GEAR TECHNOLOGY

August 2009

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The Journal of Gear Manufacturing

25 YEARS 1984-2009

Productivity

Features

- Lean Strategies for Lean Times
- Gear Expo 2009—All Roads Lead to Indy

Technical Articles

- How Axle Deflection and Tooth Flank Modification Affect Gearing
- CFD Analysis of Gearbox Windage Loss

Plus

- Addendum: Gears and Sweet Science

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GEAR TECHNOLOGY

August 2009

C O N T E N T S

FEATURES

TECHNICAL ARTICLES

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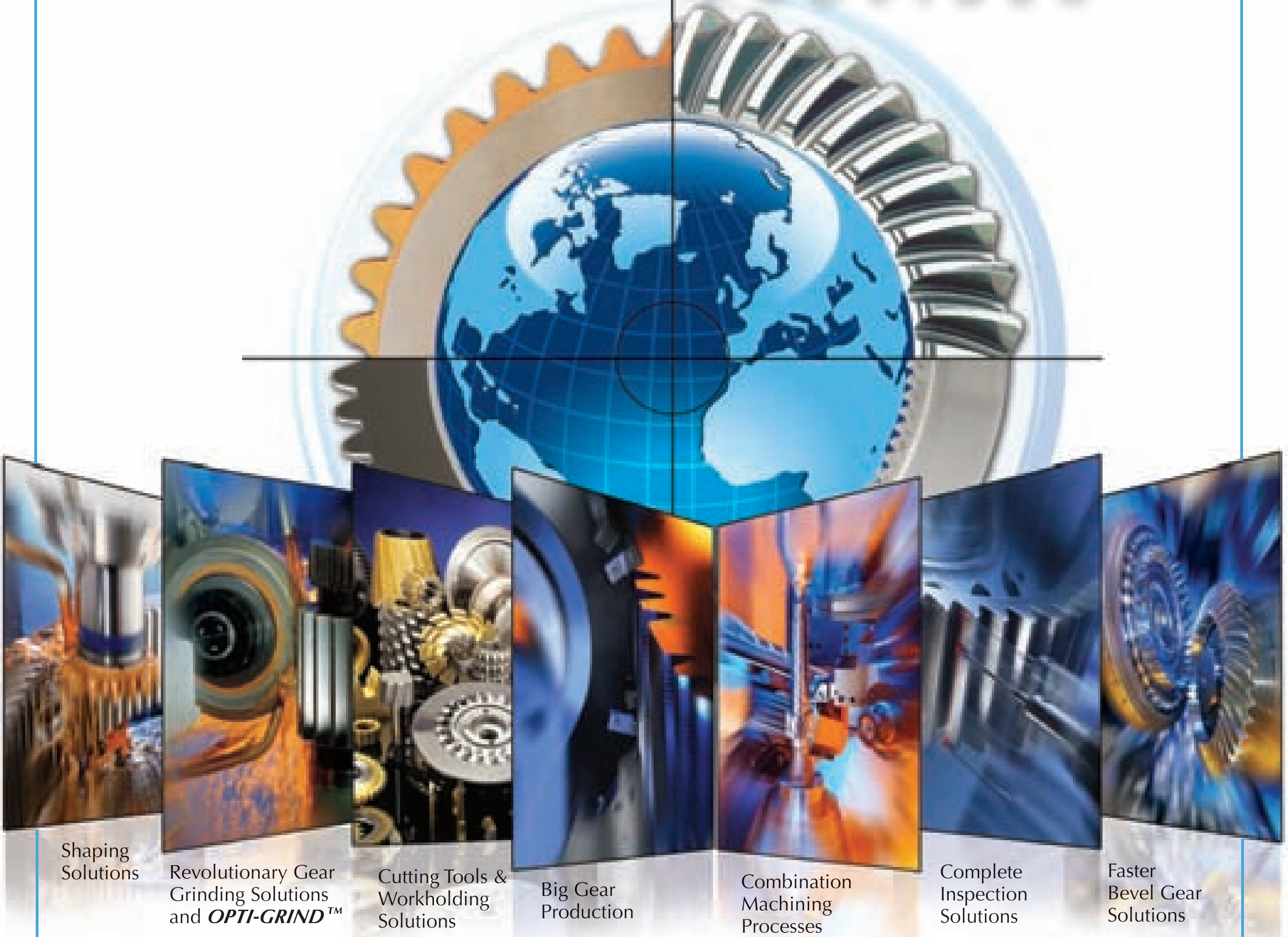

Shaping Solutions
Revolutionary Gear Grinding Solutions and *OPTI-GRIND*™
Cutting Tools & Workholding Solutions
Big Gear Production
Combination Machining Processes
Complete Inspection Solutions
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Top 10 Reasons You Should Go to Gear Expo

Let's face it. It's been a bummer of a summer economically speaking. Orders have been cancelled, and many in our industry have been forced to cut back, slow down or shut down, either temporarily or permanently.

It doesn't seem like the ideal time for a trade show, does it? But Gear Expo is coming to Indianapolis September 15–17, and there are plenty of good reasons to go:

1. You Can Never Stop Learning. I've said this before, and I'll say it again. At Gear Expo, you will find the greatest collection of gear knowledge assembled under one roof. If you attend the show, you'll have the opportunity not only to see the latest technology, but to talk to the people who design, manufacture, sell, install, service and repair gear manufacturing equipment. You'll also have access to the experts in cutting tools, heat treating, inspection and every aspect of gear manufacturing and processing.

2. New Technology for Invigorating Your Business. We've heard from a number of exhibitors who will be demonstrating new technology at the show. You can get a sneak peek at some of this technology by reading our pre-show coverage starting on page 30 and by reading next issue, but to get the full benefit, you have to go to the show, kick the tires, talk to those experts and find out how the changing technology can benefit you. I promise you this: There are solutions at Gear Expo that can help your company improve its gear manufacturing operations.

3. Time Is on Your Side. I don't want to insinuate that you have nothing better to do, but when business is slow, there probably isn't a line of customers waiting for their orders to be filled or phone calls to be returned. I know some of you are probably doing twice the work in order to save your company money, but when business is really good, you're probably tempted to say you can't afford to get away. Turn this lull into an opportunity—make the most of what Gear Expo has to offer.

4. Bonus Learning at the Fall Technical Meeting. AGMA's Fall Technical Meeting takes place September 13–15, with the last day overlapping the first day of Gear Expo. Almost 20 papers are scheduled to be presented on gear design, manufacturing, inspection, heat treating, materials and applications. For a full description of the Fall Technical Meeting, see page 34.

5. The Heat Treating Show. Gear Expo 2009 is co-located with the Heat Treating Society Conference and Exhibition. If heat treating processes are part of your operations, or if you send parts out for heat treating, more than 180 additional exhibitors will be available at the show next door.

6. Did I Mention Learning? In addition to AGMA's Fall Technical Meeting, there will be a number of additional seminars held at the same time. Presented by AGMA, SME and ABMA, these events require a separate admission but provide plenty of extra learning opportunities. AGMA will present a seminar on the wind turbine supply chain, as well as the classroom portion of the "Basic Course" of its Training School for Gear Manufacturing. ABMA will present "Why Bearings Fail," and SME will hold a two-day Gear Manufacturing Conference, featuring 14 presentations from industry experts. Gear Expo presents a unique opportunity to spread knowledge throughout your organization. Owners, managers, engineers and productions workers—everybody in your gear-related operation can become a more valuable employee by taking advantage of the learning opportunities at Gear Expo.

7. Networking. Everybody who's anybody in the gear industry is going to be at Gear Expo. You'll have the chance to meet your peers, discuss common problems and explore new opportunities. Nothing beats face-to-face communication.

8. Indianapolis. Indianapolis has many advantages over other locations where Gear Expo has been held. Indianapolis is within driving distance for much of the American gear manufacturing industry. Chances are, a bunch of you can hop in a car and see what the show has to offer. The last time the show was held in Indianapolis was 1995, and it was one of the best shows ever, both for attendance and for the overall amenities the city provided.

9. There are Deals to Be Had. All of the exhibitors are eager for your business. It's been a slow year for them too. If you have the ability to invest in new equipment and your business could benefit from the latest technology—and you want a great deal—this is the right time.

10. Free Espresso and Coffee. Once again, *Gear Technology* will have its coffee bar. Along with Goldstein Gear Machinery, we will be serving free espresso and cappuccino. Stop by and see us at booth #1241.

Michael Goldstein,
Publisher & Editor-in-Chief

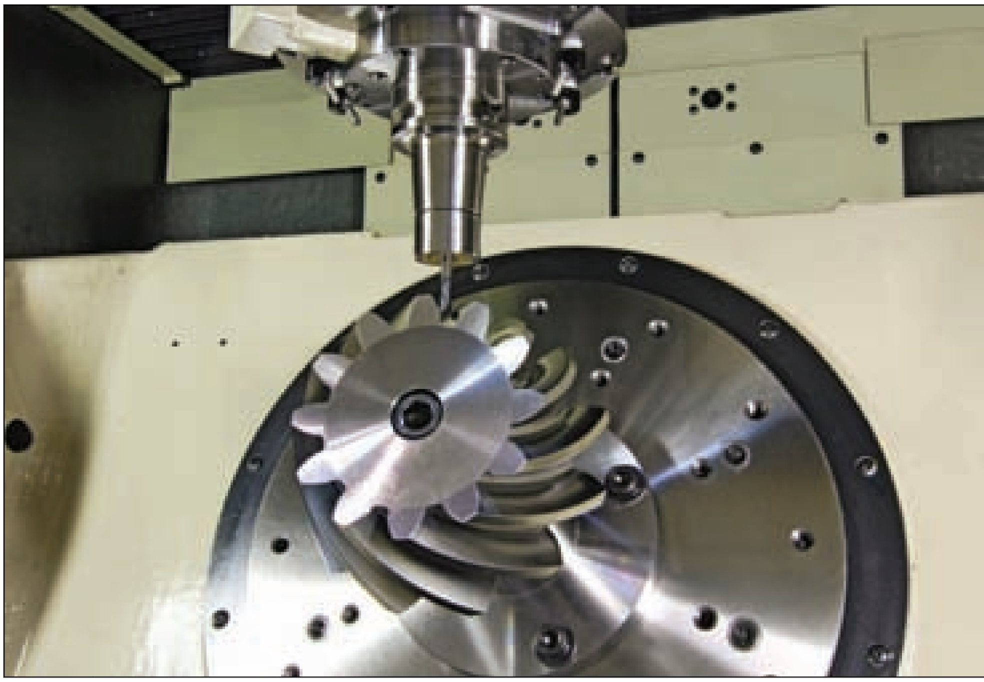
Mitsui Seiki Machines

CUT SPIRAL BEVELS

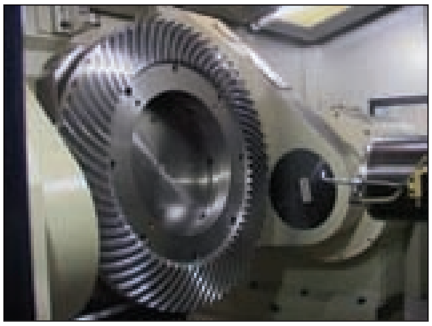
Several customers of Mitsui Seiki USA have reported success cutting 10–14 class ring gears in low- to mid-volume applications, such as for aerospace and power generation, using CNC vertical and horizontal machining centers. The company's Vertex machine is capable of cutting ring gears up to 16 inches. A gear making model of the machine features a trunnion table for the finish turning operations.

"This machine can turn the gear faces, the final profile of the internal bore and generate the gear teeth," says Mark Speier, sales engineer at Mitsui Seiki.

On the HU80A-5X, one of Mitsui Seiki's largest five-axis centers, customers are manufacturing gears up to 35 inches. "One of the benefits of producing gears on that machine is that the relative gearboxes or gear cases, and even reduction gearboxes, can also be processed on this one machine," Speier says. "The gear housing is a critically precise piece. The accuracy of both parts has a direct correlation to the transmission performance over the life of the motor. The end product reliability is a positive factor, too. Further, the gear is mounted flat and then turned up 90 degrees—or another angle—so that the end mills can cut at the optimum attitude to the gear profile. This results in excellent roughing efficiencies. For finishing, the ball nose end mills generate the final profile before heat treating."



The Vertex five-axis machine cuts spiral gears up to 16 inches.



The HU80A-5X horizontal machining center cuts gears up to 35 inches by mounting the gear flat and then turning it up in an angle, so the end mills can cut at the best attitude to the gear profile.

Initially, Mitsui Seiki experimented in gear cutting by cutting the teeth, roughing and semi-finishing operations before heat treating. By adding turning operations to the Vertex machine, all the operations' accuracies have improved through the single setup. Turning is not yet available on the HU80A-5X, but Mitsui Seiki expects it will be in another six months.

"The traditional gear cutting machines may run faster; however, [with] the tooling economics, improved accuracy through one-setup machining and improved process control, the overall cost may be advantageous, especially in low volume runs," Speier says. "Plus, this application may enable our current gear making customers to get more use out of their Mitsui Seiki five-axis machining centers. Our knowledge base is growing exponentially in this area."

The Mitsui Seiki machines wouldn't be cutting gears successfully without the software. The company has partnered with *Mastercam* developers CNC Software, Inc. in this venture for generating the tool paths for spiral bevel gear cutting.

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Franklin Lakes, NJ 07417
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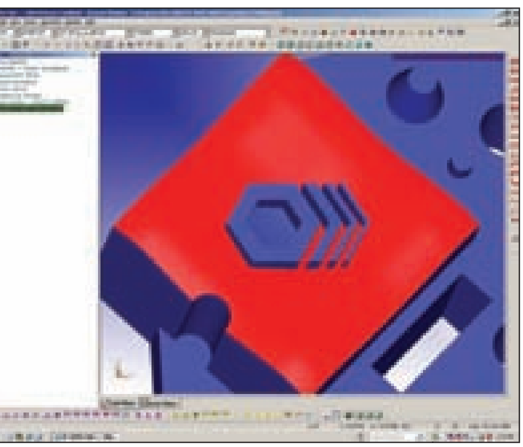
Wilcox

ROLLS OUT ENHANCED CAD METROLOGY SOFTWARE, INTROS STAND-ALONE MODULE



Sold under the banner of Enterprise Metrology Solutions (EMS), the *PC-DMIS 2009* is the latest version of the CAD-based metrology software from Wilcox Associates, a Hexagon Metrology company. The upgrade enhances the pre-existing *PC-DMIS CMM* and *PC-DMIS Vision* software while introducing *PC-DMIS Planner* and *PC-DMIS Reporting* suites. The software suite also includes NC and Portable modules.

"*PC-DMIS 2009* is a very significant release for Wilcox," says Ken Woodbine, president of Wilcox Associates, Inc. "Far from being simply an incremental release of *PC-DMIS, 2009* is the culmination of development projects we have been working on for several years, and represents the tightest integration yet of the product suite. It also brings together new hardware categories that have been added to the Hexagon Metrology group since the last major release of *PC-MIS*. The… machine tool probe integration with *PC-DMIS NC* for CNC machine tools is one of the most significant."

The *PC-DMIS CMM* is considered the core product of the 2009 upgrade. It is used mostly on automated CMMs and is now equipped with functional and visual improvements. One new feature is the protected mode execution, a run-only mode with password protection against any editing, program changes or reports. This feature is designed for companies that have a library of programs and don't want operators altering them, like those with medical certification requirements.

The *PC-DMIS Vision* upgrade features a MultiCapture technology that automatically locates several features, such as holes, slots and edges within the same view field and measures them simultaneously. It functions as the default setting for the software and can typically improve measurement productivity by 35 percent. *Vision* includes a feature that allows operators to adjust RGB pixels, so for a colored part with edges that are difficult to detect on a grayscale, users can increase the contrast and detect edges more clearly.

The visual programming improvements allow users to see specific move paths before and after a chosen feature; visualize and animate the machine's working volume within a model view; and observe translucent clearance plane. The grid view was expanded, so points are defined at any cross section automatically.

Support for geometric dimensioning and tolerancing is improved in the 2009 upgrade. It includes support for ASME and ISO and more options. Measurement capabilities for non-contact 3-D laser probes include laser stripe display, measured features and points. Laser hole measurement is also a new feature.

The *PC-DMIS 2009* is available with new machines under the brand banner of Hexagon Metrology, Brown and Sharpe, DEA, Leitz and Sheffield. It can be retrofitted as a software upgrade for most other CMM makes and models. Existing customers who have current software maintenance agreements are eligible for a free upgrade.

Wilcox also recently introduced the *PC-DMIS Reshaper* software module, which is a standalone product and is not included in the 2009 upgrade; however, Wilcox has future plans for it to be available in the core product suite eventually. The *Reshaper* is a program designed for 3-D point-cloud processing. It collects and imports 3-D point data for manipulating and processing in downstream processes, like CAD modeling, CAM or rapid prototyping.

PC-DMIS Reshaper collects data live, via direct connection to a digitizing device—a Romer portable measuring arm is one example—or the software collects data offline through file import. It is compatible with more than a dozen 3-D data file formats, including STEP, IGES, ASCII, DXF, DMIS, ISO and RAW.

The *Reshaper* quickly converts cloud to mesh with proprietary polygon organization algorithms that produce lightweight file size models. Point clouds can be imported without file size or point quantity limitations. They are cleaned, merged and edited from the user interface. Hole filling, deformation and smoothing the mesh models are examples of further manipulation the *Reshaper* is capable of.

"*PC-DMIS Reshaper* is an excellent package for the user who wants to do a relatively discrete set of tasks, namely collection and cleanup of point clouds, and quickly getting them into a format that can be taken to the next stage in the development process," Woodbine says. "It has a short learning curve and is very intuitive to use. At the moment, *PC-MDIS Reshaper* is a standalone module, but in time, we will be incorporating elements of the technology into the core *PC-DMIS* product suite."

For more information:

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North Kingstown, RI 02852
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info@hexagonmetrology.us
www.hexagonmetrology.us

Grieve Hearth Oven

STABILIZES MATERIAL FOR PERFORMANCE

The number 815 electric rotary hearth oven, from Grieve Corporation, is currently being used by a customer to preheat various gears, usually steel and sometimes aluminum, before assembly operations.

The dimensions of the unit's interior measure 76" wide x 76" deep x 24" high. A 72" diameter rotary hearth is made from angle rings with 90 1-3/8" wide x 1-3/8" long x 3-5/8" high slots that hold the workpieces on edge during processing. A 1/4 hp motor drives the hearth through a gear reducer with a torque limiting device. Each time the loading door is opened and closed, the hearth indexes one position, which signals a long dwell time.

The long cycle preheating suggests the customer is using the oven to stabilize material by preheating it, according-

continued

ing to Frank Calabrese, vice president for sales and marketing. The hearth oven can also be used, for example, to preheat gears prior to motor assembly, so they shrink fit into a shaft. The 815 could also be used to preheat gears before working them into an assembly, Calabrese says.

A vertical, downward airflow over the workload is achieved by two 2,000 CFM, two-hp recirculating blowers. The 815 features special safety equipment that handles flammable solvents, which includes a manual reset excess temperature controller, separate heating element control contactors, a 325 CFM powered exhauster and purge timer. The 815 is constructed of aluminum steel and has 4" insulated walls.

For more information:

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500 Hart Road
Round Lake, IL 60073
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Fax: (847) 546-9210
sales@grievecorp.com
www.grievecorp.com

Sandvik

SECURES HEAVY ROUGHING

The Hydro-Grip HD is an extension of the Hydro-Grip tool line designed to perform securely in heavy roughing applications.

The Hydro-Grip HD provides a high clamping force and torque transmission, which benefits solid carbide end mill, drill and reaming tool performance. The tool is equipped with damping features that minimize vibrations during machining.

Cylindrical shank tools are clamped with a symmetrical force to keep tool runout to a minimum and allow for the high torque transmission. The chucks are balanced to G2.5 for speed. The Hydro-Grip HD is based on hydraulic tool clamping systems and can be adjusted with a torque wrench. There is no external equipment necessary in the clamping. The Hydro-Grip line of toolholders is used in applications ranging from finishing to heavy roughing bores from 0.236" to 1.26".

For more information:

Sandvik Coromant Company
1702 Nevins Road
Fair Lawn, NJ 07410
Phone: (201) 794-5223
Fax: (201)794-5217
www.coromant.sandvik.com/us

Zeiss Accura CMM

RAMPS UP SPEED, PROTECTION

In response to customer feedback, Carl Zeiss Industrial Measuring Technology (IMT) developed the Accura, a multi-sensor capable measuring system that allows for quick, economical, precise and flexible measuring.

The Accura features a thin, rigid measuring machine bridge constructed from steel and aluminum components, which are coated by CARAT (coated aging resistant aluminum technology). The moving parts are lightweight, so the CMM achieves a maximum vectorial travel speed of 800 mm/s, contained in the Performance Package.

Due to the increase in speed, Carl Zeiss has equipped the Accura with added protection features. The Performance Package also contains a special safety system with laser scanners that supervise the protection zone around the machine when it's in high-speed mode. Speed is automatically reduced within a second if the safety

continued

system detects movement in this zone, and it automatically picks back up once the area is clear.

The active performance of the bridge is enhanced by air bearings with a thinner air gap, so they are more rigid and need less compressed air than other bearings. The bridge is also protected by foam insulating technology that allows the housing covers to resist temperature. The Accura maintains the same level of precision when operated between 20 and 26 degrees Celsius.

The standard CAD-based measuring software Carl Zeiss offers is integrated with *Gear Pro* and *NT* for freeform surface measurements. The Accura is available in four sizes, the smallest of which measures 900 x 1,400 x 800 mm with a linear measuring tolerance of 1.6 µm + L/333

For more information:
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6250 Sycamore Lane
Minneapolis, MN 55369
Phone: (763) 744-2400
Fax: (763) 533-0219
www.zeiss.com/imt

Solar Furnace

INSULATED WITH EIGHT LAYERS FOR ENERGY EFFICIENCY

A custom sintering vacuum furnace capable of an operating temperature of 1,800 degrees Celsius was recently shipped to a customer in the aerospace and defense industries by Solar Manufacturing.

The hot zone dimensions of the model HFL-5748-2EQ are 36 inches wide x 36 inches high x 48 inches deep. Since the customer required such a high temperature with uniformity, the hot zone is insulated with eight layers of 0.5 inch-thick, high purity graphite felt, which makes it more energy efficient. A hot face of 0.040 inch-thick Flex Shield, a flexible carbon fiber reinforced graphite foil, protects the insulation pack. The hot zone has thin graphite heating elements mounted cylindrically inside and divided into several trim zones. The hearth has a weight capacity of 2,000 pounds.

Other features include the SolarVac 3000 control system, a high-capacity copper heat exchanger, 150 hp drive motor and a radial blade fan for high velocity gas quenching through "forward tapered" graphite nozzles. The front door uses a pneumatically operated, locking ring closure for positive pressure quenching to 15 psig (2 bar). High vacuum performance of 1 x 10^{-5} Torr is possible because of a 20 inch Varian diffusion pump.

"Our customer needed a robust vacuum furnace to sinter heavy tungsten alloys at very high temperatures," says Pete Reh, vice president of sales for Solar. "We demonstrated that our vacuum furnaces can achieve high performance operation with low cost of ownership through the use of state-of-the-art-materials."

Solar also recently delivered an R&D vacuum heat treating furnace for use in the metallurgical development lab of a specialties metal industry customer. This furnace will be used for steel, low pressure vacuum carburizing, magnetic metal developments, alloy testing and process development.

The horizontal, front loading model HFL-2624-10IQ furnace has a work zone 18 inches wide x 14 inches high x 24 inches deep, work load capacity of 750 pounds and maximum operating temperature of 2,400 degrees Fahrenheit meeting AMS 2750D tem-

continued

perature uniformity. The furnace is designed for 10 bar fast gas quench by incorporating Solar's proprietary design radial fan and gas diffuser/distributer, which features an internal 100 hp drive motor and a locking ring, O-ring sealed, autoclave front door. Instrumentation includes vacuum controls, Honeywell temperature control/programming, Allen Bradley PanelView and Eurotherm high speed digital display recorder.

For more information:
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info@solarmfg.com
www.solarmfg.com

Tyrolit Grinding Wheel

ACHIEVES MAX PROFILE RETENTION WITH MINIMAL WEAR

The CSS Ultra grinding wheel from Tyrolit features a restructured micro architecture that allows for high profile retention with minimal wear. It avoids the erosion that often occurs between the grain and bond structure and the grinding area in high-performance grinding applications where heat builds up.

Tyrolit has tested the product in O.D. cylindrical, O.D. plunge, O.D.

inner raceway and O.D. spherical roller path grinding applications and reported positive results. Areas of improvement in grinding performance include abrasive usage per piece, an increase in the amount of parts per dress and a reduction in cycle times per part. The CSS Ultra grinds with lower cutting forces, so improved geometry occurs. Other benefits include less wear to the abrasive grain, high profile retention and cooler grinding, which reduces the chance for burn.

Tyrolit is targeting the CSS Ultra to the automotive, bearing and tooling industries as well as job shops complementing these industries. The grinding wheel is suitable for use on crankshafts, camshafts, cv joints, drive shafts, tracker inner rings, flange inner rings, nozzle pins, cylindrical rollers, taps and tension screws.

For more information:
Tyrolit LLC
3010 Disney Street
Cincinnati, OH 45209
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Fax: (513) 458-8232
www.tyrolit.com

Cimcool Fluid

APPROVED BY BOEING FOR AEROSPACE APPLICATIONS

The Cimcool Cimtech 46C metalworking fluid has received Boeing approval under BAC 5008REVr-Areas five and six, including titanium alloys. The approval number is Boeing PSD 6-134.

The metalworking fluid is recommended for moderate duty grinding of hard metals like cobalt, Stellite and titanium alloys, including chrome plated and HVOF thermal spray coating components.

Cimtech 46C is very clean and has high foam control. It can be maintained easily and allows for odor control and a long sump life. It is resistant to depletion and reduces the amount of concentrate required for makeup, saving on costs. It also features a proprietary blend of inhibitors that protect ferrous machine tool components and mini-

continued

mize dissolved cobalt in solution.

Cimtech 46C is low misting without smoke or leaving parts, machines and surrounding areas with an oily film. It is a clear mix and rejects tramp oils for easier removal by oil-skimmers. This Cimcool fluid joins three others approved by Boeing. Cimcool offers a free trial to interested customers.

For more information:
Milacron Marketing Co.
3000 Disney Street
Cincinnati, OH 45209
Phone: (888) 246-2665
Fax: (800) 205-3293 or
(513) 458-8298
www.cimcool.com

Kinefac Centrifuge

CLEANS PARTS WITH 350 GS FORCE

The 601 Versafuge from the Kine-Spin/Barrett Division of Kinefac is designed for fluid cleaning, chip wringing, sludge drying, parts cleaning and washing and drying. The centrifuge uses a cleaning force of 350 Gs for greater range in fluid reclamation and part cleaning potential than other single machines of its size.

The Versafuge has a 10-gallon bowl for fluid reclamation in process lubrication and cooling systems. It is capable of handling 130 pounds per load of chips and swarf. The Versafuge features a touch screen control, an out-of-balance safety system, a safety lid latch and optional hoist and bucket dump units. It is small enough to sit near the production operation it supports.

The Kine-Spin Barrett Division can supply part racks, special bowls, baskets, heaters, pumps, tankage and other ancillary devices as well as application validation by lab tests at the Kinefac facility.

For more information:
Kinefac Corporation
Kine-Spin/Barrett Division
156 Goddard Memorial Drive
Worcester, MA 01603
kvuona@kinefac.com
www.barrettinc.com


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Thanks to lean principles, an operator in Colonial's spline department can run three machines at once, including two CNC spline grinders and a manual grinder (courtesy of Colonial Tool Group).

Steadfast & Streamlined

CAN LEAN SOFTEN THE ECONOMIC BLOW?

Matthew Jaster, Associate Editor

Two high-volume gear production cells grace the shop floor at Delta Research Corporation in Livonia, Michigan. Thanks to lean manufacturing, these cells have never shipped a defective part to a customer since they were developed over three years ago. With the help of robotics, conveyors and an efficient organizational process, the pieces are turned, hobbed, gear ground, cleaned, roll-tested and laser marked completely hands-free. They are poka yoked and sent through a Production Part Approval Process (PPAP). Delta employees merely need to "check-in" once in awhile on the work before shipping—typically ahead of schedule—to the final destination. Lead times were shortened and the automated assembly process has been a complete success as far as sales and project manager Tony Werschky is concerned.

These cells were put in place at Delta Research when the company expanded its lean manufacturing initiatives. They are a big reason it has been able to survive and prosper in Michigan, where the industrial and manufacturing sector has seen better days.

"Growth must be calculated and conducted in a way that prevents you from creating volatile periods in your company's business cycle," Werschky says. "Our lean programs have kept us from over-hiring, losing sales volume and then shedding employees just to survive. We have seen minimal changes in net income as a result of lean processes."

These processes have been discussed before in *Gear Technology*, where many a Publisher's Page and feature article have addressed the

continued

importance of lean manufacturing. Call it overkill or simply a bias toward systems that seem to work, but there's truth behind all the rigmarole. Recent economic activity, or lack thereof, has only solidified the benefits of lean.

If your organization neglected to implement some kind of lean strategy before the economic downturn, it might be in worse shape today than it needed to be. Sure, it's been rough out there, with higher production costs and a significant drop in orders, but the companies that have actively pursued lean manufacturing seem to be in a better position than those that failed to implement these strategies prior to 2008.

How the Commitment Pays Off

"The pursuit of lean principles is more important now than ever before," says Jim Sonderman, consultant for the Lean Learning Center in Novi, Michigan. "Those companies that pursued a lot-size reduction strategy through faster setups prior to the economic downturn are better positioned from an inventory perspective and have less cash tied up in unsold product."

Sonderman says that focusing on waste elimination is critical, especially during times when recovery must be swift and problems should have been resolved years ago.

One of Schafer's many manufacturing cells are marked on the floor to maintain lean guidelines throughout the shop (courtesy of Schafer Gear).

Colonial has put two conventional universal grinders and one CNC universal grinder in the same work area as a lean initiative. A jib crane was added for ease of handling (courtesy of Colonial Tool Group).

"Many companies are in survival mode, slashing manpower and cutting costs wherever they can just to stay afloat. They are simply trying to weather the storm without wrecking the ship," Sonderman says.

"Labor has been terribly affected. We have seen even the leanest manufacturers reduce manpower through temporary layoffs and reduced work hours to accommodate for the decline in customer demand," Sonderman says. "For most companies, it's a matter of survival. Those that have flexible workforces and processes as a result of standard work, cross-training and cellular manufacturing can adjust faster to the variations in customer demand."

Keeping a staff trained on how to identify and eliminate waste is half the battle, according to Sonderman.

"One particularly nasty side effect is the brain drain. When highly-talented employees are temporarily or permanently let go, the factory floor has difficulty with solving problems. The companies that spend considerable time and effort on coaching and mentoring all employees through structured problem solving activities are able to recover quickly, even in crisis," Sonderman says. "The companies that consider employees as simply a means to an end will be plagued with chronic problems that affect quality, delivery and cost."

While industries like agriculture and food are somewhat recession proof, manufacturing, particularly automotive, has been devastated from the recent economic collapse.

"Many companies are in survival mode, slashing manpower and cutting costs wherever they can just to stay afloat. They are simply trying to weather the storm without wrecking the ship," Sonderman says.

Fortunately, there are companies within the gear industry that have benefitted greatly from lean. Whether it's simply faster deliveries, more organized shop floors or an overall lean philosophy throughout the organization, success stories have prevented some of the bleeding.

Colonial Tool Group, located in Windsor, Ontario, has done quite a bit of work involving machining cells to increase productivity, incorporating some basic lean manufacturing techniques into the day-to-day routine with substantial results.

"We've placed machines so one operator can utilize between two to three machines at one time, depending on the operations," says Chris Scott, plant manager. "We've also installed better hoists to make it easier and safer to load and unload work pieces."

These simple practices have tightened up many of the processes at Colonial, allowing an operator to run a CNC grinder and universal grinder at the same time. With the addition of a jib crane for ease of handling, the staff can do more in their allotted work space.

Scott says that implementing lean has allowed Colonial more flexibility for scheduling and for making faster deliveries, not to mention the reduced costs for the manufacturers.

"The economy has been very slow for the past several months and we have been working reduced hours," Scott says. "Lean has helped us with shortening our required times to manufacture."

The company deals mainly with broach and spline racks, building spindles and machines. They've been working on different lean scenarios not only to adjust to the current market, but in preparation for the often-discussed economic rebound.

"The manufacturing processes that are used for most industries can benefit if people have an open mind to the necessary changes that must be made to increase productivity," Scott says. "Most of our employees have bought into this idea and are key to its development."

In order to present lean initiatives to the staff, Scott conducted a presentation for the proposed changes and also conducted lean groups to gain employee feedback and buy-in—the same sort of communication that has made lean a success at Delta Research and Tifco Gage and Gear.

Werschky has seen lean principles increase profitability and reduce losses by eliminating excess overhead costs, employee costs and work-center foot prints.

continued

Schafer Gear demonstrates how the 5S strategy keeps its work stations organized and efficient. The gages missing at this station have a replica photograph under the plexiglass (courtesy of Schafer Gear).

"Our cross-training program has allowed us to transfer company personnel from one department to another seamlessly," Werschky says. "This has kept us from having to layoff personnel."

And during slow periods, the company has been able to move forward thanks to the lean practices that were implemented years ago, like buying into new technology to cut downtime on the production floor. Capital investments in new high-speed gear grinders and hobbers, ring-loaders, conveyors and robots will allow for greater speed, efficiency and ergonomics in the near future.

"We expect these machines to be used for small- to medium-volume gear projects for electric vehicle transmission, defense work and off-highway applications," Werschky says.

These investments will come in handy as the company anticipates increased market demand for precision gears in the next two years. Since lean methodology is practiced throughout each department, employees have the opportunity to modify existing processes when needed.

"As a short run and prototype supplier, our technicians are in constant communication with management and discuss each job prior to actually cutting chips. It's a common sense approach that is in line with our quality standards, promotes employee satisfaction and saves the company money in the long run," Werschky says.

A Case for Continuous Improvement

Robert Doshi, plant manager at Schafer Gear Works Inc., says the company is not focused on any one specific lean principle, but is applying many aspects across the board.

"We've applied the principles that are needed in each area as the situation allows. As a job shop, it has proven difficult to apply lean in mass. By keeping the overall goal of improving quality, delivery times and reducing cost while maintaining a safe and healthy environment, we employ whatever tools will help us achieve our goals."

The economic downturn has given Schafer the opportunity to focus internally on customer satisfaction with shorter lead times, lower inventories and better quality products.

"It has also provided more time to streamline our processes and concentrate on our 5S program," Doshi says.

What lean ultimately provides for Schafer are the tools to become a growing, vibrant and customer-oriented company with international reach. Continuous improvement and involvement strategies include employees, customers and suppliers, and the company plans to spend the next five to 10 years providing its customer base with "what they want, when they want it and at a cost that allows both the customer and company to grow."

"We feel the lean philosophy infused in every aspect of our culture. Our processes and our people will be our strength and biggest asset," Doshi says.

Today, the company looks to its employees, the most important asset of the organization, to stand out.

"Our team's resolve to not only survive, but also shine during this time, is critical to ensuring our success," Doshi says. "We know that there is business out there and we know that we should be the one to get it."

This wouldn't be possible if the Schafer staff was unable to embrace a team concept.

"Without open lines of communication and the willingness to forgive mistakes, Schafer would not be as strong as it is today," Doshi says. "As we learn, we share. Knowledge is a commodity that we feel grows as it is shared by our employees, and it sparks new life into areas that we thought could not get any better."

In addition to its employees, Schafer continues to fortify relationships with both suppliers and customers.

"These relationships are open and based on win-win thinking. By making ourselves transparent, we have found that, together, arrangements can be made to allow all of us to survive," Doshi says.

While Schafer has always had a culture of continuous improvement, Doshi explains that a long term commitment is necessary to see these lean principles succeed.

continued

"Competitive benchmarking, visiting other lean plants, on-site assessments and lean education and training at the executive level are good places to start," Sonderman says.

"Not everything we have tried has worked. Sometimes, before getting the results we were striving for, we have tried an improvement or technique several times in the same area," Doshi says. "By staying the course and sticking to our core values and principles, we know that we will achieve our end results."

The Lean Learning Center instructs companies to get involved in these lean programs, sooner rather than later, and urges those truly hit hard by the economic downturn to open the communication lines with employees to achieve success and longevity.

"Competitive benchmarking, visiting other lean plants, on-site assessments and lean education and training at the executive level are good places to start," Sonderman says.

That's not to say that a commitment to lean doesn't come with an array of challenges and a hint of skepticism.

"Companies that have been profitable because of a niche market or have been immune to competition for whatever reason have less force on them driving change," Sonderman says. "We often hear 'Why should we adopt lean?' or 'We have always been successful.' A past history of financial success does not always guarantee future success. The objective should be to get leadership to see the gap between current reality and the ideal state. You want them to discover how ugly the current situation is."

With a computerized manufacturing floor at their fingertips, Sonderman reminds companies to be creative.

"Technology has changed, sure, but the lean tool box remains the same. The steps for reducing setup times and improving workplace organization through 5S are the same."

It's the understanding of lean concepts and principles that is constantly evolving.

"Lean is not about what you see when you visit a Toyota plant. It's what you don't see that is most important. What you don't see is the critical thinking that links lean rules and principles to meaningful progress on the shop floor."

Sonderman adds that this type of thinking will take organizations miles farther than simply repackaging old ideas or adding new programs or twists in technology.

"We saw this with Six Sigma. It's simply a repackaged form of problem solving. It's a great tool if you do not have systematic problem solving in your organization, but a tool is all it is. Hopefully, many organizations now understand that lean is essentially critical thinking guided by interdependent rules and principles, rather than simply a collection of tools to implement."

Companies like Delta, Colonial and

Schafer are keeping busy—with vested interest in the future of U.S. manufacturing—and seem to have gotten the message regarding lean.

"Our persistence has shown that lean is not a passing fancy. It is inevitable," Doshi says. "Although at times it can be implemented as a survival tool, we see it as a thriving tool, a shift in paradigms."

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The Indiana Convention Center will bustle with about 30,000 attendees and 175 exhibitors representing 43 states and 36 countries at Gear Expo 2009 (courtesy of the Indiana Convention and Visitors Association).

Gear Expo—
The Show of Shows for All Things Gearing

Jack McGuinn, Senior Editor

GEAR EXPO 2009 & FALL TECHNICAL CONFERENCE
INDIANA CONVENTION CENTER
INDIANAPOLIS, IN
EXPO: TUESDAY–THURSDAY, SEPT. 15-17, 10 A.M.–6 P.M.
FTM: SUNDAY–TUESDAY, SEPT. 13-15, 10 A.M.–6 P.M.

As Gear Expo 2009 approaches (Sept. 15–17), the show finds itself in an "It was the best of times, it was the worst of times" mindset. Worst first: everyone is hurting, and ponying up for show exhibiting is painful, to say the least. Best: because of the downturn, attendees may have more time to spend at the show meeting new suppliers or reconnecting with existing ones. More time to talk, more time to spend on checking out machinery and tooling, etc., more time to take in the AGMA Fall Technical Conference (*see sidebar on page 34*) and other educational opportunities. And, this year's show will be co-located with the ASM Heat Treating Society, presenting a distinctly relevant synergy between industries not seen before at Gear Expo.

There may also be some advantageous timing at play, too. As the show approaches, recent media reports indicate that while we are not out of the woods yet, the "worst of times" may be behind us. But don't bank on it.

Gear Technology interviewed AGMA president Joe Franklin, as well as a number of show exhibitors, in order to get a pulse of what to expect from Gear Expo 2009.

Perhaps one of the more significant changes in the '09 show is that it is being held in Indianapolis. For many, that is a distinct upgrade, but it didn't come easily.

Speaking of Indy, Franklin says, "The special significance is that Indianapolis was an outstanding location—the exhibitors and attendees loved it; the problem has been in getting back there. Indianapolis caters to Indiana-specific events before they cater to out-of-state events. So if you were a local flower club and you were having an orchid show, you got preference over a heavy-machinery or manufacturing show. That was a dominant reason why we weren't able to go back."

Returning to the positive, Franklin points out that "All the hotels are directly connected, and if there's any kind of inclement weather you don't have to actually go outside. It's just convenient for being together and networking."

Others we interviewed are in agreement that the show's location in Indianapolis will have a positive effect—more or less. The true deciding factor for this year's show's success is the E-C-O-N-O-M-Y.

"Only time will tell," says Al Finegan, Gleason director of marketing. "There are gear markets in (both Indiana and Michigan), and we have had successful Gear Expos at both locations. Given the state of the U.S. and global economies, the specific location of the show is probably less important than usual."

Says Dennis Richmond, Reishauer vice president, "Indianapolis is a vibrant city full of culture and energy. The downtown area has gone through an extensive transformation over the past two years, with the new stadium (RCA Dome) and the renovation of the (Indiana) Convention Center. It's a downtown area that show attendees will feel safe to explore and warmly invited wherever they go."

Reishauer RZ 1000 (courtesy of Reishauer).

Says Koepfer America's (and AGMA chairman emeritus) Dennis Gimpert, "In the past, Indianapolis has been a positive location for the AGMA Gear Expo. It offers a great venue, good restaurants and a convenient, drivable Midwest location. However, the state of our global economy will make it a challenge for any location."

And last, Ray Mackowsky, president of Great Lakes Gear Technologies says, "I think it's somewhat central to a lot of the automotive industry plants and the aerospace people such as Rolls-Royce, so there is some automotive presence there, which should help the attendance. But you never know. It's a question of the economy."

One thing that never changes is exhibitor expectations for a show, and Gear Expo is no exception. Everyone seeks satisfactory bang for their buck, including the AGMA.

"The show has multi objectives and purposes," says Franklin. "Obviously it is a meeting place for buyers and sellers. It is a place people can come and evaluate tooling or equipment or suppliers who are working in the industry, and they can come and evaluate gear manufacturing. People on the fence can come in and say, 'Do we want to invest in a factory or do we want to buy the gears from another company?'"

Using the AGMA's annual meeting last March as an analogy, Franklin offers that, as with the expo, "People felt they needed to be there, particularly in tough times, just to make sure they knew what was going on. And you're with people who are going through the same pain you are going through. But our annual meeting was extremely upbeat, and business was just as bad then as it is now. So I think there will be some important networking."

As for Gleason's goals and objectives, "Gleason expects to reinforce its position as the total gear solutions provider at Gear Expo," says Finegan. "This means more than just exhibiting the few products that we are able to bring to the show. It also means presenting and promoting the full range

continued

Gleason Sigma 350GMM (courtesy of Gleason).

of solutions that we have to offer to all gear producers for all processes and all applications. The 'goal' is to help our customers improve quality, increase productivity, reduce costs and more effectively compete in their markets."

Says Reishauer's Richmond, "It is our goal to showcase our company and its capabilities and demonstrate how we stand behind the claim that we offer the 'lowest cost-per-piece' hard finishing process on the market today, bar none."

As for Koepfer, says Gimpert, "Our plans are to introduce only new or advanced technology."

And says Great Lakes' Mackowsky, "We have a 20 x 50 booth alongside the Höfler and Fässler booths, so we'll probably have the biggest showing in terms of floor space. And the equipment there, there's probably four million dollars in equipment on the floor. It represents a huge expense for us and is kind of an indication of our commitment to the AGMA, and hopefully we'll have good participation by heavy industry. And we have some really great products, anyway. Hopefully, with the downturn in business, people will have a little more time to commit to the show and send more people and spend some time at the booth and maybe spend more than a day."

Moving on to another show- and industry-related issue, wind power just can't seem to catch a break. Despite the Obama administration's firm support for its place in the alternative energy realm, the state of the global economy has put the skids on most continued development. In contrast to the wind turbine buzz that energized the 2007 show, its impact will be considerably muted this year.

"I think the market reality is as we're hearing—that there is significant difficulty in getting financing for wind power," says Franklin. "If you are a company looking to make a wind power gearbox, you're probably going to have some difficulty in acquiring financing right this minute. The last time I went around and talked to people in the wind turbine business, money was extremely tight; demand is obviously not quite there. All sources of energy dampened down in price right now, and wind turbines are reflecting the same thing as far as I read."

Monument Circle (courtesy of the Indiana Convention and Visitors Association).

Höfler's machinery line capabilities will be on full display at Gear Expo (courtesy Höfler).

As for Richmond at Reishauer, "I'm not certain; it seems as if the manufacturing capacity and demand at this time are in sync. I've read a little about the issue of 'energy credits' when it comes to the business of alternative energy, and from my narrow understanding, these energy credits (created by Congress in the recent energy legislation as an inducement to begin alternative—wind—energy projects) have become a trading commodity on Wall Street, and their short-term future is unclear at this time."

"I think the level of intensity will be greatly reduced," says Koepfer's Gimpert. "(But) the wind energy business has committed to many programs and has an established focus."

Says Great Lakes' Mackowsky, "Wind power, like just about everything else, is experiencing the same amount of downturn. I don't see the activity level now that we saw two years ago."

Taking the long view, "The wind energy market has not been immune to the economic downturn," says Gleason's Finegan. "In spite of the current lull in the feverish growth of wind energy, the long-term demand and outlook for alternative energy sources remains strong, and we expect a rebound in all energy markets, including wind."

As for the co-location with the heat treaters, says Finegan, "Heat treating is an integral part of gear processing, and, as such, has a role to play at Gear Expo."

"Co-location is a new concept for Gear Expo," says Richmond. "The plan is to meld two common processes under one roof to broaden the appeal of the show. I think it's a good formula. The attendance numbers will tell the final story, notwithstanding current economic conditions."

"It can't hurt," says Mackowsky. "I would have thought some of them would probably have exhibited at Gear Expo anyway. If this brings more traffic, all the better."

And last, we come to the question that pops up every two years: Is Gear Expo in its current iteration still relevant? (*Ed.'s note: For AGMA's response to this question, please see Joe Franklin's upcoming Voices piece in our September/October show issue.*)

"It would be easy to say that Gear Expo is no longer relevant, given the current level of market activity," says Finegan, "but this may be shortsighted. The mission of Gear Expo has always been to bring together the suppliers of gears as well as gear equipment,

continued

technologies, tooling and services to promote ourselves to the market as one industry. While the economy, and manufacturing in particular, are in a severe recession, history would indicate that recessions eventually end. Some would argue that now is exactly the time to promote at events like Gear Expo."

Relevant?

"Absolutely," says Richmond. "Not only can attendees shop for gear manufacturers for their products, they can shop for the equipment necessary to make them in-house should they decide to do so. Gear Expo has broad appeal to people that make gears, buy gears and those that want to understand the gear process better. As a company, we're sending some of our newest employees to Gear Expo for the excellent educational programs they offer.

Attention Students of All Ages— The Fall Technical Meeting is Back September 13–15, 2009, Indianapolis, Indiana

It is no secret that industry-relevant technical papers are the lifeblood of Gear Technology *magazine. Indeed, over the years, scores of you have told us so. And so it was a no-brainer when AGMA asked us to publish the list of presentations taking place just prior to Gear Expo this year. The 2009 Fall Technical Meeting is being held before the show, so that you can take advantage of the technical expertise available at the FTM, and then stay for the latest technology offered at the trade show. The FTM will be held September 13–15, 2009 at the Marriott Indianapolis Downtown. (*The editors.*)*

(To view the full abstracts of these presentations, visit www.agma.org *and choose* the *Events drop down menu.)*

Sunday, September 13 Session I—Manufacturing & Inspection

- "Influence of the Residual Stresses Induced by Hard Finishing Processes on the Load Carrying Capacity of Gears," Fritz Klocke, Christof Gorgels, Vasilios Vasiliou, RWTH Aachen University.
- "Implementing ISO 18653, Evaluation of Instruments for the Measurement of Gears," Rob Frazer and Steve Wilson, UK National Gear Metrology Lab.
- "Producing Profile and Lead Modifications in Threaded Wheel and Profile Grinding," Antoine Türich, Gleason Corporation.
- "New Developments in Gear Hobbing," Oliver Winkel, Liebherr Verzahntechnik GmbH.
- "Hypoloid Gears with Small Shaft Angles and Zero to Large Offsets," Hermann Stadtfeld, Gleason Corporation.

Monday, September 14 Session II—Design Issues

- "Dependency of the Peak-to-Peak Transmission Error on the Type of Profile Correction and Transverse Contact Ratio of the Gear Pair," Ulrich Kissling, KISSsoft AG.
- "Optimizing Gear Geometry for Minimum Transmission Error, Mesh Friction Losses and Scuffing Risk," Rob Frazer, UK National Gear Metrology Lab, Mike Fish and Dave Palmer, Dontyne Systems, Ltd.
- "Load Sharing Analysis of High Contact Ratio Spur Gears in Military Tracked Vehicle Application," M. Rameshkumar, P. Sivakumar, S. Sundareshm, Combat Vehicles Research and Development Establishment, and K. Gopinath, IIT.
- "Designing for Static and Dynamic Loading of a Gear Reducer Housing with FEA," M. Davis, Y.S. Mohammed, A.A. Elmustafa, Old Dominion University and C. Ritinski, Sumitomo Machinery Corporation America.
- "The Effect of Flexible Components on the Durability, Whine, Rattle and Efficiency of a Transmission Gear Train System," Brian Wilson, Romax Technology, Inc.

Monday, September 14 Session III—Materials & Heat Treatment

- "Unique Design Constraints for Molded Plastic Transmissions," Rod Kleiss and Eric Wiita, Kleiss Gears, Inc.
- "The Anatomy of a Micropitting-Induced Tooth Fracture Failure—Causation, Initiation, Progression and Prevention," Raymond J. Drago, Roy J. Cunningham and Steve Cymbala, Drive Systems Technology, Inc.
- "Bending Fatigue, Impact Strength and Pitting Resistance of Ausformed Powder Metal Gears," Nagesh Sonti and Suren Rao, Pennsylvania State University, and Gary Anderson, Keystone Powdered Metal Company.
- "Design Development and Application of New High-Performance Gear Steels," Jason Sebastian, Chris Kern, James Wright and Rich Kooy, QuesTek Innovations LLC.

Tuesday, September 15 Session IV—Application Considerations

- "High-Performance Industrial Gear Lubricants for Optimal Reliability," K.G. McKenna, J. Carey, N.Y. Leon and A.S. Galiano-Roth, ExxonMobil Research and Engineering.
- "Allowable Contact Stresses of Jacking Gear Units Used in the Offshore Industry," Alfred Montestruc, Friede & Goldman, Ltd.
- "Variation Analysis of Tooth Engagement and Load-Sharing in Involute Splines," Kenneth Chase, Carl Sorenson and Brian DeCaires, Brigham Young University.
- "Does the Type of Gear Action Affect the Appearance of Micropitting and Gear Life?" Allen Williston, A&J Engineering.
- "The Effect of Gearbox Architecture on Wind Turbine Enclosure Size," Charles D. Schultz, Beyta Gear Service.

As David Letterman might say—And the No. 1 reason to attend Gear Expo? Networking!"

Says Gimpert, "The AGMA Gear Expo show is still relevant, but the format and content will continue to change."

And Mackowsky, "I think it is. It's a question of where it's at and how the industry looks at it. But Gear Expo gives us our own stage."

If indeed "all the world is a stage," Gear Expo will assume its rightful place.

Indiana State Museum (courtesy of the Indiana Convention and Visitors Association).

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Effects of Axle Deflection and Tooth Flank Modification on Hypoid Gear Stress Distribution and Contact Fatigue Life

H. Xu, J. Chakraborty and J.C. Wang

Management Summary

As is well known in involute gearing, "perfect" involute gears never work perfectly in the real world. Flank modifications are often made to overcome the influences of errors coming from manufacturing and assembly processes as well as deflections of the system. The same discipline applies to hypoid gears. This paper, first of all, presents an approach on validating FEA-predicted axle system deflections. Next, influences of axle deflections and typical flank modifications (lengthwise crowning, profile crowning and twist) on contact pattern and stress distribution of the hypoid gear set are simulated by using a face-hobbed hypoid gear design. Finally, two groups of experimental hypoid gear sets are made with two different designed flank modifications. Actual tooth surface topographies are examined by using a CMM to assure the desired flank modifications are achieved. These experimental gear sets are tested to investigate the impact of flank modifications on actual gear life cycles. Test results of the sample gears are reported to illustrate the effect of tooth flank modifications on contact fatigue life cycles.

Introduction

Hypoid gears are widely used in many applications, such as axles and four-wheel drive transmissions for on- and off-highway vehicles. Recent studies on hypoid gearing are found in the subject of tooth surface generation and contact analysis of hypoid gears manufactured by the face hobbing process (Refs. 1–4), noise (Ref. 5) and dynamics (Ref. 6), friction and efficiency (Refs. 7–8), wear (Refs. 9–10), lubrication (Ref. 11), as well as lapping and superfinishing (Ref. 12). For hypoid gear drives applied in heavy vehicle axles, durability has been the primary concern. Axle deflections have a significant impact on gear tooth strength (Ref. 13) while axle deflection data are typically obtained through experimental measurements of a loaded axle under certain controlled conditions (Ref. 14). Unexpected deflections can cause severe edge loading that is detrimental to gear surface life as well as noise performance. For heavily loaded hypoid gears, flank modifications are particularly critical to achieve required durability performance under relatively large axle deflections (Ref. 4). There are basically three types of flank modifications—profile crowning, lengthwise crowning and twist (Ref. 15). For hypoid gears, in addition to tool geometry and basic machine settings, higher-order machine settings are also very important to achieve desired flank modifications (Refs. 15–16).

The objective of this paper is to study the impact of axle deflection and tooth flank modification on hypoid gear stress distribution and contact fatigue life. First, an approach to validate axle system deflections will be proposed. Then, by using computer programs and an example of a face-hobbed hypoid gear design, influences of axle deflections and typical flank modifications on contact pattern and stress distribution of the hypoid gear set will be simulated. And finally, several experimental hypoid gear sets are made with two differently designed flank modifications. These samples are tested under the high-cycle fatigue drive side in an axle assembly to investigate the impact of flank modifications on actual gear life cycles.

Methodology

Axle deflection. Axle deflection is one of the most critical issues in the design and analysis of hypoid and spiral

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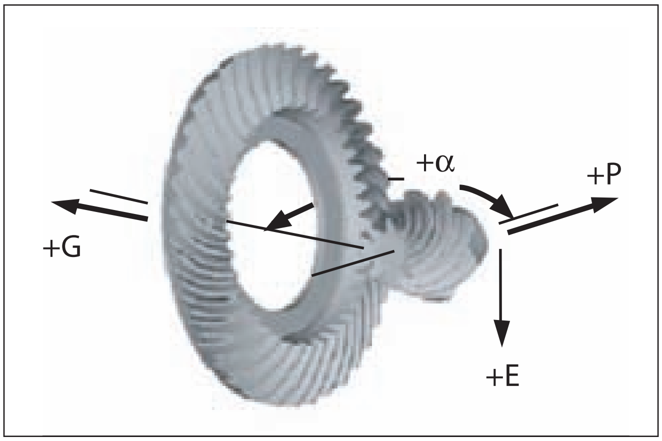

Figure 1—Definition of E, P, G and α.

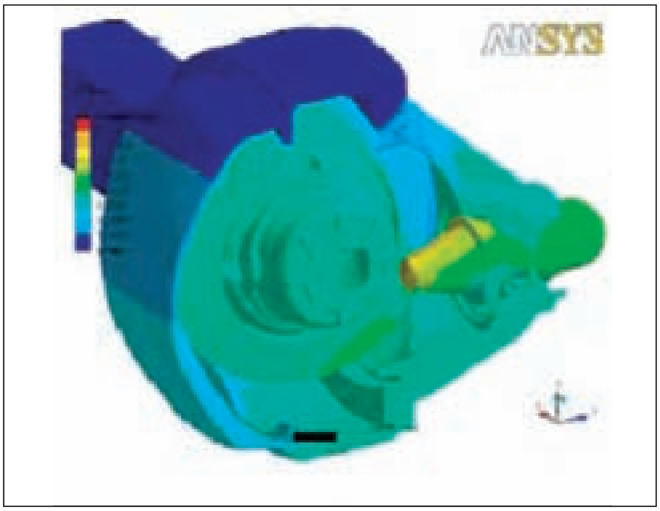

Figure 2—FEA model of an axle deflection analysis.

Figure 3—Experimental measurement of an axle deflection.

bevel gear drives. Axle deflection is commonly defined, as shown in Figure 1, in terms of E, P, G and α, which are normally derived from experimental measurements. Positive E, P, G and α represent deflections under certain load conditions that would enlarge the pinion offset, pinion mounting distance, gear mounting distance and shaft angle, respectively. Countless gear design and analysis software packages have been developed and are commercially available today that take a predefined set of E, P, G and α to describe the rigid body motions and incorporate them into gear contact analysis to simulate the loaded contact characteristics of the gear drives.

Without knowing the deflections of the axle for which the gears are designed, an ideal gear design on paper or a perfect development showing on a loose gear set may possibly lead to poor performances in axle assembly, such as excessive gear tooth wear, low fatigue or impact life cycles and unacceptable noise and dynamic behaviors. Before a physical axle is built, the numerical or analytical method is the only way to estimate the deflections. In this study, an FEA model is created using *ANSYS* as shown in Figure 2. The predicted deflection data need to be validated or corrected.

Experimental measurement of the axle deflection is the conventional approach to validate the FEA predictions. With the availability of a physical axle, actual measurement can be conducted. In this study, measurements are taken based on the procedure that is similar to Gleason's procedure (Ref. 14). Figure 3 illustrates the setup used in this measurement.

However, this type of measurement is very costly and time-consuming. Furthermore, measured results for a particular axle do not apply to other axle models or the same model with different configurations. It is not practical, and perhaps impossible, to repeat the measurement across different axle models or different configurations. To overcome these disadvantages, in this study, an indirect approach is proposed to validate the FEA-predicted deflections.

It is known that axle deflections will alter gear contact patterns in terms of contact area size, contact path, positions and shapes on tooth surfaces as well as transmission errors. In other words, under certain controlled conditions, variations of contact patterns for a gear set are the direct responses from axle deflections. This led to the idea to use computer simulations with FEA-predicted deflections to compare simulated contact patterns to the ones from actual loaded contact tests. If, under the same load condition, the simulated contact patterns agree with the actual patterns obtained from loaded contact tests, then one can consider that the deflection data predicted from FEA are valid. If not, the FEA model needs to be refined. This is also a development process to achieve a valid FEA model for axle deflection analysis. In this study, the validation is carried out following the procedures described below:

- Conduct loaded contact test per Dana Commercial Vehicle System procedure. In this study, loaded contact tests were performed at five loading conditions, i.e.—no load; 25% of full load; 50% of full load; 75% of full load; and 100% of full load. Pictures of the contact patterns under these loads are recorded as shown in Figure 4 (a'–e');

- Use a computer program *Loaded Tooth Contact Analysis* (*LTCA*) to simulate the contact patterns under the same five levels of loads. Deflections predicted by the FEA analysis at these five loading conditions are used;
- Compare respective patterns between simulated and actual ones;
- If the comparisons show good agreement between calculated patterns and actual patterns, then the FEA-predicted deflections are validated. Otherwise, refine the FEA model and repeat steps 2 and 3.

In this study, the resulting contact patterns from computer simulation with FEA- predicted deflections are shown in Figure 4 (a–e). At all five of these loading conditions, the *LTCA*-simulated patterns agree well with the actual patterns. Thus the deflections predicted by the FEA program are considered valid. The validated deflections can then be used for further gear analysis and design improvement. This approach can be used for other axle models, provided the loaded contact patterns are available. With the development of this process, the FEA model can be further refined and trained so that one can rely on the FEA-predicted deflections with good confidence for future axle/gear design and development.

Flank modifications. Flank modifications to a conjugate gear pair are normally designed to avoid edge contact and stress concentration, which could result from deflections under load, manufacturing errors and misalignment, etc. Flank modifications are also desired for ease of manufacturability. There are basically three types of gear tooth flank modifications—lengthwise crowning, profile crowning and longitudinal twist.

For hypoid and spiral bevel gears, lengthwise crowning is mainly a result of cutter radius change. Lengthwise crowning can also be achieved by cutter head tilt in conjunction with blade angle modification (Ref. 15). Figure 5 (a)

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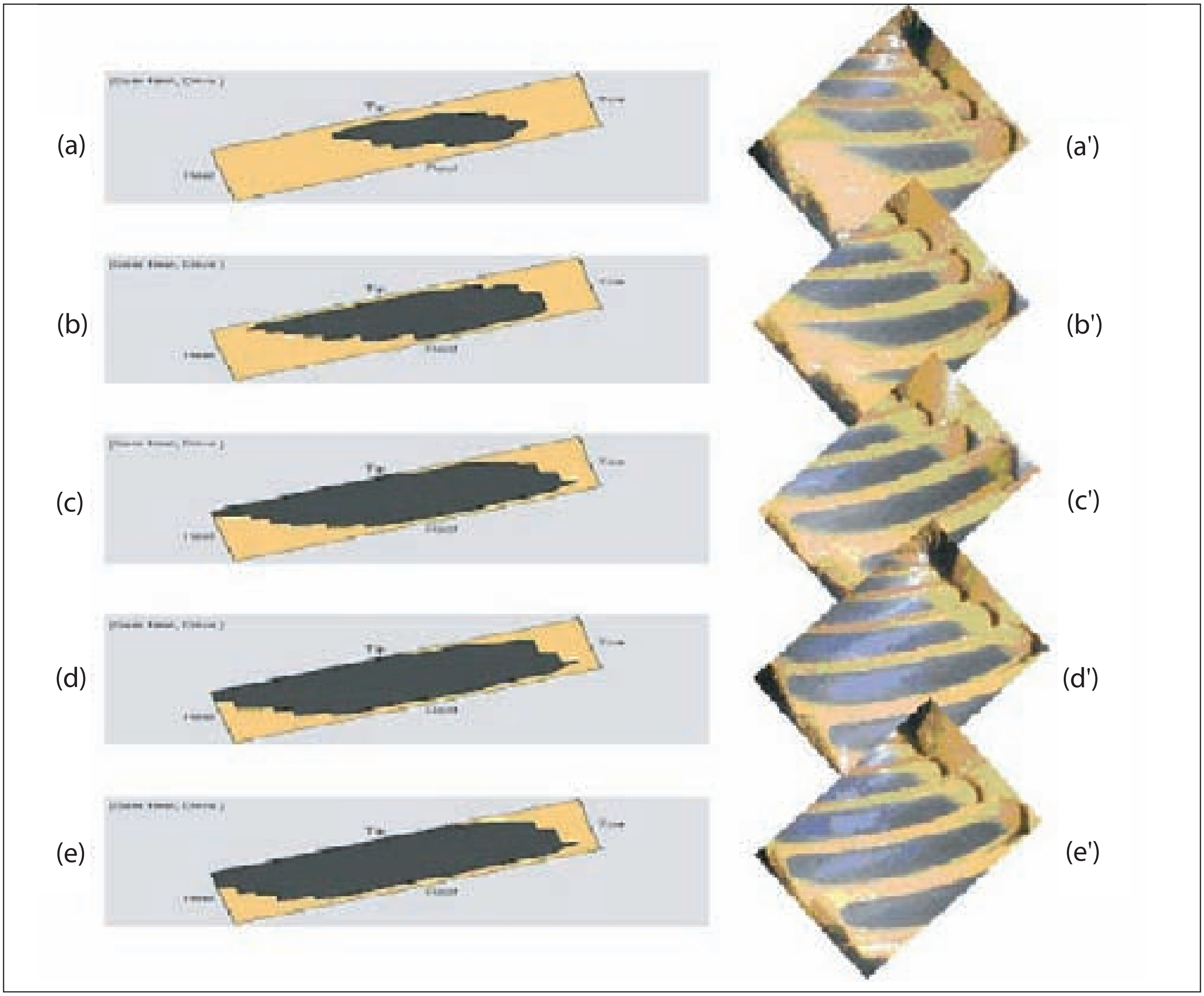

Figure 4—Comparison between simulated contact pattern (a–e) and actual painted pattern (a'–e'): (a–a') no load; (b–b') 25% of full load; (c–c') 50% of full load; (d–d') 75% of full load; (e–e') 100% of full load.

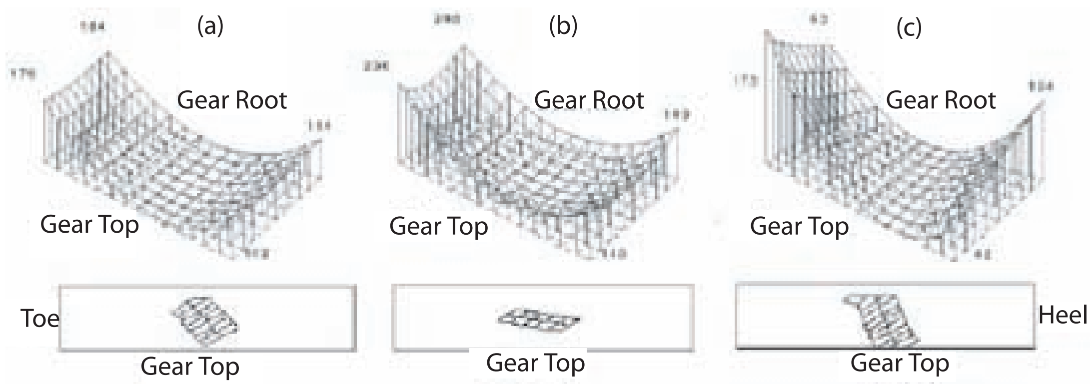

Figure 5—Illustration of flank modification and resulting contact patterns.

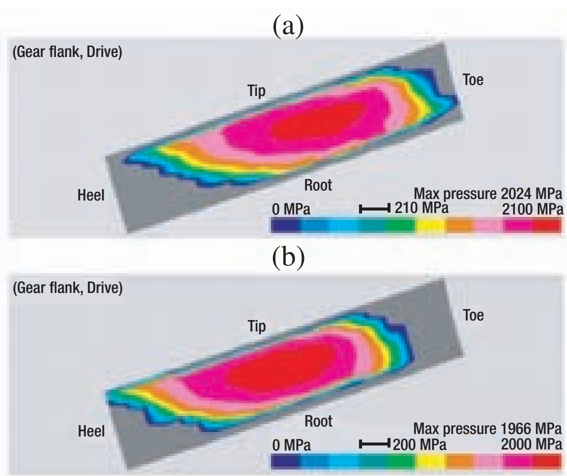

Figure 6—Contact patterns and stress distribution analyzed (a) without deflections; and (b) with deflections.

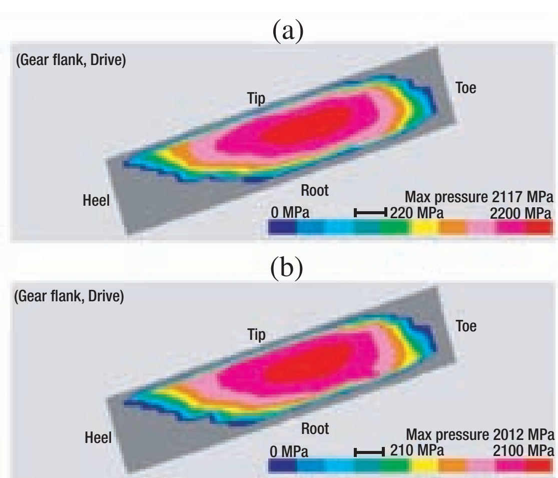

Figure 7—Contact patterns and stress distribution analyzed with pinion blade profile radii of curvature (a) 20 inches; and (b) 100 inches.

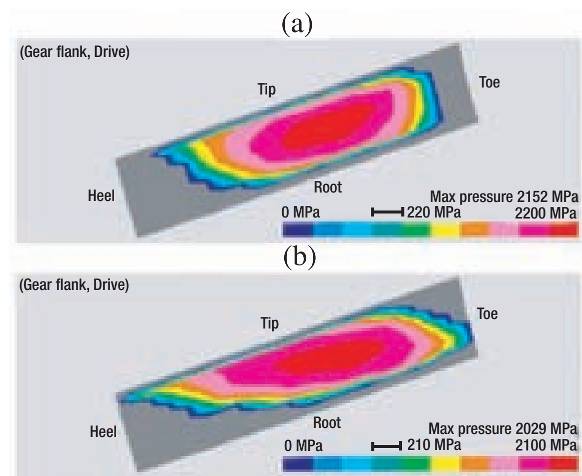

Figure 8—Contact patterns and stress distribution analyzed with pinion lengthwise crowning (a) 0.007 inches; and (b) 0.005 inches.

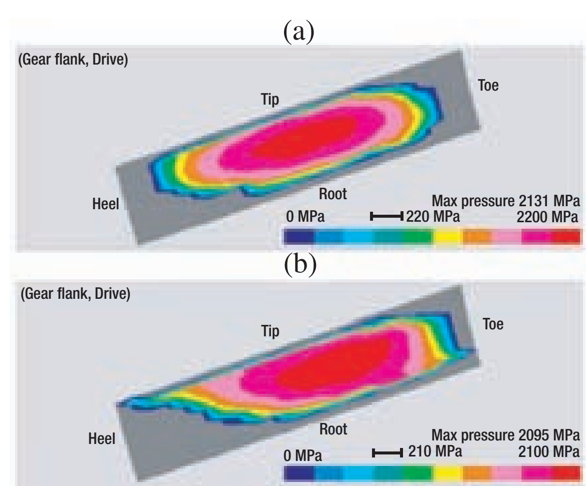

Figure 9—Contact patterns and stress distribution analyzed with pinion longitudinal twist (a) 0 degrees; and (b) 1.5 degrees.

illustrates a typical ease-off (also called mismatch, a term used to describe the deviations of the actual tooth surfaces to theoretical conjugate surfaces) and TCA (Tooth Contact Analysis) as a result of lengthwise crowning to the pinion member. Profile crowning normally results from blade profile curvature. It can also be achieved by a mechanism called modified roll (Ref. 15). Figure 5 (b) shows the ease-off and TCA as a result of profile crowning with added blade profile curvature. Shown in Figure 5 (c) is an example of ease-off and TCA as a result of tooth twist. Tooth twist—also known as bias—can be achieved by cutter tilt or using higher order machine motions, such as higher orders of helical motion and modified roll. These three types of flank modifications are often combined to achieve the desired contact pattern, ease-off and transmission error. Flank modifications can be made to both pinion and gear surfaces, although in practice, they are often designed for pinion surface only, for hypoid and spiral bevel gears.

In the following section, the impact of flank modifications on hypoid gear contact pattern and stress distribution will be simulated by a computer program. In this program, ease-off is characterized by using a two-dimensional quadratic model as a function of spiral angle difference, pressure angle difference, lengthwise crowning, profile crowning and twist (Ref. 17). The resulting coefficients from a least square approximation for lengthwise crowning, profile crowning and twist of the quadratic model are defined as the amount of respective flank modifications that will be referred to in the next section.

Computer simulation of the impacts of deflections and flank modifications on hypoid gear contact pattern and stress distribution. Given the validated axle deflections—E, P, G and α—*LTCA* is used to investigate the impacts of axle deflections and flank modifications on gear contact pattern and stress distribution. In this paper, a hypoid gear designed with the face hobbing process is used as an example. Figure 6 (a) shows a loaded contact pattern and contact stress distribution simulated by the computer program without considering any deflections. From this figure, one may be concerned about the edge contact at toe while having no concern at heel. However, performing the same analysis—but with the consideration of the axle deflections—Figure 6 (b) clearly indicates this design may have edge contact at heel with no concern at toe. Based on Figure 6 (a), one may consider making a reasonable adjustment to shift the pattern toward heel, which will, in fact—as is evident in Figure 6 (b)—adversely worsen the contact by having severe edge contact at heel that could lead to early contact failure. Thus the gear contact pattern must be designed and developed appropriately, based on the axle deflection characteristics to avoid the unfavorable contact.

Figures 7–9 show the results from *LTCA* with axle deflections and with different amounts of flank modifications. In this paper, flank modifications are made to the pinion only and the ring gear is unchanged. In this study, profile-crowning variations are controlled by using different pinion blade curvatures, while all other parameters remain unchanged. Figures 7 (a) and 7 (b) show the contact pattern and stress distribution with 20- and 100-inch radii of curvature on the pinion blade cutting side, respectively.

It is observed that while the overall contact patterns do not differ significantly under load, the computed maximum contact stress does vary from 2,117 to 2,012 MPa—more than a 5% reduction with 100-inch radius of curvature on the pinion blade.

In this study, lengthwise crowning is achieved by changing pinion machine settings, including basic and higher-order motions with no blade geometry change. Figures 8 (a) and 8 (b) show the results with 0.007-inch and 0.005-inch lengthwise crowning designed on the pinion tooth surface, respectively. It is evident that with 0.005-inch lengthwise crowning, the contact pattern is much longer and the maximum contact stress is about 6% lower.

Figures 9 (a) and 9 (b) show the results with 0-degree and 1.5-degree longitudinal tooth twist designed on the pinion tooth surface, respectively. It is obvious that with 1.5-degree longitudinal twist, the contact pattern is longer in the diagonal direction, with less than 2% reduction on the maximum contact stress. In this study, longitudinal twist is obtained by changing basic and higher-order machine settings while locking the blade geometry. It should be mentioned that in the comparisons above—in Figure 9, for example—as a result of longitudinal twist there is also some amount of lengthwise and profile crowning change as calculated by the computer program. For the comparisons in this section, care has been taken to keep the differences—other than the targeted modification—as small as possible. Meanwhile, for hypoid and spiral bevel gears, the flank modifications can be achieved through approaches other than those used in this paper, which may result in some different tooth topography. Thus, the simulated results should not be taken as exclusive.

Experimental Study of the Impact of Flank Modifications on Hypoid Gear Contact Fatigue Life Cycles

Design and test samples. Based on the study in the previous section, both axle deflections and tooth flank modifications can evidently impact the contact pattern and stress distribution. With the given deflection data from FEA analysis, two designs are made with the same macro geometry, i.e., same tooth combination, pitch diameters, tooth depth proportions, pressure angles, spiral angle, face width, cone distances and angles, etc. Ring gears for these two designs are kept exactly the same. But these two designs have different flank modifications on the pinion tooth surface that is often called microgeometry change. Seven experimental gear sets are developed, four samples for Design 1 and three samples for Design 2. Figure 10 (a) shows the representative no-load contact pattern for Design 1, and Figure 10 (b) shows the representative no-load pattern for Design 2. The theoretical

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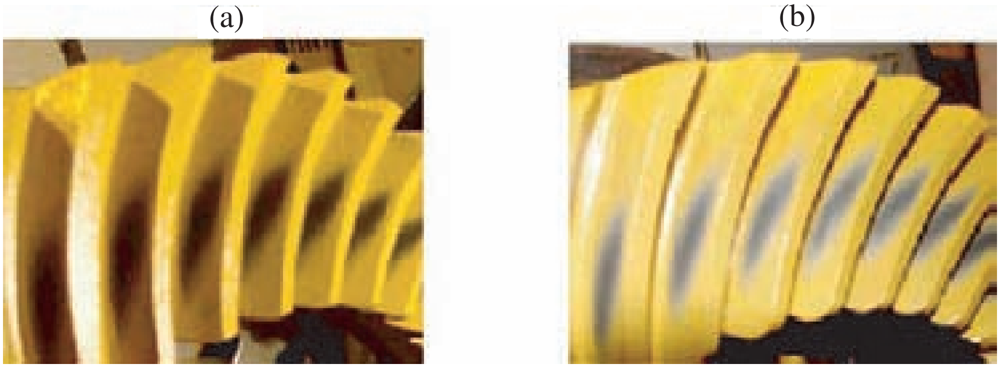

Figure 10—Representative contact patterns from samples of (a) Design 1; and (b) Design 2.

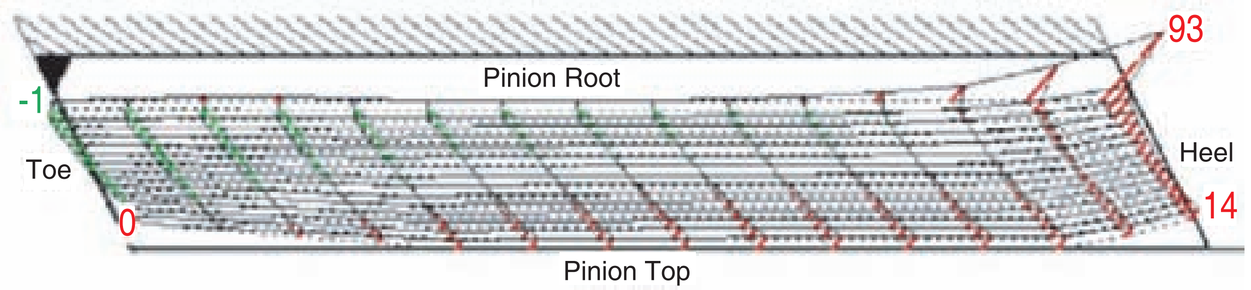

Figure 11—Comparison of theoretical pinion drive side topography: Design 1 (base) and Design 2.

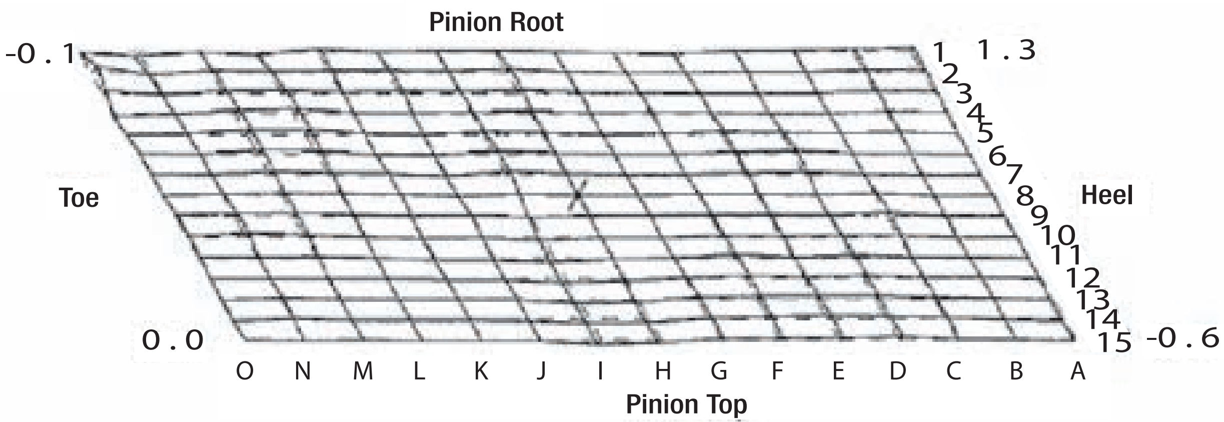

Figure 12—CMM measurement of Design 1: actual pinion drive side topography versus designed Theory 1.

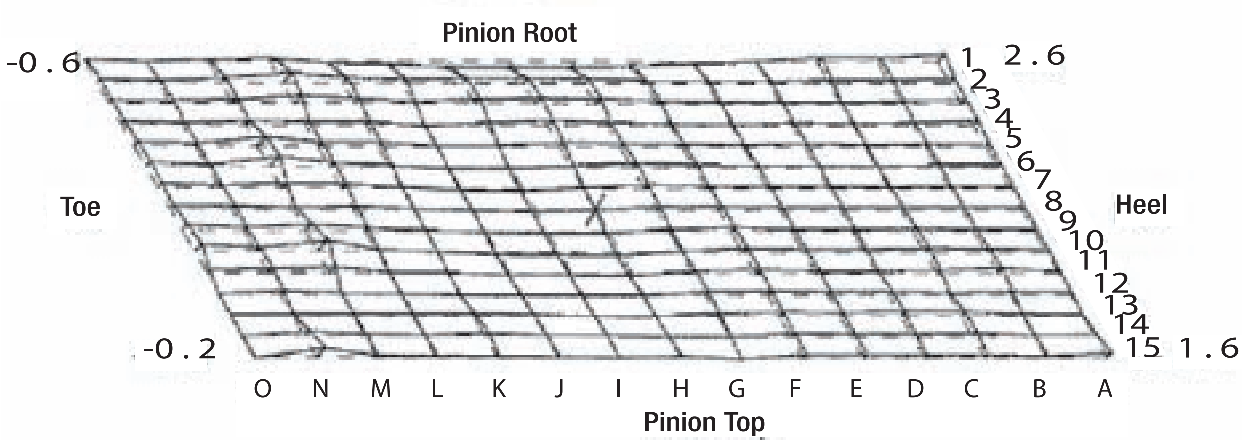

Figure 13—CMM measurement of Design 2: actual pinion drive side topography versus designed Theory 2.

pinion drive side (concave side) tooth topography of Design 1 and Design 2 are compared in Figure 11. The numbers in Figure 10 are in the unit of 0.0001 inch. It is evident that the main differences between these two designs are the ease-off at the pinion heel root. Compared to Design 1, Design 2 has a 0.0093-inch larger relief at the pinion heel root, an additional amount of flank modification designed to avoid edge contact under heavy load. Other differences between these two designs that are calculated by the computer program are: spiral angle difference of 0.03 degree; pressure angle difference of 0.14 degree; lengthwise crowning of 0.0005 inch; profile crowning of 0.0017 inch; and longitudinal twist of 0.555 degree.

A CMM is used to ensure that the actual tooth surface topography agrees with the designed theory. In this study, four teeth are measured, and the results are averaged to eliminate tooth-to-tooth variations. A total 225 points are measured by a 15 x 15 grid setup as shown in Figures 12 and 13. In this paper, only the concave side of the pinion surface is reported. The outputs shown in Figures 12 and 13 are also in the unit of 0.0001 inch. Figure 12 shows the measured pinion concave side topography against the theory of Design 1. As indicated in this figure, the actual surface topography matches the theory very well, with a Sum of Squared Errors of 210 $(0.0001\text{ in})^2$. This measurement also reported 31 seconds and 0 seconds in pressure angle error and spiral angle error, respectively. The same conclusion can be drawn from Figure 13, which shows the actual pinion surface of Design 2 against the theory of Design 2. In the case of Design 2, the measurement reported 276 $(0.0001\text{ in})^2$ in Sum of Squared Errors, 14 seconds in pressure angle error and again 0 seconds in spiral angle error.

Test Results

The four samples from Design 1 and three samples from Design 2 are tested for drive-side-only, high cycle fatigue per Dana Heavy Vehicle Systems Group's standard testing procedure. All tests resulted in the pinion as the primary failed component and pitting failure as the primary failure mode. A representative failure of these samples on the pinion is shown in Figure 14. The test results are summarized in Figure 15, which clearly shows that all the samples from Design 2 with larger pinion heel root relief consistently yielded significantly better fatigue lives than samples from

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Figure 14—Representative pinion failures of the seven test samples.

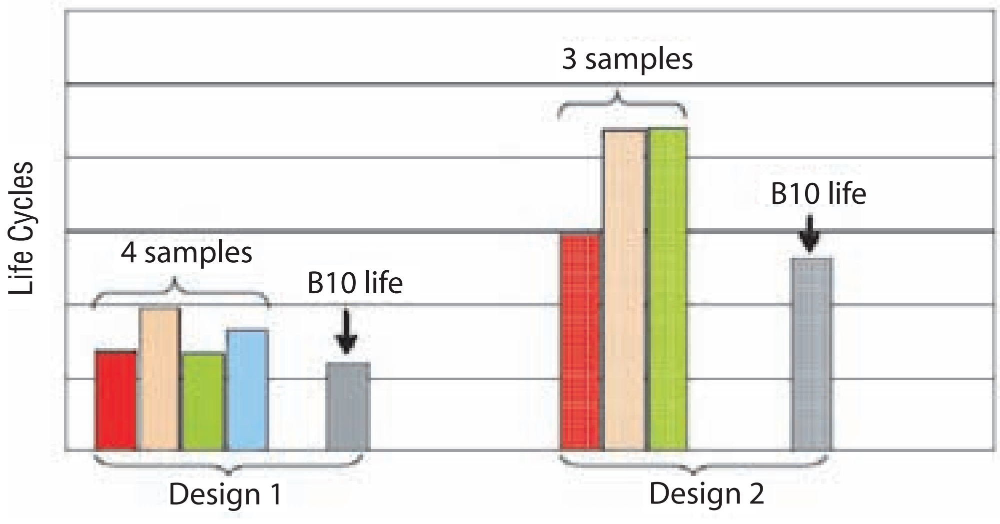

Figure 15—Drive side only high cycle fatigue test results.

Design 1. Resulting B10 life for Design 2 is more than double Design 1's.

Conclusions

This paper presents a study of the impact of axle deflection and tooth flank modification on hypoid gear stress distribution and contact fatigue life. An approach to validate axle deflections has been proposed that eliminates the cost and complexity of actual measurements. By using a face-hobbed hypoid gear design as an example, the influences of axle deflections and typical flank modifications on contact pattern and stress distribution have been simulated. High-cycle fatigue test results of several experimentally made hypoid gears show that appropriate flank modifications can significantly improve gear surface fatigue life.

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CFD Technology for Rotorcraft Gearbox Windage Aerodynamics Simulation

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Lyle N. Long, Philip J. Morris and Robert F. Handschuh

(Presented at the American Helicopter Society 64th Annual Forum, Montreal, Canada, April 29–May 1, 2008.

Management Summary

A computational fluid dynamics (CFD) method is adapted, validated and applied to spinning gear systems with emphasis on predicting windage losses. Several spur gears and a disc are studied. The CFD simulations return good agreement with measured windage power loss. Turbulence modeling choices, the relative importance of viscous and pressure torques with gear speed and the physics of the complex 3-D unsteady flow field in the vicinity of the gear teeth are studied.

Introduction

Gearbox windage refers to the power losses associated with rotational deceleration torques exerted on spinning gears by aerodynamic forces (pressure and viscous) within the air-oil atmosphere in a gearbox. Windage losses are a source of significant heating and fuel consumption in rotorcraft and other systems. Rotorcraft systems require the gearing components to be lightweight and heavily loaded. The components are also required to operate at high rotational speeds where windage losses become significant with respect to other gearbox losses (rolling, sliding and lubrication) Windage losses are relevant to aircraft design for several reasons:

1) They can consume several percent of the transmitted power. This has significant implications for onboard oil cooling requirements and lube system capacity, thereby compromising range and standby military readiness for rotorcraft and carrier-based aircraft.

2) Rotorcraft platform survivability under transmission *oilout* conditions is exacerbated by windage losses, which are manifested as added dissipative flow heating to these already critically thermally stressed systems.

Despite this significant relevance, design efforts aimed at reducing gearbox windage losses have generally fallen into the trial and error category. Nevertheless, it has been shown by Winfree (Ref. 1) and others that modest geometric modifications to control the air flow path, such as shrouding and baffle configurations, can significantly reduce both windage losses and lubricating oil consumption (80% and 40% reductions observed respectively [Ref. 1]). However, these hardware-specific approaches are empirical, expensive and time consuming, and to be relevant, they need to be performed late in the design cycle.

A host of experimental studies have appeared in the literature (Refs. 1–8). These studies employ either closed-loop systems (Refs. 2–6) or treat isolated gears (Refs. 1, 7 and 8) where windage (and other) losses are determined by measuring spin-down velocities once the gear and shaft assembly is disconnected from the drive torque. Figure 1 shows a diagram of the high-speed helical gear train test facility at the NASA Glenn Research Center. It is a closed-loop system that has been set up to study the thermal behavior of aerospace-quality gear components under various speeds, loads and lubricant flow rates (Ref. 5). These studies parameterize gear geometry elements, rotational speed, enclosure geometry and lubrication system characteristics (flow rate, jet location, lubricant rheology), using dimensional analysis to develop correlations for the power losses. These correlations, although useful in the design process, are inherently limited by the large number of system variables and the attendant limited range of their applicability. Of particular concern here is the paucity of data/correlations available for high-speed gears of interest. Indeed, compressibility effects are mostly not even considered in the literature, although high-speed gears can have tip Mach numbers reaching 0.75.

Unfortunately, the physics of these systems are so complex that to date there have been no attempts made to employ many modern elements of 3-D computational fluid dynamics (CFD) in analyzing gearbox windage. Recent 2-D studies (Ref. 9) were performed using the commercial CFD solver FLUENT, where a side correlation factor was used to account for 3-D effects (although these authors state that work is under way to extend their simulations to 3-D) (Ref. 10). Specifically, the fluid mechanics involve complex, separated air flow, disperse multiphase flow (oil droplets), continuous multiphase films (lubricating oil on gears), moving boundaries in contact and all modes of heat transfer. Accordingly, for a CFD tool to resolve all of the relevant physics of this problem, it must:

- support moving meshes (either adaptive/deforming or overset) necessary to resolve the gears in relative motion and contact at the gear face;
- contain non-equilibrium multiphase flow capability (separate continuity and momentum equations for each phase; slip between phases) to accommodate the disperse mist/droplet and continuous film flows;
- support suitable turbulence modeling to accommodate the complex high-speed, separated flow within the gearbox and to accurately represent the cascade of energy through turbulence scales into viscous heating;
- possess suitable preconditioned time-stepping algorithms to efficiently accommodate Mach numbers ranging from near-zero through high-subsonic;
- support conduction, convection and (for near-failure conditions) radiation modeling;
- be parallelized to run efficiently on modern high-performance computing (HPC) systems.

Theoretical Formulation Governing Equations

Governing equations. The conservation of mass, momentum and energy can be written in integral conservation law form for a compressible flow through a moving mesh as:

$$\frac{\partial}{\partial t}\int_{\forall} \rho d\forall + \int_{S} \rho(\underline{V} - \underline{W}) \cdot d\underline{S} = 0 \qquad (1)$$

$$\frac{\partial}{\partial t}\int_{\forall} \rho \underline{V} d\forall + \int_{S} \rho \underline{V}\,(\underline{V} - \underline{W}) \cdot d\underline{S} = -\int_{S} p d\underline{S} + \int_{S} \underline{\underline{\tau}} \cdot d\underline{S} \qquad (2)$$

$$\frac{\partial}{\partial t}\int_{\forall} \rho E d\forall + \int_{S} \rho H\,(\underline{V} - \underline{W}) \cdot d\underline{S} = \int_{S} \left(\underline{\underline{\tau}} \cdot \underline{V}\right) \cdot d\underline{S} + W_f + q_H \qquad (3)$$

In equations 1–3, $\underline{V}$ is the velocity vector, and $\underline{W}$ is the velocity of the surface element $d\underline{S}$, both in the absolute frame of reference. In the present work, all verification and validation flows studied are either incompressible, or they have maximum local absolute Mach numbers of less than 0.35. Accordingly, for all simulations presented in this paper, an incompressible assumption is invoked and the energy equation is not solved (except for the thermal Couette flow simulation where it is solved subject to a constant density constraint).

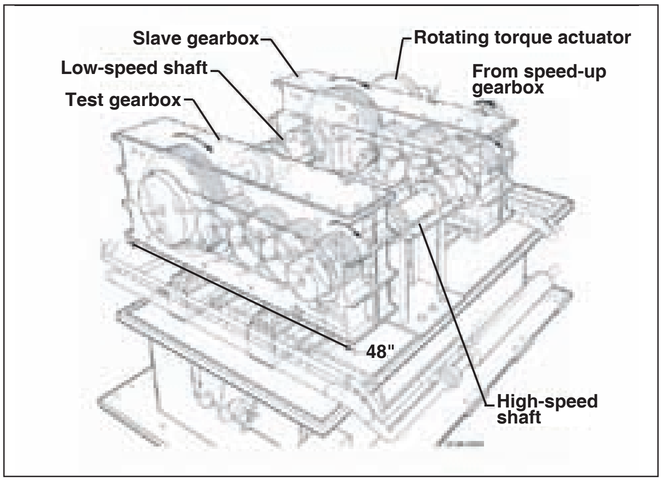

Figure 1—NASA High-Speed Helical Gear Train Facility (Ref. 5).

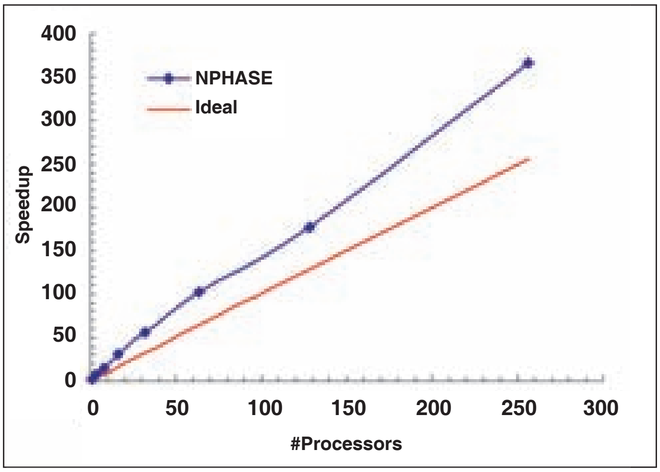

Figure 2—Parallel efficiency of *NPHASE-PSU* on Columbia system for a l.1x10[5] cell spinning cylinder case.

A high-Reynolds number k-ε turbulence model and a sublayer resolved hybrid k-ε/k-ω turbulence model, due to Menter (Ref. 11), are used in the studies that follow. No explicit transition model was employed as justified, for now, by the small contribution of near-axis viscous torques on windage loss.

CFD numerics and code. The CFD code used in this work, *NPHASE-PSU* (Ref. 12), is a parallel face-based, cell-centered, arbitrary-element unstructured multiphase flow solver which has been instrumented with overset mesh capability. The baseline algorithm follows established, segregated pressure-based methodology. A co-located variable arrangement is used and a lagged coefficient linearization is applied (Ref. 13). Diagonal dominance-preserving, finite-volume spatial discretization schemes are used for the scalar transport equations. Continuity is introduced through a pressure correction equation, based on the SIMPLE-C algorithm (Ref. 14). In constructing cell face fluxes, a momentum interpolation scheme (Ref. 15) is employed, which introduces damping in the continuity equation. Grid motion/deformation terms are implemented in a Geometric-Conservation-Law (GCL) preserving fashion (Ref. 16). A dual-time formulation is employed where at each physical time-step, between five

continued

and 20 pseudo time-steps of the SIMPLE-C algorithm are applied. Specifically, at each pseudo time-step, the discrete momentum equations are solved approximately (using a simple point iterative scheme), followed by a more exact solution of the pressure correction equation (using the *PETSC* (Ref. 17) *parallel LU pre-conditioning + GMRES utilities*).

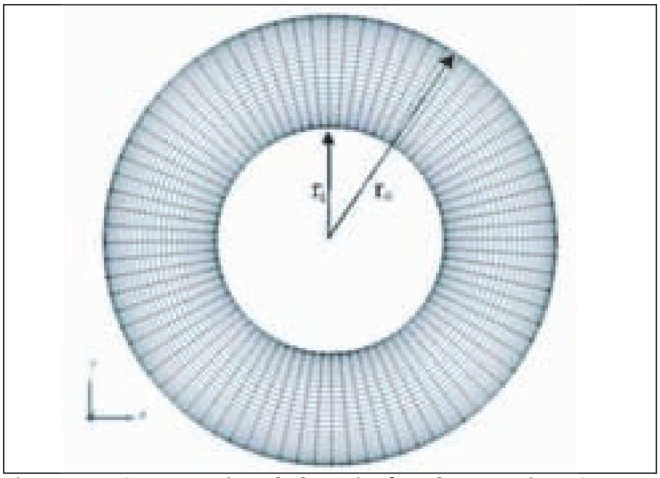

Figure 3—Computational domain for the rotating Couette flowcase.

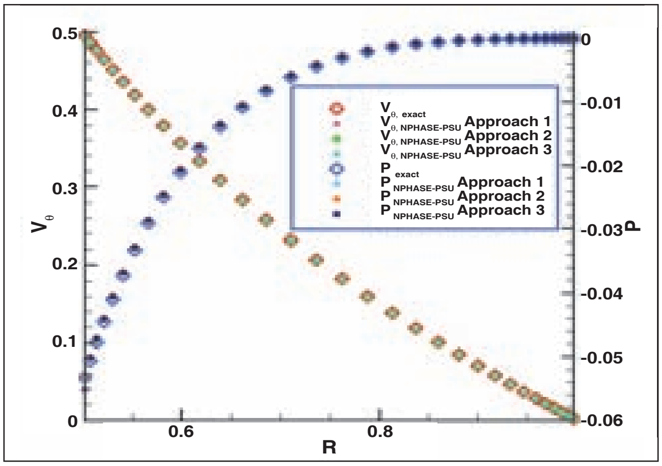

Figure 4—Comparison of *NPHASE-PSU* and analytical solutions for the rotating Couette flow case.

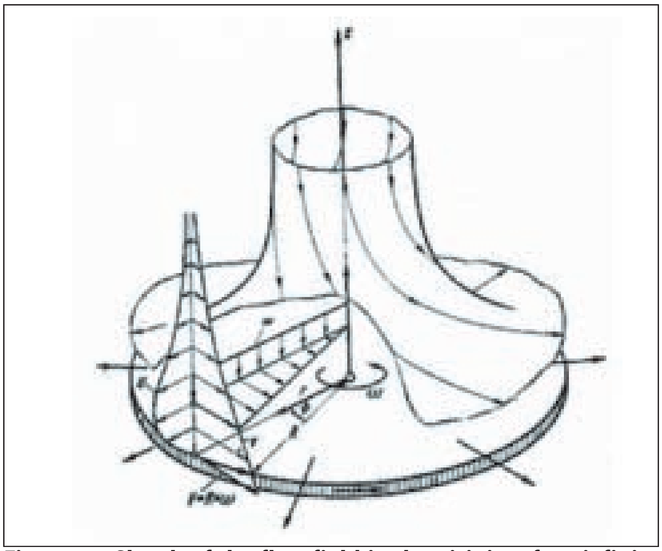

Figure 5—Sketch of the flow field in the vicinity of an infinite span rotating disc.

Turbulence scalar and energy equations are then solved in succession. Parallelization is implemented in a standard fashion by invoking domain decomposition based on *METIS* (Ref. 18) in the front end, and MPI-based message passing in the CFD code. All of the large-scale simulations presented in this paper were executed on the Columbia supercomputer at NASA Ames Research Center. The code scales very well on this system, as illustrated in Figure 2.

DiRTlib and SUGGAR. The overset grid approach (Ref. 19) utilizes a composite grid consisting of a set of overlapping component grids to discretize the domain. No point-to-point or face-to-face matching is required between component grids. The solution on the component grids is linked by identifying appropriate intergrid boundary points (IGBPs) where the solution is given by a specified boundary value obtained by interpolation from another overlapping donor component grid. The overset domain connectivity information (DCI), which consists of the identification of the inter-grid boundary points and corresponding interpolation sources, is obtained by an overset grid assembly step. The current effort utilizes two overset software libraries to add the overset capability to *NPHASE-PSU*.

DiRTlib (Ref. 20), which stands for *Donor Interpolation Receptor Transaction library*, is a solver-neutral library that encapsulates the functionality required by the solver to utilize the overset domain connectivity information. It is independent of the solver grid storage and topology, dependent variables, etc., and can be used with any solver.

The current overset grid assembly process is performed using the *SUGGAR* code (Ref. 21), which stands for *Structured, Unstructured, Generalized overset Grid Assembler*. *SUGGAR* is a general overset grid assembly code with the capability to create the domain connectivity information at node and/or element centers for most current grid topologies, including any combination of structured Cartesian and curvilinear, unstructured tetrahedral and mixed element, general polyhedral and octree-based Cartesian grids. For static grid assemblies with no motion between component grids, the grid assembly is a pre-processing step. The case of solution and time-dependent motion requires the solver to communicate the new body and grid positions to the grid assembly process, wait for it to complete, and then load the new DCI. For the case of prescribed motion, such as used in the present study, the DCI is a-priori-computed and saved in a file for each time step in the simulation, and the solver simply loads the file appropriate for each time step.

The donor interpolations produced by *SUGGAR* are a set of linear weights that multiply the values at the donor members. For a cell-centered flow solver, such as *NPHASE-PSU*, the interpolation stencil will use as members the cell in the donor grid that was found to contain an IGBP and the neighboring cells that share a face with the donor cell. The interpolation weights are computed using an un-weighted, least-square procedure.

Results

Verification studies. In the context of the overset meshing strategy employed for gearbox windage simulations, the meshes will be in motion relative to one another. As indicated above, the approach taken here is to solve the flow in the absolute frame of reference for the entire computational domain, i.e., on all meshes—those that are rotating and those that are stationary. In order to verify that *NPHASE-PSU* correctly handles these gear-relevant rotating mesh systems, two verification studies were performed—rotating Couette flow, and flow near an infinite rotating disc—both of which have available analytical solutions.

Rotating Couette flow. Figure 3 is an illustration of the 33 x 81 (radial x azimuthal) computational domain for the incompressible rotating Couette flow case. The r_{inner} and r_{outer} boundaries are walls. In this case, inner = 0.5 and outer = 1.0. The outer cylinder is held stationary and a rotation rate of ω= 1s^{-1} is specified for the inner cylinder. The Reynolds number independent analytical solutions for the tangential velocity and pressure are:

$$V_\theta = Cr\left(1 - \frac{1}{r^2}\right) \quad (4)$$

$$p = \rho\left(\frac{C^2 r^2}{2} - 2C^2 ln(r) - \frac{C^2}{2r^2}\right) \quad (5)$$

$$C = -\frac{\omega}{3} \quad (6)$$

Figure 4 shows a comparison of the analytical solution with three *NPHASE-PSU* runs, designated Approaches 1, 2 and 3. Approach 1 solves the absolute velocities in the absolute frame on a stationary grid (adapting inner cylinder boundary conditions accordingly). Approach 2 solves for the relative velocities in the relative frame on a stationary grid (i.e., frame-of-reference rotating with angular velocity, ω, adapting the momentum equation source terms and outer-cylinder boundary conditions accordingly).

Approach 3 solves for absolute velocities in the absolute frame using a time-accurate analysis on a rotating mesh. Approach 3 is the most relevant for gear analysis. Figure 4 illustrates that the code returns the analytical solution for all three simulation approaches to within the accuracy of the second-order accurate discretization numerics and grid used.

Flow near an infinite rotating disc. The second verification case is a classic 3-D exact solution to the incompressible Navier-Stokes (N-S) equations. An infinite radial span disc rotates with an angular velocity, ω. This induces tangential flow in the direction of rotation, radial outflow and an axial flow towards the center of the disc. In this case, the N-S equations reduce to a system of non-linear ODEs, which can essentially be exactly solved numerically. Figure 5 is a notional sketch of the flow field from Schlichting (Ref. 22).

Figure 6 shows the 232,662-element unstructured mesh employed for the analysis. The extent of the computational domain was selected to be r_{max} = 1.0, z_{max} = 1.0. For a choice of ω = 1.0 and μ= 1.0 x 10^{-2}, this domain provided that the solution sampled within the region r ≤ 0.2, z ≤ 0.4 compares very closely with the exact solution despite the necessarily finite extent of the domain.

NPHASE-PSU was applied using two approaches. Approach 1 solves the absolute velocities in the absolute frame on a stationary grid (adapting disc boundary conditions accordingly). Approach 2 solves for absolute velocities in the absolute frame using a time-accurate analysis on a rotating mesh. Figure 7 illustrates that the code returns the exact solution for both simulations to within the accuracy of the second-order accurate discretization numerics and grid used.

Couette flow with wall heating. The third validation performed sought to verify the viscous dissipation term implementation in *NPHASE-PSU*. The relevance of viscous dissipation physics to gear windage is significant, as discussed above. The analytical solution for the temperature distribution in a laminar linear Couette flow was chosen. Figure 8 shows a diagram of the configuration. The product of the Prandtl number ($Pr \equiv \mu Cp/k$) and the Eckert number ($Ec \equiv U_1^2/C_p(T_1 - T_0)$), *PrEc*, is a measure of the role of viscous dissipation in a flow. The nearly exact comparisons between CFD result and the analytical solution, shown in Figure 9, across a range of *PrEc*, illustrates that the viscous dissipation terms in *NPHASE-PSU* are implemented correctly.

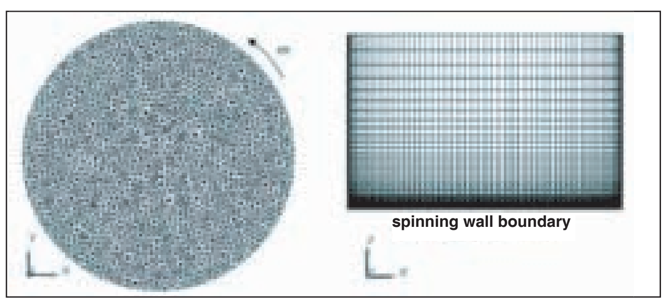

Figure 6—232662 element unstructured mesh employed for the infinite spanning rotating disc.

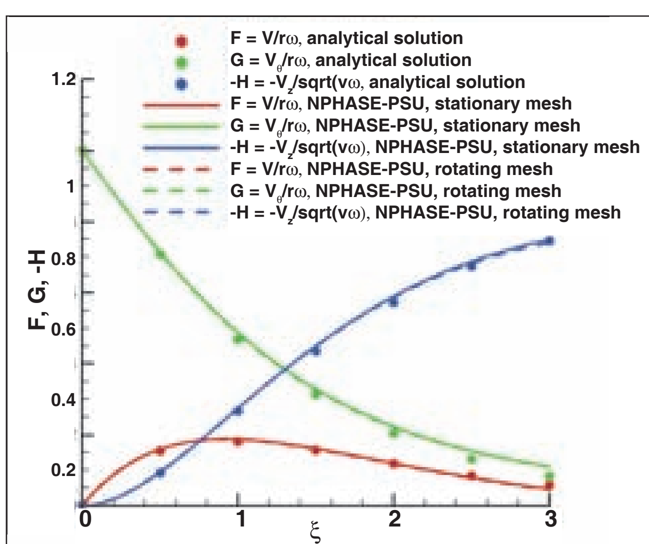

Figure 7—Comparison of *NPHASE-PSU* and exact solutions for the infinite span rating disc.

Validation studies. The experimental data of Diab, et al. (Ref. 8) was used to validate *NPHASE-PSU* for the case of un-shrouded, isolated, rotating spur gears. Diab, et al. tested four different spur gears and a disc in free air on a spin-down test rig. The gears varied in diameter, width and tooth count. The properties of the gears and disc are provided in Table

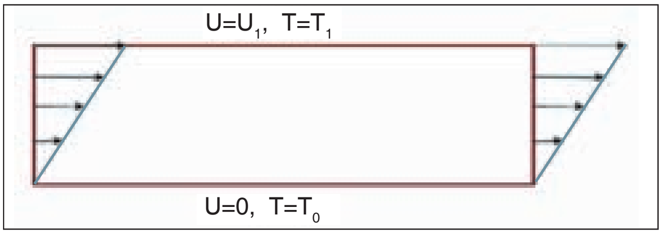

Figure 8—Illustration of the linear heated Couette flow case.

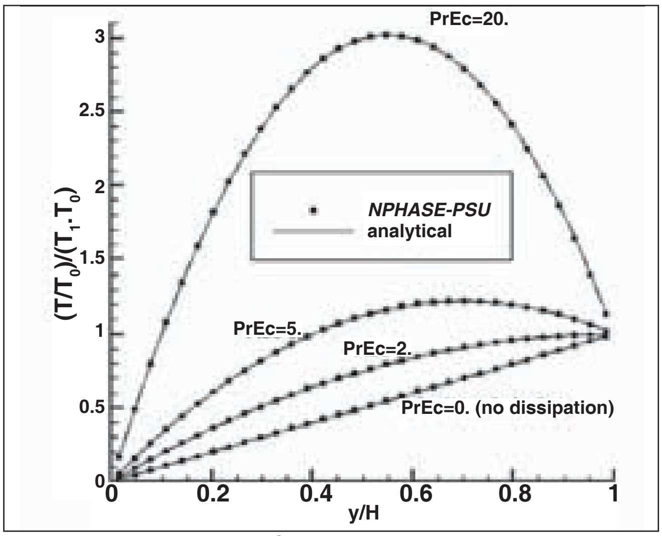

Figure 9—Comparison of *NPHASE-PSU* and exact solutions for the linear heated Couette flow case.

Table—1 Diab et al.(Ref. 8). Gear Properties.			
	Pitch Diameter(mm)	Tooth Width (mm)	Module (mm)
Gear 1	288	30	4
Gear 2	144	30	4
Gear 3	144	60	4
Gear 4	144	60	6
Disk	300	30	

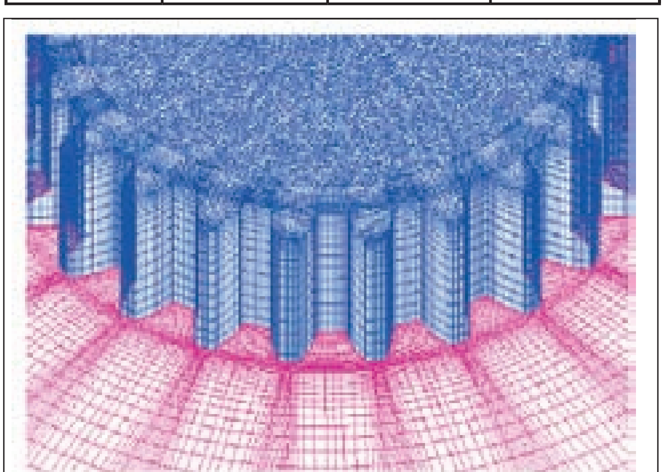

Figure 10—Grid topology of Gear 4.

1. Diab, et al, did not study the effects of gear enclosure or lubrication. A sequence of prescribed constant rotation rate simulations was used to replicate the experiment.

Single grid simulations. Grids were generated for all four spur gears and the disc. For the gear studies where the high-Reynolds number k-ε turbulence model was used, near-

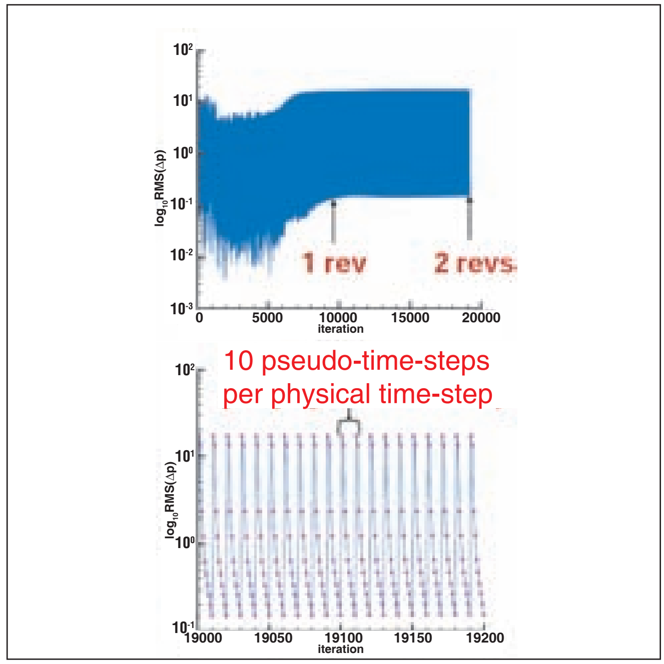

Figure 11—Example convergence history for Diab Gear 4.

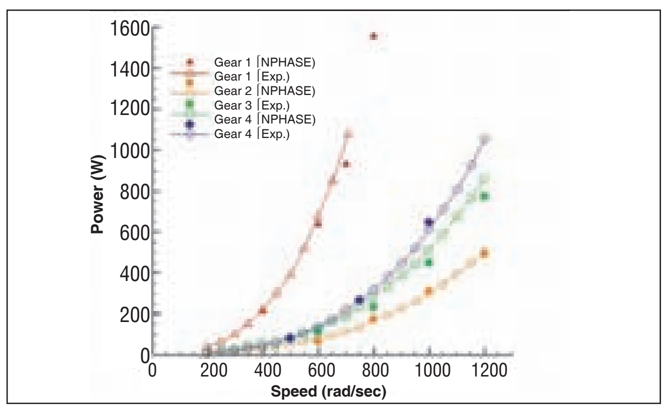

Figure 12—Comparisons between the experimental results and the *NPHASE-PSU* analysis.

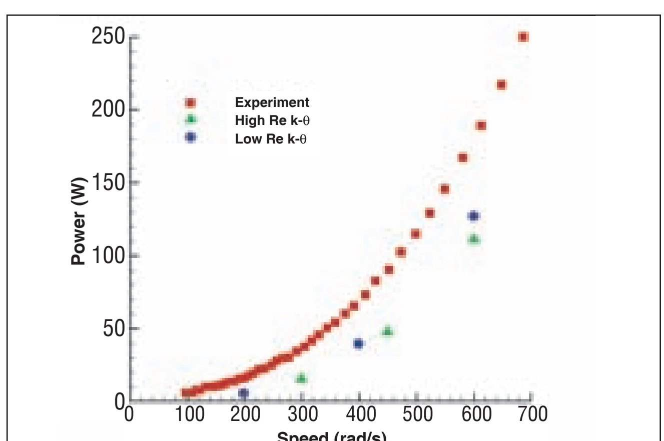

Figure 13—Effect of turbulence model selection on viscous work prediction.

wall grid spacing was defined to accommodate wall-functions (e.g., y+ ~ 70 for gear 1, ω= 1000s^{-1}). The single plane of symmetry in the problem was exploited to reduce total cell count by a factor of 2. Grid cell counts for the different cases varied between 2 x 10^6 (Gear 4) and 8 x 10^6 (Gear 1). Grid generation was further simplified by employing a hybrid mesh topology, as illustrated in Figure 10. Specifically, for the regions above the surface of the gear teeth to the outer boundary, structured hexahedral cells were used. For the region above the gear face surface, unstructured prism cells were employed. The meshes were generated using the commercial grid generation software package *Gridgen* (Ref. 23). The computational domain of the isolated gear grids was extended to approximately five times the gear radius from the gear surface in all directions. This distance was adequate for defining a symmetry boundary condition since the flow is nearly stagnant there.

An azimuthal step size of 1/40th of one tooth passage duration (the time it takes one tooth to rotate to the position of the tooth adjacent to it) was used in all CFD calculations. This corresponds to 2,880 time-steps-per-gear revolution for Gear 1, 1,440 time steps for Gears 2 and 3, and 960 time steps for Gear 4. All cases used 10 pseudo-time iterations per physical time step.

CFD runs were made for four gears and the disc at a number of rotation speeds. All cases were run for at least two complete revolutions to remove simulation startup transient behavior. Convergence histories show that transients leave the solution after about one revolution, as illustrated in Figure 11, where it is also observed that pseudo-time residual drop approximately two orders of magnitude in each physical time step when 10 pseudo-time steps are used per physical time step.

Comparisons between the power loss results of Diab et al., (Ref. 8) and the *NPHASE-PSU* analysis are presented in Figure 12 for all four gears. The CFD analysis for all four gears exhibited very good agreement with experiment. The disc case, however, did not share this same level of agreement, as illustrated in Figure 13, where *NPHASE-PSU* results are seen to under-predict the measured power loss. In order to elucidate the reasons for the deterioration in solution accuracy observed for the disc case, a number of observations and studies were made. First, it is observed that the measured (and computed) windage loss power levels for the disc are much smaller than the comparably sized spur gear (Gear 1, D ~ 300 mm). This arises due to the absence of any azimuthal pressure variation in the disc flow. Torque losses are due entirely to viscous effects, and these are clearly under predicted. Indeed the absolute magnitudes of loss under-prediction between the disc and Gear 1 are comparable (e.g. ~ 50W @ 600s^{-1}), so presumably this under prediction of shear is present in all of the gear simulations; however, its relative magnitude is small.

To explore this further, the low-Reynolds number Menter

continued

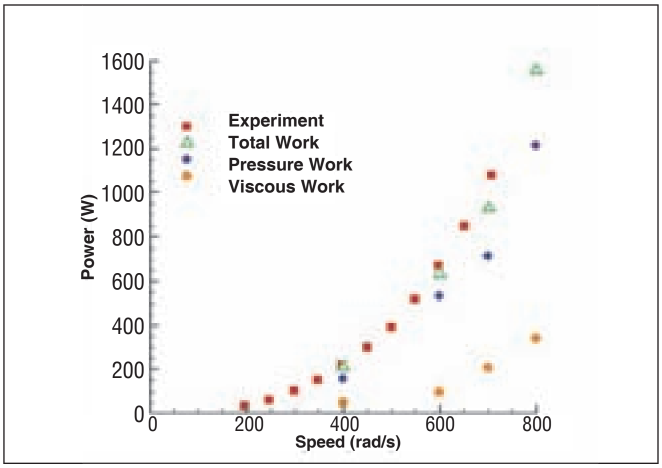

Figure 14—Breakdown of windage power losses for Diab 1.

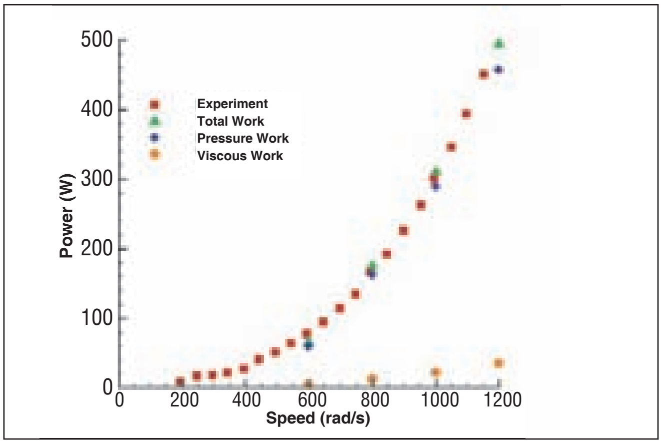

Figure 15—Breakdown of windage power losses for Diab 2.

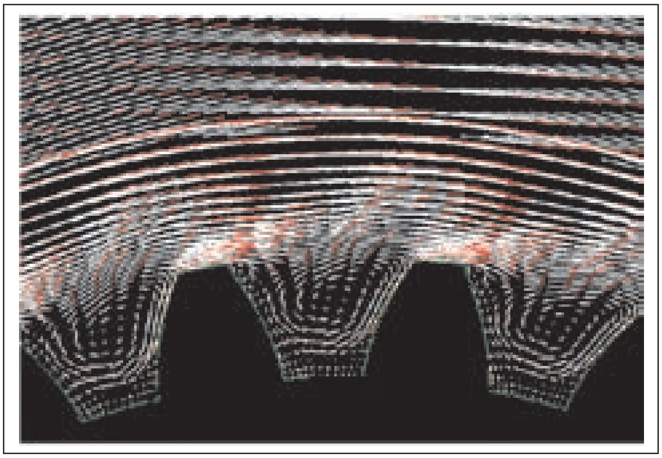

Figure 16—Predicted velocity vectors in the symmetry plane of a Diab gear.

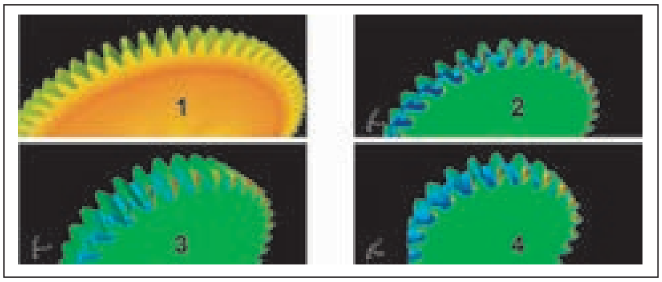

Figure 17—Predicted surface pressure distributions for the four Diab gears.

model was applied to the spinning disc case (using an appropriate sublayer resolved mesh). Figure 13 illustrates that improved turbulence modeling does benefit solution accuracy, especially at higher rotation rates. This observation is not as important for the gear cases since the spindown torques

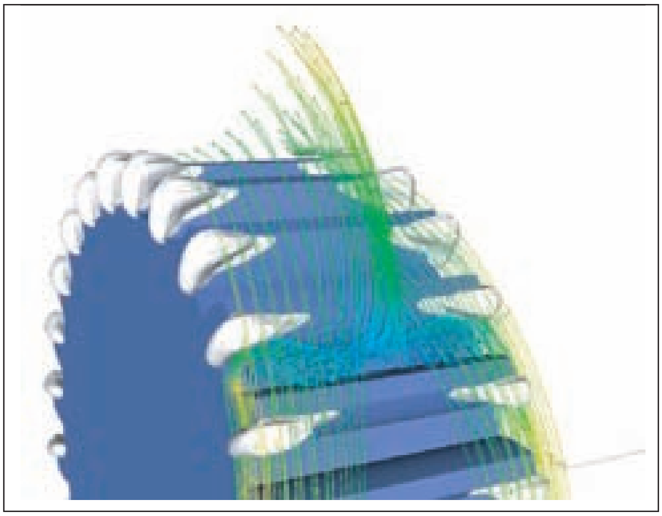

Figure 18—Predicted relative frame streamlines and isosurface of a high pressure region for Diab Gear 4.

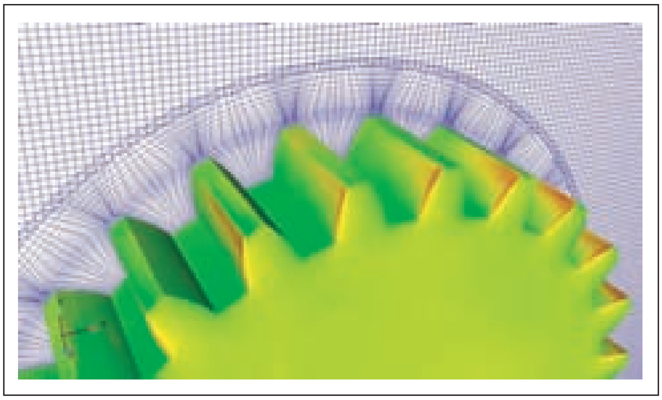

Figure 19—Verification study: 3-D overset grid solution and topology for Diab Gear 4.

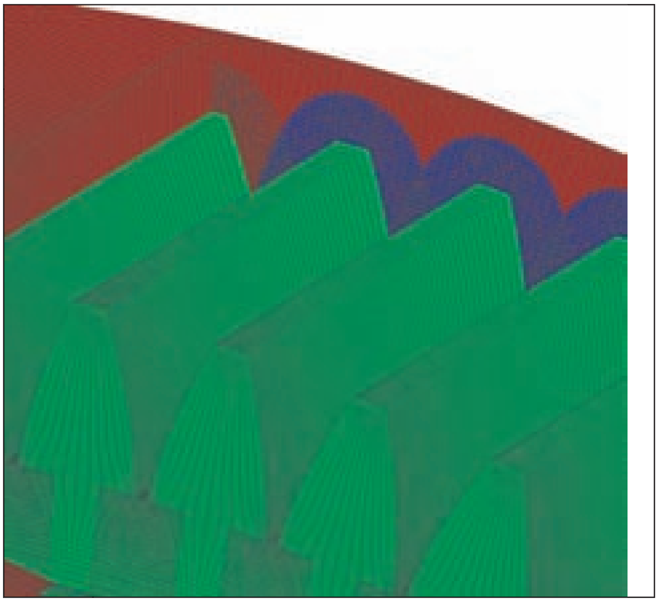

Figure 20—Validation study: 3-D overset grid topology for Dawson shrouded gear.

associated with azimuthally varying pressure forces in the vicinity of the gear teeth dominate the viscous forces as shown in Figures 14 and 15. It can be seen that, especially at lower rotation rates, the contribution of viscous loss to total windage loss, is small. However, we do observe that at higher pitchline velocities, the relative magnitude of the viscous torque increases with respect to the pressure torque. This can be seen for higher rotation rates on Gear 1 (Fig. 14), as well as by considering the smaller size (and hence lower pitchline velocities) of Gear 2 (Fig. 5).

Results suggest that for the very high-speed gears to be encountered in rotorcraft (and other high-performance aircraft) transmissions, viscous effects will become more important than encountered here and will require attendant research attention.

Details of 3-D flow field. A number of important physical features of the predicted flow field are available upon interrogation of the CFD simulations. Figure 16 shows a view of the predicted secondary velocity vectors on the symmetry plane in the gear-relative frame of reference for one of the Diab cases. One can see a significant vortical structure within the gear tooth region, and the tooth-to-tooth periodicity that has been achieved in the transient simulation. Figure 17 shows a view of the predicted surface pressure distributions for the four Diab gears. There, comparatively large vs. small pressures are observed on the leading and trailing tooth faces, this difference being the source of the pressure component of the spin-down torque. The 3-D nature of the flow in these relatively low aspect ratio spurs gears is also clearly seen (figure shows only 1/2 of each gear). Significant 3-D effects are also clearly visualized in Figure 18, where gear-relative streamlines are displayed in the near-tooth region along with an isosurface of predicted static pressure in a region of high pressure.

Overset grid simulations. As of this writing, the overset capability for spinning gear simulations has been established in *NPHASE-PSU*. In this context, we are pursuing an overset verification effort and a relevant validation effort. The verification effort involves solving isolated spinning gear cases studied above using a rotating near-gear mesh and a stationary far-field mesh, the necessary approach to be used in ongoing gearbox windage activities. Figure 19 shows a view of an overset Diab Gear 4 simulation. Surface pressure contours are displayed, along with overset gear and background meshes on the symmetry plane. As expected, the CFD code returns nearly identical results for this moving grid overset simulation to the non-overset results reported above. We continue to parameterize gridding requirements in the overlap region, including the proximity of the overlap region to the gear in assessing the retained accuracy of the overset approach.

The validation effort under way involves simulating a series of shrouded low-speed gears for which windage loss measurements were made by Dawson (Ref. 7). To date, we have developed valid overset assembly grid topologies for this, as shown in Figure 20, and anticipate reporting CFD analysis for these configurations in the near future.

Conclusion

This paper has summarized the adaptation and validation status of a CFD method for gear windage aerodynamics. Validation studies of 3-D spur gears in free space demonstrate very good agreement with published data. The following conclusions apply:

1) Viscous/turbulence modeling was identified as a shortcoming since loss power was consistently under-predicted for the viscous-drag-only spinning disc cases.

2) Low-Reynolds number (sublayer resolved) turbulence modeling exhibited improved performance for this case.

3) High-Reynolds number two equation modeling proved appropriate for modeling the moderate speed Diab spur gear suite, due apparently to the dominance of the pressure torques on spin-down.

4) The budgets of viscous and pressure components of spin-down torque suggest that viscous effects will become much more important, perhaps exceeding 50%, for gears with pitchline speeds approaching twice that investigated here.

5) Overset meshing is and will continue to be a critical enabler in this effort. The capability has been established and demonstrated here and will become integral in further studies where the isolated gear assumption will not be relevant.

Acknowledgments

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September 7-9—Gear Manufacturing Troubleshooting Course. Anaheim, CA. This training school for gear manufacturing is a basic course offered by the Gear Consulting Group in regional versions throughout the year to reduce the time employees spend out of the office while training. Another session this year will take place in Ontario, Canada, date to be announced. Instructors Geoff Ashcroft and Ron Green teach participants both theory and practical aspects of gear manufacturing while imparting knowledge of everyday problems and understanding how to think through troubleshooting. Tuition is $750 and includes a reference manual and certificate of completion from AGMA. For more information, call (269) 623-4993, or e-mail *gearconsulting@aol.com*.

September 15-17—Gear Expo. Indianapolis. For the first time since 1995, the gear industry's premier trade event returns to Indianapolis featuring five pavilions on the show floor: aerospace, breakdown, energy, powder metal/plastics and tooling. AGMA anticipates more than 175 exhibitors and 3,000 attendees from 43 states and 36 countries. This year's Gear Expo is co-located with the Heat Treating Society's Conference and Exposition, which is expected to add another 3,000 attendees and 180 exhibitors. For more information, go to *www.gearexpo.com* or visit our *Gear Technology* **Gear Expo Showroom** at *www.geartechnology.com/gearexpo*.

September 15-17—SME Gear Manufacturing Conference. Indianapolis Convention Center, Indianapolis. This SME conference within Gear Expo runs Tuesday and Wednesday from 9 a.m. to 4 p.m. Features include a full lineup of 14 speakers and diverse topics from calibration and measurement uncertainty with Edward Lawson of Gleason-M&M Precision Systems Corp. to tool resharpening procedures for maximizing tool life with Ken Nemec of American Broach and Machine. Other topics include carbon dioxide cooling for cutting gears, coatings, metalworking fluids, gear metals, process optimization and developments in the wind industry. For more information, visit *www.sme.org/gears.*

September 28-30—Gear Failure Analysis Seminar. Big Sky Resort, Big Sky, MT. AGMA's Technical Academy and Robert Errichello of GEARTECH present students with complete knowledge of gear failure, what to watch out for and how to resolve problems. The seminar was expanded this year to two full days of discussion plus a half-day workshop for students to investigate and solve real gear failure scenarios. Errichello uses lectures, slide presentations, hands-on workshops with failed gears and Q&A sessions. The course is suitable for gear engineers, users, researchers, maintenance technicians and lubricant experts or managers. Cost is $895 for AGMA members, $995 for nonmembers. Register online at *www.agma.org* until August 28.

September 29-October 1—Aero and Defense Test 09/ITEA Annual Symposium. Baltimore Convention Center, Baltimore, MD. This annual event for aerospace and defense R&D, test and evaluation and operational test and evaluation features a trade show with approximately 150 exhibitors providing testing, inspection and evaluation software and products. The expo is complemented by a series of technical, business and educational programs that includes the International Test and Evaluation Association's (ITEA) annual symposium, the Society of Manufacturing Engineers' aerospace quality manufacturing conference, the Aerofuel Alternative Fuel and Fuel Cells Symposium and the Global Aircraft Recycling Symposium. For more information, visit *www.aerodefensetest.com*.

September 30-October 2—Fundamentals of Gear Design. UWM School of Continuing Education, Milwaukee, WI. This beginning knowledge course is presented by Raymond Drago and the University of Wisconsin School of Continuing Education. It presents basic modern gear system design and analysis with emphasis on proper selection, design application and use, as opposed to fabrication. Topics include a short history, basic gear nomenclature, types of gears, gear arrangements, theory of gear tooth action and failure modes and prevention. Cost is $1,095. For more information, contact Murali Vedula, program director, (414) 227-3121 or *mvedula@uwm.edu*.

October 26-29—Furnaces and Atmospheres for Today's Technology. Holiday Inn Express, Meadville, PA. This annual event hosted by Seco/Warwick allows industry specialists to present the latest improvements in heat treat furnaces and provide practical information for companies new to heat treating. The format this year has been changed to present information on support technologies and industry trends. Speakers will address the history and progress of the technology while providing information on process development over the past year. Topics include furnace selection and application, fundamentals of heat transfer, nature of vacuum, leased atmospheres, alloy applications, temperature control, heating elements and power control units. Dan Herring, aka the "heat treat doctor" is the keynote speaker. For more information, visit *www.secowarwick.com/F&A.html*, or contact Gary Armour at (814) 332-8558 or *garmour@secowarwick.com*.

Merit Gear

EXPANDS HEAT TREATING CAPABILITIES

Plunge—accelerated—cooling of the large furnace loads prior to quenching can be accomplished by passing cool air through the inside of the radiant tubes (courtesy Merit Gear).

Merit Gear LLC, a precision gearing company, has invested in a major plant expansion to accommodate in-house machining and heat-treating equipment. The company was founded in 1952 to service tractor replacement and general machine applications. Merit Gear has continuously expanded its capabilities and operations to service and broaden its customer base. That includes new industries that utilize gearboxes in applications such as mining, water well drilling, oil field, fire trucks and the rapidly growing wind energy market.

This recent investment consisted of a 52,000-square-foot building expansion, of which 10,000 square feet were dedicated to a heat treating cell and additional machining equipment. The expansion has allowed Merit Gear to increase machining capability for processed parts up to 132" (3.35 meters) in diameter. The in-house heat treating capability, which was previously limited to small-batch, integral quench furnaces, has been increased to include large-atmosphere, pit-type furnaces and auxiliary equipment capable of processing 30,000-pound loads up to 90" in diameter. The new heat treating equipment was designed to process large gear and pinion products that require optimal temperature and atmosphere control to meet challenging process requirements.

The heat treating facility expansion was designed, manufactured and installed by Surface Combustion, Inc., located in Maumee, OH. The heat treating cell features three radiant-tube-heated, atmosphere-type pit carburizing furnaces, two direct-fired pit temper furnaces and two companion oil quench tanks. Surface Combustion completed the commissioning of the equipment and the training of Merit Gear's personnel in January of 2009. In addition to the heat treating equipment, auxiliary equipment to complete the expansion included two 25-ton building cranes, a washer system and a shot blast system.

Heat Treating Equipment Design Features

The new pit-carburizing furnaces include many features and provide consistent, repeatable process cycles resulting in high-quality parts being produced. The furnaces are in effect heated by radiant tubes surrounding the outside diameter of the workload area. These tubes use non-recuperated natural gas burners. This design approaches the system efficiency of recuperated designs due to the correct application of the burners on long heat treating cycles required for deep case depths. As an added feature, "plunge cooling"—or accelerated cooling of the large furnace loads prior to quenching—can be accomplished by passing cool air through the inside of the radiant tubes.

Each pit-carburizing furnace is configured to operate with Merit Gear's existing nitrogen/methanol atmosphere system. The system includes a high/low flow feature to allow atmosphere conservation during the long heat-treating cycles. A closed-loop carbon potential control system is included for precise furnace atmosphere control. This system utilizes a process controller and oxygen probe arrangement to monitor carbon levels in the furnace. As an enhancement

Each quench tank includes multiple agitators working in conjunction with a fully baffled workload area to direct high-velocity oil around the parts to be quenched (courtesy Merit Gear).

The expansion has allowed Merit Gear to increase their machining capability for processed parts up to 132" (3.5 meters) in diameter (courtesy Merit Gear).

to the control system and its capabilities, a sample part test port is included in the furnace cover to allow in-process evaluation of the carburizing process. The test port provides for the removal of test pins for quenching and review of the results prior to completion of the cycle for the load being processed. This evaluation allows for the long furnace cycles to be adjusted in real time as needed for precise part carbon profiles.

To provide uniform temperatures and atmosphere flow to the work being processed, each furnace is provided with Surface Combustion's patented vibration damping fan design mounted on the furnace cover. The fan works in conjunction with an internal alloy shroud for improved atmosphere and heat circulation. Thermal profiles performed during the commissioning period of the furnaces showed temperature uniformity within the effective workload area of the furnace to be within ± 10 degrees Fahrenheit between the temperatures of 1,550 and 1,750 degrees Fahrenheit.

After heating and processing parts in the carburizing furnaces, the overhead building crane is utilized to remove the load and transfer it into one of the 30,000-gallon oil quench tank systems. Each quench tank includes multiple agitators working in conjunction with a fully baffled workload area to direct high-velocity oil around the parts being quenched. The quench system includes an air-to-oil heat exchanger system and a gas-fired immersion radiant-tube heating system to either cool or heat the oil and provide precise control of the quench oil temperature for the critical quenching process.

At the completion of the quench portion of the heat treating process, the parts and fixture are transferred to the batch washer unit. The washer is an integrated cleaning unit that uses a gas-heated, alkaline-type system. It incorporates a

continued

high-pressure spray arrangement to remove residual quench oil from the parts prior to the tempering portion of the cycle.

Two direct gas-fired pit temper furnaces are provided—not only to provide the post-quench temper requirements, but also to allow for load pre-heating prior to loading into the pit-carburizing furnaces.

The furnaces have a wide operating temperature range to service both the pre-heat and temper portions of the overall process requirements. The maximum operating temperature is 1,200 degrees Fahrenheit. The furnaces are an extension of Surface Combustion's patented high-convection design, which utilizes a circular wind flow along the inside of the furnace wall in conjunction with a second circular pattern in the center of the furnace. These patterns are fed back to the cover-mounted fan unit and burners to promote overall temperature uniformity throughout the work area of the furnace. With this design, the measured temperature uniformity in the effective workload area was within ± 10 degrees Fahrenheit.

Specific Heat Treatments

As previously stated, components heat treated in Merit Gear's new pit furnace equipment include very large gears and pinion products. The largest gear products may exceed 12,000 pounds per gear, with gross loading capacity in the furnaces being 30,000 pounds for multiple-part loads. The typical carburizing process cycles require very deep, effective case depths between 0.080" and 0.120". Cycles to obtain these case depths can require days.

The current and future growth of the energy market requires ever-increasing part sizes, specifically requiring larger and better-engineered gearboxes. Merit Gear has invested in the equipment and technology to produce these products efficiently.

Merit Gear has invested in a major plant expansion to accommodate in-house machining and heat treating equipment (courtesy Merit Gear).

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PM Conference

AWARDS FELLOW, DISTINGUISHED SERVICE

The 2009 International Conference on Powder Metallurgy and Particulate Materials took place June 29 in Las Vegas, and the industry used the opportunity to present awards to Animesh Bose, named to the 2009 Class of Fellows, and several individuals recognized for distinguished service to the field of powder metallurgy.

The following professionals received a Distinguished Service to Powder Metallurgy Award: Gary L. Anderson, vice president of engineering, Keystone Powdered Metal Company; John C. Hebeisen, former president, Bodycote HIP, Inc.; Thomas J. Jesberger, chief technology officer, Abbot Furnace Company; Shiz Kassam, director of advanced product engineering, Keystone Powdered Metal Company; Lou Koehler, president, Koehler Associates LLC; Kalathur S. Narasimhan, vice president, chief technology officer, Hoeganaes Corporation; Charles L. Rose, former sales manager of PM Tooling division, Bronson & Bratton Inc.; John A. Shields, Jr., principal, PentaMet Associates, LLC and president, Mill Creek Materials Consulting; Thomas L. Stockwell, Jr., former business account manager, Burgess-Norton Mfg.; Ted A. Tomlin, former vice president of tech-

The MPIF handed out various industry awards at the Industry Recognition Luncheon held during PowderMet2009 (courtesy of MPIF).

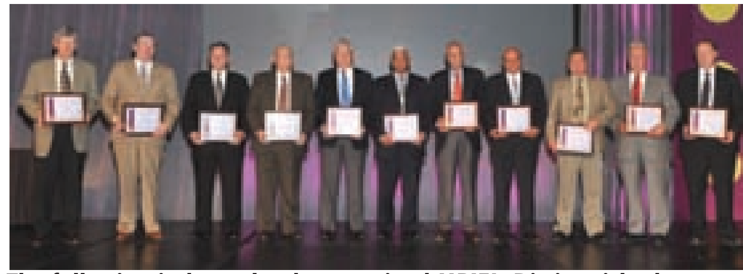
nology, FloMet LLC; and Robert F. Unkel, former manager of PM marketing, Cincinnati Incorporated.

Bose is president of Materials Processing, Inc., in Haltom City, TX. The Fellow Award is given to American Powder Metallurgy Institute (APMI) members who have made significant contributions to the society and have great expertise in PM technology and the practice or business of the PM industry. Fellows are elected based on their professional, technical and scientific achievements, continued professional growth and development, mentoring/outreach and APMI contributions.

With 25 years dedicated to the PM industry, Bose is recognized for his work in materials processing. His promotion of powder injection molding technology is known internationally from his licensing and technology transfer undertak-

continued

Animesh Bose (right) accepts the 2009 Fellow Award from Nick Mares, APMI president (courtesy of MPIF).



The following industry leaders received MPIF's Distinguished Service to Powder Metallurgy Award at PowderMet2009 (shown from left to right): Charles L. Rose, John A. Shields, Jr., Thomas L. Stockwell, Jr., Ted A. Tomlin, Robert F. Unkel, Kalathur S. Narasimhan, Lou Koehler, Shiz Kassam, Thomas J. Jesberger, John C. Hebeisen, and Gary L. Anderson (courtesy of MPIF).

ings. He has also made contributions in alloy development emphasizing refractory metals, carbides, hard metals, intermetallic compounds and other advanced materials.

Bose received a bachelor's degree in metallurgical engineering and a doctorate in engineering from the Indian Institute of Technology, Kharagpur. He co-founded Materials Processing, Inc. in 1999, which specializes in precision injection molding of hard materials, cermets and advanced ceramics.

Bose has been a member of APMI for more than 23 years, and he has served on the board of directors. He also has served as co-chairman of several international conferences, including six Metal Powder Industries Federation (MPIF) conferences on tungsten, refractory and hard materials, and he has served on various technical program committees. He has authored over 115 technical papers, several books and is named in eight U.S. patents.

Kisssoft

APPOINTS ENGINEERING MANAGER

James Marsch is now engineering manager, North America for Kisssoft, U.S.A., LLC. He has over 40 years of practical engineering design and manufacturing experience including eight years of specific application support and consulting projects involving metal and plastic gearing for a range of customers. He has been employed by Allis-Chalmers, Harnischfeger Corporation, Morris Material

Handling and Universal Technical Systems.

Marsch will provide engineering consulting, customer support and training in North America for Kisssoft. “We are fortunate to have Jim join our team here and look forward to offering our customers more services,” says Dan Kondritz, national sales manager for Kisssoft, U.S.A.

Moore Gear

COMPLETES BUILDING EXPANSIONS

Moore Gear and Manufacturing’s Hermann, MO facility now includes approximately 54,750 square feet after two expansion projects were completed.

The east side of the building is now 7,500 square feet bigger than before. This improved the shipping department by adding loading docks and space for maneuvering shipments in and out of the factory. A former industrial facility adjacent to the property was acquired as part as the expansion to the west side of Moore Gear. This is a 13,500-square-foot building that rests on four and half acres of level land. Moore intends to use the facility to store surplus machines, stock material and to free manufacturing space in Moore’s original building.

The building expansions also included new additions in CNC equipment to increase capacity and productivity. Machinery added includes a CNC gear hobber, hob sharpener, gear checking machine, 10-foot long CNC machining center, gear rack milling machine and cylindrical grinder.

Nordex

Opens North American Headquarters

On May 5, German wind turbine manufacturer Nordex officially opened its U.S. headquarters in downtown Chicago. The decision to set up shop here was influenced by the central geographic location in North America, proximity

continued


(courtesy of Nordex)

to areas of major wind industry growth and environmental leadership by the city.

"Centering our business in Chicago brings us closer to our customers and suppliers and puts us in the heart of the wind industry," says Ralf Sigrist, president and CEO of Nordex. "It will also support our strategy of generating 20 percent of global revenues here, while helping the U.S. to achieve its ambitious renewable energy goals and to build a vibrant domestic industry."

Mayor Richard M. Daley expressed his enthusiasm and welcomed Nordex USA to Chicago at a news conference. "When a company such as Nordex makes a commitment like this one, it sends a strong message to the business community that our leaders work together and that Chicago can meet the needs of any company in the world—from the largest to the smallest."

Nordex currently employs 2,200 people worldwide and has experienced over 50 percent growth in sales for the

(courtesy of Nordex)

fourth consecutive year, with 2008 sales reaching $1.5 billion. "Nordex sees the U.S. as one of the biggest growth markets for wind energy in the world," Sigrist says. "That's why in addition to setting up operations in Chicago, we will also manufacture our turbines here."

Plans to build a manufacturing plant in Jonesboro, AR were announced in October 2008. Nordex estimates investing $100 million in the factory, which should create more than 700 jobs in Jonesboro and 100 in Chicago by 2015. Construction is expected to begin this year and production planned for 2010. In Jonesboro, Nordex plans to manufacture every component of its multi-megawatt turbines except the tower, hoping for annual assembly capacity of 750 megawatts. Nordex is also looking to build a home grown supply chain in the country.

"Establishing a firm operating and manufacturing presence will enable Nordex to keep better pace with strong demand in the U.S., which has outstripped our ability to import turbines manufactured abroad fast enough," Sigrist says. "From Chicago, we will be in the capital of the wind industry, and from Jonesboro, we will be at a geographic center for product distribution."

Vestas Americas

APPOINTS PRESIDENT

Martha Wyrsch (courtesy Vestas Wind Systems).

Martha Wyrsch has been selected to serve as president for Vestas Americas, the business unit responsible for wind turbine sales, installation and service and maintenance in the United States and Canada. Wyrsch has almost 20 years of experience in the North American energy sector. She began work June 15 at Vestas Americas' headquarters in Portland, OR.

Over the past two years, Wyrsch served as president and CEO of Spectra Energy Transmission, a Houston-based nat-

continued

ural gas infrastructure company, and was president and CEO of Duke Energy Gas Transmission.

"Martha's commitment to safety, customer satisfaction and communication, combined with proven business results, makes her an ideal fit for our growing North American market," says Ditlev Engel, president and CEO of Vestas. "I know she will further enhance our vision of 'wind, oil and gas' in North America."

M.M. Gears Sold

Coimbatore, India-based LG Balakrishnan & Bros (LGB) has entered into an agreement to acquire 100 percent shares in M.M. Gears Pvt. Ltd., according to multiple sources in the Indian media.

LGB manufactures automotive chains, sprockets, tensioners and belts as well as blanking. The company had planned a strategy to enter the gear manufacturing industry, according to IndiaTimes, and M.M.'s 30,000-square-foot manufacturing facility is likely to aid this endeavor.

M.M. Gears is an ISO 9001:2000 certified company, established in 1995. The company produces gears, gearboxes, helical gearboxes, geared motors and non-standard gearboxes.

Alpha Machining and Grinding Inc. Established

RP Machine Enterprises, Inc. has acquired the Statesville, NC division of Alpha/Sullivan Steel. The newly formed division is called Alpha Machining and Grinding Inc., and it is managed by Hank Kohl.

The acquisition provides RP with grinding capabilities up to 144 inches and a magnetic division to offer magnetic lifting devices, fixturing, tables and chucks. Some of the new division's products and services will be on display at RP Machine's booth, B-401, at Gear Expo.

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SERVICE

HEAT TREATING

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Candy Gears—Where Mesh Meets Marshmallow

On the production floor at Knechtel, food scientists, chemists and engineers take part in Willy Wonka-like experiments in search of the perfect piece of candy. Whether salty, sweet or something in between, the consulting firm has the daunting task of mixing and matching various flavors all in the name of great taste. It's a tough job testing chocolate, peanut butter and marshmallow combinations, but somehow the Knechtel team seems to manage.

Since 1956, Knechtel, one of the largest and oldest confectionary consultants in the world, has serviced major brands in the candy industry. The firm covers everything from creative development, engineering and scale-up studies to assisting clients with pilot plant manufacturing.

"Besides chocolate, gummy bears and chewing gum, the company has evolved into other markets like nutraceuticals, snack foods, pet foods and pharmaceuticals," says Bob Boutin, president at Knechtel. "Drugs don't have to taste bad to be good for you anymore."

The 27,000-square-foot laboratory and test kitchen in Skokie, Illinois features cooking burners, extruders, rotary presses, revolving pans and chocolate kettles.

And did we mention gears?

"Almost everything on the premises incorporates gears of some kind," Boutin says. "From an old wheat grinder to a forming extruder for granola bars and a caramel wrapping machine from the '50s."

Knechtel still utilizes drop frame rollers from the '30s and '40s for proof of concept equipment. Though the volumes have changed, the methodology and principles of candy design have remained the same.

"With all the transporting and transferring of materials that goes on in the candy industry gears are an intricate part of what we do day-to-day," Boutin says.

When asked by a client to wrap 1.7 million pieces for a clinical trial using an old-fashioned wrapping machine, Boutin says the gears were ground off the machine not once but twice before the project was completed. "You sometimes come up with very viable methods to save your clients money and yet you destroy pieces of equipment along the way," Boutin says. "Each project is about resolving issues and that includes engineering and manufacturing."

Knechtel also has a chewing gum line that Boutin calls, "a gear driven nightmare."

"The bubblegum sausage goes through two sets of sizing rollers to cut and form it into pillow shapes," Boutin says. "If you want to change the size and shape of the bubble gum, you have to change the gears each time."

While gears remain ever-present at Knechtel, Boutin says they aren't as prevalent in the industry as they once were.

"We've got some direct drives and hydraulic drives on some of our equipment, and we're always looking at different methods to get the most out of our machines."

For projects that require high viscosity, strong power and torque, however, Boutin says the best method is still the gear drive.

"For every gear that might be lost to other methods, you'll find plenty of products that will need gears in the future."

Although Knechtel isn't permitted to share trade secrets or recipes, Boutin can't walk down a snack aisle at the supermarket without smiling at all the products his company has helped to create.

"I have thousands of children [products] on the market that nobody knows we worked on. It's an exciting and challenging job, but satisfying to see these projects come to fruition."

And maybe eat a couple along the way.

For more information on Knechtel, visit *www.knechtel.com*.

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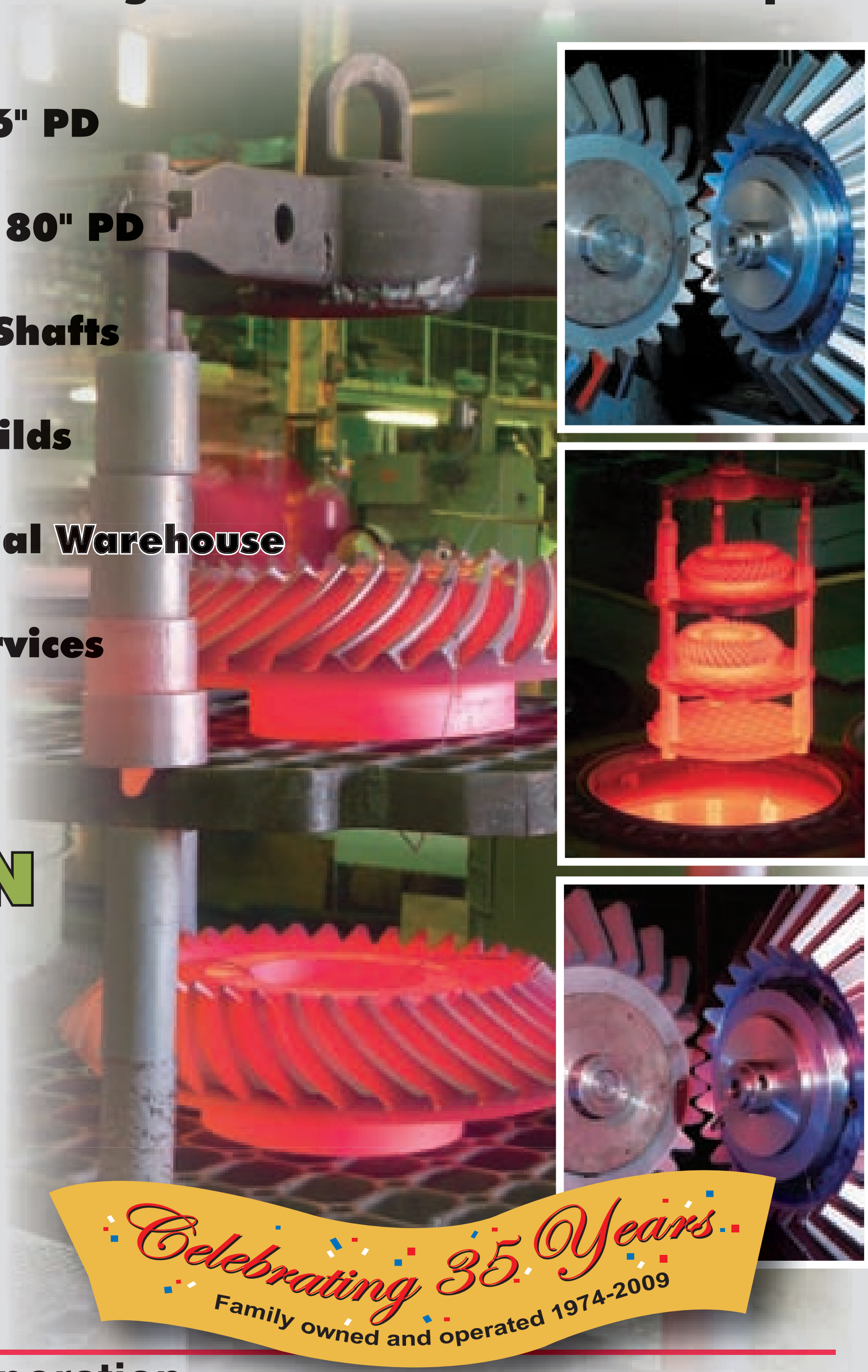

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