November/December 2009

GEAR TECHNOLOGY

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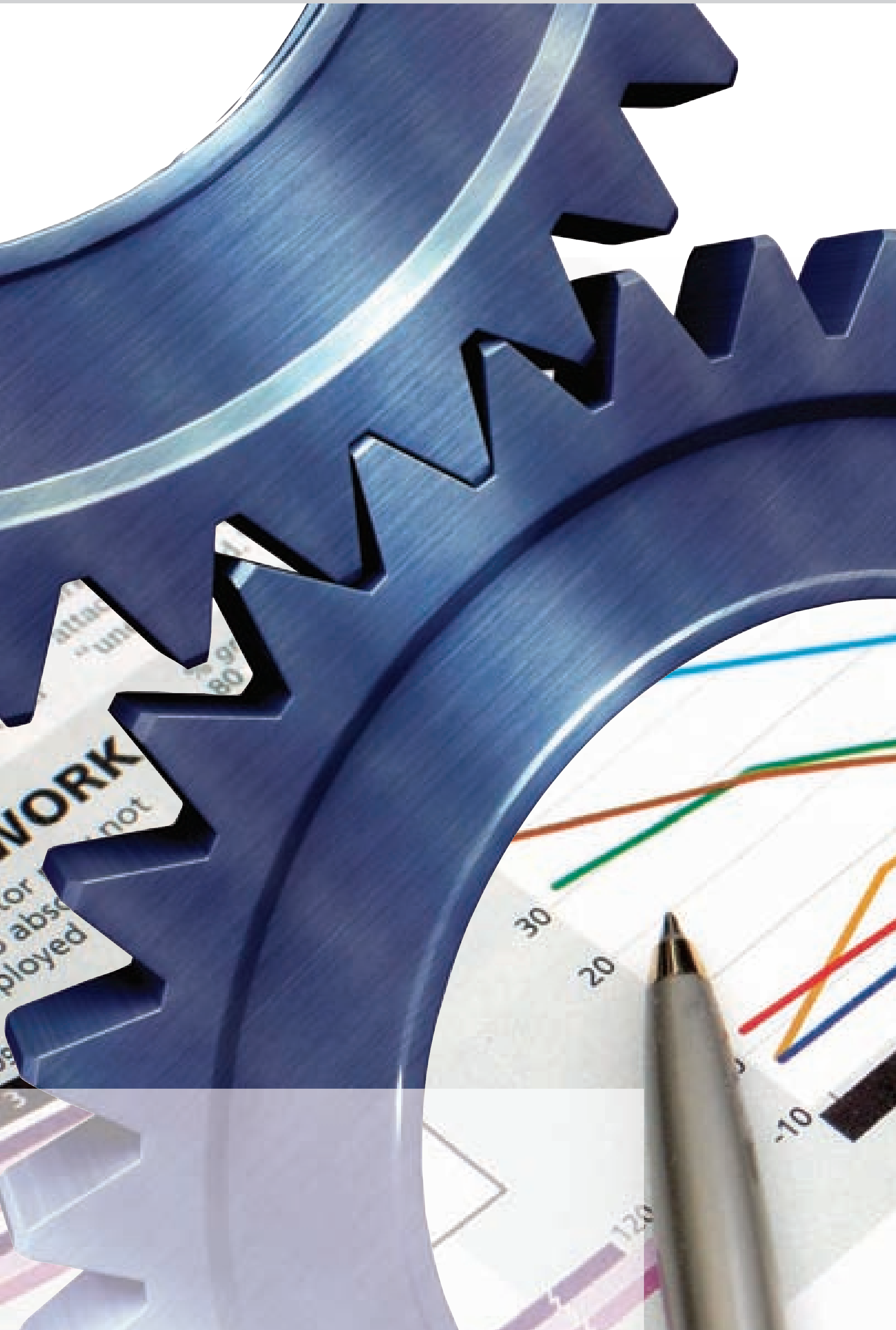
The Journal of Gear Manufacturing



25 YEARS 1984-2009

State of the Gear Industry 2009

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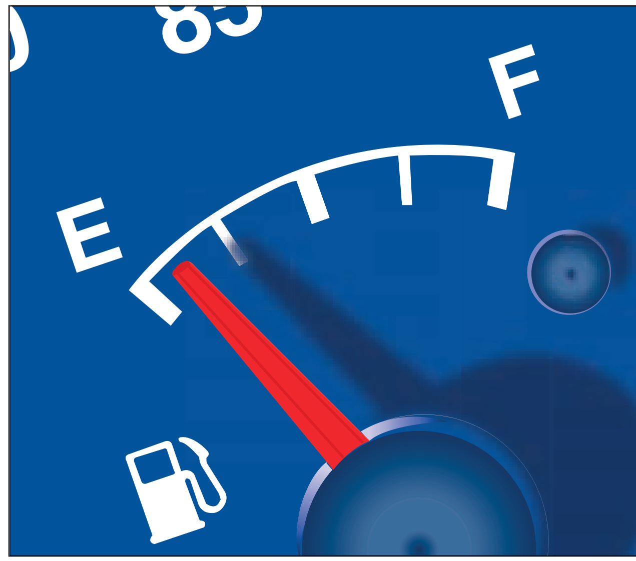

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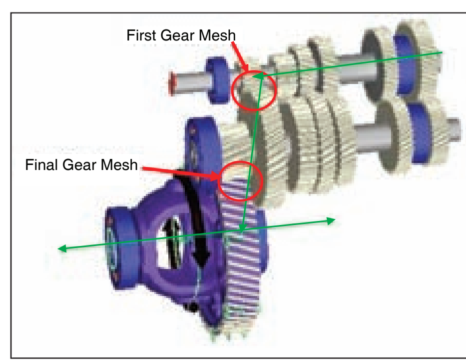

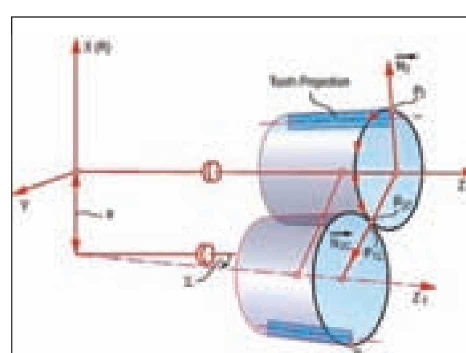

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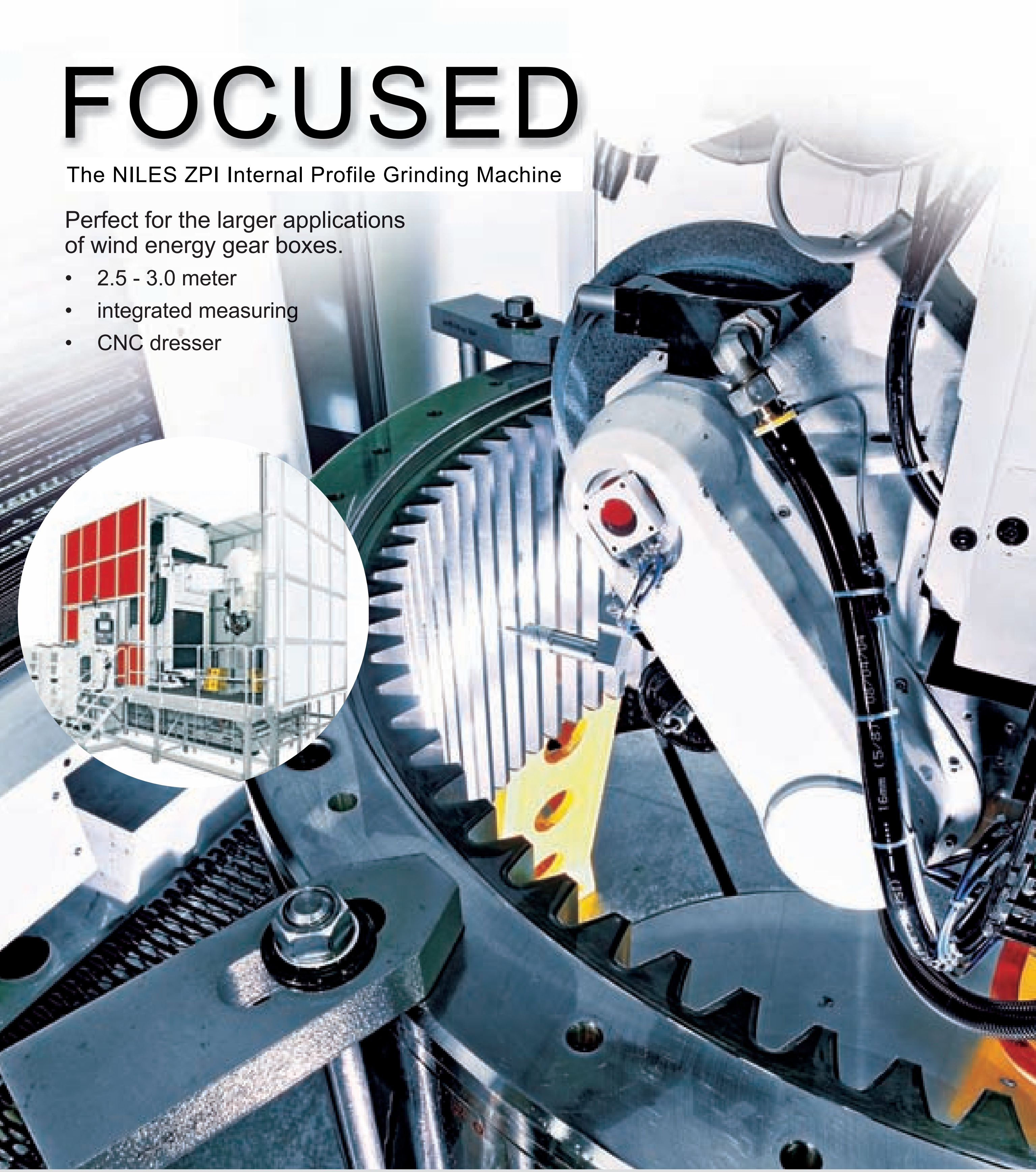
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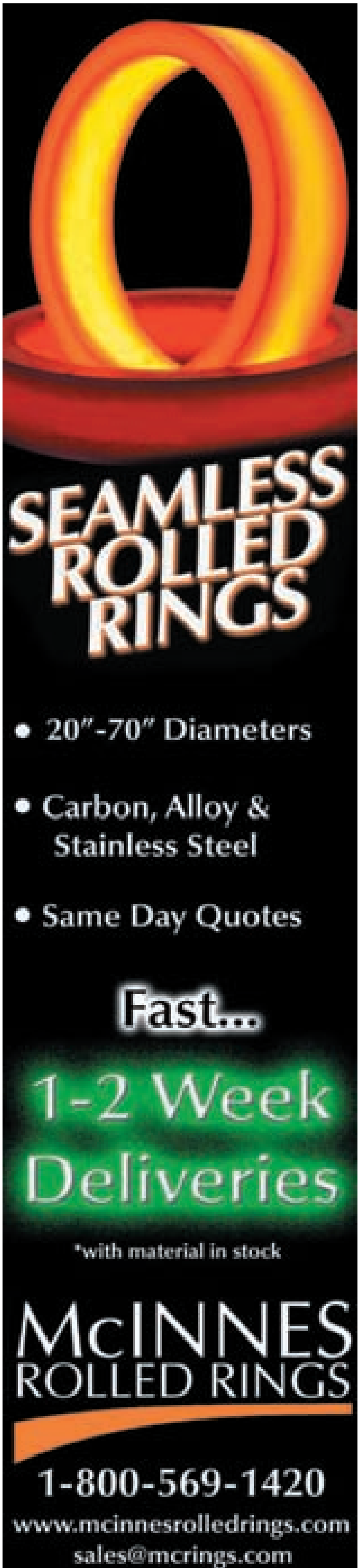

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Fallen Leaves

The change of seasons at this time of year fills us with complex and often conflicting emotions and ideas. Fall is both a time of reflection and a time of expectation for the year that's about to come. We find comfort in the warm fall colors as the trees turn to red, orange, yellow and brown, but we're also reminded that the vacation's over and it's time for harvesting and hunkering down.

Life is often colored by the season, and the cornucopia of feelings that's natural at this time of year seems particularly relevant in light of recent news and events in the gear industry. While I had originally planned to write this editorial about the positive feeling I got from visiting Gear Expo, we've also received sad news over the past few months about the passing of some close friends whom the gear industry will miss dearly.

Irving Laskin passed away at age 85. Irv was an expert in fine-pitch, plastic and powder metal gears who helped us many times as an author and guest technical editor. He was also a great contributor to AGMA and its technical community. His leadership on the committees he served has left a void that will be difficult to fill.

Georges Henriot passed away at age 87. Henriot was already a giant of the gear industry when I got into the business in 1964. In 1946, he helped found l'Institut de l'Engrenage et des Transmissions (IET) in order to disseminate technical gear information via training and publications. He helped organize several world gearing congresses and was highly involved in the development of ISO 6336 and other gear standards. Even today he is known the world over for his book *Traite Theorique et Pratique des Engrenages*, a seminal reference in the field of gearing.

With the passing of these two men, the end of a season also marks the end of an era.

We also heard about the sad passing of two who were too young to go. Kyle Dean Haley, president of Haley Marine Gears, died in October. I didn't know Kyle, but I've known Ray Haley, his father, for 40 years, both in business and through his involvement in AGMA. Ray was AGMA chairman in 1994.

Most recently, Bennie R. Boxx, Jr., president of B&R Gear, died suddenly at age 53. I've known the Boxx family for most of my career. Bennie L. Boxx (Bennie Sr.) worked for my father when I was first starting out. His children, Brenda Sudzum and Bennie Jr., I've known since we were all kids.

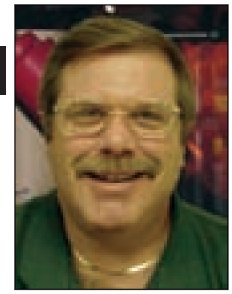
All of these men are part of our industry's heritage. Their passing is a reminder that none of us knows how far out our horizon is, so we should all learn to live life as if there is no tomorrow.

Our heartfelt condolences go out to the Haley, Haley Marine Gears, Boxx, Sudzum and B&R families, as well as to the Laskin and Henriot families.

Sincerely,

Michael Goldstein, Publisher & Editor-in-Chief

P.S. You can learn more about our positive experience at Gear Expo by reading our recap on page 79. Although many exhibitors and attendees I talked to before the show were apprehensive, I found most people in Indianapolis to be in good spirits—even optimistic. They seemed to feel that the worst was behind us. Cutting tool sales are inching up, and suppliers of tooling and fixtures are quoting a lot of jobs. There's a sense that the gear industry is in for a change of seasons, too, and we're ready to climb out of the economic doldrums.



Green Heat Treating? No Sweat!

Bob McCulley, Comprehensive Heat Treat Specialists

While manning my booth at the joint ASM Heat Treating Conference/ Gear Expo in Indianapolis, I noticed a young lady looking at our brochures. I asked if I could help her, due in part to the puzzled look on her face. Her reply—"How can heat treating be green?"—was exactly the question I was looking for.

Allow me to introduce myself. My name is Bob McCulley, and I have spent my life, since the age of twenty, in different roles of supervision in a variety of manufacturing environments. Twenty-six of those years were spent with Chrysler Corp. I was lucky enough to land a job in the heat treat department at Chrysler's Kokomo Transmission Plant in 1988. This heat treat department is without a doubt one of the largest in North America, if not the world. During my last few years at Chrysler, I had the privilege of helping lead a joint effort between management and the UAW that strove to bring the heat treating process up to world class standards. Starting in 2002, The Heat Treat Team was rewarded with both national and international awards, along with several benchmarks from Underwriters Laboratories.

I am now retired from Chrysler and have formed a company to service the heat treat industry, Comprehensive Heat Treat Specialists. We offer a program of green rewards, which we feel will help the industry meet the environmental responsibilities we all share and will soon be mandated. The experiences and knowledge gained during my tenure at KTP give me the ability to answer the young lady's question.

My response to her question was with a series of questions: If a heat treat reduces natural gas consumption by 25-35 percent and has a matching reduction in greenhouse gas emissions, is that green? Does reducing quench oil consumption by capturing and recycling fit into the green concept? When a company uses lubricants and cleaners that are designated as Earth-friendly, are they promoting the green directive?

Her response to these questions was in the affirmative, and she expressed her surprise that heat treating processes could indeed be operated with environmental consciousness. Recognizing the need is only the first step.

To expand on how to approach green heat treating, we need to differentiate between the two major types of heat treating operations: commercial and captive. First, we have the commercials. These folks live and breathe heat treating as their primary business. The bottom line of their operations determines if they open the doors next week. Captive heat treaters heat treat as part of a process to manufacture a product. Heat treating is a necessary operation for them, but it's not the final product. The bulk of contacts we received at the ASM/ Gear Expo were captive heat treaters. That is where we will focus our discussion here in this article.

Heat treat is that smoky, hot area at the back of the plant. We only go there when we have quality issues or to see the fire trucks. How did the concept of heat treating being a necessary evil develop, and what can we do about it? Every heat treat department had a beginning with new equipment, trained personnel and a set of operating guidelines. What happened? The answer is simple; time marches on, equipment wears, trained personnel leave, there are layoffs, transfers, lost records, and

continued

there is no shortage of explanations for the problems. The real shortage is in viable solutions to the problems. I personally have seen employee education—of both hourly workers and management—resolve most of these issues, but there is a lot of work involved.

There is no rocket science here; the very items that can improve bottom line operating costs are the same items that can reduce waste and pollution. It is up to management to bite the bullet and absorb the initial costs of training. The rewards are real, and they are there to cash in on.

At Chrysler, we taught a class in combustion. The class was composed of instrument men (pyrometer men), skilled trades and supervision. It was taught over an eight-week period and totaled 64 hours. The cost incurred was $36,000 or about $2,000 per student. The class was split 50/50 between classroom and the shop floor where they worked on burner tuning, optimizing gas and air train piping and general maintenance. At the end of the first month, half-way through the class, we recorded a drop in natural gas usage of $30,000. This was done while operating at the same production levels. The class paid for itself before it was completed. As it worked out, the state paid for the class on a training grant, and all the participants were awarded three college credit hours by a local technical college. Does this meet the criteria for immediate payback? Don't lose sight of the fact that the natural gas saved reduced our greenhouse emissions by the same amount. In fact, our reductions met the reduction requirements for the entire corporation that year. Just remember that natural gas consumption is only one facet of the total conservation effort.

In closing, let's return to the question that started this article: How can heat treating be green? There are many viable options for both the commercial and captive heat treaters that offer reduced operating costs through green practices. Quench oil recovery and recycling, non-permitted surface treatments (shotblast and shotpeen), peak electrical energy reduction devices and Earth-friendly lubricants and solvents are just to name a few. I suppose that one word really sums up what we need to strive for, and that is ownership. Someone needs to ask the pertinent questions regarding current and past practices and where we want to strive to be in the future. That someone has to be management at the highest levels. Allocating funds for training and setting best practice methodology in the short term will be rewarded when we see the economic upturn, and survival mode is no longer the standard operating procedure. We must become cognizant of and responsible for our actions, or future generations will bear the brunt of our excesses.

Cutting Gears on a Machining Center

DEPO PROVIDES ALL-IN-ONE MACHINING CAPABILITIES FOR GEAR INDUSTRY

A large spur gear finished using the Depo concept (courtesy of Depo).

In an age of continuous improvement and lean manufacturing, the gear market seems in favor of flexible technology now more than ever. What if a company could provide the software, the CAM system, the cutting tools and multi-axis machining centers capable of cutting any type of gear? This was the question engineers at Depo, headquartered in Marienfeld, Germany, asked in 2005.

A coarse pitch double helical gear completely machined by Depo, including chamfering and deburring (courtesy of Depo).

High speed machining, a milling process that uses standard, high performance solid carbide and indexable 3-D milling tools, has long been used in the mold and die industry. The technology allows high performance tools, in conjunction with multi-axis machining centers, to run virtually lights out. In addition, it allows a manufacturer to minimize operator involvement, thus reducing labor costs while improving workpiece accuracy and surface finishes.

"Depo transitioned into a complete solution provider in the mid 1990s with its *DepoCAM* software and its own line of optimized, high-end vertical and horizontal multi-axis machining centers," says Brian Nowicki, vice president of Tech Tool & Abrasives and a North American sales agent for Depo. "This made Depo globally capable of providing their customers with a fully integrated turnkey machining solution all from a single supplier, with all aspects manufactured and designed in-house."

In 2005, Depo was asked by a large European gear manufacturer to visit their facility to evaluate the possibility of using their successful multi-axis machining solutions for manufacturing gears. In evaluating this request, the management and engineering staffs came to the realization that a gear tooth form is nothing more than a complex 3-D shape. As they continued their investigation, talking to potential customers, they asked themselves why this technology wasn't already in use in the gear industry.

"The fact was that every gear print—including all of the necessary gear data to manufacture a gear using traditional gear cutting processes—did not translate for high speed machining," Nowicki says.

Depo immediately went to work to develop a solution for this issue, starting with spur and helical gears. By the end of 2007, the company introduced the first version of its *Gear Engineer* software.

"By taking a step-by-step process defining the gear's or pinion's dimensions, tool geometry, tolerances and tooth profile data, a 3-D model could be generated from the existing, readily available gear data in less than 15 minutes," Nowicki says. "This model could then be used in conjunction with *DepoCAM*, which includes a complete cutting tool library, to generate a cutter path for each of the tools in an additional 15 minutes. With the introduction of *Gear Engineer*, the gear industry is now wide open for high speed machining technology."

The company has sold machines in both the European and Asian markets and is now looking closer at providing its unique system capabilities in North America. Depo has made external and internal spur and helical, straight bevel, spiral bevel, double helical and herringbone gears for both service and production parts.

"Companies in heavy equipment, farm and the mining industry have an interest in this technology specifically for service parts," Nowicki says.

The system is best-suited for short-run gears ranging from 12 inches to 16 meters. "While cycle times are not as quick as conventional methods on smaller gears, the benefits come as you get into the larger sizes," Nowicki says.

"In the traditional gear cutting world, each of the gear families requires a different type of machine. With this new technology, one machine is equally effective for all gear types within its given diameter range."

In addition, the technology can be utilized for both roughing and semi-finishing of pre-heat treated gears, but it also offers the ability to "hard mill" either induction hardened or through hardened gears. From a quality standpoint, all the gears can be machined either pre- or post-heat treatment to an AGMA 12 quality or better.

"A single machine tool cuts all gear and pinion types, it can machine all lifting and mounting holes, machine gearboxes complete and in some cases, even turn the parts prior to machining the gear teeth," Nowicki says. "With Depo *Gear Engineer* and *DepoCAM* software, a new gear can go from gear print to CNC program in less than 60 minutes."

In order to use these high-speed machining principles to manufacture gears, the machine tools must be incredibly accurate and repeatable, according to Nowicki. "These are the same requirements necessary for some

continued

Inspection software from Depo allows for on-the-machine inspection of a large bevel gear (courtesy of Depo).

Advances in Depo's *Gear Engineer* software now allow the following gears to be produced utilizing this integrated technology in the following size ranges:

External Gears
- A maximum outside diameter of 16,000 mm
- Spur gears/helical gears

Internal Gears
- A maximum outside diameter of 16,000 mm, depending on the face width dimension
- Complex workpiece up to a maximum outside diameter of 3,300 mm can be cut on a vertical machining center
- Spur gears/helical gears

Bevel Gears
- Straight, skewed-tooth, spiral
- A maximum outside diameter of 4,000 mm
- Spiral (Klingelnberg Palloid and Cyclo-Palloid, Gleason system)

Pinions
- A maximum shaft diameter of 350 mm (depending on the table options)
- Total workpiece length, including the teeth, can be customized as needed by modifying the foundation layout

Double Helical/Herringbone Gears
- A maximum outside diameter of 16,000 mm
- Continuous-tooth herringbone gears also possible

Worm and Worm Wheels

of the high-end mold and die applications that Depo was already very familiar with."

Depo recently went to work on what is now known as their Depo Expert Line. This new line consists of five- and seven-axis vertical and horizontal machining centers, which are all dual-column machines with a five-axis simultaneous positioning accuracy of five microns or better. They include thermal compensation, broken tool detection and on-the-machine workpiece inspection; all features necessary to produce gears of the highest quality.

"When gear manufacturers first hear of this technology, the first question is commonly, 'What type of tool do you use?' Understandable, as our industry has been built using hobs, shaper cutters, shaving cutters and stick blades, all with the tooth form already existing to a large degree," Nowicki says. "Not anymore. Using high speed machining principles, all types of gear forms can be manufactured using standard, conventional, off-the-shelf solid carbide and indexable carbide cutting tools."

In high-speed machining, the tooth form is generated by way of the CAM software and machine tool control. The result is a fully-integrated gear manufacturing system that includes *Gear Engineer* to generate the surface data, *DepoCAM* to generate cutter path, Depo's Expert Line machine tools for accuracy and Depo's high-end tooling solutions, all integrated and designed to produce the gears.

"The flexibility that this technology brings will help to free the industry from the long lead times traditionally considered acceptable in the gear business," Nowicki says. "Low lot sizes, coarse pitch gears, large gears and much more can now be produced with significantly shorter lead times.

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jhowes@nameco1.com
www.nameco1.com

Gleason Cutter Head

IMPROVES TOOL LIFE AND PRODUCTIVITY

The Pentac Plus is the latest generation of Gleason's Pentac bevel gear cutting system. It is designed to allow much higher tool life and improved productivity, especially for cutters using multiple face blade geometry.

The blade clamp block design of the Pentac Plus is a new feature that makes height and radial adjustments easier and faster to perform, so precise axial blade movement during cutter building and truing results.

The Pentac Plus prevents chip packing, the accumulation of chips between cutter blades during gear cutting, which is a frequent issue with previous cutter designs. Chip flow is often insufficient in front of the outside blades because the side rake angle obstructs the chip chamber in the direction of centrifugal force, which results in weak chip evacuation. If this issue is not resolved, pressure increases and extreme temperatures of the highly compressed chip packing will eventually distort blade geometry. The result is early blade failure and rejected parts, and in the most severe scenarios, multiple cutting blades may break.

"To avoid chip packing, machines are usually operated with fewer cutting blades at conservative speeds and lower feed rates. The new Pentac Plus is designed to enhance chip flow and prevent chip packing," says Hermann J. Stadtfeld, vice president of bevel gear

continued

technology for Gleason. "Therefore, gears can be cut with more efficient cycles without premature degradation of the cutting blade efficiency. The net result is longer tool life and lower cost per part."

The Pentac Plus cutting system is available for face hobbing and face milling in all cutter sizes, and it can be adapted to any existing Gleason gear cutting process without new software or hardware. The Pentac type cutters are sold in Japan under the name Superi-Ac.

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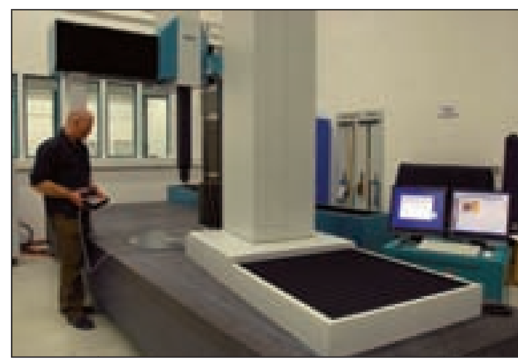
Hybrid CMM/GMM

MEASURES WIND TURBINE GEARS



The LHGT 2600 Hybrid CMM and GMM is designed for wind energy industry measurement needs.

Wenzel Geartec introduced a hybrid gear measuring machine at Gear Expo this year, which is specifically designed to measure the large gears and pinions used in the wind energy industry.

The Hybrid LHGT 2600 machine features a prismatic measuring volume of 1,500 mm x 2,500 mm x 1,200 mm, and it has an embedded hydrostatic rotary table flush-mounted inside an Impala black granite machine base. The table and fixture measures and supports gears up to 2,600 mm in diameter and up to 20,000 pounds. The machine features a removable tailstock column that can mount on the base to measure and support pinion gear shafts up to 1,900 mm in length. The LHGT 2600 uses Renishaw SP80 scanning technology.

"Wenzel has developed this

machine to specifically meet the demand of the wind energy gear manufacturing community, where large internal and external gears and pinions require highly accurate measuring as well as traditional CMM measuring of prismatic parts," says Keith Mills, president of Xspect Solutions, Inc., the wholly owned subsidiary of Wenzel GmbH. "Traditional gear inspection machines are typically mechanical bearing devices with horizontal arms holding the scanning probe. To simply expand this type of machine design concept that was originally developed to measure 500 mm diameter gears, and apply it to 2,500 mm diameter gears, doesn't work. For that reason, Wenzel has developed this new hybrid machine design that uses an all-granite, air bearing structure, with a bridge-type construction, so the probe can provide a much higher level of dynamics and scanning performance with no mechanical bearing wear over time. In addition, the machine requires no special foundation."

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Robotic Gear Deburring System

AUTOMATES CHAMFERING

Compass Automation unveiled its Robotic Deburring System at Gear Expo 2009. It features a touch screen HMI, so operators can seamlessly upload specs of a custom gear to the robot for automatic deburring or chamfering of gears, even if the customer is not mass producing the same sizes and types. The system is customized to individual specifications, and it can be integrated into existing CNC hobbing machines for complete automation.

"This system will help gear manufacturers reduce operating costs and save valuable time in an application

continued

that tends to be one of their biggest nuisances," says Patrick O'Rahilly, director of Compass Automation, Inc.

"This can truly be a game-changing product for the gear manufacturing industry," says Robert Perly, director of engineering for Compass. "It just does not make sense to allocate human operators to the deburring process. The technology has finally arrived for robots to be able to handle small runs and the varying types and sizes of gears simply and easily."

For More Information:
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sales@compass-automation.com
www.compass-automation.com

Leitz CMM

HANDLES EXTRA LARGE COMPONENTS

Hexagon Metrology announced the Leitz PMM-G gantry CMM series at Gear Expo 2009, featuring improved specifications and extra size availability, so it's appropriate for highly precise inspection of extremely large components, like gears used for wind power, gear segments, gear racks and geared shafts of up to 5,000 mm in diameter.

The PMM-G is configured based on customer specifications. It is made in 55 standard measuring sizes from 3,000 mm x 2,000 mm x 1,200 mm to 7,000 mm x 4,000 mm x 3,000 mm. The maximum part load is 15 metric tons. Gear types suitable for inspection include cylindrical gears—spur, helical, double helical, internal and external spline, internal and external clutch, gear segments and gear racks—in addition to straight, spiral and hypoid bevel and crown gears. They can be evaluated to all major standards, including DIN, ISO, AGMA, ANSI, JIS, CNOMO and CAT.

"The PMM-G represents the ultimate in Leitz large-scale gear inspection," says Pete Edge, product manager of Leitz products. "Unlike other gear inspection products, it does not require a rotary table, which makes part loading and unloading much easier. It also allows a maximum part weight of 15 metric tons. This system is ideal for the extremely large gears used in the wind power industry, for power generation and power transfer products. Even better, the PMM-G system is not a single purpose inspection station just for gears but a fully capable coordinate measuring machine that can be used to inspect many other kinds of large machined assemblies, such as gearboxes and engine blocks."

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Fax: (401) 886-2727
info@hexagonmetrology.us
www.hexagonmetrology.us

Air Gaging Honing Tools

PRODUCE TIGHT TOLERANCES

The Precision Hone tooling system from Sunnen uses integral air gaging and an automatic shutdown device to produce non-contact, in-process bore sizing to tolerances of 0.005 mm (0.0002 inches). They are suitable for honing diesel cylinder liners, compressor cylinders, automotive engines, small engines and aircraft cylinder bores with diameters from 57 mm (2.25 inches) to 300 mm (12 inches).

The air gaging system is a unique feature. Bob Davis, global communications manager for Sunnen explains how it works. "The PH Precision Hone tooling system incorporates air lines into the tool, which conduct pressurized air terminating in small ports on the edges of the tool. A feedback loop

continued

in the machine controller measures the pressure, which builds up between the hone head and the wall of the part being honed. As the diameter of the part gets larger, the pressure drops. The gaging system circuitry built into the honing machine measures the pressure and translates it into a diameter. The machine is set up to hone to a certain diameter and automatically stops when that diameter is reached."

The PH tools have multi-stone tool heads that are custom-designed; the number and placement of stones is dictated by the application. Bayonet air connections on the tool heads help initiate fast changeovers. The tools can connect to the rotary feed system of Sunnen's SV-310 for precision stone feeding or the linear feed system of the SV-500 for two-stage roughing and finishing applications. They can also be used with other manufacturers' machines. They include three abrasive options: metal-bond superabrasive (diamond or CBN), conventional abrasive (aluminum oxide/silicon carbide) and plateau brush (abrasive impregnated filament).

For more information:
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Measurement Software

PROJECTS PROFILE TOLERANCE BAND

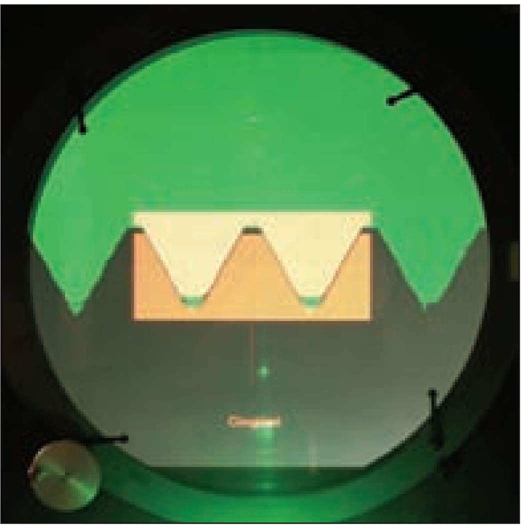
The eCAD electronic overlay package from Optical Gaging Products, Inc. (OGP) consists of software and internal comparator hardware that enables a

CAD to project a profile tolerance band onto a comparator screen. The software runs on a standard Windows PC, which can be networked to download CAD files from a server over a secure link for protecting the original CAD files.

Operators line up eCAD projected images with a part image on the comparator screen, and eCAD incorporates various tolerance zones, as defined by the CAD file, to express whether a part is in or out of tolerance, indicated by different color bands.

The projected image can be coupled to the part screen image, so if an operator moves the worktable, the CAD image follows what is on screen. The need to maintain physical overlay templates is unnecessary with eCAD.

"eCAD would allow a customer to manually compare a gear shape to the nominal CAD geometry. A total profile tolerance could be set around the part," says Bill Verwys, applications engineering manager for OGP. "Of course, this would not be appropriate for all gear classifications, but [it] could be very helpful for some, or as an in-process check."



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info@ogpnet.com
www.ogpnet.com

25 Bar Furnace

ACTS AS ALTERNATIVE TO OIL QUENCH

continued

Seco/Warwick introduced a 25 Bar Single Chamber Vacuum Furnace as a process alternative to vacuum furnaces using an oil quench. The 25 Bar HPQ provides the same hardness properties as an oil quench, and when it is equipped with optional PreNit and FineCarb advanced LPC vacuum carburizing technology, the furnace can reduce cycle time by up to 50 percent in certain applications.

Using helium as a quench medium, the 25 Bar furnace lowers distortion and renders parts washing unnecessary. Loads are both heated and quenched in the same chamber with the single

chamber furnace. Many of the problems associated with oil quenching are minimized with the 25 Bar HPQ including the disposal of spent quench fluids, the requirement for a washer to clean parts and post heat treating machining needed to compensate for part distortion in oil.

Helium is used as a process atmosphere to maximize cooling. Recycling systems are available to recover and reuse the helium, which tends to be higher cost than other process gases; however, there are many choices for supply systems, and helium follows the same installation guidelines as nitrogen.

Seco/Warwick is offering free trials for a limited time at their R&D facility, so companies interested in the process can obtain a full metallurgical report for their samples without any risk.

For more information:
Seco/Warwick
P.O. Box 908
Meadville, PA 16335
www.secowarwick.com

Single-Coil Dual Frequency Induction System

TREATS MID-SIZED GEARS

Inductoheat's Single-Coil Dual Frequency Induction Gear Hardening System was designed specifically for heat treating gear-like components with fine teeth, and it was recently shipped to an automotive engine and power-train component supplier. The machine is designed to be capable for optimum hardness patterns of medium and fine teeth gears.

The Single-Coil Dual Frequency Induction Gear Hardening System is appropriate for high-volume single shot hardening of several powertrain components. The machine minimizes distortion of heat treated parts and distributes residual stresses favorably. Medium frequency (10 kHz) and high frequency (120 kHZ–400 kHz) power supply modules combine for 1,200 kW of total power, and both modules work simultaneously or in any sequence to optimize gear properties. The total heat time is about 1.5 seconds.

The system uses Allen Bradley controls with a PC touch screen operator interface for monitoring. An integrated closed-loop water circulation system reuses water for quenching and cooling. Other features include a high-speed servo spindle drive to control rotation speed, a heavy-duty aluminum splash door with safety interlock switch and light curtains as well as other system components with QA, precise position control and safety measures.

For more information:
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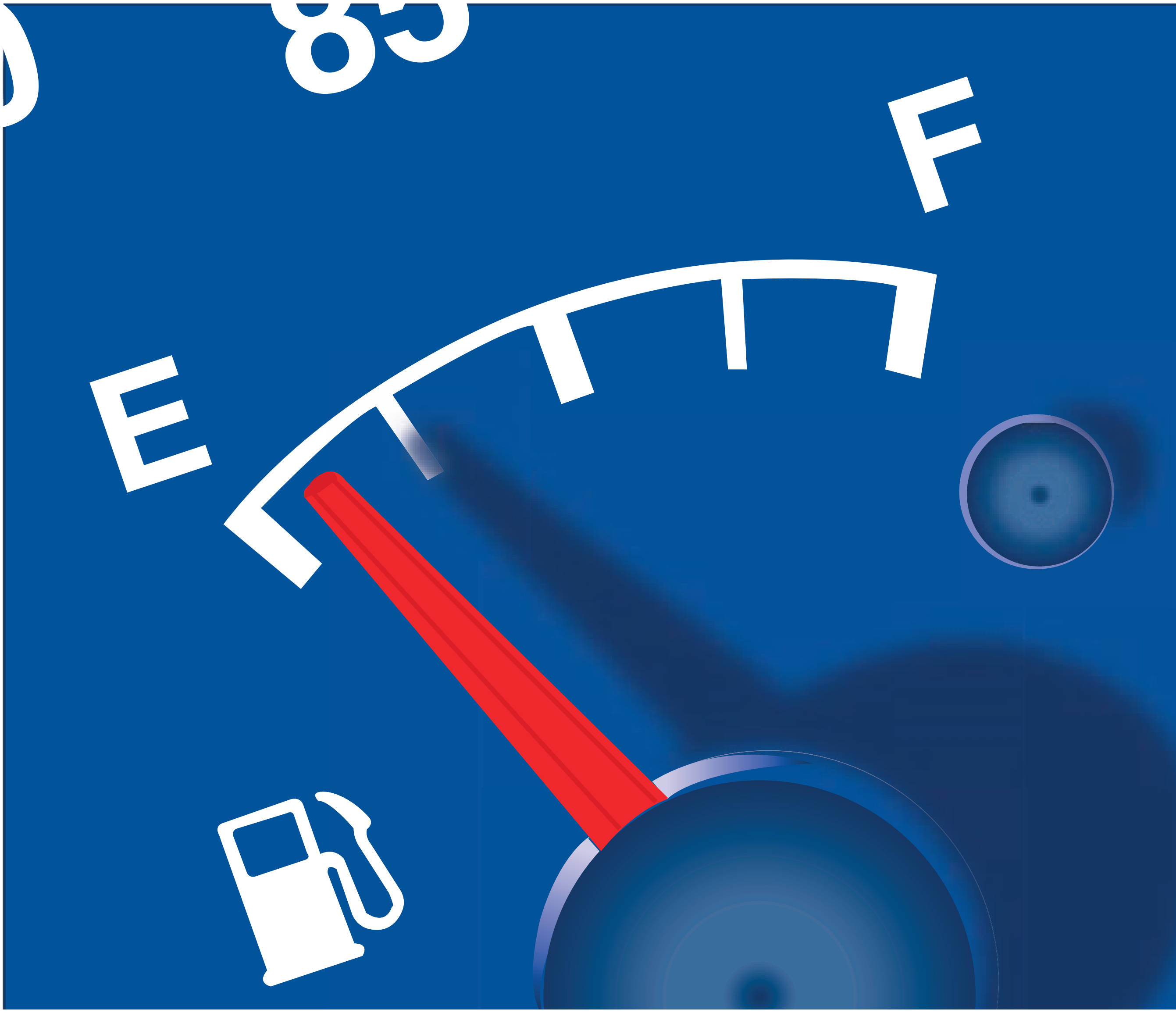


American Manufacturing:

CAN IT BE SAVED?

Jack McGuinn, Senior Editor

If anyone should ever need convincing that the state of American manufacturing is in ongoing decline, consider this: the state of Michigan has the highest concentration of engineers in the country, yet also has the highest unemployment rate. But there are ripples of hope out there as grassroots and otherwise organized groups are fighting the good fight in an attempt to reverse that trend. One such example is the American Alliance for Manufacturing (AAM)—a Washington D.C.-based non-profit/non-partisan group working to influence policy on such issues as international trade, energy security, healthcare and retirement security to the benefit of American manufacturing—for both management and labor. The AAM's genesis was a partnership between major American manufacturing companies and the United Steelworkers. Some generally lesser-known facts about the steelworkers union: it is the largest industrial union in America, but fewer than 15 percent

continued

Scott Paul, AAM executive director.

of its members actually work in the steel industry; it is the largest auto parts union, with more workers than the UAW; it is also a tire union; and it has a stake in the glass, fiber optics, pharmaceutical and oil refining industries. Following is an extensive Gear Technology *Q&A with Scott Paul, AAM's executive director.*

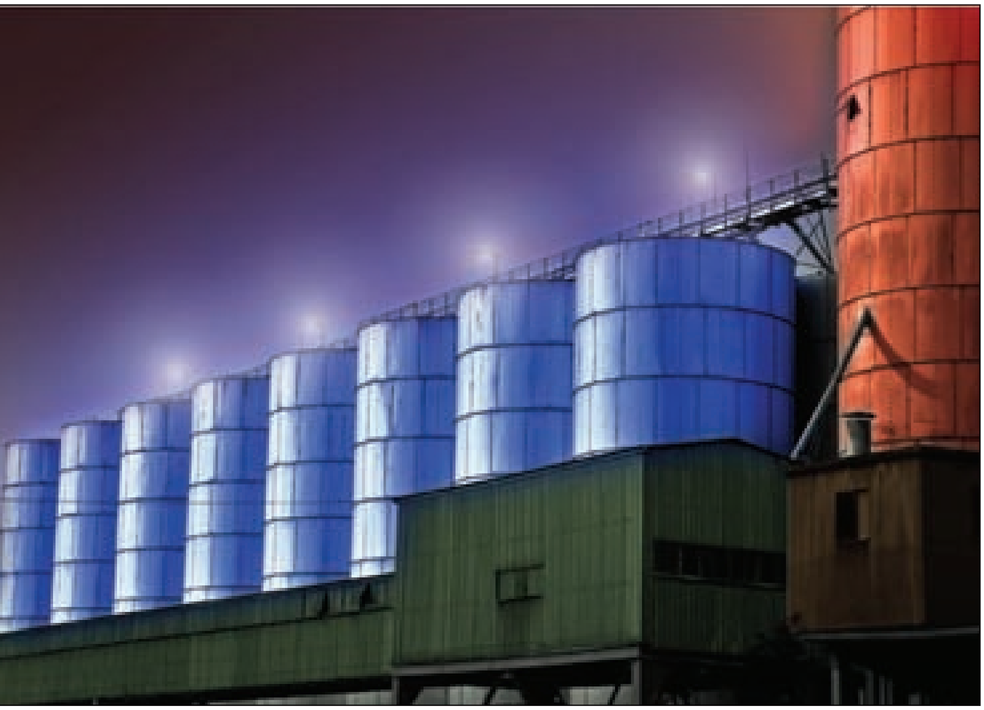
Why and when did the United States stop making things?

It's a big question. I think there have been two precipitating events—one is longer-term and one is shorter-term. In the longer term, I think—and this is a process that's been taking place for decades—oftentimes our foreign policy took priority versus domestic concerns. And at the end of World War II and several decades thereafter, the United States was the principal industrial nation in the world; we really didn't have any competition, and we were really the 'factory for the world.' And our foreign policy—and I don't think this was shortsighted in particular—was geared toward aiding Germany and Japan to rebuild, which is a good thing, I think. But it was also geared toward Cold War politics, and so we gave a lot of market access to countries in exchange for their support during the Cold War. Over time, the combination of this—along with a lack in domestic investment in manufacturing—took a toll. Over time, that eroded our position. So I think that's step one. Step two; I think the really short-term precipitating event has been the emergence of China as both a trading nation and, in a lot of ways, an industrial superpower. I think that the erosion that we've seen over the last eight or nine years in particular has been the result of the emergence of China as a competitor and the myriad issues that that represents.

'From just a value-added perspective, the reason why manufacturing is so important, aside from actually making things that help advance an economy and advance a civilization, is that there's more valued-added for the economy. A manufacturing job and the wages that it provides supports four or five other jobs in the economy. A government job doesn't do that; a retail job doesn't do that; a financial services job doesn't do that.'

In television and radio interviews, you have commented extensively on the displacement of manufacturing jobs in favor of the financial services, retail and other service-related industries. Please compare and contrast that development in relation to the accrued benefits to the nation of a healthy manufacturing sector.

If you look at the share of our overall domestic output, manufacturing makes up only about 9 percent of that now. Healthcare is 18 percent of our economy; the retail services sector is about 20 percent; that has a profound impact. From just a value-added perspective, the reason why manufacturing is so important, aside from actually making things that help advance an economy and advance a civilization, is that there's more valued-added for the economy. A manufacturing job and the wages that it provides supports four or five other jobs in the economy. A government job doesn't do that; a retail job doesn't do that; a financial services job doesn't do that. Also, manufacturing provides more innovation, R&D, technological advancement—the types of things that support our math and sciences—than any of these other sectors. Manufacturing is currently about 12 percent of our GNP, despite being only 9 percent of our working force. And even though it's only 9 percent of employment, manufacturing employs 40 percent of all engineers that are employed in the United States. It is responsible for two-thirds of all the R&D in the private sector that's conducted here. It's responsible for about



80 percent of the patents that are filed in the United States, and it is the largest buyer of technology. So when you're shrinking that sector, you're shrinking a lot more than just factories. You're shrinking R&D and the opportunities for math, science and engineering. There's a tremendous loss that way. Another example of how (manufacturing downsizing) is a tremendous loss and why it's so important is the revenue stream, and it's simply because when manufacturers are in a local community, they're usually the largest local taxpayer. The wages are good, and there's more tax revenue flowing in the economy. But when you replace manufacturing jobs with service jobs, you're shrinking the tax base, which in turn has an effect on public schools, transportation and the kinds of investments that can make a community better. Saying that a transformation away from manufacturing into these other sectors is a good thing and inevitable is completely misguided, and it's very dangerous.

What is the origin and/or basis for the devaluation of manufacturing?

I think there's a theoretical background for it, which is a kind of churning capitalism that destroys and creates. If (capitalism) is destroying manufacturing jobs and creating other jobs, that's a good thing. And so what the theory holds is that if you're losing manufacturing jobs, the jobs that replace them are going to be higher skilled, or pay better, or have more value added. That's the theory. But as we've seen, that's not what happens at all. I think another reason is that there is truly an image that is perpetuated in pop culture, in government and in the media that 'Factory jobs are old, that they're yesterday, dirty, low-skilled, not desirable. What we need is to work in an office park, we need to write screenplays; this is what America should be doing.' It's really this image that's damaging, too—and the opposite is true. Manufacturing is very advanced, very automated; the jobs tend to be very high-skilled

continued

'You can make tons of money on Wall Street, whereas if you're a small or mid-size manufacturer—you're doing the right thing, you're making a great product, providing for your workers, you're highly efficient—if you're lucky, you may turn a little bit of a profit, but you're certainly not going to be a billionaire.'

and people take a lot of pride in their work—there's an extraordinary amount of pride in making something. And in being able to show what you did at the end of the day, and where it ends up, rather than creating a financial derivative that makes you and a couple of your buddies rich. Not only is there this view, but I think there are government policies that support this. There is a pretty heavy corporate tax burden on manufacturing. For most financial services exchanges that take place there are a minimal amount of taxes; there's no transaction taxes on a lot of different things. If you want to be in financial services, in the course of your everyday work, you don't encounter nearly the same kind of tax structure, and the financial benefits are vastly different too. You can make tons of money on Wall Street, where if you're a small or mid-size manufacturer—you're doing the right thing, you're making a great product, providing for your workers, you're highly efficient—if you're lucky, you may turn a little bit of a profit, but you're certainly not going to be a billionaire. There's a vastly different set of incentives, and part of it is market-based, but part of it is really driven by government policy.

What about disincentives to manufacturing, like out-of-control healthcare costs, labor cost, recalcitrant unions and environmental regulations that discourage manufacturing—how do you respond to that?

Look at Germany; are their labor costs any lower than ours? Are their environmental regulations any less? No—in fact, they're higher. They have higher compensation costs and more environmental regulations; same with Japan. If you look at most of the developed countries, the U.S. wages are not on a par with these other countries—or are below in many cases. Yet Germany is still a manufacturing powerhouse, as is Japan. And in taking the low road and engaging in a race to the bottom, we're never going to be able to win that. No matter what we do, Mexico is always going to be able to have lower

'And when (workers) are reasonably compensated you can still compete, but what manufacturers can't compete with is a tax structure that is sometimes very difficult and a healthcare system where, if they're providing healthcare, they're sharing a huge burden for that. And that's a burden that German manufacturers don't face, or Japanese manufacturers don't face, or Canadian manufacturers don't face.'

wages, and China lower wages than Mexico, and Vietnam is always going to have lower wages than China. So we're never going to win that race if we're not investing in our workers, and there are, what I would call, viable high-road strategies to compete. And when (workers) are reasonably compensated, you can still compete, but what manufacturers can't compete with is a tax structure that is sometimes very difficult and a healthcare system where, if they're providing healthcare, they're sharing a huge burden for that. And that's a burden that German manufacturers don't face, or Japanese manufacturers don't face, or Canadian manufacturers don't face. I'm not saying that we need a single-payer healthcare system, but we obviously need a way to contain costs and to look at a different way of doing things. The other thing that these countries have going for them is that they have a manufacturing strategy. They actually have a strategy to keep manufacturing jobs in their country. And the view of this—and this was true in the Clinton administration and was true in the Bush administration; it remains to be seen from the Obama administration—has been that (corporations and jobs) were meant to leave—and we'll go with what we have (as a nation) rather than trying to set any goals.

What incentives would you like to see implemented in order to reverse this trend?

First, let's look at skills and training. I think our education system is so focused on test scores that we've lost sight of vocational education and in really having a seamless program—from high school to community college—to train people for manufacturing jobs. I think one of the perverse things about the situation that manufacturers are going to face in the next 10 years is that their existing workforce is retiring, and there are not a lot of skilled workers available who are coming into manufacturing. We've gotten away—in the high schools and community colleges—from having a seamless program that works with local employers and that is well funded to help provide a talented pool of workers. I think that, unfortunately, what job training has become is basically a subsidy for shifting people out of manufacturing and into lower-paid jobs. And they're moving them into retail and service jobs and the government is doing the training for the employer. That's not where we should be spending our money. It should be on developing skills for high-wage jobs, and I think that's a big point. That requires the right kind of investment, and it requires a paradigm shift. Next is trade policy, and I know this is controversial. If there's free trade, fine. But it's more of a theory than a reality. And China puts up all sorts of barriers—they subsidize their industries, and they have an exchange rate manipulation that gives them an advantage. If the United States is going to counter that, it's not protectionism. If China is not playing by the rules, we have to call them on that, and we shouldn't be afraid to be aggressive about it. The European Union is very aggressive about that, Japan, etc. We have nothing to be ashamed of, and we need to counter that.

'Look at what Ronald Reagan did. He certainly was a free market guy, but he stood up for Harley Davidson motorcycles; he got tough with Japan; he forced Japan and Europe to revalue their currencies so that they weren't so mercantilist. And Obama needs to channel a little bit of that and to reassert our rights on trade.'

Why the inaction by the United States to enforce its own trade regulations and policies?

Number one, I think our trade policy has been hijacked by what I would call global companies who have an interest in low-cost imports—even if they're displacing domestic employment. There's a view that we can compete through financial services, but if you look at our trade picture and add up the surplus that we have in education and financial services, it adds up to $80 billion a year. Look at our trade deficit in kitchen appliances alone—$84 billion—and that's a tiny segment of manufacturing. We will never balance our trade account by prioritizing services; you have to do it through manufacturing. And you have to demand that those markets are opened up. I hear some companies screaming about Panama and Columbia, but those are pea-sized markets. You have to open China, you have to open Japan, you have to open big consumer markets like that. Look at what Ronald Reagan did—he certainly was a free market guy. But he stood up for Harley Davidson motorcycles; he got tough with Japan; he forced Japan and Europe to revalue their currencies so that they weren't so mercantilist. And Obama needs to channel a little bit of that and to reassert our rights on trade. Number two, I think there is just this reticence to try and help manufacturing. And one broader point—we need to value manufacturing again. The president

continued

needs to say that and Congress needs to say that. One of the things I work on, and I admit it may sound superfluous, but I also think it's important to get Hollywood and others to understand it too, so that every image they project of a manufacturing worker is not like an Archie Bunker guy. Or every image they project of the factory floor; it's either one of two things—it's either dirty and so 1970s, or it's abandoned and there's some chase scene through it. People get their images from what they see on TV and there needs to be an effort to project a more positive image. It sounds like a little thing, but I think it's a pretty big thing at the end of the day.

Number three is taxes. We really need to think about a new kind of corporate tax system that provides a lot of incentive for producing things here and exporting them. That shakes off some of the incentives that companies get for keeping money offshore, and also for companies that have a lot of different things going on. So much of the corporate tax burden is on U.S. manufacturing rather than on financial services, and it needs to be shifted a little bit. So there needs to be tax reform. And number four, we have to look at healthcare and reforming the healthcare system, and doing it in such a way that it contains costs and will make us more competitive globally. And we need to do something about energy costs. We need to provide—and I think this is important for your readership—a lending facility with the availability of capital to small and mid-size manufacturers to retool, to become more energy efficient and to be able to compete for work in the clean energy economy as well. Because clearly the direction this country is heading in is more renewable types of energy and for more fuel-efficient cars. It doesn't happen overnight or automatically; we have to put some muscle into it. A small manufacturer in the industrial heartland is not going to have the capital right now to retool; there needs to be a lending facility for that. Wall Street has been the beneficiary of all the bailouts and yet has certainly been a bit stingy getting the money back out there into the heartland.

Given the existing acrimony in our politics today at both the state and federal level, how can one be optimistic that the politicians will ever come to their senses and try working together for the benefit of the nation? Witness the healthcare reform standoff, for example.

The healthcare fight is not a good example of working together. The one thing we (AAM) have found, and we've worked with Republican and Democratic members of Congress, is that (the parties) may have different reasons for (supporting manufacturing). There might be Republicans who support manufacturing because of a small business angle where they think it's good for national security. There may be Democrats who support it because it provides high-paid jobs or some other factor. But there's actually a lot of commonality on this, and I think there's actually a moment of opportunity here. There's still so much frustration with Wall Street, and how everything is geared toward Wall Street and not Main Street, that we can capture a little bit of that. But I think the big thing is that manufacturing is not looking for an $800 billion bailout; we're basically looking for a more level playing field and maybe a little more investment. But the ripple effect from the recession, the Wall Street crisis and also, what has happened to GM and Chrysler, is far and wide, and it goes well beyond the assembly plant—it's all over. It's going to require some work to get that back, and it requires some investment.

How do you view the effect of President Obama's economic stimulus initiative?

If you ask most mainstream economists, they thought that the overall cost of the stimulus was probably about right for what needed to be done. My main criticism was that enough of it wasn't in infrastructure, that too much of it was in activities that weren't going to have enough value added. It does take a little bit more time for infrastructure projects to create jobs. But we're not talking about the pork barrel 'bridge to nowhere' projects; we're talking about things that need to be done to reduce congestion, to build high-speed rail or other things that are going to have long-term benefits for the American economy. We have short-changed those types of investments for a long time. Shanghai has high-speed rail from its airport to its downtown; we have nothing that approaches that. Our infrastructure is crumbling, and that's the type of thing we need to be investing in.

We've heard a lot lately about "buy American." Realistically, how can that work in a global economy?

'Buy American,' from a governmental procurement perspective, is something we have done for more than 70 years. It actually had broad support: Ronald Reagan expanded the 'buy American' program for highways and mass transit, Dwight Eisenhower used it to build the nation's highway system, so this is nothing new. And every other country does it, media reports notwithstanding. It's just common sense. If you're going to invest American tax dollars in some sort of project, you want those resources directed toward helping American workers and American companies. We have foreign aid programs to help other countries, but we don't need to be doing that at the expense of our own manufacturing base. And then there's consumer choice. I was delighted when President Obama said that 'If you're considering buying a new car, I hope you consider buying American.' I think that set the right tone; he didn't say you have to buy one. I don't think we are dictating that consumers buy American products, but I think we can do a better job of educating people as to the benefits they are going to get back, in terms of economic growth over a product's lifetime for example.

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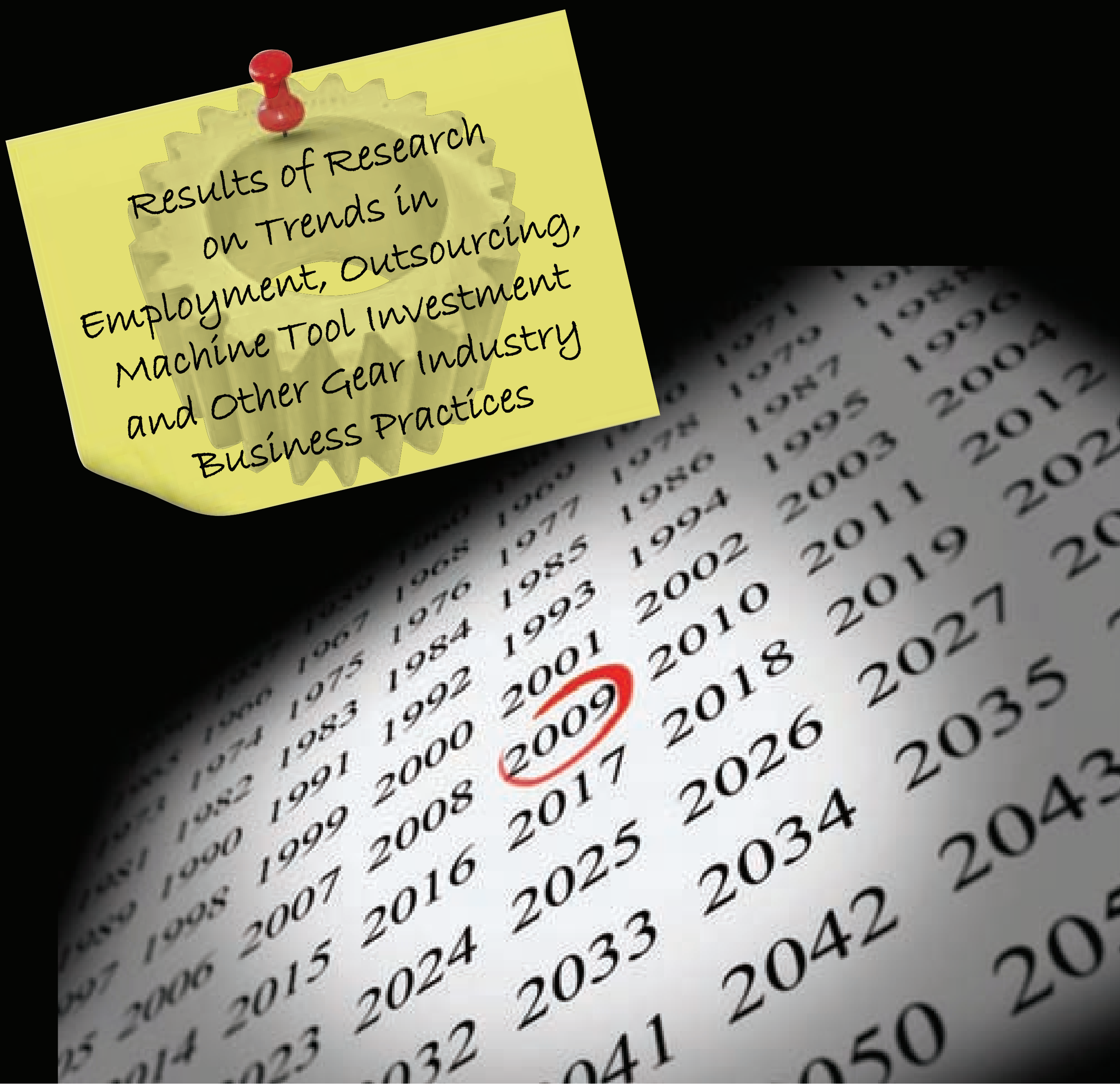
STATE OF THE GEAR INDUSTRY



In October, Gear Technology *conducted an anonymous survey of gear manufacturers. Invitations were sent by e-mail to thousands of individuals around the world. More than 300 individuals responded to the online survey, answering questions about their manufacturing operations and current challenges facing their businesses.*

The respondents considered here all work at locations where gears, splines, sprockets, worms and similar products are manufactured. They work for gear manufacturing job shops (44 percent), captive shops at OEMs (52 percent) and shops manufacturing gears for maintenance, spares and their own use (4 percent).

The survey covers gear manufacturing around the world, with 54 percent of respondents working in the United States, and 46 percent outside the United States.

A full breakdown of respondents can be found at the end of this article.

continued

What Factors Are Presenting Significant Challenges to Your Business?

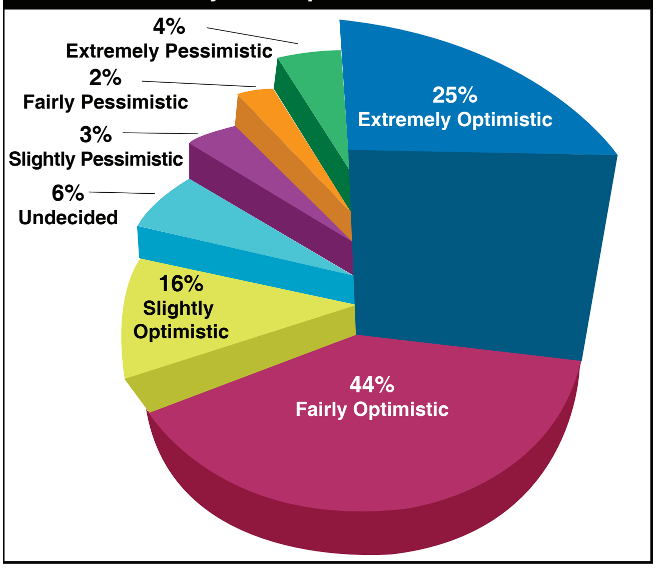
"Availability of raw material, production to meet targets."
—Manufacturing engineer at a manufacturer of gear machines in India

"Average age of the workforce is pretty high."
—Design engineer at a U.S. manufacturer of gas turbines

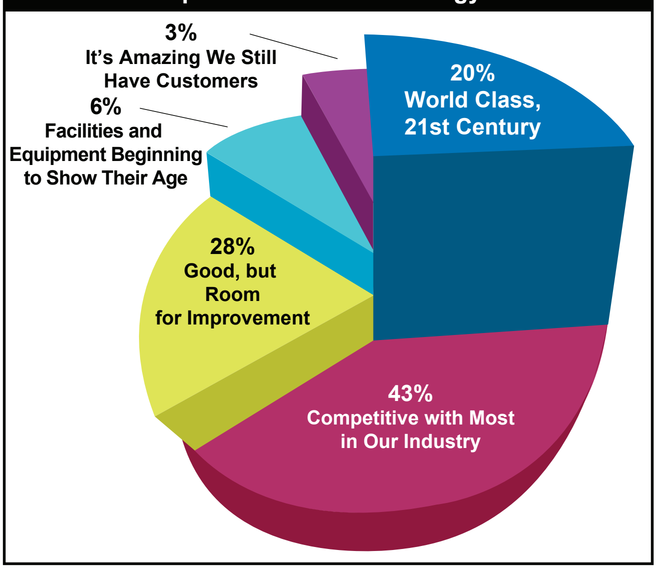
"Bad management."
—Design engineer at a U.S. manufacturer of overhead trolley cranes

"Bargaining agreement."
—Manufacturing engineer at a U.S. manufacturer of light and medium duty driving axles

85% of Gear Industry Respondents are Optimistic About Their Ability to Compete Over the Next Five Years



How Do Respondents Describe their Manufacturing Operations and Technology?



"Change in technology in auto industry. Capability to afford modernization of infrastructure."
—Manufacturing engineer at a manufacturer of inspection and testing equipment in India

"Changing customer expectations, shortening product development time, meeting cost targets with increased features."
—Design engineer at a manufacturer of agricultural tractors in India

"Competition quoting prices lower than the cost to produce the products in order to maintain or increase market share."
—Corporate executive at a U.S. gear manufacturing job shop

"Concerns about tax liability exposure if we enlarge our facilities. Also, the type of young people that society (schools, parents, media, etc.) sends in the direction of industry are not the ones that are smart enough to do well in my business."
—Corporate executive at a U.S. gear manufacturing job shop

"Cost."
—Design engineer at a manufacturer of linear actuators in Taiwan

"Cost competition with intact quality."
—Corporate executive at manufacturer of particleboard

"Cost of new equipment for gear grinding."
—Manufacturing engineer at a U.S. gear manufacturing job shop

"Currency changes making it more difficult to export."
—Corporate executive at a gear manufacturing job shop in Denmark

"Current administration in D.C. will destroy the mining industry, and hence a large portion of our customers."
—Corporate executive at a U.S. gear manufacturing job shop

"Customer demand for lower prices."
—Corporate executive at a U.S. gear manufacturing job shop

"Customer demands for price decreases."
—Corporate executive at a U.S. designer and manufacturer of custom gears and gear assemblies

"Develop business in Middle and Far East."
—Sales manager at a manufacturer of marine and industrial transmissions in Italy

"Economic uncertainty being promulgated by D.C. politicians is impacting capital investment."
—Corporate executive at a U.S. manufacturer of gearmotors

"Energy crisis is the major challenge."
—Corporate executive at a manufacturer of gears and splined shafts in Pakistan

What Factors Are Presenting Significant Challenges to Your Business?

"Export demand drop-off."
—Design engineer at a U.S. manufacturer of grinding equipment

"Financing."
—Corporate executive at a U.S. manufacturer of aerospace gears

"Foreign ownership and plant closures to transfer manufacturing work out of the U.S.A."
—Manufacturing engineer at a U.S. manufacturer of 4WD transfer cases

"Funding from banks difficult."
—Employee at a U.S. manufacturer of milling equipment

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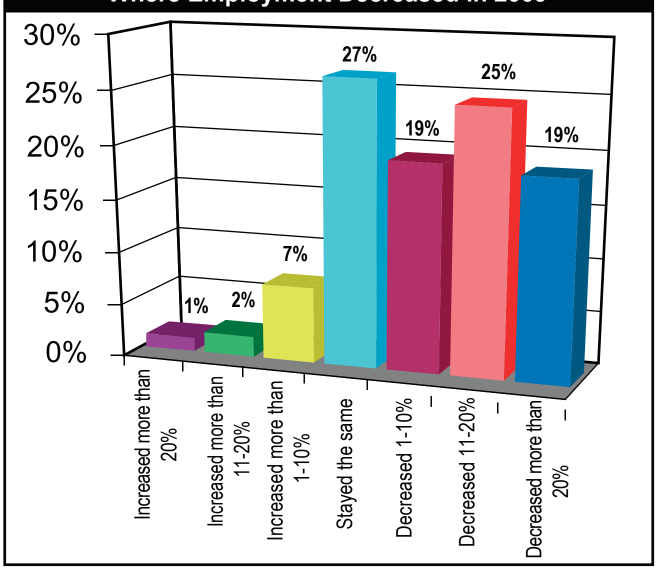
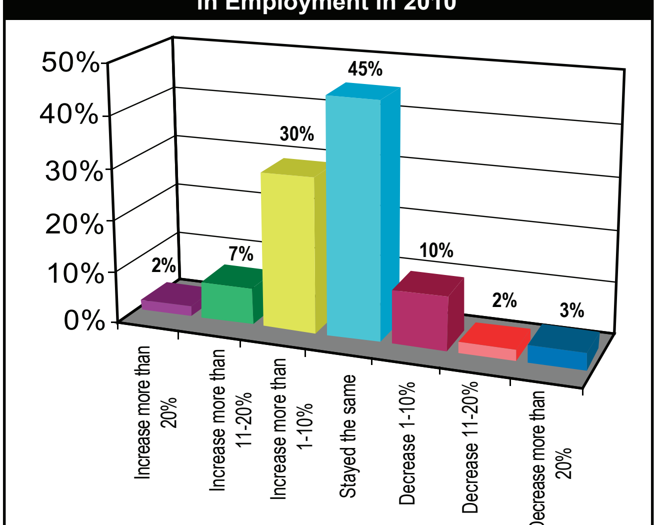
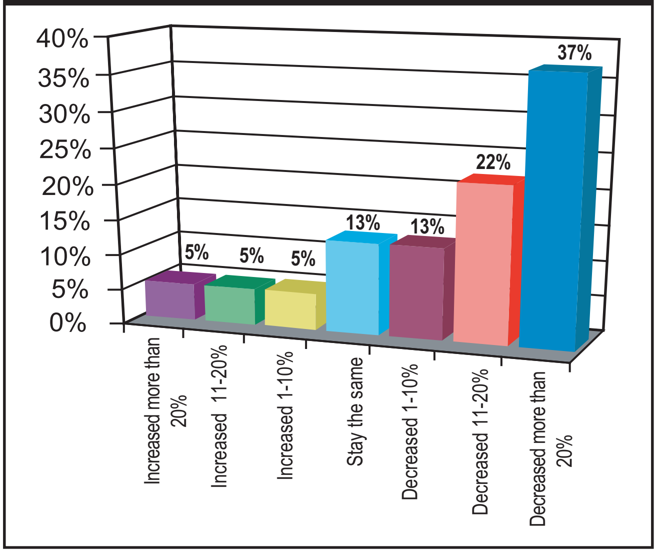
63% of Gear Industry Respondents Work at Locations Where Employment Decreased in 2009



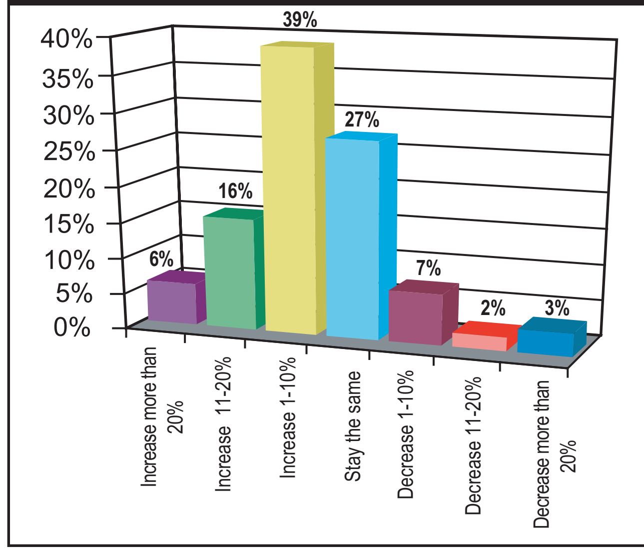
Most Gear Industry Respondents Expect Little Change in Employment in 2010



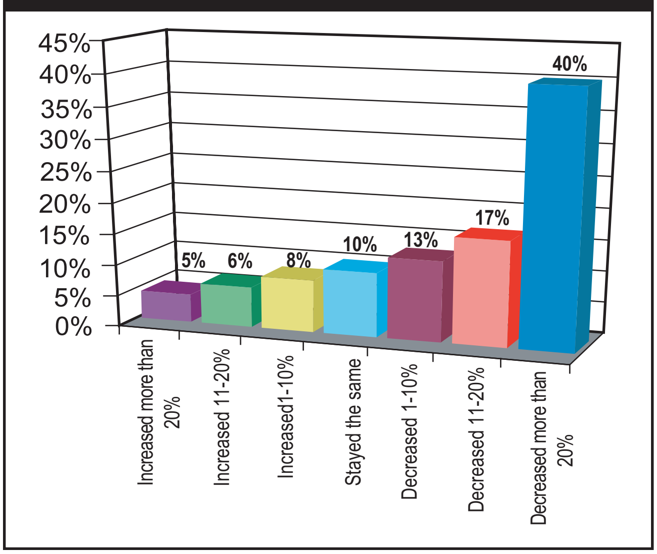
72% of Respondents Saw Production Volumes Decrease



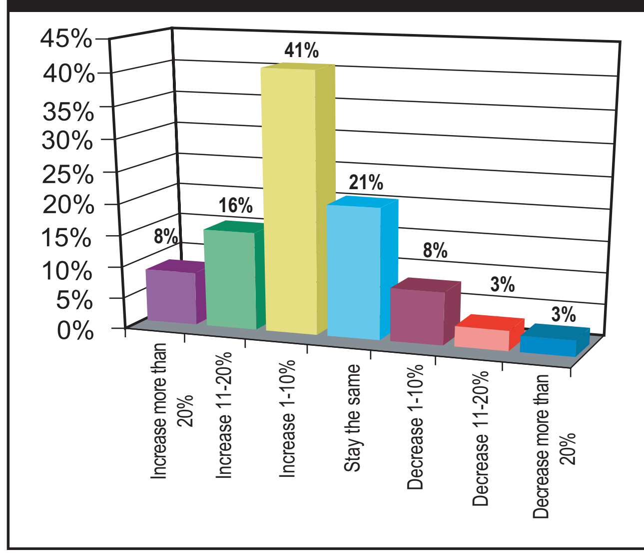
61% Expect Production Volume to Increase in 2010



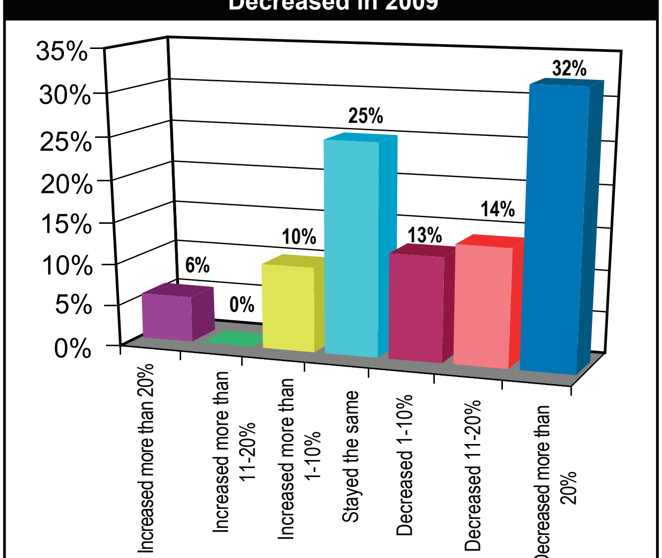
70% Saw Sales Volume Decrease in 2009



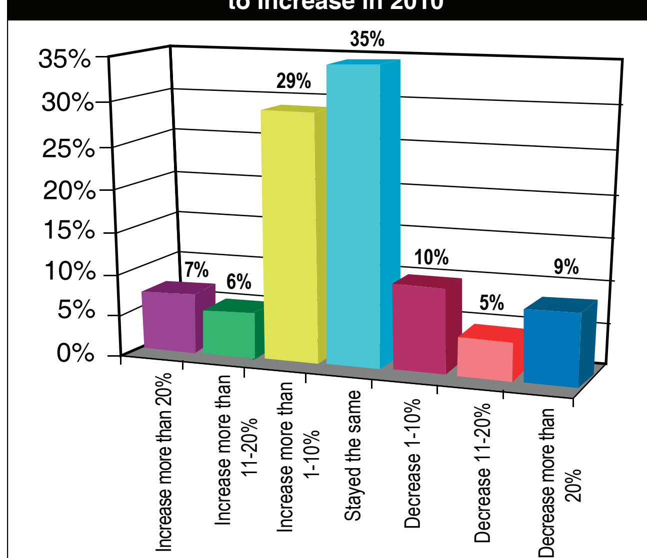
65% Expect Sales Volume to Increase in 2010



59% Work at Locations where Capital Spending Decreased in 2009



42% Expect Capital Spending at their Locations to Increase in 2010



What Factors Are Presenting Significant Challenges to Your Business?

"Global pricing in China and Europe. Due to the economic crisis, Europe's pricing has become more competitive than the U.S. local pricing, but we believe this to be very temporary."
—Purchasing professional at a U.S. assembler of wind turbine gearboxes

"Higher quality standards versus lower cost prices."
—Manufacturing engineer at a manufacturer of engine timing gears in Belgium

"Increased competition from other countries, high tooling costs, lengthy procurement process for quality tooling."
—Manufacturing production employee at gear manufacturing job shop in India

"Increased taxes."
—Design engineer at a U.S. machinery manufacturer

"Knowledge management process and organization-wide process quality."
—Design engineer at a German manufacturer of automobile differentials

"Lack of engineering expertise at customer end is leading to delays in development."
—Corporate executive at a hydraulic equipment manufacturer in India

"Lack of financing to build in U.S.A."
—Purchasing professional at a U.S. manufacturer of planetary gearboxes

"Lack of sales."
—Corporate executive at a U.S. manufacturer of overhead electric cranes

"Long design cycle time."
—Corporate executive at a U.S. sales office

"Low capital."
—Manufacturing engineer at a U.S. manufacturer of rack and pinion steering components

"Low cost, high quality, fast delivery."
—Manufacturing engineer at a manufacturer of automatic transmissions in India

"Major concern is dollar volatility and world over-concern for alternate world currency."
—Corporate executive at a manufacturing company in India

continued

What Factors Are Presenting Significant Challenges to Your Business?

"Many assemblies that we make gears for are being made overseas, so we no longer get a chance to quote the gears. Our U.S. customers are facing tough foreign competition and are always asking for price decreases. Quality, 100 percent on-time delivery and a fair price is not good enough any more."
—Corporate executive at a U.S. manufacturer of spline shafts and hydraulic pump gears

"Non-manufacturing/gearing people running business."
—Manufacturing engineer at a U.S. manufacturer of power transmission equipment

"Protectionism in other countries."
—Design engineer at a U.S. manufacturer of custom gear units

"Quality and cost."
—Manufacturing engineer at a manufacturer of gearboxes in Brazil

"Quality of supplier parts."
—Quality engineer at a U.S. manufacturer of pneumatic and turbine starter motors

"Reduced volumes and the ability to change to these volumes and make a profit."
—Sales manager at a British gear manufacturing job shop

"Skilled, dedicated manpower; competition; imports."
—Corporate executive at a manufacturer of machine tools in India

"Small lot size of orders challenges profit margin due to high setup costs."
—Corporate executive at a U.S. manufacturer of loose gearing

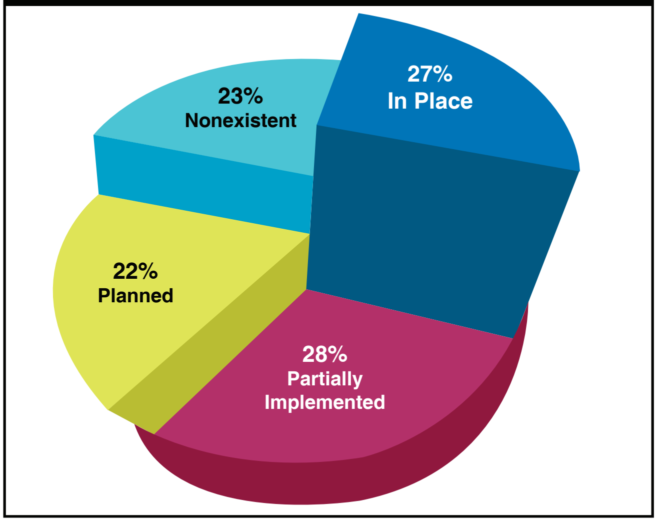
"Sudden spurt in the global economy, unpredictable scenario with auto majors."
—Manufacturing production employee at a manufacturer of gears and gearboxes in India

"Sustaining consistency in quality and delivery performance of suppliers. Catering to low volume products (reduction in minimum batch quantity in production). Handling variety with greater efficiency."
—Purchasing professional at a manufacturer of tractors in India

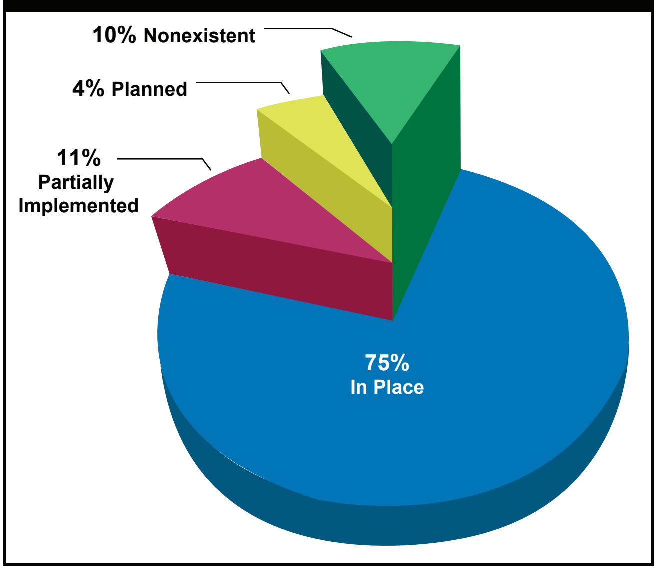
"Taxes, workmen's comp, product liability."
—Corporate executive at a U.S. manufacturer of oilfield gears

continued

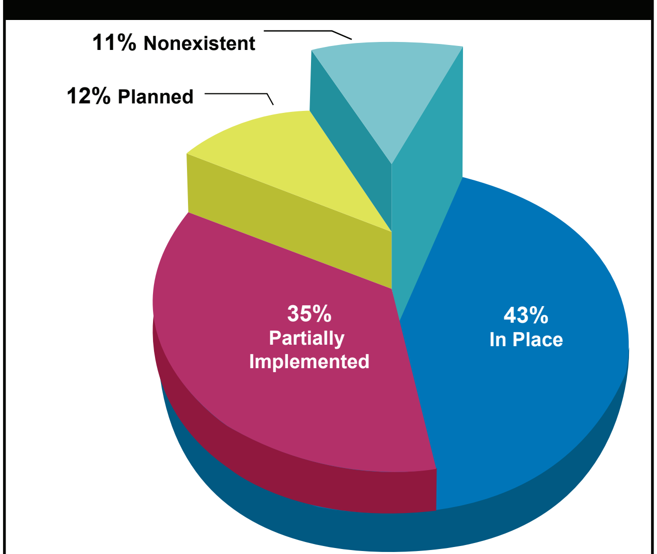
Green or Sustainable Manufacturing Implementation



ISO 9000 Implementation



Lean Manufacturing Implementation



What Factors Are Presenting Significant Challenges to Your Business?

"Timely service of imported equipment, upgrade in suppliers, availability of people eager to work with own hands."
—Manufacturing engineer at a gear manufacturing job shop in India

"Vendor lead times."
—Manufacturing production employee at a manufacturer of space robotics in Canada

"Volatility of raw materials."
—Corporate executive at a U.S. manufacturer of worm gear blanks

"World economy has many of my defense programs on hold. Don't see this changing until the end of 2010."
—Corporate executive at a U.S. manufacturer of aerospace gears

What are Your Company's Greatest Manufacturing/Engineering Challenges for 2010?

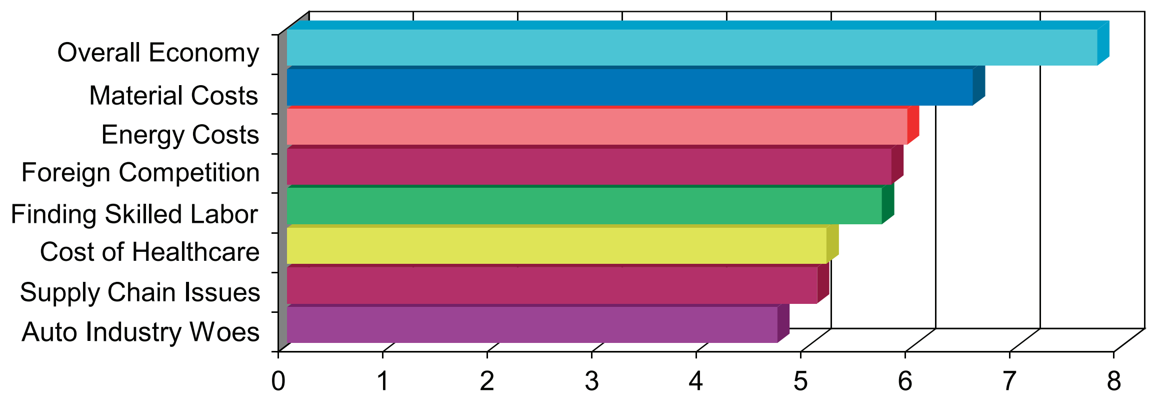
"Ability to re-invest."
—Corporate executive at a U.S. gear manufacturing job shop

"Being a quality supplier globally."
—Corporate executive at a grinding wheel manufacturer in India

"Bring our new Mexico plant up to speed."
—Manufacturing engineer at European manufacturer of engine timing gears

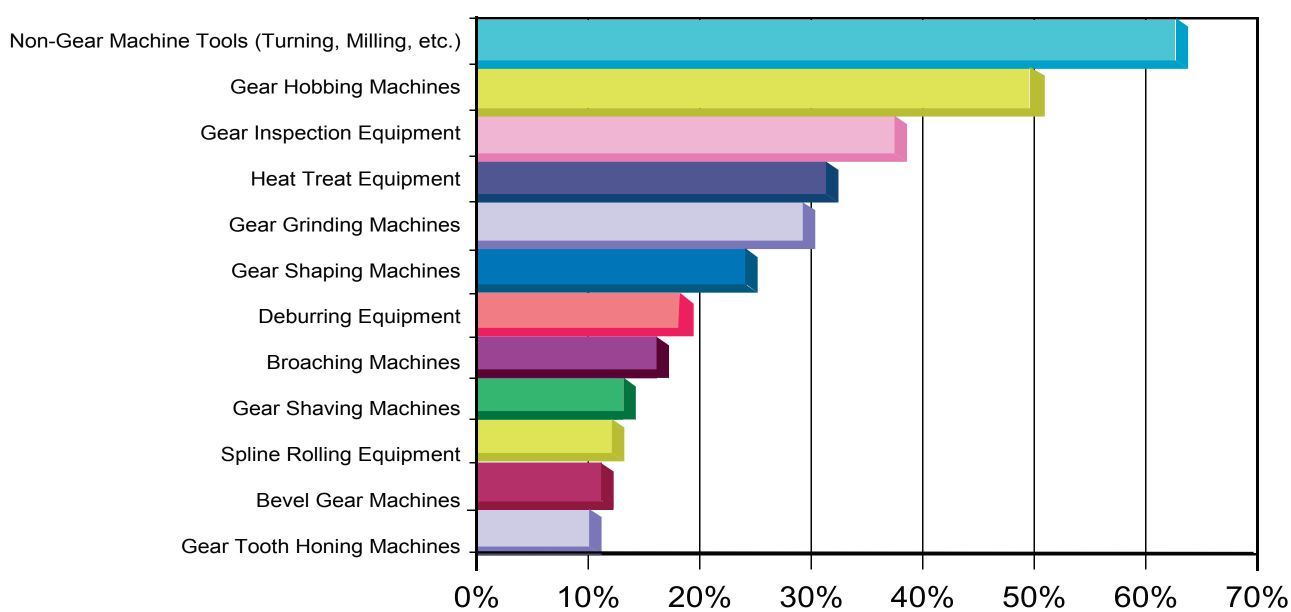
"Closing down manufacturing plants in the U.S.A."
—Design engineer at a U.S. manufacturer of overhead trolley cranes

What are the Most Significant Challenges Facing Gear Industry Companies?



Average 1-10 Ranking (with 10 being the most significant challenges)

Machine Tool Purchase Plans 2010



Of those planning to purchase capital equipment, the percentage planning to purchase in each category

What are Your Company's Greatest Manufacturing/Engineering Challenges for 2010?

"Continuing with developing product in a low volume year is most challenging."
—Design engineer at a U.S. manufacturer of construction equipment

"Cost competitiveness."
—Manufacturing engineer at a manufacturer of automatic transmissions in India

"Cost containment."
—Design engineer at a U.S. machinery manufacturer

"Customers are pressed for sales, so when they do get an order they want things in unrealistic delivery times."
—Corporate executive at a U.S. manufacturer of aerospace gears

"Customers are requiring more engineering assistance since they have downsized their organizations."
—Sales engineer at a U.S. manufacturer of gears and machined components

"Cutting warranty costs and delivery time; forcing standardization; launching new production technologies; maintaining process stability."
—Design engineer at a manufacturer of automobile transmissions in Germany

"Decrease costs. Decrease size and weight on the type of units we produce."
—Design engineer at a manufacturer of all-wheel-drive systems in Sweden

"Demand for specialty type products."
—Corporate executive at a U.S. manufacturer of speed reducers

"Develop expertise."
—Manufacturing engineer at a manufacturer of gearboxes in the United Kingdom

"Development of lower cost, lighter, highly robust mechanical power transmission components in a crushed industry and recessive economy."
—Design engineer at a U.S. automotive supplier

"Development of new materials and processes."
—Corporate executive at a U.S. manufacturer of gearmotors

"Environmental issues."
—Manufacturing engineer at a manufacturer of automobiles in India

"Fast response to customer requirements."
—Manufacturing engineer at a manufacturer of inspection and testing equipment in India

continued

Statement of Ownership

Page 1

Statement of Ownership, Management, and Circulation
(Requester Publications Only)

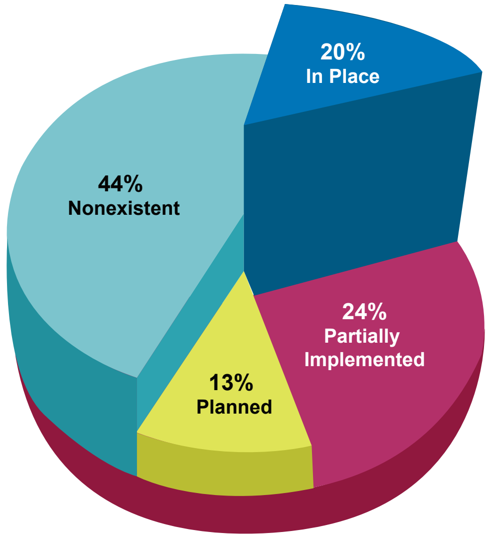
GEAR TECHNOLOGY, the Journal of Gear Manufacturing

Page 2

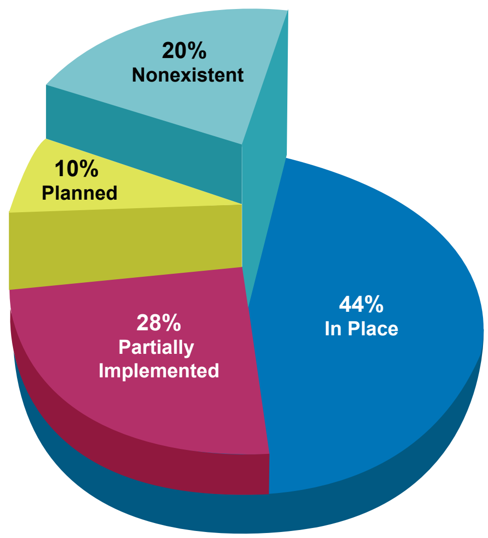
GEAR TECHNOLOGY, the Journal of Gear Manufacturing

Michael Goldstein, Publisher

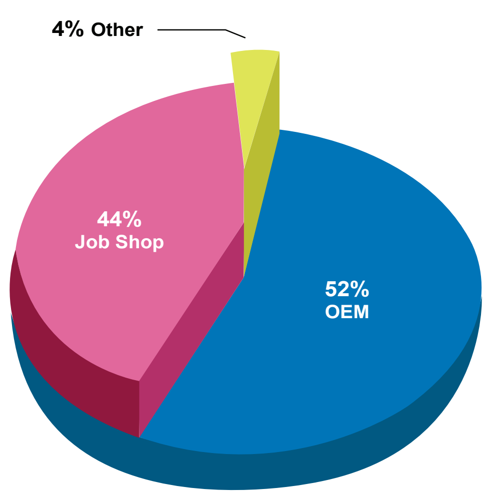
Six Sigma Implementation



Statistical Process Control (SPC) Implementation



Type of Operation



What are Your Company's Greatest Manufacturing/Engineering Challenges for 2010?

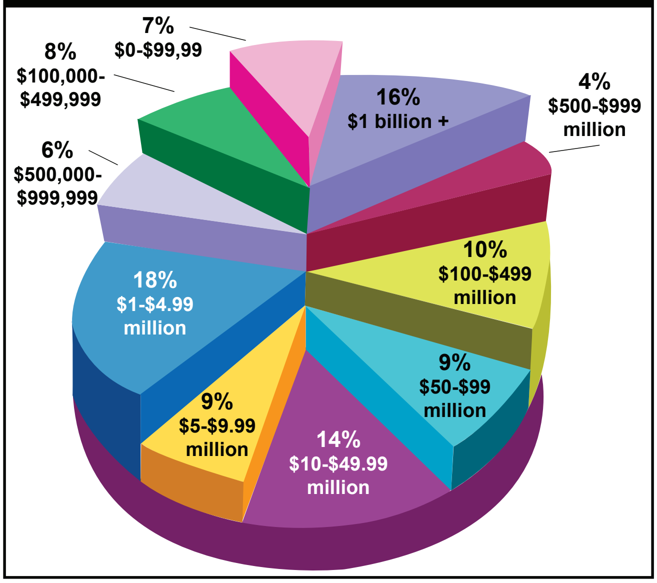
"Faster new product development at most competitive prices to compete with global manufacturers."
—Manufacturing engineer at a manufacturer of steering gear assemblies in India

"Finding products that fill a niche that will keep U.S. moving forward. Current product line is aging."
—Design engineer at a U.S. manufacturer of grinding equipment

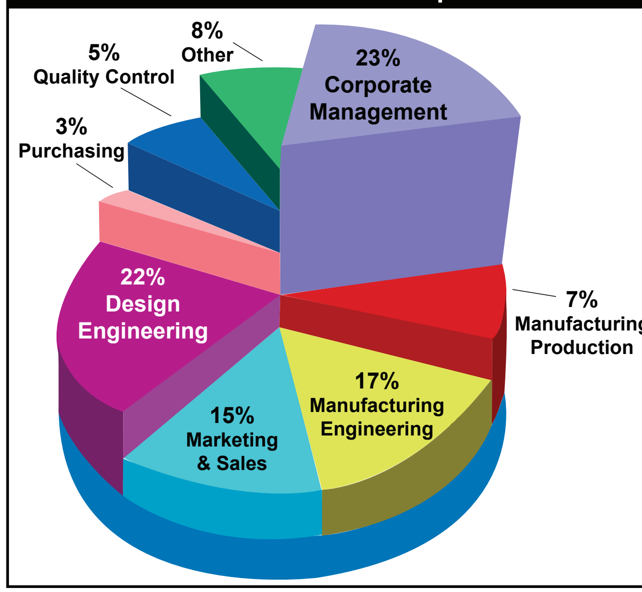
"Foreign ownership, plant closure to transfer manufacturing work out of U.S.A."
—Manufacturing engineer at a U.S. manufacturer of four-wheel-drive transfer cases

continued

Annual Sales Volume of Company



Job Title/Function of Respondent

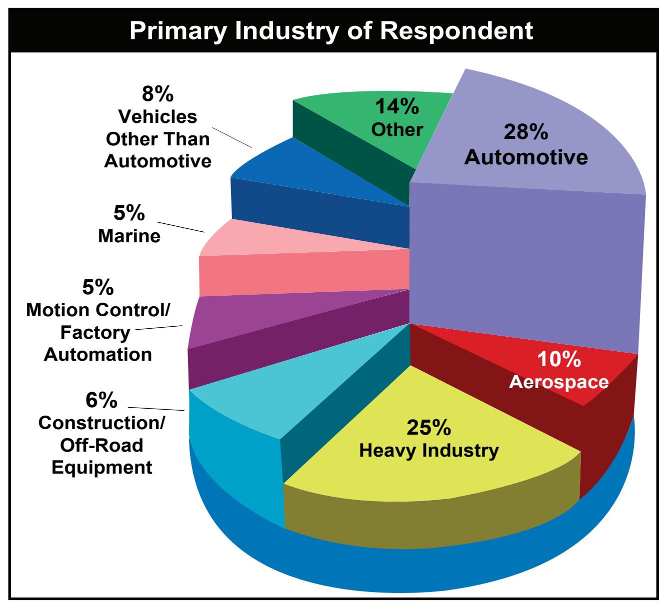


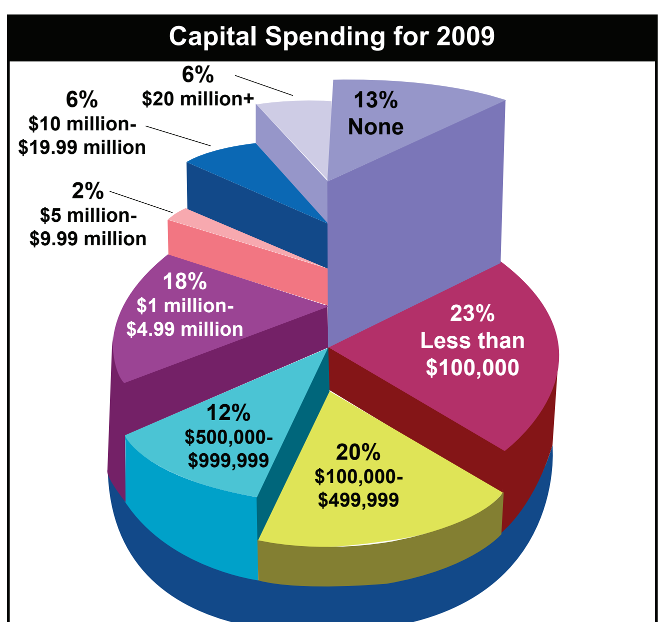
What are Your Company's Greatest Manufacturing/Engineering Challenges for 2010?

"Gaining new customers in a significant down market."
—Corporate executive at a U.S. manufacturer of loose gearing

"Global presence."
—Purchasing manager at a manufacturer of tractors in India

"Improving efficiencies and improving throughput with existing resources."
—Corporate executive at a U.S. manufacturer of open gearing





"Improving efficiency of our products through improved manufacturing practices and tighter tolerances."
—Quality engineer at a U.S. manufacturer of compressors

"Improving productivity and ability to produce more variants in the same production line."
—Design engineer at a manufacturer of agricultural tractors in India

"Increase business with new customers."
—Manufacturing engineer at a U.S. gear manufacturing job shop

"Integration of the global workforce."
—Design engineer at a U.S. manufacturer of gas turbines

"Keeping the place going."
—Employee at a gear manufacturing job shop in Canada

"Launch several new lines and projects while maintaining profitability."
—Manufacturing engineer at a U.S. manufacturer of rack and pinion steering components

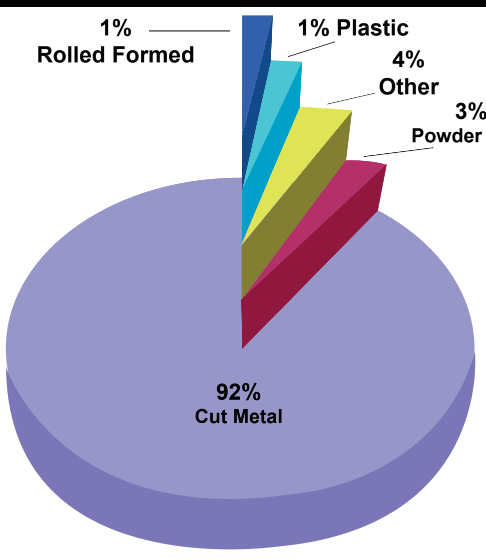
"Lead times."
—Corporate executive at a U.S. sales office

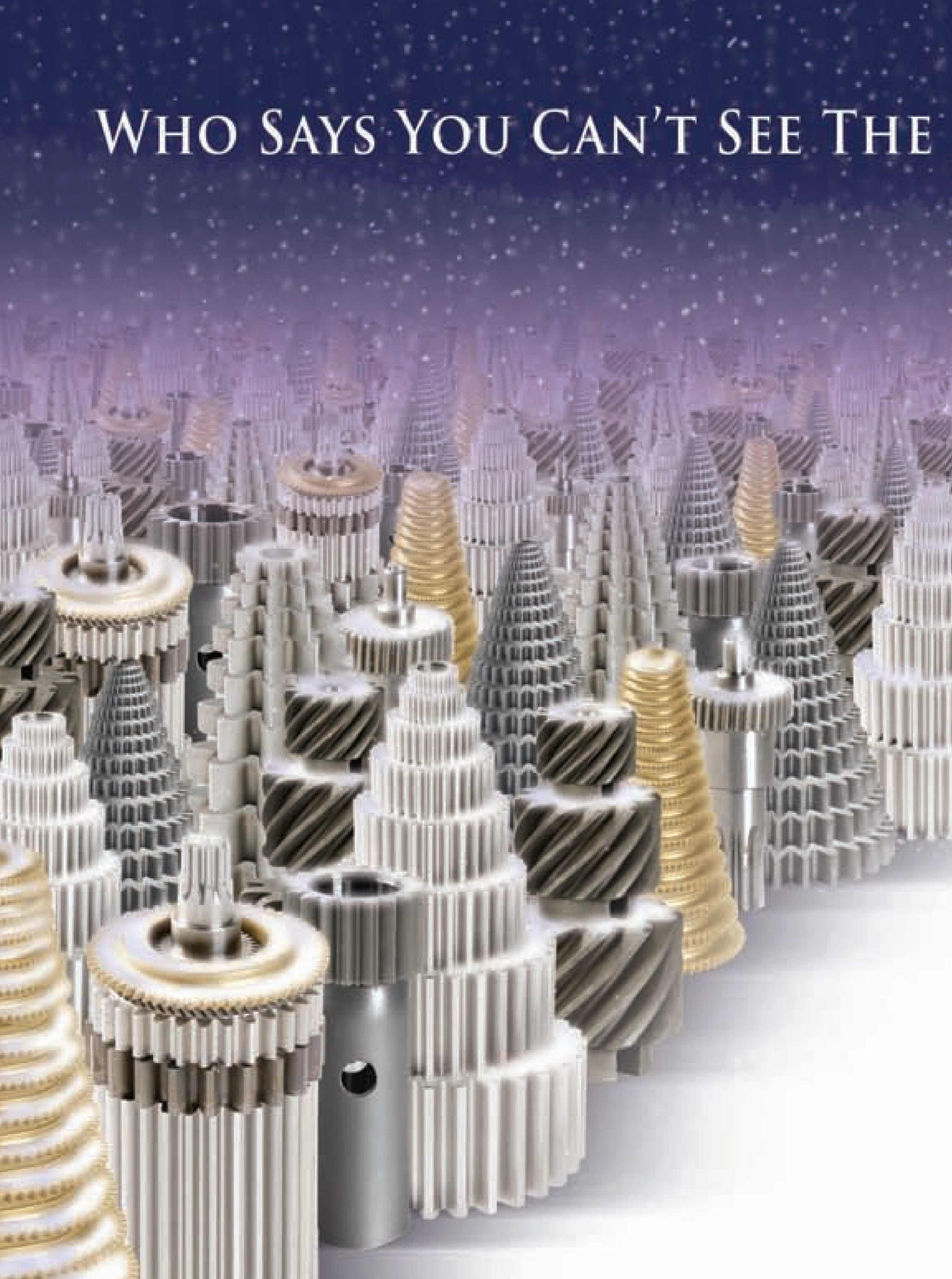
"Locating new aerospace engineers."
—Corporate executive at a U.S. aerospace gear manufacturer

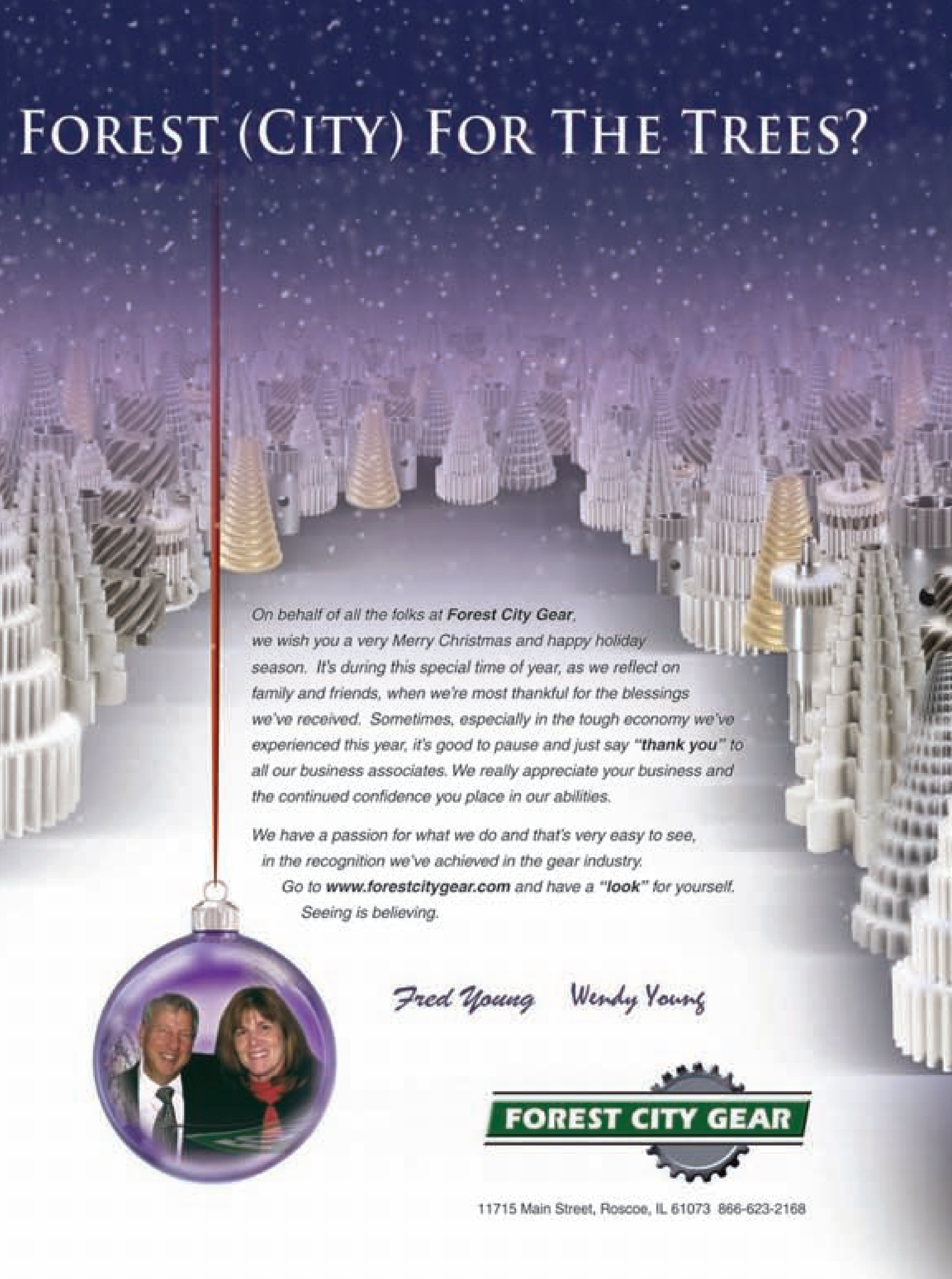
"Low cost."
—Design engineer at a manufacturer of linear actuators in Taiwan

"Maintaining and/or improving the current workforce in terms of abilities."
—Corporate executive at a U.S. manufacturer of gear assemblies

Primary Method of Manufacture




WHO SAYS YOU CAN'T SEE THE


FOREST (CITY) FOR THE TREES?
On behalf of all the folks at **Forest City Gear**, we wish you a very Merry Christmas and happy holiday season. It's during this special time of year, as we reflect on family and friends, when we're most thankful for the blessings we've received. Sometimes, especially in the tough economy we've experienced this year, it's good to pause and just say **"thank you"** to all our business associates. We really appreciate your business and the continued confidence you place in our abilities.
We have a passion for what we do and that's very easy to see, in the recognition we've achieved in the gear industry. Go to **www.forestcitygear.com** and have a **"look"** for yourself. Seeing is believing.
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The Effect of Flexible Components on the Durability, Whine, Rattle and Efficiency of an Automotive Transaxle Geartrain System

Amol Korde and Brian K. Wilson

Management Summary

Gear engineers have long recognized the importance of considering system factors when analyzing a single pair of gears in mesh. These factors include important considerations such as load sharing in multi-mesh geartrains and bearing clearances, in addition to the effects of flexible components such as housings, gear blanks, shafts and carriers for planetary geartrains. However, in recent years, transmission systems have become increasingly complex—with higher numbers of gears and components—while the quality requirements and expectations in terms of durability, gear whine, rattle and efficiency have increased accordingly. With increased complexity and quality requirements, a gear engineer must use advanced system design tools to ensure a robust geartrain is delivered on time, meeting all attribute, cost and weight requirements. As a standard practice, finite element models have traditionally been used for analyzing transmission system deflections, but this modeling environment does not always include provisions for analysis of rattle and efficiency, nor considerations for attribute variation, which often require many runs to be completed in a short timeframe. An advanced software tool is available for the analysis of transmission system durability, whine, rattle and efficiency—all within a single programming environment, including the effects of flexible components such as housings, gear blanks and shafting. An example transaxle case study is examined here in detail.

Introduction

Throughout the gearing industry, the natural progression of higher consumer expectations requires that gear design engineers be tasked with creating quieter, more durable and efficient designs while at the same time reducing costs and development time. Previous accepted practices of optimizing a gear pair independently of the intended application or "system," performing expensive and time consuming durability and noise/vibration testing of system prototypes, then adjusting the gear designs accordingly before repeating the testing cycle, is quickly becoming impractical and unaffordable. Companies simply do not have the resources, especially during an economic downturn, to rely on prototype testing to drive the geartrain design. Testing should only be utilized as a final verification of a design optimized using various statistical methodologies in conjunction with state-of-the-art geartrain system computer-aided engineering (CAE) analysis tools (Refs. 1–2).

These advanced CAE tools have been shown to allow for prediction of the system gear whine performance of a complex automatic transmission used in an automotive application (Refs. 3–4). The predictions included static transmission error of a planetary gearset accounting for the effects of time-varying factors, such as load sharing and carrier deflections, mode shapes and natural frequencies, absolute levels of vibration due to the gear mesh forces and manufacturing variation due to microgeometry variation.

Additional studies using the advanced geartrain system CAE tools included analysis of the high-mileage gear whine performance of an automatic transmission, as well as microgeometry inspection methods used to accurately represent the actual planetary gearset hardware (Ref. 5). Predictions of high mileage performance are important to several industries for varying reasons: for automotive applications, the residual value of previously owned vehicles can be negatively affected by the presence of passenger compartment gear whine, even if the noise itself is not indicative of an impending gear failure; for aerospace applications, the rate of gear wear due to geartrain system effects can be critical to designing a robust gearset beyond just following basic gear standards.

Further studies using the same geartrain system CAE tools have shown the importance of including representative boundary conditions, such as the driveline downstream inertia and gearbox housing loads, and the resulting effect on noise, vibration and durability predictions (Ref. 6). Clearly, the flexible housing containing the geartrain was a critical component, enabling the correct mesh misalignment to be predicted as part of the total system; therefore, allowing a more robust non-linear gear contact study to be performed. Additional investigations also showed that the downstream effects of the durability rig (inertia, dynamics) can inadvertently affect the outcome of the durability testing itself when compared to how the geartrain would perform in the actual vehicle. The study demonstrated that durability rig testing—without proper analysis—may provide an incorrect indication of actual durability performance, possibly leading to unexpected failures in the field. An issue not clearly demonstrated for geartrain systems such as transmissions and transaxles used in various industrial applications is the need for including flexible components as part of the system analysis, specifically for analysis of performance attributes such as gear durability, whine, rattle and total system efficiency with predictions for individual component efficiency contributions. For transmissions with rigid housings, explicitly designed to not deflect significantly even under high geartrain loads, perhaps the flexibility of the housing is not so critical for making accurate gear mesh misalignment predictions, for instance. However, for applications where the gearbox housing is optimized for weight using materials such as aluminum and magnesium with thin-walled designs, housing flexibility becomes exceedingly important when analyzing geartrain deflections—not only for high loads, but across a wide range of loading conditions as well.

This paper will investigate the housing flexibility issue using a generic manual transaxle used in an automotive application as an example. The transaxle was modeled using the advanced CAE tool previously referenced (Refs. 1–6), both with and without the housing, as shown in Figure 1. All gear, bearing and shafting details were the same, except that the outer bearing race connections to the condensed finite element model of the housing were set to ground for the configuration without the housing. Therefore, the differences

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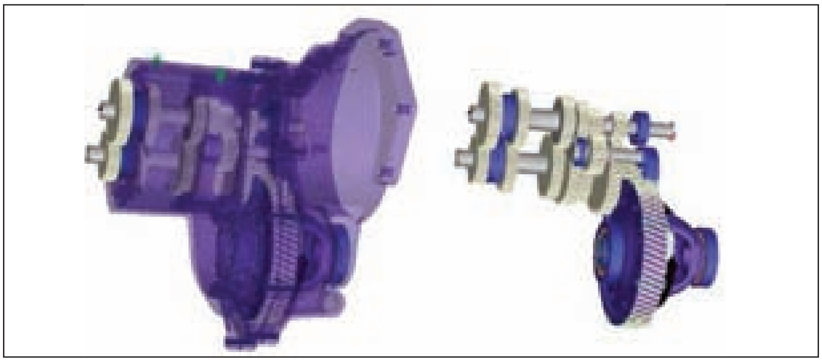

Figure 1—Advanced CAE transaxle system model, with and without the housing.

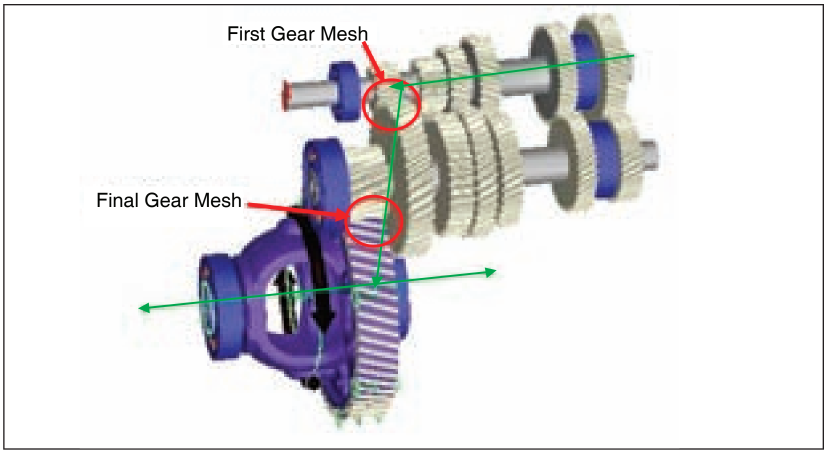

Figure 2—First gear power flow (green) and mesh locations (red) for transaxle system model.

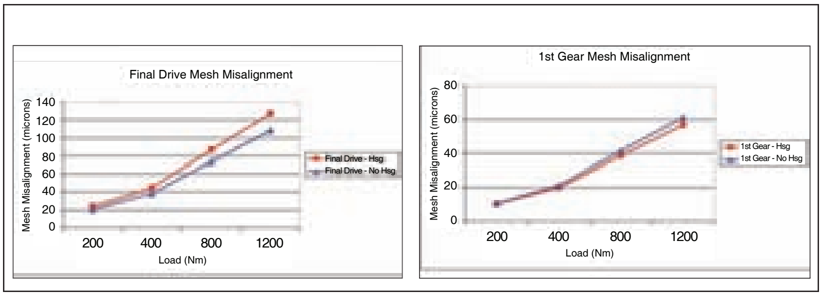

Figure 3—First gear and final drive mesh misalignment predictions, with and without the housing, various loads.

Table 1—Misalignment contribution analysis, with and without the housing, final drive mesh, 1,200 Nm.		
1st Speed	Hsg	No Hsg
Final Drive Pinion → Final Drive Wheel Gear Mesh	**-127.05**	**-108.04**
Final Drive Wheel	**-24.29**	**-7.92**
Gear	0	0
Gear Bearing Outer	0	0
Gear Bearing Inner	0	0
Support Shaft	8.32	6.25
Bearing Inner	0.68373	1.68
Bearing Outer (Hsg)	-33.3	0
Final Drive Pinion	**-102.76**	**-115.96**
Gear	0.87111	0.82193
Gear Bearing Outer	0	0
Gear Bearing Inner	0	0
Support Shaft	-117.37	-117.12
Bearing Inner	0.31704	0.33041
Bearing Outer (Hsg)	13.42	0

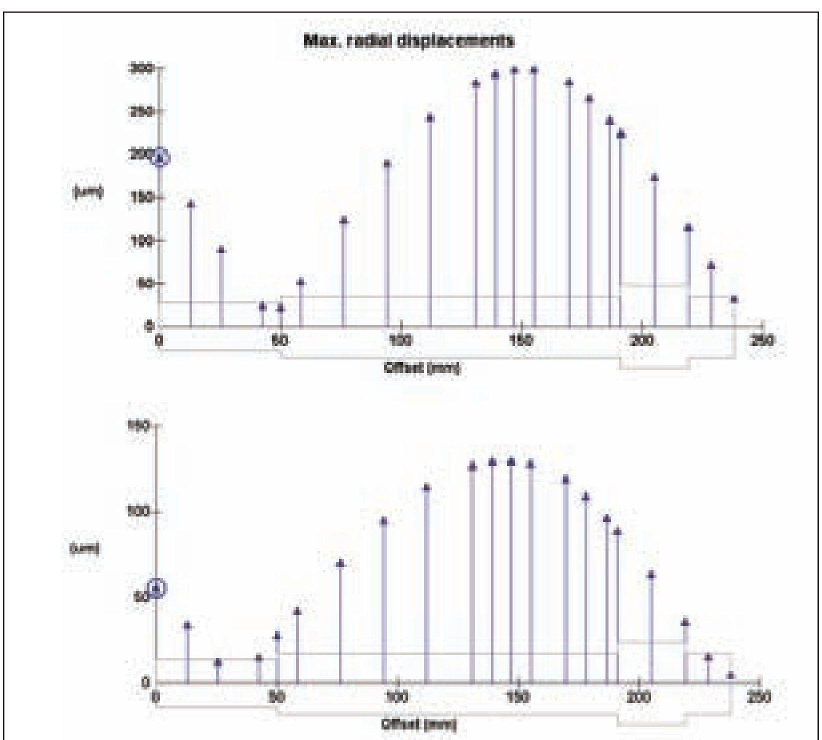

Figure 4—Lay shaft deflections, 1200 Nm, with (top) and without (bottom) the housing.

between the performance attributes analyzed and presented below represent the effect of the housing. Additional capabilities inherent to the inclusion of the housing as part of the geartrain system analysis will also be demonstrated.

Mesh Misalignment

For the purposes of the mesh misalignment investigation, the aforementioned transaxle was analyzed with the power flow of the system set through first gear only, predicting the alignment effects at the first gear and final drive mesh locations, as indicated in Figure 2.

The geartrain was subjected to loading conditions covering light to heavy throttle in an automotive application, both with and without the housing. The resulting mesh misalignments were predicted using calculations encompassing the fully coupled, six-degree-of-freedom system model for each configuration. The mesh misalignment predictions are shown in Figure 3. A more detailed analysis of the 1,200 Nm load case shows the contribution to the mesh misalignment from individual components and the associated clearances and deflections for each configuration as shown in Table 1.

The importance of including the flexible housing as part of a fully coupled transaxle system in the mesh misalignment predictions can therefore be substantiated analytically, providing opportunities to manage undesirable misalignment as a system, rather than immediately assuming options are either microgeometry modifications, such as crowning, or housing stiffness actions, such as adding ribs. Perhaps changing the shaft material properties or dimensions would be a more feasible and effective solution, or perhaps a combination of all approaches. Figure 4 shows the lay-shaft deflections, for example, with and without the housing influence at 1,200 Nm, demonstrating a substantially lower deflection of the shaft with the bearings set to ground. Using statistical methods such as Design of Experiments (Refs. 1–2), the mesh misalignment can be managed objectively.

Transmission Error and Contact Patterns

The foundation of a successful non-linear gear mesh contact analysis is to fully understand and quantify the relative positions of the two meshing gears (Ref. 7). Determining the housing influence on the misalignment predictions is therefore a prerequisite for accurately predicting static transmission error and the load distribution throughout a tooth mesh cycle. For the theoretical gears used in this investigation, five microns of lead crowning and involute barreling were added to both the first gear and final drive gear pairs in order to avoid some level of edge loading over the wide range of geartrain torques applied. No other significant microgeometry modifications were used in the analysis.

Table 2 lists the peak-peak static transmission predictions, as well as the first three harmonics for the 400 Nm load case of the previous misalignment study, with and without the housing influence. From a system dynamics standpoint, clearly the housing is needed in order to follow any quality function deployment (QFD) process for gear whine. This is accomplished by factoring in the customer requirements cascaded to vibration targets at a system housing location (the QFD process for gear whine is clearly outlined in Ref. 1), then proceeding to cascade to the subsystem, and finally to the component level. A QFD example for gear whine is given in Figure 5.

An example of predicted housing vibration due to the first gear mesh order, the "system" part of the QFD process, exerted to 400 Nm of output load, is shown in Figure 6.

Without the housing, a gear designer will typically attempt to minimize the transmission error without factoring in details of the system influence under all design loads, which includes the "path" between the mesh excitation creating forces and related vibration along the shafting, through the bearings, thus forcing the housing to vibrate at the mesh frequency. However, without the appropriate boundary conditions, including the housing influence, the source optimization process (e.g., static transmission error) cannot be properly implemented without some level of risk. Even the geartrain "subsystem" dynamics cannot be confidently evaluated, either in terms of amplitude or frequency content, without the effects of the gearbox housing influence as evidenced by the dynamic transmission error predictions shown in Figure 7.

Furthermore, including the housing effects in the transaxle system analysis allows examination of various mode shapes that could potentially negatively affect the housing vibration. Presenting in terms of displacement, strain and kinetic energies allows the entire transaxle design team to work together in order to find a solution to desensitize the transaxle to

continued

Table 2—Static transmission error: peak-peak, harmonics and percentage difference, final drive—with and without the housing.

	Final Drive, Hsg	Final Drive, No Hsg	Final Drive, % Diff
TE (pk-pk)	2.93	2.45	20
TE (1st harmonic)	1.44	1.21	19
TE (2nd harmonic)	0.1	0.07	43
TE (3rd harmonic)	0.07	0.01	600

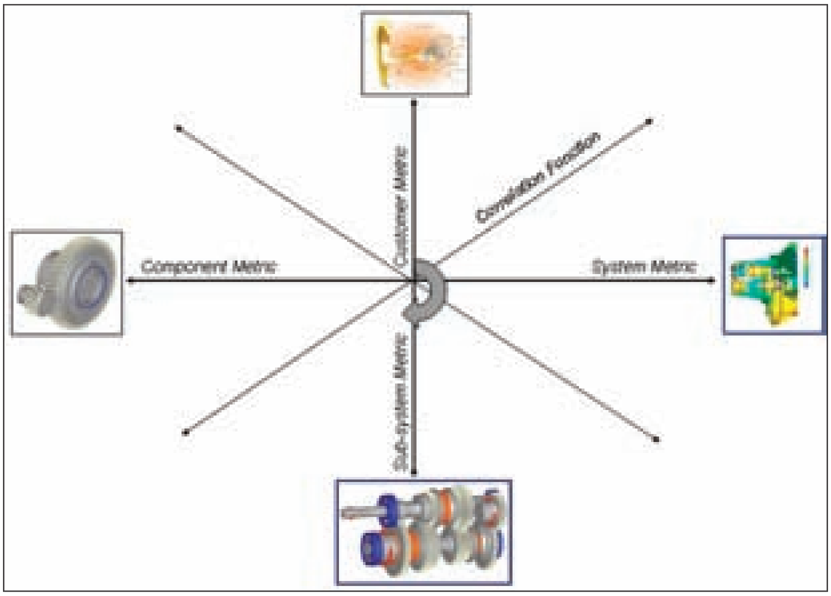

Figure 5—Quality function deployment (QFD) plot for management of system gear whine.

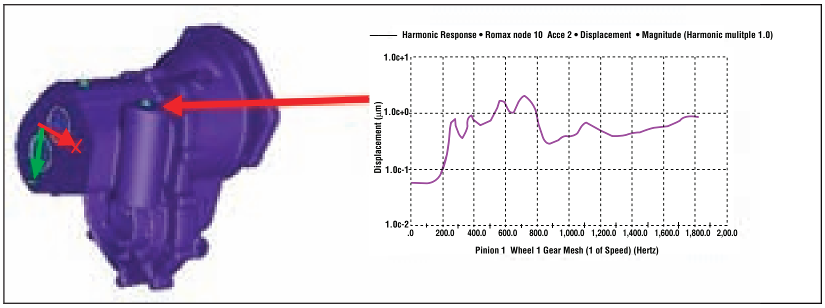

Figure 6—Predicted housing vibration due to gear mesh vibration, 400 Nm.

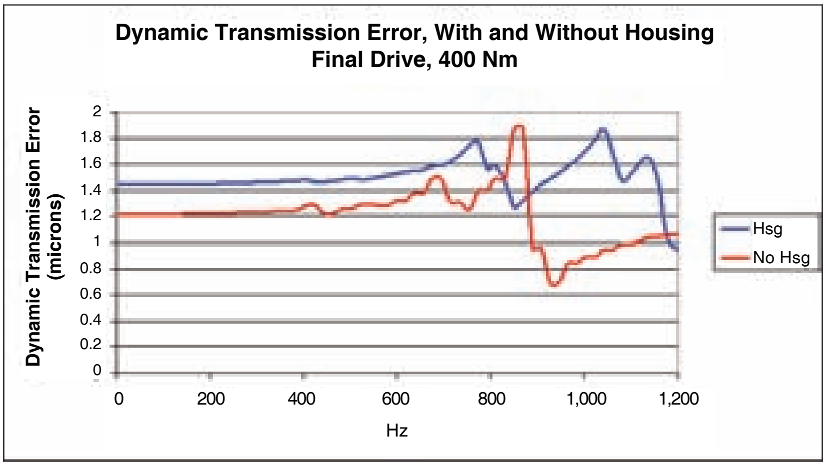

Figure 7—Dynamic transmission error—first harmonic, final drive, 400 Nm—with and without the housing.

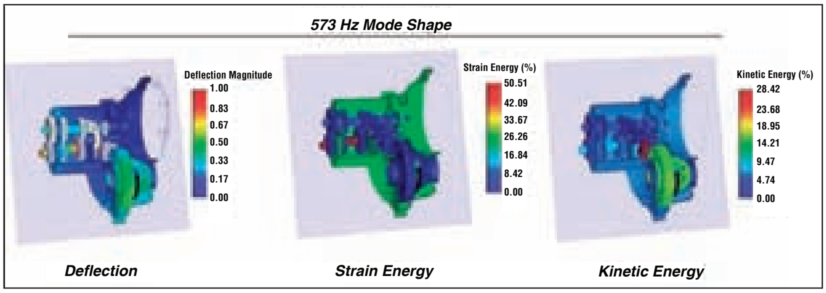

Figure 8—CAE model of transaxle, 573 Hz mode—displacement, strain energy and kinetic energy—includes housing influence.

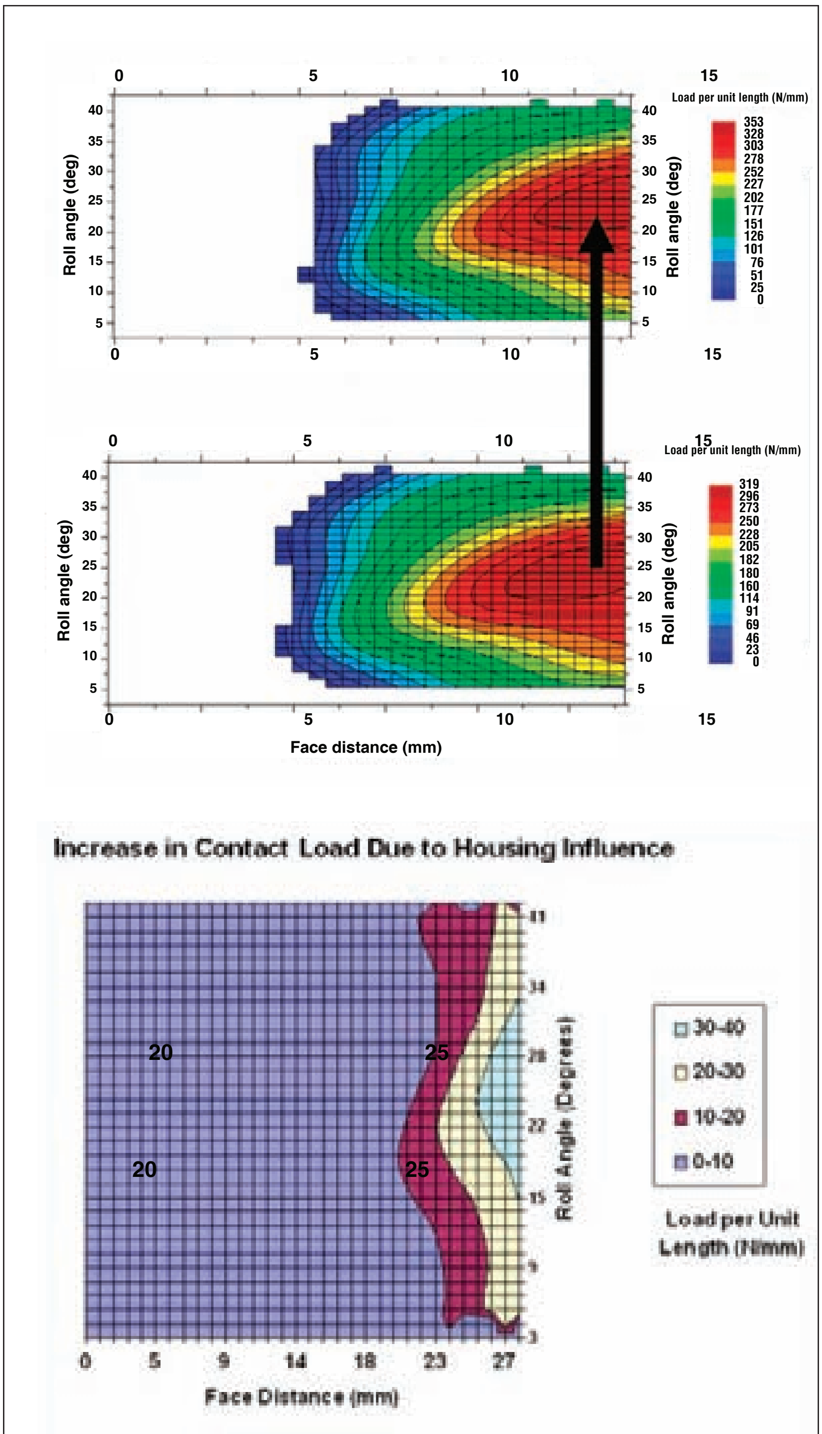

Figure 9—Contact patterns, final drive gear mesh, 400 Nm, with (top) and without (bottom) housing.

the inherent static transmission error excitations (the transfer functions in the lower QFD quadrants). An example of such a CAE analysis is shown in Figure 8.

In order to optimize the load distribution, reviewing static transmission error values is of course not sufficient. Standard practice is to review load distribution plots for a complete tooth mesh cycle. Again, the effect of the housing influence is evident by comparison of the plots in Figure 9, showing the load distribution for the final drive gear mesh for both configurations, exerted to 400 Nm half-shaft torque. With the flexibilities of the housing, the final drive gearset is demonstrating slightly more edge loading and a higher load-per-unit length than when considering bearings restrained to ground using fully coupled six-degree-of-freedom calculations for both instances.

The implications of an incorrect contact pattern analysis may result in the specification of unnecessary or overaggressive microgeometry modifications—especially for higher loads—as the difference in mesh misalignment between housing/no-housing configurations increases, as previously shown in Figure 3. As the gears are modified to accommodate higher loads, often the contact at lighter loads is compromised, resulting in increased static transmission error and subsequently higher levels of passenger compartment gear whine.

Durability

Traditionally, durability performance is the gear designer's first priority, and since this irrefutable, self-evident requirement has been in place for so many years, with an abundant effort by thousands of engineers and researchers worldwide for more than 100 years, it can be perplexing that gear failures are still all too common of an occurrence. The practical issue facing gearbox design engineers is that the gearbox performance requirements seem to constantly push the design technology. For example, within a few short years, the automatic transmission used in automotive applications has increased from various four-speed combinations to eight speeds and beyond. Since most major transmission OEMs produce durable products, many with warranties up to 100,000 miles, the other performance attributes have become the true differentiators, putting durability design activities in direct competition with noise and efficiency efforts. Using traditional methods of optimizing for durability first, followed by a secondary effort for noise and efficiency, is no longer feasible for some industrial applications, such as automotive. For others, such as aerospace, durability will remain the primary concern, but even in this industry, noise and efficiency are becoming more prevalent.

The cornerstone to any geartrain durability analysis, whether performed using advanced CAE system tools or on a test rig, is the development of representative duty cycles to accelerate the extremes of the wear expected in the field. Duty cycles will vary by application, industry and company, using both experience-based and statistical-based tools to develop the most efficient approach. For this investigation, the duty cycle used on the generic manual transaxle being studied was developed based on previous experience, but it is not intended to be fully correlated to the actual hardware used by the customer, since this transaxle is only a derivative of an actual transaxle. But for illustration purposes, the same model used for the misalignment and vibration studies was used for the durability study in the same programming environment, both with and without the effects of the housing influence. The results are shown in Table 3.

Table 3—Durability results, first gear and final drive, with and without housing.

	Hsg Combined Contact/Bending Life (hrs)	No Hsg Combined Contact/Bending Life, hrs
Wheel 1	3.5	4.1
Pinion 1	1.0	1.2
Final Drive Wheel	173.6	323.1
Final Drive Pinion	42.7	79.5

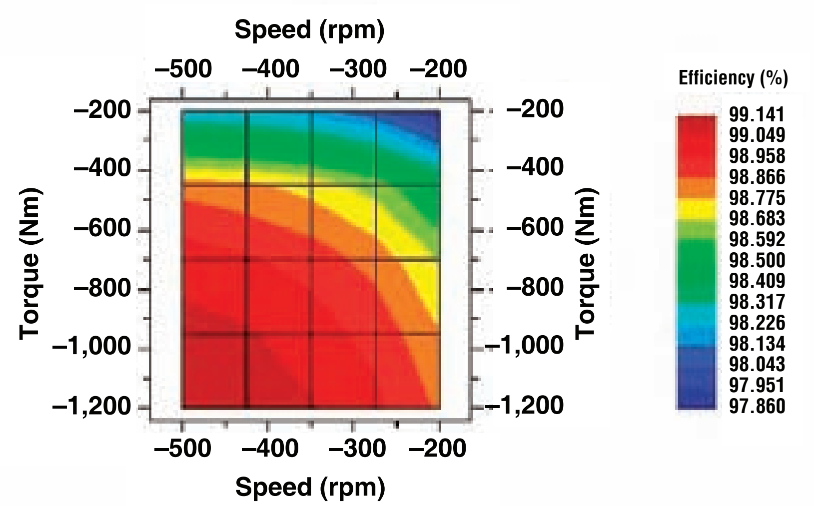

Figure 10—Efficiency map.

Table 4—Efficiency result examples: total system, first gear and final drive. Total efficiency = 98.60%.

	Watts
Total Gearbox Losses	183.4
1st Gear Mesh	50.7
Final Drive Mesh	59.5
Input Shaft Left Brg.	25.4

The substantial difference between the two durability life predictions for the final drive mesh can be directly attributed to the flexibilities of the housing as part of the transaxle system, as previously explained. For this reason, the gear design engineers and the transaxle system engineers should work together to ensure any geartrain durability analysis includes provisions for the entire system.

Oftentimes, the complete transaxle design—including the housing—is not finished by the time the geartrain design requirements are needed to satisfy production and manufacturing timelines. With compressed timing on the delivery of new transaxle designs in the automotive environment, for example, it is not unusual for the manufacturing plants to order the gear tooling and determine the final production manufacturing processes before the first prototype has been tested. In situations like this, which are unfortunately becoming more common, the need for a CAE-based transaxle system design tool for durability analysis—and for all attributes for that matter—becomes even more prevalent.

Efficiency

Conservation of energy and concern for the environment have become a central area of worldwide focus in recent years. Geartrain technology plays an integral role in helping world communities succeed in the goals being established. For example, gearboxes can contribute to reducing greenhouse emissions through helping make automotive powertrains more fuel-efficient by mechanically coupling wind energy to electric generators—thus reducing the need for new coal burning plants—and by being used in propulsion vehicles used for public transportation. Also, more fuel-efficient powertrains require less fuel, reducing consumer fuel costs and thereby increasing vehicle residual values.

Efficiency calculations were performed using the ISO 14179-2 (US) standard for gear and bearing drag on both geartrain configurations, with and without the housing influence. Options for

continued

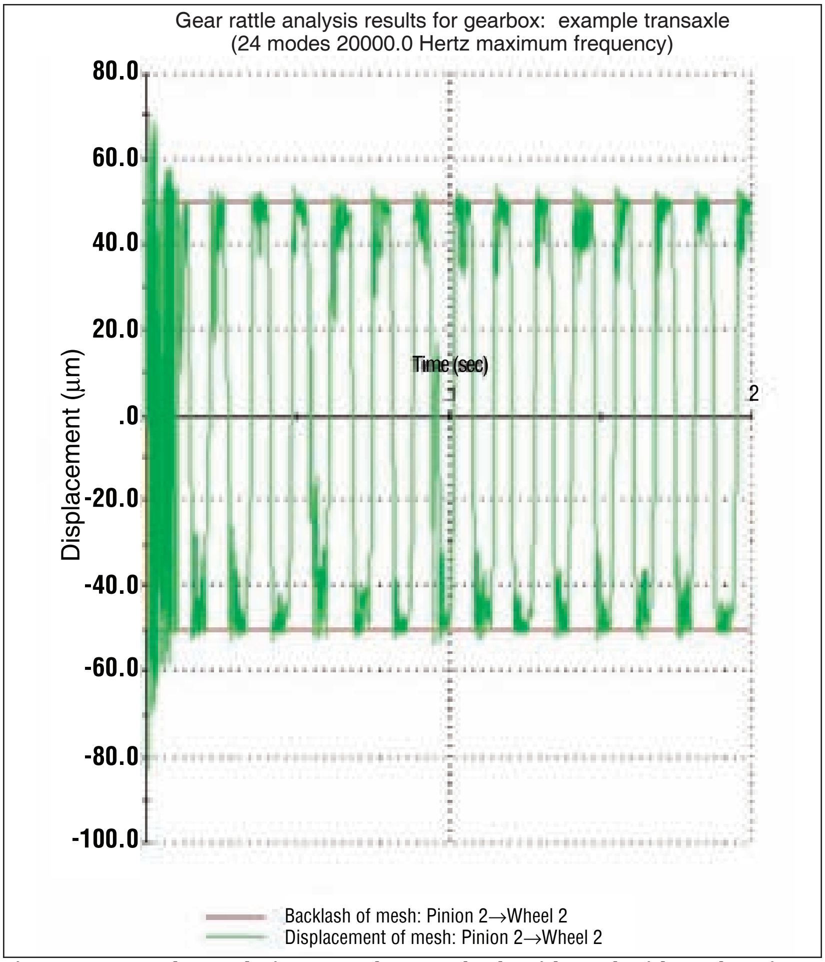

Figure 11—Rattle analysis, second gear—both with and without housing—demonstrated a similar trend (with housing is shown).

including the oil fill level were also included, even though this would of course not be possible without the housing in actual hardware evaluations. However, since the standard does not use the microgeometry for the calculation, no change was predicted, as expected. Table 4 shows an example of numerical results for 400 Nm. Figure 10 shows an efficiency speed/torque map.

While the equations do not show any differences between configurations, in reality, slight differences could be attributed again to the mesh misalignments and the bearing loading induced by the effects of the housing flexibility. Essentially, the efficiency can be predicted not just for the entire transaxle system but also for individual component contributions, allowing the transaxle design engineer to objectively quantify design iterations, such as when changing gear designs, oil viscosity, bearing, etc. However, it stands to reason that the housing influence should eventually be factored into the calculations in order to predict results reflective of the actual hardware behavior, which is due to mesh losses caused by misalignment-induced contact variations, compared to conditions with little misalignment (Ref. 7).

Rattle

Traditional methods for dealing with a geartrain rattle issue were to build prototype transmissions, transaxles and engine gear accessory drives following standard practices for such designs, test the prototypes and then subjectively evaluate various operating conditions for any objectionable rattle. If a rattle condition were discovered, usually at a substantially late date after the geartrain design has long been finalized, and production is fast approaching, the development engineer will resort to swapping parts one at time, hoping to alleviate the rattle issue. For manual transmissions and transaxles, this usually means tuning the damper springs. For engine accessory drives and "live" power take-off units, the challenge can be more substantial, often looking for a combination of effects, such as increasing bearing and gear drag, adding inertia to the system at strategic locations, changing gear backlash values and, if all else fails, adding scissor gears. Quite often, these design actions pose a risk to gear whine, efficiency and durability.

To help estimate the potential effectiveness of any proposed design actions, the CAE team would be asked to build a simple torsional degrees-of-freedom model to investigate the different combinations. For light loads, this is usually sufficient since smaller geartrain deflections are occurring, containing the issue to the geartrain subsystem (gears, shafts and bearings, modeled as lumped masses and inertias) (Ref. 8). For medium-to- heavy loads, where housing deflections may be a possibility, bearing stiffness and drag values change proportionately to the load, and clearances change accordingly; rattle may also occur. For this case, the housing influence may play a role, and it needs to be accounted for.

Figure 11 shows a rattle analysis for the first gear power flow, examining the non-loaded second gear pair for single-sided or double-sided rattle for both the housing and no-housing configurations. While a few subtle differences were noted (rms power, frequency of impacts), both configurations demonstrated similar double-sided impact behavior.

The rattle model was based directly on the same full-system transaxle model used for whine, durability and efficiency, allowing multi-attribute studies to be performed in the same programming environment, reducing development time, allowing the performance of statistical studies such as Monte Carlo for manufacturing variability and Design of Experiments for optimization, thereby improving accuracy.

Conclusions

As geartrain architectures continue to become more complex, with more stringent requirements for performance attributes, development time and costs, geartrain system CAE tools will also continue to evolve to meet these demands. This investigation has shown that in order to optimize the gear components for durability, efficiency, gear whine and rattle, the geartrain must be analyzed as part of the total transaxle system, and in some cases, including the effects of housing influence. Without the housing flexibility factored into the design process, the gear designer runs the risk of:
1. Incorrectly predicting the geartrain durability performance; 2. Incorrectly predicting static transmission error; 3. Not properly optimizing the efficiency factoring in microgeometry. And for high-load operating conditions: 4. Incorrectly predicting rattle performance. Current state-of-the-art CAE tools and research results are available to help the gear design engineer reduce these potential risks.

Acknowledgments

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Hypoloid Gears with Small Shaft Angles and Zero-to-Large Offsets

Dr. Hermann J. Stadtfeld

Management Summary

Beveloid gears are used to accommodate a small shaft angle. The manufacturing technology used for beveloid gearing is a special setup of cylindrical gear cutting and grinding machines. A new development, the so-called Hypoloid gearing, addresses the desire of gear manufacturers for more freedoms. Hypoloid gear sets can realize shaft angles between zero and 20° and at the same time, allow a second shaft angle (or an offset) in space that provides the freedom to connect two points in space. The first application of Hypoloids is found in all-wheel-drive vehicles. Because of their unique geometry, Hypoloids can be used to connect the transfer case to the front axle without the use of CV joints, allowing for greater efficiency, reduced NVH characteristics and tighter packaging. The Hypoloid technology does not apply only to automotive drive trains. Its advantages apply also to aircraft as well as general gearbox manufacturing.

Introduction

If two shafts are neither parallel nor perpendicular, but include a small angle in the plane that is defined by the axis of rotation, then two possible gearing solutions are known to accomplish a motion transmission.

One possible solution is called beveloids. Beveloids are manufactured like cylindrical gears using, for example, a hobbing process for soft manufacturing and a threaded-wheel grinding for hard finishing. Shaft angles between 0° and 15° can be realized according to the beveloid method—which results, depending on the ratio—in gear pitch angles between 0° and 7.5°. Or, in case of the combination of one conical gear with one conventional cylindrical gear, the maximal required pitch angle might be as high as 15° (Refs. 1–2).

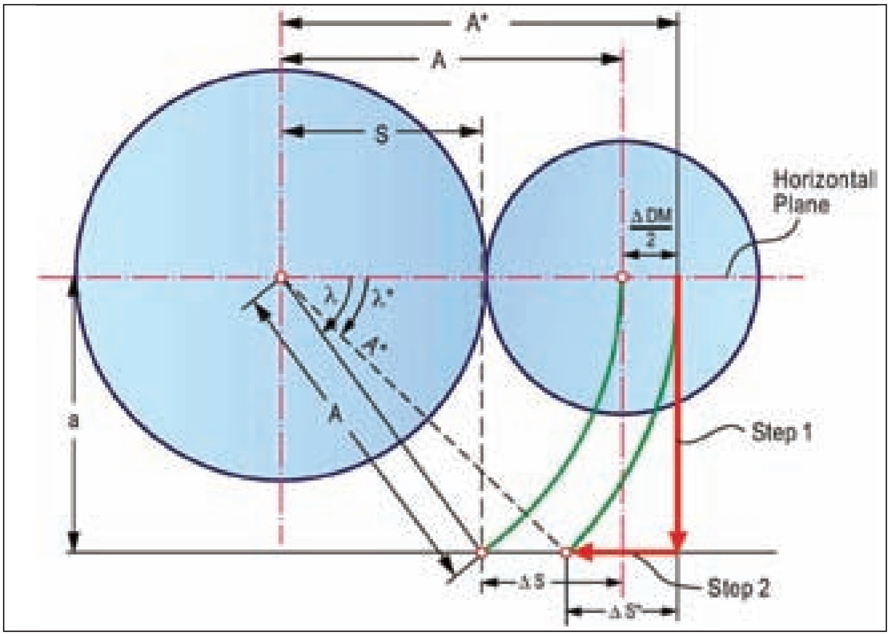

Figure 1—Pinion offset position (see ANSI/AGMA/ISO 23509-A08).

The second possibility is the application of angular spiral bevel gears. The ratio in most real applications is close to miter, which results in pitch angles between 0° and 7.5°.

The described gearsets are generally used in automotive transfer cases to transmit rotation and torque from the output shaft of a transmission to the front axle of an all-wheel-drive vehicle.

The mechanical function of both tapered cylindrical gears (beveloids) and spiral bevel gears is to provide an angle between the shafts in the plane that their two axes define. In most cases concerning all-wheel-drive vehicles, this will still require two constant velocity joints or two universal joints (one on each end of the drive shaft) in order to connect the output shaft of the gearbox with the input shaft of the front axle, which commonly have different vertical locations.

In order to connect two points in space, as in the case of a propeller shaft between the output of a transfer case and a front axle input, it is necessary to provide one angle and a linear offset or two angles in perpendicular planes. Hypoid gears represent such a general valid solution of input/output shaft orientation in three-dimensional space. However, the features of today's hypoid gear designs do not cover the case of low shaft angle and high offset. The different hypoid theories applied today do not even allow gear engineers to design low shaft angle gears with any offset. The common hypoid theories rely on a flat or conical generating gear as the basis for basic setting and tool parameter calculation (Ref. 3). Shaft angles close to and including 90°—combined with ratios of 2.5 and higher—lead to gear pitch cone angles of 68° and higher and pinion pitch cone angles of 22° and lower. This leads to a typical ring gear whose cone is close to a plane, with a tangent plane to the pitch cone, which is close enough to the pitch cone in the neighborhood of the contacting line. This allows application of certain amounts of hypoid offset, derived in the pitch cone tangent plane in the traditional hypoid theory. But the traditional theory fails in cases of high hypoid offsets (close or equal to half the ring gear diameter). The traditional hypoid theory also fails in cases of low ratio (close to 1.0). In cases of high ratios, worm gear drives can be used to realize a 90° shaft angle and an offset of half the gear diameter, plus half the worm diameter (like center distance in cylindrical gearing). In the case of low ratios, crossed helical gears can be used to achieve any desired shaft angle combined with an offset equal to the center distance of those crossed helical gears.

The freedom of any small shaft angle (e.g., 0° to 20°) combined with any offset between zero and the sum of half the mean pitch diameters of the two members will, for the first time, be possible by applying the Hypoloid system.

The Basics of Hypoloids

The generating principle is applied between the driving pinion and the driven gear. Although, in most cases, pinion and gear might have the same number of teeth, the gear is used as a generating gear. The new method even goes one step further and uses a non-generated gear with straight or curved tooth profile as generating gear for the pinion. In the bevel and hypoid gears, the non-generated principle is generally used only in cases when the ring gear pitch cone angle is 68° and higher. The Hypoloid method derives, in a first step, bevel gear machine basic settings for a non-generated gear member. Those settings are used to derive, in a second step, the basic settings for a bevel gear generator in order to manufacture the pinion. The cutter head for the pinion cutting (positioned by the basic settings and rotated around the cradle axis) represents one tooth of the non-generated gear member on which the pinion rolls during the generating roll process.

The principle of applying a non-generated gear member in order to generate the mating pinion is the only technique that delivers a precise conjugate relationship between pinion and gear, even if the axes of the two members are not in one plane. A conjugate basic geometry also requires the pitch cone to be parallel to the root cone. It has been observed that in the case of low shaft angle spiral bevel gear sets, the tooth depth was calculated to be taller at the toe (reverse tooth taper) in order to fulfill the requirements of completing (matching tooth thickness and opposite member slot width). One element of the Hypoloid geometry is a parallel-depth tooth design, which will lead to more optimal tooth proportions than a reverse taper, and also fulfill the requirement of parallelism between pitch line and root line. If the axes of the two members are in two parallel planes, the distance between the planes is defined as offset. In the case of conical pitch elements of the two members, this offset is commonly called hypoid offset.

One member is defined as a pinion (generated member) and one member is defined as a gear (non-generated member). In spite of the traditional definition, Hypoloid gears and pinions can have a similar number of teeth. It is even possible that the pinion has a higher number of teeth than the gear.

The conjugacy between the two members is only the basis for the generating principle. In order to make the gearset insensitive to tolerances in manufacturing and assembly, a located contact is achieved using flank surface crowning in the direction of the tooth profile, the lead and the path of contact.

If the non-generating process of the gear member is performed with straight cutting blades, then the generation of a pinion tooth will cause additional profile curvature versus an involute (or more precisely defined as spherical involute or octoid). The additional pinion profile curvature can cause undercut in the pinion root area and a pointed topland. To reduce the additional profile curvature in the generated pinion, it is possible to manufacture the non-generated gear teeth with curved blades. If the gear cutter blades are formed like the involute of a similar generated gear, then the pinion tooth profiles will be regular involutes without additional profile curvature, without additional undercut in the root area and with no pointed topland versus a standard profile. It is also possible to approximate the involute function of the gear blade profile with circular or parabolic shape functions. This will achieve a similar effect and reduce the complexity of blade grinding or grinding wheel dressing kinematics.

The adjustment of the offset is done in two steps starting from the spiral bevel non-generated gear design. The axis of the spiral bevel gear set lies in a horizontal plane (Fig. 1). The first step to offset the pinion relative to the gear is to move the pinion axis in a

continued

vertical direction. A positive offset for pinions with left-hand spiral direction means a down movement of the pinion if the view is directed onto the front of the pinion, and if the pinion is located to the right (gear to the left). The rule for positive offset is identical to hypoid gear sets. The amount of the down movement is identical to the amount of offset; however, this vertical movement would increase the center distance (e.g., at the center of the face width) as well as the diameter of the pinion (of the same amount as the center distance increase). In contrast to regular hypoid pinions where the diameter is also increased (in case of a positive offset), the diameter increase of the Hypoloid pinions would be larger than required to compensate for the increasing pinion spiral angle. This is the reason for the correction of the pinion diameter, which is accomplished by a second movement of the pinion axis in a horizontal plane towards the gear. The amount of this movement is determined such that the original center distance is re-established. A pinion diameter increase—because of the spiral angle increase due to the offset—is not required (and would lead to a small addendum modification), but it can be introduced in order to achieve a minimal impact of the hypoid offset onto the pinion profile.

Four-Step Approach to Develop the Blank Geometry

In order to present a possibility to optimize the generated pinion tooth profiles along the face width, a pinion diameter increase or reduction is proposed, which leads to a profile shift or addendum modification. The procedure used for this pinion diameter increase has to assure that the offset remains constant. This is achieved if center distance and offset angle are calculated as follows:

$$A = \frac{(m_2\ z_2 +\ m_2\ z_2)}{2} \qquad (1)$$

$$\lambda = \arcsin\left(\frac{a}{A}\right) \qquad (2)$$

$$A^* = \frac{A + \Delta DM}{2} = \frac{\left(m_2 z_2 +\ m_2 z_1 +\ \Delta Dm\right)}{2} \qquad (3)$$

$$\lambda^* = \arcsin\left(\frac{a}{A^*}\right) \qquad (4)$$

where

A is center distance, calculated like in case of cylindrical gears at center face width of conical gears;

λ is offset angle;

a is hypoid offset;

A* is center distance in case of pinion diameter increase;

ΔDM is pinion diameter increase;

m_2 is face module of gear;

z_1 is number of pinion teeth;

z_2 is number of gear teeth.

The horizontal movement in order to re-establish the pinion diameter is calculated:

$$\Delta s = A\,(1 - \cos\lambda\,) \qquad (5)$$

or in case of a pinion diameter increase:

$$\Delta s^* = A^*\ (1 - \cos\lambda^*) \qquad (6)$$

where

ΔS is horizontal movement of pinion axis toward gear axis;

ΔS^* is horizontal movement of pinion axis in case of a pinion diameter increase.

Initially, the pitch cone angles are calculated for spiral bevel gears using the following equation, solved with an iteration process:

$$\frac{\sin\delta_{2\text{-spiral}}}{\sin\delta_{1\text{-spiral}}} = \frac{z_2}{z_1} \qquad (7)$$

where

$\delta_{1\text{-spiral}}$ is pitch angle of spiral bevel pinion before introduction of offset;

$\delta_{2\text{-spiral}}$ is pitch angle of spiral bevel gear before introduction of offset.

The Hypoloid geometry takes into account that the offset will significantly change the cone angle of the pinion, rather than the spiral angle (as commonly expected in hypoid gears). In order to keep the cone angles of pinion and gear similar (to the spiral bevel gear design) and avoid exotic pinion tooth profiles—i.e., in the root fillet or undercut area—it is proposed to change the gear cone angles depending on the offset:

$$\delta_{2\text{-hypoid}} = \gamma_{gear-\ spiral}\cos(\lambda) \qquad (8)$$

or

$$\delta_{2\text{-hypoid}} = \gamma_{gear-\ spiral}\cos(\lambda^*) \qquad (9)$$

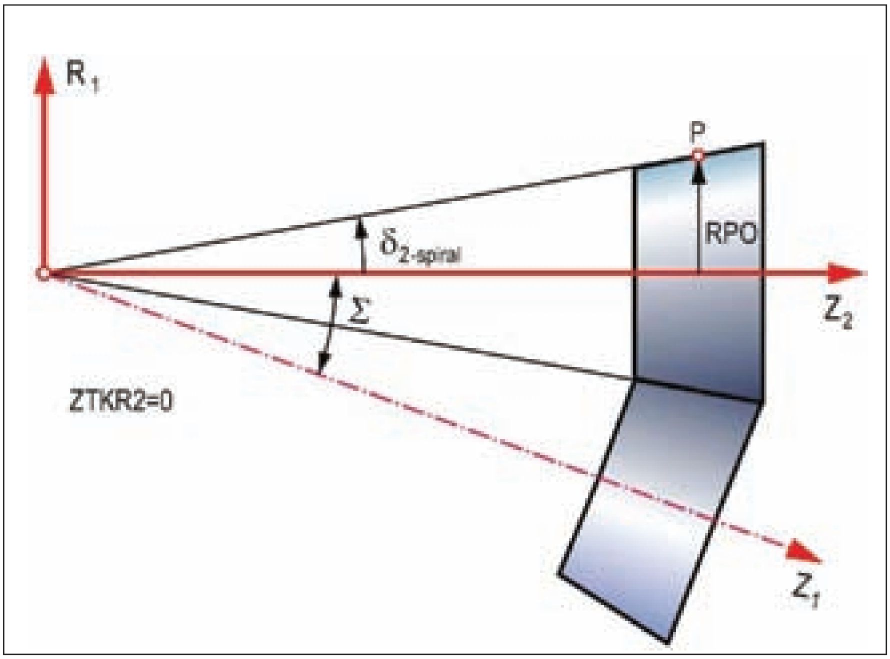

Figure 2—Spiral bevel gear cones.

where

$\delta_{2\text{-hypoid}}$ is pitch angle of hypoid gear set member.

Establishing the gear blank dimensions is explained in a four-step process:

1. The spiral bevel gear version has a pitch angle of $\delta_{2\text{-spiral}}$ and a distance crossing point to pitch cone (ZTKR2) of zero (Fig. 2).
2. In case of a pinion diameter increase ΔDM, the crossing point moves in negative z_2 axis direction and establishes a new coordinate system origin (Fig. 3):

$$ZTKR2^* = \frac{\Delta DM}{2} \quad (10)$$

$$ZTKR2^* = \frac{\Delta DM}{2 \sin \Sigma} \quad (11)$$

where

ZTKR2* is crossing point to pitch apex.

3. The changed pitch angle of the gear for a hypoid pair shifts the location of the pitch apex (while the pitch point P at the center of the face width remains unchanged) as shown in Figure 4. The value of ZTKR2** is negative, because the gear cone apex is now shifted in negative z_2 direction and lies left of the R_2 axis.

$$ZTKR2^{**} = \frac{\Delta DM}{2 \sin \Sigma} + \frac{RPO}{\tan \delta_{2\text{-spiral}}} - \frac{RPO}{\tan \delta_{2\text{-hypoid}}} \quad (12)$$

$$\delta_{2\text{-hypoid}} = \delta_{2\text{-spiral}} \cos \lambda^* \quad (13)$$

4. The horizontal movement (Fig. 1) of ΔS (or ΔS^*) will move the pinion axis in case of positive ΔS values toward the gear axis, and move the crossing point in positive Z-axis direction by $\Delta S/\sin(\Sigma)$, which will establish the final distance crossing point to pitch apex (Fig. 5). The value of ZTKR2*** is negative because the gear cone apex

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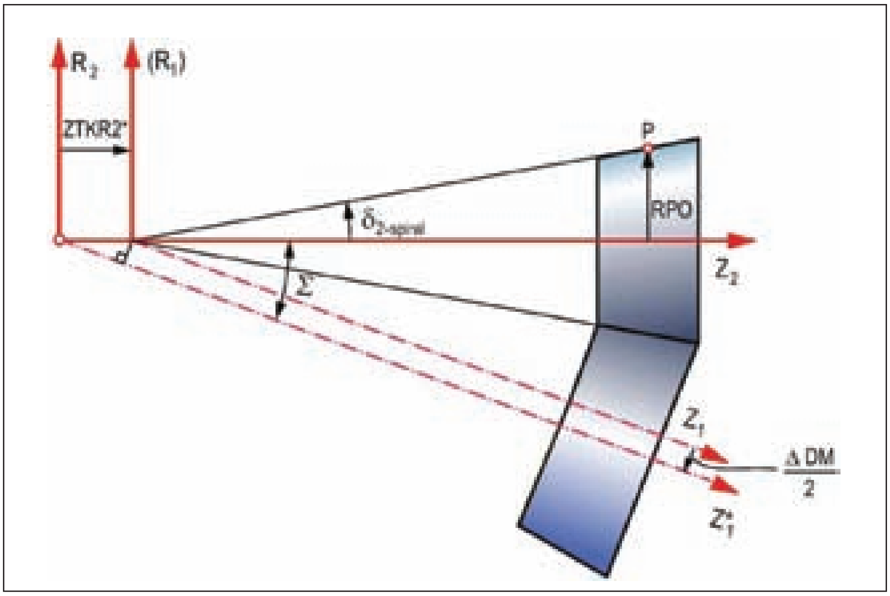

Figure 3—Pinion diameter increase.

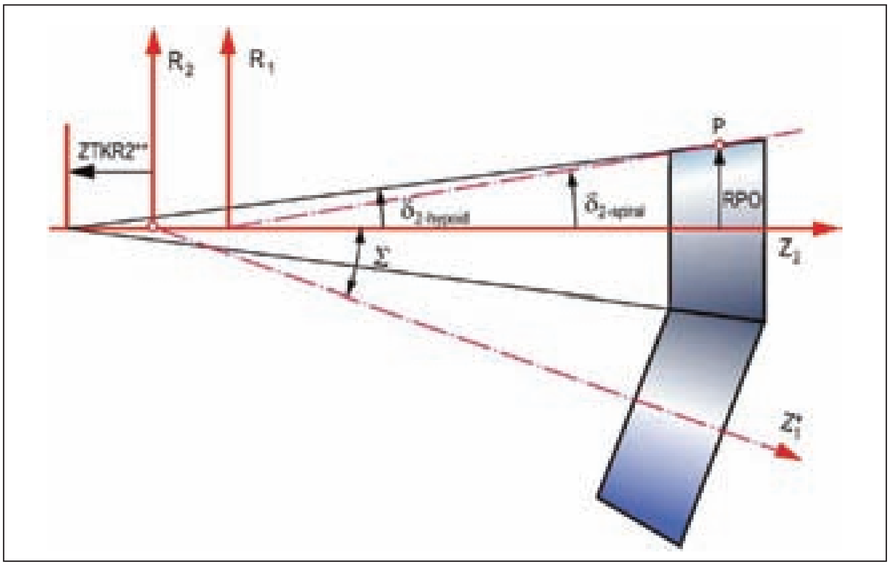

Figure 4—Gear hypoid pitch angle.

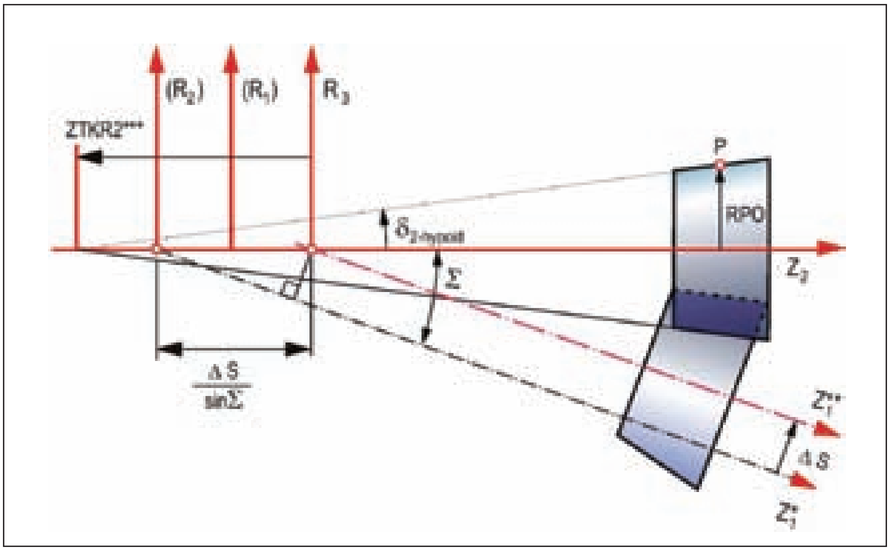

Figure 5—Hypoid crossing point.

is now shifted in negative z_2 direction and lies left of the R_3 axis.

$$ZTKR2*** = \frac{\Delta DM}{2\sin\Sigma}$$

$$+ \ RPO\left(\frac{1}{\tan\delta_{2\text{-spiral}}} - \frac{1}{\tan\delta_{2\text{-hypoid}}}\right)$$

$$- \frac{\Delta S}{\sin\Sigma} \qquad (14)$$

The pinion cone angles are calculated using the three-dimensional point generating principle between two axes in a general three-dimensional arrangement in space (Fig. 6). This principle is based on a given gear cone and a given pinion axis. A pinion cone—or, more correctly a hyperboloid—around the pinion axis is calculated such that it eases perfectly onto the gear-enveloping surface.

Basic Setting Calculation for the Non-Generated Gear

A basic machine setup is the method used to define the manufacturing machine setup and kinematics. This will indirectly also define the flank surfaces as well as the tooth root geometry of both members. Figure 7 shows the non-generated gear with its axis Z3 in the horizontal basic machine plane Y4-Z4. The crossing point on the gear axis is located at the machine center (origin of the coordinate system Y4-Z4). The axis Y4 is the cradle axis. The gear is positioned with the angle $\gamma_{gear\text{-}hypoid}$ such that the pitch line and root line are parallel to the axis Z4. The cutter radius vector is adjusted to achieve the desired spiral angle at the center face with mean cone distance. All relevant formulas for non-generated gear basic machine setup can be derived from the graphical representation in Figure 7.

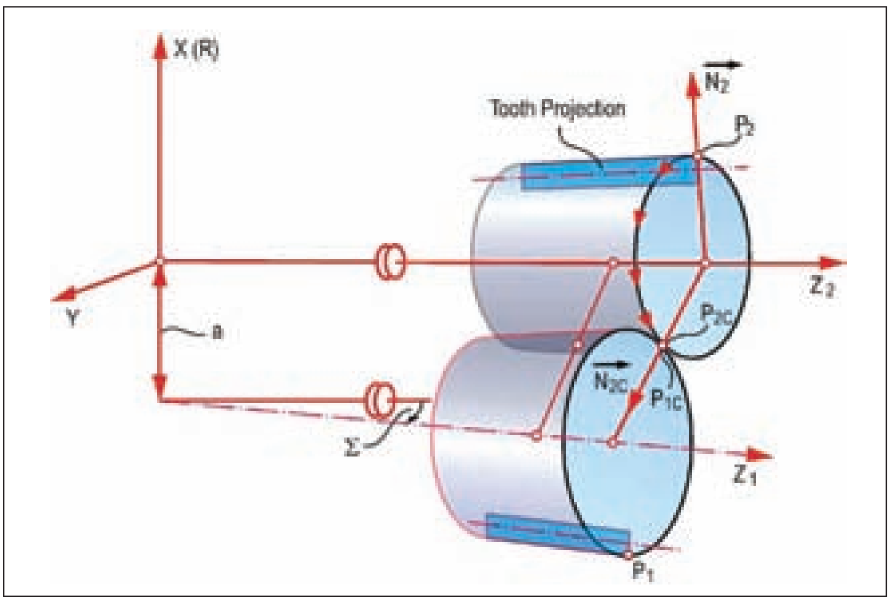

Figure 6—Principal of pinion blank dimension calculation.

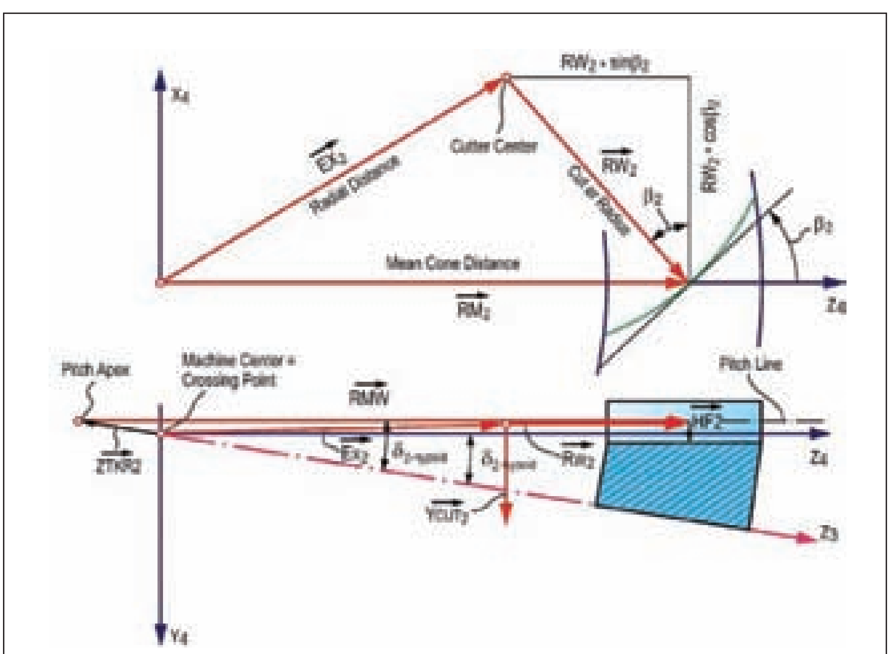

Figure 7—Basic settings for non-generated gears.

$$\vec{RMW} = \begin{Bmatrix} 0 \\ 0 \\ RM_2 \end{Bmatrix} + \begin{Bmatrix} 0 \\ ZTKR2\ \sin\delta_{2\text{-hypoid}} \\ ZTKR2\ \cos\delta_{2\text{-hypoid}} \end{Bmatrix} \qquad (15)$$

$$\vec{RM}_2 = \vec{RMW} + \vec{ZTKR2} \qquad (16)$$

$$\vec{RW}_2 = \begin{Bmatrix} -RW_2 + \cos\beta_2 \\ 0 \\ RW_2 + \sin\beta_2 \end{Bmatrix} \qquad (17)$$

$$\vec{HF2} = \begin{Bmatrix} 0 \\ HF2 \\ 0 \end{Bmatrix} \qquad (18)$$

$$\vec{EX}_2 = \vec{RM}_2 + \vec{HF2} - \vec{RW}_2 \qquad (19)$$

Basic Setting Calculation for the Generated Pinion

In order to establish the generated pinion basic machine setup, the triangular Vector RM_2, RW_2 and EX_2 has to be rotated by $\gamma_{gear\text{-}hypoid}$ about the X4-axis. Then the three vectors are rotated by 180° about the Y4-axis and in a third rotation about the X4-axis by 90° in order to line up the pinion axis with the Y4-axis (as shown in Figure 8). The cutter axis vector Y_{cut2} also has to perform all those rotations and then be reversed in its direction to define the correct cutter or grinding wheel orientation (Y_{cut1}).

$$\vec{Ycut}_1 = (ROT2)(ROT0)(ROT1)(ROT0)\ \ \vec{Ycut} \qquad (20)$$

$$\overrightarrow{EX}_1 = (ROT2)(ROT0)(ROT1) \begin{Bmatrix} EX_{2x} \\ EX_{2y} - HF2 + HF1 \\ EX_{2z} \end{Bmatrix} \quad (21)$$

$$\overrightarrow{TT}_1 = \begin{Bmatrix} -a \\ 0 \\ 0 \end{Bmatrix} \quad (22)$$

The tool definitions, such as point radius, blade angle, etc., of inside and outside cutting blades for pinion and gear, are calculated using the common rules for bevel and hypoid gear sets manufactured in a completing process. After defining the pressure angles of the gear tool first, the pinion tool pressure angles have to be calculated differently than normally done for bevel and hypoid gears (derived from a flat generating gear).

Non-Generated Pressure Angle Calculation

In order to achieve correct pressure angles between pinion and gear flanks, it had been observed that flank points or surface elements are generated in surface lines while they are passing through the generating plane (or more correctly, the generating surface). The trapezoidal profile of the gear teeth is oriented around the gear root cone (not bent around). The gear tooth profile, not the slot profile, has to be used to define the blade pressure angles for the pinion cutting in order for the blades and the basic setting arrangement to duplicate the non-generated gear while generating the pinion slots.

Hypoloid presents a new solution to eliminate the mismatch problem between pinion and gear teeth cut with identical corresponding blade angles. The effect of trapezoidal slots wound around a cylinder or a slim cone requires a correction or adjustment of the pinion blade pressure angle (Fig. 9) of:

$$\Delta\alpha = \frac{-360^\circ}{(2z_2)} \quad (23)$$

where

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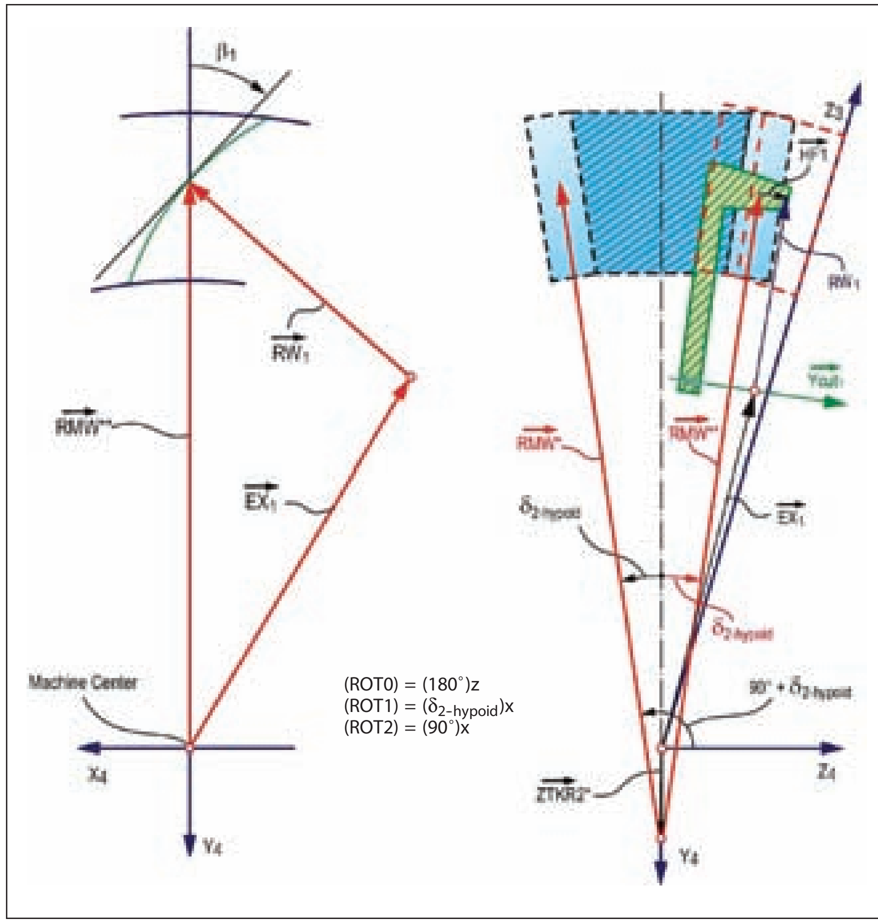

Figure 8—Basic settings for generated pinion.

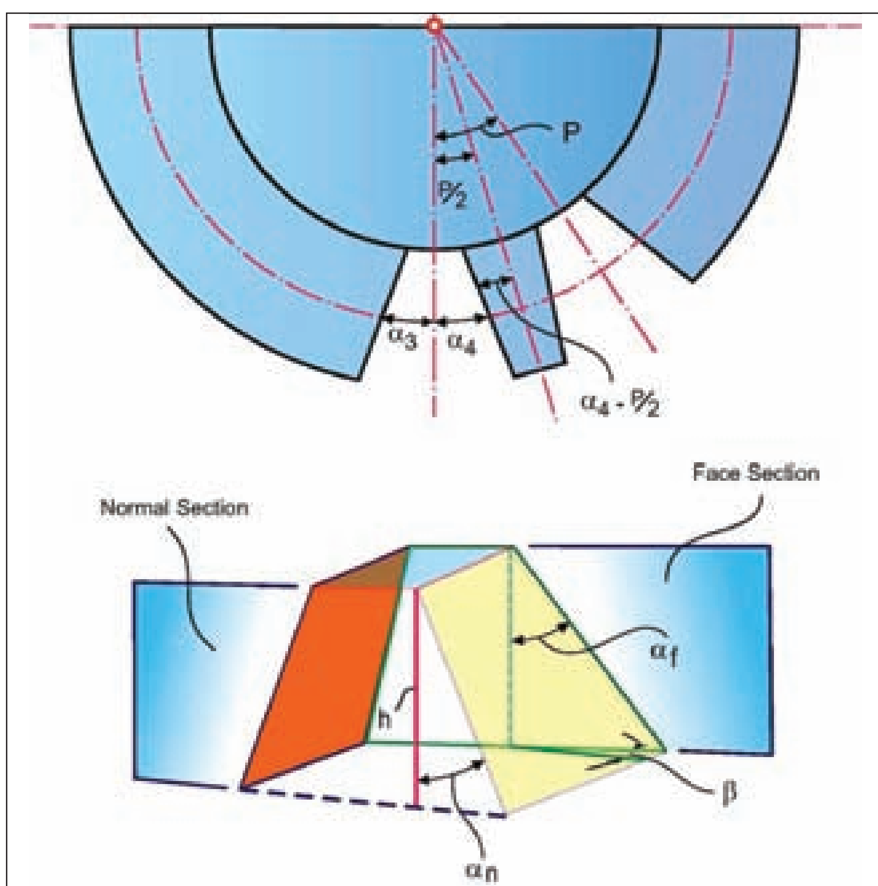

Figure 9—Pressure angle calculation.

$\Delta\alpha$	is change in pinion pressure angle due to non-generated gear member.

Where teeth are oriented under a spiral angle to an axial plane (in addition to the curved shape in longitudinal direction), the angle $\Delta\alpha$ is calculated as:

$$\Delta\alpha_F = \frac{-360^\circ}{(2z_2)} \tag{24}$$

$$\Delta\alpha_N = \arctan\left\{\tan\left[\arctan\left(\frac{\tan\alpha_N}{\cos\beta}\right) - \frac{360^\circ}{(2z_2)}\right]\cos\beta\right\} \tag{25}$$

where

$\Delta\alpha_F$	is a change in pressure angle in face section;
$\Delta\alpha_N$	is a change in pressure angle in normal section;
β	spiral angle at center face width of gear

The choice of completing tools will generate a certain amount of length crowning between the mating pinion and gear flanks. This length crowning might be reduced or increased by a cutter tilt and subsequent blade angle adjustment (as known in the art).

Other elements of crowning, such as profile crowning, flank twist or, in general terms, first, second and higher-order flank modifications, can be applied to Hypoloid gearsets in order to optimize their physical properties. For those modifications, the existing Gleason bevel and hypoid gear correction software can be applied.

Example. The input data for an example Hypoloid development are listed in the Table in Figure 10. The ratio is 1.056, the shaft angle is 12° and the pinion offset is 50 mm.

Optimal values for tooth depth, profile shift (addendum modification) and pinion diameter increase are found as in a standard bevel gear design calculation in an iteration process. At first, the default values given by the program are used in order to conduct the first-tooth contact analysis and undercut check. Further optimization steps are done to avoid undercut and maximize the active working profile of pinion and gear flanks. The resulting tooth contact analysis is shown in Figure 11.

The left vertical sequence in Figure 11 displays the coast side analysis (pinion concave flanks in mesh with the gear convex flanks). The right vertical sequence in Figure 11 displays the results of the drive side (pinion convex flanks in mesh with the gear concave flanks). The top section of the graphic shows the ease-offs, which represent

```
***************************************************************************
***        INPUT DATASET FOR THE PROGRAM   H Y P O L O I D             ***
***    CALCULATION OF BASIC MACHINE SETTINGS FOR HYPOLOID GEARS        ***
***************************************************************************
* [SAMPLE                                                                ]*
*                                                                          *
***************************************************************************
***                         GENERAL DATA BLOCK                          ***
***************************************************************************
I                                                                         I
[   36.000]          Z1       NUMBER OF TEETH PINION              [-]    1
[   38.000]          Z2       NUMBER OF TEETH GEAR                [-]    2
[   10.000]          BETA2    SPIRAL ANGLE OF GEAR              [DEG]    3
[LH]                 HOSP     HAND OF SPIRAL PINION (LH OR RH)    [-]    4
[   20.000]          ALF3     PRESSURE ANGLE I.B.               [DEG]    5
[   20.000]          ALF4     PRESSURE ANGLE O.B.               [DEG]    6
[   35.000]          F        GEAR FACE WIDTH                    [MM]    7
[  122.000]          DUMR2    OUTER DIAMETER GEAR                [MM]    8
[   12.000]          AWI      SHAFT ANGLE                       [DEG]    9
[   50.000]          TTX      OFFSET                             [MM]   10
I                                                                         I
***************************************************************************
***                      MISCELLANEOUS DATA BLOCK                       ***
***************************************************************************
I                                                                         I
[  152.000] 12"      RCP      CUTTER RADIUS NOMINAL VALUE        [MM]   11
[    0.000]          KZW      NUMBER OF CUTTER STARTS             [-]   12
[    1.000]          WROW1    BLADE EDGE RADIUS PINION           [MM]   13
[    1.000]          WROW3    BLADE EDGE RADIUS GEAR             [MM]   14
[     .000]          PCR      PROFILE CROWN (0.0=STRAIGHT EDGE) [MM]   15
[     .000]          LCR      LENGTH CROWNING                    [MM]   16
[    0.075]          SPLF     BACKLASH                           [MM]   17
[   -0.600]          X        V0-PROFILE SHIFT +/- BASED ON PIN [-]   18
[   -0.600]          Y        PROF SIDE SHIFT +=>THICKER PIN TOP[-]   19
[   15.000]          DELDM    INCREASE OF PINION MEAN DIAMETER  [MM]   20
[    1.000]          DPTHF    (1.0->STD, 0.8->STUB, 1.2->HIGH)   [-]   21
I                                                                         I
***************************************************************************
```

Figure 10—Input data for Hypoloid calculation.

length and profile crowning as well as flank twist in the interaction between pinion and gear. The bottom section shows the calculated tooth contact between pinion and gear flanks, drawn within the boundaries of the gear tooth. The center section shows the motion transmission error resulting from the tooth contact and ease-off development. After this development step, the contact size and motion transmission error, as well as the contact position, can be changed without changing the basic parameters of Figure 10. Tooth contact optimization programs identical to those used for regular hypoid gears can be employed.

After geometrical- and strength-related optimizations are finished, the settings for the manufacturing machines (for blade sharpening, cutting and grinding) can be directly retrieved from the basic setting data file. Figure 12 shows the basic settings for pinion and gear cutting, as they can be directly entered into the control of a Phoenix bevel and hypoid gear cutting or grinding machine.

The finished gearset of this example calculation is shown after heat treatment and tooth grinding in Figure 13. The testing performed with the manufactured sample Hypoloid gear sets confirmed the high degree of insensitivity to deflections of the gear box housing, bearings and gears under load.

Summary

A new development—Hypoloid gearing—addresses the desire of gear manufacturers for more versatility. Hypoloid gearsets can realize shaft angles between zero and 20° and at the same time, allow a second shaft angle (or an offset) in space, which provides the freedom to connect two points in space.

The first application of Hypoloids is found in all-wheel-drive vehicles that typically use a transfer case with a pinion/idler/gear arrangement or a chain. In those cases, the exit of the transfer case needs to be connected with the front axle. The obstacle here is the fact that the propeller shaft between the transfer case and the front axle will require two CV joints because the front axle input point has a vertical offset and is shifted sideways with respect to the transfer case exit. The tight packaging of modern vehicles requires the possibility to offset the two connecting points of a front propeller shaft. The axle housing in vehicles with independent front axle is in most cases directly mounted to the bottom of the engine, such that no variations in shaft angle is required. However, the penalty for such a design is the cost of two CV joints as well as the reduced efficiency of the front drive train, which could range

continued

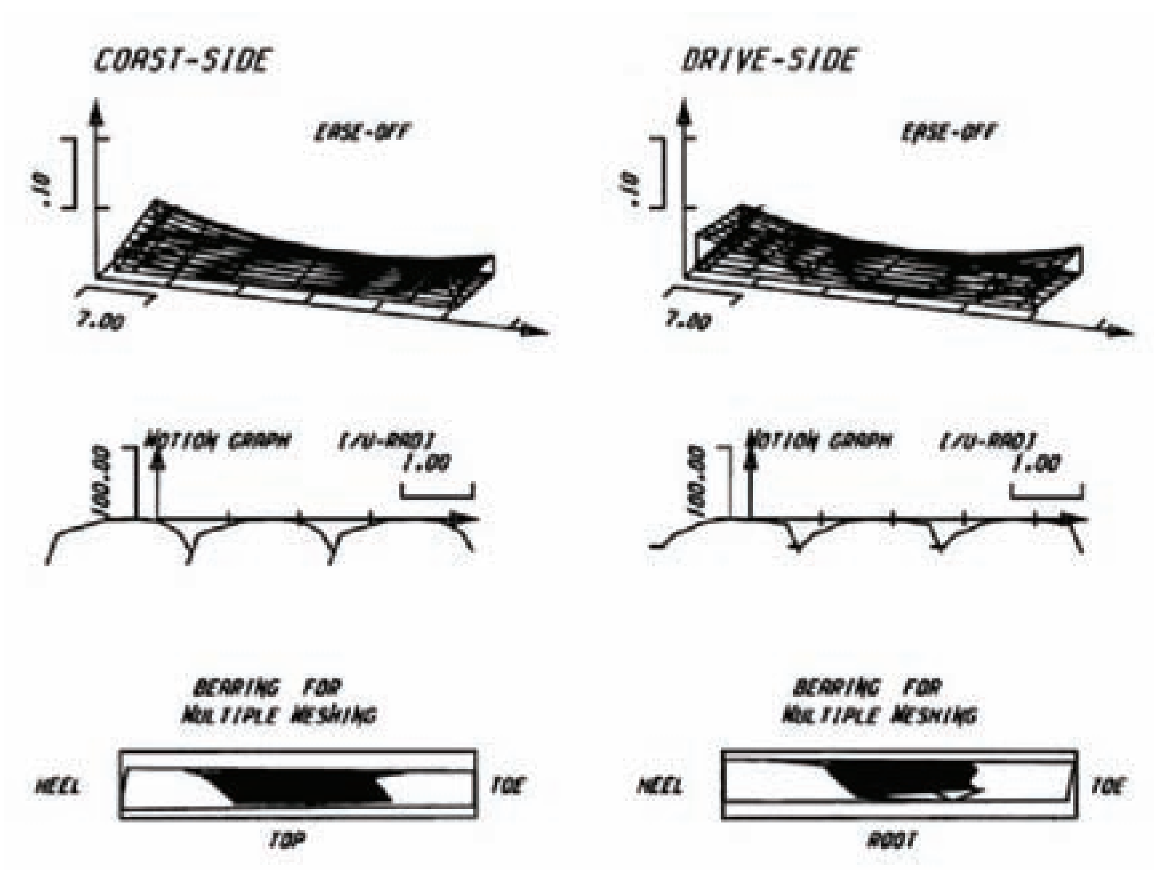

Figure 11—Ease-off, motion transmission and tooth contact analysis.

```
COPYRIGHT (c) 2008   G L E A S O N  R&D - GEAR TECHNOLOGY
FORMATE HYPOID SUMMARY No. SAMPLE

 P I N I O N  - Finishing -   C U T T I N G  SPECIFICATIONS

26. RADIAL DISTANCE. . . . . . . . . . . . .      165.705 mm
27. TILT ANGLE . . . . . . . . . . . . . . .       82.912 deg
28. SWIVEL ANGLE . . . . . . . . . . . . . .      -21.313 deg
29. WORK OFFSET. . . . . . . . . . . . . . .       49.999 mm
30. MACHINE ROOT ANGLE . . . . . . . . . . .      -77.809 deg
31. MACHINE CENTER TO CROSSING PT. . . . . .        1.724 mm
32. SLIDING BASE . . . . . . . . . . . . . .      477.712 mm
33. RATIO OF ROLL. . . . . . . . . . . . . .     1.089291
34. CENTER ROLL POSITION . . . . . . . . . .       93.067 deg

 G E A R  - Finishing -   C U T T I N G  SPECIFICATIONS

41. VERTICAL. . . . . . . . . . . . . . . .       149.691 mm
42. HORIZONTAL. . . . . . . . . . . . . . .       533.180 mm
43. MACHINE CENTER TO CROSS PT. . . . . . .        53.678 mm
44. MACHINE ROOT ANGLE. . . . . . . . . . .         5.560 deg
```

Figure 12—Basic settings for Hypoloid pinion and gear cutting.

Figure 13—Ground automotive Hypoloid gear set.

between 0.5% and 2% of the power that flows through the front axle.

Beveloids can realize an angle in one plane, which in most cases is not sufficient to connect the two points in question without the additional requirement of two CV joints. Only the newly developed Hypoloids can connect those two points due to the shaft angle and the additional offset and thereby make the use of CV joints obsolete.

The Hypoloid technology not only reduces cost and increases efficiency, but also has an enhanced performance compared with beveloids with straight teeth. The curved Hypoloid teeth enhance the NVH characteristic and show less contact displacement under load. Flank form generation, tooth contact analysis, ease-off calculation and coordinate measurement with corrective feedback are already possible with today's cutting and grinding machines.

The Hypoloid technology is not restricted to automotive drive trains; all of the mentioned advantages apply also to aircraft as well as general gearbox manufacturing.

(*Editors' note: Hypoloid is a trademark of the Gleason Corporation.*)

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3. Stadtfeld, H.J. Handbook of Bevel and Hypoid Gears—Calculation, Manufacturing, Optimization, Rochester Institute of Technology, Rochester, New York, 1993.

Dr. Hermann Stadtfeld *received a bachelor's degree in 1978 and in 1982 a master's degree in mechanical engineering at the Technical University in Aachen, Germany. He then worked as a scientist at the Machine Tool Laboratory of the Technical University of Aachen. In 1987, he received his Ph.D. and accepted the position as head of engineering and R&D of the Bevel Gear Machine Tool Division of Oerlikon Buehrle AG in Zurich, Switzerland. In 1992, Dr. Stadtfeld accepted a position as visiting professor at the Rochester Institute of Technology. From 1994 until 2002, he worked for The Gleason Works in Rochester, New York—first as director of R&D and then as vice president of R&D. After an absence from Gleason between 2002 to 2005, when Dr. Stadtfeld established a gear research company in Germany and taught gear technology as a professor at the University of Ilmenau, he returned to the Gleason Corporation, where he holds today the position of vice president-bevel gear technology and R&D. Dr. Stadtfeld has published more than 200 technical papers and eight books on bevel gear technology. He holds more than 40 international patents on gear design and gear process, as well as tools and machines.*

Bending Fatigue Tests of Helicopter Case Carburized Gears: Influence of Material, Design and Manufacturing Parameters

G. Gasparini, U. Mariani, C. Gorla, M. Filippini and F. Rosa

Management Summary

A single tooth bending (STB) test procedure has been developed to optimally map gear design parameters. Also, a test program on case-carburized, aerospace standard gears has been conceived and performed in order to appreciate the influence of various technological parameters on fatigue resistance and to draw the curve shape up to the gigacycle region. In phase-one testing, up to 10 million cycles have been performed on four test groups differing by material (VAR and VIM-VAR 9310, and VIM-VAR EX-53) and by manufacturing process (ground fillet versus un-ground fillet). In the second phase, the VIM-VAR 9310 ground fillet specimen has been tested up to 100 million cycles. All the gear types were shot peened. FEM analysis, strain gauge measurements and rating formula of AGMA standards are used to express test loads in terms of tooth root stresses. Final testing addressed failure analysis—based on SEM, failed specimens and ultimate load tests.

Introduction

The safety, performance and reliability required for helicopter gearboxes are constantly increasing, and gears are therefore subjected to increasing bending fatigue loads at the tooth root, while at the same time longer service life is demanded (Ref. 1).

Many aspects of gear design and manufacturing must be controlled in order to obtain such results—including material cleanliness, case depth and hardness, tooth root shape and roughness and compressive residual stresses. Gear design and manufacturing processes, developed and optimized during many years, are therefore key to the increasing performance of helicopter transmissions, and a deep knowledge of the influence of each single design and manufacturing parameter on the fatigue strength is required. Moreover, helicopter gears are designed to withstand loads in the very high-cycle field (>108 cycles), but they are also subjected to short duration overloads, so a precise knowledge of the shape of the S-N curve is of great importance for precisely assessing their service life.

Rating standards, like AGMA 2101-D04 (Ref. 2) and ISO 6336 (Ref. 3), provide methods to assess gears' bending fatigue performances based on the comparison between the stress induced at the tooth root and the material allowable stress. Both terms are calculated in detail, taking into account, with appropriate factors, many influencing aspects such as tooth geometry, gear mounting conditions, contact ratio, overloads, velocity, number of cycles, roughness, dimensions, etc.; some limitations can be pointed out, in particular:

1. Material data provided indicates lower limits, which can be allowed if the conditions specified by the standard are respected, yet they cannot take into account the actual performances that are achieved through appropriate design, development and manufacturing.
2. The stress cycle factor/life factor, which represents the shape of the S-N curve, is not specified in the highest number of cycle region that is represented as a range by a shaded area. In that

area, the actual value of the factor depends on such items as material cleanliness, ductility, fracture toughness and pitch line velocity (Fig. 1). Therefore the responsibility of selecting a value is left to the designer, based on his specific knowledge. The range between the lower and the upper limit of the factor, at 1010 cycles, varies from 0.8 to 0.9—according to AGMA, and from 0.85 to 1.0, according to ISO.

For these reasons, in applications requiring an accurate evaluation of gear performances, i.e.—helicopter transmissions—manufacturers must perform a systematic testing program in order to determine material fatigue limits that must take into account specific design and manufacturing conditions as well as the shape of the S-N curve in the range of interest.

Initial bending fatigue tests are generally performed using an STF (single-tooth fatigue) scheme rather than reproducing gear meshing. The data for actual running conditions can then be determined by means of an appropriate factor, which can be explained as a consequence of a different load ratio *R* and of statistical considerations depending on the number of teeth loaded during the tests (Ref. 9). The load ratio *R*, which is defined as the minimum test load versus the maximum test load in a load cycle, is $R = 0$ in running gears and typically $R = 0.1$ in STF tests.

Test setup. STF tests are usually performed by means of hydraulic machines or resonance machines. Two basic load application schemes, with several variations, are known:

1. In a "true" STF scheme, like a SAE J1619 (Ref. 4) test rig for instance (Fig. 2), the gear is supported by a pin; one tooth is tested while a second one, which is loaded at a lower position along the profile, acts as a reaction tooth. Such a scheme is more common in the United States. With this scheme, some problems can arise if the tests are performed on mechanical resonance machines and the tests are not stopped before reaching the final breakage.
2. A second test scheme, more common in Europe (Refs. 11–12), in which two teeth are actually loaded at the same time, is a consequence of the involute profile properties and of the span measurement (the so-called "Wildhaber span") in particular. In this case the gear blank can be left unsupported since the two equal and opposite applied forces are perfectly balanced (Fig. 3).

The test fixture (Fig. 4), designed specifically for the present research program, can be used for both testing schemes. By changing the length of the anvil on the left

continued

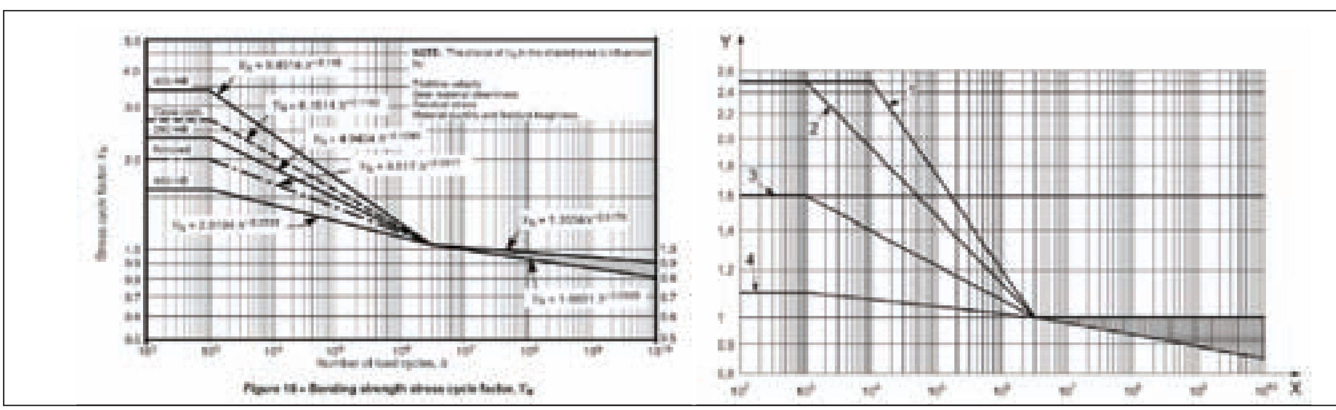

Figure 1—AGMA stress cycle factor (left) and ISO life factor (right).

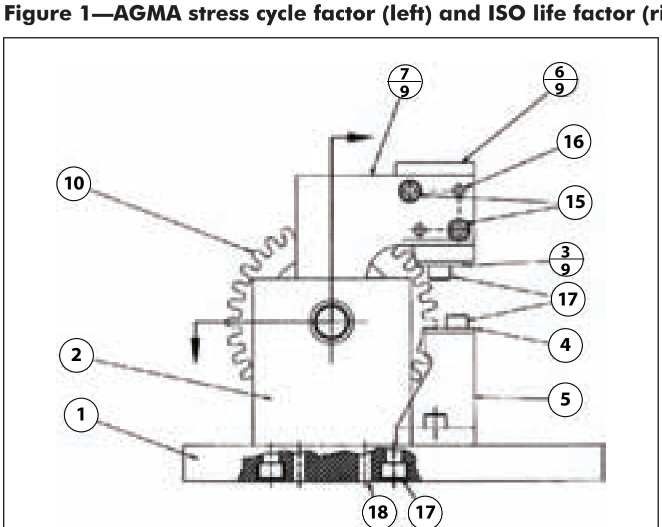

Figure 2—SAE J1619 test scheme.

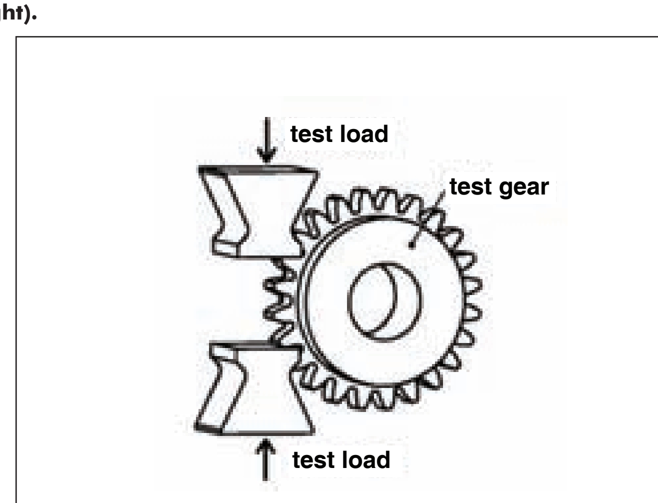

Figure 3—Testing scheme without supporting the gear blank (Ref. 11).

side, the position of the load along the flanks of the tooth can be varied, thus changing the stresses on the two loaded teeth. With an appropriate length of the anvil, the symmetric condition can be obtained, and the pin—which in this case is used only for the positioning of the gear—can be removed. In this way, no load can be absorbed by the pin, and the load and stress on the two teeth are the same. The tests have been performed on a mechanical resonance 60 kN Schenck pulsator, without the pin (Fig. 5).

Gear data and test groups. Table 1 summarizes the main gear data. For this test program, a specifically designed test gear was defined and manufactured with different technological options. The gear proportions have been selected after several iterations optimizing test machine capabilities and representation of typical parameters of main power gears used on Agusta-Westland helicopter transmissions. This test gear has now become the standard Agusta-Westland specimen for gear technology evaluation and screening.

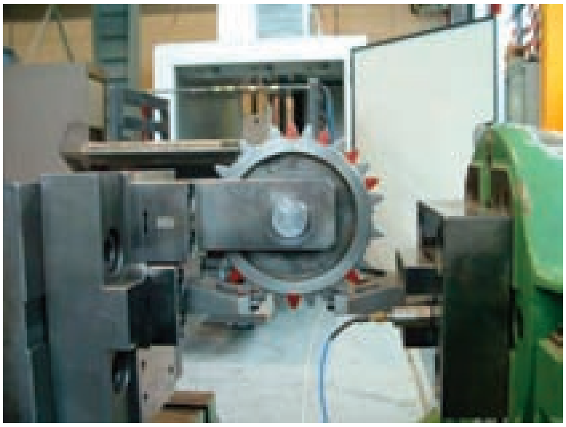

Figure 4—Fixture designed for Agusta-Westland tests.

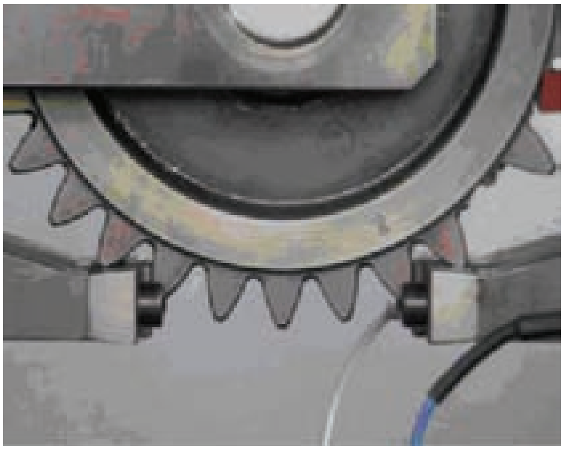

Figure 5—Gear specimen during test.

Table 1—Main Gear Data		
Number of Teeth	–	32
Normal Module	mm	3.773
Helix Angle	°	0.0
Normal Pressure Angle	°	22.5
Transversal Pressure Angle	°	22.5
Transversal Module	mm	3.773
Working Pitch Diameter	mm	120.74
Base Diameter	mm	111.55
Effective Face Width	mm	15.0
Tip Diameter	mm	130.0

The test gear has 32 teeth and the anvils span five teeth for the STF test. Consequently, eight independent tests can be performed on each gear specimen because the teeth nearest those already tested are not used for testing.

Four test groups have been manufactured in order to quantify the influence of design, manufacturing and material parameters (Table 2).

Investigations, like roughness and micro-hardness measurements, have been performed to confirm the compliance of the specimens to the design specifications included in technical drawings.

In the first phase of the research, the four test groups have been tested and compared up to 10 million cycles. In the second phase, the test group 451 has been selected to extend the testing range up to 100 million cycles.

Two ultimate load tests have also been performed on two specimens for each group by fitting the anvils to a hydraulic universal testing machine (Fig. 6).

Test loads and tooth root stresses. The relation between the applied load and the tooth root stress has been investigated with three different approaches—AGMA standard, finite element analyses and strain gauge measurements.

The calculation according to the AGMA standard is based on the following basic equation:

$$\sigma_F = \frac{F_t}{b\, m_t} \frac{1}{Y_J} \qquad (1)$$

Table 2—Test Groups		
Test Group Number	Material	Manufacturing
451	VIM-VAR 9310	Ground Fillet, Shotpeened
551	VIM-VAR 9310	Unground Fillet, Shotpeened
651	VAR 9310	Ground Fillet, Shotpeened
751	VIM-VAR EX53	Ground Fillet, Shotpeened

Figure 6—Ultimate load test.

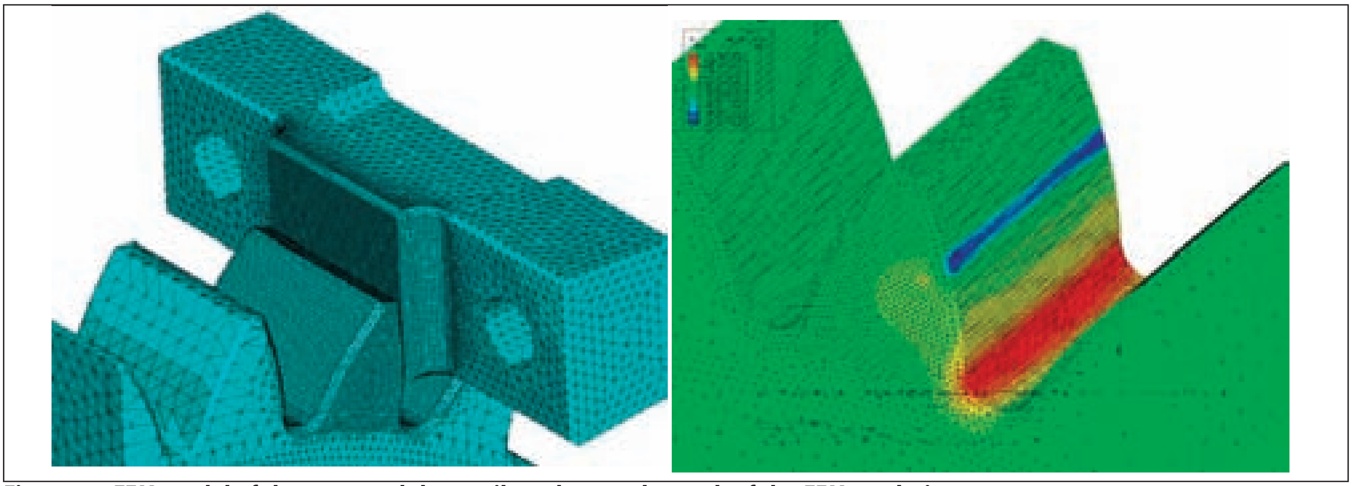

Figure 7—FEM model of the gear and the anvil, and example result of the FEM analysis.

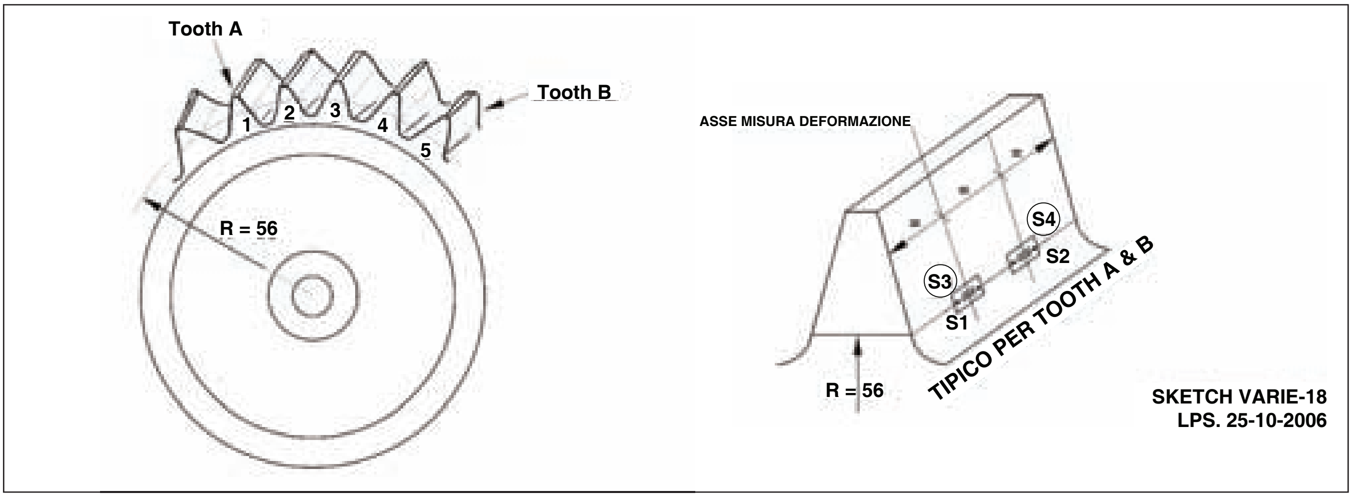

Figure 8—Strain gauges application sketch.

Table 3—Load vs. Root Stress according to Different Calculation Methods

Test Group	Fillet Geometry	Load, kN	FEM Stress, MPa	Strain Gauage Stress, MPa	ANSI-AGMA 2101-D04 Bending Stress, MPa
451, 651, 751	Ground	10	421.9	442.8	382.2
551	Unground	10	417.6	427.3	361.6

in which the form factor has been calculated by considering a virtual gear pair having the HPSC (high point of single-tooth contact) for the z=32 gear under consideration, coincident with the point-of-load application in the tests.

In the FEM calculation—performed with *ABAQUS* software—due to symmetry considerations, the half gear and one anvil in contact have been modeled. The gear has been constrained on the symmetry plane, and a displacement has been applied to the anvil (Fig. 7).

The tooth root stresses have also been determined by means of strain gauges, which have also been used to verify the alignment of the test gear. For this reason, eight strain gauges corresponding to two teeth, two sides (compression and tension) and two ends of the face widths have been applied to the two specimens representing the two different fillet geometries—ground and un-ground. The details of the strain gauges' application are given in Figure 8.

Table 3 summarizes the comparison between the applied load and the root stress, according to different methods.

Test results. As Agusta-Westland rating procedures are based on the use of a continuous S-N shape curve, the test results have been analyzed by means of various curves—from both Agusta-Westland experience and from other sources that belong to the family:

$$\frac{S}{S_L} = H + A\,(N + C)^B \qquad (2)$$

where

S is the stress, N is the number of cycles, S_L is the fatigue limit, and H, A, B and C are constants that correspond to the different shapes.

continued

Two curves—named GEAR05 and GEAR06—have proved to best fit the experimental data, and are therefore plotted along with the test data (Figs. 9–12). In the curve GEAR05, the parameters *H*, *A*, *B* and *C* are fixed and correspond to a shape-curve previously used and accepted by Agusta-Westland, while in the curve GEAR06, they have been optimized on the basis of the present test data.

Test results for test group 451 also include the data of the second phase of the research, up to 100 million cycles. Very high fatigue cycle test results have not been plotted separately because they are consistent with the estimations done on the basis of the shorter tests; i.e., the forecast of the fatigue

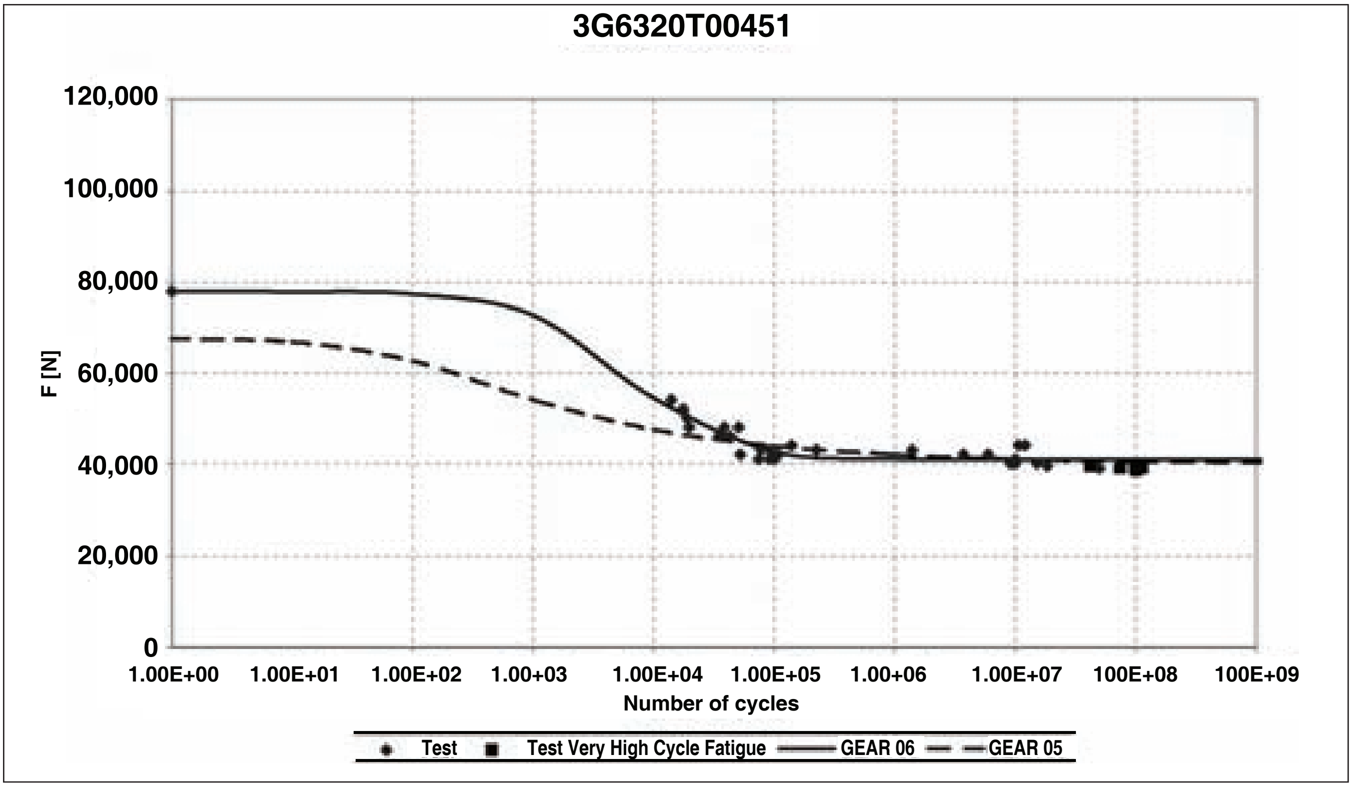

Figure 9—Test data, in terms of applied load, and curves GEAR05 and GEAR06 for test group 451.

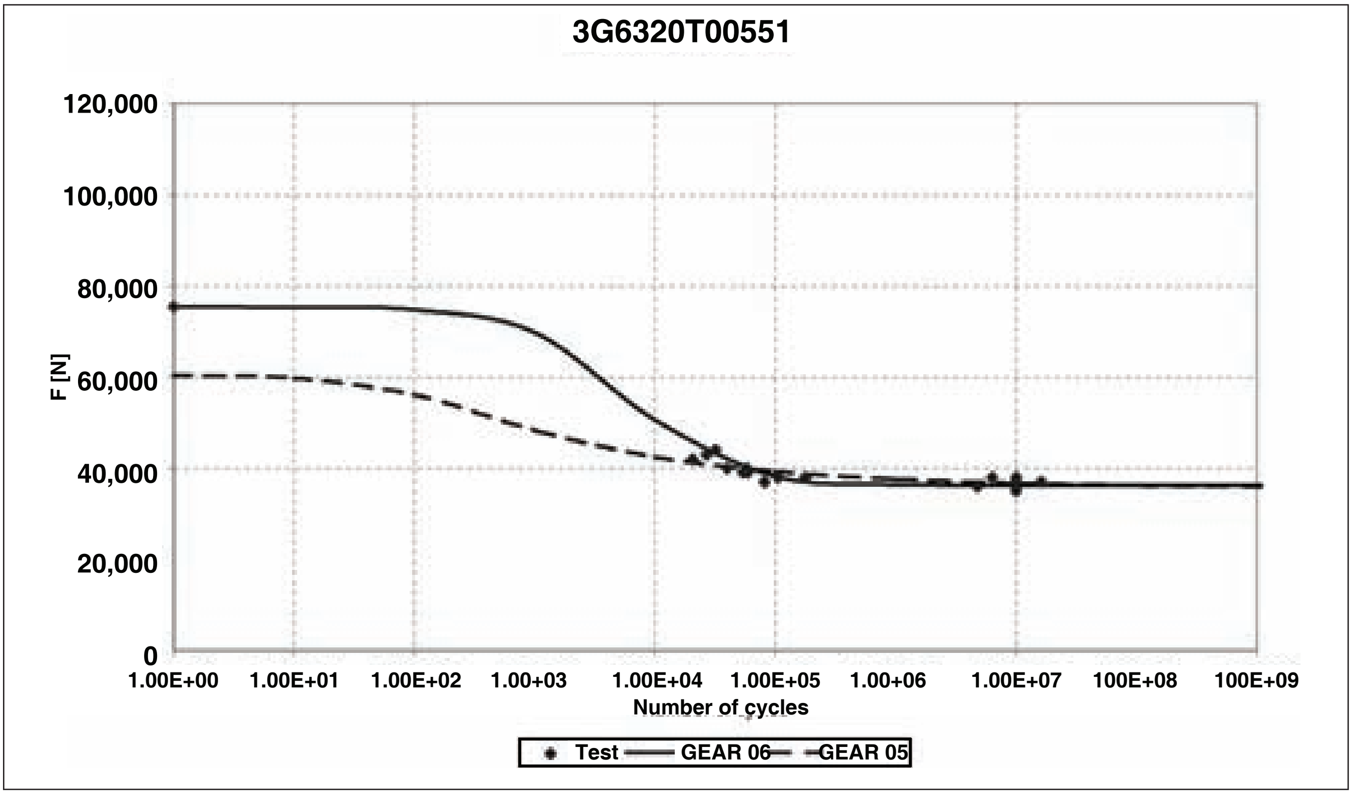

Figure 10—Test data, in terms of applied load, and curves GEAR05 and GEAR06 for test group 551.

limit based on the shorter duration tests is only slightly modified by the data obtained with gigacycle tests.

The comparison between the four test groups is made in terms of applied load in Figure 13 and in terms of stress in Figure 14. The fatigue limit that is the asymptotic value of the shape curve appears similar for the test groups 451 and 751, with a slightly higher value for the 751. The values of the fatigue limit estimations according to curve GEAR05 are reported in Table 4.

In the first phase, VIM-VAR EX53 and 9310 (both according to Agusta-Westland proprietary specifications) have shown the highest values of fatigue resistance, with a slightly higher figure for EX53. The fatigue limit of 9310 VIM-VAR with un-ground fillet is about 8% lower, while the

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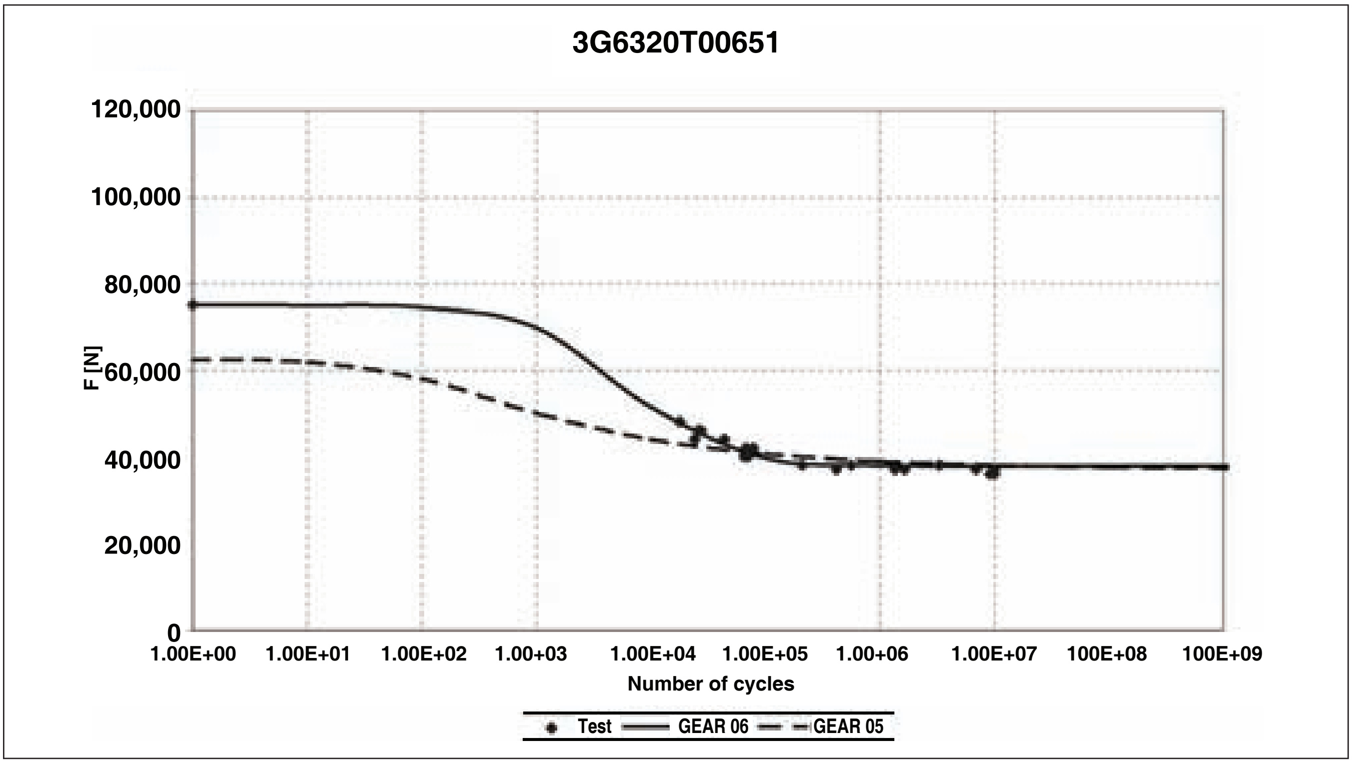

Figure 11—Test data, in terms of applied load, and curves GEAR05 and GEAR06 for test group 651.

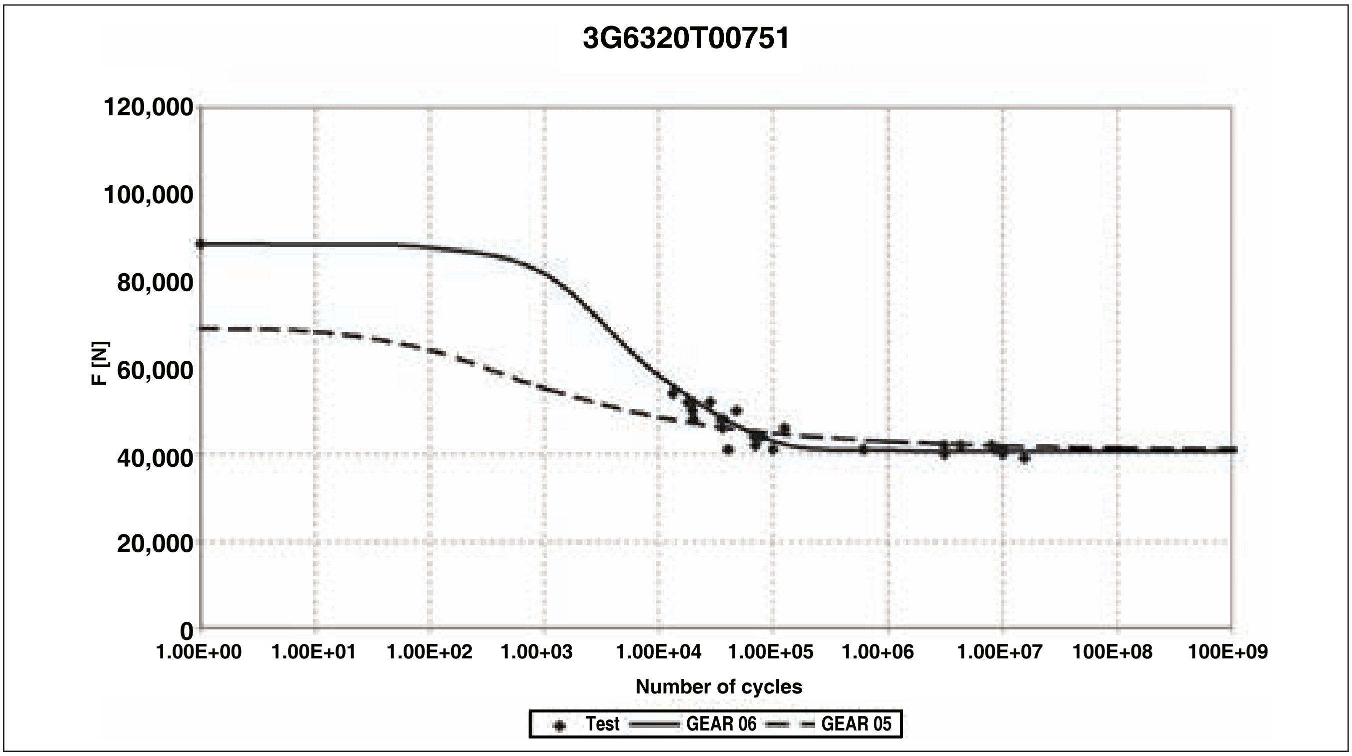

Figure 12—Test data, in terms of applied load, and curves GEAR05 and GEAR06 for test group 751.

fatigue limit of 9310 VAR—according to AMS6265 (Ref. 13) and form grinding—is about 11% lower. In the very high cycle fatigue tests on 9310 VIM-VAR, two failures occurred in the range between 10 and 100 million cycles. The results of the very high cycle tests confirm the curve determined with the ordinary tests and its asymptotic value.

The fatigue limits obtained in the present test program are much higher than those included in AGMA and ISO rating standards, but the opinion of the authors is that a direct comparison with that data is not meaningful because they are not specific to the aerospace applications and do not consider the influence of such parameters like shot peening or residual stresses. Rather, the present data are obtained with an STF test, and have a different load ratio *R* and different statistical conditions, as explained in Reference 9. Literature data for a similar material and application can be found in Reference 8 for the low cycles field, and they are consistent with those of the present research in the same cycle range.

Furthermore, as mentioned, static tests of breakage have been performed on the gears to check the ratio between the static strength and the endurance limit with results in the range of 1.93 to 2.17, which are reasonably consistent with

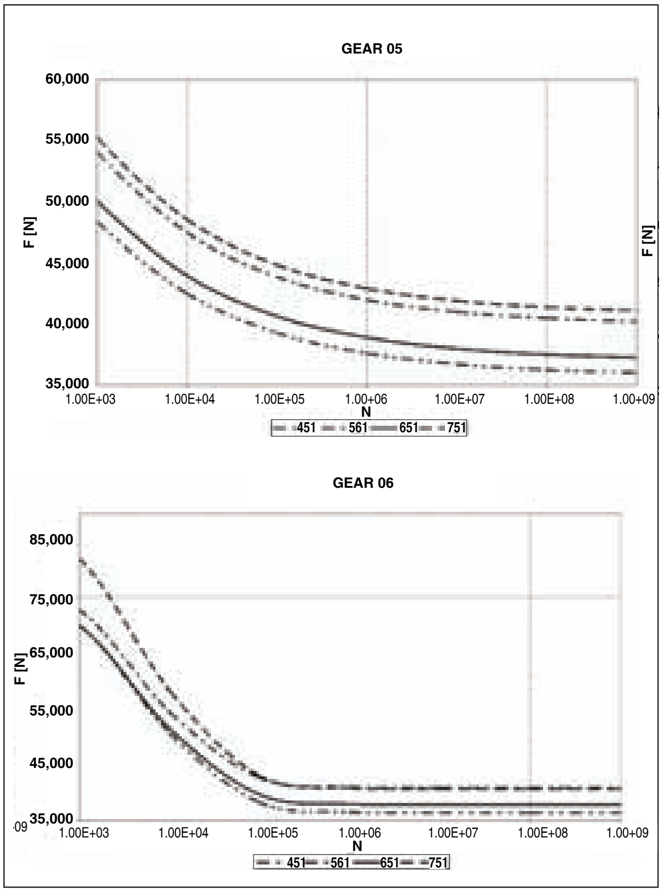

Figure 13—Comparison, in terms of load (N), among the four configurations by means of the curves GEAR05 (top) and GEAR06 (bottom).

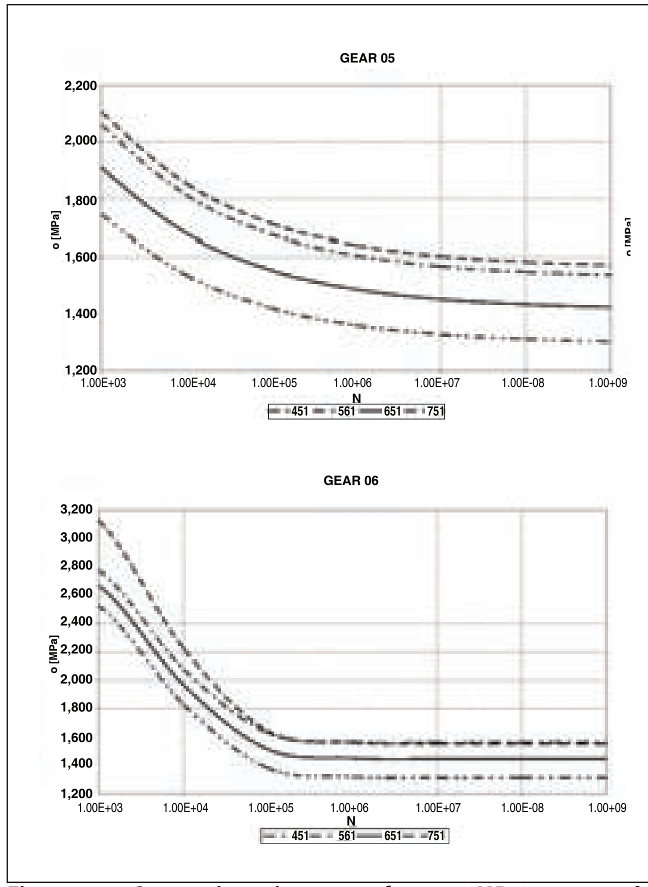

Figure 14—Comparison, in terms of stress (MPa), among the four configurations by means of the curves GEAR05 (top) and GEAR06 (bottom).

Table 4—Fatigue Limit Estimations with Curve GEAR05 (the values in terms of stress are derived according to ANSI/AGMA 2101-D04)

Test Group	451 1st Phase	451 1st + 2nd	551	651	751
Fatigue Limit, N	40,281	39,928	35,758	36,989	40,819
Fatigue Limit, MPa	1,540	1,526	1,293	1,414	1,560

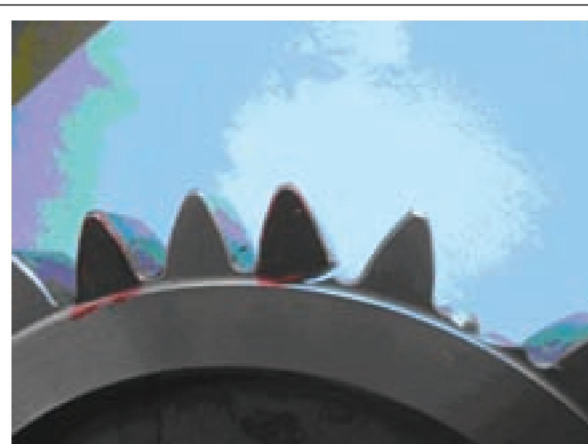

Figure 15—Typical appearance of the failure surface.

the ISO and AGMA standard curves for carburized gears—2.50 and 2.70, respectively (Fig. 1).

Crack nucleation and propagation. The tooth failure surface shows the typical shape of case-hardened AISI 9310 gear teeth (Refs. 6 and 8) with a typical, cone-cup final fracture. An example of fracture surface is shown in Figure 15.

From the SEM observation of the fracture surfaces, it has been possible in some cases to identify the crack nucleation point, which sometimes corresponds to a defect or inclusion. In other cases, it has not been possible to observe the crack nucleation. All the crack nucleation points detected are near the surface of the tooth (Fig. 16). Some other authors (Ref. 6), for the same material, have proposed the possibility of nucleation at the case-core interface. In this test regimen, nucleation of this sort has not been observed. As the explanation of the phenomenon is based on stress gradients and on the relation between the case depth and case versus core characteristics, it seems reasonable to maintain that local conditions at the tooth root of the cited paper could have been different from those of the present case.

In some cases, crack growth marks have been found on the failure surface, as shown in Figure 17.

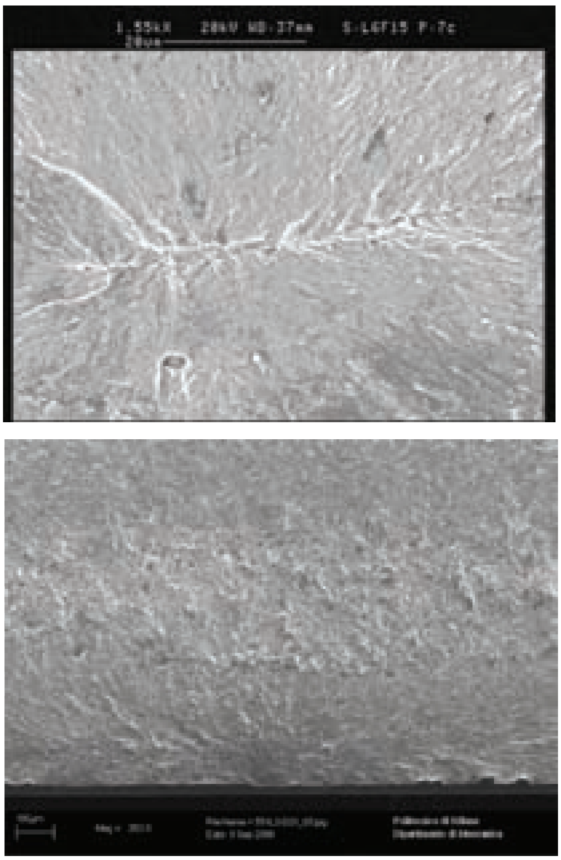

Figure 16—Examples of crack nucleation corresponding to a non-homogeneity of the material (top), and not corresponding to a defect or inclusion (bottom).

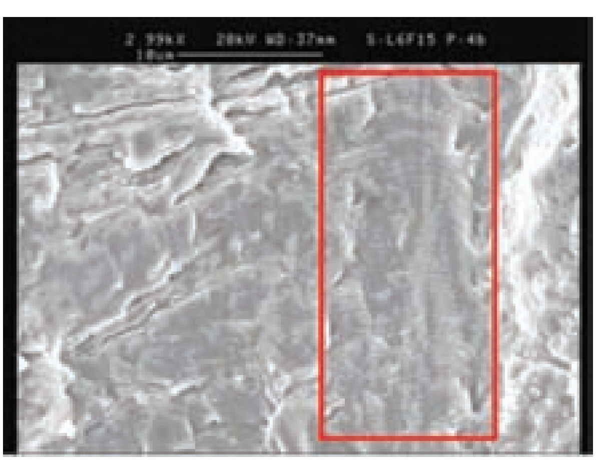

Figure 17—Crack growth marks.

Conclusion

Extensive testing has given precise information concerning the fatigue limits of the four tests groups, both in absolute and relative terms. The results have been analyzed by means of different curve shapes, from both the Agusta-Westland experience and from other sources, and the most appropriate have been selected. Very high cycle tests confirm the estimations done on the basis of the shorter tests, both in terms of fatigue limit and of curve shapes.

The test procedure developed has now become the standardized approach at Agusta-Westland to evaluate, compare and qualify new materials, new processes and new designs, and therefore the test program is continuing with tests on nitriding gears. In the first phase of the research, with tests up to 10 million cycles, 102 gear tooth specimens have been tested for an amount of 434 million cycles, while in the second phase—up to 100 million cycles—eight specimens have been tested for an amount of 734 million cycles.

In order to have a deeper understanding of the fatigue behavior in the low cycle range, further investigations in this field have been scheduled. Testing on carburized case- hardened gears with a hydraulic testing machine is also in progress, both under constant- and variable-amplitude loading. In order to improve the transferring of test data to transmission design, some bending fatigue tests on a back-to-back rig have also been planned.

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Mauro Filippini *graduated in mechanical engineering at Politecnico di Milano in 1994. In 1998 he received his doctorate in mechanical behavior of materials at the University of Pisa, Italy. From 1997–1998, he worked as scientific collaborator in the laboratories of the Fraunhofer-Institute for Structural Durability and System Reliability (LBF) in Darmstadt, Germany. Since 1998, Filippini has been doing research at the department of mechanical engineering of Politecnico di Milano as a research fellow, and from July 2002 to present as assistant professor. Filippini is mainly focused on the structural integrity and fatigue of metals—especially for high-temperature engineering applications—and on the effect of residual stresses on the durability of metals.*

Giuseppe Gasparini *graduated in mechanical engineering from the Universitiy of Padua, Italy. After professional experience at a mechanical engineering firm, he joined Agusta in 1983 in the transmission design and development department, with a main focus on gear vibration analysis and testing. He then moved to Danieli & C. in the field of mechanical transmissions for steel mills, and then to MAAG Italy in the field of industrial gearboxes and gear pumps. Gasparini then returned to Agusta as head of transmission manufacturing engineering and later in 2000 was named head of transmission design and development. In 2007, his responsibilities were extended to the UK department. During his career at AgustaWestland, he has had the opportunity to work on the design and development of all the transmission systems of the current product range. He is also president of the technical committee of ASSIOT (Italian Transmission Manufacturers Association) and technical director of the TRASMEC journal of ASSIOT.*

Carlo Gorla *graduated in mechanical engineering at Politecnico di Milano. He has worked in the department of mechanical engineering of Politecnico di Milano—initially as a researcher, and since 1998 as associate professor. Currently, Gorla is teaching courses in machine design that address machine design, power transmission and gears, all with special focus on design, rating, transmission error and efficiency. He is also the technical director of the Journal on Power Transmission and Gears (Organi di Trasmissione). Gorla is an academic member of AGMA and a member of ASME.*

Ugo Mariani *has been working for AgustaWestland on the fatigue certification of metallic and composite structures in helicopters for more than 20 years. During that time, he has published several papers on fatigue and damage tolerance of helicopters at ICAF, ERF and RTO conferences and IJoF. He has served on various panels addressing fatigue requirement improvements, and is co-chairman for implementing FAR/JAR 29 flaw tolerance requirements for transport helicopters. Since 1998, as head of the fatigue department—scientist and compliance verification engineer—Mariani has been involved in civil and military certifications of AW leading projects like A109 variants, A129, EH101, NH90 and AW139. AW139 is the first helicopter fully certified according to damage tolerance requirements, including airframe, rotors and transmission shafts and gearboxes.*

Francesco Rosa *is an assistant professor at the department of mechanical engineering, Politecnico di Milano, Italy. His research topics include methods and tools for geometric modeling of gears, simulations of manufacturing technologies and simulations of component behavior in actual working conditions.*

Dr. Mike Bradley (inset) presents the gear market report at the Solutions Center during Gear Expo 2009 (courtesy of AGMA).

Gear Expo 2009

ECONOMY FRONT AND CENTER IN INDIANAPOLIS

Is economic relief on the way? This was the general consensus coming out of Indianapolis after Gear Expo 2009 closed its doors in September. Though the numbers were slightly down—2,539 exhibitors and attendees compared to 2,992 in 2007—it appeared to be steady as she goes at the gear industry's biennial main event, good news considering the state of the gear industry since Gear Expo 2007 in Detroit.

Exhibitors and attendees had mixed opinions regarding the venue change, extended show hours and quality of leads generated in Indianapolis.

"The expo was a bit slow, but overall worth exhibiting," says Ian Shearing, vice president of sales at Mitsubishi Heavy Industries America, Inc. "The AGMA needs to get more exhibitors excited about displaying better products and booths for future shows. Like most marketing efforts, you only get out of it what you are prepared to put into it."

"With the economy as it is, there was a level of apprehension coming into this show due to the uncertainty of customer commitment and attendance," says John Terranova, vice president of sales-Americas at Gleason. "However, the resultant customer turnout was positive and was one indicator that there is a turn being made in the economy, and more specifically for our gear manufacturing community."

"Gear Expo does not have the results of IMTS or EMO as measured by new leads, new applications and new programs that may lead to a machine sale," says Bill Miller, vice presi-

continued

Companies like Mitsubishi Heavy Industries, Inc. discussed the latest technological developments and advancements in gear machinery (courtesy of AGMA).

dent of sales at Kapp Technologies. "The value of Gear Expo was the efficiency of meeting the 40 to 50 customer contacts (representing 20 to 25 companies). Our show expenditure is roughly comparable to the alternate cost of key customer site visits. Even with a large staff, it is impossible to give each visitor the appropriate attention."

At the Kapp booth, visitors were treated to live video feeds from its facility in Boulder. These educational sessions were a welcome change of pace for attendees and a popular talking point at Gear Expo.

"The best testimony of our 'lesson program live from Boulder' concept was an early visitor who commented that he comes to Gear Expo for education and that sales rhetoric or show model girls don't do him any good," Miller says. "Observers noted that the live aspect held visitor's attention much better than professional videos. Several other exhibitors expressed interest in the concept."

Forest City Gear CEO Fred Young caught up with customers, suppliers and colleagues at Gear Expo, and he emphasized the importance of getting out and talking to people at these events.

"We use Gear Expo as a vehicle to gain more exposure to our company," Young says. "I prefer Gear Expo to getting lost at a larger show like IMTS; for me it's perfect because of the gear equipment and technology that's available to see. It was a great opportunity to say hello to friends and peers in the industry."

Conversations at the show ranged from new technologies to alternative energy opportunities with plenty of small talk regarding the economy.

"It was basically the conversations you would expect in these tough economic times," Shearing says. "However, we did get some feeling of upcoming optimism. Naturally, everyone was hoping for a quick economic recovery rather than a protracted one. In addition, there was quite a bit of talk about diversification into different industry sectors."

"Things seem to be business as usual for us," says Dan Kondritz, national sales manager for KISSsoft. "Gear Expo did not reflect any signs of impending doom. For us, it was a great turnout. We were extremely busy the first two days with qualified prospects."

Dr. Stefan Beermann at KISSsoft added, "It was more or less the same as it was in the past, which is already notable. Gear Expo is small and dedicated, which is why it is so

Though attendance was down slightly from previous shows, Gear Expo 2009 was considered a success due to the customer contacts and potential leads generated in the exhibit hall (courtesy of AGMA).

unique."

AGMA's economic consultant, Dr. Mike Bradley, returned to Gear Expo with his keynote presentation on the gear market forecast. Bradley suggested that the general manufacturing sector had probably hit bottom and that the gear market was likely close to bottoming out. He concluded that there appeared to be a light at the end of the tunnel and the turning point, specifically for the gear industry, could occur in 2010, led by investments and exports.

"The financial crisis and resulting panic of early 2009 was NOT raised as a topic. Instead most visitors reported a slight boost in demand and were relatively hopeful of a slow but continued recovery," Kapp's Miller says. "Increased activity levels of the last few months were reflected in the discussions and follow-up provided during the show."

AGMA president Joe Franklin agreed that many manufacturers echoed Bradley's report with positive activity occurring this summer as well as preparations to ramp up production in 2010.

With lower attendance numbers than past shows, Franklin was still pleased with the quality of Gear Expo visitors. According to Franklin, many of the same companies that came through Gear Expo in 2007 were on hand in 2009.

"All the major players showed up in Indianapolis. GM, Chrysler, Ford, Caterpillar, John Deere and Magna were all present. The state of the economy didn't matter. They came to see what new technologies and products the gear industry has to offer," Franklin says.

And the move from Detroit to Indianapolis was welcome by many in the gear industry.

"Nice city, good venue and a pleasant show," says Michael McKernin, sales manager at Circle Gear. "I enjoy this show because it focuses on what I've spent my entire career working towards. It's a great opportunity to meet other professionals in our industry."

"The Indianapolis venue was a refreshing change of location for Gear Expo," says Scott Yoders, vice president of sales at Liebherr Gear Technology, Inc. "Judging from the various gear companies that visited the Sigma Pool booth, Indy is truly a central hub for gear manufacturing in North America."

"We were blessed with good weather, and exhibitors and attendees enjoyed walking around the city of Indianapolis,"

continued

Franklin says. "Everything is in close proximity, which makes it that much nicer."

"Many visitors commented that Indy was more attractive than Detroit as a venue. It was significantly more accessible for a larger number of attendees with travel restrictions that limited the length of stays to day trips or a single night," Miller says.

"We enjoyed the venue," Shearing says. "But in terms of sheer number of attendees, Detroit is hard to beat."

Franklin adds that the AGMA has not ruled out a return to Detroit in the future. "The city has some work to do politically, obviously, but we've always been very pleased with the reception and support coming out of Detroit."

In preparing for the 2011 installment in Indianapolis, Franklin will soon sit down with trade show analysts to discuss changes and improvements that need to be made to future shows.

"Parking was a bit of a problem, specifically signage throughout Indianapolis. It made it difficult for visitors driving into the city to navigate and find the appropriate parking lots," Franklin says.

Many exhibitors questioned show hours and felt they could be reduced depending on the amount of foot traffic. The attendance definitely seemed to drop toward the end of the show.

"The heavy traffic was Tuesday afternoon and Wednesday. Tuesday morning was slow and Thursday was very slow," Miller says.

"I am not sure of a plausible solution," adds Terranova at Gleason, "but the mid to late afternoon times were very low for customer attendance."

While 61 percent of Gear Expo attendees visited the heat treat show, Franklin believes this number would have increased significantly if the Heat Treating Society Conference and Exposition stayed open the final day of Gear Expo. "This is something we're going to discuss in the future," Franklin says.

Franklin is pleased to report that 80 percent of the exhibition space for Gear Expo 2011 was booked before the show ended, proving that many in the industry are expecting good things to come to the gear market in the near future. He's not concerned with comments that the show is too small or doesn't bring in enough new business.

"Gear Expo is an 'industry-centric' event where the gear community comes together to encourage one another," Franklin says. "There's tremendous support across the board in this industry."

"Those that came to the show last minute and made a half-hearted effort will not think they got the most bang for their buck, so to speak," Forest City Gear's Young says. "The key to these events is the preparation you put into it prior to the show."

While the market waits to swing in a more positive direction, the feeling throughout Gear Expo was a comeback of sorts is on the way in 2010.

"We've seen some areas that are a little spunkier than others right now," Young says. "When the dam bursts, it's going to be difficult to satisfy all the immediate needs with the right personnel and the right equipment. The gear industry needs to be prepared."

The emotion and enthusiasm from both exhibitors and attendees is why Franklin is not worried about the current economic state of the industry.

"Given the sign of the times, the booths were a little smaller this year and the crowds weren't as large, but many exhibitors were still able to attract plenty of potential clients, and that's a very good sign of things to come," Franklin says.

Gear Expo 2009 shared floor space with the ASM Heat Treating Society Conference and Exposition and will do so once again for the 2011 event (courtesy of AGMA).

Many exhibitors commented that Gear Expo 2009 was successful thanks to the foot traffic in the first two days of the show (courtesy of AGMA).

December 8-9—AGMA Strategic Resources Network/Regional Meeting. Haas Automation, Inc. headquarters, Oxnard, CA. This event combines a tour of Haas Automation, Inc.'s facility with educational sessions addressing gear marketing and manufacturing as a unique niche, tools to weather the economic downturn, manufacturing in a green economy and an introduction to AGMA's new System Efficiency Initiative. The first day of the meeting consists of a golf outing and networking dinner. The Strategic Resources network is a group consisting of new and upcoming gear industry professionals in AGMA. The goal is for participants to grow by providing educational forums addressing leadership, best business practices, AGMA programs and personal development. Cost is $395 for members, $450 for nonmembers. For more information, visit *www.agma.org/events-training/detail/strategic-resources-network-regional-meeting/*.

December 8–10—Basic Gear Manufacturing Technology. Gear Manufacturing, Inc. headquarters, Anaheim, CA. The Gear Consulting Group presents this three-day course to emphasize basic gear theory applications to different machining methods. The problems encountered with each gear manufacturing process are covered, focusing on inspection. Participants will learn to understand the results of inspection data for identifying and correcting problems. Some of the topics covered include basic gear theory, cutting speeds and feeds, cutter materials, cutter coatings, cutter sharpening, tool selection, standards and manufacturing methods. Cost is $850 for AGMA members, $950 for nonmembers. Register online through the Gear Consulting Group website, *www.gearconsultinggroup.com/Registration Form.htm*.

December 8–10—Wall Colmonoy's Brazing School. Wall Colmonoy Brazing Engineering Center. Cincinnati, OH. This three-day brazing course from Wall Colmonoy Corporation covers brazing design, metallurgical aspect of modern furnace brazing, brazing material selection, brazing operations, quality control, real-life applications and case studies. New this year is a half-day of practical experience on the shop floor consisting of pre-cleaning, blasting, selecting fixture, setting furnace cycle, examining brazed parts and filler metal application methods. For more information, visit *www.wallcolmonoy.com*.

January 28–30, 2010—PM-10. Sheraton Rajputana Palace Hotel, Jaipur, India. This international conference and exhibition on powder metallurgy in processing of particulate materials and products is organized by the Powder Metallurgy Association of India. A trade exposition is complemented by a technical program addressing processing and production of particulate materials through powder metallurgy, with emphasis on new technologies that expand component application range. An industrial workshop is held where manufacturing specialists discuss the equipment and techniques for processing and evaluating metallic, ceramic, cermet and diamond tool components. For more information, e-mail *support@kandoimetals.com*, or visit *www.pmai.in*.

February 16–18, 2010—Gear Materials Seminar. Sheraton Sand Key Resort, Clearwater Beach, FL. This course demonstrates how gear design engineers first approach material selection and heat treatment technology by the performance and life requirements of a gear set. It also demonstrates how gear metallurgists can participate in and optimize the final gear manufacturing process. Part of the program includes examples of gear-related problems, failures and improved processing procedures, while analysis and commentary of various relevant failures are presented. The seminar is designed for gear design engineers, management involved with designing and manufacturing gear-type components, metallurgists and materials engineers, lab technicians, quality assurance engineers, furnace design engineers and equipment suppliers. For AGMA members, cost is $1,895 for the first registrant per company and $1,695 for each additional registrant. For nonmembers, the cost is $2,395 for the first registrant per company and $2,195 for each additional registrant. For more information, contact *events@agma.org* or visit *www.agma.org/events-training/detail/gear-materials/*.

March 17–19, 2010—Basic Gear Noise Short Course. Gear and Power Transmission Research Laboratory, The Ohio State University. Columbus, OH. Having been offered for over 30 years, the Basic Gear Noise Short Course teaches participants how to design gears to minimize the major excitations of gear noise, which include transmission error, dynamic friction forces and shuttling forces. Other topics include fundamentals of gear noise generation, gear noise measurement, gear rattle, transmission dynamics and housing acoustics. Demonstrations of specialized gear analysis software and Ohio State gear test rigs will be performed. An interactive workshop allows attendees to present their specific gear and transmission noise concerns. An advanced version of this course is offered March 22–23. For more information, contact Jonny Harianto, *harianto.1@osu.edu*, or visit *www.gearlab.org/shortcourse*.

Errichello

HONORED WITH AGMA LIFETIME ACHIEVEMENT AWARD

Bob Errichello and his dog Corny.

The 2009 AGMA Lifetime Achievement Award was given to Bob Errichello, founder of consulting firm Geartech, which focuses on gear design, research and failure analysis. He has also been a *Gear Technology* technical editor since 1992.

Errichello's Geartech software specializes in engineering tools for gear rating, analysis and design. He currently conducts AGMA's Gear Failure Analysis Seminar in Big Sky, MT, and he is credited for helping introduce the first gear standards for wind turbines.

He holds bachelor's and master's degrees in mechanical design and structural dynamics from the University of California at Berkley. He has contributed to several AGMA committees, including Helical Gear Rating, Nomenclature, Epicyclic Enclosed Drive and Component Design in addition to helping create the AGMA/AWEA committee for wind energy standards.

Errichello's achievements have previously been recognized with the Technical Division Executive Committee and E.P. Connell Awards. In addition to involvement with AGMA committees, he is a member of ASM International, the Society of Tribology and Lubrication Engineers and the ASME Power and Transmission and Gearing Committee.

Gleason

APPOINTS VP WORLDWIDE SALES

Udo Stolz.

Udo Stolz is vice president of worldwide sales and marketing for Gleason Corporation, as announced September 1. Stolz has global responsibility for sales, marketing and product management activities for all Gleason products and services.

Stolz joined Hermann Pfauter GmbH in 1987, and he has held various sales and management positions throughout his career. Most recently, he served as vice president, sales in Europe for Gleason.

"Udo Stolz brings the necessary combination of experience and technical knowledge in gearing, a strong commitment to serving our customers and a global perspective, which make him an ideal leader," says John J. Perrotti, president and chief executive officer of Gleason. "I am confident he will be a significant contributor to our company in his new role as we pursue our mission to be the 'Total Gear Solutions Provider.'"

Gear Technology

SIGNS CONTRACT WITH RAYTHEON

Rancho Cucamonga, CA-based Gear Technology signed an annual contract with Raytheon Systems Limited to manufacture eight high-performance gears for use by the U.S. military.

"We are pleased to have received this high level contract this year," says Tom Marino, president of Gear Technology. "Raytheon has been a customer of ours for over 23 years. This new business commitment reflects Raytheon's continuing confidence in our precision gear manufacturing capabilities and our focus on the highest quality control standards.

"The eight precision gears specified in this new government contract will be included in the U.S. military AMRAAM missile guidance control assembly," he says.

continued

Greenfield Industries

NAMES PRESIDENT

Ty Taylor.

Ty Taylor was appointed president of Greenfield Industries, Inc. (GFII), effective October 1. He reports directly to Jeff Chee, president and CEO of Top-Eastern Drill Company (TDC), which acquired GFII earlier this year. Taylor is responsible for overall management of GFII's brands: Cleveland, Chicago-Latrobe, CLE-LINE, Putnam, Bassett, Vermont Tap and Die, Geometric, H & G, Vers-O-Tool and Acme-Fette.

Active in the cutting tool industry for over 32 years, Taylor's background includes leadership roles in manufacturing, research and development, marketing and sales management. He most recently served as director, global distribution for Kennametal, Inc; GFII was acquired by Kennametal in 1997.

"I am very pleased to be leading a dedicated group of employees whose primary mission is to satisfy our customers with the high quality cutting tools that the company has always been known for," Taylor says.

AFC-Holcroft

NAMES PARTNER IN RUSSIA, CIS, BALTIC

An exclusive distribution agreement was signed between Michigan-based AFC-Holcroft and JSC Nakal Industrial Furnaces of Solnechnogorsk, Moscow Region, Russia. Under the agreement, Nakal provides sales, service, parts and support of AFC-Holcroft equipment in the partnership area, which consists of Russia, the CIS countries and the Baltic region.

Nakal has manufacturing facilities in the Moscow Region that include over 8,000 square meters of production area with welding, metal treatment, insulation, painting and other equipment. All necessary manufacturing equipment is owned by the company, allowing it to perform all processes on-site.

As the largest electro-thermic equipment manufacturer on Russian Federation territory, Nakal covers developing and manufacturing heat treat furnaces, melting furnaces for non-ferrous metals, drying ovens and lab furnaces for all industries. Nakal tests and develops new thermo-chemical solutions, like catalytic gas nitriding, at its research and testing laboratory for heat treat machinery.

"As our major decision, we want to leverage our strengths to capture the same market share in AFC-Holcroft's Russian market as we have in North America," says Marc Ruetsch, director of European operations for AFC-Holcroft. "With the help of our Russian partners, we will increase our product range considerably in this market."

Nakal also views the partnership as an advantageous opportunity. "Everybody benefits from this alliance," says Nikolay Ityaksov, general manager of Nakal. "Our company gets a chance to benefit from vast experiences of the American company and ready-made solutions for our customers. On the other hand, AFC-Holcroft significantly enlarges its presence in the above-mentioned markets. Moreover, manufacturing companies that use these furnaces and equipment will also benefit from our alliance, as it improves accessibility of the equipment produced by one of the world leaders, as well as service support and pricing."

AFC-Holcroft has over a hundred installations in the former Soviet Union in a diverse range of plants. "The close collaboration with Nakal Industrial Furnaces is a strategic decision for us, allowing us to build on our large installed base of furnace equipment in this region," says Bill Disler, AFC-Holcroft vice president. "As a leader in heat treatment equipment technology, we will be able to better support our existing Russian and CIS state customers as well as develop new customer relationships. We will continue to make adjustments in our organization to support our global activity as we expand our footprint around the world."

Emuge

DISTRIBUTES EXCLUSIVELY FOR HOHENSTEIN

Massachusetts-based Emuge Corp. joins forces with the Hohenstein Company of Germany as the latter's exclusive North American agent. The sales agreement combines the special purpose workpiece clamping fixtures from Hohenstein with Emuge's application experience in demanding workholding and tooling solutions.

"By adding the specialized clamping fixtures from Hohenstein to our lines, we further demonstrate our commitment to our customers to fulfill their unique application requirements," says Peter Matysiak, president of Emuge. "The fixtures are a natural addition, as our precision workholding department specializes in customized solutions where accuracy and repeatability play a major role."

Hohenstein clamping fixtures are now available in North America through a sales agreement with Emuge.

The two companies view their partnership as a symbiotic relationship. Hohenstein provides Emuge with plumbed pneumatic and hydraulic manifold base plates, which are used in conjunction with Emuge workholding and workholding nests. Hohenstein mounts Emuge workholding to its tombstone and pallet devices.

"Emuge's reputation for offering the highest quality cutting tools, workholding solutions and engineering/application support made them the logical choice to be our agent in North America," says Michael Franzki, managing director of Hohenstein.

Carl Zeiss

OPENS WEST COAST TECH CENTER

Irvine, CA is the home to the Carl Zeiss IMT West Coast Tech Center. "We are dedicated to supporting the high-tech industry on the West Coast by providing customers easy access to our most modern and advanced technology," says Andy Sisler, vice presi-

continued

dent of sales at Carl Zeiss IMT. "The new technical center will provide more local resources and support for this fast-paced market. It's an exciting time for us because this is a chance to be even closer to our customers and show our commitment to customer support after the sale."

The site is located in Irvine's modern technology park, and it focuses on application support, contract inspection services, software training and Zeiss equipment demonstrations. "Providing contract inspection services is an exciting part of what we are building here," says Drew Shemenski, software and applications manager for Carl Zeiss. "With a full suite of metrology systems at this facility, we have the capability to support the inspection needs of everyone from micro-molders up through traditional CNC job shops, as well as specialists such as gear and turbine manufacturers."

Shemenski expresses enthusiasm about the technology and capabilities at the West Coast Tech Center. "This will be a first-class experience for our customers. We're very proud to have available a full range of our industry leading bridge-type machines and our most advanced metrology systems," he says. "We're excited about the type of technology we have in Irvine. The Metrotom 1500 is an X-ray based computed tomography system specifically designed for 3-D metrology of small, complex low-density parts made of plastic, composite materials or ceramic.

"The O-Inspect is a multi-sensor system that features both tactile and optical scanning and provides tremendous flexibility for measuring parts that approach the micro range of size.

"We have a variety of surface form and geometry systems to really round out our measuring and demonstration capabilities. The team we have in place also brings a depth and variety of experience that really complements the technology. We are looking forward to bringing all these elements to support our customers."

The West Coast Technical Center address is 18 Goodyear, Irvine, CA 92618; by phone: (800) 327-9735, or e-mail *imt@zeiss.com*.

GH

BUYS MAJORITY INTEREST IN INDUCTION ATMOSPHERES

GH Electrothermis A. A. and Induction Atmospheres signed a letter of intent in September for GH to purchase a majority interest in Induction Atmospheres (IA). Both companies expect the partnership to increase sales and allow them to expand into new markets.

"Induction Atmospheres is very excited to become part of the worldwide GH Group," says IA president and CEO Steve Skewes. "They will provide international sales and service for our turnkey induction heating systems, and we will bring sales, service and production of the highly respected GH product line into the United States."

IA systems include induction heating processes, which is a non-contact, fast and accurate heating method that saves space, time and money. It provides a lean, environmentally-friendly, energy efficient industrial heating process that reduces fossil fuel consumption.

"Induction Atmospheres brings new products and markets to the worldwide GH Group," says José Vicente González, GH Group president. "With their staff and facilities, we will be able to effectively deliver our induction heating systems into the United States. This is exactly the type of synergistic relationship we were looking for in a U.S.-based company."

Induction Atmosphere's VF-30 vacuum furnace.

Skewes notes other advantages to the agreement. "Both companies use the same computer design systems for product development, so we're looking forward to advanced engineering collaboration and easy product design transfer. This really is one of those rare win-win business scenarios, and we look forward to a long and profitable relationship."

Foundry

REPORTS GROWTH POINTING TO AUTO REBOUND

Grede Foundries Inc. managed to increase employment due to expanded work serving automotive and other manufacturing industries. Over the summer months, Grede gained new, multi-year contracts worth over $23 million annually, reports Richard Koenings, chairman of Grede. This has allowed employment at its U.S. plants to rise 30 percent.

"There's been talk of the U.S economy starting to prepare for economic recovery, and our experience at Grede seems to indicate some support for that," Koenings says. "In addition to increasing orders from existing and new customers, we have been able to steadily expand employment. The goal of our recent right-sizing and restructuring efforts has been to position Grede for immediate profitability in what is expected to be a gradual turnaround as the U.S. emerges from its most tumultuous economic period in generations. The hikes we've seen in work and employment indicate Grede is on a solid, positive path."

Grede Foundries filed for Chapter 11 bankruptcy proceedings in June and began reorganization efforts. It is phasing out two plants in Vassar, MI and Wichita, KS as a result. The economic downturn, particularly in the automotive sector contributed to this action. The summer rebound is credited in part to reduced inventory and the "Cash for Clunkers" program. The rise in employment has occurred at Grede facilities in Reedsburg, WI, St. Cloud, MN, Waumatosa, WI, Iron Mountain, MI and New Castle, IN, which collectively serve the automotive, construction, manufacturing and agriculture industries.

"The increase in work, increase in jobs and increase in potential new contracts all indicate Grede is headed in the right direction."

Boeing

APPOINTS GM IN PORTLAND

Perry Moore was named general manager of Boeing Fabrication's Portland manufacturing site. Moore also serves as the site executive in Oregon, where he represents Boeing with government and community agencies.

continued

Perry Moore.

Moore reports to Ross Bogue, vice president and general manager of Boeing Fabrication, a Boeing Commercial Airplanes organization. The Boeing Portland site, in Gresham, OR, is the manufacturing center of excellence for fabrication and assembly operations of complex machining, gear systems and end-item pilot controls for commercial airplanes.

Hexagon

ACQUIRES VISION METROLOGY COMPANY

All the outstanding assets and technical intellectual property of Mahr Multisensor GmbH have been acquired by Hexagon Metrology. The business will be reorganized by Hexagon Metrology, and it has agreed to employ some technical service, development and application engineering staff from Mahr Multisensor.

The vision business unit and products will be integrated into Hexagon Metrology, brands of which include Brown and Sharpe, CE Johansson, CimCore, CogniTens, DEA Leica Geosystems (Metrology Division), Leitz, m&h Inprocess Messtechnik, PC-DMIS, Romer, Sheffield and TESA.

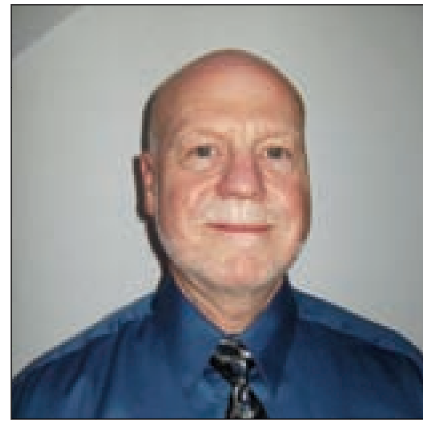
"This acquisition will further enhance our worldwide product offering in multisensory vision technology and confirms Hexagon Metrology's commitment to offer the widest range of measuring systems for all industrial applications," says William Gruber, CEO and president of Hexagon Metrology.

Auburn Gear

WELCOMES SALES MANAGER

Craig Wisner was appointed regional sales manager for Auburn Gear. He reports to Greg Henderson, director of marketing. He is responsible for all Power Wheel sales functions in the upper Midwestern parts of the United States and central Canada by working with Auburn's distributors and OEM customers in the region.

Wisner comes to Auburn Gear from Power Gear/Power-Packer, a division of Actuant, Inc. Power Gear is a recreational vehicle Tier One supplier, and Power-Packer provides hydraulic actuation products serving off-highway markets. Auburn Gear, of Auburn, IN, manufactures planetary gear drives and differentials for agricultural, construction, specialty equipment and automotive OEMs and aftermarket.



Craig Wisner.

AMT

ELECTS BOARD AND OFFICERS

The Association for Manufacturing Technology elected its 2009-2010 officers and directors at its annual meeting in Orlando this October.

The board of directors of AMT represents more than 400 American manufacturers of machine tools, manufacturing machinery and related products. The board elected Daniel D. Janka, president of MAG Global, Hebron, KY as chairman. Janka comes on the heels of Ronald F. Schildge, president, Eitel Presses, Inc., Orwigsburg, PA. Schildge will serve the association as an ex-officio member of the board.

The board also elected Eugene R. Haffely, Jr., COO, Assembly and Test Worldwide, Inc., Dayton, OH, as first vice chairman. Second vice chairman and treasurer is now Timothy B. Dining, president and CEO, Greenerd Press and Machine Company, Inc., Nashua, NH.

Kim W. Beck, president and CEO, Automatic Feed Co., Napoleon, OH, continues in the role of secretary. Steven R. Stokey, executive vice president, Allied Machine and Engineering Corp., Dover, OH, was elected to a three-year term as a member of the board of directors. Carl Reed, president and CEO, Abbot Workholding Products, Manhattan, KS, was reelected to another three-year term as board member.

MP Groups

ELECT OFFICERS

Michael E. Lutheran.

Michael E. Lutheran, vice president of United States Metal Powders Inc. (USMP), of Flemington, NJ, was elected president of the Metal Powder Industries Federation; and Barton White, president of SCM Metal Products Inc., of Research Triangle Park, N.C., was elected president of the Metal Powder Producers Association.

Lutheran follows Mark C. Paullin in the position. Paullin is president and CEO of Capstan, Gardena, CA. Prior to joining USMP in 2007, which was formerly U.S. Bronze Powders Inc., Lutheran was senior vice president of North American Höganäs, Inc., Hollsopple, PA. Previously serving as president of MPPA and a director of APMI International, the PM industries professional society, Lutheran has a degree in metallurgical engineering from Penn State.

Before joining SCM in 2004, White served as vice president and general manager of AMPAL Inc., Palmerton, PA. He holds a bachelor's degree in chemistry and a master's in business administration from Concordia University in Montreal.

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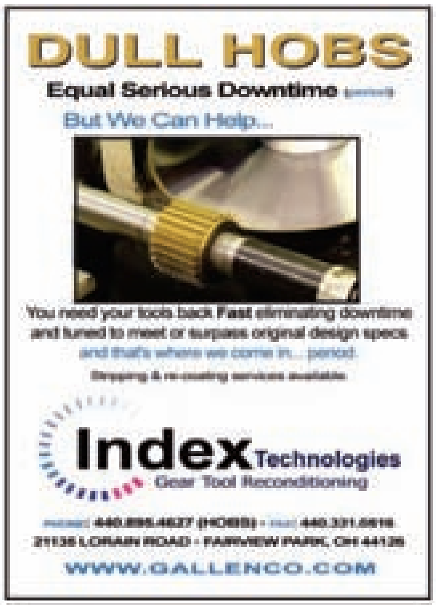
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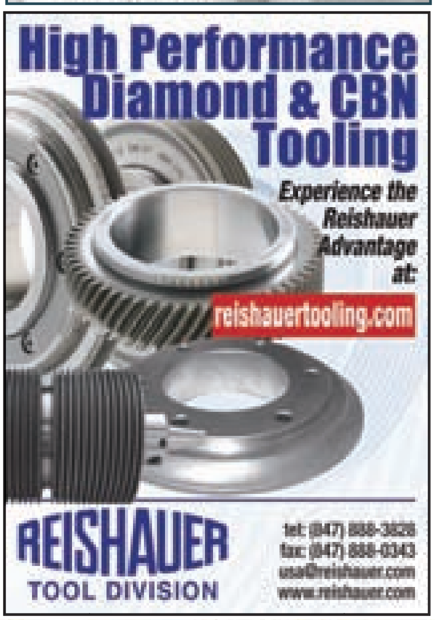
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REASSEMBLING GEAR DRIVE HISTORY

Getting rid of personal mementos is an arduous housekeeping ritual for some of us; every last gear has a memory. One man's trash is another man's gold, after all, or in some cases, one failed business is a forgotten piece of personal and mechanical genealogy. Such is the case of the Hill-Climber chainless bicycle, the remains of which were pulled from a family junk pile after nearly half a century.

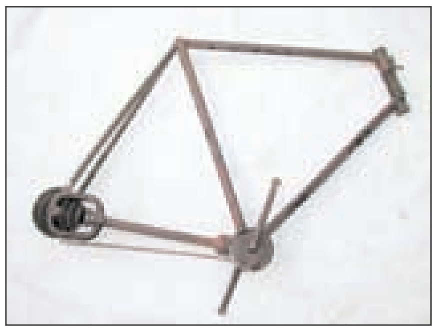
The Hill Climber's patented three-speed shaft, changeable gear drive assembly occupies a special place in transportation history as the first model of its type to appear in North America. The gear drive was pretty high-tech for 1902, but many bike historians and enthusiasts are unaware it existed. The story was only recently unearthed by a descendent of one of the original investors. What began as a mysterious paper trail found in 2003, led Al Tietjen on a journey to unearth a relic of both gear technology and his family's history. [*Ed. note: Full details are documented in a memoir penned by Tietjen, "Restoration," which is available from Amazon*]

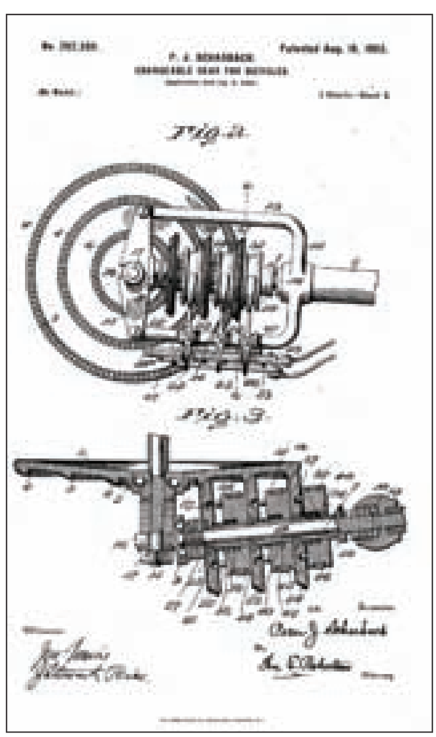
Tietjen recovered the basic frame assembly of the bike from his uncle Louie Muller, and he eventually discovered most of the critical components necessary to reassemble it from a crawl space in the farm garage. "The bicycle remnants I received had the gear mechanisms and clutching devices fully intact, though the bearings in the crank assembly were missing," Tietjen says. "I did not even need to disassemble the drive train, merely clean and lubricate it externally. This was fortunate, as I would have had to manufacture some special tools to take it apart and reassemble it."

Gear engineering is not Tietjen's area of expertise, so he was lucky the restoration project didn't require him to machine any parts. One exception was a missing crank assembly adjustment ring, which he learned had a non-standard size. A nephew of his was learning machining techniques in school, so he was able to make this part with help from his teachers.

As a former architect and graphic designer, Tietjen didn't have trouble reading the complex patent illustrations recovered, and he could tell they were cutting edge. "What is noteworthy about the configuration is that it was an improvement over other single-speed bevel-gear shaft drive bicycles at the time, in fact, certainly the first multi-speed bicycle of any kind, to be produced in America," Tietjen says. "Though its production and ultimate success was severely hampered by market conditions in the bicycle trade at this time, it would have been considered the 'top-of-the-line' in this product category."

Historically, as the Hill-Climber was developed and marketed around 1902, the transportation industry was on the verge of dramatic transformation. With the advent of the automobile and its mass production, the Hill-Climber's advanced





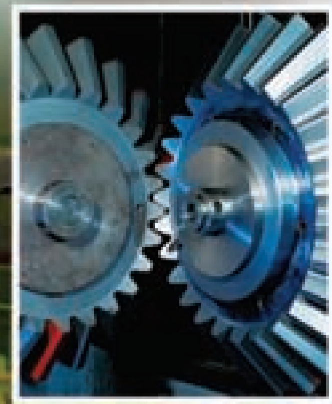
gear assembly was probably doomed from the start. "The bicycle industry was in a downward spiral," Tietjen notes. "Between 1900 and 1903, roughly two-thirds of manufacturers just dropped out of the business. The remaining big players put together a consortium to prop up prices, and that failed too. It was going downhill fast. Automobiles were right there ready to be developed."

Tietjen's research, with help from his brother William, led him to conclude that the Hill-Climber's original inventor, Peter J. Scharbach, was in tune to these transportation technology trends rapidly advancing. There was a line in Scharbach's manufacturing partnership agreement that stated they would eventually produce autos and other equipment. "Scharbach had the prescience to know there were other things they were going to make," Tietjen says.

Sadly, the biggest mystery that remains is why the Hill-Climber Manufacturing Corporation ultimately failed. Tietjen has entertained many theories, and the most likely scenario is that for one reason or another, they simply ran out of money. The inventors would have undoubtedly been proud to know their original design appeared on the street a century later. Although it exists mainly as a historical object, Tietjen did manage to ride the restored Hill-Climber. "I put it back together and rode it around the block," Tietjen says. "It was fun; a little scary because it was so old. The gears worked, you could change them, and you could see how it would have been an interesting ride in 1902.

"What I came away with was a new view of 'technology' at the time, and the ability of small-scale machine shops (mostly former blacksmiths) to produce a high-quality product that they hoped to mass-produce," Tietjen says. "Machine tool technology and general knowledge was pretty far advanced. There were a great many blacksmiths who were making the transition to becoming machinists through bicycle production, automobiles, airplanes and small motors applied to a variety of tasks. There were multiple 'revolutionary' ideas that came together at this time that determined the course of the next century."

To learn more about the Hill-Climber restoration project, visit *www.fusionstudios.com/hill-climber.*



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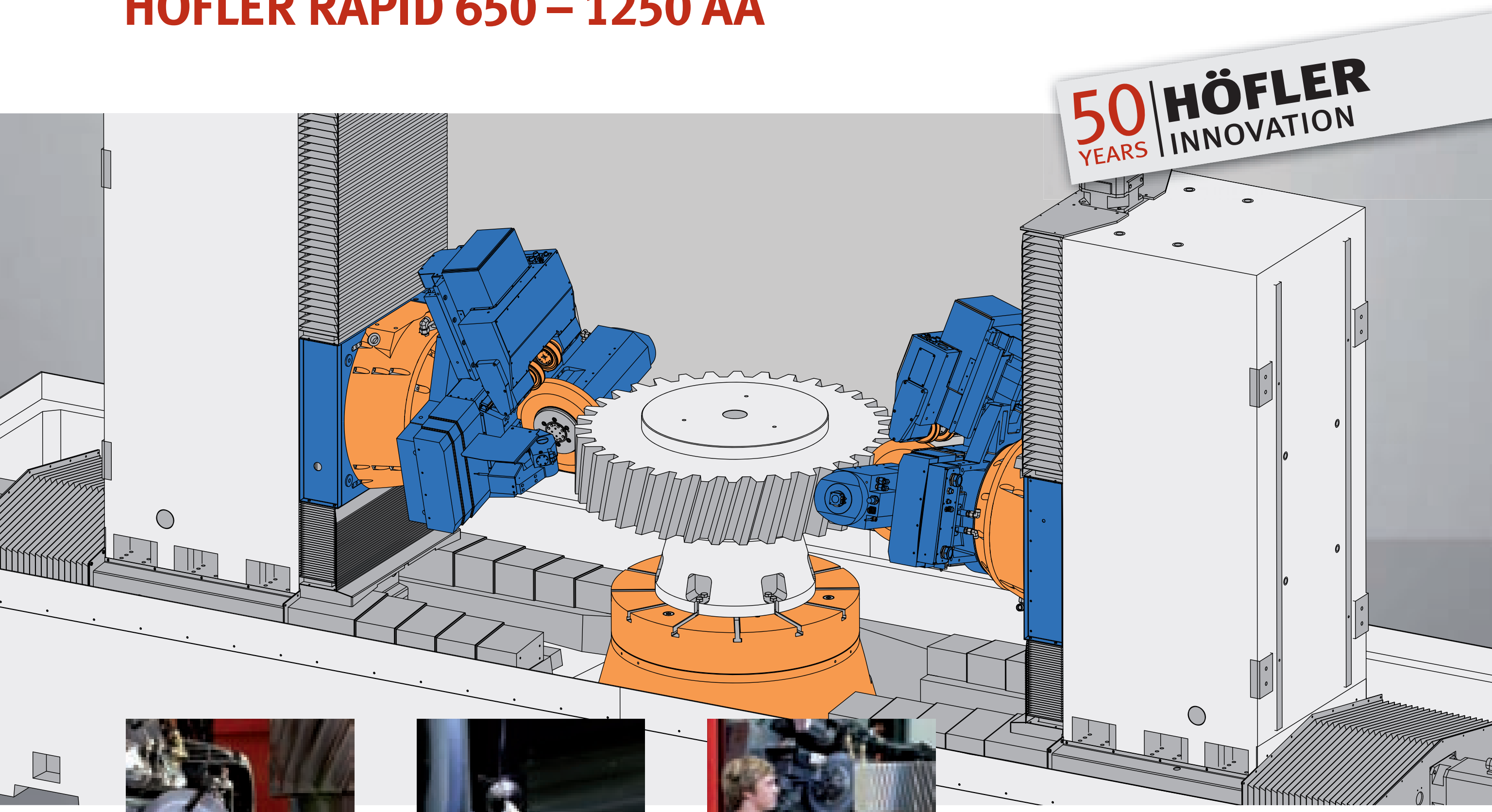

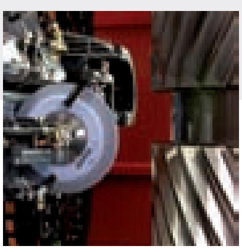

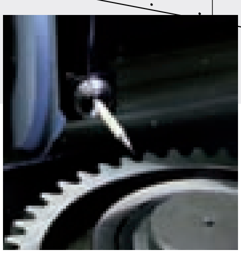

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