March/April 2012

GEAR TECHNOLOGY®

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The Journal of Gear Manufacturing

BIG GEAR HEAT TREATING

PLASTIC GEARS
More Than An Alternative

Technical Articles
- Ask the Expert
- Distortion and Stress Control in Heat Treating
- PEEK vs. Steel Spur Gear Performance

Addendum
- Workforce Sustainability

THE GEAR INDUSTRY'S INFORMATION SOURCE

Long spline and gear shaft hobbing

The Bourn & Koch 400H CNC horizontal hobbing machine is a 7-axis CNC machine that can hob spur gears, helical gears, splines and threads on cylindrical blanks or shafts.

Its powerful, direct drive work spindle and extremely stable, steel-polymer composite components make it ideal for manufacturing large and heavy shaft parts up to 406 mm in diameter and 6.4 module. Shaft lengths up to 76” or longer can be processed by the extended bed versions.

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IMTS 2012 | See us in booths N 6924 and W 2232!

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Photos courtesy of Metlab

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GEAR TECHNOLOGY®

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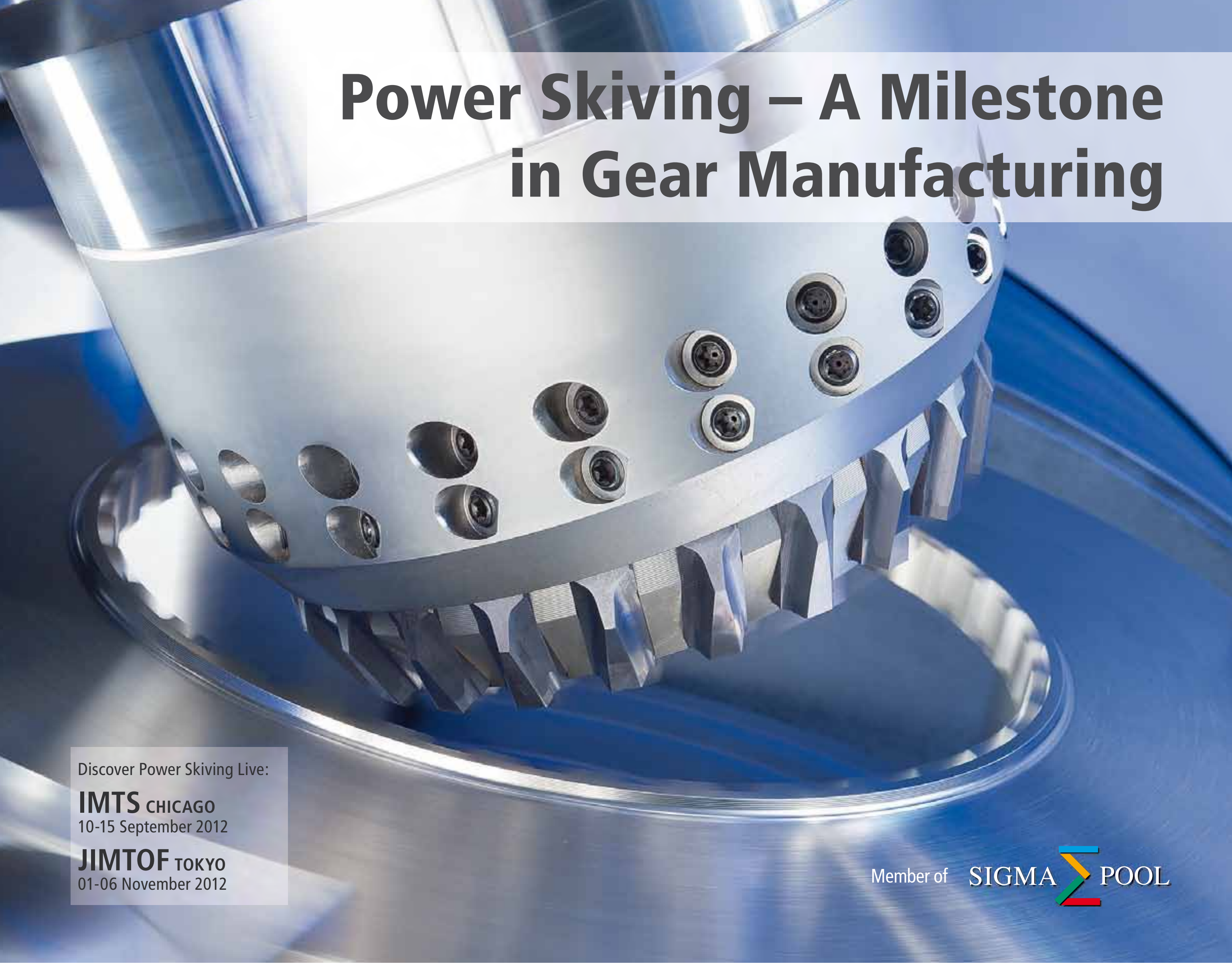

Power Skiving – Klingelnberg Presents its Latest Innovation

The newly developed tool system can be used on Klingelnberg bevel gear cutting machines. It guarantees a productive, stable and precise production process, particularly for internal gears. Klingelnberg enables the breakthrough of Power Skiving by finally unleashing the full potential of this 100 year old manufacturing method.

- up to 10 times faster processing times compared to other manufacturing methods
- smooth flanks with advantageous surface texture
- high gear quality due to precise tooling and dynamic machines

► Learn more about Power Skiving at www.klingelnberg.com

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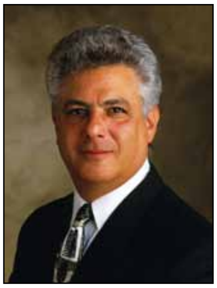


Report FROM India

Whenever I meet with readers, I find that—without exception—they express their deep appreciation for *Gear Technology* and its educational mission. Time and again they tell me the impact this magazine has had on their understanding of gear manufacturing and, as a result, on their careers. I've experienced such gratitude especially when I've traveled to Gear Expo or the AGMA annual convention.

On my recent trip to India, I was delighted to find an appreciation just as profound among our Indian subscribers, many of whom have read our magazine for decades.

Gear Technology has developed an outstanding reputation as the leading publication in the gear industry, everywhere in the world. Those of you who travel for business have no doubt seen it on desktops, on shop floors and in break rooms in virtually every country where gears are made. But in India, like most places, our reach has been limited by the fact that paid subscriptions have been required in order to receive a paper copy. Most of the Indian subscribers who have known us for so long are the department managers and CEOs of gear companies who were willing to pay for those subscriptions.

But for India, at least, that all changed with my recent trip. I traveled to Mumbai to exhibit at the IPTEX 2012 show and to launch *Gear Technology India*.

This new magazine now gives us the opportunity to expand the reach of our educational mission—not only geographically, but also in terms of subject matter. Now our top-notch technical information has a greater reach in an important industrial marketplace. In addition to gears and gear manufacturing, *Gear Technology India* includes coverage and technical articles on bearings, motors, couplings, clutches and other power transmission components, similar to *Power Transmission Engineering*.

Having their own industry magazine was a big deal over there. Our Indian partners, Virgo Publications, hung giant signs promoting the new magazine throughout the exhibit halls. At a formal ceremony before the show started, I was given the opportunity to introduce the new magazine. I explained how *Gear Technology India* would embrace the educational model that we've followed for 27 years, and I described how the comprehensive body of knowledge we've developed will serve as a vital resource for Indian industry.

Exhibitors and attendees alike were effusive in their gratitude for us having brought this type of educational resource to their marketplace. We signed up thousands of new subscribers at the show, and I expect many of them will become long-time readers.

Those of you whose products are sold in India should take a look at *www.geartechnologyindia.com*, where you can see the first issue. *Gear Technology* will continue to go there, but the interest in *Gear Technology India* is much broader, including those readers and advertisers who have little interest in the gear and power transmission industry markets outside of India. Not only can this magazine give you a window into the Indian marketplace, but also, it can give your company a new potential way to reach it.

Besides the successful introduction of our new magazine, IPTEX itself was a big success. In many ways it's similar to Gear Expo, with about 60 percent of exhibitors representing suppliers to gear manufacturers, and the remaining 40 percent representing gear and power transmission product manufacturers. Although the show started slowly, attendance was strong both the second and third days. The exhibitors I talked to were extremely satisfied with both the number and quality of the attendees.

It's clear to me also that the gear industry is taking the Indian marketplace quite seriously. Global exhibitors flew in the VPs and top executives from Europe and the United States, in addition to staffing their booths with their Indian sales agents.

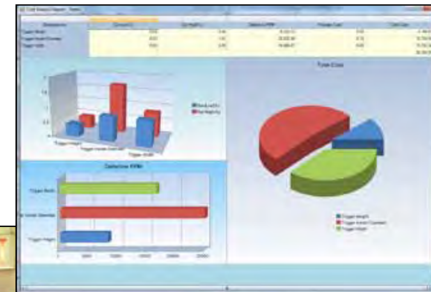
My impression is that IPTEX is a show to watch. If you're at all interested in the Indian marketplace, you might consider attending or exhibiting in 2014 (visit *www.iptexpo.com* for more information). My personal expectation is that—with the additional help and promotional venue provided by *Gear Technology India*—the exhibitor and attendance base of this show could easily double by the next time around.

All of our readers—whether they're in India, the U.S.A or anywhere around the world—can rest assured that we'll be there for you as we continue to expand our role as "the gear industry's global information source."

Michael Goldstein,
Publisher & Editor-in-Chief

Quality Assurance Gains on the Manufacturing Floor

ZONTEC'S SPC SOFTWARE INCREASES PRODUCTIVITY FOR GEAR MANUFACTURER



In today's increasingly competitive landscape, companies that do not pay attention to their quality data do so at their own peril, according to Danei Edelen, marketing manager at Zontec Inc. "Capturing and utilizing quality data can reduce scrap, reduce work, increase user productivity, assist with tool lifecycle management and help generate new business."

Zontec Inc., located in Cincinnati, Ohio, is an international developer of Statistical Process Control (SPC) software solutions. The company recently updated its *Synergy 2000* software to maximize the users' access to information. "These new capabilities are focused on running a business more efficiently and effectively," says Warren Ha, Zontec president. "We are leading the industry by providing superior functionality so users have multiple ways to access the wealth of information available at the click of mouse."

This includes increasing productivity, reducing product defects, boosting production rates and generating new business. "*Synergy 2000* enables you to fine-tune your business by adding value at every step in the process. It's logically designed with the user in mind. Therefore, you are able to rapidly implement a quality solution, saving you time and money. Your users are easily able to navigate the system and utilize numerous ways to input data efficiently. Data is passed through SPC calculations, so that real-time charting and reporting is constantly available for decision-making," Edelen says.

Synergy 2000 is designed in three levels: engineer, manager and operator. This means that as operators are entering data, managers and engineers can be monitoring and reviewing this data in real-time. If a process goes out-of-specification, the appropriate people can view this information immediately on their screens and automatic e-mail notifications are sent out as well. With the tools available, a customer can integrate *Synergy 2000* with any system in your enterprise. With company-wide monitoring in place, key individuals, regardless of location, can supervise production to meet company objectives. Also, if your industry requires secure controls over your quality data, *Synergy 2000* has such security measures available.

United Gear Gains Business with Synergy 2000. When Douglas Winfrey, director of quality, started at United Gear and Assembly, the *Synergy* software had already been purchased, but was not fully utilized. "I inherited *Synergy*, and I enforced it," Winfrey says. He immediately saw the benefits of utilizing the quality assurance software. "The real issue was that we were collecting all of this data, but not looking at the data. *Synergy* gave us a way to easily pull up the data and act on what we are seeing; it also gave us the ability to access the data anywhere in the world, including our customer sites."

United Gear has been in business for 50 years. During that time, they have evolved from a family-owned business into a multi-million dollar company and a core supplier of precision gears, shafts and related assemblies to companies in the automotive, agriculture, forestry, construction, mining, marine and rail industries. "We are now expanding our presence along with our parent company, United Stars, based out of Beloit, Wisconsin, into the Pacific Rim and recently opened an office in China,"

continued

Winfrey says.

Once United Gear began using *Synergy*, they found that the software made it easy for individuals without a statistics background to create charts on their machines, setup to receive notifications, reduce the number of errors and assist the inexperienced operator in understanding the process clearly. "It's a very good teaching tool to be able to explain with visuals to describe where the process is running at and where we want to be," Winfrey says. "Within seconds, we can call up a part number on a machine and know what's going on with that machine or the current production run."

"Since implementing *Synergy*, the reduction in paperwork is huge. Before every entry took us about 3½ minutes per sample size and now it takes us less than 30 seconds. There are 240 critical characteristics we could be measuring at any given time. Using *Synergy* has saved us about 12 man-hours per day," Winfrey adds.

One of the benefits United Gear has experienced is that they came to a better understanding of their machines and their capabilities. "Through data gathering, charting and analysis, we can analyze data on every product produced in a particular machine. We can get to the root cause, whether it is the people, the process or the machine," Winfrey says. "We run product on several machines; with *Synergy* we can compare a machine's capability, which gives us the least variation and best product. We can see inconsistencies and make systematic changes across the entire process; we can see data points for all products, regardless of machine and resolve inconsistencies for all processes."

Synergy also gives United Gear the ability to effectively manage the lifecycle of its tools. Through the use of Run Charts and other *Synergy* tools they can determine tool life and predict how many parts can run before needing to make adjustments or change out the tool. "We can budget our tool life management more accurately and effectively based on this data," says Winfrey. "*Synergy* can show us if a particular machine can't produce a particular product in a specific tolerance range. This data can then be used to justify procurement of new equipment."

Additionally, *Synergy* has helped United Gear with their Six Sigma and continuous improvement initiatives. "In the aspects of our business where we are using *Synergy*, we have seen our PPM (parts per million) decrease," Winfrey says. "On average, we have reduced our non-conformities by 20 percent. We also have a very low scrap rate in those applications."

Winfrey says they use *Synergy* for new business development. "I have been in meetings at the customer's location where we are discussing a new product. *Synergy* gives us the ability to log into our server, show them the exact machine that would be used to produce the new product, what tolerance the machine is currently running and the capability history of that machine," Winfrey said. "This type of information shows the customer what they need to see before moving forward. *Synergy* provides us that edge to win the business."

The Future of SPC. From a quality management perspective, Zontec has developed a solution that fully supports mobile technology and cloud computing architecture. Zontec's *Synergy 3000* SPC software was designed from the outset so that users can gather, organize, analyze and report on the huge data sets dictated by real-time, statistical process control over the Internet from highly dispersed global locations. "We see the use of cloud computing and mobile technology particularly applicable as it relates to managing your suppliers," Edelen says. "With *Synergy 3000*, suppliers have access to customer standard operating procedures, engineering drawings and contract specifications during their production runs. Suppliers enjoy data collection and gage interfacing through the browser in addition to charting, process monitoring, real-time feedback and reporting."

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GWJ

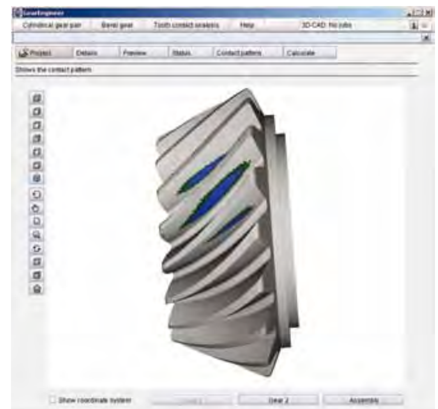
UPDATES GEARENGINEER SOFTWARE

GWJ Technology GmbH, headquartered in Braunschweig, Germany, recently introduced a new version of its *GearEngineer* software. The version comes with a variety of new features and functions including profile and flank modifications as well as the tooth contact analysis (TCA). Additionally, the user can calculate the load capacity of bevel gears according to ISO 10300. The *GearEngineer* is a software

continued

application for the calculation of the accurate 3-D gear tooth form of cylindrical and bevel gears based on the mathematical simulation of the manufacturing process.

The accurate gear tooth form is the basis for manufacturing gears, in conjunction with multi-axis machining centers or non-cutting manufacturing processes. The standard exchange formats STEP and IGES serve as a neutral file format to transfer the accurate tooth geometry. The geometry data can be used for further developmental purposes, for example for a universal manufacturing or used as 3-D nominal data for additional measurements. Profile and flank modifications were now added to the *GearEngineer* calculation module for cylindrical gears. A drop-down menu allows the user to select linear and circular tip or root relief as well as symmetric profile crowning.



In addition to the profile modifications, the gear flank modifications lead crowning and profile crowning are available. The user can decide between symmetric and asymmetric lead crowning. End relief can be applied to both tooth ends or to the left or right end of the tooth.

Additionally, the *GearEngineer* now includes TCA to calculate and visualize the contact pattern of gears. After completion of the gear calculation, the tooth contact analysis allows the calculation of the size and position of the contact pattern without load. The contact pattern is visually displayed in the 3-D model. The analysis is possible for external and internal spur and helical gears and helical, straight and Zyklo-Palloid spiral bevel gears. The engineer can optimize spur and bevel gears before the manufacturing begins. Deviations and displacements from the ideal position are taken into account. The new *GearEngineer* version provides the possibility to determine the load capacity of straight, helical and spiral bevel gears according to ISO 10300.

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Birchwood Casey

IMPROVES BLACK OXIDE COATING

Metal surface cleaners and conditioners from Birchwood Casey improve black oxide coating and other metal finishing processes. Available in a range of biodegradable liquid cleaners and mild acid conditioners, they provide the just-right surface preparation to achieve top quality finishes. For example, most machined and fabricated metal components carry cutting oils or coolants that coat the metal surface and collect in threaded holes and recessed areas. Heat treat scale and light rust are also commonly seen. These surface soils must be completely removed prior to blackening or coating in order to achieve high quality results. These conditions are easily handled by choosing the right surface preparation from the following products:

Birchwood Casey's Presto Kleen powdered cleaner and Safe Scrub ST biodegradable liquid cleaner are designed for medium- to heavy-duty soak tank cleaning of iron and steel parts. These products mix easily with water and operate at temperatures of 120–180 degrees F to quickly lift oily residues from the metal surface and hold them in suspension. Their unique blend of detergents make them free-rinsing in cold water, giving them the ability to produce waterbreak-free surfaces that are receptive to subsequent coating operations. Also available is Safe Scrub M for effective cleaning of light metals, such as aluminum, brass and zinc without discoloring the metal.

Birchwood Casey's Oxyprime primer/surface prep serves as an activator and primer to make the metal surface more receptive to the subsequent coloring or blackening operation. Tool steels and heat treated parts must be activated and/or de-scaled by means of a surface

continued

conditioner prior to subsequent finishing operations. The Oxyprime solution provides that function for black oxide, cold blackeners and antique finishing. It provides a mild acid surface conditioning to ensure uniform adhesion across the part, without the risk of hydrogen embrittlement. In some cases, the Oxyprime descaling operation can also be used in conjunction with ultrasonic rinsing to remove all traces of surface particulates, thereby producing a white-glove clean black oxide finish.

Oxyprime is available in powdered and liquid concentrate for a variety of finishing jobs, including activation, oxide removal or the formation of a base coat for subsequent Tru Tempo low temperature black oxide finishing. All metal cleaners and surface conditioners from Birchwood Casey are available in container sizes for small and large scale finishing operations and for use in various types of process lines, such as black oxide, phosphatizing and other metal coating systems.

Complete technical information for each Birchwood Casey product is available online. A technical service expert is also available by phone to determine which metal cleaner and surface conditioner is best for a specific application.

For more information:
Birchwood Laboratories, Inc.
7900 Fuller Road
Eden Prairie, MN 55344
Phone: (800) 328-6156
www.birchwoodlaboratories.com

Mitutoyo

RELEASES HAND-HELD MEASUREMENT TOOL

Mitutoyo America Corporation announces the availability of its new, High-Accuracy Digimatic Digital Micrometer, the first micrometer to offer 0.1 µm resolution measurement. Now, high-accuracy measurement can be had in a convenient, hand-held tool. The Digimatic Micrometer utilizes the

Absolute rotary sensor (patent pending) manufactured utilizing Mitutoyo's own high precision screw machining technology. This sensor reduces instrument error to ±0.5 µm to deliver high accuracy with no trade-off in operability. The Absolute system eliminates the need to reset the origin each time power is turned on thus enabling measurement immediately upon start-up. In addition, the measurement origin can be preset to any value within the display range to reduce set-up time and improve repeatability. The display can be zeroed at any position, making comparison measurement easier. Display resolution can be switched to 0.5 µm if 0.1 µm measurement is not required.

The Digimatic Micrometer features an extremely rigid frame for stable measurement while a constant-force barrel/spindle mechanism eliminates the possibility of overspeed errors. Transference of body heat to the instrument is reduced by use of a heat shield (removable), minimizing errors attributable to thermal expansion while handheld measurements are performed.

Additionally, it supports output to measurement data applications such as *MeasurLink*, Mitutoyo's proprietary statistical-processing and process-control program which performs statistical analysis and provides real-time display of measurement results for SPC applications. The program can also be linked to a higher-level network environment for enterprise-wide functionality.

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Micro Precision Gear

UTILIZES HOLROYD GRINDER

Holroyd Precision, a division of the Precision Technologies Group, has recently completed a customer satisfaction survey with major customer Micro Precision Gear Technology Limited of Hemel Hempstead, Hertfordshire. Having supplied Micro Precision Gear Technology Limited with a GTG2 model gear and thread grinder some eight years ago, the Milnrow, Lancashire operation canvassed Micro Precision Gear Technology's Phil McIntyre, section leader, gear grinding, for feedback on living with the machine on a daily basis.

The GTG2 machine in question is used by Micro Precision Gear Technology Limited in the manufacture of worms, helical and spur gears while Holroyd is also currently working with the company to develop bespoke worm software for the machine. The machine is used to grind worms from 15 mm to 250 mm in diameter with a smallest gear of 0.6 module right up to the largest of 4 module. According to McIntyre, "The machine has been extremely reliable. It's incredibly accurate and will run all day for six days a week. Its flexibility is another major plus. And, just as importantly, it's also remarkably easy to use and program with a new operator usually able to get the hang of things within just two weeks."

The Holroyd GTG2 is an extremely versatile, multi-purpose grinding system for the batch or volume production of precision spur and helical gears, worms, screws and rotors. Sophisticated yet simple to operate, the machine combines rigidity with high power for either CBN or conventional deep grinding operations with class-leading levels of accuracy and finish. Fast setups optimize productivity while the advanced and highly integrated user interface facilitates the production of a finished component from the initial design drawing. In addition to the production of all types of spur, helical and worm gears, the machine can also be configured for grinding ball-screws, small compressor rotors, internal gears and threads.

Typical applications include high-performance aerospace, automotive, precision motion, low noise and master gears. An on-board 3-D scanning probe maximizes accuracy using profile correction feedback and improves productivity by removing the need for off-machine profile inspection.

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Grieve

OFFERS HIGH TEMPERATURE INERT ATMOSPHERE CABINET OVEN

No. 855 is a 1,250-degree Fahrenheit electrically-heated, inert atmosphere cabinet oven from Grieve, currently used for heat treating at the customer's facility. Workspace dimensions on this oven measure 38" × 26" × 38". 40 kW are installed in Incoloy-sheathed tubular elements to heat the oven chamber, while a 1,500 CFM, 1½ HP re-circulating blower provides horizontal airflow to the workload. This Grieve cabinet oven features 10" insulated walls comprising 2" of 1,900-degree F block and 8" of 10 lb/cf density rockwool insulation, Type 304, 2B finish stainless steel interior with continuously backwelded seams, plus inner and outer door gaskets with the inner gasket sealing directly against the door plug while the outer gasket seals directly against the face of the oven. Full inert atmosphere construction further includes a pressure regulator, flow meter, pressure gauge, internal high-temperature gasket, all welded expansion connection in door-

continued

way throat, air jacket on inner oven for cooling, ½" thick silicone rubber atmosphere seal, blower shaft seal, positive latching door hardware, adjustable offset door hinges, outlet with pressure relief, interior seams welded gastight and all wall penetrations fitted with compression fittings. A 325 CFM blower pulls air through the air jacket on the inner oven for cooling. Controls on No. 855 include a special heating/cooling temperature controller to control heating elements for heating and modulating damper on cooling blower for cooling. The oven also has an SCR power controller and circular chart recorder onboard.

For more information:

The Grieve Corporation
500 Hart Road
Round Lake, IL 60073
Phone: (847) 546-8225
sales@grievecorp.com
www.grievecorp.com

LMC

RELEASES CHANDOX SE SERIES CHUCKS

Chandox SE Series Super Thin Chucks are now available from LMC Workholding. These chucks are well suited for holding workpieces for gaging and metrology applications. The chuck knob is rotated directly for gripping and loosening without the need for a handle. The SE Series chuck bodies are made of durable steel. Jaws are reversible to grip various sizes more conveniently; small sizes of 0.8 mm can be gripped with 2" chucks. LMC Workholding engineers and manufactures high quality chucks and cylinders along with special workholding devices, including aluminum wheel chucks, high volume machining power chucks and fixtures, standard and special hydraulic steady rests, special application and large cast type manual steady rests, Stiefelmayer specialty clamping tools, and Chandox brand chucks and cylinders. LMC Workholding will be exhibiting at IMTS 2012 in Booth No. W–1314.

For more information:

LMC Workholding
1200 West Linden Avenue
Logansport, IN 46947
Phone: (574) 735-0225
www.lmcworkholding.com

MAE Press Technology

SERVES DIVERSE MARKETS

During the upcoming AISTech show, May 7-10 in Atlanta, MAE Maschinen-und Apparatebau Götzen GmbH (Erkrath, Germany) will display its various press technologies for the iron and steel industry and related business sectors in Booth 1536. MAE recently announced its formation of a partnership with American Wera here for representation throughout North America. In the last decades, MAE has developed increasingly from a manufacturer of standard hydraulic presses to specialists for select niche markets. The company has established a market position with products in the fields of straight-

continued

ening machines, hydraulic presses and assembly machines, serving metals producers, rail, heavy equipment, energy and marine markets.

Straightening.MAE has the broadest portfolio of manual and automatically controlled straightening machines for handling round, profiled and complexly shaped workpieces available worldwide. Press forces from 15 to 25,000 kN make it possible to straighten workpieces with lengths from 40 mm to 30 m and weights from 5 g to 20 tons. Straightening accuracy to 0.01 mm is possible. In addition to the conventional bending-straightening method, MAE also offers peening-straightening for through-hardened workpieces and torsion-straightening for twisted section bars. The MAE straightening controller for the manual straightening presses in the S-RH and P-H RH Series guarantees precise and repeatable metalworking and does not necessitate specially trained operators. Measurement and straightening in one setting ensures optimal cycle times. The M-AH, ASV and ASRU Series enable automatic straightening of small, large and complex shaped workpieces. The software of the RICOS straightening controller is the result of decades of experience with various applications. Innovative MAE design ideas are further making the straightening process increasingly more powerful and faster. Various interlinking concepts allow continuous operation with low manpower requirements.

Hydraulic presses.The broad range of hydraulic standard presses in the S and DS Series with C- and O-frames as well as the four-column presses in the VS Series are based on a modular system. By recombining and adapting the individual modules, MAE finds an inexpensive, individually optimized solution with press forces up to 25,000 kN for customer needs. Hydraulic presses are exposed to considerable stresses in daily use. With 60 years of experience, MAE has a reputation for sturdy dimensioning on all components.

Assembly.Whether you want to assemble gear parts, rotor shafts or wheelsets, MAE offers many suitable solutions. The MAE machine Series S and M-S with hydraulic or mechanical servo drive are robust machines tailored to customer application. The OPUS controller with flexible software that can be modified to fulfill customer-specific requirements guarantees control and documentation of the entire assembly process. Our horizontally acting wheel set presses in the RADS Series with forces up to 8,000 kN are the industry choice for mounting and dismounting wheel sets from railway vehicles. They stand out primarily for their innovative underlying concept, rational interlinking systems and extensive control functions.

Service. An innovative and high-quality machine is only the basis for high customer satisfaction. Equally important for continuous duty with high availability are quick-response service from experienced technicians and spare parts available immediately from stock. North American installation and service is provided by American Wera service technicians in Ann Arbor, Michigan and Queretaro, Mexico. Additionally, optimally staffed service centers at located in Erkrath, Germany and Beijing, China. Telephone support and remote diagnostics onboard the machines usually allow MAE to correct minor problems without complication or onsite service.

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Iscar

OFFERS FACE MILLING SOLUTION

Helido S890 FSN is a new family of right-hand indexable face mills with an 88 degree cutting edge angle with eight helical cutting edges, which can be used for up to 9 mm depth of cut. The new family was designed for rough to semi-finish, high-efficiency face milling, primarily on cast iron and steel components. The Helido S890 FSN face mills are available in a diameter range of 50 to 160 mm in coarse and fine pitch configurations. Every cutter body features coolant holes directed to

continued

the insert cutting edges, for the most efficient cooling effect.

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Ticona

SUPPORTS HI-LEX POWER LIFT GATE TRANSMISSION

An innovative transmission from Hi-Lex America Inc. continues to reliably and quietly open and close automotive lift gates thanks to design and development assistance from Ticona Engineering Polymers, which helped the automotive tier supplier create new injection molded high-precision plastic shafts and gears.

"For several years, Hi-Lex customers have used a two-stage reduction transmission that relies on precision steel ball bearings mounted on plastic shafts and accompanying 2.5-inch diameter plastic gears to achieve the desired reduction between the electric motor and a flexible torsional cable assembly to lift and close big, heavy automotive rear lift gates," said Fred Eberle, technical engineer at the Hi-Lex Automotive Center in Rochester Hills, Michigan. Hi-Lex is a supplier of automotive electromechanical, power closure devices and control cables. "A first generation model used a powder metal shaft system, which was subsequently replaced with a plastic shaft system that provides an immense improvement in NVH (noise, vibration and harshness) and makes our customers very happy."

With input from Ticona, the American Gear Manufacturers Association, Ohio State University Gear and Power Transmission Research Laboratory and gear software developer Universal Technical Systems, Hi-Lex optimized and refined the second generation lift gate transmission via extensive research and development and testing. It relies on first- and second-stage plastic splined shafts attached to plastic gear wheels in a gearbox with a rated torque output capacity of about 12 Newton meters (106 inch pounds).

"From the outset we knew we want-

continued

ed to design the transmission with plastic gears to reduce cost, weight and especially, noise," Eberle said. "We knew Ticona had the gearing and material expertise to help Hi-Lex achieve its business goals."

To avoid any timely and costly setbacks during development of the two-stage transmission, Hi-Lex established a plastic gear team early on that included Eberle and David Sheridan, senior design engineer at Ticona. The team defined, analyzed and highly optimized the design to take advantage of many considerations unique to plastic gearing. These considerations can be significantly more complex than those for standard metal gears and they pose challenging implications for gear and drive designers.

"Although Eberle has extensive experience and skill in regards to gearing and drive development, the Ticona/Hi-Lex gear team took the design and optimization process to the highest level of geometry analysis, material application and plastic gear experience," Sheridan said. "Ticona used its 50-plus years of plastic gear experience to help Hi-Lex develop this high-precision plastic gear transmission."

Once the requirements were defined, the team identified materials for the gears and shafts that would maintain the required mechanical properties and dimensional stability, even at elevated temperatures. The gear team selected Ticona grades of Celcon acetal copolymer (POM) and Celstran long fiber reinforced plastics (LFRT): Celcon M90, a general purpose, unreinforced POM that provides a good balance of toughness and fatigue strength for the first-stage gear and shaft, Celcon GC25T, a 25 percent glass-coupled POM that provides the necessary stiffness and fatigue strength for the second-stage output gear and Celstran PA 66-GF50-02, a 50 percent long glass fiber polyamide 66 with high strength and stiffness combined with high heat deflection for the second-stage output shaft.

"For several years, original equipment manufacturers have used our power lift gate transmissions in a variety of automotive platforms," Eberle said. "Not once has a gear broken, worn out or failed in any of our testing, even with multiple design lives, or in service. The gears are nice and quiet. In fact, they get even quieter at elevated temperature, exactly like they were designed to do." Added Sheridan: "It's nice when things work out the way you expect them to. You know you have it right when the design behaves the way the analytical models predicted it would."

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With this issue *Gear Technology* introduces what will be a continuing feature accepting and addressing reader questions on all things gearing, i.e.—*Ask the Expert*.

Here's how it works: Have a standards question? Design query? How about a backlash or tooth profile problem that needs fixing? Or maybe you need a material recommendation or are wrestling with a tricky noise issue. And just which lubricant is best for those open gearing applications?

Well, you need look no further. That's because *Gear Technology* will call upon its deep reserve of industry experts from around the world to help solve your dilemma and get you back on track—whether on the drawing board or shop floor. Any question—if it's about gears—is fair game.

Got a Gear Question?

Ask the Expert!

Our extensive roster of licensed engineers, engineering school professors, respected consultants and others are here for you.

And did we mention there is no fee for receiving this expert knowledge acquired by these individuals over many years of hands-on experience?

Simply e-mail your question—along with your name, job title and company name (If you wish to remain anonymous, no problem)—to:

Jack McGuinn, Senior Editor
jmcguinn@geartechnology.com

The Question

I am currently writing a design procedure for the correct method for setting up bevel gears in a gearbox for optimum performance. I have read your excellent guides, but the answer I seek is not written in your guides or I have not found it. I have written about shimming so that the correct mounting distance is achieved and the correct backlash is maintained. However, when it comes to the bearing, we have a choice of pre-load or end-float.

What is the best way to maintain the correct mounting distance, and, hence, contact tooth pattern?

If a pre-load is used on the bearing, then this would push the bevels together. If end-float is used, the gears would be allowed to move apart in the axial direction, possibly shifting the contact tooth pattern over to the edges of the teeth.

Is there any literature on this subject or is it possible for you to recommend a suitable method? I believe the bearings should be pre-loaded to take out the axial play so that the teeth are always in contact. I believe (this) is an issue that not many design engineers think about. Thank you.

Stephen Marsh, design engineer
Goodrich Actuator Systems U.S.

Answer Number One

Dear Steve,

It is necessary to point out that—should spiral bevel and hypoid gears be assembled in their housing—the axial, radial and vertical positions—as well as the shaft angle—must be correct within a certain tolerance. The vertical position (offset) and the shaft angle are given by the machining operation of the housing. Bevel gear sets with a module of 4 mm already show a severe contact pattern change with a misalignment of three angular minutes if the profile crowning is small. An offset error of ± 50 microns leads to a contact pattern change of about the

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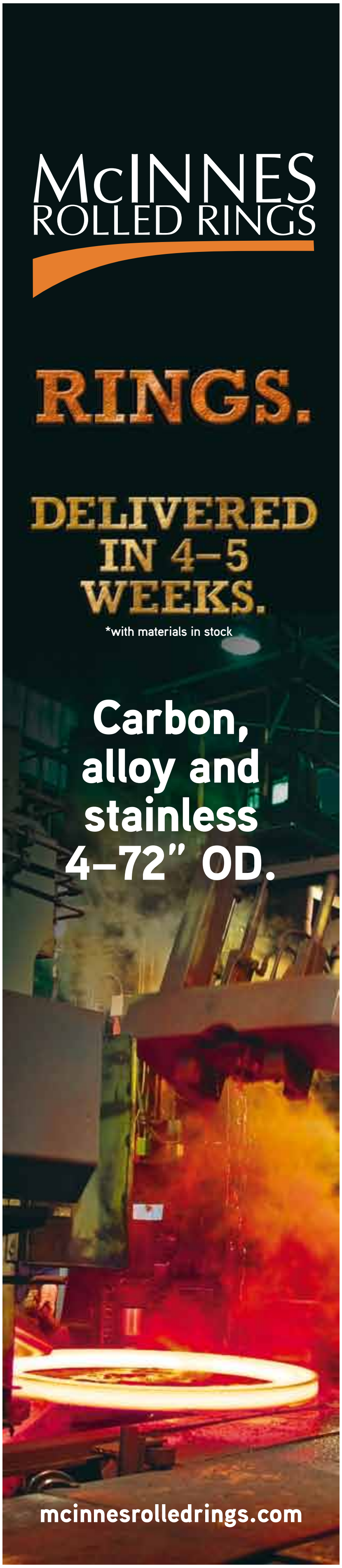

same magnitude; the gearbox housing accuracy and stiffness must be assured accordingly.

Assembly of a gearbox affords one the opportunity to realize and understand the optimal axial location of pinion and gear, independent of the housing accuracy. At the outset there already exists a 50-micron deviation of the axial pinion location from the correct position, leading in turn to more severe changes than mentioned in connection with the offset. The axial ring gear position is vital due the fact that it controls the backlash. A 50-micron error in the gear axial position might change the backlash by 35 microns.

Axial pinion and gear positions depend not only on the geometrically correct assembly, but also on the correct preload on the pinion shaft and gear carrier bearings. The pinion shaft should be supported with tapered roller bearings in an "O" or "X" arrangement. The pinion bearing preload can be achieved with pre-machined bushings or with a collapsible bushing; the latter is preferred for modern, low-friction bearings. The axial position of the bearing pre-assembly must be achieved independent of the bearing preload arrangement with shims, as shown in Figure 1, Items 1–2.

After the pinion is in position, the tapered roller bearings of the gear assembly are pre-loaded; at the same time the gear assembly is placed axially in the housing and the threaded rings shown in Figure 1 are torqued (Items 3–4). However, during torquing the deflection of the bearing preload influences the axial ring gear position. In turn, the gear preload influences the gear position due to asymmetric housing deflections. The backlash must be measured and threaded ring corrected. In order to keep the preload constant (before and after a ring gear axial position change) the one ring must be rotated clockwise and the opposite side ring counter-clockwise by the same ring rotational angles. Shims or snap rings of various thicknesses can also used to position the gear sideways to the correct backlash.

If a gear set is built in the correct position, using the recommended preload, a tooth contact pattern (for very light torque) then matches with the theoretical tooth contact analysis results. The size of the contact pattern increases if increased torque is applied in the operation of a bevel gear transmission; subsequently the housing, shafts and bearings deflect from their initial position. The so-called "V-H-deflection characteristic" of a bevel gear set can be matched to the typi-

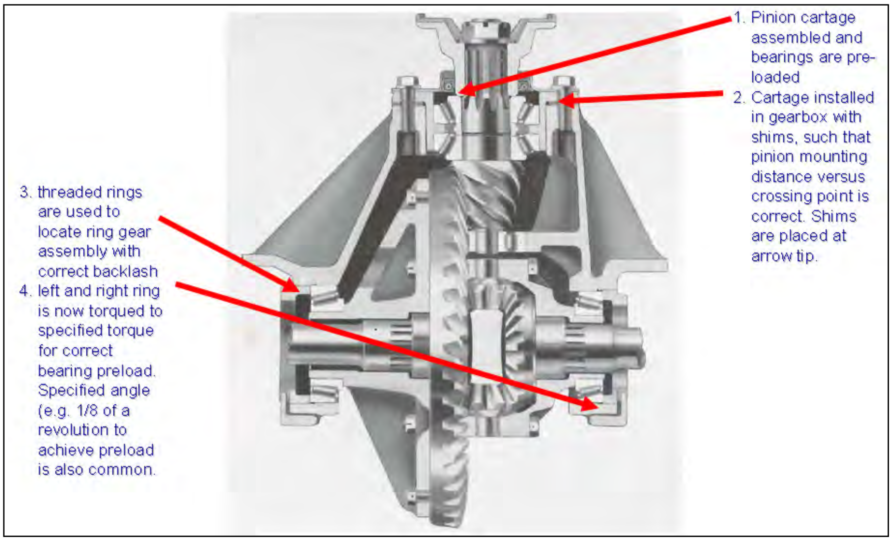

Figure 1—In Items 1 and 2 the axial position of the bearing pre-assembly must be achieved independently of the bearing preload arrangement with shims. After the pinion is in position the tapered roller bearings of the gear assembly are pre-loaded; at the same time the gear assembly is placed axially in the housing and the threaded rings (Items 3 and 4) are torqued.

cal deflections under load. As a result, increasing load will move the center of the contact pattern towards the larger gear diameter, while the size of the contact area increases. The contact area should cover the entire flank surface (without edge contact concentration) if the nominal load rating is reached.

If the preload is too low, pinion and gear then move away from their build position as soon as load is applied and edge contact occurs. If the preload is too high the efficiency of the unit drops and the operating temperature increases.

Best regards,

Dr. Hermann J. Stadtfeld,
Vice President
Bevel Gear Technology/ R&D,
Gleason Corporation

Answer Number Two

Mr. Marsh,

You have touched on the “fly in the ointment” in setting position; the bearings play a significant part in setting proper position. The real issue is not so much where you *set* it, but more in where it *runs*. If you assemble bearings with preload, you usually do not have much variation in measurement; you are essentially working with some elasticity in the components, and the dimensional changes are small. There is always some variation in measurement and shim sizes in the nature of one or two thousandths of an inch, and bevels are not normally that sensitive where it is a problem.

End-play, however, can cause quite a problem. The traditional response would be to set the gears in the position they will run. That is, if the gears will move in a particular direction under load, force them that way at assembly, taking out endplay in that direction. If the gears run in both directions—or the operating conditions greatly affect end-play or position—the technique is not so simple.

Bearings typically like to run at a preload. If operating conditions are stable and the housing and shafts do not move or grow, the preload can be built-in at assembly. Ideally, that is the case.

However, if there is growth or movement, you want the bearings to go to light preload so all the rotating elements share the load. If you have done an advanced analysis of the system to predict the growth and movement, use the results to compensate for position at assembly. I might also add that those results should be considered in the bevel design to manufacture the teeth with the proper loaded tooth contact pattern. Most customers cannot predict how the components will be affected in service and, unfortunately, there is only one solution—testing. Build with your best estimate and then run the gearbox at operating conditions; then check to see what happened. Tear down and re-shim to compensate. What you are *really* looking for is, what is the *loaded* contact pattern? Regardless of how it looked at assembly, it is how it runs that is important.

Besides the papers and videos on our website, there is a national standard on bevel gear assembly: ANSI/AGMA 2008-D11—Assembling Bevel Gears. This document was just updated to include information on how to conduct a contact pattern test. There is some duplication with the material on our website, but it is still a useful document with additional material.

Hope this helps.

Robert F. Wasilewski,
Design Engineering Manager,
Arrow Gear Company

THE PLASTIC GEAR PAY-OFF

Eliminating Noise, Weight and Wear Proves Valuable in 2012

Matthew Jaster
Associate Editor

The only plastic gear applications mentioned in Darle Dudley's *Handbook of Practical Gear Design*—originally published in 1954—involved items like toy trains, film projectors and cash registers. Thanks to energy efficient manufacturing as well as a desire to cut down on costs, the plastic gear has significantly evolved. Opportunities readily available to plastic gear manufacturers today include automotive, business and printing machines, lawn and garden equipment and medical applications—and business is booming.

"I can't speak about other segments of gear manufacturing, but plastic molded gears still seem to be the focus in the industry for improved performance and cost savings," says Rod Kleiss, president of Kleiss Gears, Inc., located in Grantsburg, Wisconsin. "We are stretched to keep up with demand."

continued

Adds Andrew Ulrich from Thermotech, located in Hopkins, Minnesota, "Though we are not acutely aware of how the machined gear market is doing, we can say the molded gear market is strong and growing."

"Especially from a custom gear/gear tooth perspective," adds Bruce A. Billmeyer, president/owner, Plastic PowerDrive Products, LLC, located in Elk Grove Village, Illinois. "Although a portion of the U.S. molded gear market does come from foreign sources, the innovation still resides here in the United States. This innovation comes in the form of materials, gear combinations with other components and gear assembly techniques."

ABA-PGT, Inc. specializes in both external and internal spur and helical plastic gears in addition to worm, face and bevel. Glenn Ellis, senior gear engineer, ABA-PGT, says, "Plastic gears have a place in the industry just as metal gears do. They both have their own marketplace, this being size, strength, weight and even the quantity required."

There's always a push for reducing cost and weight and that continues to increase the interest in plastic gearing, according to David Sheridan, senior design engineer at Ticona. "Certainly lately, with all the bells and whistles added to automobiles outside of the drivetrain, we're seeing huge gains in automotive applications. Many plastic gear applications were once found only in luxury car models, but these features are now being integrated into standard models as well."

"We're not back to pre-recession numbers but business is good," adds John Winzeler, president of Winzeler Gear in Harwood Heights, Illinois. "Today there are more opportunities for plastic gears, especially where both sound and cost reduction are a factor. More and more, we're getting interest in transmitting power, not just motion."

A Tale of Two Segments

Plastic gears can be cut like their metal counterparts and machined for high precision with close tolerances. Plastic cut gears can also be utilized for the development of prototypes. Injection molded plastic gears are fast, economical and can cost significantly less than machined, stamped or powder metal gears. When determining which type to consider for a specific application, costs, quantity, quality and performance must be considered.

"Historically, molded gear advantages have been considered to be lightweight, quiet, resistant to corrosion, and may be used without external lubrication. While they held these properties, plastic gears were also considered to be less accurate and flimsy. There has been significant progress on many fronts to address these disadvantages," Ulrich at Thermotech says. "First, considerable work developing engineering materials and the understanding of the mechanical properties of these materials has been completed. Secondly, computer programs have been developed along with routine tooth proportion manage-

ment to leverage the ability to build molds without restriction to standard steel gear manufacturing tooling."

"Remember, in molded plastic gears we only cut metal once and then can make millions of copies by injecting liquid into that mold," says Thomas McNamara at Thermotech. "This is the most cost-effective means of producing a high volume of gears."

Adds Kleiss, "Cut plastic gears can replace metal with plastic. This can be a solution to a specific problem if materials replacement is the answer. Molded plastic gears offer a few more opportunities. The gear design can be easily optimized for the specific application. We use a method we call shape forming to fit the needs of the transmission. The molded solution offers unique part characteristics outside of the gear itself that would be difficult—if not impossible— to build into in cut gears."

"High production is much easier on molded gears, which leads to a lower price point. With a quality mold, the repeatability is very high," Ellis says. "Once the mold has been qualified, the future production runs should not have much variation. The potential quality of a cut gear is still higher than the molded gear. One of the things a designer must know is what quality is required for their application. Why request and pay for a quality higher than needed?"

In the end, both methods have advantages and disadvantages and it's up to the customer to determine what plastic gear solution will best fit their specific application.

Making millions of copies of a plastic gear from a mold is a cost-effective way to produce high volume (courtesy of Thermotech).

Overcoming the Limitations of Plastic

The limitations in plastic gearing remain fairly straightforward. "Quite simply, plastic gears are weaker than metal. They can't operate at the same high temperatures. The most precise plastic gear will not be as accurate as the most precise metal gear, unless we start

continued

Kleiss uses their own internal software for the design, inspection and testing of molded gears (courtesy of Kleiss).

talking about micro-gears, which can be much smaller and more accurate than their cut metal counterparts," Kleiss says. "I think a bright spot for plastics is PEEK (polyetheretherketone), and its derivatives are promising much improved performance at high temperatures and high loads. New compositions of nylons are hitting the market now with improved properties. I expect even further material improvements in the coming years."

"The biggest limitation is strength, especially for higher RPM and horsepower requirements," adds Billmeyer. "The future does hold some intriguing solutions with metal plastic hybrids, or over-molded metal frameworks. Some of the new high-temperature combination plastics such as nylon with phenylpolysulfone look promising."

"Strength and temperature are the biggest limitations," Ellis says. "New materials have been gaining ground on both these laminations. With higher temp materials plastic gears are now found commonly under the hood of automobiles."

Load capacity, especially at temperature, is the most significant limitation according to Sheridan. "The automotive transmission is all metal for obvious reasons. There needs to be more done in the future to challenge life expectancy and critical failures. Most plastic gears don't run continuously, but I believe new materials will become available in the future that will address strength, wear and friction modifications."

Plastic Gear Lubrication

How has the lubrication evolved in plastic gearing? Plastic gear manufacturers believe that many factors affect the compatibility between lubricants and plastics.

"Plastic gears can be internally lubricated. Anything from silicone to Teflon can be molded into the material for self-lubrication. Most engineering plastics are inherently low friction. Unfilled nylon is a particularly good example. In addition, external lubricants can be used to good effect in specific applications," Kleiss says.

"Some plastics do not require any lubrication because they are internally lubricated. However even some of these will work better if a break-in grease is used. Some other plastics work best if they are well greased," Ellis says. "Caution must be taken as some plastic will react with certain lubricants."

"External lubrication does not have to be a challenge. Start with the basic soap-based products and escalate from there. Care must be taken to ensure all of the ingredients in the lube are compatible with the molding material," Ulrich at Thermotech says.

"There are cases where this was overlooked and incompatibility was the root cause of failure. Keep in mind that many plastic gear applications can be run dry with the aid of internal lubricants such as PTFE, silicone, molybdenum disulfide and other compounds and blends. This is a huge advantage to end users over externally lubricated transmissions, eliminating the need for replacement or replenishing of the external lube," adds McNamara at Thermotech.

Spreading the Plastic Gospel

The AGMA Plastic Gearing Committee evaluates materials, design, rating, manufacturing, inspection and application of molded or cut-tooth plastics gearing. They recently conducted a meeting in Michigan to discuss the test methods for plastic gears, the inspection of molded plastic gears and the identification of plastic gear failures.

"We focus a great deal of our time on the standards and I think if we made the committee more accessible to the entire plastic industry, it would be beneficial," Sheridan says. "We'd love to have more bodies show up and get involved in the relevant issues that are affecting plastic gearing today."

"AGMA's Plastics Gear Committee works on various documents to assist design engineers with the unique aspects of the design, manufacture and metrology of plastic gears. With the release of these documents, designers and manufacturers will have more uniform knowledge and understanding for the application of plastic materials into the gear industry," McNamara at Thermotech says.

"AGMA is a metal-focused organization," Billmeyer says. "It does not provide anywhere close to the required research or technological information required. What limited software, consultancy, or market research comes from the plastic suppliers such as DuPont or Ticona."

"I am not aware of any real focused effort on the part of AGMA to understand or further develop the potential for molded gears or for truly bracketing the molded accuracy of a plastic gear," Kleiss adds. "This would require a different kind of inspection analysis than has proved successful for cut metal gears. We use our own internal software for everything, from the design to the inspection and testing of molded gears and their transmissions."

Perhaps there are other ways to promote technological solutions in plastics. Education is one area that has proven successful for Winzeler Gear.

"Our Ultra Light Urban Vehicle project, in cooperation with Bradley University, continues to evolve," Winzeler says. "This project has given us knowledge of power transmission in small vehicles and allows us the opportunity to present the benefits of plastic gearing from a weight, friction reduction and sound quality perspective. The project continues to grow, as well as the interest from transmission manufacturers."

If meetings and educational collaborations can't get the job done, Sheridan at Ticona turns to the tried and true initiatives of other areas of gear manufacturing. "Gear Expo is always a great venue to start discussions on the latest in plastic gear technology. We also hold in-house training sessions as well as webinars to provide as much assistance as we can to our customers now and in the future."

An Alternative to the Alternative

For several issues of this magazine, *Gear Technology* has considered plastics to be an alternative form of gear manufacturing along with powder metals and forging. Can the argument be made that plastics are no longer on the outside of gear manufacturing looking in?

"It is actually becoming the other way around these days," Kleiss says. "Metal is sometimes considered as a possible alternative manufacturing method, but only if every possible solution in plastic has been rejected. We promote performance as the key goal. Performance is cost- effective. Cost-effective means dollars saved and a

Winzeler Gear has reaped the benefits of plastic gearing from a weight, friction reduction and sound quality perspective (courtesy of Erich Schrempp, Schrempp Studios).

better product."

"Molded plastic gearing has considerable potential still. With new molding materials continuously entering the market, coupled with the ability to design and build highly accurate mold tooling and injection molding machines capable of producing and maintaining a consistent process shot after shot, injection molded gears are replacing machined gears at a higher rate than ever before. It still remains the most economical method of producing high volumes of gears," Ulrich says.

"We are continually trying to research and develop higher temperature materials that behave more like conventional gear materials," Winzeler says. "The challenge is that we see very little R&D activity outside of advanced product design. Most R&D has a timetable and there's no extra time to experiment. Metal gears have had years of knowledge and once plastic gearing can attain the same levels of research and development, more and more plastic applications will become available to us."

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Kleiss provides molded plastic gears for a variety of applications (courtesy of Kleiss).

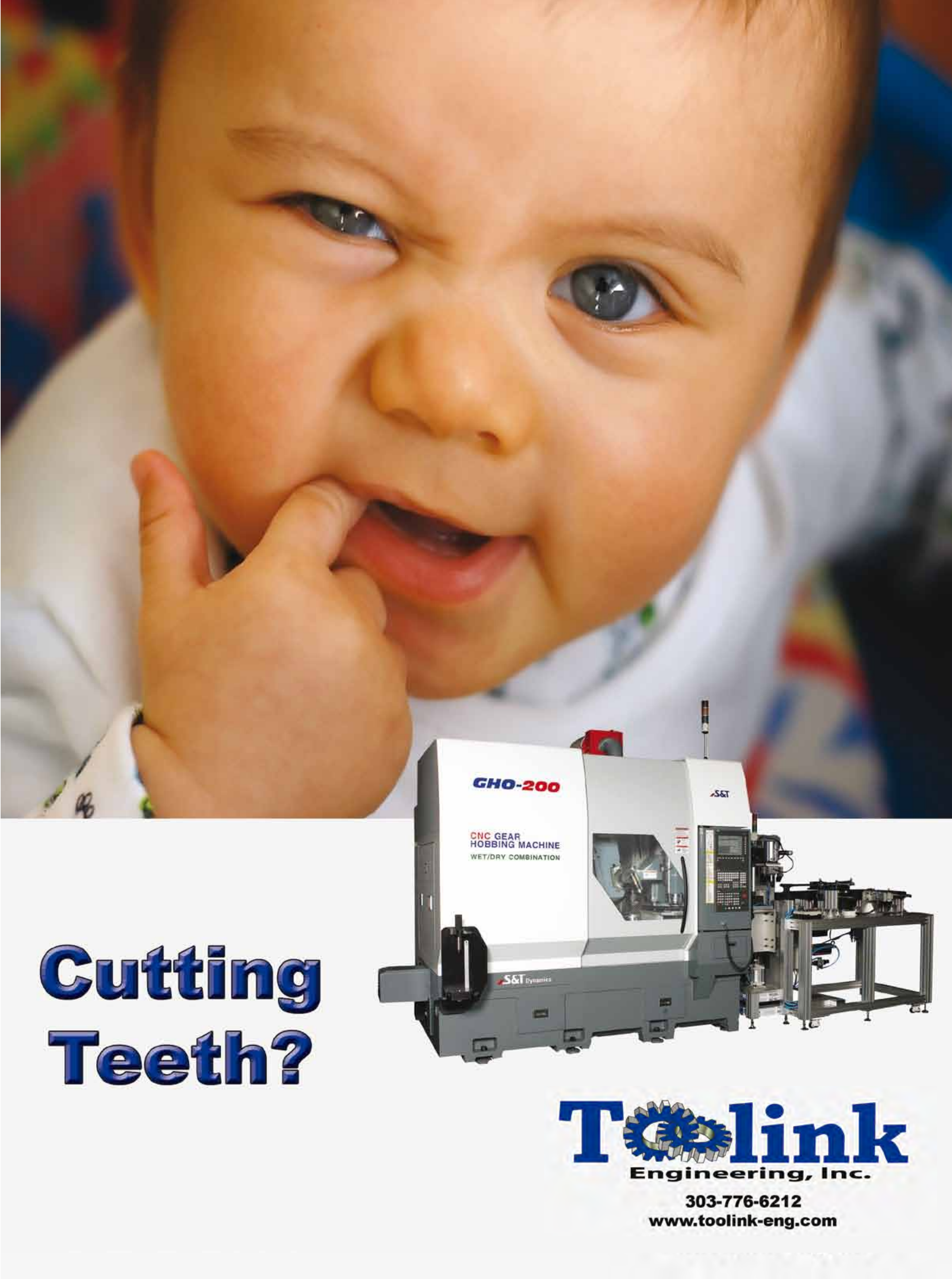
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Photo courtesy of Metlab

Manufacturer's Guide to Heat Treating Large Gears

Matthew Jaster, Associate Editor

The large gears found in mining, steel, construction, off-road, marine and energy applications—massive and robust in nature—need to tackle the greatest production demands. This, in turn, means that a special emphasis must be put on the heat treating methods used to increase the wear resistance and strength properties of gears this size. So what process works best and why? Companies like Metlab, Surface Combustion, Stack Metallurgical Services and Ipsen offer services/advice on the unique challenges of heat treating large gears.

"No single process can be singled out as having the greatest advantage, but the optimum selection depends upon design requirements, production requirements and quality issues," says Jim Conybear, director of operations at Metlab, located in Wyndmoor, Pennsylvania.

While the heat treating methods have rarely changed since the early days, it's the technology that has offered significant improvements. "Better insulation and heating technologies, improved process control sensors and better quench modeling/design," says John Gottschalk, director special products at Surface Combustion, Inc. "As such, the temperature uniformity, carburizing or nitriding potential uniformity and quenching are significantly better than in the past."

Heat Treating Large Gears

What methods work best for heat treating large gears? *Gear Technology* posed this question to these companies and found that the heat treating of large gears can be achieved through processes like carburizing, nitriding, induction hardening and through hardening. "Each one is selected to achieve the maximum benefit of the properties imparted by the particular process," Conybear says.

Carburizing is used to ensure maximum wear and pitting resistance of the gear tooth while maintaining the maximum possible ductile core for bending strength and impact resistance according to Marc Angenendt, vice president of operations at Ipsen.

"The benefits of carburizing are higher mechanical properties, strength and resistance. The drawback to carburizing is that quench can cause distortion and the need for a second process, like grinding. Some companies anticipate distortion and engineer the part for the distortion, but all of this can increase costs."

The carburizing process consists of imparting carbon to the surface of the gear, and diffusing the carbon into the teeth until the appropriate depth is achieved. "Carburizing is generally carried out at temperatures between 1,650 and 1,750 degrees F," adds Mark Podob, vice president marketing and sales at Metlab. "When the carburized case depth has been achieved, the temperature of the furnace is lowered, the part allowed to equalize and then it is quenched and tempered. Carburizing is selected for maximum wear protection of the gear teeth. It also is a choice over through-hardened gears as it can handle significantly more load than a through-hardened gear."

"Large gears have typically been done in pit furnaces," says Nels Plough, president and general manager at Stack Metallurgical Services, Inc., "However, we are now doing large gears in a vacuum carburizing furnace with an oil quench. This process method offers advantages for some applications that have critical surface requirements and are difficult to finish machine on all surfaces."

Nitriding is a surface only hardening application that develops a very thin layer at the surface part. "The layer is much harder than a carburized surface with additional benefits of wear and corrosion resistance over carburizing," says Gottschalk at Surface Combustion. "The nitriding process can be done after quench and temper processes, with some losses to the material core strength, based on tempering of the product at nitriding temperaratures (≈950 degrees F)."

Nitriding gives a higher surface hardness and avoids distortion. "The drawback to this process is that certain metallurgical results cannot be achieved but are sometimes required—especially when it comes to larger shafts and gears. However, the nitriding process is ideal for larger ring gears."

Through hardening is a historical process where gears are generally heated under a protective atmosphere to minimize the potential for decarburizing in the austenitic range, then quenched in oil or a similar media, and tempered, according to Conybear at Metlab. "The hardness specified for the gear is normally a function of the carbon content of the steel. For large gears, there is an inevitable compromise between the surface strength required and the core properties of the part. To achieve properties similar to case hardened parts, more expensive materials are required, which also are more difficult to form and fabricate."

Induction hardening—in which the surface or areas requiring high strength or wear resistance are heated to the hardening temperature using localized induction fields—is another method for large gears. "This process is often used to produce a hard layer on the gear tooth surface and root while maintaining a softer, tougher core to avoid tooth breakage and provide reasonable wear resistance," Conybear adds. "By considering the design requirements and the design of the specific part, all of these heat treating processes can often be interchanged or used in combination."

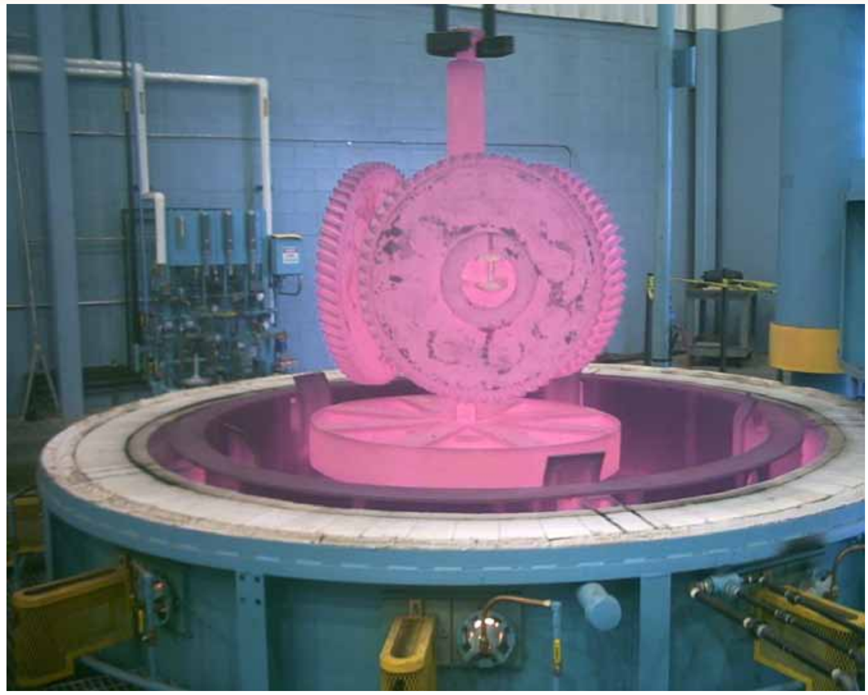
Distortion and Other Challenges

Once a process has been determined, it is equally important to know what changes can occur during the different stages of the heat treat. Gottschalk at Surface Combustion says that part geometry plays an important role in dimensional change but is not the only factor. "Previous processing steps such as forging, machining, stress relieving/normalizing, hardening and quenching processes will all affect the final dimensional variance. Elimination of unpredictable residual stresses from as many of these processing steps as

A 39,000 pound gear is lifted out of the carburizing furnace (courtesy of Metlab).

possible will be required to improve the final part dimensions," Gottschalk says. "With gears increasing in size, distortion challenges are greater, as the same percentage of distortion equates to a much larger absolute distortion. All steps with regard to the process need to be evaluated, as the final heat treating step can make the distortion worse, but generally is not capable of improving distortion characteristics."

Larger gears often require deep case depths, which means that the process time will be relatively longer, especially in the wind turbine business. It is not uncommon to first create a large case depth and later apply a hard machining process in order to eliminate distortion, but at the same time reducing the case depth again.



Gears leaving a Surface Combustion pit carburizing furnace (courtesy of Merit Gear).

"This is just one example to show how crucial distortion is for very large gears. Besides distortion, the major challenges are temperature uniformity, which is harder to achieve if there is a massive load in the furnace; uniformity of carbon within the process gas;, transport of very large gears from one furnace component to the other, especially due to the fact that the transport time is always crucial; investment costs/running costs; handling equipment and construction of the quenching equipment," Angenendt at Ipsen says.

According to Podob, "The challenges also include the capital investment and operating expenses of large furnaces.

continued

The large furnaces at Metlab used for carburizing are 15' in diameter by 12' deep and use 4,000,000 BTU/hour. The other issues related to heat treating large gears are the physical size of the gears and equipment required for lifting out of the furnace and into quench tanks, cryogenic tanks and tempering furnaces; and the expertise necessary for heat treating large parts without damage."

"Geometry dictates heat treat method, which then determines alloy options for a given part. For example, large ring gears are extremely difficult to successfully oil quench without huge distortion. This means that nitriding or induction hardening must be used. Part orientation and uniform quenching are important when designing part fixturing (hanging vs. laying flat, etc.)" Plough says. "Distortion control is one of the most difficult challenges. Also, the capital cost of equipment and facility. Effective equipment and processes are available, but are very expensive for large parts."

In-House Vs. Outsourcing

Many large gear manufacturers keep heat treatment in house if the floor space is available and they have the capital to pull it off. If in-house heat treatment isn't a viable option, there are commercial partners available for the heat treatment of large gears. There are several factors to consider when deciding which route is best for the organization.

"If a very high quality is required, it might be easier to achieve this requirement if there is an in-house heat treating facility where the furnaces can be optimized for a certain product," says Ipsen's Angenendt. "Another major factor is the volume of parts. This means that if a company has enough through-put to utilize a heat treatment line, the decision is often to do in-house heat treatment. Additionally, the availability of a commercial heat treater close by—this applies especially to large gears where it can be quite expensive to transport them to a commercial heat treater."

"In house heat treating requires a large capital outlay for equipment, plant improvements and personnel, including not only heat treat specialists and technicians, but a metallurgist to develop and implement the processes and parameters. As an example, to duplicate the furnace installations at Metlab including a 12' deep pit, overhead crane, furnace and quench tank, would be an investment in excess of $3 million. The second draw back towards such an installation is that for a captive manufacturer, the number of large gears for heat treating is somewhat limited, hence payback of the initial investment may not be justified," Podob says.

"Internal vs. external heat treating evaluation is most often reduced to three conditions: delivery time of the service being outsourced, cost of the service, and final part quality. Internal heat treating has the advantage of faster turnaround due to reduced transportation times and routine scheduling issues at commercial heat treaters for furnace time. Total quantity of parts is the biggest driver of both equipment and service costs. If production volumes are low, it virtually never makes sense to bring heat treating inside," Gottschalk says. "Final part quality can be the biggest factor in the decision as internal heat treating processes tend to be specifically designed for a given part. Commercial processors typically have universal equipment to allow for more flexibility with a variety of customers and processes, which may or may not provide the best technical solution."

High Stakes Heat Treat

Heat treating large gears can come with its own set of high stakes challenges as well. These gears must adhere to strict inspection requirements and tight deadlines. In many situations, the customer may have needed the end product three weeks ago. "Prior experience, proper quality control procedures and internal company auditing procedures are a *must* for any commercial or captive heat treating. They become even more important with large gears because of the tremendous amount of time and expense to get the product up to this point in manufacturing. Any failure at this time correlates to incredible costs," Gottschalk says.

"Many heat treat companies handle work that comes from a wide range of industries, each having their own specification requirements. For heat treat companies with a strong quality system, such as NADCAP, spec review and compliance is routine and expected. Designing heat treat processes that meet spec requirements and produce good properties with minimum distortion are the result of experience and expertise with a wide variety of materials," Plough says.

"In defense and military applications, for example, strict inspection is required as well as tight deadlines for project completion. What better prepares a heat treat company for these unique applications and the inherent obstacles that come with each job? Metlab uses its own internal process specifications developed individually for each and every heat treatment job. For any of the processes which are done on gears, these process specifications are based on AMS specifications as well as MIL specs and in-house experience. We also rely on not only our own expertise, but that of our customers as well, working in partnership to develop the processing parameters to produce quality parts," Conybear says.

"Under normal circumstances the specification of very large gears are fixed and the related processes to achieve this specification were developed by some preliminary trials. It is always easier if the process, as well as the specifications, is well established and it is a proven fact that the specification can be reached. However, under certain circumstances it is necessary to develop further already existing recipes in order to achieve an even more demanding specification," Angenendt at Ipsen says.

Design and Metallurgical Collaboration

Another key factor in heat treating large gears is to plan ahead, discuss the design and metallurgical issues early and often, preparing for the challenges to come. "Design, manufacturing processes and metal chemistry will all play a critical role in final part performance, so it is best to discuss these issues in the early planning stages of the project. In many cases, required part properties cannot be physically achieved based on limitations in the heat treating process or selected metal chemistry," Gottschalk says.

"There should always be close communication between a gear design engineer and a gear metallurgist in order to prevent gear specifications and load assumptions on gears which can never be achieved," Angenendt at Ipsen says. "Besides the communication between a gear design engineer and a gear metallurgist, it is always wise to consult a general heat treatment expert in certain cases in order to ensure that the gear or shaft, which was developed by the gear design engineer and then by the gear metallurgist, can be produced and heat treated. In order to achieve this target, all three parties need to communicate closely."

"There is no question that gear designers and the gear metallurgist need to work together to ensure a successful product. This includes ensuring that the metallurgical results can be achieved, the part can physically be processed and distortion can be minimized," Conybear says. "As an example, Metlab recently worked with one gear manufacturer to carburize and harden a 75,000 pound reduction gear for a steel mill. The final gear measured about 12" diameter, was a double helical gear, with an 18" face width, and total gear thickness of 48". In working closely with the manufacturer, it was decided to produce the gear in two halves, each 24" tall to first allow for ease in lifting into and out of the furnace, particularly when the gear was hot, reduce the volume of oil required for a successful quench, and to minimize the potential for distortion. These were fabricated gears, and producing the gears in halves allowed for thicker webs and an increased number of stiffening supports, again aimed at minimizing distortion."

New Developments in Larger Sizes

What does the future hold for the heat treating of large gears? "An installed equipment base of larger size must be developed to meet the increasing production demands," Gottschalk says. "Unfortunately, this will be a slow devel-

continued

Test load of ring gears for a customer order (courtesy of Ipsen).

opment as many companies will not make the large capital investments necessary to process these larger parts. Firm commitments will be required regarding both part quantity and future market changes. This growth must be driven by product end users as return on investment is reduced if new large product manufacturing cells are under-utilized. In addition to larger processing equipment, it is expected that better material grades will be developed, making it easier to achieve more demanding process standards."

"There is a trend in the market to heat treat larger and larger parts. There will be a requirement for bigger furnaces capable of handling larger loads than today. This trend was seen in the past and will be further developed in the future. These larger furnaces also require bigger loading and unloading systems as well as bigger surrounding equipment. To develop these bigger furnaces and the related auxiliary equipment will be the challenging task in the future. In general the race will be to make the parts/machines as 'small' and 'light' as possible, because 'big' and 'heavy' requires a lot of energy and money," Angenendt at Ipsen says.

"The main technological advance has been the implementation of sophisticated models of the processes that can be used in real time for on-line process control." Conybear says. "Coupled with industrial hardened controllers and high speed computers, the processes can be run with high predictability and reproducibility with low initial cost and low maintenance. In the early nineties, such models were only usable in the laboratory, ran at speeds that could not reach to the process changes."

Adds Plough at Stack Metallurgical, "Heat treaters need to push for additional alloy development for large cross-section gears. The ability to gas quench thick sections and attain high core properties will open the door to additional process refinements and distortion control."

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Stack Metallurgical opened in 1984 with a couple of atmosphere furnaces and has become a versatile provider of heat treat services, particularly in large gears (courtesy of Stack).

Controlling Gear Distortion and Residual Stresses During Induction Hardening

Zhichao Li and B. Lynn Ferguson

Management Summary

Induction hardening is widely used in both the automotive and aerospace gear industries to minimize heat treat distortion and obtain favorable compressive residual stresses for improved fatigue performance. The heating process during induction hardening has a significant effect on the quality of the heat-treated parts. However, the quenching process often receives less attention even though it is equally important. Deformation Control Technology's (DCT's) past experiences have shown that the cooling rate, the fixture design and the cooling duration can significantly affect the quality of the hardened parts in terms of distortion, residual stresses and the possibility of cracking. *DANTE*, commercial, FEA-based software developed for modeling heat treatment processes of steel parts, was used to study an induction hardening process for a helical ring gear made of AISI 5130 steel. Prior to induction hardening, the helical gear was gas-carburized and cooled at a controlled cooling rate. The distortion generated in this step was found to be insignificant and consistent; therefore, the modeling investigation in this paper focused on the spray quench of the induction hardening process. Two induction frequencies in a sequential order were used to heat the gear teeth. After induction heating, the gear was spray quenched using a polymer/water solution. By designing the spray nozzle configuration to quench the gear surfaces with different cooling rates, the distortion and residual stresses of the gear can be controlled. Tooth crown and unwind were predicted and compared for different quenching process conditions. The study demonstrates the importance of the spray duration on the distortion and residual stresses of the quenched gear.

Introduction

High-frequency induction hardening is more environmentally friendly than traditional quench hardening processes such as gas furnace heating followed by immersion quenching in oil. It also provides flexibility in control on the case depth, residual stress state, and part distortion. Due to these advantages, the induction hardening process is widely used in the gear industry for case hardening. During induction heating, the energy to heat the part is generated internally by eddy currents in response to the imposed alternating magnetic field. The energy density distribution in the near-surface layer is directly related to the distance between the inductor and the part, as well as the frequency of the inductor. Lower frequency heats the part deeper over a longer time period because the eddy current gradient in the part surface is lower, meaning the Joule heating extends deeper into the part interior. In contrast, higher induction frequency heats a shallower layer over a shorter time. The temperature distribution in the part is a combined result of induction heating, thermal conduction and phase transformations.

In many induction hardening processes, both medium and high frequencies are used to reach the desired temperature field and hardened case depth. The heating may be a two step process, i.e., a different frequency for each step, or a single step with dual frequency application. Simultaneous dual frequency (SDF) induction heating applies both medium and high frequencies in the part simultaneously to generate a more uniform temperature distribution in curved surfaces such as gear tooth profile (Ref. 1). The energy percentage of medium and high frequencies during SDF induction heating can be adjusted, which provides greater flexibility in controlling temperature distribution in complicated part shapes. The other common induction hardening process for gear components is to apply two sequential induction frequencies. Lower frequency is normally used first to heat the gear root, followed by higher frequency to heat the gear tip. A time delay can also be applied between the two frequencies to more flexibly control the temperature distribution in the component.

Induction hardening is a transient thermal process. During induction hardening of steel components, both the thermal gradient and the extent of phase transformation simultaneously contribute to the evolution of internal stresses and distortion. Recent developments in heat treatment modeling technologies make it possible to understand the material's response during heat treatment processes, such as how the internal stresses and distortion are generated. *DANTE* is a commercial FEA-based software developed for heat treatment modeling of steel components, including furnace heating with liquid or gas quenching, or induction hardening processes with spray quenching (Ref. 2). *DANTE* was not developed to model the electromagnetic physics of induction heating. A temperature distribution predicted from an induction heating model or from experimental measurements can be imported to drive the model. *DANTE* can also be effectively used to simulate the temperature field produced during induction heating by using Joule heating, i.e., i^2r heating, based on the depth of the hardened case in the part (Ref. 3). In this paper, a carburized helical gear was induction heated using two

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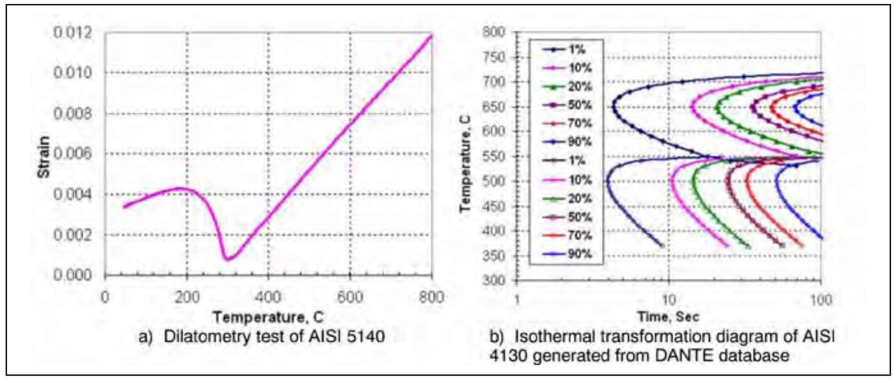


Figure 1—Phase transformation kinetics.

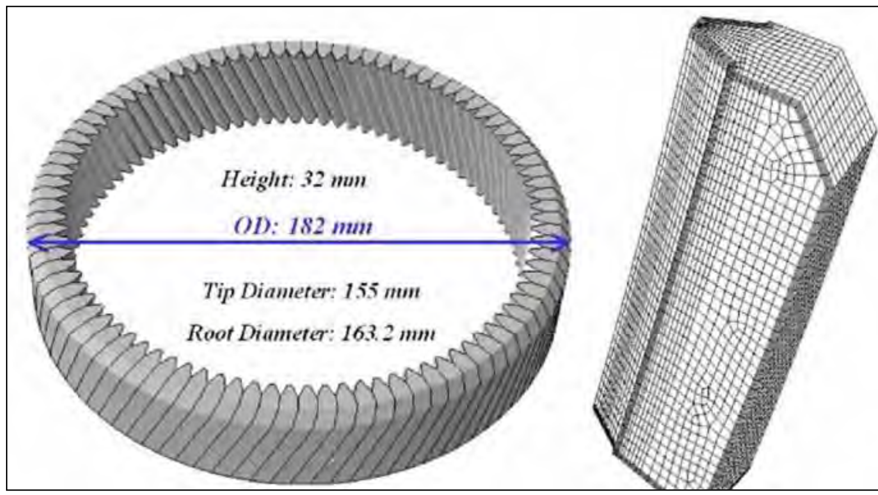


Figure 2—(a) CAD model of transmission gear and (b) single-tooth finite element model.

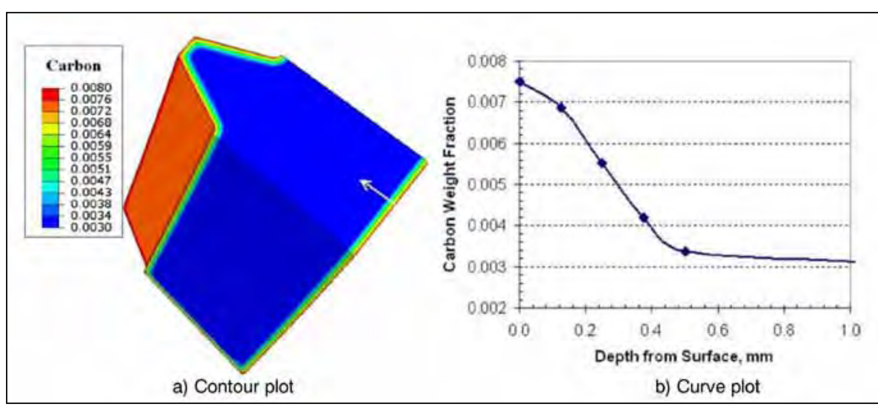


Figure 3—Carbon distribution.

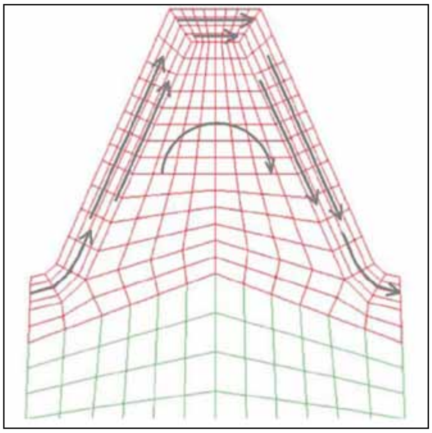


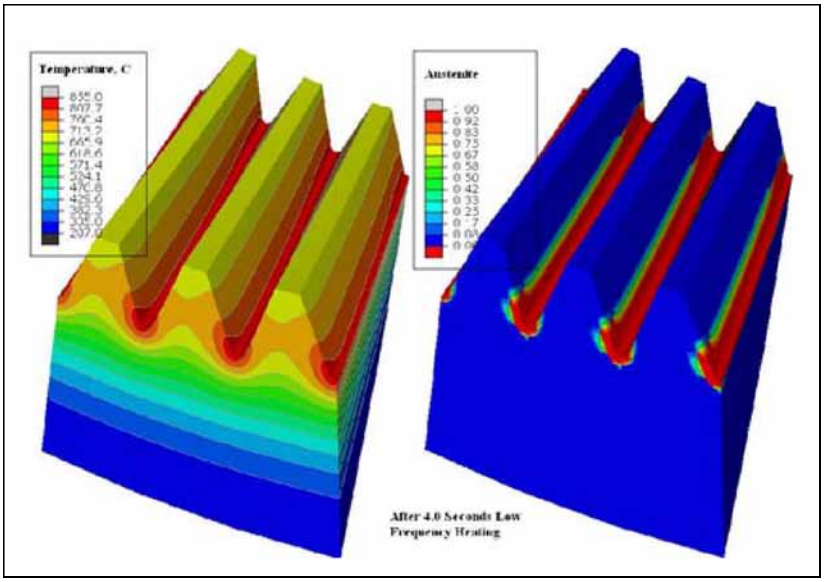
Figure 4—Schematic plot of eddy currents in the part during induction heating.

sequential induction frequencies, followed by spray quenching. The effect of spray quenching on the distortion was studied using the modeling results.

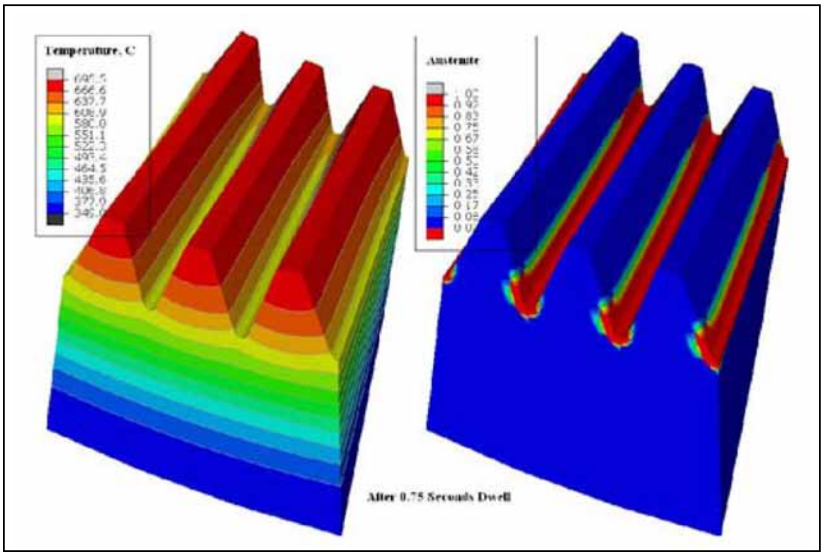
Material Characterization for Heat Treatment Modeling

The ring gear studied in this paper was made of AISI 5130 with a chemical composition of 0.83% Mn, 0.22% Si, 0.15% Ni, 0.80% Cr, 0.04% Mo and 0.30% C in weight percentage. The gear was gas-carburized prior to induction hardening to improve the strength of the surface layer. To model the induction hardening process, the phase transformation data of base carbon and high carbon steels of this grade are needed. Dilatometry experiments were done previously for this steel grade with series of carbon levels (Ref. 4). Figure 1a shows the dilatometry experimental data for continuous cooling of AISI 5140. The phase transformation kinetics for both martensitic and diffusive phase transformations were fitted from this type of dilatometry data, with different carbon levels and testing conditions. Isothermal transformation diagrams (TTT diagrams) can be generated from a *DANTE* database (Fig. 1b) for AISI 5130. The isothermal and continuous-cooling diagrams can be generated to evaluate the hardenability of a given steel grade and carbon level.

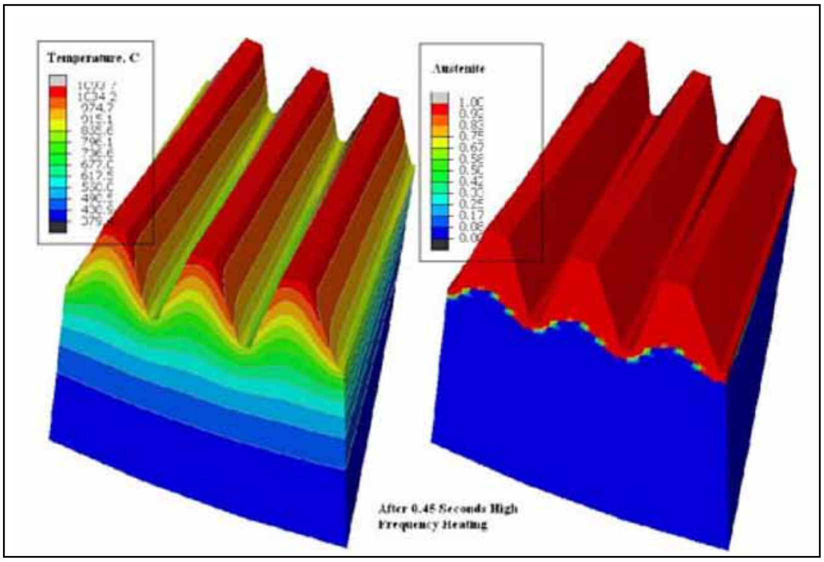
The mechanical properties are also required to model the distortion and residual stresses from the heat treatment of steel parts. The mechanical properties—yield, hardening and recovery—change with the composi-



a) After 4.0 seconds low frequency heating



b) After 0.75 seconds dwell



c) After 0.45 seconds high frequency heating

Figure 5—Temperature and transformed austenite during heating.

tion of different phases, carbon content and temperature. In *DANTE*, the mechanical properties of individual phases are defined based on experiments. A mixture law is used to describe the global response of the material linking with the phase transformation kinetics.

Finite Element Modeling (FEM)

A CAD model of the ring gear is shown in Figure 2a. The internal helical gear has 92 teeth. The tip diameter is 155 mm, the outer diameter is 182 mm and the height is 32 mm. A single-tooth finite element model was created and is shown (Fig. 2b). The finite element model has 23,372 nodes and 20,784 hexahedral elements. Fine elements are used in the shallow surface of the gear to more accurately catch the carbon and thermal gradients during heat treatment. Cyclic symmetric boundary conditions are applied so that the single-tooth model represents the whole gear, with an assumption that all the teeth behave the same during the heat treatment process.

Pre-Induction Hardening Process

Prior to induction hardening, the gear was gas carburized, followed by a controlled, slow cooling. The carburization process was used to increase the hardness and strength of the surface layer. The carburization temperature was 875 °C and the carbon potential of the furnace was 0.80%. The total carburization time was 2.0 hours. Figure 3a shows a cut view of carbon distribution at the end of the carburization process. The sharp corner of the gear tip has a slightly higher carbon than the other surfaces due to the geometry effect. The carbon distribution in terms of depth from the outer surface is shown (Fig. 3b). The approximate carbon case depth, defined by 0.45% carbon, is 0.35 mm. After carburization the gear was cooled to room temperature in a controlled atmosphere. The obtained microstructure in the core of the gear is mainly pearlite; the carburized case has a combination of martensite and bainite. The distortion from the controlled cooling process is consistent, which can be compensated for in the

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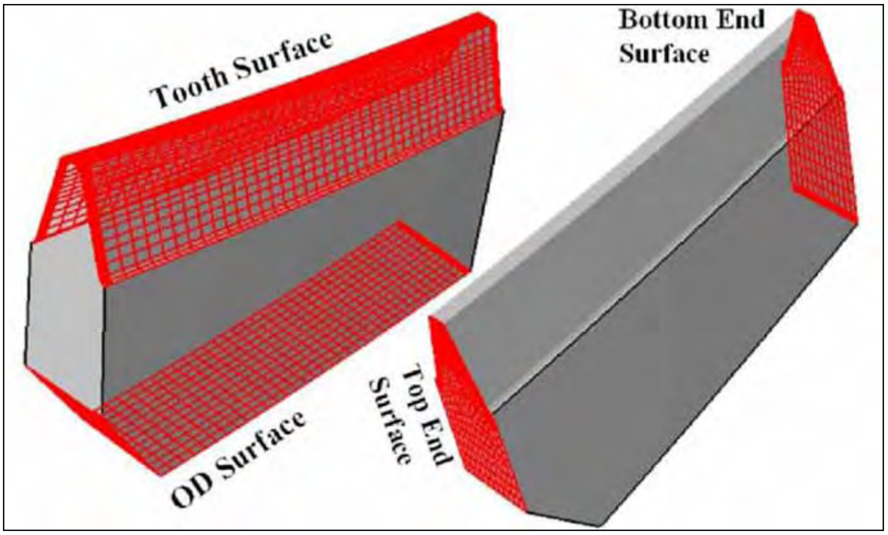

Figure 6—Part surfaces defined for setting up spray quenching model.

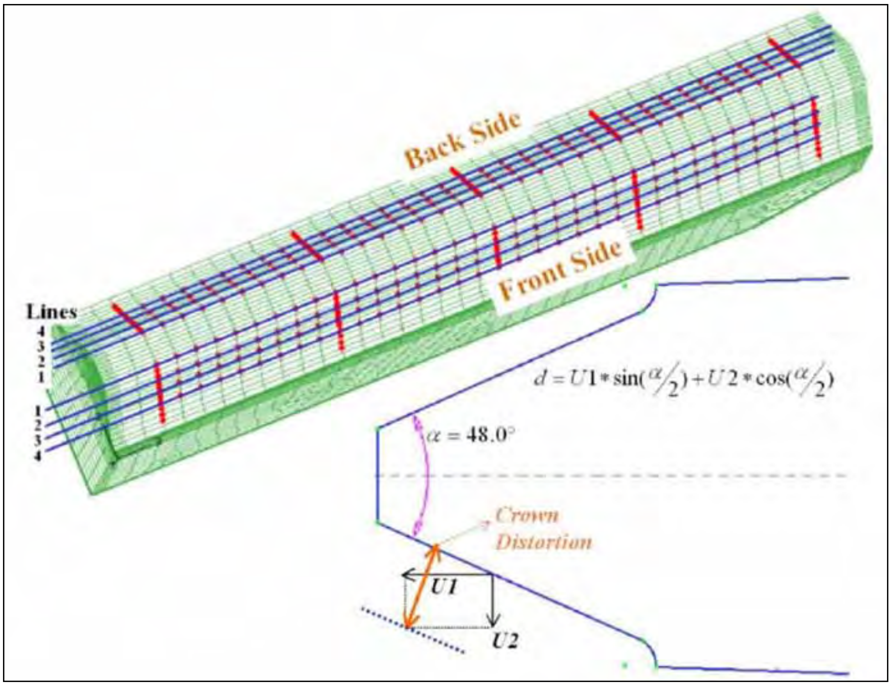

Figure 7—Tooth surface crown distortion calculation using *DANTE* modeling results.

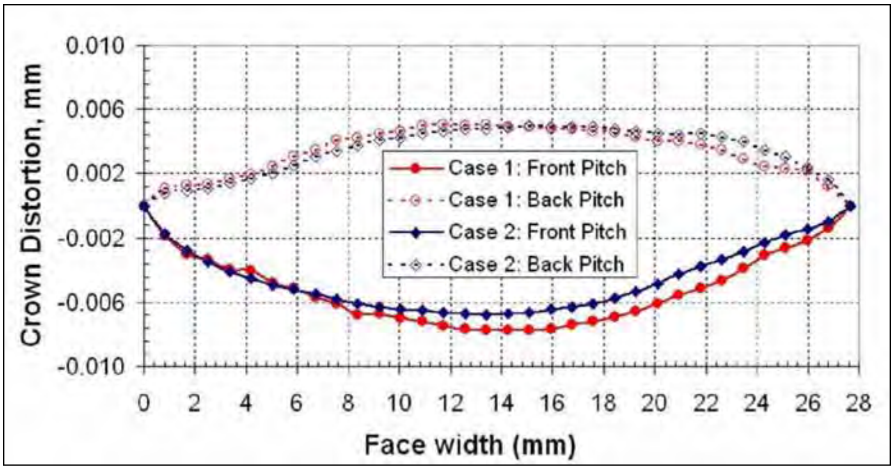

Figure 8—Comparison of crown distortion for the two quenching processes.

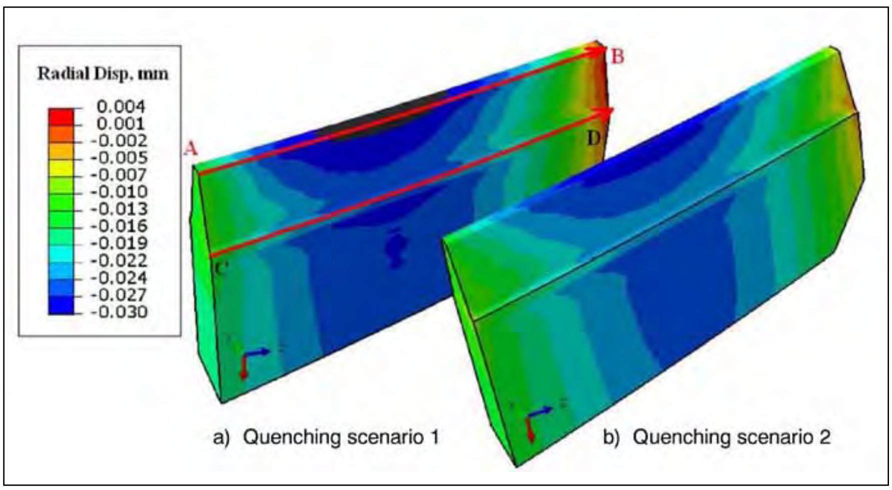

Figure 9—Contour plots of radial displacements after induction hardening.

gear design by adjusting the green shape dimensions. Therefore, this study focused on the induction effect of the induction hardening process.

Induction Hardening Process

Two sequential induction frequencies were used to heat the inner gear teeth; there was a short delay between the two heating stages. A brief schedule of the induction hardening is listed below:

- Medium frequency heating for 4.0 seconds
- Dwell for 0.75 seconds
- High-frequency heating for 0.45 seconds
- Spray quench

Instead of modeling the physics of the electromagnetic field generated by the inductor, the *DANTE* model directly applies the heat power by the eddy current in the part following the Joule rule, as shown (Fig. 4). Uniform heat energy distribution in the gear axial direction was assumed. Medium-frequency heating generates more heat in the gear root, while high-frequency heating generates more heat in the tip of the tooth. The dwell time between the two heating stages is important, as this allows time for thermal diffusion. The heat energy applied in the model can be adjusted to improve model accuracy using data from experiments with thermocouples and metallography of the hardened case profile; the latter method is used in this paper. Alternatively, the power distribution predicted by induction software such as *ELTA* could also be used to drive the *DANTE* model (Ref. 5). In this paper, results for one induction heating and two spray quenching scenarios are presented. Spray quenching is assumed to start immediately after the heating step—without delay. Residual stress states and distortion were predicted by *DANTE* and the effects of the process variables on distortion are discussed.

The temperature and austenite distribution after each heating stage are shown (Fig. 5). After 4.0 seconds of heating at a medium frequency, the surface temperature of the gear root is about 815 °C, the tooth tip is about 700 °C and the OD surface temperature is about 280 °C. The gear root area is predicted to have formed austenite, but the tooth tip has not. During the 0.75-second dwell, the heat diffuses from the inner to the outer surface by thermal conduction. A small amount of heat is lost to the environment by radiation and air convection, which are also included in model. At the end of the 0.75-second dwell period the gear tip temperature has had a small drop; but the temperature at the gear root has dropped significantly—from 815 °C to 595 °C. The temperature at the outer diameter surface has increased—from 280 °C to 350 °C. No phase transformation occurs during the dwell time. The third stage is a high-frequency heating for 0.45 seconds. At the end of the third-stage heating the temperature at the tooth tip has increased to 1,050 °C, the root temperature has increased to 850 °C and the OD surface temperature has increased to 380 °C. The austenite distribution profile is shown (Fig. 5c).

After induction heating the gear is spray quenched to room temperature without delay. As shown (Fig. 6), the gear surface is defined as four regions to model the quenching process: i.e., 1) tooth surface; 2) OD surface; 3) top-end surface; and 4) bottom-end surface. Quench fixture and spray nozzle configurations were designed to flexibly quench each individual surface at a controlled rate. In this paper a water/polymer solution was used as the quenching media. The average heat transfer coefficient was assumed to be 5.0 (kW/m^{2}K) during the spray quench. Two spray scenarios were modeled to investigate the quenching effect on distortion. Scenario 1 sprayed all the exposed surfaces; scenario 2 sprayed the tooth surface only.

Distortion Analysis Using Finite Element Models (FEMs)

The gear modeled in this paper has a thin wall thickness and the cooling rate of the water/polymer spray is sufficiently fast to miss the nose of the diffusive phase transformations (Fig. 1b). The martensitic phase distribution in the actual hardened ring gear closely matches the predicted austenite distribution (Fig. 5c). The crown distortion and unwind of the teeth are the two main distortion modes for this gear. *DANTE* models predicted the nodal displacements after the heat treatment process and these nodal displacements were used to calculate the crown distortion and unwind angle. The crown distortion in this paper is defined as the bowing amount of the tooth face at the pitch diameter line, as shown by Line 3 in Figure 7 for both sides of the tooth. A simplified equation is used to convert the predicted nodal displacements to the values of bowing.

$$d = U1 \sin\left(\frac{\alpha}{2}\right) + U2 \cos\left(\frac{\alpha}{2}\right)$$

where:

- d is bowing value, representing how far the surface point moving away from its original position
- $U1$ is radial displacements from the model results
- $U2$ is circumferential displacements from the model results
- α is tooth angle (Fig. 7)

The crown distortion is defined as the maximum bowing value from the original position.

The crown distortions of the pitch lines on both sides of the tooth are shown (Fig. 8). The X-axis represents the axial position from the bottom end surface to the top end surface, with $X=0$ located at a point 2 mm from the end. The displacements are calculated with around 2 mm from each end to avoid the significant distortion on the edge. Without any distortion all the lines will align perfectly with $Y=0$. For the front tooth surface a negative

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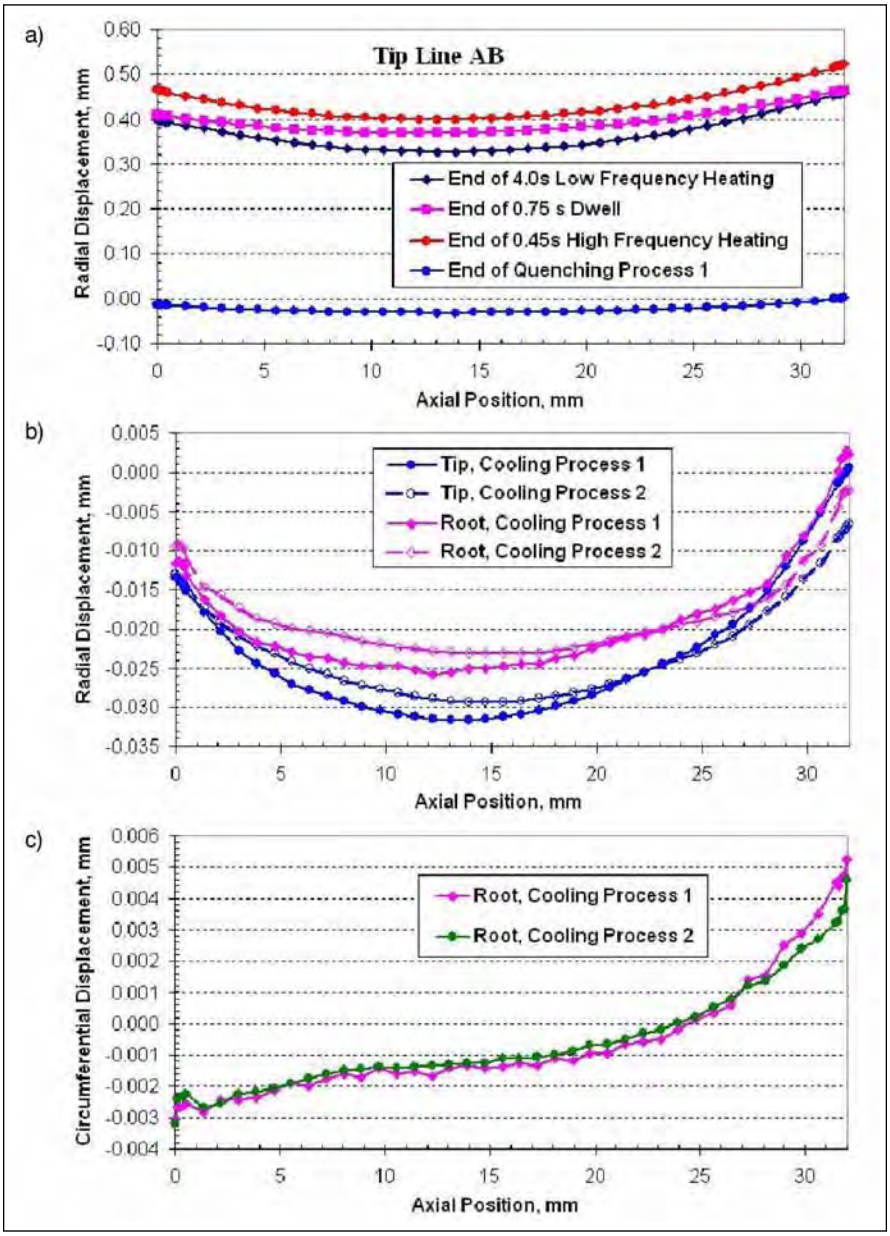

Figure 10—(a) Radial displacement of the gear tip line AB at different stages of heat treating processes; (b) radial distortion at the end of quench; (c) gear tooth unwinding distortion.

crown distortion value means bow outward. For the back-tooth surface a positive crown distortion means bow outward. For quenching scenario 1, the crown distortion of the front pitch is 7.8 µm and that of the back pitch 5.8 µm. The crown distortion of the front pitch is reduced by about 1.0 µm for the second quenching scenario. However, the crown of the back pitch has no significant difference between the two quenching scenarios.

Both the thermal gradient and phase transformations contribute to the gear distortion. Computer modeling makes it possible to determine the intermediate gear shapes during heating and quenching processes, and to understand how the distortion is generated. With this knowledge the process can be improved to reduce the distortion without heavy reliance on trial-and-error experiments; these can be accomplished on a computer. Two straight lines—AB and CD (Fig. 9)—are selected to investigate the intermediate gear geometry during the induction hardening process. Line AB is located along the tip edge of the gear and line CD is along the middle of the gear root.

During induction heating the gear expands in both the radial and axial directions. The displacements at the end of each heat treatment stages are plotted in Figure 10. The *X*-axis (Fig. 10) represents the axial position, starting from the bottom end surface. Both points A and C have *X* values of 0.0 mm. A global Cartesian coordinate system as shown (Fig. 9) is used to plot the displacements; a positive radial displacement represents expansion and a negative radial displacement represents shrinkage.

Using scenario 1 as an example, the radial displacements of gear tip (line AB) are plotted at the end of each stage (Fig. 10a). At the end of the 4.0-second, medium-frequency heating, the radial displacement at point A is 0.4 mm, compared to the 0.45 mm at point B located at the opposite gear end. The lowest radial expansion along the line AB is 0.32 mm—located mid-height of the gear. The gear tip surface has an inward bow, due to the thermal expansion of the inner teeth. The top end has a large chamfer on the OD surface and its wall is thinner, leading to a higher temperature at point B than that at point *A* during heating; as a result, point B has higher radial expansion. After the 0.75-second dwell, the heat transfers from the inner teeth to the outer surface and the thermal gradient in the radial direction decreases. Without any significant change of the radial displacements at point A and B, the radial displacement at mid-height increases, thus reducing the inward bow of the tooth.

After the 0.45-second, high-frequency heating period the temperature of the inner teeth has increased to 1,050 °C. The temperature gradient between the inner teeth and the OD surface has increased during this stage. Figure 10a shows that radial expansion has increased—as has the amount of the inward bow.

The thermal stress and stress induced by phase transformation can cause plastic deformation during both heating and quenching. After quenching the gear to room temperature the thermal expansion of the gear is gone; any plastic deformation generated during the process will end up as distortion. Note that the volume change due to phase transformation will cause some level of size change, which should be uniform. Figure 10b shows the radial distortion at the end of the quenching process. The gear tooth shows an average radial

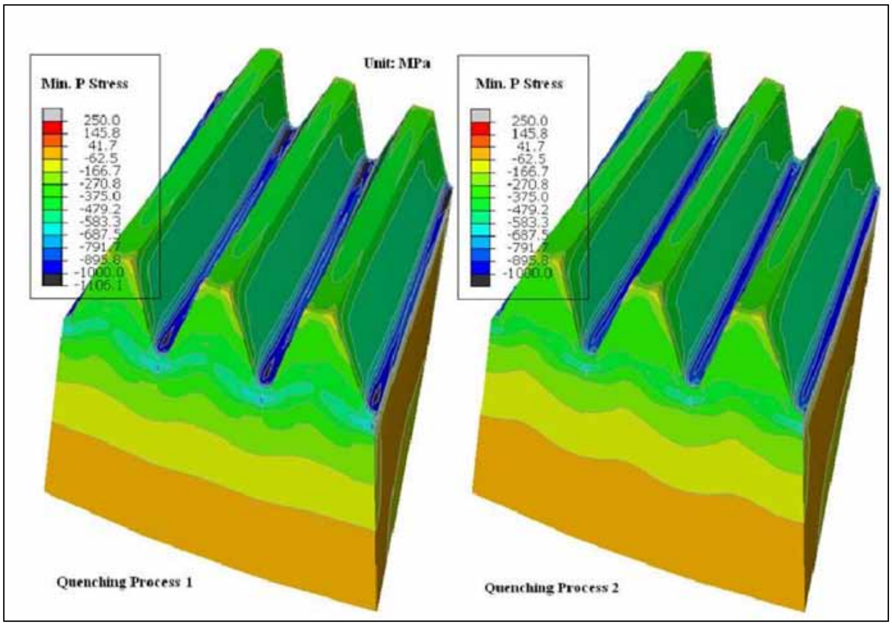

Figure 11—Residual stress state after hardening, showing minimum principal stress.

shrinkage of 0.02 mm and the inward bow is reduced in comparison to that at the end of the heating stages. About a 3 μm difference in axial bow distortion is shown between the two quenching scenarios. The gear tip has less radial shrinkage compared to that of the gear root, meaning that the gear tooth thickness has increased after hardening.

Another important distortion mode is the gear tooth helical angle change after the hardening process. The circumferential displacements (along the root line CD in Figure 9) are plotted for both quenching scenarios (Fig. 10c). The circumferential displacements are used to calculate the helical angle change due to the induction hardening process. The average unwind angle of the teeth is about 0.025° and there is no significant difference between the two quenching scenarios. The axial height of the gear after induction hardening increased slightly.

Residual stresses after heat treatment are important to the fatigue performance of the gear. As shown (Fig. 11), the gear root is predicted to have a compressive residual stress of 1,000 MPa in compression after induction hardening. The two cooling scenarios do not have a significant difference on residual stress distribution in the root area, so the gear resistance to bending fatigue should be similar.

Summary

Using computer simulation, two induction hardening scenarios have been examined for a carburized ring gear made of 5130 steel. Induction hardening using a two-step heating method, followed by spray quenching, was shown to produce the desired residual compressive stress in the gear root area, but also to cause a small amount of unwind and radial shrinkage. The tooth shape moved radially inward a small amount and also hour-glassed slightly as the carburized layer was transformed to martensite. Knowing this in advance, the green tooth form can be altered so that it moves to the proper, final shape during induction hardening.

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The Relative Performance of Spur Gears Manufactured from Steel and PEEK

A. K. Wood, V. Williams and R. Weidig

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Management Summary

Polymer gears offer many advantages over their metal counterparts:

- More cost effective production for large runs
- No need for additional finishing operations
- High resilience and internal damping capacity result in quiet operation
- Lighter, lower inertia
- Good corrosion resistance
- Possible to integrate several components in a single molding operation
- Excellent fatigue performance

Victrex has constructed two gear test rigs capable of running gear combinations at torques up to 60 N-m and speeds up to 6,000 rpm. The rigs are equipped with shaft encoders, resolving to 0.0007 radians, and torque transducers on both input and output shafts. The instrumentation on the rig allows the capture of data related to tooth deflections, gear flank wear and the general performance of the gears.

This paper seeks to compare the data generated from the shaft encoders and torque transducers when using steel-steel, steel-plastic and plastic-plastic gear combinations in order to understand the differences in performance of steel and plastic gears.

Introduction

Plastics have long been used in the production of gears due to their many advantages:

- Thermoplastic gears can be produced by injection molding. This can provide a significant cost saving for large-scale production, the possibility to integrate intricate design features, the ability to reduce part count and short production cycles are possible with minimal requirements for secondary operations.
- The low density of polymers results in potential weight saving.
- Plastic gears have high resilience and internal damping, giving quieter operation.
- Plastic gears have the ability to run successfully with no lubrication.
- Plastics generally have good corrosion resistance.
- Plastic gears can be over-molded onto metal hubs for ease of assembly.

However, the use of plastic gears has so far been limited due to:

- The yield strength and elastic modulus of common plastic gear materials are roughly an order of magnitude and two orders of magnitude respectively lower than steel.
- The mechanical properties of plastics are temperature sensitive, and the usable temperature range is often limited when compared to steel. Frictional heating which occurs in the gear mesh exacerbates this problem.
- Some plastics are sensitive to moisture, resulting in changes in dimensions and mechanical properties.
- Plastics usually have a higher coefficient of expansion than metals and thus dimensional changes need to be considered where applications involve significant temperature variations.
- Plastic gears cannot usually be molded to the same dimensional accuracy as machined metal gears because of post-mold shrinkage.

These factors often limit the load carrying capacity of such gears and so they only tend to be used in lightly loaded applications.

The subject of plastic gears first appeared in the literature in the mid 1950s and was related to the performance of polyamide gears (Ref. 1).

Since then, a considerable amount of research has been published, the literature focusing on polyamide and acetal gears which represent approximately 80–90% of the plastic gear market (Refs. 2–6).

Design data and design methodology is available for these materials and is readily available in standards such as British standards (Ref. 7), Polypenco (Ref. 8) and American standards (Ref. 9). However, it is generally accepted that the only reliable way of predicting gear performance is by testing gears under real life conditions using different applied loads, speeds and lubrication scenarios.

Plastic gear failure often results from either tooth root failure or tooth wear. This paper is aimed at investigating the former and so further discussion will be limited to tooth root failure. Tooth root failure is normally the result of either too high a mechanical stress, the combination of a high mechanical stress with the effects of temperature or simply too high a temperature such that the material softens and can no longer support any load. Theories have been developed to provide a means of determining the thermal effects in gears in relation to direct thermal failure (Refs. 6, 10–11). However, this work seeks to understand the nature of the tooth engagements found with plastic gears in order to attempt to provide some understanding of the effects occurring which may limit tooth lifetime.

Experimental Setup

Victrex, through a knowledge transfer partnership with the University of Birmingham, U.K., designed and constructed a test rig (Ref. 12) to enable the measurement of gear design data. The rig has two 40 kW motors—one driving, the other acting as an electrical brake—and both the input and output shafts are equipped with encoders and torque transducers. The gears used in this work had a module of 2 mm, a pitch circle diameter of 60 mm, a face width of 12 mm, a pressure angle of 20° and 30 teeth.

All tests were carried out under lubricated conditions, and the test temperatures used were at room tempera-

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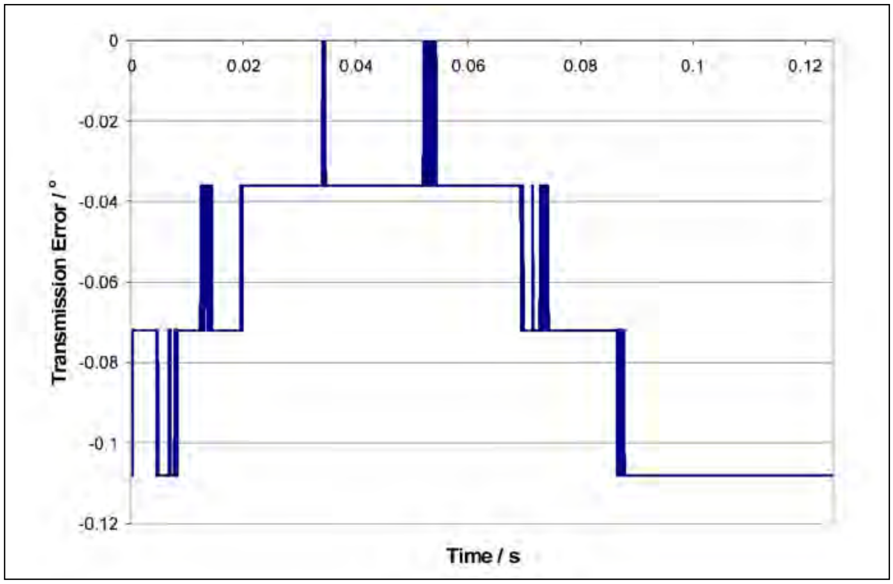

Figure 1—Transmission error with a steel shaft.

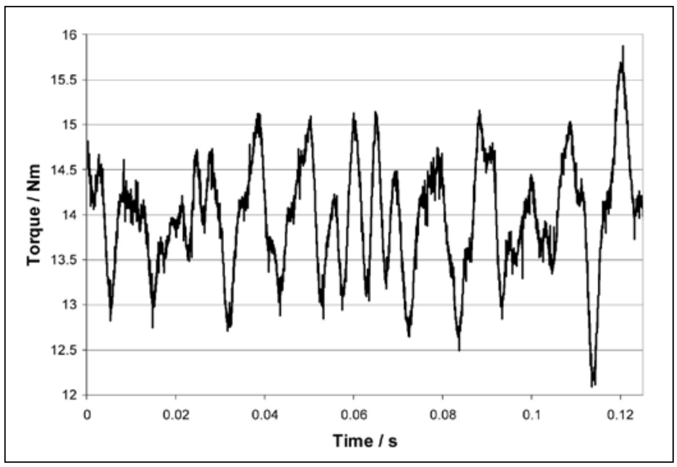

Figure 2—Torque variation with a steel shaft.

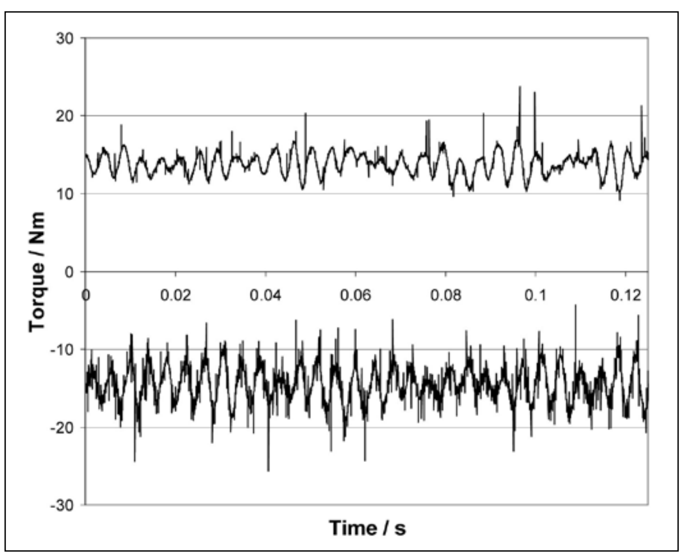

Figure 3—Torque data for the steel-steel gear combination.

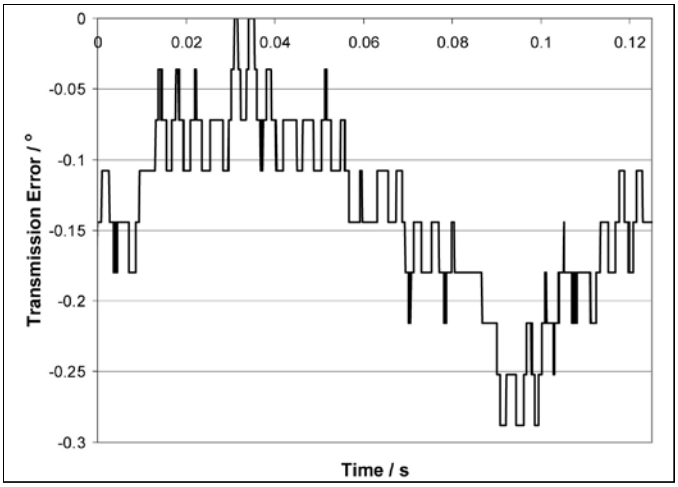

Figure 4—Transmission error data for steel-steel gear combination at room temperature.

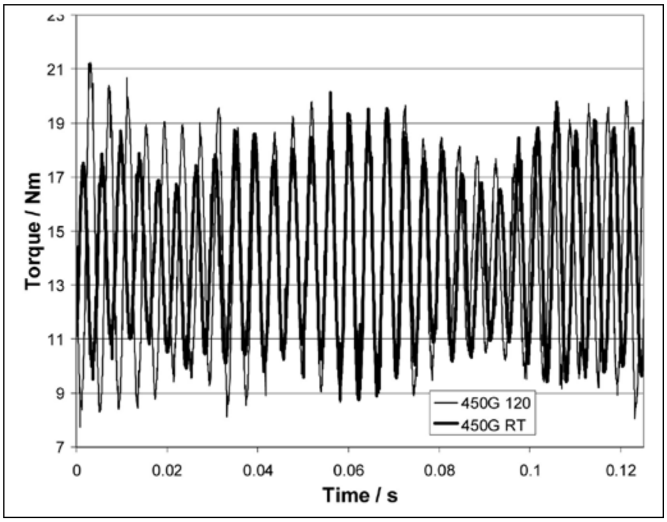

Figure 5—Torque data for Victrex 450G/steel gear combination.

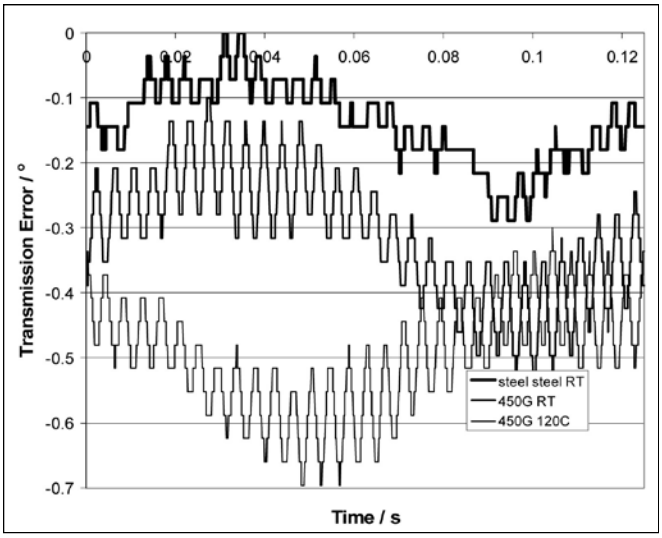

Figure 6—Transmission error data for Victrex 450G/steel gear combination.

ture and 120 °C. However, frictional heating did occur—the gearbox not being actively cooled—and what is classed as room temperature was in fact around 60 °C. The lubricating oil used was Gear Oil S320 supplied in the U.K. by John Neale Ltd.

The transmission error was determined by subtracting the output values from the incremental encoders on the input and output shafts. As the data is relative, it has been arbitrarily offset so that the various data sets can be differentiated on the graphs.

Test data generated for a specific gear pair at different test temperatures were produced using the same gear pair without dismounting the gears between tests.

Testing consisted of running the gear pairs at 500 rpm at a torque of 15 N-m. In cases where one steel gear was used, the steel gear was always mounted on the input shaft.

Test gears were manufactured from Victrex PEEK 450G, Victrex PEEK 450CA30 and Polyamide 4, 6. The plastic gears were molded by IMS Gear (Germany). The gear pairs tested were steel/steel; steel/Victrex 450G; steel/Victrex 450CA30; steel/PA46; Victrex 450G/Victrex 450G and PA46/PA46.

Results

The point at which logging of data commences relative to a specific tooth on a specific gear varies between tests; thus there is a time shift between data sets in that maximum and minimum values for different tests do not coincide in time. Due to the digital nature of the output from the encoders, transmission error plots do exhibit a stepped nature. Where a single torque trace is shown, this is for the output shaft.

Steel shaft. The rig was set up with a solid steel shaft coupling the drive and brake in order to remove any effects related to the gears. The encoder data (Fig. 1) shows a small, cyclic variation in the transmission error equivalent to four bits of data; a mistaken measurement generally is of the order of ± 2 bits, this being equivalent to approximately ± 0.08° and the angular error being based on the encoders resolving to 10,000 bits/revolution. It thus appears that this may be the cause of the observed variation.

The torque data is shown (Fig. 2). The mechanical load on the system should be constant when the drive and brake are linked with a steel shaft. It seems likely that the variation in torque shown (Fig. 2) arises due to electrical reasons. Two electronic control systems are used—one to control the speed of the drive motor, the other to control the torque on the brake motor.

While a feedback loop is used to trim the torque controller, there will inevitably be some variation due to the drives "fighting" each other.

The data is intended to be used as a reference for subsequent data sets. The variation in torque is mainly in the range 13–15 N-m, although there are some minor excursions beyond these limits.

Steel/steel combination. The steel/steel combination was tested to provide a control data set. Figure 3 shows the torque data (input and output) for one revolution of a gear pair at room temperature. The large spikes are thought to be noise as the related timescale is very short, being of the order of 2×10^{-5}s.

The peaks seen (Fig. 3) appear to correspond to the teeth engagement; it is apparent that the torque is not stable. If the large spikes are ignored, the torque—nominally set at 15 N-m—varies between 11–17 N-m; the variation being greater than that found with the steel shaft. It could thus be concluded that the gears do influence the stability of the torque.

Figure 4 shows the transmission error for the steel gear combination at room temperature. The angular shift of approximately 0.3° corresponds to approximately 2.5% of the tooth pitch. The transmission error shown with the steel gear combination is approximately double that found with the steel shaft. Thus while the transmission error could be considered small, the gears do exhibit some error. The transmission error at 120 °C was the same as that at room temperature—which was expected due to the material properties.

The cyclic variation in the transmission error and torque data is typical of all gears tested. It is unclear at this stage why this cyclic variation occurs.

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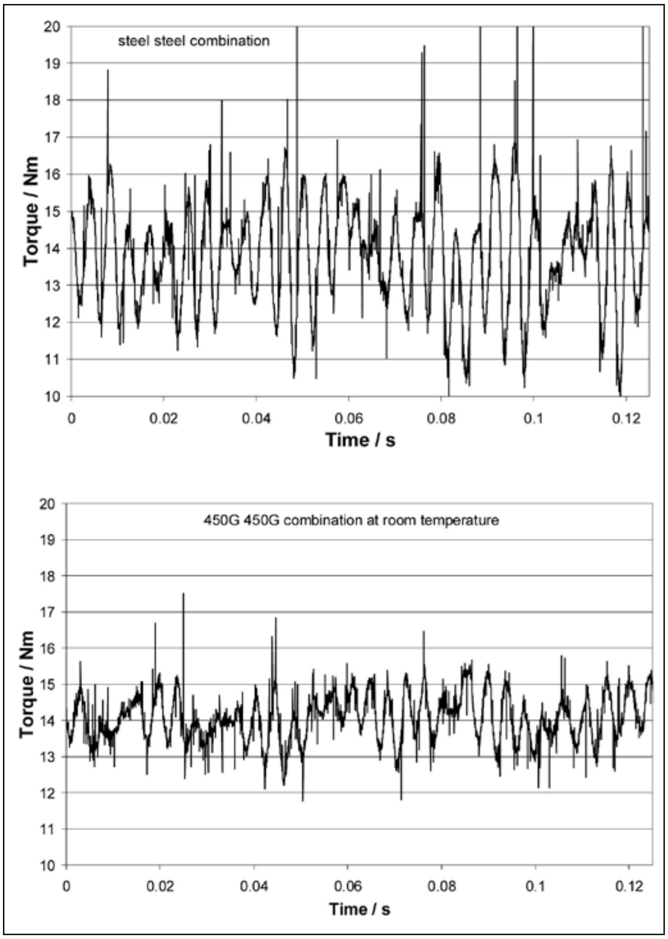

Figure 7—Torque data for steel-steel and Victrex 450G/Victrex 450G gear combinations.

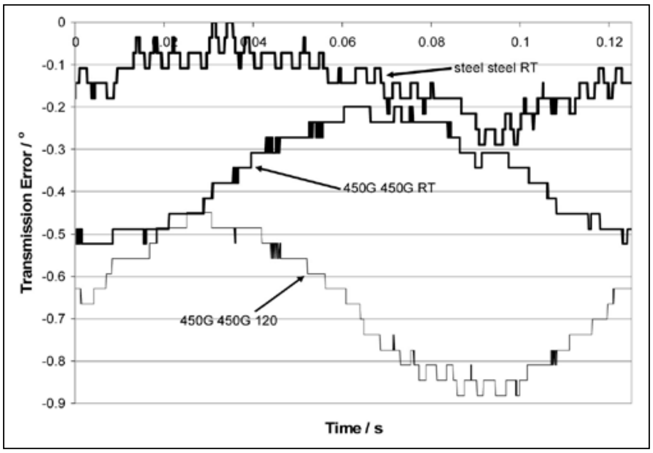

Figure 8—Transmission error data for Victrex 450G/Victrex 450G gear combination.

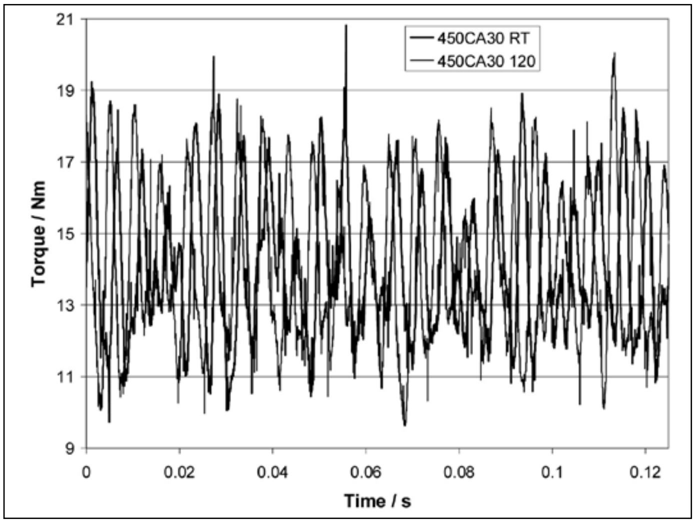

Figure 9—Torque data for Victrex 450CA30/steel gear combination.

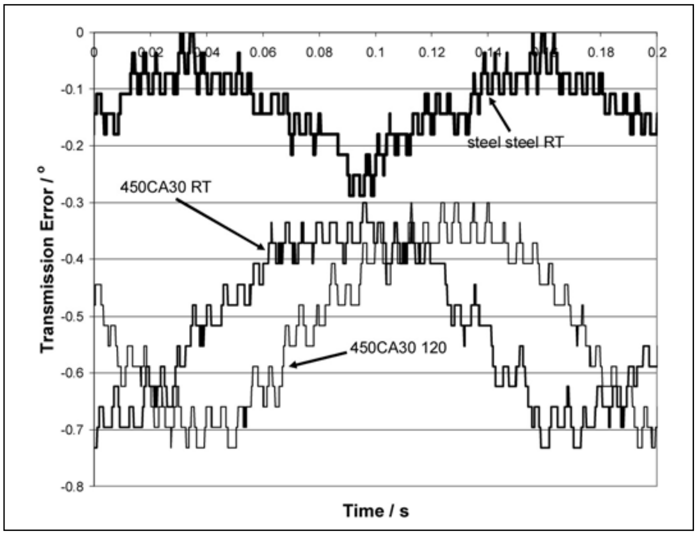

Figure 10—Transmission error for Victrex 450CA30/steel gear combination.

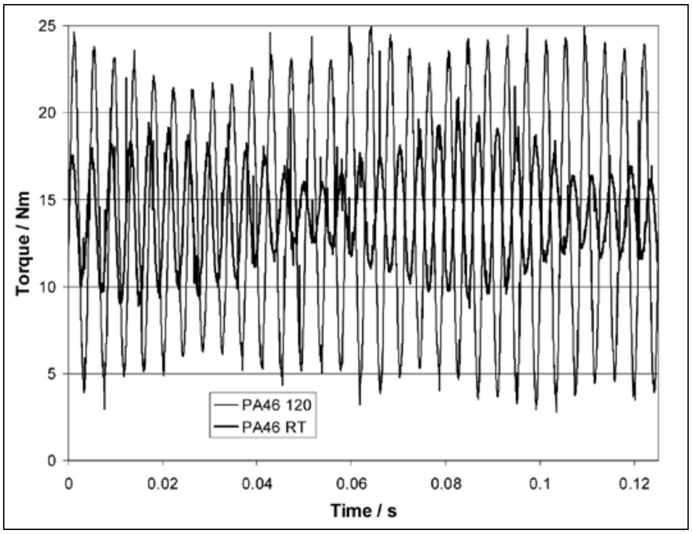

Figure 11—Torque data for PA46/steel gear combination.

There are several possible reasons, including:

- ***Lobed gears***. In the case of the polymer gears this may be possible but seems to be very unlikely with machined steel gears and thus is probably not the cause of the cyclic variation.
- ***Misalignment of the shafts***. If the center lines of the two shafts were not correctly aligned, complex wear patterns on the teeth would result; but the load should remain stable, as should the transmission error.
- ***Eccentric rotation of the input/ output shafts***. The gears used in this work have been mounted on a variety of different shafts and so the possibility that the shafts were not machined accurately is unlikely. Run-out on the output shaft has been measured to be 0.002 mm and the run-out on the input shaft was so small it could not be accurately determined. Thus, this does not appear to be a likely cause.
- ***The gears could, due to the mounting, be running eccentrically to the drive shafts***. The shafts on the steel gears were machined as one component and thus any significant misalignment of the gear to the shaft is very unlikely.
- ***An electronic drive instability***. Wider testing has indicated that the frequency of the sinusoidal pattern is always the same as the drive rotation frequency, irrespective of the speed and torque being used. Thus, this explanation also appears to be an unlikely cause for the observations.

Victrex 450G/steel gear combination. The torque data and transmission error data are shown (Figs. 5–6). The torque data shows that the variation associated with tooth engagement is greater than that found with the steel-steel gear combination.

There is limited difference between the Victrex 450G at room temperature and at 120 °C, which is as would be expected as the polymer is below its glass transition temperature **(T_g)**, which is 143 °C. The torque data shows a regular, higher-frequency variation that occurs once per-tooth-engagement. However, the data does not allow for a direct linking of the relative position of the teeth in relation to the torque variation.

The transmission error (Fig. 6) follows a similar pattern in that there is a variation that is clearly linked to the frequency of tooth engagement.

The magnitude of the torque and transmission error data does seem to be significant and is certainly larger than can be explained through experimental error. The torque variations are happening over a period of around 0.002 s. Assuming that the torque rises from 10 N-m to 20 N-m over this period, and taking the diameter of the gear to be a nominal 60 mm, this results in an increase in force of around 300 N over a period of 0.002 s. Examination of the transmission error would suggest a variation of around 0.2° in the same timescale, this corresponding to an angular acceleration of approximately 100° per second. Such changes could be considered to be significant with respect to the lifetime of a plastic gear.

Victrex 450G/Victrex 450G combination. The torque and transmission data are shown (Figs. 7–8).

The torque data indicates that even though the stiffness of the Victrex 450G gears is lower than that of the equivalent steel gears, the torque variation is significantly smaller with the Victrex 450G/Victrex 450G combination than found with the Victrex 450G/steel combination in terms of both the general cycle-to-cycle variation and tooth-to-tooth variation.

Thus it could be concluded that the torque variations are not related solely to the stiffness of the gears, but rather, to the relative stiffness of the two gear materials.

The variation in the transmission error is reduced with a Victrex 450G/Victrex 450G combination when compared to the Victrex 450G/steel combination. While the overall magnitude of the variation through a cycle is similar, the variation with tooth engagement is much reduced to a level similar to that found with the steel/steel combination of gears.

Victrex 450CA30/steel combination. The torque and transmission error data are shown (Figs. 9–10).

The torque data for the Victrex

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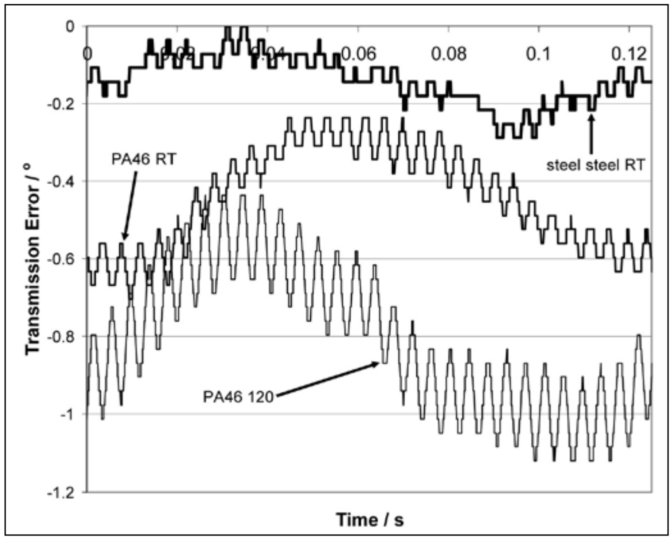

Figure 12—Transmission error data for PA46/steel gear combination.

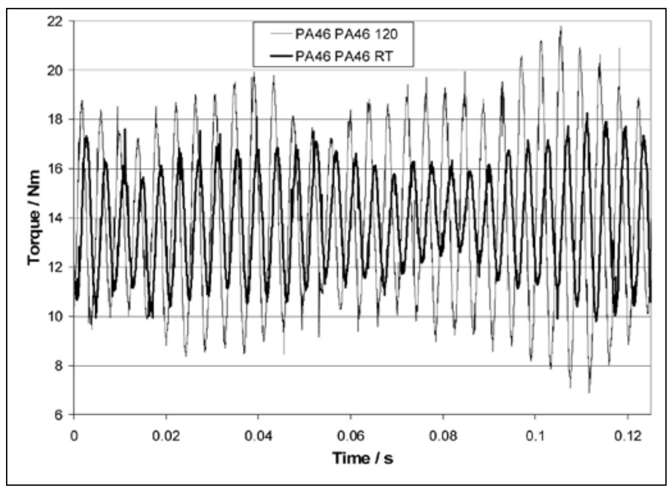

Figure 13—Torque data for PA46/PA46 gear combination.

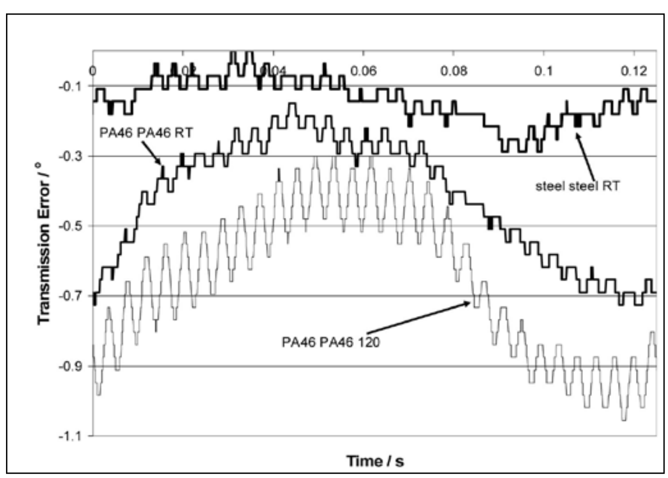

Figure 14—Transmission error data for PA46/PA46 gear combination.

Figure 15—Typical failure found with a Victrex 450G spur gear.

450CA30/steel combination varies slightly more than is found with the Victrex 450G/Victrex 450G or with the steel/steel combination. However, it is slightly reduced when compared to the Victrex 450G/steel combination.

The transmission error data indicates that the gear combination is not subject to the variations related to tooth engagement, as found with the Victrex 450G/steel gear combination. The transmission error with the gears does not change with temperature, as would be expected, the material being below the T_g. However, it is interesting to note that the transmission error for the Victrex 450G/Victrex 450G combination at room temperature is less that than that for the Victrex 450CA30/steel combination, which is similar to that for the Victrex 450G/Victrex 450G combination at 120 °C.

PA46/steel combination. The torque and transmission error data are shown (Figs. 11–12).

The torque data at room temperature shows a slightly increased overall variation when compared to a Victrex 450G/steel combination at room temperature. It is noticeable that the cyclic variation related to the speed of rotation has increased to approximately twice the frequency of rotation. This phenomenon probably requires further investigation in order to determine the cause. The tooth-to-tooth variation still exists. However, the variation in torque increases significantly when the test temperature is increased to 120 °C. The assumption could be made that this is due to the reduction in the stiffness of the gear with increasing temperature. It is noticeable that the higher frequency cyclic variation observed at room temperature no longer exists.

The transmission error data at room temperature is indicative that the variations cycle to cycle are not regular whereas the data at 120 °C indicates some stability. In this case stability is defined as the exit point on the right-hand side of the graph being at a similar value to the entry point on the left-hand side of the graph. The transmission error data shows that the PA46/steel combination gives a slightly poorer performance than the Victrex 450G/steel combination in terms of overall variation. The variation occurring during tooth engagement is, however, slightly less. At 120 °C the transmission error is significantly larger than that for the Victrex 450G/steel combination.

PA46/PA46 combination. The torque and transmission error data are shown (Figs. 13–14).

The room temperature torque results for the PA46/PA46 combination show a smaller overall variation than those found with the PA46/steel combination. Similarly, while the overall variation is greater at 120 °C than at room temperature, the variation with the PA46/PA46 combination is less than that found with the PA46/steel combination. Both sets of data show a slight tendency towards a higher frequency cyclic variation.

The variation in the torque found with the PA46/PA46 combination at room temperature is worse than that found with the Victrex 450G/Victrex 450G combination. Similarly, the transmission error occurring with the PA46/PA46 combination is significantly worse than the steel/steel combination and the Victrex 450G/Victrex 450G combination. It is very noticeable that the variation at the frequency of tooth engagement is still very prominent.

Failure mechanism. The steel/steel combination has not undergone any lifetime tests and so is excluded from the following discussion. In lifetime tests the various gear combinations result in failure of the plastic gear by tooth fracture. A typical fracture is shown (Fig. 15).

Cycles to failure. Table 1 shows the average lifetime for gear combinations featuring Victrex gear materials. The data indicates that using gears made from the same polymer material is advantageous, which suggests that the tooth-to-tooth variation in the torque is an important factor in the lifetime of a gear.

Discussion

There appear to be two main features of the data considered: 1) the cyclic variation of the transmission error data at a frequency equivalent to the rotational frequency of the drive; and 2) the tooth-tooth variation in the torque and transmission error data. The two effects may be linked but the data suggests this is not the case.

Cyclic variation in the transmission error related to the gear rotational speed. The magnitude of the overall variation does seem, in part, to be related to the stiffness of the materials of construction of the gears, the variation being greater with the PA46 gears than with the Victrex 450G and steel gears. However, it seems unlikely that, in the case of the steel/steel combination, there is significant tooth deflection and thus it may be concluded that the fundamental cause of the effect may not be related to tooth deflection. The torque data for the steel/steel combination does show some variation that appears to be related to the tooth engagement process, although the background effects—as determined using the steel shaft—are presumed to be a significant factor in the observations with the steel/steel combination.

If, as mentioned, the stiffness of the gear material does influence the magnitude of the variation, and it is not specifically linked to tooth engagement,

Table 1—Comparative cycles-to-failure for various gear combinations at 25 N-m, 120 °C and 1,020 rpm

Materials	Steel-Polymer	Polymer-Polymer
Victrex 450G	605,000	1,135,000
Victrex 450CA30	2,847,000	11,921,000

then it would seem that the effect is related to deformation of the gear as a whole and this would suggest that the magnitude of the effect is related to deformation of the web joining the central hub and gear tooth hub. In the case of the plastic/steel gear combinations, there does seem to be some cyclic variation of the torque, and so this inference seems plausible.

It therefore seems likely that the variation has a base component, and as shown by the steel shaft, this effect is exacerbated by the deformation of the plastic gears.

Variation related to the tooth engagement. The torque and transmission error variations associated with each tooth engagement can be considered to be imposing significant shock loads on the individual teeth; this effect would be expected to reduce the life of the gear.

It seems likely that the effect is related to the deflection of the individual teeth—i.e., the lower the modulus of the material, the greater the deflection expected.

Where the stiffness of the two gear materials is matched, the variation in transmission error is very much reduced. The torque variation associated with the process is also reduced and therefore any shock loading is likely to be reduced. In the case of the Victrex 450CA30, the stiffness is higher than that of the unfilled polymers and so there is a better match of modulus between the two gears.

Conclusions

Significant variations in torque and transmission error have been observed when plastic gears run against steel gears; the situation improves when plastic gears are run against plastic gears. Gear lifetime data suggests that this tooth-tooth loading variation has a significant effect on the lifetime of a plastic gear. The results indicate that using gears made from the same polymer material is advantageous, as opposed to running plastic gears against metal gears.

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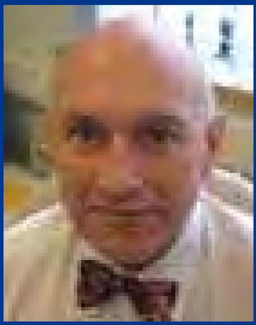

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AFC-Holcroft

ADDS TWO PARTNERS IN CHINA

From left to right: Xie Fei, Janusz Kowalewski, Feng Li-Hua and Nancy Kowalewski (photo courtesy of AFC-Holcroft).

AFC-Holcroft recently announced the addition of two new partners in China: G-Wang Precision Auto Parts Company Ltd. in Jiangshan, Zhenjiang Province, and Jilin Plate Heat Treating Company Ltd. in Changchun, Jilin Province in the northeast of China. G-Wang Precision is a member of the San Yung Group Taiwan, who specializes in continuous mesh belt type atmosphere furnaces. They will focus exclusively on AFC-Holcroft Aluminum Brazing (CAAB) technology for China and Southeast Asia. Their new 12,000 square meter facility is dedicated to the manufacturing of continuous furnaces for the aluminum brazing and aluminum process systems. San Yung Group is one of the largest furnace manufacturers in Asia, with sales worldwide, primarily to the fastener industry.

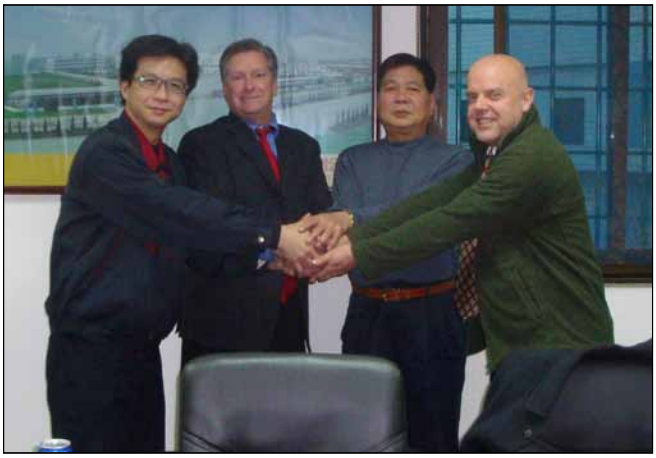
Jilin Plate Heat Treating Company, Ltd. specializes in pusher carburizing furnaces, mainly for customers requiring large-scale production, such as the automotive, railroad and bearing industries. The company history spans over 50 years, and incorporates professional design and development teams into a single-source supply for technical consultation, workshop design, equipment design, manufacturing, installation, debugging, service and staff training. Jilin Plate Heat Treating Company Ltd. holds an ISO2000 International Quality System certificate.

The partnership with Jilin Plate Heat Treating Company rekindles a relationship originally formed in the 1980s at FAW (First Automobile Works) when Jilin Plate was a wholly owned subsidiary of China FAW Group Corporation, prior to its restructuring. Mr. Xie Fei, the present-day president of Jilin Plate and William Disler, executive vice president of AFC-Holcroft, worked together at FAW in the 1980s as young engineers, installing a large amount of Holcroft equipment.

The signing of these new Chinese partners brings the total to three, including longtime AFC-Holcroft partner Shanghai Powermax. Shanghai Powermax will continue to focus their efforts on marketing and manufacturing AFC-Holcroft's UBQ (Universal Batch Quench) and UBQA (Universal Batch Quench Austemper) and auxiliary equipment.

"These changes in China represent further proof of AFC-Holcroft's ongoing commitment to global expansion and support," says Disler. "Not only are we focused on new regions, but we are also constantly improving our ability to service existing regions."

Adds Janusz Kowalewski, managing director of the AFC-Holcroft Shanghai Office, "We are very pleased with our new partners and existing partner PowerMax to expand our market coverage of China and Southeast Asia. AFC-Holcroft is committed to excellence in service and looking forward to provide advanced technology with local support and manufacturing capabilities."



From left to right: Steve Yang, William Disler, Yang Yung-Hsu and Janusz Kowalewski.

Gleason

FORMS STRATEGIC ALLIANCE WITH MANUTEC

Gleason Corporation and Manutec VaWe Robotersystem GmbH (Fürth, Germany) have announced the formation of a strategic alliance to serve the global gear manufacturing technology markets. Effective immediately, Gleason and Manutec will cooperate in the development and sale of robots for chamfering and deburring of large-module gears. The base model robot, the R500CHD, has a work table load capacity of 500 kg, with a table load capacity of up to 6 tons available upon request. Maximum gear diameter is limited only by the robot mounting and distance from the work table. Gleason-Manutec robots offer short cycle times, exceptional path accuracy and simple, automated operation without complex programming requirements. Karl-Josef Schäferling, director of product management for chamfering and deburring solutions for Gleason, said "The Gleason-Manutec robot provides the customer with a flexible, accurate and efficient solution for complex gear chamfering and deburring operations. It is the perfect complement to Gleason's line of gear cutting machines." These products and solutions will be sold through Gleason's worldwide sales channels with technical support provided by both Gleason and Manutec.

Gear Motions

ACQUIRES PRO-GEAR

Gear Motions Inc. has acquired Pro-Gear Co. Inc., in Buffalo, New York. Pro-Gear is a gear manufacturer for original equipment manufacturers such as Mack Truck, and also provides quick-turnaround gear grinding services for gear manufacturers that need additional capacity or companies that need external gear grinding services. Gary Rackley, founder and president of Pro-Gear, has more than 45 years in the gear industry, and will transition the company as it joins the Gear Motions family of precision ground gear specialists. "As Pro-Gear becomes part of Gear Motions, we will continue to offer a high-level of flexibility and customization to our customers," said Gear Motions President and CEO Sam Haines. "The transition should be seamless as all personnel from the Pro-Gear production team join the Gear Motions team at our Oliver Gear location."

"This is a great merger of Gear Motions' state-of-the-art gear grinding technology with Pro-Gear's proven ability to turn around its customers ground gears needs in a hurry," said Rackley.

Manufacturing Technology

SURGE HIGHLIGHTS 2011

December U.S. manufacturing technology orders totaled $519.98 million, according to the Association for Manufacturing Technology (AMT) and the American Machine Tool Distributors' Association (AMTDA). This total, as reported by companies participating in the United States Manufacturing Technology Orders (USMTO) program, was up 12.2 percent from November and up 12.7 percent when compared with the total of $461.48 million reported for December 2010. With a year-to-date total of $5,508.81 million, 2011 was up 66.4 percent compared with 2010. These numbers and all data in this report are based on the totals of actual data reported by companies participating in the USMTO program.

"USMTO finished its strongest year in more than a decade as manufacturing led the U.S. recovery into 2012," said AMT President Douglas K. Woods. "The 67 percent increase is nearly 20 points higher than forecasters predicted; which is great news in terms of reducing the foreign trade deficit. Manufactured goods represent more than 65 percent of trade, so the rise of U.S. manufactured products will help reduce our reliance on imports and support growth in exports."

The USMTO report, jointly compiled by the two trade associations representing the production and distribution of manufacturing technology, provides regional and national U.S. orders data of domestic and imported machine tools and related equipment. For more information, visit *www.amtonline.org*.

Seco/Warwick

SIGNS AGREEMENT WITH EXPANITE

Seco/Warwick Group, a worldwide industrial furnace and heat treatment equipment supplier and Expanite A/S, a ThinkTank technology company from Denmark, signed an agreement for Seco/Warwick to be the exclusive supplier for the Expanite and SuperExpanite processes. Expanite and SuperExpanite are patented processes for the surface hardening of stainless steel to achieve superior surface and material properties, such as high hardness, extraordinary corrosion and fatigue properties.

Seco/Warwick developed an advanced installation technology based on their longstanding experience with Expanite. The heat treatment unit is designed for the integration into the customer's production lines even if the customer has limited heat treating experience. The infrastructure requirements are relatively small. The companies are calling it a plug-and-play approach to heat treatment technology. With the unique process knowledge of Expanite and the vast furnace expertise of the Seco/Warwick Group, both companies are expecting breakthrough successes in the market from this cooperation. The first installations will be installed in Expanite's development and customer center in the second quarter of 2012 in Denmark.

Schafer Gear

HONORED WITH ECONOMIC AWARD

Schafer Gear Works was recently honored with the Economic Impact Award from the Chamber of Commerce of St. Joseph County, Indiana. Presented at the Chamber's Annual Salute to Business Luncheon, this award recognizes a company's strategic vision and its sustainable capital investment in the local economy. In early 2011, Schafer Gear announced a joint venture with Somaschini S.p.A. of Italy to produce engine gears for the heavy-duty truck market in North America. As part of this joint venture, a new 50,000-square-foot plant was built on the Schafer Gear campus on Nimtz Parkway in South Bend. The total joint venture investment was $18 million, including the new manufacturing facility. As a result, 25 jobs will be added by the end of 2012. For more information, visit *www.schafergear.com*.

Seco

DOUBLES RECYCLING EFFORTS IN 2011

Seco has released the annual results of its North American Carbide Recycling Program, revealing that the company collected and processed 57,368 lbs. of used carbide tools in 2011. This represented more than double the company's goal of 26,500 lbs., thanks to steady growth of the program throughout the year. With its Carbide Recycling Program, Seco provides manufacturers with small, medium or large storage containers to place within their facilities. Small containers hold approximately five lbs. of carbide, medium containers hold approximately 50 lbs., and the large drums accommodate approximately 1,500 lbs. As tools reach the end of their useful life, they can be placed in these containers,

NEWS

which are then collected by Seco. Any carbide products from any manufacturer can be submitted, including carbide inserts, solid drills, solid end mills, wear parts and PCD/PCBN-tipped inserts. Manufacturers are paid at the market rate when the carbide is returned.

"Over the past year, we've really spread the word to customers on just how easy it is to recycle used tools and inserts with the Seco program," says Vic Bruni, manager of quality at Seco Tools Inc. "Since launching the program in February 2011, we've seen a tremendous amount of growth and we're well on our way to our goal of recycling 50 percent of the carbide inserts we sell by 2014."

In addition to the well-publicized environmental benefits of recycling, Seco's Carbide Recycling Program helps to address the growing global demand for tungsten, which comprises 75 percent of cemented carbide. Up to 95 percent of the material in a typical carbide insert can be reclaimed, helping to ensure the long-term sustainability of the metal cutting industry. Manufacturers interested in participating in the Seco Tools Used Carbide Recycling Program can visit *www.secotools.com*.

ASM Trustee

VISITS LOCAL CHAPTERS

In 2012, Bob Hill, president of Solar Atmospheres of Western Pennsylvania, will continue his term as a trustee on the ASM International's Board of Trustees. The board of ASM is comprised of four officers and nine trustees. Three new trustees are elected by the membership every year, and each serves a three-year term. Throughout the year, Hill will visit a variety of ASM Chapters and present "Vacuum Heat Treating of Titanium in Commercial Airframes." In January and February, Hill visited the Canton/Massillon Chapter in Ohio and the Savannah River Chapter, Georgia. Additional visits scheduled to date include: March 8th at the Inland Empire chapter in Spokane, Washington; and May 10th at the Old South chapter in Greenville, South Carolina. If you are not an ASM member and would like to attend, please contact Hill at *bobh@solaratm.com*.


Bob Hill, president of Solar Atmospheres.

PowderMet2012

FOCUSES ON LATEST TRENDS AND TECHNOLOGIES

PowderMet2012, an annual conference sponsored by the Metal Powder Industries Federation (MPIF) and APMI International, will highlight the latest developments and trends in metal powders, as well as powder metallurgy (PM) processes, products, and applications. This International Conference on Powder Metallurgy & Particulate Materials will be held June 10–13 at the Gaylord Opryland Hotel, Nashville, Tennessee. The conference technical program will feature over 150 technical presentations by authors from more than 30 countries, and a trade exhibition will showcase leading suppliers of metal powders and particulate materials, processing equipment, and PM products.

The conference opening general session will include a keynote presentation, "America's New Auto Industry," by Drew Winter, editor-in-chief, *WardsAuto World* magazine. It will also include an overview of the annual MPIF State-of-the-Industry Report. Additional conference events include the Industry Recognition Luncheon and the PM Design Excellence Awards Luncheon. The social highlight of the conference will be an All-American Evening at the Grand Ole Opry.

In addition to the comprehensive technical program, the conference will include management-focused programs open to MPIF-member companies: "Powder-Handling Concerns"; "Outside Perspectives on PM's Value"; "PM Activities at North American Universities"; and "PM Technology Scans" focusing on lightweight PM materials and alternative energy.

Technical sessions, poster presentations, and a slate of four special interest programs will cover a range of subjects such as metal injection molding, powder production, machinability, high-density materials, PM titanium, wear and surface properties, non-destructive testing, process modeling, atomization, dynamic properties, lubrication, PM stainless steel, hot isostatic pressing, refractory metals, carbides, magnetic materials, and PM aluminum alloys. Other in-depth programming will cover topics on delubrication science and developments, magnesium powders and composites, spark-plasma sintering, and dual-phase materials. For more information, visit *www.mpif.org*.

W.T. Walker

ACQUIRES PMT INDUSTRIES

W.T. Walker Group, Inc., the parent company of Walker Forge, Inc. and Precision Thermal Processing, Inc., recently announced the acquisition of PMT Industries LLC. PMT, headquartered in Surgoinsville, Tennessee, is a manufacturer of complex, high-alloy steel forgings for safety critical engine and chassis applications. Established in 1997, PMT employs nearly 250 people.

"This is a very strategic acquisition that strengthens both companies," says Willard Walker, CEO of W.T. Walker Group. "Together, Walker Forge and PMT offer the broadest range of mechanical forging presses among any competitors in North America, ranging in size from 850 tons up to 8,000 tons. We are uniquely positioned to offer our customers a wide range of products and product sizes as well as solutions that will enable them to consolidate their supply chains and improve overall performance."

The companies have very complementary forging capabilities. Walker Forge produces forgings on presses from 850 to 4,000 tons, while PMT makes forgings on presses from 4,000 to 8,000 tons. In addition, the companies offer customers a broad range of value-added services that include machining and heat treating as well as metallurgical analysis and mechanical and chemical testing. "Our future is very bright. We are grateful to our customers and suppliers for their loyal support, and look forward to the new possibilities the acquisition opens for all of us," Walker says.

Financial terms of the transaction were not disclosed. For more information, visit *www.walkerforge.com*.

March 27-29—Westec 2012. Los Angeles Convention Center, Los Angeles. Westec returns in 2012 redefined with a renewed commitment to local manufacturing. The manufacturing event includes keynote presentations from industry leaders in aerospace/defense, renewable energy and the manufacturing economy. The show also consists of technical sessions on topics that include small parts machining, high-speed alloy machining, milling, drilling, cutting advanced carbon fiber, carbon laminates and advances in additive manufacturing. Attendees view emerging technologies and emerging equipment applications and many other topics with an emphasis on using technology to innovate. Westec offers a place to network, form relationships and build partnerships, putting an emphasis on new developments, integration, lean methods, and how to manufacture with composites, titanium, or other advanced materials. For more information, visit *www.westeconline.com*.

April 23-27—Hannover Messe 2012. Hannover Fairgrounds, Hannover, Germany. The world's leading trade show for industrial technology returns in 2012 with a full lineup of trade shows. The eight co-located shows include Industrial Automation, Energy, MobiliTec, Digital Factory, Industrial Supply, CoilTechnica, IndustrialGreen Tec and Research and Technology. China is the official partner country in 2012. Discover new perspectives on energy, automation and industrial supply and engineering topics as well as a broad range of events and displays affecting the global industrial market today. Other Hannover highlights include Metropolitan Solutions, TectoYou, Job and Career Market and Energy Efficiency in Industrial Processes. For more information, visit *www.hannovermesse.de*.

May 8-10—Mfg4 2012. Hartford, Connecticut. GE Energy, Medtronic, Boeing, Raytheon, Sikorsky and other manufacturing organizations know the best source of innovations and solutions may be outside their industries. That's why they—in partnership with a dozen additional industry innovators—are presenting Mfg4 with the Society of Manufacturing Engineers (SME). Mfg4 presents solutions for buyers and sellers across the aerospace, defense, medical and energy manufacturing industries. Conference sessions include improving manufacturing processes, digital manufacturing, machine accuracy and volumetric compensation, fundamentals of robotics and many more. Exhibitors include Carl Zeiss, Fanuc, Heidenhain, Marposs and many more. At the heart of the Mfg4 event floor is the Insight Intersection, an area where small groups of professionals meet for practical exchanges of information. Each morning at Mfg4, exhibitors and sponsors can reserve this space to host breakfast meetings or working sessions with customers and prospects. For more information, visit *www.mfg4event.com*.

May 8-10—Modern Furnace Brazing School. Cincinnati. Preserving the tradition originated by the late Robert Peaslee, a brazing pioneer who invented the first nickel-base brazing filler metal, Wall Colmonoy offers another session of Modern Furnace Brazing School at the Aerobraze Engineered Technologies' Brazing Engineering Center. Engineers, technicians, quality managers and others will experience "hands-on" applications and learn about brazing technology from leading industry experts. This three-day seminar offers knowledge and practical application about brazing design, metallurgical aspects/brazing operation, brazing atmosphere and furnace equipment, brazing material selection and applications and quality control. Brazing School attendees will tour the facility and see the actual brazing application on the shop floor. They will also have the opportunity to apply different forms of filler metal to Wall Colmonoy supplied samples, have them vacuum brazed and discuss the outcomes. Attendees are encouraged to bring brazing issues, parts/components to the seminar where they will be provided expert advice regarding their brazing difficulties or concerns. For more information, visit *www.wallcolmonoy.com*.

May 10—Analytical Gear Chart Interpretation: Reading Between the Lines (Part 1). Dwight Smith, president of Cole Mfg. Systems, presents this AGMA Gear Education Webinar Series from 1:00 pm to 2:30 pm Eastern time. The webinar is an introduction to the methodology of analytical gear inspection and the evaluation and interpretation of the resulting data. The application of this information to identify and correct manufacturing errors will be explored. Attendees will gain knowledge in identifying major gear characteristics measured and methods used, evaluating pitch, profile and helix and using inspection data to understand the causes and cures of manufacturing errors. People relatively new to gear manufacturing/inspection, including quality control personnel and manufacturing employees, will achieve a better understanding of how gears are measured and evaluated. Others from quoting, processing and sales also can gain knowledge of inspection reports beyond the "wiggly lines." For registration information, visit *www.agma.org*.

May 14-16—Lubrication and Wear: Advanced Concepts. South Bend, Indiana. Attendees will bridge the gap between component design and failure as a result of relative motion between surfaces in contact and apply the latest lubrication technology to bearings. Course participants will receive an understanding of regimes of lubrication, 2-D and 3-D surface topographical characterization, surface and subsurface stress analysis, grease lubrication, applications in rolling element bearing design and much more. The American Bearings Manufacturers Association (ABMA) is focused on keeping the American bearing industry up-to-date through comprehensive educational programs and real-world applications. For more information, visit *www.americanbearings.org*.

May 15-17—Gear Materials: Selection, Metallurgy, Heat Treatment and Quality Control. Milwaukee. Instructors Raymond Drago and Roy Cunningham of Drive Systems Technology, Inc. help attendees discover how both the gear design engineer and the gear metallurgist can better grasp their related, critical roles in the exciting world of gear processing, heat treatment and inspection. The gear design engineer is responsible for the initial selection of material and heat treatment, but the finalization of both material and thermal processing must be a joint effort. This seminar shows how the gear design engineer first approaches the problem of material selection and heat treatment technology, as influenced by the performance and life requirements of the gear set. It also shows how the gear metallurgist can participate in and thereby optimize the finalized gear manufacturing process. Interspersed in the course are examples of gear-related problems, failures and improved processing procedures. Analyses and comments on a number of relevant failures are given. For more information, visit *www.agma.org*.

May 22-23—Vacuum Carburizing Symposium 2012. Troy, Michigan. This two-day event from ALD-Holcroft will be held at the Michigan State University, Management Education Center and will include round trip transportation for an evening visit to ALD Thermal Treatment in nearby Port Huron, Michigan to tour their 100,000+ square foot facility. The operation features more than 35 vacuum carburizing chambers and nine 20-bar quenching chambers for nitrogen and/or helium. These modules are spread across six totally automated ModulTherm systems. The Technical Symposium will cover topics including the Mathematical Model of LPC, Comparative Analysis of Carbon Sources, LPC in the Aircraft Industry, High Temperature LPC, Gas Quench Design, Vacuum Carburizing in the Commercial Heat Treating Arena, Materials Developed Specifically for Vacuum Carburizing, and much more. All of the technical papers are developed and presented by industry experts who are routinely involved with the practice of Low Pressure Vacuum Carburizing (LPC), and the speakers will be available for question-and-answer as well as open discussion during several networking opportunities. For more information, visit *www.ald-holcroft.com*.

June 19-20—International VDI Congress Drivetrain for Vehicles 2012. Friedrichshafen, Germany. Sustainable driving, lower CO_2 consumption, a paradigm shift towards electromobility: the automotive industry has some difficult demands to satisfy. Vehicle transmission developers and users will be gathering at this important industry meeting-point now in its tenth incarnation. The conference will be directed by Dr.-Ing. Hans-Joerg Domian, director of new products and methods, design tasks, ZF Friedrichshafen AG. Opening papers tackle the subjects of the future of driveline development, potential CO_2 savings and the role of electrification' as well as electromobility. Alongside future-oriented transmission components for electric and hybrid vehicles, the program will also include current developments in the fields of double-clutch and automatic transmissions, manual transmissions and all-wheel drives, efficiency, components, materials and production engineering as well as clutches and operating strategies. The machines section is entirely new: here attendees can learn about, for example, technical trends in agricultural machines, new developments in construction machinery drives, infinitely variable power take-off drives or improvements in the ease of gear shifting. For more information, visit *www.transmission-congress.eu*.

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City: ______________________
State/Province: ______________________
ZIP/Postal Code: ______________________
Telephone: ______________ Fax: ______________
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6) What is your primary job function responsibility? (Check one)
- ❏ Corporate Executives (B)
- ❏ Manufacturing Production Management (C)
- ❏ Manufacturing Production Department (D)
- ❏ Manufacturing Engineering Management (E)
- ❏ Manufacturing Engineering Department (F)
- ❏ Product Design, R&D Management (H)
- ❏ Product Design/ R&D Personnel (I)
- ❏ Purchasing (L)
- ❏ Marketing & Sales, Communications (M)
- ❏ Quality Control Management (P)
- ❏ Quality Control Department (Q)
- ❏ Other (N) ______________

7) How is THIS LOCATION involved in the gear industry?
(Check all that apply)
- ☐ WE MAKE GEARS (or Splines, Sprockets, Worms, etc.) (20)
- ☐ WE BUY GEARS (or Splines, Sprockets, Worms, etc.) (22)
- ☐ WE SELL NEW MACHINES, TOOLING OR SUPPLIES TO GEAR MANUFACTURERS (24)
- ☐ WE provide SERVICES to gear manufacturers (25) (please describe) ______________
- ☐ WE distribute gears or gear products (including agents and sales reps. (26)
- ☐ WE are a USED MACHINE TOOL dealer (30)
- ☐ Other (please describe) ______________ (32)

8) Which of the following products and services do you personally specify, recommend or purchase? (Check all that apply)

Machine Tools
- ☐ Gear Hobbing Machines (50)
- ☐ Gear Shaping Machines (51)
- ☐ Gear Shaving Machines (52)
- ☐ Gear Honing Machines (53)
- ☐ Gear Grinding Machines (54)
- ☐ Gear Inspection Equipment (55)
- ☐ Bevel Gear Machines (56)
- ☐ Gear/Spline Roll-Forming Equipment (57)
- ☐ Broaching Machines (58)
- ☐ Heat Treat Equipment (59)
- ☐ Deburring Equipment (60)
- ☐ Non-Gear Machine Tools Turning, Milling, etc.) (61)

Tooling & Supplies
- ☐ Functional Gages (62)
- ☐ Workholding (63)
- ☐ Toolholding (64)
- ☐ Cutting Tools (65)
- ☐ Grinding Wheels (66)
- ☐ Gear Blanks (67)
- ☐ Lubricants/Cutting Fluids (77)

Service & Software
- ☐ Heat Treat Services (69)
- ☐ Gear Consulting (70)
- ☐ Tool Coating (71)
- ☐ Tool Sharpening (72)
- ☐ Gear Design Software (73)
- ☐ Gear Manufacturing Software (74)

Power Transmission Components
- ☐ Gears (75)
- ☐ Gear Drives (76)
- ☐ Bearings (78)
- ☐ Motors (79)

9) What is the principal product manufactured or service performed at **THIS LOCATION?**
____

10) How many employees are at THIS LOCATION (Check one)
☐ 1-19 ☐ 20-49 ☐ 50-99 ☐ 100-499 ☐ 500+

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Gear Machinery Exchange	79	(847) 437-6605	michael@goldsteingearmachinery.com	www.gearmachineryexchange.com
Gear Motions Inc.	71	(315) 488-0100	ron.wright@gearmotions.com	www.gearmotions.com
The Gear Works—Seattle, Inc.	78	(206) 762-3333	sales@thegearworks.com	www.thegearworks.com
Gleason Corp.	40-41, 79	(585) 473-1000	dmelton@gleason.com	www.gleason.com
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Mitsubishi	8	(248) 669-0614		www.mitsubishigearcenter.com
Mitutoyo	14	(888) 648-8869		www.mitutoyo.com
Niagara Gear	4	(800) 447-2392	info@niagaragear.com	www.niagaragear.com
Overton Chicago Gear	78	(630) 543-9570	sales@oc-gear.com	www.oc-gear.com
Presrite Corp.	17	(216) 441-5990		www.presrite.com
Process Equipment	70	(800) 998-4191		www.gearinspection.com
Proto Manufacturing	13	(519) 737-6330		www.protoxrd.com
PTG Holroyd	25	+(44) 0-1706-526590	info@holroyd.com	www.holroyd.com
Quality Transmission Components	70	(516) 437-6700	QTCsupport@qtcgears.com	www.qtcgears.com
Riverside Spline & Gear	15	(810) 765-8302	valerief@splineandgear.com	www.splineandgear.com
Sandvik Coromant	49	(800) 726-3845		www.coromant.sandvik.com/us
Schnyder S.A.	72	(630) 595-7333	hanikcorp@aol.com	www.hanikcorp.com
Sicmat	19	(847) 649-1450	sales@star-su.com	www.star-su.com
Sigma Pool	5	(734) 429-7225	info.lgt@liebherr.com	www.sigma-pool.com
Solar Atmospheres	23	(800) 347-3236	info@solaratm.com	www.solaratm.com
Star SU LLC	IFC–1, 19, 72, 79	(847) 649-1450	sales@star-su.com	www.star-su.com
Stock Drive Products/Sterling Instrument	69	(516) 328-3300	SDP-SIsupport@sdp-si.com	www.sdp-si.com/e-store
Tokyo Technical Instruments USA	31	(201) 634-1700		www.tti-geartec.jp
Toolink Engineering Inc.	39	(303) 776-6212		www.toolink-eng.com
VDI Drivetrain for Vehicles 2012	26	+(49) 211-6214-201		www.transmission-congress.eu

GEAR MANUFACTURING

SERVICE

The New Now:
U.S. Workforce Sustainability

Faithful Addendum readers are accustomed to finding upbeat, whimsical and oddball stories about gears in this space. What follows is not about gears, exactly. Rather, it is, as opposed to the usual bleak news about America losing its manufacturing mojo—a look at a positive, hopeful development in that regard.

But first this sobering fact: By 2018 30 million new and replacement jobs will require some college education, yet there will not be available enough high school graduates with the necessary college credentials to meet the need. The no-longer-new reality is that adult workers—either currently in the workforce or those underutilized—will need to upgrade their educational skills. The obvious, long-ignored disconnect here is that while higher education programs continue as a gateway to advanced economic status, millions of American workers have insufficient education.

A positive force working to change that trend is Shifting Gears (*shifting-gears.org*)—a Midwest-based, manufacturing and other skills program in place since 2007 with the mission of "strengthening post-secondary, adult basic education and skills development systems so that more low-skilled workers gain the education skills and credentials needed to advance and succeed in our changing economy."

In other words, what is needed right now is not just environmental sustainability; what is needed is workforce and family sustainability to sustain and further the goals and dreams of American middle-class workers as they face the uncharted waters of today's world economy.

Sustainability also means having the capacity to endure, and the Shifting Gears initiative strives to help endangered workers accomplish that. Backed by grant funds from Joyce Foundation (*www.joycefdn.org)*, a longtime Great Lakes- and Chicago-based charitable organization (established in 1948 by Beatrice Joyce Kean of Chicago, the sole heir of the Joyce family) whose mission is "igniting state leaders' desire for change and to spark their imaginations to chart a new course for low-skilled adult workers to acquire post-secondary credentials" valued by employers in Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin. (To be clear, the core work of the Shifting Gears initiative ended December 31, 2011. However, a select number of states will be continuing on in some capacity.)

Meanwhile, workers see their wages drop and families see their quality of life diminish. True, indications are that the economy is improving, whatever that means to a father or mother out of work and now contending with through-the-roof gas prices that may slow things down yet again. But the "Great Recession" exacerbated the already bad economic outlook for the under-educated or under-trained, whose grip on a middle-class life and the American Dream has inexorably weakened over recent decades.

We're all familiar with the "leave no child behind" mantra that promises to provide each and every child in this country with a quality education. And that is as it should and must be. But what to do about the 40- or 50-something father of four with a manufacturing job that's about to be shipped to Mexico or China? Or Vietnam? When that happens—as it does all too frequently these days—the possibility exists that an entire family is left behind.

"Igniting" most politicians' desire to do anything they fear doing—or don't profit from in some way—is a very tall order. But the Joyce Foundation's longevity in the region at the very least supplies much needed credibility to the endeavor. More significant are the foundation's competitive grants, which help provide the necessary resources, tools and guidance to create improved and targeted educational opportunities for adult workers.

But given the monumental task at hand, the Joyce people are under no illusions that completing an initiative of this scope will come easily, and readily acknowledge it will require that "policymakers, practitioners and other stakeholders" acknowledge that "change is necessary (and that) the answers and architecture for a new world of improved, accelerated and occupationally driven education for working adults" are not "ready-made or readily apparent."

A good many manufacturing jobs of the future—which, if you haven't noticed, is already here—require more than a high school education. The good news is that they are attainable with a two-year associate's degree or a short-term, post-secondary certificate. The bad news: millions of Midwesterners nevertheless lack the skills and credentials needed to compete for those jobs.

Employment in higher-skill, higher-wage jobs is the desired, ultimate outcome for the Changing Gears initiative. But realizing that outcome will require "changing and implementing" new state policies in the six-state region, which in turn will necessitate some very "heavy lifting" to get this done, which is at the very core of what Shifting Gears does.

And what businesses need in return from the workforce in this partnership is something that only changing the education and workforce preparation systems can provide: a readily available, high-tech-trained brain and labor pool. Time to get cracking, don't you think?