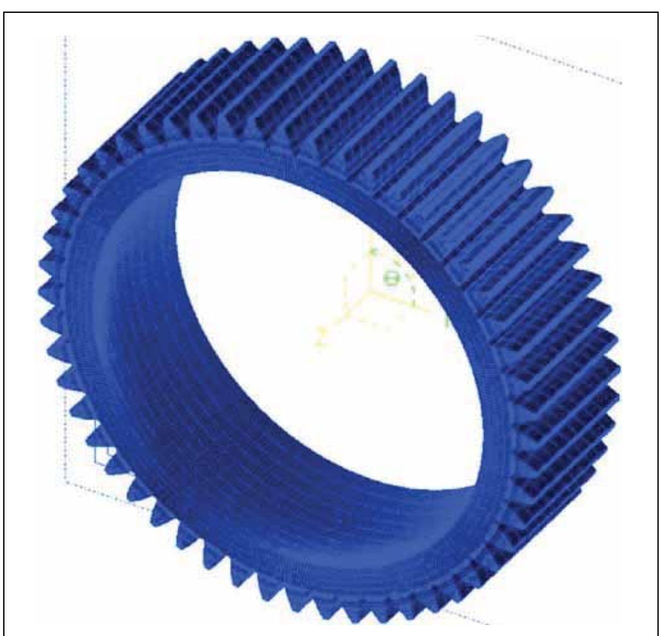

Figure 6—Example of 3-D FEM.

Using the Lundberg/Palmgren relationship, a contact condition can be defined at any roller *j* as:

$$Q_j = 0 \quad \text{if} \left(u_j - \frac{P_d}{2}\right) \leq 0$$
$$Q_j = K\left(u_j - \frac{P_d}{2}\right)^b \quad \text{if} \left(u_j - \frac{P_d}{2}\right) > 0 \tag{3}$$

Where P_d is the diametral clearance; b = 3/2 for point contacts and b = 10/9 for line contacts.

Combining Equations 2 and 3 and writing the force equilibrium along the O-x axis yields the following system of N + 1 equations, where N is the number of rollers:

$$u_i - u_0 \cos(\psi_i) - C_i^{Fs} F_s - C_i^M M - K\sum_j \left[C_{ij}^{Qj}\right]\left\{\left(u_j - \frac{P_d}{2}\right)\right\}^b = 0 \quad : \varepsilon_i \tag{4}$$

$$F_t - K\sum_j \tau_j \left(u_j - \frac{P_d}{2}\right)^b \cos(\psi_i) = 0 \quad : \varepsilon_0$$

With,

τ_j = 0.5 for ψ_j = 0° or ψ_j = 180°

τ_j = 1 in all other cases

As suggested by the authors (Refs. 3–4), the non-linear system can suitably be solved by using the iterative Newton Raphson method (*Ed.'s note: the "Newton-Raphson" method is a root-finding algorithm that uses the first few terms of the Taylor series of a function* f(x) *in the vicinity of a suspected root. A "Taylor series," developed by nineteenth-century mathematician Brook Taylor, is an infinite sum giving the value of a function* f(z) *in the neighborhood of a point a in terms of the derivatives of the function evaluated at* a).

Remarks on the model formulae. In the Jones/Harris model, the symmetric system is solved on a half ring. Therefore, the τ_j coefficients were introduced in the force equilibrium equation (ε_o) to take into account half of the loads at roller positions ψ_j = 0° and ψ_j = 180°; i.e., solving:

$$F_t - \frac{Q_1}{2} - Q_2 \cos(\psi_2) - \ldots - Q_j \cos(\psi_j) = 0 \tag{5}$$

In displacements equations (ε_i), the displacement at any point *i* of the ring is calculated by considering a pair of roller loads Q_j symmetric with respect to the O-x axis (Fig. 4-a). It follows that when the effect of the force of Roller 1 is taken into account, it should be divided by two and not considered a pair of loads Q_1, as shown in Figure 4-b.

A modified system of equations is proposed to solve this problem by introducing the coefficient τj in the term:

$$K\sum_j \left[C_{ij}^{Qj}\right]\left\{\left(u_j - \frac{P_d}{2}\right)^b\right\} \tag{6}$$

It yields:

$$\begin{cases} u_i - u_0 \cos(\psi_i) - C_i^{Fs} F_s - C_i^M M \\ \quad - K \sum_j \tau_j \left[C_{ij}^{Qj}\right] \left\{\left(u_j - \frac{P_d}{2}\right)\right\}_b^b = 0 \quad : \varepsilon_i \\ F_t - K \sum_j \tau_j \left(u_j - \frac{P_d}{2}\right)^b \cos(\psi_i) = 0 \quad : \varepsilon_0 \end{cases} \qquad (7)$$

With,

$\tau_j = 0.5$ for $\psi_j = 0°$ or $\psi_j = 180°$

$\tau_j = 1$ in all other cases

Comparison of analytical models to FEM. Two different FEMs have been built in order to validate the results obtained with the initial Harris model and the proposed, modified analytical model.

The first FEM uses one-dimensional finite elements (Fig. 5):

- The ring is modeled as an assembly of beam elements accounting for tension, bending and shear effects.
- The roller contacts are modeled as non-linear springs with a force-deflection relationship introduced via tabulated data following the Lundberg/Palmgren contact deflection law. This force deflection law accounts for the diametric clearance of the bearing (Eq. 3).

The second FEM uses 3-D (Ref. 3) finite elements (Fig. 6):

- The ring is meshed with 3-D linear hexahedric and pentahedric elements.
- The roller contact force deflection is described in the same way as in the previous 1-D FEM. In addition, rigid body elements connect the outer race nodes to each roller spring in order to distribute the contact load along the race width.
- The gear mesh loads are assumed to be uniformly distributed across the gear width.

The example used in this article is based on the data presented in Table 1.

Figure 7 displays the roller loads for the initial Harris model, the 1-D and 3-D FEM, and the modified Harris model according to Equation 5. The abscissa represents the roller number according to convention given in Figure 2. The plots show good correlation between the 1-D FEM and the modified Harris model for all rollers, whereas the initial Harris model predicts a significantly lower contact load for Roller 1 and higher loads for the other rollers. This result confirms that the missing term in the Jones/Harris model has a strong influence on the roller load distribution and must be taken into account.

The agreement between the 1-D FEM and the modified, analytical model also confirms that neglecting the tension and shear effects in the elastic ring deflection formula of the Harris analytical model is a valid assumption.

Finally, the plot in Figure 7 shows that the roller load distribution given by the 3-D FEM is similar to that of the 1-D FEM and the modified Harris model. In this case, the contact loads are greater, but are distributed on a smaller number of rollers since Rollers 5 and 9 are not loaded for the 3-D FEM. These small differences demonstrate that the impact of tooth stiffness and 3-D effects do not play a significant role in the load distribution.

Figure 8 illustrates the ring radial displacement for the modified analytical model and the 1-D and 3-D FEMs. The FEM results appear to be in agreement, while the predicted displacements differ significantly from the analytical model. The area of greatest difference corresponds to the unloaded zone of the bearing (Rollers 6–8)—which explains why there is no impact on the load distribution, as observed in Figure 7.

These differences are believed to be a consequence of the effects of tension and shear, which are not taken into account in the analytical model.

The effect of how the gear mesh force is applied to the model has been investigated; the 3-D FEM has been run for two configurations:

- The reference model considers the gear mesh force as unique, applied at the gear pitch diameter and along the line of action.
- The second model accounts for the actual load application points on the different teeth in contact. In this case (Fig. 9), the contact is assumed to be distributed on three teeth (HCR gears).

continued

Table 1—Sample Data	
Number of rollers per row	12
Number of rows	1
Roller diameter	12.5 mm
Roller length	40 mm
Bearing clearance	0 mm
Roller contact angle	0˚
Outer ring section moment of inertia	3,081 mm⁴
Radius of outer ring neutral axis	70.3 mm
Gear pitch radius	79.5 mm
Gear mesh tangential force	27,096 N
Gear mesh separation force	9,862 N
Gear moment	249,372 N-mm

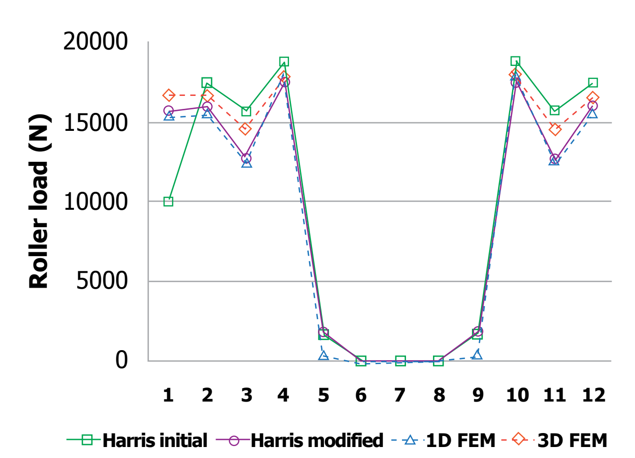

Figure 7—Roller load distribution for several models.

Figure 10 shows that the roller load distribution obtained with both models is very similar. A precise description of the tooth load distribution on the planet gear is thus not necessary as far as the assessment of the roller load distribution is

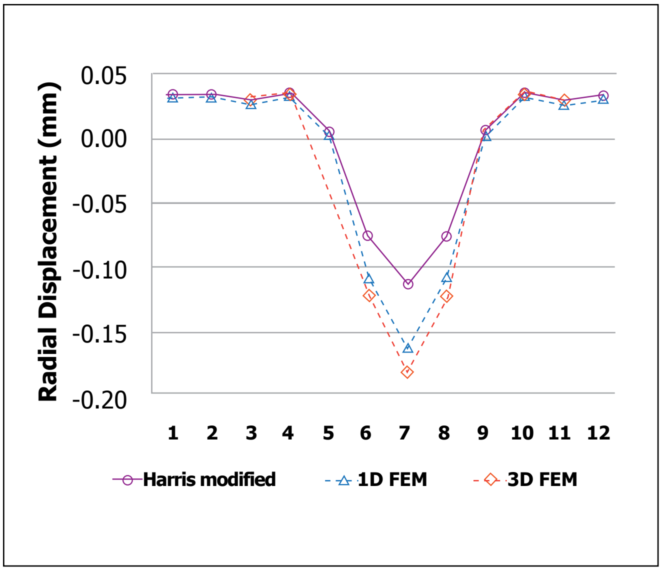

Figure 8—Ring radial displacement for several models.

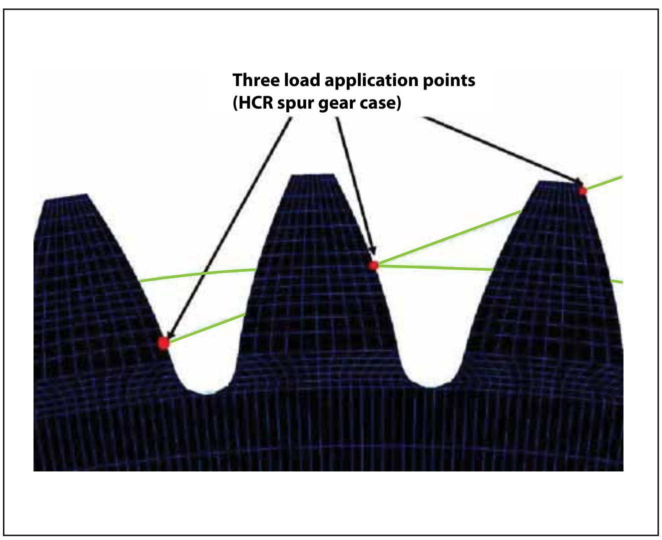

Figure 9—Influence of the gear mesh force application.

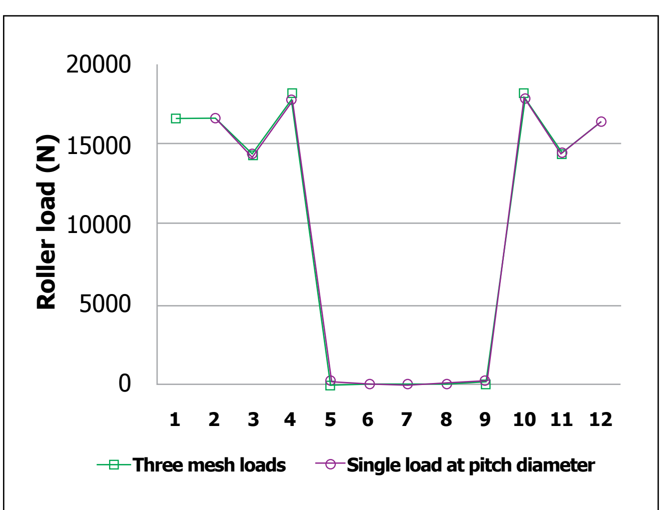

Figure 10—Roller load distribution for several models.

concerned.

The results from Figures 7–10 validate the use of a simplified analytical model in the prediction of roller load distribution. This is an important result since the analytical models can be fast to run and enable performance of parametric studies in a short time, which is not the case with 1-D or 3-D FEMs.

Improved Analytical Model

Model description. In the preceding sections, the Jones/Harris model was modified to include a missing term in the equations that appeared to be crucial in the analysis of load distribution in planet gear bearings. But this model is based on the assumption that the problem studied is symmetric about the O-x axis. This prevents, in particular:

- Accounting for the centrifugal force F_c induced by planet carrier rotation that is directed along the O-y axis. This new force will increase roller loads on the lower part of the bearing while decreasing the load on the opposite side.
- Studying the roller load distribution with an arbitrary position of the rollers with respect to the O-x, O-y axis.

The improved model presented below enables study of a dissymmetric problem by considering the roller loads Q_{jk}—not coupled symmetrically by pairs, but independent—one from the other. In order to define the radial deflection of the ring at any point *i*, located by the angle ψ_i and induced by a single force Q_j defined by the angle ψ_j, the influence coefficients developed by Jones/Harris (Ref. 3) for the load Q_1 were used. Indeed, these influence coefficients give the deflection at any point i due to a single load located by the angle $\psi_1 = 0$.

A local basis is created for each load application point Q_j, in which the O-x axis corresponds to the O-j direction. In this local basis, the point *i*2 at which the deflection needs to be calculated is defined by an angle ψ_{i2} (Fig. 11). In this local frame, the load Q_j is equivalent to the load Q_1 in the initial frame.

Therefore the influence coefficients given by Jones/Harris for Q_1 can be used in this basis, accounting for the relative angle ψ_{i2}. The value of this angle is given by Figure 12 and:

$$\psi_{i2} = \psi_i - \psi_j \qquad (8)$$

Using influence coefficients of Reference 3, the deflection calculation is given by:

$$u_i^{Q_j} = \frac{1}{2} C_{i2\,j2}^{Q_1} Q_j \qquad (9)$$

Where $C_{i2\,j2}^{Q1}$ represents the influence coefficient defined for Q_1 (Ref. 3), but with the change of basis defined by the angle ψ_{i2}.

Once this deflection equation is defined for the elastic ring, the system of equations can be defined as follows:

- The force equilibrium equation along the O-x axis remains the same as in the original model.
- When the planet carrier centrifugal force F_c is consider

- a new equation is necessary to ensure the force equilibrium along the O-y axis. Moreover, a new rigid-body displacement u_{0b} along the O-y axis needs to be introduced.
- The equality of displacements on all ring points includes the new deflection (Eq. 9) and the contribution of the rigid body displacement u_{0b}.

It yields the following set of $N + 2$ equations:

$$\begin{cases} 2F_t - K \sum_j \left(u_j - \frac{P_d}{2}\right)^b \cos(\psi_i) = 0 & : \varepsilon_{0a} \\ -F_c - K \sum_j \left(u_j - \frac{P_d}{2}\right)^b \sin(\psi_i) = 0 & : \varepsilon_{0b} \\ u_i - u_{0a} \cos(\psi_i) - u_{ob} - \sin(\psi_i) - C_i^{Fs} F_s - C_i^M M & \\ \quad - K \sum_j \left[C_{j2\,j2}^{Q_1}\right] \left\{\left(u_j - \frac{P_d}{2}\right)\right\}^b = 0 & : \varepsilon_j \end{cases} \quad (10)$$

Analysis of the effect of centrifugal force. The planet gear bearing defined in Table 1 is used to illustrate the effects of the centrifugal force induced by a planet carrier rotational speed of 1,500 rpm. The planet gear outer ring weight is equal to 2.38 kg and its center is located at a distance of 150 mm, relative to the planet carrier axis of rotation. In this calculation, the gear mesh forces and moment are: F_s = 6,680 N; F_t = 18,553 N; M = 168,908 N-mm.

Figure 13 shows a plot of the roller load distribution for the analytical model previously described in this paper, and for a 1-D FEM. Both curves are in agreement—thus validating the new analytical model.

The roller load distributions are no longer symmetric with respect to the O-x axis—i.e., Rollers 1 and 7. The rollers located at the radial outer part of the bearing (Rollers 1–6) carry a lower load than those located at the inner part of the bearing (Rollers 7–12). The difference in the maximum loads carried by each area of the bearing is equal to 18%—which is significant. The effect of centrifugal force shall therefore not be neglected in the design phase—both for the sizing to contact pressure and to the sliding in unloaded zones.

Influence of roller position relative to the gear mesh. Due to the natural symmetry of a bearing, the system returns to an identical state at every cage rotation. In the Jones/Harris model (Ref. 3), an important assumption is that Roller 1 is by necessity located along the O-x axis—at angle $\psi_1 = 0$. Between $\psi_1 = 0$ to $\psi_1 = \frac{2\pi}{N}$ the original Jones/Harris model cannot predict the load distribution.

This new model makes possible the modeling of the different roller position configurations by introducing a shift angle in the calculation of ψ_{i2}. This possibility is illustrated in the numerical application shown in Table 2.

Figure 14 shows the roller load distribution for the initial position with an 11.43° angular shift. The main impact is seen on the rollers close to the gear mesh; i.e., Rollers 5–6 for the ring gear mesh and Rollers 13–14 for the sun gear mesh. This is due to the sudden change in the outer ring deformed shape in the vicinity of the mesh forces and

continued

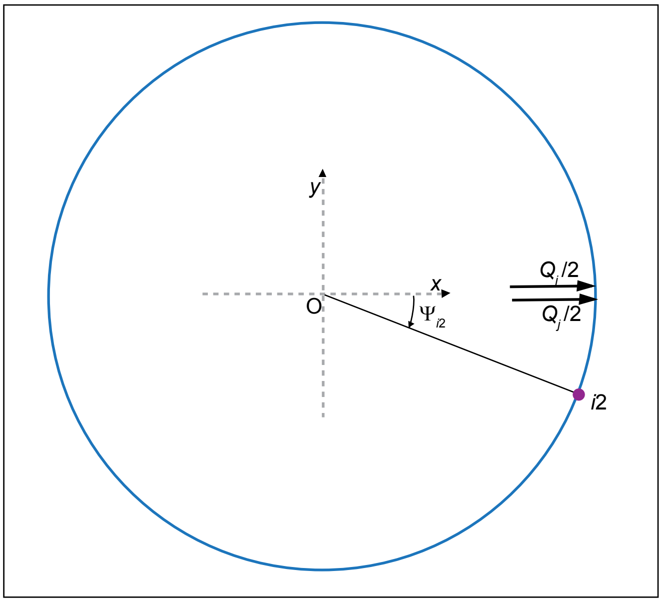

Figure 11—Definition of the local frame at Q_i.

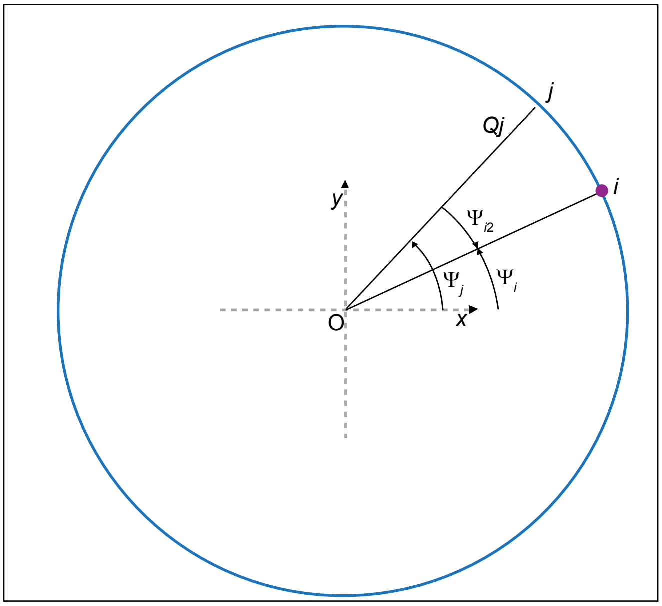

Figure 12—Change of basis definition for the improved model.

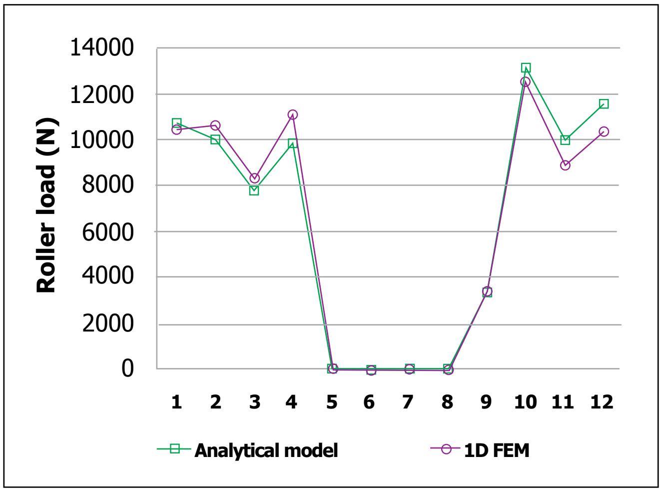

Figure 13—Effect of planet carrier rotation centrifugal force on the roller load distribution.

moment, which affects the bearing clearance and thus the contact load (Fig. 15). The consequence is a significant increase in the maximum roller load from 5,867 N to 7,689 N (+ 31%). This high roller load variation could be lowered by stiffening the outer ring.

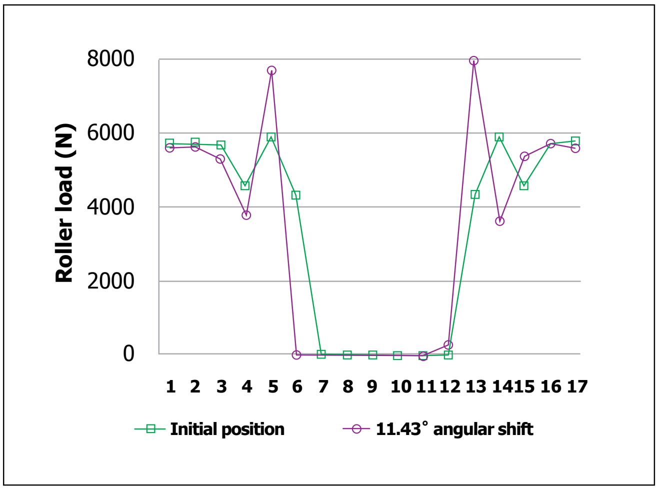

Figure 14—Effect of roller positions on the roller load distribution.

Table 2—Shift angle in the calculation of ψ_{i2}	
Number of rollers per row	17
Number of rows	2
Roller diameter	16 mm
Roller length	16 mm
Bearing clearance	0.03 mm
Roller contact angle	10.9°
Outer ring section moment of inertia	2,375 mm^4
Radius of outer ring neutral axis	70.49 mm
Gear pitch radius	79.5 mm
Gear mesh tangential force	27,096 N
Gear mesh separation force	9,862 mm
Gear moment	244,210 mm

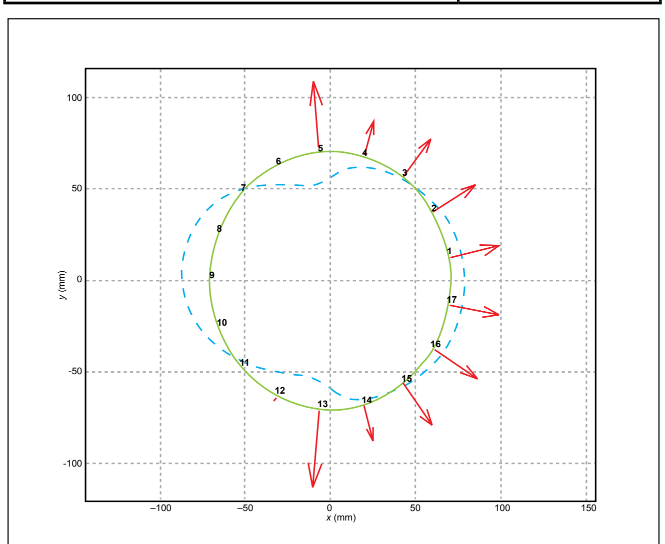

Figure 15—Outer ring—deformed shape—and corresponding roller loads.

Conclusion

In the first part of this article, a missing term in the Jones/Harris model has been identified; the corrected system of equations showed correlation with 1-D and 3-D FEMs. In particular, the practice of modeling precisely the gear teeth and the tooth load distribution has a negligible effect on the prediction of roller load distribution. The ability to use simplified, analytical models with reasonable confidence in the result is important, since designers generally need a fast tool to perform parametric studies at an early stage of the design. A limitation in the use of simplified models is the fact that they can't assess the stress state in the outer ring as precisely as do FEMs; in certain cases the stresses might be the limiting factor in the design of the outer ring.

A new model has also been presented that enables the study of dissymmetric systems—such as the ones that take into account planet carrier rotation centrifugal effects or that simulate arbitrary roller positions. Centrifugal effects tend to create asymmetric load distribution in the bearing, with a load increase in the sun gear mesh area. The position of the rollers relative to the gear mesh forces has also shown to be a critical parameter, since in this area the outer ring deformation is maximal.

The model improvements will be directed towards the integration of rollers' individual centrifugal loads that may affect the load distribution in the bearing. In addition, efforts will be made to include in the model the assessment of the planet rim stresses. This latter improvement should allow optimization of the rim thickness as a function of rim stresses and roller load distribution.

__Vincent Abousleiman__ is chief design engineer/power transmission division at Hispano-Suiza; __Loic Bonnard__ is a hydraulic engines application engineer at Poclain Hydraulics and __Louis Mignot__ is a power transmission design engineer at Eurocopter.

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AGMA Gear Expo returns "Home" for 2011 Event.

Perhaps When You Need It Most:

GEAR EXPO 2011 MAY WELL BE A SPECIAL EVENT

By Jack McGuinn, Senior Editor

Showtime! Gear Expo Time! And the ASM will be there! (*See accompanying story on p.66.*)

That's right folks—Gear Expo 2011—the American Gear Manufacturers Association's (AGMA) every-other-year geerzapalooza is back—back in "hometown" Cincinnati and back looking to do some brisk business. Then add the annual AGMA Fall Technical Meeting and the ASM Heat Treating Society Conference and Exposition to the mix, and things are really cooking.

"Cincinnati was home to the first full Gear Expo back in 1987," says Jenny Blackford, AGMA director of marketing and communications. "Gear Expo has grown and changed a lot since then, but even more than 20 years later, Cincinnati is still a great location for the show. The city is rolling out the red carpet for Gear Expo attendees and exhibitors with their hospitality, discounts at restaurants and more."

What's more, rare opportunities like Gear Expo—don't tell anyone, but that's why it's only every two years—provide exhibitors and attendees alike a degree of important, hot-spot face time.

Blackford explains, "In times of economic turmoil, Gear Expo takes on added significance, not only as a place for companies to find new prospects and new technologies; it is also a great time for gear professionals to network with one another and to keep in touch with their peers and the pulse of the industry."

One change to look for at this year's show is the absence of Dr. Mike Bradley, the popular professor and economist who in shows past delivered the "State of the Gear Industry" address for AGMA. This year will definitely be different in that the presentation will be a team approach.

"We plan on introducing our new economic consultants from IHS Global Insight (*Ed.'s note: IHS is a global information company addressing energy, economics, geopolitical* *risk, sustainability and supply chain management issues.*) who will do both a state of the gear industry (presentation and) forecasts on some of the end-use industries that gear manufacturers sell to," Blackford says, adding, "(They have) been hired by AGMA to provide quarterly forecasts on the gear industry and allied industries."

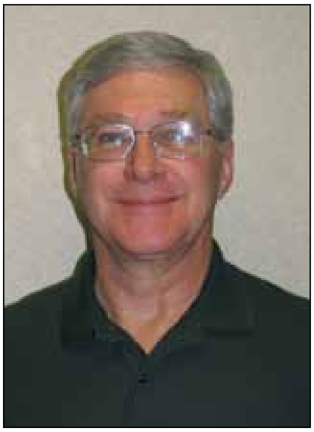
Jenny Blackford, AGMA director of marketing and communications.

Speaking of allied industries, this year's show will once again co-locate with the ASM show. It makes perfect sense; so much so that industry partnerings for trade shows are becoming quite common.

Blackford says that "ASM and Gear Expo both benefited from the co-location in 2009, so we are continuing the partnership. Gear Expo attendees can take advantage of the additional exhibitors at the ASM Heat Treat show, while exhibitors benefit from the additional attendees that come to the combined show. It's a great opportunity to see the entire gear manufacturing process all in one event. This year's Gear Expo is shaping up to be a great event, with a sold out exhibit hall, expanded education programs and a great location."

But be aware that Gear Expo—particularly in years when it coincides with the FTM—is also a learning experience. With that in mind, we talked with Charles Fischer, AGMA vice president/technical division, and Jan Alfieri, AGMA education manager. Look for them to be two of the busiest and more popular folks at the dance.

"Every other year, when AGMA's Fall Technical Meeting and Gear Expo occur consecutively, a great opportunity arises to hear the latest technical presentations, participate in a variety of excellent short courses and take part in the world-premiere event for gear manufacturers and gear buyers all in the same location," Fischer enthuses. "It is just the perfect storm for education, networking and demonstrations!"



Charlie Fischer, AGMA vice president/technical division.

Among that "perfect storm" of all-things-technical are Alfieri's teach-ins conducted by gear industry experts.

"In addition to Basic School at Gear Expo (the Training School for Gear Manufacturing)," Alfieri explains, "this year we will have some new short courses on topics covering how to organize and manage a failure investigation, bearings failure, materials selection and heat treatment of gears, gear health monitoring and program/project planning and management."

Given one of the most precious commodities—time—one wonders how the instructors are recruited for the event. For most, it's a labor of gear-love.

"For example—"Alfieri begins, (Gleason Cutting Tools Corp. senior product manager) "Mike Tennutti conducting the gear manufacturing sessions. We find our instructors understand the importance of FTM and Gear Expo to those in the industry, and they want to be a part of it. It is clearly the place to meet, exchange ideas, learn and network with those in the industry. AGMA is lucky indeed to have experts well such as Mike Tennutti who share their knowledge though our courses, year after year."

And then there is the cattle-call of FTM presentations. But this is one prime round-up—Great Thoughts from around the globe, presented first-hand without interruption. A good part of the presentations, according to Fischer, are all about failure—but in a good way.

"I see this year's show will address bearings failure, gear failure and materials selection," he says. "We look for programs we feel will appeal to those attending FTM and Gear Expo. This year attendees have the rare opportunity to participate in a class presented by (longtime *Gear Technology* technical editor) Bob Errichello. Bob's classes are usually taught in Montana and are always sold out almost immediately." Fischer points out that "AGMA and ASM are teaming up to present a joint course on materials selection and heat treatment of gears. Dr. William Mark (a major contributor to *Gear Technology*'s August issue feature on gear noise) and Jason Hines are doing cutting edge research on acoustics and vibration at the Pennsylvania State University Applied Research Laboratory and have agreed to present a short course on fundamentals of gear health monitoring." He concludes by explaining that "'Risk or Reward: How to Maximize Your Return on New Opportunities,' presented by David K. Watkins, came from a conversation with a member who said a concept like this turned their business around." (*Please see page 69 for Gear Expo 2011 dates, FTM presentations, etc.*)

Next Stop Cincinnati

WHAT'S NOT TO LIKE ABOUT A MORE FOCUSED, USER-FRIENDLY GEAR EXPO?

Matthew Jaster, Associate Editor

Gear Expo 2011 returns to Cincinnati with more education and training courses and a diverse group of exhibitors.

There are trade shows like IMTS or EMO Hannover that offer huge attendance numbers and the latest in manufacturing technologies. There are industry-specific fairs that cater to particular areas of interest such as aerospace or medical devices. The recently developed Interactive Manufacturing Experience (imX) promises to "re-invent" the trade show formula altogether. While gear industry professionals might argue that these exhibitions offer exciting opportunities for finding new business, you'll be hard-pressed to find another trade show that puts as much emphasis on gears, gear products and gear services as AGMA's Gear Expo.

Taking place November 1–3 at the Duke Energy Convention Center in Cincinnati, AGMA has upped the ante for the biennial exhibition. This year's show includes more education and training courses, offers 40,000 net square feet of exhibit space and a diverse and highly specialized group of exhibitors. It is also co-located once again with the ASM Heat Treating Society Conference and Exhibition.

But in these fiscally challenged times, is spending large amounts of money to bring gear industry buyers

continued

Gear Expo 2011 returns to Cincinnati for the first time since 1987.

and sellers together in Cincinnati, Ohio a good idea? Absolutely, according to several key players in the industry, who cite AGMA's event as an essential part of their marketing and communication campaigns and a unique opportunity to meet new customers, discuss trends with peers and get a firsthand look at new technology.

"Visitors should attend to keep abreast of the latest technologies and solutions available for gear manufacturing," says John M. Terranova, vice president, sales—Americas at Gleason. "For exhibitors, trade shows are always an excellent opportunity to introduce new products, reinforce existing relationships and create new relationships. The unique format of Gear Expo affords the opportunity to showcase one's capabilities to a diverse and yet highly focused captive audience, and to better understand the activities of competitors and customers alike."

This highly focused audience is the one benefit of Gear Expo that most in this industry will not find from other, larger exhibitions."As an exhibitor, there is no better venue than the Gear Expo to reach our target customer base. Unlike general tool shows, everyone at this show is about making gears. Likewise, attendees will have the opportunity to see new products and get technical advice from industry experts for every method of gear manufacturing," says Frank Berardi, product manager gear machining, Ingersoll Cutting Tools.

Star SU president David W. Goodfellow adds, "Attendance to the Gear Expo is important for networking and one-on-one discussions between suppliers and users of gear tools and equipment for enhanced gear manufacturing technology."

"We always look forward to visiting with fellow exhibitors who are either customers or competitors. Gear Expo is like a family reunion that convenes every two years," says Thomas Kelly, senior vice president, Mitsubishi Heavy Industries America, Machine Tool Division.

"This Gear Expo will be a transitional one, that is to say that manufacturing is one of the leading sectors of the economy to show growth and prosperity," says Dennis Richmond, vice president, Reishauer Corporation. "I can't walk into a manufacturing plant today without noticing new investments in equipment, technology and personnel. I believe manufacturing will continue to be a bright spot for some time to come. The U.S. dollar is practically worthless. The products we manufacture in this country are on sale to the rest of the world!"

Talking Shop in Cincinnati

It's safe to say topics like the economy, the global gear industry and skilled labor will come up during the duration of the show, but many exhibitors feel there are plenty of other conversations and debates to entertain at Gear Expo 2011.

"Everyone is going to be speaking about wind again, but more likely on the service side than OEM supply," says Jim Mantei, vice president of business development at Vancouver Gear Works. "While the OEMs are subcontracting some work, they are still keeping it to a minimum. Many turbines are getting to the end of their effective life and will need to be replaced or repaired. Material availability might also become a conversation point. We see more and more European and Asian steel requirements but are unable to find suppliers for those materials."

"Our main focal points will be the automotive and construction industry. We specialize in hobs that require high accuracy and also coarse-pitch hobs for construction and mining equipment. Presently, the automotive industry accounts for 60–70 percent of our business," says Alex Roh, general manager, for DTR USA. "Our main topics of discussion with our customers are regarding high quality performance and long tool life. Most manufacturers are looking for a way to save on production costs and improve productivity."

Fred Young, Forest City Gear CEO, is interested in discussing trends in aerospace, pump gears, medical applications and racing vehicles. "Re-shoring initiatives will be discussed as well as new equipment and technology that works," he says.

Ingersoll will be focused on mining, wind, rail and heavy industry, according to Berardi. "We look forward to meeting with our customers, and establishing new relationships within the gear manufacturing industry."

Ingersoll will be featuring its cutting tools at booth #215.

"We believe the main focal points of Gear Expo will be automotive and agriculture. EMAG will be discussing how we can contribute to improve these industries and their machining processes," says Peter Loetzner, CEO of EMAG LLC. "We'd like to attract as many high-caliber prospective clients as possible at Gear Expo," he adds. "We want to see the people who are in charge of making buying decisions so that we can demonstrate our latest technologies."

continued

The Economic Mindset

Economic, political and financial question marks have undoubtedly consumed headlines leading up to Gear Expo, though many in the industry remain confident that the gear market is much better now than it was before the Indianapolis show in 2009.

"The biggest difference in the domestic gear machinery market between 2009 and 2011 is a decrease in demand for large-diameter gear machines and the resurgence of the automotive and transportation industries in 2011, increasing the demand for highly productive automated equipment," Kelly at Mitsubishi says.

"2009 seemed to be a wait and see attitude; today it is either we're in the gearing business or not, can't wait any longer," says Dan Kondritz, general manager, KISSsoft USA, LLC. "That 'can't wait any longer attitude' is evident in the new customers to KISSsoft and older customers adding new capabilities."

Roh of DTR USA agrees. "Since the establishment of DTR USA in 2008, we have seen the gear manufacturing industry grow in various markets, especially automotive and construction. There has been a substantial increase in the requests of our customers with larger orders being placed year over year ever since the economic downturn in 2008. We have a very positive outlook on the future of gear manufacturing in the United States and around the world."

"In 2009 there was clearly a certain tension in the air, from the largest companies to the smallest of companies. Even the strongest and most confident of us had some concerns about the time needed for recovery, stability and growth," says Gerald Kuo, general

Gleason will offer its measuring technology at booth #815.

manager at Luren Precision Chicago Co., Ltd. "As we head to Gear Expo 2011 there is less uncertainty and a lot of excellent signs that seem to indicate that we are gaining some positive momentum."

"For us, the gear market has picked up significantly compared to 2009, especially in mining and heavy industry," Berardi at Ingersoll says. "We are optimistic that the trend will continue."

"The economic tailspin of 2009 seems to have leveled off and we are busier than ever. For a long time Asian countries, specifically China, looked to be taking an ever larger share of the market, but with increased costs in labor and the shortages of material they are experiencing, especially quality material, they are becoming less competitive," says Mantei. "We have had Chinese companies approach us (Vancouver Gear Works) because they admit that they cannot attain the level of standards, both in quality and material, in China that they require. Too many people in industry have heard too many outrageous stories about Asian-made products for them to ignore anymore. This will mean that Asian manufacturers' costs are only going to rise as they try to achieve better standards. This can only benefit North American manufacturers."

"The state of the gear industry in 2009 was far more a reflection of the global economy than of the industry itself. In 2011 manufacturing—including the gear industry—is healthy and robust across a broad and diverse spectrum. There are major investment programs underway with United States, Asian and European-based customers in automotive, power tool, agricultural equipment and other markets. What we hear from many customers is that business is good," Terranova says.

Goodfellow at Star SU would like to see potential economic improvements have a direct impact on Gear Expo itself. "Gear manufacturing has improved dramatically from '09 to 2011, especially with the improvement in the automotive industry, truck and tractor, and oil and mining. Hopefully, this will lead to improved attendance and serious buyer intentions."

The Great Venue Debate

The very first Gear Expo took place at the Cincinnati Convention Center in 1987, but much has changed since then, according to AGMA president Joe Franklin. "In 1987, we took one

continued

small hall of the Cincinnati Convention Center. This year we are taking the entire Center with an expected 200 exhibitors."

The return to Cincinnati for Gear Expo has been met with varied opinions. Some believe it opens doors for new attendees and others wonder if key industries will be missing from the event.

"Cincinnati should be a good location since a large percentage of gear production occurs within a 300 mile radius of Cincinnati. The location should allow easy access for visitors," Goodfellow says.

"I'm personally looking forward to exhibiting in Cincinnati; the Duke Energy Center has been very engaged working with the AGMA Trade Show Advisory Committee," Richmond adds. "I'm certain exhibitors will notice the cooperative spirit. AGMA has worked tirelessly promoting the show to provide value to its exhibitors and content to the attendees."

"I believe that the venue change to Cincinnati will be great for the show. It is something different and exciting," Loetzner says. "Cincinnati is a very central location. It is within driving distance of many big cities, and a short plane trip from many others, so we are hoping this leads to a larger attendance."

Adds Mantei at Vancouver Gear Works, "It's good to see the show move around as it makes it more accessible to different businesses each year."

Terranova at Gleason is taking a wait-and-see approach. "We are keeping an open mind. Although Gear Expo was held before in Cincinnati, that was a number of years ago and both the economy and the market dynamics are somewhat different now. As with any show that changes venues, we of course wonder if people will come to Cincinnati. By November 4th, we'll have the answer. We are hoping that Gear Expo has been sufficiently promoted by AGMA and that as a result, the change in venue becomes a non-issue in the minds of potential visitors."

"I like Cincinnati; however, it is not a 'hot-bed' for automotive, aerospace or industrial applications," says Tony Werschky, sales/partner, Delta Gear Inc./Delta Research Corp./Delta Inspection. "I hope they are able to attract more people to the show—especially engineers, buyers and other gear professionals."

"We hope for an improved turnout with the improved economic situation,

Reishauer will highlight its RZ 260 gear grinding machine at booth #239.

The concentration of expertise offered by exhibitors and attendees alike only happens every two years. Come look, listen, learn or teach!" Kelly at Mitsubishi says.

Werschky from Delta Gear offers four reasons to come to Cincinnati. "For one, to support the industry in the U.S.; two, to learn about new machines in the industry for capability; three, as a small business I would hope our customers (that attend the show) will continue to understand the value of working with

continued

especially in the automotive industry," Goodfellow adds. "Hopefully, AGMA can attract more attendees. We need to reach beyond traditional AGMA membership to encourage more gear manufacturers to attend. The quality of the visitor is important, but also quantity as we need to hit more potential buyers that may not be AGMA members."

Why Gear Expo Remains Relevant

From its modest beginnings in 1987 to its large industry presence today, there is no mistaking the significance of a trade show directly catered to the gear market. For Kondritz at KISSsoft, "Gear Expo is an opportunity to re-establish contacts with existing customers as well as introduce KISSsoft products to new prospects and finalize ongoing sales."

Kuo at Luren expects to meet many gear manufacturers at Gear Expo interested in utilizing the company's various machine tools. "I believe that anyone associated with the gear industry should attend the 2011 Gear Expo. The benefits of talking to a potential customer face to face are invaluable. The modern age of communication lets us stay connected easier than years past but until they invent a way to stick one's hand through a computer or phone, there's still nothing better than a handshake and smile to build friendships."

"If you are at all involved in the gear industry, Gear Expo is a must to attend.

the Delta Companies. I can also see what my competition is doing."

"Our expectations for Gear Expo 2011 are that the AGMA brings together a great group of new potential customers for us to share our innovative technologies with," Loetzner at EMAG says.

"To stay strong as an industry we need to see what the latest/greatest products and services are. The sharing of knowledge only makes the whole industry more productive and globally competitive," Mantei says. "The greatest advantages for exhibiting, is that a lot of people are exposed to your company that you wouldn't necessarily meet if you were just walking. Walking the floor exposes you to a lot more faces and companies, you also get to spend time talking with people without turning away a prospective customer."

"This year we don't have any competing venues so exhibitors can commit all of their resources," Richmond adds. "It's not only up to AGMA to improve the show; we as exhibitors must bring new and exciting products and services to display that motivate gear manufacturers to attend."

Forest City's Young sums up the importance of attending Gear Expo like this: "I have pals call every time to see what happened and find out what was new at the show because they didn't have time to attend. One must see and feel new developments to keep from falling further behind. Unfortunately too many are ostriches with their head in the sand. They are doomed to follow the dinosaurs!"

Gear Expo 2011 is co-located with the ASM Heat Treating Society Conference and Exhibition at the Duke Energy Convention Center. For more information, visit *www.agma.org* or *www.asminternational.org*.

GEAR EXPO 2011 Show Stoppers

Show Stoppers

GEAR EXPO 2011 | ASM Heat Treating Society 26th CONFERENCE and EXPOSITION

HEAT TREAT SOCIETY

CO-LOCATED ASM/AGMA EXPOS A HOT TICKET

Jack McGuinn, Senior Editor

The ASM International Heat Treating Society will once again partner with the American Gear Manufacturers Association in co-locating their Heat Treat 2011 Conference and Exposition (ASM's 26th show) with Gear Expo 2011 at the Duke Energy Center in Cincinnati, Ohio. Note that ASM show dates are October 31–November 2, while Gear Expo will run November 1–3.

The partnership—begun in 2006 and cemented with the first co-location in 2009—is a strong one, says Joe Zion, ASM's senior manager of sales, who touts the partnership's ability to "boost attendance for both groups" and to create a "synergy" that doesn't exist with some other co-located expositions.

Terry Brown, president of ASM Heat Treat Society.

That "synergy" is also a big hit with Terry Brown, Heat Treat Society president.

"The HTS Conference & Expo 2011 we expect to be one of the best-attended events in HT Society history," says Brown. "The relationship and synergy developed with the partnership of AGMA will prove to be one of the most powerful collaborations to draw innovators and influencers to one of North America's largest buying and selling experiences in the industry.

"The expo show floor will introduce the latest technologies and new products to the industry. An extensive conference and learning schedule will provide interactive learning experiences that will help professionals stay up to date and competitive in an ever changing market."

Zion points to three events that he feels make the show a must-attend for anyone in either the gear or heat treat industries.

One is a special "Honorary Symposium" presentation by Bill Jones, CEO of Solar Atmospheres, one of the most successful developers and implementers of vacuum processing technology.

Another is the first-ever Materials Camp—where more than 500 high school and college students are expected to gather for presentations and meet-and-greet sessions with industry leaders and experts.

Third is the melding—for the first time—of a number of Solutions Center presentations conducted by both ASM and AGMA experts addressing gear/heat treat issues.

Zion also points to another show-first for ASM—daily publication online throughout the shows' run of the latest news nuggets and developments via *Headliner*—a daily, ASM e-news product.

As with Gear Expo, the ASM show will feature first-time presentations of technical papers addressing a host of heat treat-relevant topics. Abstracts include:

Low Pressure Carburization and Quench Hardening of a 9310 Steel Gear. Dr. B. Lynn Ferguson, Deformation Control Technology, Inc., Cleveland, OH; Zhichao Li, Deformation

continued

Control Technology, Inc., Cleveland, OH; Andrew Freborg, Deformation Control Technology, Inc., Cleveland, OH.

Modeling of Deformation and Residual Stresses in Large Component Gears After Carburization and Heat Treatment. Koen Decroos, Catholic University of Leuven; Marc Seefeldt, Catholic University of Leuven.

The Use of Cryogenic Treatment for Non-Destructive Testing on Engines and Transmission Components. Victor Sloan, Victor Aviation; Rosalia Papp, Air Liquide U.S. LP; Frederick Diekman, Controlled Thermal Processing.

Austenite Grain Growth Kinetics. Wendi Liu, Worcester Polytechnic Institute; Chun-Min Chou, Worcester Polytechnic Institute; Zhijia Jin, Worcester Polytechnic Institute; Erik Khzouz, Worcester Polytechnic Institute; Lei Zhang, Worcester Polytechnic Institute; Dr. Richard D. Sisson, Worcester Polytechnic Institute.

New Carbonitriding Processes. Prof. Franz T. Hoffmann, Stiftung Institut für Werkstofftechnik (IWT); Matthias Steinbacher, Stiftung Institut für Werkstofftechnik (IWT); Dr. Brigitte Clausen, Stiftung Institut für Werkstofftechnik (IWT); Sebastian Bischoff, Stiftung Institut für Werkstofftechnik (IWT); Dr. Heinrich Klümper-Westkamp, Stiftung Institut für Werkstofftechnik (IWT); Prof. Hans-Werner Zoch, Stiftung Institut für Werkstofftechnik (IWT).

Austempered Gears and Shafts—Powertrain Solutions. Justin J. Lefevre, Applied Process Inc., Technologies Division, Livonia, MI; Kathy L. Hayrynen, Applied Process Inc./ Technologies Division, Livonia, MI; John R. Keough, Applied Process Inc./Technologies Division, Livonia, MI.

Integral Pre-Oxidation of Aerospace Gear Steel. Timothy De Hennis, Boeing Philadelphia, Philadelphia, PA; Dale Weires, Boeing Philadelphia, Philadelphia, PA; Tyler Pounds, Northstar Aerospace Chicago, Bedford Park, IL.

November 1–3, 2011

Duke Energy Convention Center
Cincinnati, Ohio

Registration: Register online or download a form at *www.gearexpo.com/registration*

The ASM Heat Treating Society Conference & Exposition will co-locate at Gear Expo 2011

Exhibit Hall Hours

Tuesday, November 1, 2011:
9:00 a.m.–6:00 pm
(networking reception
5:00 p.m.–6:00 p.m.)

Wednesday, November 2, 2011:
9:00 a.m.–5:00 p.m.

Thursday, November 3, 2011:
9:00 a.m.–4:00 p.m.

2011 Fall Technical Meeting

Sunday, October 30–
Tuesday, November 1
7:00 a.m.–5:00 pm

Training School for Gear Manufacturing

Tuesday, November 1–
Thursday, November 3
8:00 a.m.–12 Noon
Instructor: Mike Tennutti, Gleason Cutting Tools Corp.
Pricing:
Member Price $445
Non-member Price $575

Hotel Hilton Cincinnati Netherland Plaza (Headquarters Hotel & FTM Location two blocks from the Duke Energy Convention Center)

Address: 35 West Fifth Street, Cincinnati, Ohio, 45202
Phone: (513)-421-9100

Reservations: 1-800-HILTONS
A discounted block of rooms has been reserved for October 26, 2011–November 4, 2011.

The special room rate will be available until October 5, 2011

For questions regarding AGMA Membership, please contact *membership@agma.org.*

CONFERENCE PROGRAMMING FEES	
Training School for Gear Manufacturing	Price
AGMA Member	$445
AGMA Non-Member	$575
How to Organize and Manage a Failure Investigation	
AGMA Member	$525
AGMA Non-Member	$655
Why Bearings Fail Presented by: American Bearing Manufacturers Association (ABMA) Course Price	$325
Materials Selection and Heat Treatment of Gears	
AGMA Member	$499
AGMA Non-Member	$625
Fundamentals of Gear-Health Monitoring	
AGMA Member	$350
AGMA Non-Member	$450
Risk or Reward: How to Maximize Your Return on New Opportunities Systems and Tools for Success Regardless of the Size of Your Shop	
AGMA Member	$350
AGMA Non-Member	$450

FTM FEES	
Fall Technical Meeting	
	Price
Fall Meeting:	
AGMA Member	$935
AGMA Non-Member	$1,285
Single Session:	
AGMA Member	$235
AGMA Non-Member	$330

2011 AGMA Fall Technical Meeting

OCTOBER 30–NOVEMBER 1, CINCINNATI, OHIO

The AGMA Fall Technical Meeting provides an opportunity to share ideas with others on the design, analysis, manufacturing and application of gears, gear drives, and related products, as well as associated processes and procedures.

Session I—Manufacturing and Inspection

A New Way of Face Gear Manufacturing, Dr. Hermann Stadtfeld, The Gleason Works.

Generating Gear Grinding—New Possibilities in Process Design and Analysis, Fritz Klocke, Christof Gorgels and Jan Reimann, RWTH Aachen University.

Towards an Improved AGMA Accuracy Classification System on Double Flank Composite Measurements, Ernie Reiter, Web Gear Services, Ltd.

Multifunctional Gear Machining, Brian Cluff, Star SU LLC.

First International Involute Gear Intercomparison, F. Härtig, K. Kniel and S. Kraul, Physikalisch-Technische Bundesanstalt.

Session II—Design Considerations

Epicyclic Load Sharing Map—Application as a Design Tool, Avinash Singh, GM Powertrain, General Motors Company. *Gear Tooth Single vs. Reversal Bending Life Evaluation,* Joe Chen, SAIC Motor.

The Effects of Helix Angle on Root Stresses of Helical Gears, Donald R. Houser and Aaron Thaler, The Ohio State University.

A Comprehensive System for Predicting Assembly Variation with Potential Application to Transmission Design, Kenneth W. Chase and Carl D. Sorensen, Brigham Young University.

Standardization of Load Distribution Evaluation: Uniform Definition of KHß for Helical Gears, Dr.-Ing. Khashayar Nazifi, Zollern dorstener Antriebstechnik.

New Methods for the Calculation of the Load Capacity of Bevel and Hypoid Gears, B.-R. Höhn, K. Stahl, K. Michaelis and Ch. Wirth, FZG.

Marine Reversing Main Gear Rating Factor vs. Number of Loading Cycles and Shrink Fit Stress, E. William Jones, Steven R. Daniewicz and Shakhrukh Ismonov, Mississippi State University.

Session III—Micropitting

The Application of the First International Calculation Method for Micropitting, Dr. Ulrich Kissling, KISSsoft AG.

Investigations on the Flank Load Carrying Capacity in the New Developed FZG Back-to-Back Test Rig for Internal Gears B.-R. Höhn, K. Stahl, P. Oster, J. Schudy, T. Tobie and B. Zornek, Gear Research Centre (FZG)

AGMA 925-A03 Predicted Scuffing Risk to Spur and Helical Gears in Commercial Vehicle Transmissions Dr. Carlos H. Wink, Eaton Corporation—Vehicle Group.

Micropitting—a Real Damage? Testing, Standards and Practical Experience Dr.-Ing. Toni Weiss and Dr.-Ing. Burkhard Pinnekamp, Renk AG.

Gear Lubrication—Stopping Micropitting by Using the Right Lubricant Michael Hochmann and Hermann Siebert, Klüber Lubrication München KG *Morphology of Micropitting* Robert L. Errichello, GEARTECH.

Session IV—Drive Design and Application

Longitudinal Tooth Contact Pattern Shift John Amendola, Sr., John B. Amendola, III and Dereck Yatzook, Artec Machinery *Convoloid Gearing Technology—The Shape of the Future.*

Bernard E. Berlinger, Jr. and Dr. John Colbourne, Genesis Partners, LP

Case Study Involving Surface Durability and Improved Surface Finish Greg Blake and Jeff Reynolds, Rolls-Royce

Gearbox Service Life—A Matter of Mastering Many Design Parameters Hans Wendeberg, SKF

Simulation of Wear for High Contact Ratio Gear—A Mixed FE and Analytical Approach, G. Venkatesan, M. Rameshkumar and P. Sivakumar, Ministry of Defense.

Bearing Contribution to Gearbox Efficiency and Thermal Rating: How Bearing Design Can Improve the Performance of a Gearbox, Armel Doyer, SKF.

Session V—Heat Treatment

Integration of Case Hardening into the Manufacturing-Line: "One Piece Flow," Dr. Volker Heuer, Dr. Klaus Löser, Gunther Schmitt and Karl Ritter, ALD Vacuum Technologies GmbH.

Induction Hardening of Gears with Superior Quality and Flexibility Using Simultaneous Dual Frequency (SDF), Christian Krause and F. Biasutti, eldec Schwenk Induction GmbH and M. Davis, eldec Induction U.S.A.

Controlling Gear Distortion and Residual Stresses During Induction Hardening, Zhichao Li and B. Lynn Ferguson, Deformation Control Technology, Inc.

Atmosphere Furnace Heating Systems, John Gottschalk, Surface Combustion, Inc.

Manufacturing and Processing of a New Class of Vacuum-Carburized Gear Steels with Very High Hardenability, Chris Kern, Jim Wright, Jason Sebastian and Jeff Grabowski, QuesTek Innovations LLC, and Trevor Jones and Don Jordan, Solar Atmospheres Inc.

September 19–24—EMO Hannover 2011. Hannover, Germany. Metalworking technology specialists will be front and center for six days at EMO Hannover 2011. More than 2,000 companies from 38 countries will be on-hand to show off products and services, spotlighting their performance capabilities. This year's EMO Hannover is presenting its products and events under the motto "More than machine tools." The trade fair puts special emphasis on machine tools, manufacturing systems, precision tools, automated systems, computer technology, industrial electronics and accessories and is sponsored by the VDW (German Machine Tool Builders Association). For more information, visit *www.emo-hannover.de*.

October 3–7—Basic Training for Gear Manufacturing. Richard J. Daley College, Chicago. This AGMA training course covers gearing and nomenclature, principles of inspection, gear manufacturing methods, hobbing and shaping. The course is intended for those with at least six months of experience in setup or machine operation. Classroom sessions are paired with hands-on experience setting up machines for high efficiency and inspecting gears. For more information, contact Jenny Blackford at *blackford@agma.org* or (703) 684-0211.

October 4–6—Rocky Mountain Gear Finishing School. Westin Westminster Resort, Westminster, Colorado. The Kapp Group is hosting this educational event that includes presentations, hands-on lessons, a facility tour and workshops designed to offer a deeper understanding of the progressive technologies applied to gear finishing processes. Attendees can bring their own applications to discuss, and meet experts in the field of gear finishing. Topics include the fundamentals of hard and soft gear finishing methods found in aerospace, automotive, marine, mining and wind energy applications; the benefits of using intelligent software; current trends on grinding automotive gears; machine setups, grinding and programming through real practice; the benefits of gear finishing performance with non-dressable tools; and how to select a finish process based on quality and application. To register for this event, visit *www.kapp-usa.com*.

October 17–27—Discover Mazak–Tomorrow's Technology Today. Florence, Kentucky. During Discover Mazak, more than 30 new machines will be featured, as well as a demonstration of Mazak's Production-On-Demand manufacturing plant, where 100+ models of machines are produced. This unique two-week event will welcome nearly 2,000 visitors from across North America to experience the latest machine tool innovations in advanced turning, milling and multitasking metal cutting solutions, including many forms of five-axis machining technologies. During the course of the event, visitors will have the opportunity to attend a variety of technology presentations, and experience real-world application machining demonstrations. Mazak experts, as well as the company's VIP technology partners, will also be on-hand to offer a variety of technology seminars and personalized consultation on manufacturers' unique challenges. Topics covered will include automation technology, industry-segment focused process development and manufacturing technology. For more information, visit *www.mazakusa.com*.

December 6–8—Gearbox System Design. Sheraton Sand Key Resort, Clearwater, Florida. The design of a gearbox system is much like a Hollywood movie production—the "stars" often get the recognition, while the "supporting cast" barely gets a mention! In a gearbox system, the stars are the gears and bearings. The supporting cast is everything else, including seals, lubrication, housings, breathers and other details. Explore the gearbox system supporting cast of characters at the Gearbox System Design Seminar. The treatment starts with basics, such as some history of design, the environment in which the gearbox must "live" and the loading to which the system will be subjected. AGMA member: $1,895 first registrant, $1,695 for additional registrants from same member company. Nonmember: $2,395 first registrant, $2,195 for additional registrants from same company. For more information, visit *www.agma.org*.

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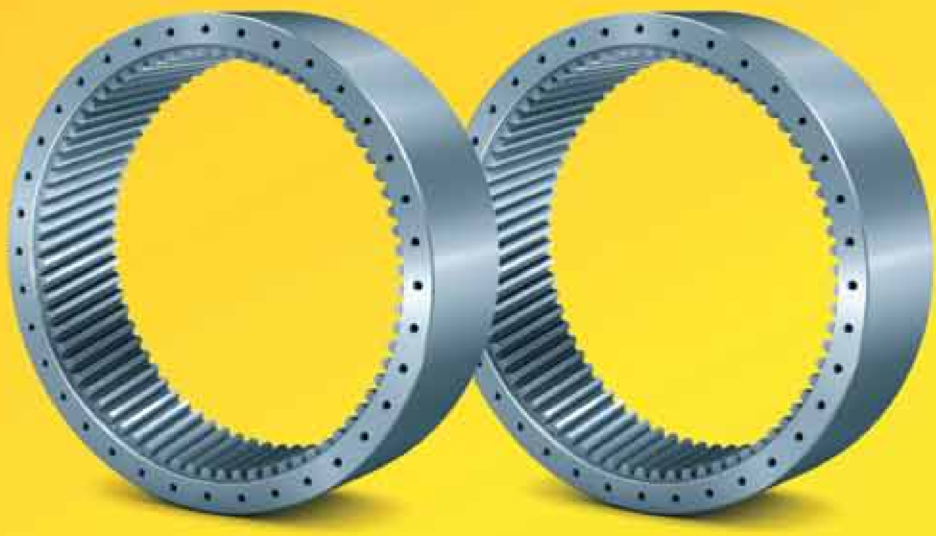

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EMAG

HIGHLIGHTS TECHNOLOGY AT EMO HANNOVER

The EMAG Group is spreading its products over three booths, demonstrating their whole range of multifunctional, future-orientated machining solutions for cubic, shaft-type and chucked workpieces at EMO Hannover 2011 from September 19–24. At Booth # C33, EMAG will present a vertical pick-up turning machine that was developed especially for the machining of small chucked and shaft-type components. The VT 2 is available in two different designs: equipped with pendulum technology for the highly productive machining of chucked components with a maximum workpiece diameter of 100 mm or equipped with a tailstock for the machining of shaft-type components with a maximum length of 400 mm. Booth # B54 will feature synchronous support grinding that radically changes the machining concept for balancer shafts, gear shafts, camshafts and crankshafts. From the complete machining of crankshafts in a single setup to the high-productivity manufacture of thin workpieces, synchronous support grinding offers a variety of machining possibilities.

Booth # G19 will have the VLC 250 WF turning, hobbing and deburring machine designed for wheel-shaped workpieces with a maximum diameter of 230 mm and Module 4. The machine offers its user flexibility, because it can be used as a hobbing machine, a single-spindle turning machine or a combination of both. Its main application is the precision machining of medium and large batches of geared components.

Earlier this year, the company hosted its two-day EMAG Technology Days event in Farmington Hills, Michigan. Michigan Congressman Gary Peters attended the event to view the industry's latest technologies. He received a tour of the EMAG shop floor, and learned about the new technologies from EMAG LLC, CEO, Peter Loetzner.

Congressman Peters also took time to address the attendees of EMAG Technology Days and gave a presentation on the importance of American-made new technology and manufacturing in Michigan. EMAG's Technology Days featured live demonstrations of turning and grinding, vertical pick-up turning machines and heavy-duty machining with presentations from EMAG, Sandvik Coromant, Koepfer, Schunk and others. The two-day event also featured discussions on the future of manufacturing presented by The Association for Manufacturing Technology (AMT) and an economic outlook from the Federal Reserve Bank of Chicago. For more information, visit *www.emag.com.*

Michigan Congressman Gary Peters spoke earlier this year at EMAG's Technology Days (courtesy EMAG).

The VSC DUO WF from EMAG features both gear turning and gear hobbing operations.

Ingersoll

BREAKS GROUND ON NEW ROCKFORD FACILITY

Ingersoll Cutting Tools is proud to announce the start of construction on a new facility at its Rockford campus. Following months of planning, one of the Midwest's

continued

oldest architectural firms, Tyson and Billy Architects, P.C., was selected to design the building. Rockford's very own Sjostrom and Sons, a design build contractor, will oversee the construction. The new building has been designed to blend with the steel and glass elements of the two existing headquarters buildings, located at 845 South Lyford Road, and will be prominently visible from Interstate 90. The construction of the third building reiterates Ingersoll's strong commitment to its employees, customers and the economic resurgence of the Rock River Valley. The new one-story facility will encompass 50,000 square feet (4,645 square meters) of space. It will house a highly automated, state-of-the-art product distribution center to serve the NAFTA market. The center will also allow Ingersoll to open up more production space in the existing buildings and expedite shipments to customers. Each year Ingersoll Cutting Tools hosts multiple training seminars, testing and demonstrations at its Rockford facility to keep end users and partners up to date with the latest metal removal products and applications. The new, well-equipped Technical Center will be used for these seminars which provide the knowledge required to maximize Ingersoll's product performance. The construction project is expected to be completed by March 1, 2012. For more information, visit *www.ingersoll-imc.com*.

Ridge and Peterson

JOIN WALL COLMONOY REBRANDING EFFORTS

Wall Colmonoy, a global materials engineering group of companies engaged in the manufacturing of surfacing and brazing products, cast products, turbine engine components and heat exchangers, recently unveiled a global rebrand initia-

AEROBRAZE
ENGINEERED TECHNOLOGIES

tive in support of the company's long-term growth strategy. The company's engineering expertise is seen throughout the aerospace, defense, automotive, oil and gas, glass, energy, food, marine, rubber and plastic industries. With more than 70 years in business, Wall Colmonoy recognized it was vital to communicate their full range of capabilities across a global platform in order to uniquely and credibly address their customers' evolving needs. Bill Clark, chairman and CEO, states, "In this highly competitive global marketplace, our business success depends on supporting our customers. As we continue to develop new products and technologies, the rebrand and enhanced communication will showcase our customized expertise that results in smart innovation and growth for our customers."


Ed Ridge

The company also recently announced the additions of Ed Ridge as chief operating officer for Aerobraze Engineered Technologies and Gary Peterson as operations manager at the Los Lunas, New Mexico facility. Ridge, a strategic business and tactical operations executive, has more than 25 years directing multi-site manufacturing organizations to increased efficiencies within a lean Six Sigma work environment. He also has a solid background in purchasing, materials management and quality control.

At Aerobraze, Ridge is building a cohesive leadership team and utilizing his expertise to execute a disciplined manufacturing and strict quality control process. He is focusing on technology, innovative applications and new product development, as well as playing an integral part in strategic collaboration with customers.

continued


Gary Peterson

Ridge previously led an international engineering company servicing the aerospace, industrial gas turbine and automotive markets. Earlier in his career, he managed a domestic high technology manufacturer of engineered metal products. He holds an MBA certificate from the United Kingdom's Cranfield School of Management as well as a BSME and a MSME from the University of Michigan. Achieving a Green and Black Belt Lean Six Sigma Certification, Ridge is well versed in securing and maintaining operational distinction.

Peterson is focusing on applying lean manufacturing practices and performance improving metrics at the Los Lunas facility. To keep pace with Wall Colmonoy's growth, he is facilitating the seamless introduction of new products into the work stream. A motivating team leader, he is also concentrating on increasing customer lead times and advancing service levels within all aspects of the plant. Peterson has significant experience working in the aerospace, defense and energy industries which afford him the insight to recommend innovative and cost-effective solutions for customers in these areas. Most recently a management consultant with Futuredge, LLC, Peterson consulted with clients in strategic planning, process re-engineering and supply chain management. His expertise in building supplier relations and driving manufacturing performance improvements also comes as a result of more than 20 years spearheading initiatives for key companies such as Thomas and Betts, CTS Electronic Components and Goodrich Aerospace. Holding a bachelor of science degree in business administration from Arizona State University, Peterson has achieved CPIM (Production and Inventory Management) certification and has Six Sigma CTS (Critical to Schedule) and Lean-Thomas and Betts training. For more information, visit *www.wallcolmonoy.com*.

Fozo

NAMED OPERATIONS MANAGER AT SOUTH BEND GEAR

Doug Fozo has been named operations manager for South Bend Gear, a new joint venture of Schafer Gear Works, Inc. with headquarters in South Bend, Ind., and Somaschini S.p.A. of Italy. South Bend Gear will produce gears for engines for


Doug Fozo

the heavy-duty truck market in North America. A new 50,000-square-foot plant is currently under construction on the Schafer Gear campus on Nimtz Parkway in South Bend. Production is scheduled to begin in late 2011 at 50 percent capacity and will reach 100 percent production capacity by the end of 2012. Fozo has been with Schafer Gear since 1993 and has held various management positions in both production and quality assurance, most recently serving as project manager. "Doug has shown us the extent of his capabilities over the past 18 years," said Bipin Doshi, president of Schafer Gear. "We are very excited for him to assume this leadership role at South Bend Gear." The new plant will employ 12 people in phase one and an additional 13 people, for a total of 25 people, when fully operational. The total joint venture investment is $18 million, including the new manufacturing facility. The plant will utilize the process technology developed by Somaschini S.p.A. in Italy with Schafer Gear managing the operations.

Romax Technology's Summit

OFFERS PRODUCT CONSULTATION

Romax Technology, a provider of bearing, gearbox and driveline systems using high performance software simulation technology, recently announced its European Summit 2011. The summit will appeal to seasoned *RomaxDesigner* or *RomaxWind* users across all industry sectors, and to manag-

continued

ers or prospective users wishing to gain an understanding of industry advances in design by simulation methods. The event will offer the opportunity to consult with Romax experts and network with industry experts and leading engineers working with Romax products to overcome the latest industry challenges. The summit will take place on October 4 at the InterContinental Hotel in Frankfurt. This year, as keynote speaker, Romax has lined up Professor Dr.-Ing. Augsburg of the Ilmenau University of Technology, head of department for automotive engineering, pro-vice-chancellor for research and chairman of the Green Mobility Innovation Center ThIMO, to deliver a lecture, "Efficiency of Rear Axles: Break Down of Losses and Rating of Optimization Approaches." As well as a host of technical presentations from experts at Romax, delegates will hear from some existing Romax software users including Renault, Getrag Ford and GKN Driveline on advances in gearbox and driveline design. Plus, partnering with Romax, Klingelnberg GmbH will deliver a presentation on bevel gear design and the significant new technical developments between the two companies. For those already members of the Romax user community, Romax is holding a User Advanced Master Class on October 5th. Here, you can learn and develop the latest advanced software techniques and discover new modules, features and improvements. The User Advanced Master Class is designed to be interactive so there will be opportunities for one-to-one question and answer sessions with Romax experts, and chances to discuss a particular issue or talk over a design scenario. Attendance at the Summit is free if you register before the end of August. For more information, visit *www.romaxtech.com/europeansummit*.

Reishauer

ANNOUNCES CORPORATE CHANGES

Reishauer AG, Wallisellen, Switzerland recently announced changes to their North American organization. As of September 1, 2011 Michael Engesser will assume the position of president of Reishauer Corporation located in Elgin, Illinois. Engesser previously held the position of chief marketing officer worldwide for Reishauer AG, he replaces retiring president George Wyss. "We thank George Wyss for his great contribution to the organization over the past 23 years and wish Michael continued success in his new position," says Dennis Richmond, vice president.

R and R Associates

REPRESENTS RITEN INDUSTRIES

Based in Westville, New Jersey, R and R Associates has been selling and servicing major cutting tool and workholding product lines since 1983. The agency was recently appointed to market Riten's line of live and dead centers, face drivers, and engineered workholding products in Pennsylvania, Maryland, New Jersey, Delaware and metro New York. The R and R team includes six outside sales reps and four inside sales associates. They are known and respected for proactive technical support to industrial distributors, OEMs, and dealers in machine tools, workholding products and tooling.

Kapp

OFFERS ROCKY MOUNTAIN GEAR EDUCATION

The Kapp Group is hosting its Rocky Mountain Gear Finishing School from October 4–6 at the Westin Westminster Resort in Westminster, Colorado. This educational event includes presentations, hands-on lessons, a facility tour and workshops designed to offer a deeper understanding of the progressive technologies applied to gear finishing processes. Attendees can bring their own applications to discuss, and meet experts in the field of gear finishing. Topics include the fundamentals of hard and soft gear finishing methods found in aerospace, automotive, marine, mining and wind energy applications. To register for this event, visit *www.kapp-usa.com*.

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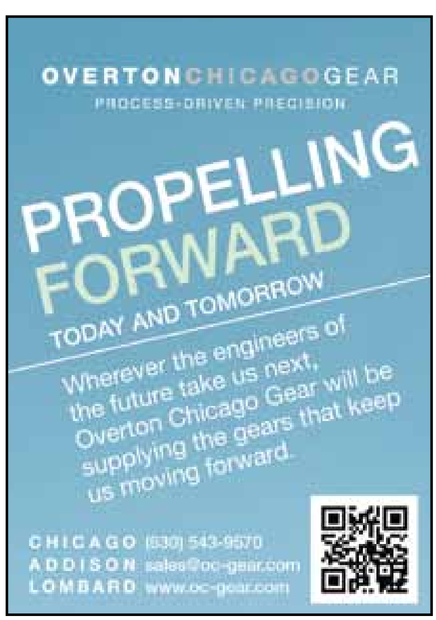


SERVICE

Brick by Brick

Lego Inspires Next Generation of Engineers, Manufacturers and Scientists

Harry Potter, Luke Skywalker, Indiana Jones and Captain Jack Sparrow have all been immortalized in Lego play sets. It's really no surprise since kids love those characters just as much as they love their Legos—an estimated 400 billion Lego bricks were manufactured by 2008 according to the company's website. But did you know that teachers, scientists and engineers might be even bigger fans of the world's most famous building blocks?

Take the recent spacecraft launch to investigate Jupiter, for example. NASA didn't invite Barbie, Mr. Potato Head, or a Slinky to hitch a ride, but they did send up three unique Lego figures—The Roman God Jupiter, his wife Juno and Galileo. "NASA has a long standing partnership with the Lego Company," says Scott Bolton, principal investigator for the Juno mission and space science and engineering director at the Southwestern Research Institute in San Antonio. "We hope that these [Lego figures] will increase awareness about the space program and get children interested."

Back on Earth, Lego bricks have been educating young engineers and manufacturers since 1982 when the first two Lego Technic sets were launched for classroom use. Today, the company boasts Simple and Powered Machine sets (exploring gear mechanisms with assorted gear wheels), Renewable Energy sets (building and exploring renewables through Lego models) and Robotics sets (incorporating software and bricks to bring robotic experiments to life). The company offers to send mini-figures to Jupiter as well as countless building block sets to engineering competitions like the FIRST Lego League (FLL).

"FIRST Lego League was developed in 1998 to introduce young people ages 9-16 to the fun and excitement of science and technology. It consists of three parts: A Robot Game, Project and Core Values. In the Robot Game, children use the Lego Mindstorms and Lego elements to create an autonomous robot that is programmed to perform various missions on a playing field," says Kim Wierman, Program Manager, FIRST Lego League.

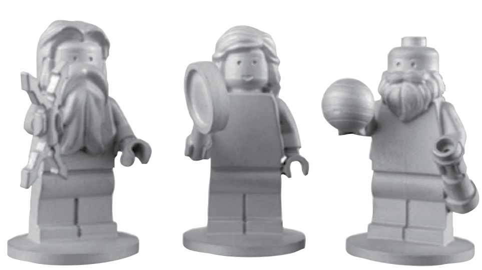
Wierman says the impact of FIRST Lego League has been tremendous around the world. "For the Food Factor season (The 2011 theme is food safety), we expect 20,000 teams to compete in more than 700 tournaments around the world. Approximately 200,000 children will participate. Through a study by Brandeis University it was determined that FIRST Lego League participants have an increased understanding of science and technology, improved attitudes toward education in general, and improved life and workplace-related skills."

This is occurring at a very important time for manufacturing, science and engineering education as many students initially scoff at the notion of getting their hands dirty after college in some of these fields. So what can the manufacturing community do to assist organizations like FIRST help get the message out?

"They can offer their time and expertise. There are many different roles volunteers can fill," Wierman says. "Currently, FIRST is supported by a large body of volunteers. Each year more than 90,000 people around the world help by coaching or mentoring a team, hosting or organizing events, and fundraising. In addition, FIRST has several strategic partners and more than 3,500 of the world's leading corporations, foundations and government agencies supporting its mission."

For more information on FIRST and its many innovations using Lego sets for engineering competitions, visit *www.usfirst.org*. For information on classroom Lego sets, visit *www.education.lego.com*.

FIRST Lego League Robots have increased the understanding of science and technology for students around the world (courtesy of FIRST).



Lego versions of the Roman god Jupiter, his wife Juno and Galileo were recently sent into space on a fact-finding mission to Jupiter (courtesy of Lego).

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