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GEAR TECHNOLOGY

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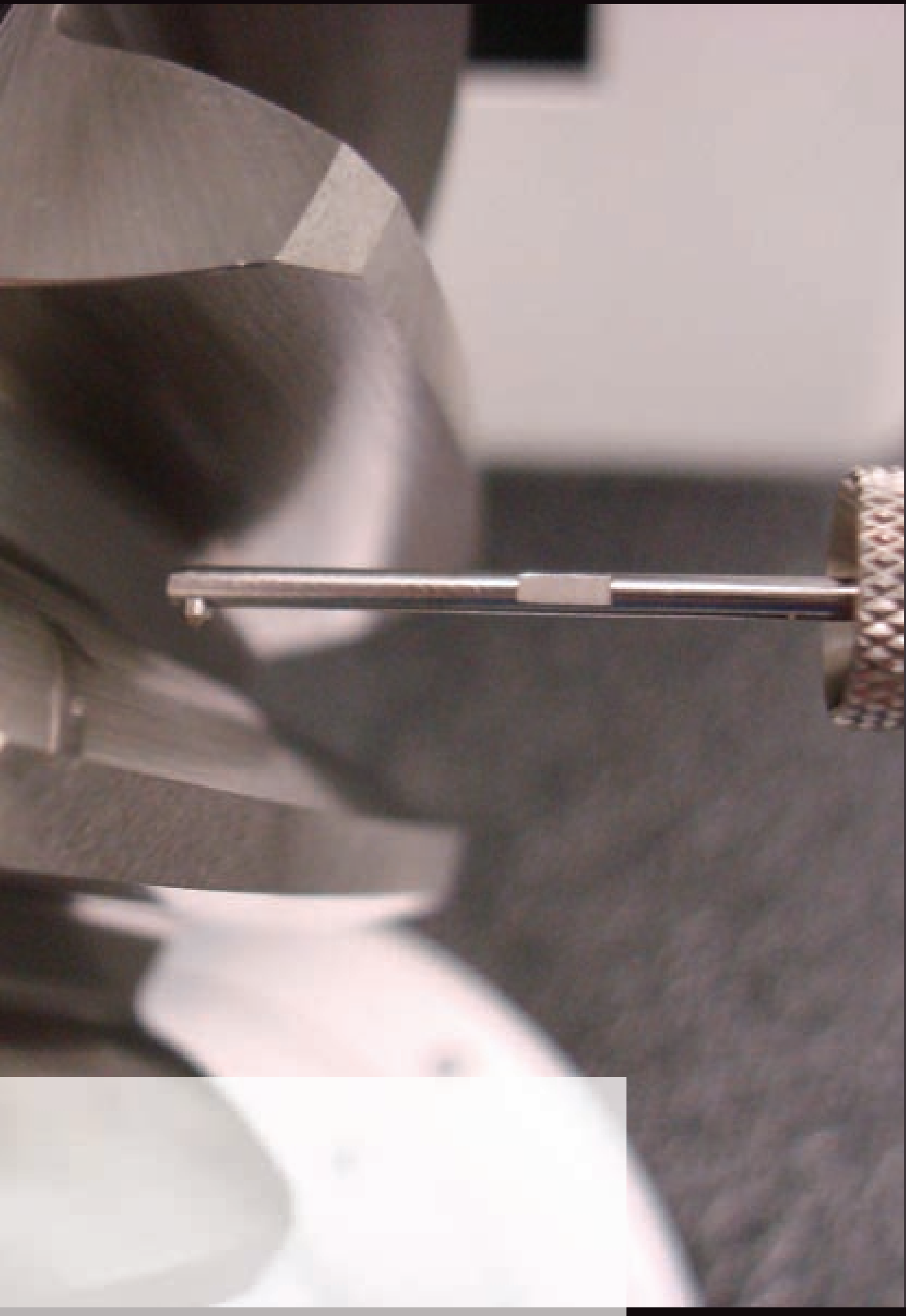
The Journal of Gear Manufacturing



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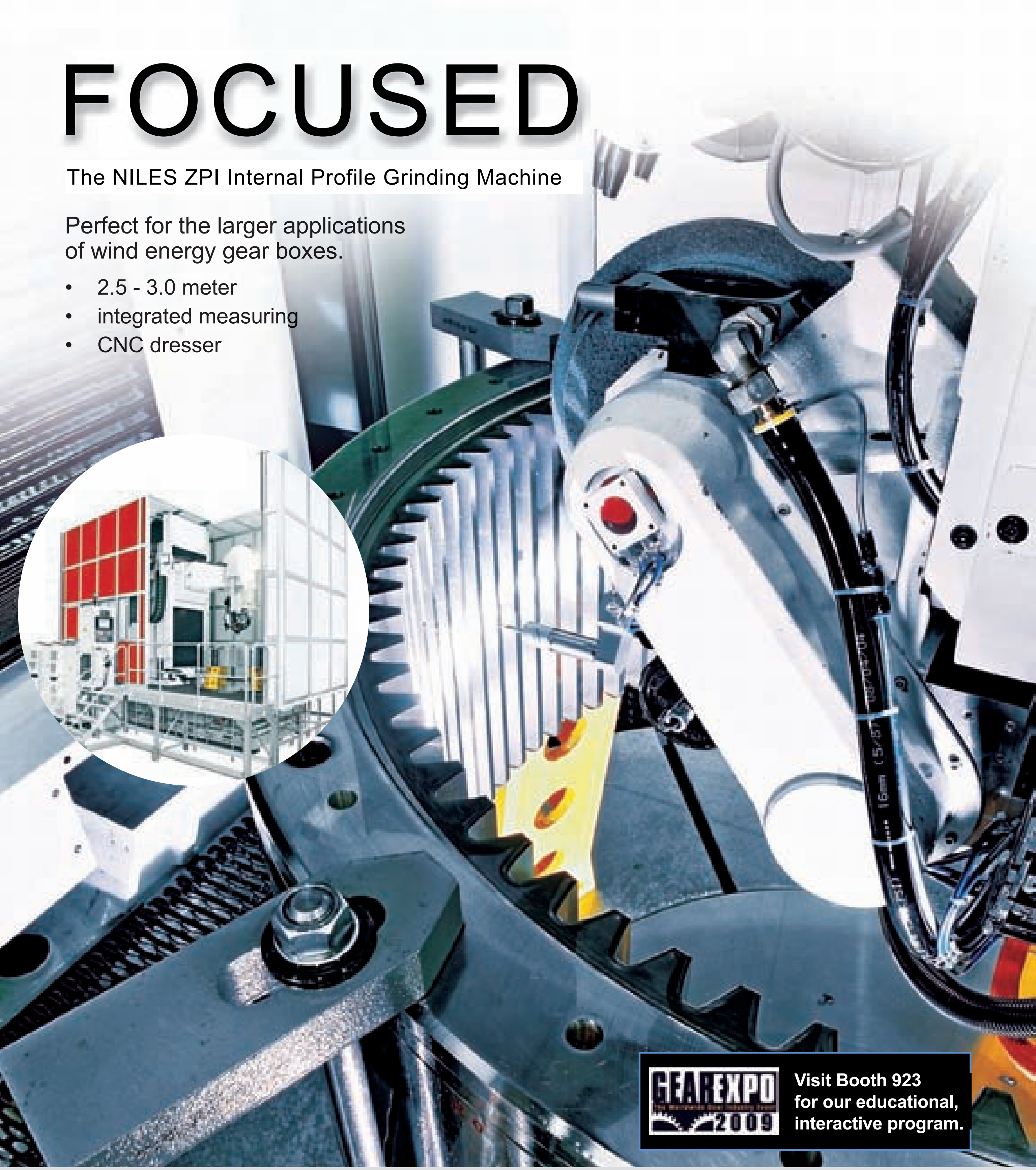

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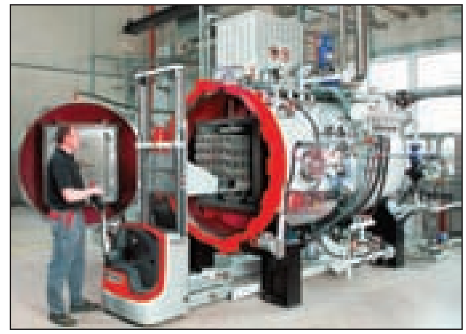

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Crossroads and Transitions
Part II

The auction has been held. The warehouse is bare. The computers and furniture are being packed, and Cadillac Machinery, the company started by my father in 1950, and of which I was president for more than 25 years, is close to being no more.

Gear Technology and *Power Transmission Engineering* magazines have been sold. They'll now be published by Randall Publications LLC, with me as the sole owner. The end of Phase I is now almost complete.

Questions abound—Why? What happened? What went wrong? Did the market take its toll?

The answers are simple and hopefully understandable and exciting, as I now plan and look forward to Phase II of my career. I enjoy very much what I do, including the people I meet and do business with and the places I go. I love the changes and challenges that have been part of *Gear Technology* magazine and our websites, providing a place where people and companies in our industry can read about the latest knowledge and technology. I'm proud we're able to give you, our readers, a resource on how to do your craft better, faster and at a higher quality, and I'm grateful for the support of our advertisers, who continue to recognize the value of our rifle-shot focus on the worldwide gear community. Although the name of our publishing company has changed, nothing about our dedication to quality and focus on our readers will change.

On the other hand, my involvement in the machinery business is going to change significantly. Unlike my grandfather, who had my father, who in turn had me, there are no heirs to continue the warehouse-style business of Cadillac Machinery that has been so good to my family. I watched often as my grandfather's and father's colleagues worked until they died, leaving their wealth in iron for their widows and children.

Two years ago, I thought I could and should plan better for my family's future.

As I said in my editorial about Phase I, Cadillac Machinery is retiring from the gear machinery business, but Michael Goldstein is not. I'm just evolving to reflect the changes in the marketplace and the place that I'm at in my life. I've created some new companies that should help both suppliers to the industry and gear manufacturers.

First, I'll continue buying and selling gear equipment, tooling and accessories under Goldstein Gear Machinery LLC. Visit my website at *www.goldsteingearmachinery.com* to learn more.

Second, I will be starting a new marketplace—the Gear Machinery Exchange—for secondhand but first-class machinery. The Gear Machinery Exchange will become the central worldwide marketplace for used gear machines.

In the past, to move from one generation of machine to the next, you often first needed to get a buyer for your machine, both to free up floor space and provide extra capital. In those cases, you often found a dealer, like Cadillac Machinery or Goldstein Gear Machinery, who would buy it and take it away, at great expense in rigging, transportation, reassembling, running and warehousing, expenses that brought no value to the seller, the dealer or the eventual buyer. The seller got a low price and the buyer paid a high price with much of the difference lost to everyone.

Now, through the Gear Machinery Exchange, you'll be able to expose your future surplus to the world, and the seller can get closer to retail and the buyer can get closer to wholesale. My father would point out that in the '50s and '60s, many of General Motors' ads for Cadillac automobiles were actually for used cars. If the new automobile buyer could get more for his used car, then he could afford to trade in for a new car more often. If you can get more for your used equipment, you can buy the latest technology more often, and the used buyer can buy later, better quality equipment at a lower capital cost. The Gear Machinery Exchange will be offered by Goldstein Gear Machinery and operated in conjunction with my second new company, Gear Machinery Trading LLC. Gear Machinery Trading will act as a broker, but also will be providing gear equipment appraisals and organizing auction sales of gear departments and companies, which require our unique knowledge and mailing list.

The third and final part of Phase II is Gear Machine Repair, a new venture that will be involved with the repair, refurbishing, maintenance and troubleshooting of gear machine tools. My longtime employees, David Gassner and Janusz Lewandowski, have extensive knowledge of gear equipment, and because of nearly 60 years of specializing in this machinery, I have probably the finest library of repair books and operator's manuals at their fingertips. Maintenance is maintenance, but repair of gear machinery is highly specialized and unique, so Gear Machine Repair is for hire (in the Chicagoland area, for now).

I look forward to talking with many of you about all these changes. A great place to do so will be at Gear Expo, which takes place September 15–17 in Indianapolis. We'll be in booth #1241, along with our espresso machine and coffee bar. Stop by and talk over a cup or two.

In the meantime, you can contact us via e-mail at *publisher@geartechnology.com*, or if you're interested in my new gear machinery ventures, *michael@goldsteingearmachinery.com*.

Sincerely,

Michael Goldstein
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Optimization through Customization

John Walter, president and CEO, Precipart Corporation

Abby Dress, associate professor, Long Island University

Many engineers and purchasing agents think it is more expensive to custom design a component or assembly these days when often customization can save on total costs. How can this be when an off-the-shelf unit typically is less expensive than its custom-produced counterpart? The varying answers to that question have led more and more manufacturing engineers to consider customization routinely as part of their design process. They have found that a decision to customize a part or develop a custom design for a complex assembly can yield the most cost-effective and optimized results without compromising design integrity.

Precipart was contracted to produce a custom design using non-magnetic materials for a national research laboratory (courtesy of Precipart).

Standardization or meeting an industry standard assumes a lower level of risk, since the part is available from multiple sources. Lowered risk can also mean reduced product inconsistencies and higher reliability. This is due to the fact that standard parts have been tested in different applications over time and have accrued a proven record of specifications and predictable performance. Taking these factors into consideration, the standard seems to offer what at the outset appears to be a quicker, easier and cheaper solution for an application.

While this seems simple enough, just because a part is called standard does not imply that it is in stock. It means that its specifications are standard and often the manufacturer must schedule and produce an order. Since this may not meet the desired timetable, a custom alternative still may be worthwhile. It may fulfill the requirement better within a suitable schedule.

So, when is customization appropriate?

An off-the-shelf component has limits on size, performance and specific operating environments. Today's companies, particularly those seeking innovation and an advantage over their competition, may find that a custom-built solution can actually provide a lower total cost in the end.

First, when a standard unit is taken from stock that requires some level of modification in order to meet a specification, it becomes a custom unit. Simply re-lubricating bearings to meet specific performance specifications also customizes what once was a standard unit. Or, replacement of bearings for higher grade or tighter tolerances for less radial play and longer life means that the customization effort has begun. However, it should be noted that as several standardized parts are used to achieve desired results instead of one customized part, there are more opportunities for failure. The implication here is that a custom design might use fewer parts, which means fewer errors.

Constraints on space also may be an important consideration for customization, especially when performance is tightly toleranced or needs to be maintained. If a standard part or assembly is specified for a project with a small envelope just to save dollars, it may cause rebuilding across other subassemblies, thereby increasing the costs of engineering and time. The old adage that "time is money" frequently comes into play in regards to development time. However, a custom-house engineer often is equipped with the requisite expertise

continued

to solve specification problems right from the beginning and resolve manufacturability in advance of the production stage, so timing may become a non-issue.

Even materials may need to be changed to meet performance expectations. Precipart, for example, was contacted by a major national research laboratory that had received funding to test magnetic fields and study how they were disrupted by nonmagnetic entities. The testing protocol required a vane that was moved in the magnetic field by a drive system. Common speed reducers typically incorporating magnetic steels could not be used. Precipart was contracted to produce a dimensionally standard design using all nonmagnetic materials, including brass housing, vespel gears and a beryllium copper retainer ring to achieve the desired specifications. This was a win-win situation for the laboratory and the project.

Another point sometimes used against specifying custom parts is that they typically require tooling or fixtures. While this may appear to be an added expense to production costs, the custom part actually may provide a competitive advantage for the entire assembly phase. At the same time it may deliver benefits to customers in achieving higher performance without any compromise. Many times these kinds of upfront, nonrecurring costs typically are amortized over a large volume order, which then makes any added cost negligible, especially if there is potential for repeat business.

Customization must be a serious contender when standardized components are reviewed and analyzed by management. Typically, they'll weigh the costs and benefits of a buy or customized decision. It may appear that initial outlays are small for the in-house alternative, but then there are purchasing costs that include purchase orders, inspection and inventory holding costs. Additionally, manufacturing costs, such as labor, benefits, workstations and floor space, must be accrued to the assembly phase. On the other hand, outsourced customization may offer solutions for total cost reduction and control without any compromises in performance.

In another example, a medical device manufacturer decided a review of its medical drug delivery system that used a pair of catalog gears in its original design was necessary. Since these plastic gears were molded rather than machined, the unit's variation was inherently greater than what would have occurred with machined gears. As a result, the variation was translated into unacceptable output performance. A subsequent feasibility study undertaken by Precipart engineers determined that the worm gear produced the most variation. The study further found that replacement of both gears would not be necessary, but that a newly installed worm with machined specifications could provide the desired predictable outcome. This small difference in design made a large difference in performance that became acceptable to the manufacturer.

Some project managers believe customization causes lead times to increase. While this is true in certain instances, standard parts or assemblies may not fully fit the total design requirements. Although lead times for custom products can run somewhat longer initially, subsequent deliveries become routine. An experienced supplier can eliminate problems and non-conformance issues in the outsourced engineering phase and production process so that when the custom solution is delivered, it is ready to install.

Customization most often provides value to the original equipment manufacturer. In the field of medical devices, most devices actually mature at an accelerated rate and are constantly replaced by improved designs that are usually smaller and multi-functional. At the same time, these devices provide higher levels of reliability and accuracy. For example, some diagnostic technologies, such as cardiosonography, were performed originally with relatively primitive devices due to their size and accuracy. Current designs, which are more streamlined, require expertise to achieve their unique design and manufacturing technology. They must be developed and constructed using non-standard components.

Customization should not be considered a last or high-end choice, but instead should be evaluated as a highly appropriate option when the commercial market cannot offer the size, performance, weight or material required for a cost-effective and timely solution. Perhaps engineers should take a cue from the British, who have a better term for customization. They call the resulting products "purpose-built" designs.

Exactly right.

For more information

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A custom design unit from Precipart incorporated a brass housing, Vespel gears and a beryllium copper retainer ring to test magnetic fields and study how they were disrupted by nonmagnetic entities (courtesy of Precipart).

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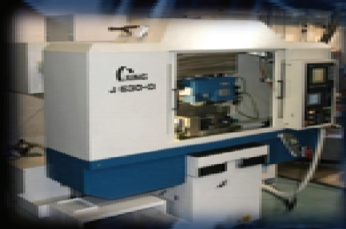

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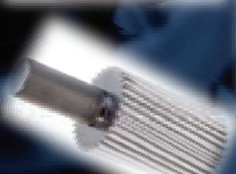

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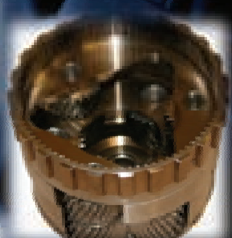

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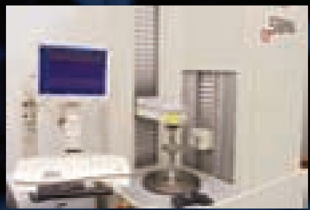

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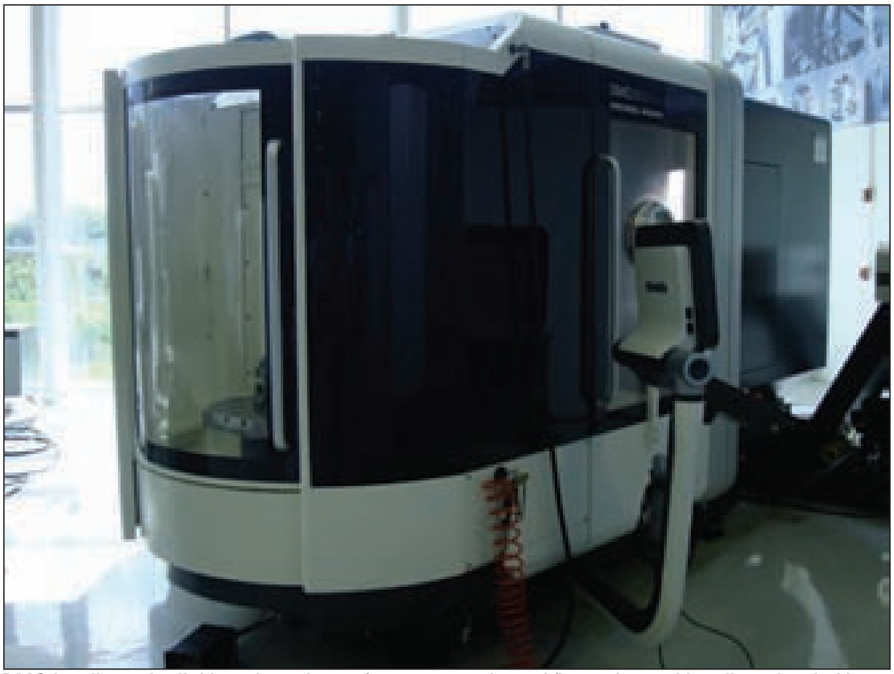


DMG has the potential to cut any type of gear on a universal five-axis machine, though spiral bevels have been the focus (courtesy of DMG).

Imagine the flexibility of having one machine capable of milling, turning, tapping and gear cutting with deburring included for hard and soft material. No, you're not in gear fantasy land. The technology to manufacture gears on non-gear-dedicated, mult-axis machines has existed for a few years in Europe, but has not yet ventured into mainstream manufacturing. Deckel Maho Pfronten, a member of the Gildemeister Group, took the sales plunge this year, making the technology available on most of its 2009 machines.

The initial focus bringing this technology to market stemmed from increased demand for energy applications, wind primarily. Spiral bevel gears have been the most common type produced using these machines, but DMG is capable of manufacturing many other types as well, including internal and external spur gears, helical and double helical gears, straight and spiral bevel—both the Klingelnberg cyclo-palloid and Gleason types—and hypoid gears.

The potential exists to make most any type of gear using this method, but the technology is so new that DMG has not yet touched upon all the possibilities. They rely on the customer to present them with a blueprint to proceed. DMG has developed software for creating the 3-D data necessary for production of high accuracy gears.

"We have developed very accurate, very specific software to calculate the tooth geometry," says Dietmar Haberlag, product sales manager for DMG America.

The gear milling software consists of several modules for design, CAM, simulation, measuring and training. DMG intends to have the components merged into one software package by EMO in October, at which time they also expect the interface to have a new, more user-friendly look, and an application for programmers. The concept for the software was prompted by some of DMG's customers who approached them with numbers and nothing more. "The idea was because not every customer is able provide the necessary gear design information data," says Albert Schäftner, team leader of the five-axis group for Deckel Maho in Germany.

The design module is a program for calculating the tooth geometry. It serves as an interface for gear data entry, designing fillet radius, defining gear backlash and profile correction and engaging simulation and collision monitoring.

The CAM module is responsible for defining tool geometry, creating roughing and finishing functions, and it serves as a post-processor for the five-axis machines. The simulation module replicates the part process. It represents the turning part geometry, provides gear geometry output, optical simulation of machine movements, optical collision check and analysis of working travels.

There are also optional modules for measuring and training. The CMM module measures data output in Deckel Maho format; other formats are possible by request. The training module offers startup, process and technological support. DMG is currently offering extra support for customers in order to cut the learning curve. They plan to make improvements based upon customer feedback and requests.

"Gear experience is not our technical expertise," Schäftner admits. "We have to rely on the customer for [this] knowledge. That's how we approach our goals."

The gear milling capability is not a retrofit option, although this may be a possibility in the future. Most of Deckel Maho Pfronten machines will be equipped for cutting gears with a

Most new DMG machines can be equipped with the gear milling technology (courtesy of DMG).

few standard options, such as a B- or A-axis, touch probe, Blum laser and 3-D quickset.

This technology essentially launches DMG's entry into the gear market, but they do not have any illusions about where they stand competitively with the industry's big machinery players. Haberlag is quick to draw a distinction between what DMG is trying to do with this technology as opposed to what a Gleason or Klingelnberg does.

"We are doing this on a five-axis machine, which is different to that which a main manufacturer like Gleason or Klingelnberg is doing. They are making this on a special purpose machine. We are doing this on a multi-tasking machine. This means on that machine you can make a turning process, you can make the milling, drilling, the tapping process and gear finish machining process in hard and soft material condition," he says.

"We are not so much in the field of mass production. We are more for multiple model types, less batch sizes, for very large parts. We don't take their business away; however, we are offering a much higher benefit in many fields."

The biggest appeal to manufacturers with this is that it provides them with the capability to use a machine to cut gears and other parts as well. So there is much more flexibility for manufacturers that produce parts that include but are not limited to gears.

"Gleason and Klingelnberg are only in the field of gear machining," Haberlag says. "We are in a very wide field. Gears are just a small part of our business. We are trying to get more because we are seeing particularly in the field of wind energy, spiral bevel gears, larger gears. It is much more economic to make them on our universal milling machines than on standard gear machining models. The idea is to use a five-axis machine with standard tooling and all the features of a machining center or universal mill-turn machine.

"Klingelnberg or Gleason, they need special tools, very expensive, very long delivery and only for this particular gear profile."

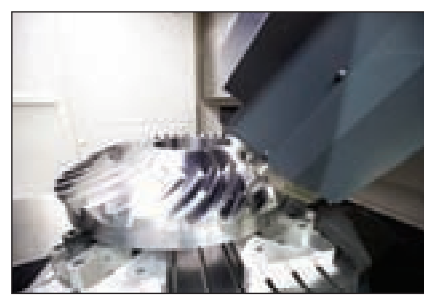
The consensus among some gear makers is that the technology is new and in an experimental stage, but there is definite potential for the industry.

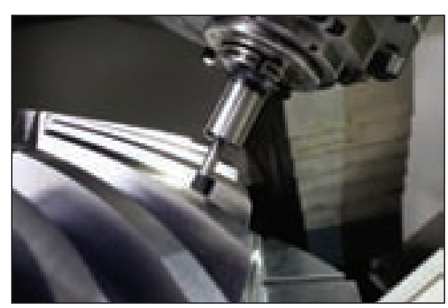
Louis Ertel, president and CEO of Overton Chicago Gear, takes a cautious, wait-and-see-stance. "It's all a question of how fast they can do the machining and how accurate and how good the surface finish is," he says.

For Larry Delp, manufacturing engineer for Fairfield Manufacturing, "The size of the machines that we have or they are capable of producing would be of interest to us.

"[The larger equipment] would give us some larger capabilities for bevels,

continued





also hard-finishing capabilities. Also you get big parts that have hubs or areas that a face mill-type cutter wouldn't be able to go through, so you can do some things a regular bevel type machine can't do," Delp says. "It's interesting. Looks like it has a ways to go on the technology and maybe the software, but I think it has certainly got potential."

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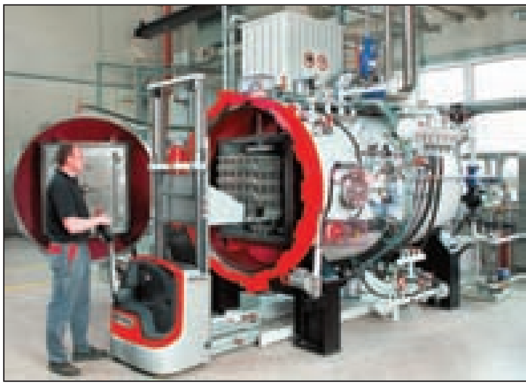

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For more information:

ALD-Holcroft Vacuum Technologies Co. Inc.
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CMM Arm Scanner Combination

LEVERAGES MULTIPLE PLATFORMS

Hexagon Metrology's combination laser scanning metrology package includes a Brown and Sharpe Global Performance bridge CMM with a Romer Infinite 2.0 seven-axis portable arm with ScanShark V4ix laser scanner. The package is plug-and-play, and both systems can be swapped. A TESA kinematic joint is responsible for the system's compatibility. The joint is shared by all Romer scanning arms and TESASTAR-m equipped bridge machines.

"This package leverages several existing Hexagon brands and technologies into one complete package offering," says Eric Bennett, product

continued

manager for bridge products. "There are definitely times when scanning with an arm is the fastest and most effective technique, for example, when the part is large and must be measured in place. Conversely, if you have lots of smaller identical products you would like to scan repeatedly, then it is useful to set up a program to scan batches of them automatically. With this package, you don't have to choose between one or the other."

A shared system such as this one can work as an inspection system while performing reverse engineering and 3-D point cloud gathering tasks. Both machines can perform point-to-point inspection without attaching the scanner. This means they both can be used simultaneously, regardless of which is using the laser scanner.

The shared scanner package comes with a Brown and Sharpe Global Performance bridge CMM (nine standard sizes available), a Romer Infinite 2.0 seven-axis arm (six standard sizes available), a ScanShark V4ix probe, complete cabling, software and control boxes for each system, application software and a computer for each system. The packages can be shipped immediately.

"There was a time when the substantial investment in a laser scanner meant it came down to buying either the bridge machine or the arm," says Dave Armstrong, product manager for portable products. "With our offering, you don't have to choose, you can have both. Other systems where the scanner is integrated or the connectors are incompatible simply don't have this flexibility."

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Mahr Gaging Amplifier

PROVIDES ANALOG DISPLAY BENEFITS

The enhanced Series 830 Analog Gaging Amplifiers from Mahr

Federal are designed to offer a low-cost alternative to all-digital gaging amplifiers. They feature dual input ports for single or differential ID or OD measurements with selectable ranges in inch or metric units. They can be used with "Federal" or "Mahr" type inductive probes. It is available as portable or bench mountable and is rugged enough for the shop floor but equally compatible in the laboratory.

"Even though we live in a digital world, analog displays still offer advantages in a number of applications," says Paul Mailloux, manager precision gages for Mahr Federal. "Analog indicators instantly reflect true measurement size. They're easier to use than digital instruments and can more readily detect trends or rates of change."

Series 830 Amplifiers are suitable for both dynamic and static gaging applications. Common applications include part centering and leveling on machine tools, exploring a surface for defects on a surface plate, detecting part out-of-roundness on a V-block and machine leveling using level sensors.

A dimensional-measuring model calibrated in both inch and metric units is included as well as a model that supports both leveling and dimensional applications in arc-seconds and inches. These two models offer three measurement ranges and resolutions designed to suit most setup and inspection jobs.

The Series 830 features two gage inputs that can be used simultaneously with polarity either normal or reversed for differential measurement setups. Calibration adjustment is an option for each input. The amplifiers include a ±2 volt analog output port and rechargeable batteries with a minimum eight hours of continuous use in addition to the 120 or 240 AC line voltage the system operates on.

For more information:

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AGMA Tolerance Calculator

ASSISTS IMPLEMENTATION OF BEVEL GEAR STANDARD

The ISO 17485, Bevel Gears-ISO System of Accuracy standard was adopted by AGMA in 2008 to complement the library of standards for gear manufacturers and power transmission products. To help implement the standard, AGMA's Computer Programming Committee developed a tool to accurately perform the calculations necessary to determine the tolerances for the gear features.

This program supplements the tool developed to aid calculating tolerances in accordance with ANSI/AGMA 2015-1-A01 for spur and helical gears, which has been available to members for several years.

The standard ANSI/AGMA ISO 17485-A08 provides tolerances for single pitch, total cumulative pitch, runout and tooth mesh component single flank composite. The tolerance calculator determines the tolerance values for gears based on their geometry and accuracy grade.

The tolerance values in the standard are determined by equations based on tolerance diameter, mean normal module (diametral pitch) and accuracy grade. Alternate geometry is an input option due to the availability of mean normal module.

The calculator functions as an MS Windows-based program where users input the basic data for a specific gear geometry, run the program, and the software displays the values of all tolerances. The software is provided free of charge to AGMA member companies. It can be found at *www.agma.org/content/navigationmenu/publications/17485calculator/default.htm.*

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www.agma.org

Holroyd Grinder

PRODUCES SMALL VOLUME WITH HIGH PRECISION

Holroyd introduces the Gear and Thread Grinder (GTG2) for precise grinding of helical/spur gears up to 350 mm in diameter. The machine aims to meet market demand for accuracy in small volume for aerospace and automotive applications, industrial optics and custom designed industrial products.

The machine is capable of grinding master gears, precision prototyping, timing gears for aerospace applications and helical gears for high performance automotive gearboxes and oil pumps.

"The new machine draws on the technology and expertise gained by Jones and Shipman in designing and manufacturing precision creepfeed, surface and cylindrical grinding machines, and combines it with the specialist helical tooth and thread profile grinding expertise of Holroyd," says Tony Bannan, chief operating officer for Precision Technologies Group, parent company of Holroyd and Jones and Shipman. "The new machine is a relatively low volume machine that provides high accuracy with fantastic flexibility and very short set-up times thanks to a lot of onboard technology making it ideal for aerospace and specialist automotive applications."

The GTG2 grinder was developed in collaboration with the Gear Design Unit at Newcastle University. It features onboard software capable of complex forms and advanced profile results from fairly simple operator controls. One feature is stress prediction software, which optimizes gear design with profile and lead to result in optimum contact conditions for low noise and high strength.

"With precision 3-D scanning, stress

continued

prediction and many other features, the technology onboard this machine is ahead of anything else on the market for high precision gear grinding," Bannan says. "We ourselves have also used these machines to manufacture bespoke worm and helical gears, which has assisted in the development of such a machine, which coupled with feedback from research institutes and customers, we continue to develop our ongoing database of manufacturing experience and provide solutions to challenges faced by users of machine tools worldwide."

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Inova GMM

USES MULTIPLE SCANNING MEASURING PROBES

Wenzel Gear Tec introduced the Inova gear measuring machine at the Control Exhibition in Stuttgart, Germany in May. The Z-axis with its integral rotary table is positioned independently from the X and Y-axes of the Inova. Highly-accurate servo drives provide dynamic performance for all linear axes.

An integrated pneumatic vibration damping system isolates the machine base, so there is no need for a special foundation. The guideways are made of impala black granite.

The Inova detects grinding burn by using multiple scanning sensors including probes. The probes and sensors are protected from dirt and damage by a probe change rack that features a protective cover.

The basic Inova GMM includes a SP600 or SP80 Renishaw scanning probe, calibration sphere, three- or six-jaw chuck, CNC controller installed in a 19-inch cabinet with PC and power unit, LAN board for centralized network integration, software for online service and an integrated joystick for manual positioning and measurements.

The GMM can be equipped with a range of Wenzel gear measuring software modules for gears, gear cutting and finishing tools and grind burn detection. Workpiece diameters range from 5-270 mm. It is capable of measuring internal gear diameters greater than 12 mm. Gear face widths up to 500 mm and gears with helix angles less than 90 degrees are measurable.

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Heidenhain

Gages High Accuracy with SPC

The Heidenhain-Certo program combines the highly accurate Certo length gage with an ND 287 digital readout (DRO) with statistical process control (SPC).

The Certo is an established gage capable of a large measuring range, including high accuracy nanometer-level measurement. The system is suitable for inspecting parts with tight tolerances and gage block calibration.

The Heidenhain-Certo program measures gages in range of 0–25 mm at ± 0.1 µm accuracy/± 0.03 µm after error compensation, and 0–60 mm at ± 0.01 µm accuracy/± 0.05 µm after error compensation. Error compensation is stored by the ND 287 along with manual input of values from the accuracy chart included with the Certo length gage.

The ND 287 has a capacity for four inputs with varying interfaces and permits toggling between multiple gages, sensors and encoders. The SPC function allows users to write up to

continued

10,000 measured values to an internal memory and evaluate them statistically. Stored data is output via USB or RS 232 interfaces.

The gage stand ensures tight tolerances with shaft perpendicularity. A vacuum chuck is an optional feature that consists of a ceramic suction plate and diaphragm pump. It increases accuracy by cutting out air gaps during the metrology process.

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Pit Furnace Line Addition

DOUBLES PLANT'S CAPACITY

Elterma S.A., a member of the Seco/Warwick global organization, commissioned two electrical PEGat-1000/18x30 pit furnaces and a G-4000-ET atmosphere generator for a Spanish manufacturer of wind turbine gears.

The furnace and generator join other PEGat furnace products including an electrical PEG-750/18x30 furnace for tempering, a WHO-18x30 oil quench tank and a MKV2-18x30 washer. The equipment has doubled the plant's capacity, according to a press release.

"The advantage of the pit furnace is that the round gears can be stacked quite high in the furnace, and bridge cranes, a relatively inexpensive material handling system, maybe used for very heavy loads," says Gary Armour, project engineer. "Large loads are the best way to affordably process these long cycle (24–48 hour) parts."

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www.secowarwick.com

L&L Furnace

SHIPPED TO GOODRICH FACILITY

A model FB series fiber-lined box furnace was shipped to the Goodrich Aerostructures' Mexicali production facility by L&L Special Furnace Company. The furnace, the second Goodrich has purchased for this location, will be used to process aerospace components.

The L&L Special Furnace model FB668 was custom made with dimensions of 72" x 72" x 96" with a 3,200 lb load capacity. A motorized loader to facilitate material handling was included with the system.

The FB model series is designed specifically to meet ASM2750D specifications for pyromitry. The furnace can achieve temperature uniformity of +/-5 degrees Fahrenheit. A convection fan provides uniformity at low temperatures.

For more information:

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Phone: (610) 459-9216
Fax: (610) 459-3689
www.hotfurnace.com

Tru Temp Finish

PROVIDES LUBRICITY, RUST PROTECTION

Birchwood Casey Metal Finishes' Tru Temp finish is a low temperature, non-polluting black oxide that boosts lubricity and resists corrosion while providing a non-dimensional, deep black finish to sprockets, universal joints, sheaves and all other types of power transmission components.

The Tru Temp finish protects parts from galling and corrosion without impeding fit and function, even in tight tolerance assemblies. The coating doesn't affect material hardness or tensile strength, and according to independent tests performed, it can handle up to 100–200 hours of neutral salt spray (ASTM B 117) or several hundred hours of humidity (ASTM D 1748), as cited in a Birchwood Casey press release.

The glossy black magnetite coating is 0.5 microns thick. The Tru Temp coating operates at 200 degrees F and uses mild alkaline chemistry, so steel does not become brittle in the process. The finish is not made with any EPA-regulated chemicals, which eliminates the need for waste treatment equipment.

Processing time takes about 25 minutes. Most tank lines can be retrofitted for the Tru Temp solution, and the process can be automated by a CNC programmable hoist system.

For more information:

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info@birchwoodcasey.com
www.birchwoodcase.com

AC Option

JOINS BISON'S FLEXTORQ GEARMOTOR LINE

The FlexTorq 762 series hollow shaft offset AC gearmotors from Bison Gear and Engineering Corp. are single and three-phase AC motors added to gearing for face or foot mount and hollow or stub shaft. They are designed as high torque, tight space drives, and they feature either a 1.25 inch inside diameter hollow shaft or a 1.25 inch diameter solid shaft in either the u-shaped or s-shaped configuration.

The fractional horsepower gearmotors are driven by 1/20, 1/4, or 1/2 hp (37, 186 or 373 W) single- and three-phase 115 and 230 volt AC electric motors. They operate with fixed output speeds from 60 to 1 rpm and provide continuous duty torque outputs from 430 to 2,500 in-lbs (48.5 to 283 N-m).

"These new FlexTorq AC gearmotors are a nice complement to our DC FlexTorq offering and are ideally suited for a variety of conveying, food service and athletic equipment applications," says Jim Parejko, vice president of continuous improvement and engineering for Bison Gear. "We have added 15 standard models to our In-Stock, Instant-Ship (ISIS) program to support our distribution partners and can readily design variations to meet specific OEM needs."

The AC FlexTorq standard package includes two dual voltage (115/230) models, nine 115 volt models and four energy saving Verdant Duty three-phase models for use with variable frequency drives. Find complete specifications and CAD drawings for these units at Bison's website.

For more information:
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St. Charles, IL 60174
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info@bisongear.com
www.bisongear.com


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GEAR EXPO

Practical Magic

METROLOGY PRODUCTS KEEP PACE WITH MACHINE TECHNOLOGY

Matthew Jaster, Associate Editor

In addition to a full range of inspection equipment for cylindrical and bevel gears, Mahr Federal has updated its software packages (courtesy of Mahr).

Gear metrology is a revolving door of software packages and system upgrades. It has to be in order to keep up with the productivity and development processes of the machines on the manufacturing floor. Temperature compensation, faster inspection times and improved software packages are just a few of the advancements currently in play as companies prepare for new opportunities in areas like alternative energy, automotive and aerospace/defense.

Wind turbines—if you haven't heard—are growing at an extraordinary rate, no doubt keeping gear manufacturers busy in the foreseeable future. In turn, the components for wind power gears are currently produced to high quality standards throughout the world and the metrology must follow suit. The necessity to keep up with technology demands has allowed metrology companies to develop the kind of products and software packages that will continue to add value to new and existing customers.

Metrology Advancements

Klingelnberg has presented a number of metrology innovations in the past two years and will be introducing new items in the near future. The company has equipped its P 26 to P 100 gear measuring centers with temperature compensation that can now make measurements outside an air-conditioned measuring space.

"This means that these measuring machines can be installed on the production line, avoiding waiting times and long transportation distances for conducting necessary tests," says Günter Mikoleizig, manager design and

continued

development gear inspection machinery at Klingelnberg. "Many companies have already exploited this advantage in planning new gear production lines."

In addition, Klingelnberg has improved software for dimension, form and position measurements enabling engineers to test typical gear parts to almost 100 percent.

"The option for integrated roughness measurement represents a great advance in simplicity," Mikoleizig says, "with significantly improved conditions for reproducible results."

Mikoleizig adds that the company is offering additional advantages to metrology users.

"One substantial advantage of our products is that hardware and software components are developed by the same company, allowing us to realize customers' special requirements. In the bevel gear manufacturing sector, Klingelnberg supplies well adapted systems for a closed-loop solution."

Gleason-M&M Precision Systems is also working in conjunction with The Gleason Works on advanced development in closing the loop on gear processing for bevel gear manufacturers.

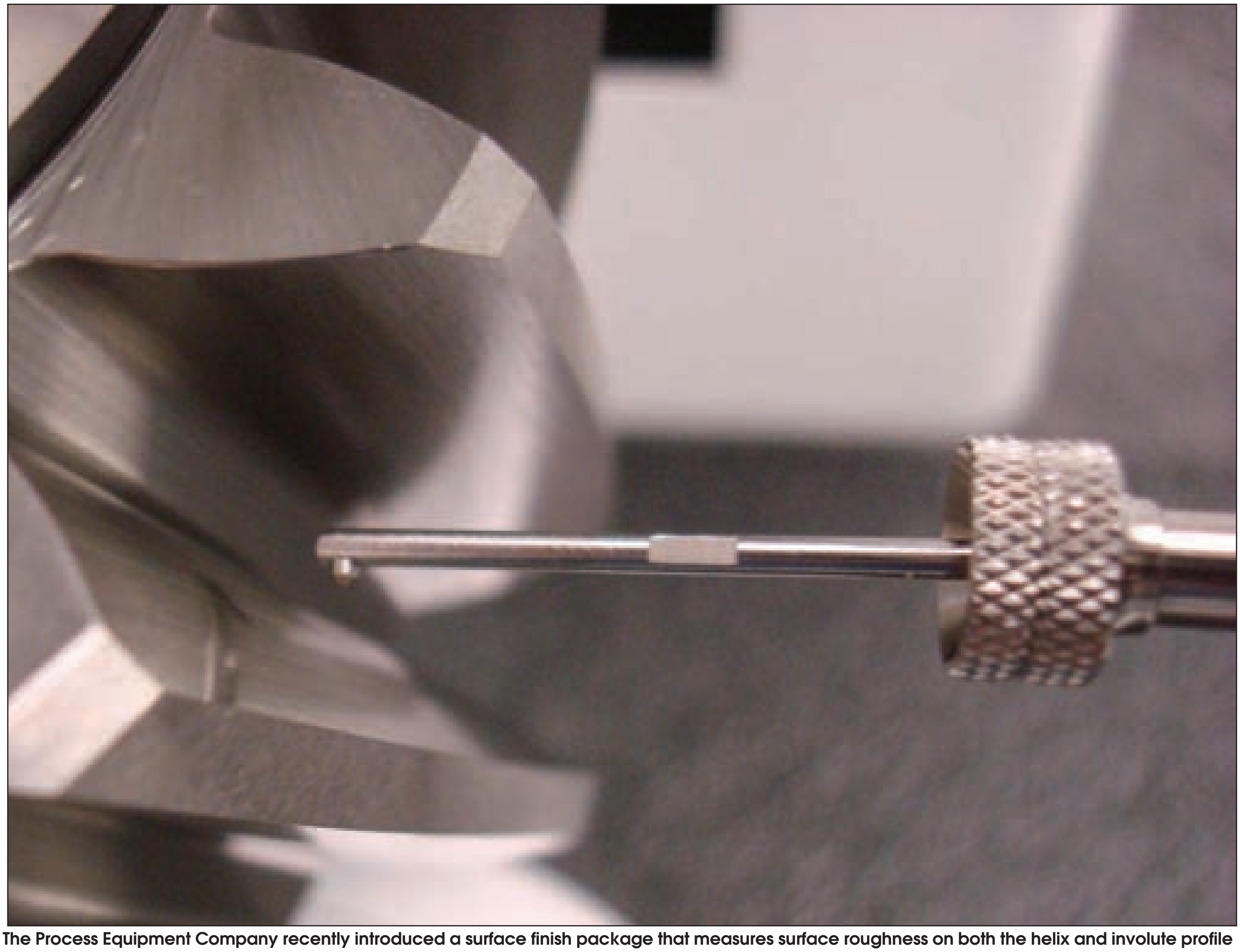
"This is where the Gleason *G-AGE* product and the Gleason-M&M *GAMA* measuring software work together," says Doug Beerck, vice president and general manager at Gleason-M&M. "We can send data back directly to the machine tool for automatic corrections to improve the manufacturing process of the gear."

Gleason introduced its *GAMA* Windows-based software package more than two years ago, and it's now working with the *G-AGE* package and the *CAGE* package for integrating the design, manufacturing and metrology processes into a single solution for the bevel gear manufacturer.

"*G-AGE* has historically worked with competitors' inspection equipment and we updated our software since our acquisition by Gleason to provide a seamless interface that allows both the inspection and bevel interface to work together," Beerck says. "As customer requirements change over time, both can be upgraded in a common path to add more features and capabilities and provide a complete solution from a single source."

Besides having a whole range of inspection equipment for cylindrical and bevel gears, Mahr Federal Inc. has completed its latest update on its software.

"We use *ESCO* software, which is globally used by many gear producers, to create a closed loop environment where our gear measuring machine



The Process Equipment Company recently introduced a surface finish package that measures surface roughness on both the helix and involute profile of a gear down to a 32 DP tooth size (courtesy of PECo).

Gleason-M&M is currently working on advanced development in closing the loop on gear processing for bevel gear manufacturers in conjunction with The Gleason Works (courtesy of Gleason).

provides the feedback for corrections to the production machine," says Lutz Berndt, product manager gear systems at Mahr. "We have also upgraded our machine software to allow our gauge head to scan the root radius on gears."

The Process Equipment Company (PECo) has introduced a surface finish package that measures surface roughness on both the helix and involute profile of a gear down to a 32 DP tooth size.

"Having the ability to measure surface roughness utilizing a skidless probe tip and our standard 3-D probe saves a tremendous amount of inspection time since it can be accomplished in one setup," says Brian Slone, business unit manager, metrology systems division.

The company is also focusing on fine pitch gear measurement and can currently measure index, helix, profile and tooth thickness on a gear with a 150 diametral pitch.

"This is the finest pitch that has been measured with any analytical gear measurement machine that utilizes 3-D probing technology," Slone says. "With the development of this fine pitch capability, manufacturers and customers no longer have to guess at the quality of gears that are finer than 64 DP. They are now able to measure all the way down to 150 DP."

continued

Crankshaft inspection from Klingelnberg allows accurate dimension, form and position measurements (courtesy of Klingelnberg).

Instant Data Equals Instant Results

Metrology companies are also focusing more on markets outside of North America and Western Europe, seeking opportunities in areas like China and India. The ability to manage a global presence is vital in every aspect of gear manufacturing, but when it comes to metrology solutions it's the driving force behind repeat business. Beerck says a key competitive advantage lies in Gleason's global support structure, especially in China.

"It's hard to imagine being a serious player in the gear metrology market without a global reach. The customers expect to be able to replicate their inspection processes no matter where they are located in the world. They have an expectation that their suppliers can support that replication," Beerck says.

The increased global support requirements include managing language, culture and time change factors. Technology allows Gleason to monitor inspection results in the field, look at global machines online and troubleshoot wherever need be.

"The ability to monitor machine performance and troubleshoot online from our Dayton, Ohio facility is invaluable," Beerck says.

According to Beerck, the required accuracies that come off the gear grinding equipment have improved significantly over time. "Some of this involves understanding the manufacturing process the customer is using, including workholding, environmental conditions and the tooling being used."

Mikoleizig at Klingelnberg says the global gear industry prefers established producers of measuring equipment so that it can confront critical discussions of its product quality.

"A new supplier in the gear metrology sector is bound to meet difficulties in gaining acceptance," Mikoleizig says.

Berndt at Mahr Federal adds, "Mahr has a lot of customers where the central purchasing department is making the sales decisions. These companies have production facilities and produce parts all over the world. Looking at all the metrology companies and the problems they face, for me personally, I would rather deal with a bigger company even if it meant I couldn't expect the flexibility of a smaller supplier."

Slone at Process Equipment describes the necessity of providing the same 24-hour response time no matter where the company is doing business.

"We've chosen our sales and service sites across the globe with companies that have been servicing their countries for years," Slone says. "They know the customer base better than anyone else and can successfully support their customer's manufacturing requirements at a local level."

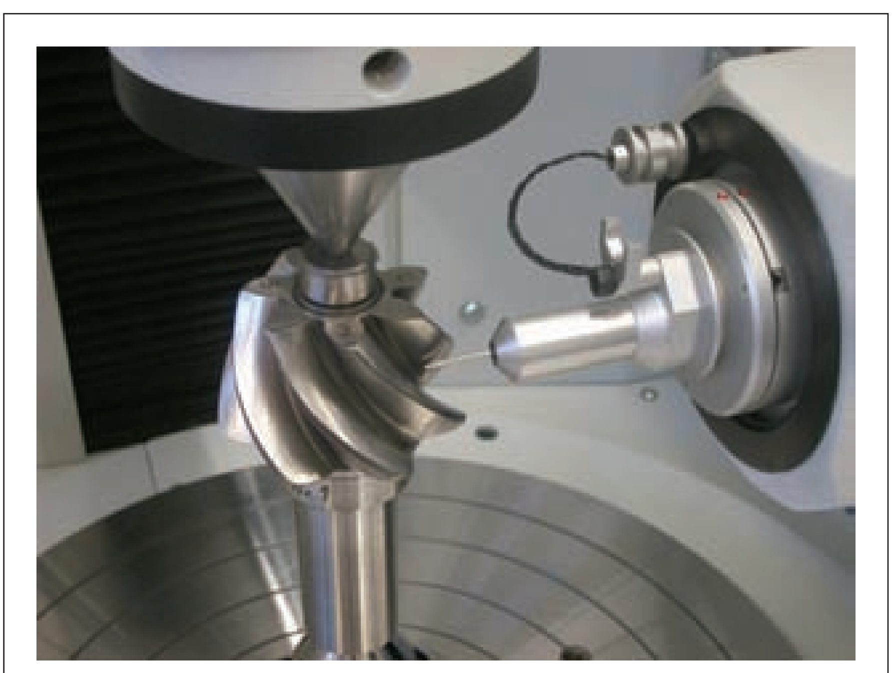
Process Equipment has partnered with tooling companies such as Star Cutter in the United States and SMF/Klink in Germany to develop extensive in-depth hob and broach inspection packages.

"Both of these companies are leaders in their fields and have vast knowledge of what needs to be measured to produce the highest quality gear tools," Slone says. "Their expertise helped us perfect our cutting tool metrology packages so manufacturers can benefit from the ease of use and the information needed to solve processing issues in their plants."

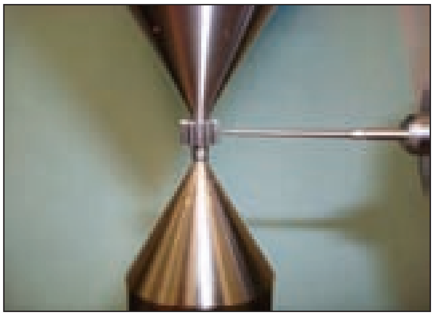
The interface between each program, from gear to hob to shaver is similar in nature, according to Slone. "This dramatically reduces operator training time and allows new users to inspect gears quickly and with confidence."

Gleason-M&M also has the ability to work with a variety of automation suppliers when needed.

"If a customer has a history with a specific automation supplier, we make sure our products can be integrated into the automation process," Beerck says. "The more players in the gear manufacturing industry, the more complexity, that's the biggest challenge—understand your customer and identify your customer's various process control needs."



Klingelnberg provides several software options for roughness measurements (courtesy of Klingelnberg).



Fine pitch gear measurement is another area the Process Equipment Company is focusing on in the metrology industry (courtesy of PECo).

Separating from the Competition

This leads us to the most intriguing aspect of the metrology industry to date—a push for much more customer service.

"Our service and support team go beyond customer satisfaction," Slone says. "We challenge Process Equipment employees to take this idea a step further with this question: 'Did you delight the customer?'

"At times it can be difficult to differentiate one metrology manufacturer from another since machine accuracy and repeatability is based on an industry standard. Our aim is to provide a gear metrology solution, not just sell an inspection machine. This is what separates us from the rest of the industry," Slone says.

Klingelnberg has seen positive responses from its customers concerning all its innovative developments, but the company always makes sure to stay in touch with its customer base for future software or hardware developments.

"In these cases, we try to find fresh solutions together with our customers," Mikoleizig says.

As a part of Sigma Pool, Klingelnberg also offers international gear seminars in order to work together with its customers on meeting new market and technology challenges. Many of these metrology developments were recently addressed at the Sigma Pool U.S. Gear Seminar held last month in Ann Arbor, Michigan. (*Ed's Note: Please refer to our events coverage on page 64 for additional information.*)

At Gleason, a complete support and service approach is the reason the

continued

AN EXPANDING MARKET FOR CMM GEAR INSPECTION

More than 200 Wenzel Gear-Tec machines are operating in gear manufacturing plants all over the world. The company has nine new bridge type measuring machine models for a variety of internal and external gear inspection applications.

"The technology for inspecting gears and gear related products is evolving as the application of CMMs with more sophisticated probing systems and software have made it a viable and less costly alternative to dedicated 4-axis gear inspection machines," says Hans Helmet Rauth, managing director at Wenzel.

Rauth anticipates that the gear inspection market will continue to grow with the expansion of CMMs into the field. "Using CMMs to inspect gears is not a compromise anymore. Their accuracy does not degrade from the smallest machine to the largest."

For many years, CMMs were not looked at favorably because it was perceived that the measurement accuracies were not good enough for gears," Rauth says. "That's all changed today with the advent of laser scanning probes with sub micron accuracy and new sophisticated software. We've been able to take our high degree of inspection know-how and experience and transfer the technology to the CMM."

Wenzel Gear-Tec recently installed a CMM at Vancouver Gear in British Columbia to inspect 9-ft-diameter gears for wind turbine gearboxes. The machine is a traveling bridge type design with a 19.68 x 9.84 x 6.56-ft measuring range. It is designed to use two three-meter measuring zones and has a 3.28-ft hydrostatic rotary table that can accommodate gears up to 3,000 lbs.

Another large machine was also recently installed at one of Liebherr's large construction crane manufacturing facilities to inspect large ring gears and bearings. Wenzel designed and built a special CMM machine that combined standard components and a proven dual-arm measuring technology with the precision air bearing mechanics of the Wenzel WGT series of gear checkers and Renishaw scanning probes. The inspection machine is capable of inspecting bearings and ring gears up to 19.68-ft diameter.

In the past, CMMs have been percieved as not being accurate enough for gears, but advances in software and laser scanning probes has changed this (courtesy of Wenzel).

Wenzel's dual arm gear measuring machine was designed to measure big gears (courtesy of Wenzel).

"In applying the use of CMMs to inspect gears we've discovered that there still remains a stigma among some gear engineers that CMMs are not accurate enough or the data they provide is not reliable. At Wenzel, our gear CMMs use exactly the same controller and software as our traditional WGT gear inspection machines. From a marketing standpoint, we refer to these CMMs as gear measuring machines (GMMs). As gear applications increase, the need for this special designation will most likely disappear," Rauth says.

Gear inspection in markets such as wind, aerospace and gear shops, has always been expensive, according to Rauth. "We've identified close to 6,000 gear shops in North America that are targets for a shop floor GMM gear checker with an embedded rotary table that could sell approximately for $100,000.

"But in the next five years, we will probably see more integration of gear measurement into the gear grinding machine itself, through the integration of scanning probes and new software. It makes sense to leave the gear right where it is to check it, and through adaptive control make the necessary changes on the machine to correct any detected machining errors. Of course, the GMM will still be required for final audit."

—Alan Hall,
industrialpublicity.com

company remains a significant player in every facet of the gear industry, including metrology.

"What we're trying to do is provide a complete solution for our customers. Whether it's Gleason's specialized gear services, dedicated gear inspection laboratory or our aftermarket support, our ability to provide a complete solution really stands out in the market." Beerck says.

Mahr Federal decided to return to the gear market based on its reputation and established credibility in the industry.

"Our reputation with our customers is what brought us back to the gear market," Mahr's Berndt says. "We have invested a lot of energy and resources to improve our products and complete the software our customers continue to ask about. I believe we are well set for the challenges the gear industry is facing today."

These challenges include a global economic slowdown, a cautious approach to future investments and the need to keep up with machine technology in the future. Companies are handling these challenges in a variety of ways.

"We're using the recent slowdown time in manufacturing to develop new products and software packages that will continue to give added value to our customers," Slone says. "For some of our prospects, financing has been an issue and Process Equipment has been working with Key Bank to offer operating lease options to gear companies faced with capital or financial constraints."

For Mahr Federal, it's about getting back into a game that is full of competition. "A lot of companies standardized on a specific gear test manufacturer and are reluctant to consider a new supplier. We hope our calibration services, seminars and metrology training programs will identify the best solutions for our customers."

It's all about big gears at Klingelnberg.

"Although we already supply measuring machines for large gears, we have many requests for equipment that can be used to test even larger components," Mikoleizig says. "The task of finding an unexceptionable concept for workpieces over 4 m in diameter that can also take cost effectiveness into account is certainly a great challenge and deserves careful consideration."

Beerck at Gleason-M&M says that the company now has more than 1,000 machines in the field worldwide. "This provides us the opportunity to support our legacy products by offering customers the ability to upgrade not only the *GAMA* software, but new probe and control technologies. Customers with vintage machines can extend the life of these machines with products Gleason is introducing to the market this year."

Beerck believes energy is going to be an important factor in gear metrology in the future, particularly wind turbine requirements and automotive design, thanks to new fuel efficiency regulations.

"I think there will be ongoing design work in gearing that will impact manufacturing processes and methods," Beerck says. "There will be no shortage of opportunities and we look forward to the gear manufacturing and metrology challenges that those opportunities will bring."

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An International Wind Turbine Gearbox Standard

Bill Bradley

The wind industry has been waiting for a definitive gear box standard for almost a decade.

Industrial gear standards have been used to support reliability through the specification of requirements for design, manufacturing and verification. The consensus development of an international wind turbine gearbox standard is an example where gear products can be used in reliable mechanical systems today. This has been achieved through progressive changes in gear technology, gear design methods and the continual development and refinement of gearbox standards.

Standards' Role

Standards are a common language through which manufacturers and users can specify and evaluate products. In business, a prudent buyer can assess cost effectiveness and the technical and manufacturing expertise of various supplier bids by the establishment of consistent engineering specifications for equitable bidding. Standards serve this role. They are also used as trade and marketing tools by manufacturers, either in penetrating new markets or protecting established ones. ANSI/

AGMA/AWEA 6006-A03—*Standard for Design and Specification of Gearboxes for Wind Turbines*, is a prime example of the development of a consensus application standard to fill the role required. The standard's foreword briefly states the why and who of its development:

"The operation and loading of a wind turbine speed increasing gearbox is unlike most other gear applications. The intent of this standard is to describe the differences. Much of the information is based on field experience. This standard is a tool whereby wind turbine and gearbox manufacturers can communicate and understand each other's needs in developing a gearbox specification for wind turbine applications. The annexes present informative discussion of various issues specific to wind turbine applications and gear design. A combined committee of AGMA and AWEA members representing wind turbine manufacturers, operators, researchers and consultants, as well as gear, bearing and lubricant manufacturers, was responsible for the drafting and development of this standard."

The finalization of an international gearbox standard should serve to answer existing questions on the part of designers and builders of wind turbines (courtesy Winergy Drive Systems).

Some could state that a consensus development process results in a standard that is the "lowest common denominator" and not necessarily good for advanced development of a highly technical industry. The content of ANSI/AGMA/AWEA 6006-A03 will be discussed later in this article, but first let us take a look at the history of its development.

History

AGMA standards development has been predominantly market-driven, ever since the first rating standard appeared in 1919 and the first gear quality standard was established in the late 1930s.

The number of standards progressed steadily and had a surge in the 1960s and 1970s, when much of the technical content for today's gear standards was documented.

A "milestone" was achieved in the 1980s, when the American National Standards Institute (ANSI) approved AGMA as the accredited national developer for gear standards, and as Technical Advisory Group Administrator for establishing national positions on international gear standards. Another was achieved in 1993, when AGMA—through ANSI—was approved as the Secretariat of Technical Committee 60 (TC 60), Gears, by the International Standards Organization (ISO).

Therefore, AGMA is responsible for the administration of gear-related standards development worldwide.

Coincidentally, in 1993 an AGMA/AWEA committee first met to develop AGMA 921–A97: an Information Sheet on the "*Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems*." The needs for the document were recognized by AGMA members who were working within this newly developing industry. The document was approved by the AGMA/AWEA Wind Turbine Gear Committee on October 25, 1996 and by the AGMA Technical Division Executive Committee on October 28, 1996.

Through the 1990s and into this century, wind turbine gearbox failures continued to slow the development of the industry. It was clear that a standard was needed, and the first draft of ANSI/AGMA/AWEA 6006-A03—to supersede AGMA 921–A97—was developed in March, 2000. The standard was approved by the AGMA membership in October, 2003 and approved as an American National Standard on January 9, 2004.

After becoming a National standard, the ANSI standard was presented to ISO as a draft international standard, using the verbatim "fast-track procedure." In October 2005, ISO 81400-4:2005 (as ANSI/AGMA/AWEA 6006-A03) was adopted, with approval by the national bodies of both ISO and IEC. The resulting ISO 81400-4 is part of the IEC 61400 Wind Turbine series. Some "turf" fighting between ISO and IEC, as to committee responsibility, resulted in the formation of a Joint Working Group (JWG) between the ISO/TC 60–*Gears* and IEC/TC 88–*Wind Turbines* technical committees (*see ISO vs. IEC sidebar*). AGMA's and ISO/TC60's operating procedures have developed

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ISO vs. IEC Standard Development

In July 2003, an ANSI/AGMA committee meeting was held that completed the American National Standard ANSI/AGMA/AWEA 6006-A03. The committee intended to fast-track the standard as an ISO standard as soon as it was approved (October 2003) by ANSI. However, in May 2003, a new international work item proposal (NWIP), citing the AGMA 6006 document, was balloted on the same topic within the International Electrotechnical Commission (IEC) Technical Committee (TC) 88. This NWIP was approved by IEC/TC 88 in October independent of ISO, which is normally responsible for "gear" standards. Therefore, in the interest of harmony between ISO and IEC, it was determined that the development of an international wind turbine gearbox standard would be accomplished by a JWG between ISO/TC 60 and IEC/TC 88. The JWG organizational meeting was held May 27-28, 2004, by mutual agreement in Geneva, Switzerland.

There were 45 persons at the meeting representing ISO, IEC and their central secretariats. The chairman of IEC/TC 88 was the convener. Discussions of member status and resolutions of issues in the absence of consensus resulted in the recommendation that each country be represented by each of its National Bodies (ISO, IEC, or both) that were present in any meeting. Other interested persons could attend, but in the absence of consensus a country would have a maximum of two votes in resolving issues. At this meeting, this resulted in 16 official votes from 10 countries represented.

It was agreed that the JWG should produce one standard that would have both ISO and IEC designation numbers. Methods of recording decisions and editing were discussed. It was agreed that the standard draft ballot comments should be reviewed by the JWG for resolution.

The JWG reviewed a proposed outline of the standard and developed work assignments for the next meeting, which was scheduled for October 2004. Because of the need internationally, it was discussed that the ANSI/AGMA/AWEA standard should be fast-tracked as a first edition while the JWG document was being developed. The U.S. delegation was asked to fast-track its document as an ISO/IEC document as soon as possible, by a vote of 10 approvals, five disapprovals and one abstention.

Issues unresolved at the first JWG meeting were who would convene the JWG, what organization would be the "parent committee," and which organization would be responsible for maintenance of the publication. The decision on the convener could not be made by consensus of those present at the meeting and a vote was not taken by the (IEC) chairman. Many of the ISO delegates present were disappointed that a convener and a "parent committee" for the JWG could not be elected. It was assumed that the management boards of ISO and IEC would solve these issues. It was later resolved that an IEC representative would convene the meetings, ISO would publish the first fast-track document and administrate the development meetings, and the revision of the publication would be by IEC.

—Bill Bradley

sidebar). AGMA's and ISO/TC60's operating procedures have developed comprehensive standards from start to finish in two or three years. The JWG is chaired by IEC and has been working on the next revision/replacement since 2004, which will be issued as IEC 61400-4 when finished.

Therefore, the timeline for the International Wind Turbine Gearbox Standard development:

- AGMA Information sheet started in 1993, completed 10/1996;
- National Standard started 3/2000, completed 10/2003;
- ISO/IEC "fast-track" adoption started in 12/2004 and finished 10/2005;
- IEC replacement (up-date) started in 10/2004 and is still working after five years.

At their last meeting, in April 2009, the JWG developed the first full committee draft (CD) for initial ballot within ISO/TC 60 and IEC/TC 88. The question could be asked, "What has occurred over the past five years?" and, "Why so long?" The answer, as it often occurs, is not due to one reason but many interrelated conditions. Experience has shown that some of the reasons could be: too much text-related information that is not necessary as requirements of the standard; delegations coming to meetings unprepared to make consensus decisions; time spent in meetings to study issues rather than deciding on content; and operating in a manner that make resolutions difficult (*see sidebar on standards development*).

Although its revision has been time consuming, ISO 81400-4:2005–*Wind Turbines/Part 4*: *Design and Specification of Gearboxes*—as developed by AGMA/AWEA—contains many items that collectively form the most comprehensive application gearbox standard in the world.

Content

The committee responsible for ANSI/AGMA/AWEA 6006-A03 development was somewhat unique, being made up of wind turbine manufacturers, users, researchers, consultants, gear and bearing manufacturers, plus lubricant and system suppliers from around the world, who brought many years of experience with this application to the meetings.

A wind turbine is one of the—if not the most—demanding applications for a gearbox. It requires a relatively small, compact, high-power-density gear drive and electric generator to transmit fluctuating loads in a very demanding environment of deflections, high vibration and temperature extremes.

The present standard applies to gearboxes for wind turbines with power capacities ranging from 40kW to 2MW and higher. It applies to all parallel-axis, one-stage epicyclic and combined one-stage epicyclic and parallel-shaft designs. It provides requirements on specifying, designing, manufacturing, operating and monitoring reliable wind turbine gearbox systems. Some of the more comprehensive gear application sections include:

- how the system loads and environment shall be specified and gear capacity calculated;
- manufacturing, inspection, testing and documentation requirements;
- advanced gear tooth contact analysis and verification;
- extensive information on the application and capacity of rolling element bearing types;
- lubricant and lubrication system requirements.

In addition, annexes supply information on wind turbine architecture; wind turbine load description; quality assurance; operation and maintenance; minimum purchaser and gearbox manufacturer ordering data; and lubrication selection and condition monitoring.

The revised standard at its present stage of development has updated all the sections of the original document, plus some additions and modifications, as follows:

- scope changed to cover drive-trains with a power rating in excess of 500 kW;
- sections on design lifetime and reliability, design process, wind turbine load calculations, gearbox components, design verification validation, operation, service and maintenance requirements;
- new annex material.

It can easily be imagined that the size of this document has increased substantively.

At this stage, it is hard to determine exactly what will be retained after the three ISO/IEC ballot stages are completed, which could take two to three years—or more—if additional changes are incurred. In the meantime, it is believed that the advent of the ANSI/AGMA/AWEA standard has improved gear reliability. However, bearings still seem to need additional work.

Standards Making

The development and balloting of both ISO/IEC and AGMA/ANSI standards is a consensus process. However, individual positions may be expressed that can enhance the contents. Members of AGMA develop new—and continue to revise—the many standards and information sheets. They are also responsible for determining the U.S. position on ISO standards. AGMA standards development has relied heavy on the actual experience of gear system performance in related applications, whereas some others are based on theoretical and laboratory research data.

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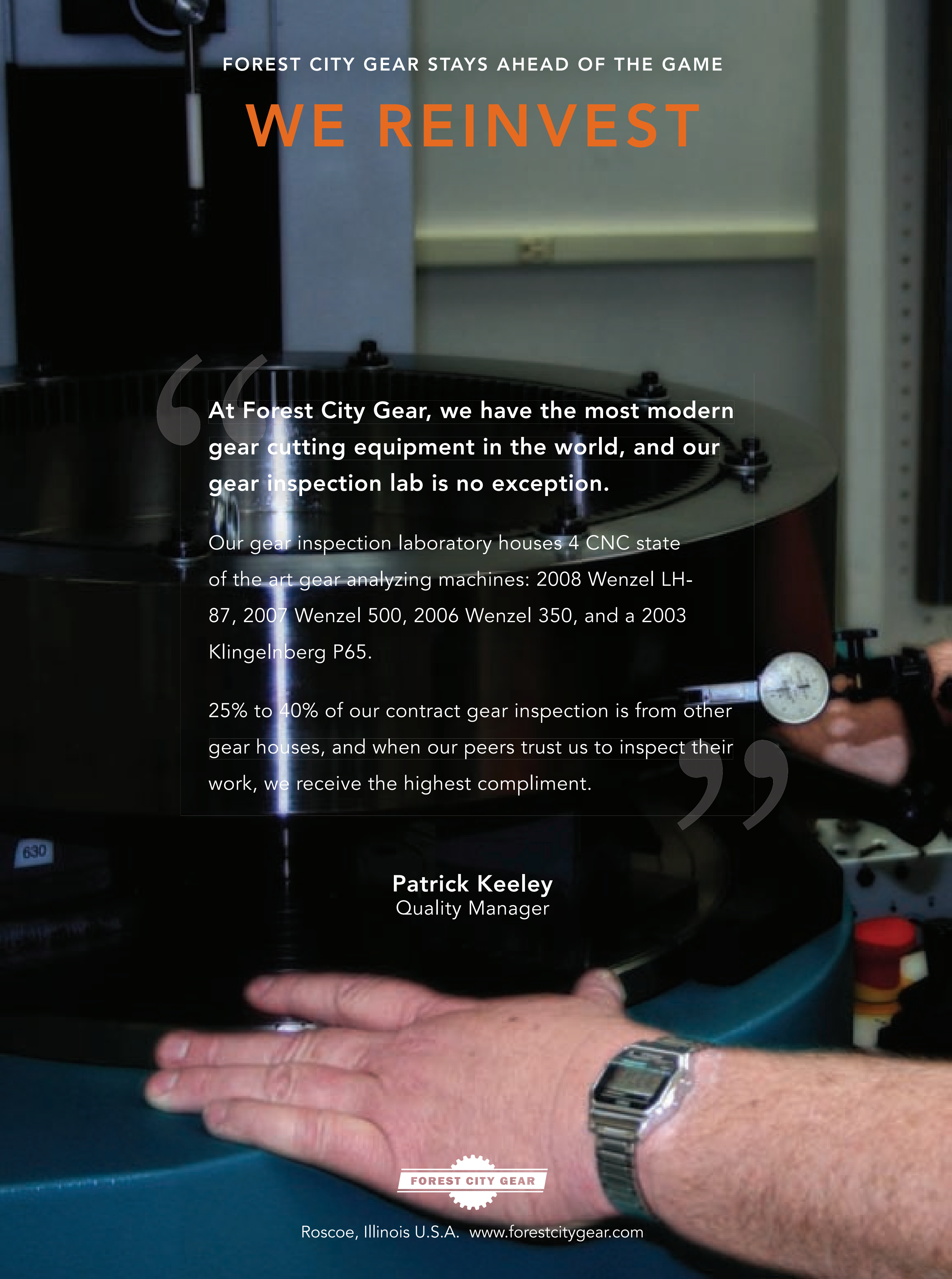
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Extending the Benefits of Elemental Gear Inspection

By I. Laskin

Management Summary

It may not be widely recognized that most of the inspection data supplied by inspection equipment, following the practices of AGMA Standard 2015 and similar standards, are not of elemental accuracy deviations but of some form of composite deviations. This paper demonstrates the validity of this "composite" label by first defining the nature of a true elemental deviation and then, by referring to earlier literature, demonstrating how the common inspection practices for involute, lead (on helical gears), pitch, and, in some cases, total accumulated pitch, constitute composite measurements. The paper further explains how such measurements often obscure the true nature of the individual deviations. It also contains suggestions as to some likely source of the deviation in various gear manufacturing processes, and how that deviation may affect gear performance. It further raises the question of the likely inconsistencies of some of these inspection results, and of inappropriate judgments of gear quality, even to the point of the rejection of otherwise satisfactory gears. Finally, there are proposals for modifications to inspection software—possibly to some inspection routines—all to extending the benefits of the basic elemental inspection process.

Introduction

The gear industry, here in the United States and internationally, has adopted two systems of specifying and measuring the accuracy of gears: one is composite inspection, which recognizes that the inspection measurements are the result of a combination of accuracy deviations, generally derived when the test gear is engaged with some form of master gear; the other is generally labeled as elemental inspection, or sometimes as analytic inspection. This inspection system looks at individual elements of gear accuracy or, at least, attempts to do so, all as part of analyzing the complete nature of the gear's accuracy. This paper deals only with the system of elemental inspection, especially as performed by modern, computer-controlled inspection equipment. Not only is the inspection process itself computer controlled, but also the processing and reporting of the inspection results. This makes possible additional or alternate data processing, with results reported in a form that clarifies or enhances current forms of inspection data reporting.

AGMA Documents

Current U.S. practice in elemental inspection closely follows a pair of AGMA documents. AGMA 9151A02 (Ref. 1) describes a variety of tangential measurements, many adopted for use in so-called elemental inspection. The second, ANSI/AGMA 20151A01 (Ref. 2), defines the elemental version of a gear accuracy classification system based on selected tangential measurements described in the AGMA 9151 document. This specification of accuracy classifications introduces tolerances for each specified elemental measurement. These tolerances, in effect, determine whether the test gear meets specifications and, upon failure to do so, will lead to rejection and scrapping, or rework. If the test gear came from some kind of molding process, the rework could extend into the molding tool.

The system of elemental gear accuracy defined in Reference 2 lists the following eight items, along with the general inspection procedures which provide the measure-

continued

ment data for each. These will be reviewed in groups later in this paper.

1) Single pitch deviation
2) Cumulative pitch deviation
3) Profile, total
4) Profile slope
5) Profile form
6) Helix, total
7) Helix slope
8) Helix form

There is another set of AGMA documents that treats composite-inspection radial measurements (Refs. 3–4), but these measurements are not directly connected to the elemental measurements discussed here. There is one exception (Ref. 3), dealing with the subject often called "hidden run out," addressed later in this paper.

Objectives

The objectives of elemental inspection are threefold:

1) To compare the inspected gear to the gear accuracy specifications, which may have been stated individually or as a group by accuracy class.
2) To indicate what in the gear manufacturing process has caused the departure from ideal gear geometry.
3) To help identify the effect of the elemental condition on the performance of the gear.

In meeting all these objectives, elemental inspection has demonstrated its benefit to the gear designer, the gear manufacturer, and the user of the gear.

The objective of this paper is to: examine the elemental inspection process as defined by the referenced AGMA documents; to indicate where and in what way it may be improved in meeting the above objectives; and to propose changes that will provide such improvements. Success in this effort can be recognized as extending the benefits of elemental gear inspection.

Definitions

Although the following terms are used in the AGMA documents, their definitions are generally by inference, rather than by readily located statements. The definitions given here conform to the general usage of the terms, inside and outside of gear technology. They are generally in agreement with their use in the AGMA documents, with the possible exception of the use of elemental, as will be noted later.

Deviation: the dimensional departure from the geometry of the ideal gear, as defined, directly or by inference, in the gear specifications, including any design modifications, such as tip relief or face crown, introduced by the gear designer.

Elemental: any component of gear accuracy which cannot be further reduced to subcomponents and, as such, may be present alone or in combination with other elemental components. Elemental components are often associated with a single source in the manufacturing process and have an individual effect on gear performance.

Composite: any gear accuracy designation applying to a combination of elemental components.

Gear Manufacture

Gear accuracy definitions and measurements are independent of the method of gear manufacture. However, each manufacturing method may produce its own set of typical accuracy deviations, requiring its own set of measurement procedures. For example, wide-faced gears made by the powder metallurgy (P/M) process tend to have a hollow condition in their face width, namely—a smaller diameter at the face center with a larger diameter near the end faces. This will be revealed in the helical inspection trace. Any inspection for profile should then be made at the face-located, larger diameters because it is these gear sections that will interact with a non-crowned mating gear on the parallel shaft. It is the responsibility of the gear designer to specify such inspection locations.

It is important to recognize that each manufacturing method may also bring its own set of typical accuracy deviations. In the measurement and data analysis methods in use for one specific accuracy deviation, another type of accuracy deviation may insert itself. This could result in a composite measurement, rather than a true elemental measurement. Such a condition, in the form of "eccentricity of mounting," is mentioned in (Ref. 1), clause 7.5, and will be further discussed below.

Run out. Run out is applied to a variety of individual, elemental accuracy deviations, each associated in some way with a varying distance of individual gear teeth—or tooth spaces—from the datum center of the gear. None of these individual, elemental deviations is listed directly as part of elemental inspection requirements, but their presence often enters into almost all of the other inspection procedures. The effect of some kinds of run out on the results of these inspection procedures will be given extensive treatment in this paper as part of an effort at clarification and enhancement of the coverage in the AGMA documents.

Three types of run out will be discussed:

- **Eccentricity**—in which the center of the ring of gear teeth, which may itself be close to ideal shape, is offset from the datum center of the gear—the one center used for all gear measurements and likely to be used in the mounting of the gear in its application.
- **Out-of-round**—in which the shape of the ring of gear teeth is not round, so that even if no eccentricity is present, measurements from all teeth or tooth spaces would not be constant.
- **Hidden run out**—a condition in which eccentricity in the gear was present in an earlier step of manufacture but, in some later step, was modified so as to "hide" one of its negative features from some inspection processes.

Eccentricity. Regardless of the method of gear manufacture, there are likely to be cases in which the inspected gear has some degree of eccentricity. Examples of some of these are:

- In the case of a machined gear, it is common practice to locate the gear blank by its datum center in the form of a through-hole. Manufacturing variation in the size of the hole—especially when several gears are stacked on a single arbor, matched to the size of the smallest possible hole—will introduce eccentricity between the hole's datum axis and the ring of machined gear teeth, into at least some of the stacked gears.
- If the gear is located during machining through some type of tooling with built-in eccentricity, such eccentricity in that tooling will be transferred to the gear.
- If the gear is molded from plastic, there exist other possible sources of eccentricity. In the mold, the core pin which produces the datum center hole may have been positioned eccentrically to the portion of the mold that forms the gear teeth. This is even more likely if the two mold features are located in different mold sections—one fixed and the other movable during the molding machine operation. This would be common for the molding of a compound, helical gear.
- Even without mold construction errors, the gears in a multiple-cavity mold may experience different rates of cooling across angular locations in their faces, resulting in different local shrink rates and the introduction of eccentricity.
- If the gear is made by the P/M process, some significant degree of eccentricity is inevitable.The compaction tool, which gives the initial shape to the gear, contains punches which must slide axially, relative to each other. The core pin, which forms the datum hole, is surrounded by a punch in the shape of the gear, which must slide in the die that forms the gear teeth. For gears with more complex features, there may be additional, concentric punches that participate in the relative sliding. To permit this sliding, there must be some clearance between the various, enveloping punches. Under the extremely high compaction pressures, these punches are pushed to one side, forcing the core pin to become eccentric to the die, and with the resulting gear teeth becoming eccentric to the datum center hole. To correct for eccentricity in higher-quality P/M gears, it is common to mold the center hole undersize and then machine it to size in a later operation that corrects the eccentricity.

The presence of eccentricity may affect gear performance in a number of ways:

1. Eccentricity introduces a once-per-rotation, varying center distance with the mating gear, a sometimes critical deviation—especially in fine pitch gears—resulting in variation in backlash between the involute flanks of the mating gears. (*Note: Eccentricity is sometimes, as in AGMA 2002 (Ref. 5), translated into a variation in tooth thickness having the same effect on backlash, leading to a so-called functional tooth thickness. This substitution does not consider the following two other variation conditions.*)

—Variation during meshing, in tooth tip to root circle clearance, and variation in tooth tip to fillet curve clearance between mating gears.

—Variation, during meshing, in contact ratio between mating gears.

2. Eccentricity introduces a sinusoidal component in the transmitted motion between the mating gears, potentially leading to once-per-revolution dynamic forces—especially if the gears are rotating at very high speed in a gear system with high mass inertia components—a rare condition which, even rarer, may impact the gear noise produced.

3. For gear systems which have a need for precise position control at output, as in computer printers, where the transmitted sinusoidal component may lead to banding in the resulting printed image.

The conditions listed under item 1 are typically resolved by design modifications to remove any critically harmful effects on gear performance. Those listed under item 2 are rarely encountered, and only in special applications. It is therefore safe to conclude that some limited eccentricity in a manufactured gear is, by itself, acceptable to the gear designer. What is not acceptable, as will be explained below, is any misinterpretation of inspection results brought on by the composite presence of eccentricity.

Analysis of Inspection Data

Inspection data will be analyzed, as follows:

- Description of the inspection process and the data produced;
- Identification of any composite components at each inspection, examples of a source in gear manufacture, and, most important, their potential effect on gear performance;
- Proposals for separating the composite components into true elemental deviations, whether by changes to the inspection process or by additions to the software

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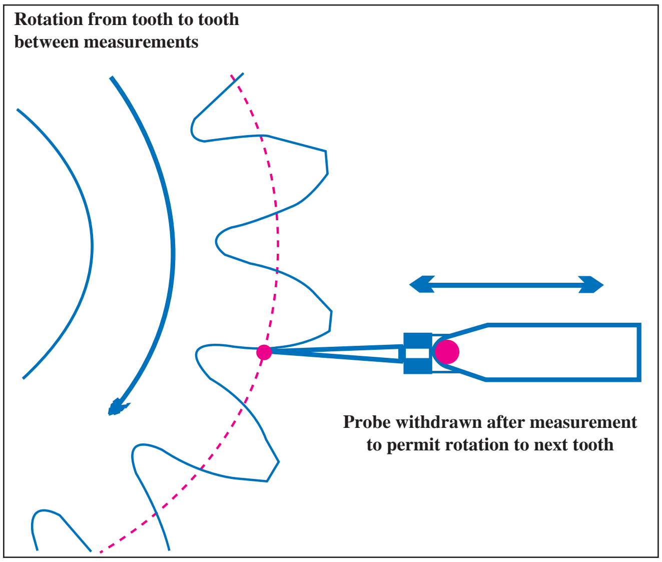

Figure 1—Measurement of pitch (or index) deviations.

that is to translate the inspection data to the preferred form.

The selected inspection items will start with those listed above as associated with the tolerances of the gear classification system. It will then move to additional gear accuracy conditions of potential interest to the gear designer, manufacturer, or user.

Pitch deviation, cumulative and single. The measurements for these deviations are made by indexing the gear about its datum axis through an angle exactly equal to the pitch angle—360° divided by the number of teeth (Fig. 1). At each indexed position, the measuring probe is inserted in a radial direction to the tolerance or inspection diameter, providing a probe deflection reading at the tooth flank. The deflection measurement is always made at the same diameter that will be centered on the datum axis. This process is then repeated for the opposite set of flanks. These readings, typically referenced to the first reading on tooth number one, are then plotted in a bar chart or stepped line, as shown in Figure 2. The full range of reading values for each flank is labeled "the cumulative pitch deviation," and the single-largest interval between successive readings is labeled "the single-pitch deviation."

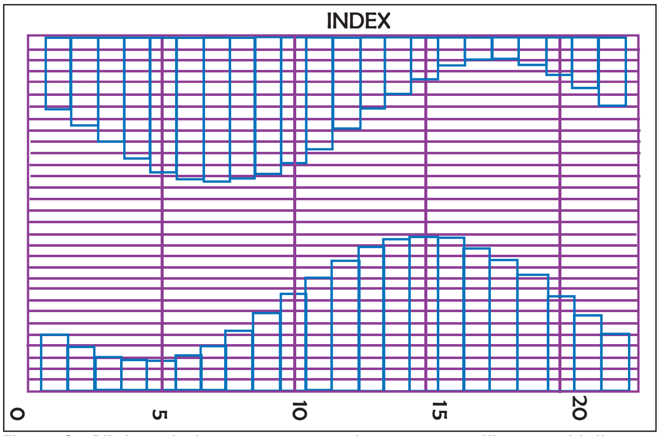

Figure 2—Pitch (or index) measurements on a gear with eccentricity.

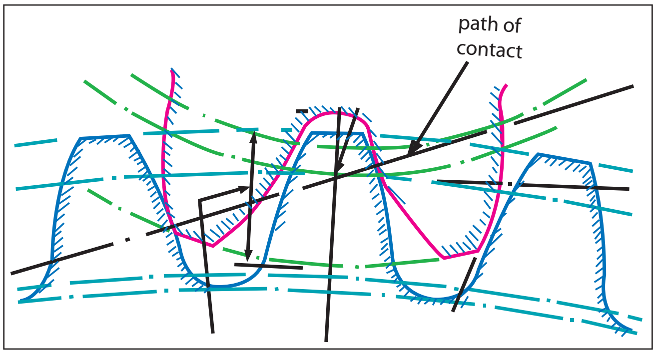

Figure 3—Transfer of contact at points on the path (line) of contact.

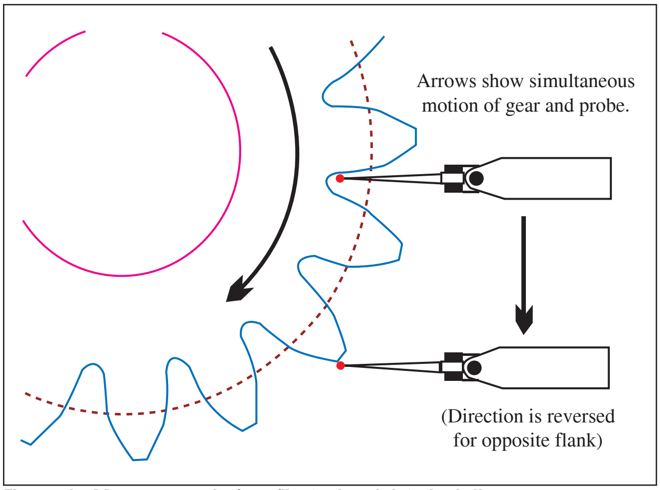

Figure 4—Measurement of profile (or involute) deviations.

The figure shows the plot for a gear with eccentricity as its dominant accuracy deviation. For each flank, the plot follows a once-per-gear-revolution mathematical sine curve. The amplitudes of the two sine curves are similar, but the apparent phase locations are noticeably different. There is a mathematically derived, and experimentally tested, relationship between the sine curve features and the eccentricity amplitude and direction (Ref. 6).

Even if the gear has other accuracy deviations that are essentially consistent around the gear—such as tooth flank pressure angle, incorrect tooth thickness, or helical gear helix angle—these curves do not change except for a possible, slight shift in the phase relationship of the two sine curves for the two tooth flanks. Therefore, the following evaluation of the information supplied for most gears with eccentricity will apply in each case:

- The cumulative pitch deviation reported by this inspection process does not provide any direct information about the gear's manufacture or performance. What it does do, indirectly, after applying the calculation noted above, is provide a measure of the eccentricity and its phase relationship to some reference on the gear. Yet, this eccentricity information, as important as it might be, is not directly included in the tolerances that define the gear's accuracy classification.
- The single-pitch deviation value reported by this measurement is directly, and even indirectly, essentially useless. What is generally needed from a tooth spacing measurement is an indication of how well the gear will transfer contact and load as one pair of mating teeth are replaced by the next pair. A smooth transfer requires that the tooth spacing of the two gears be closely matched (Fig. 3). Otherwise, any mismatch can result in added dynamic loads and gear noise. However, this mismatch to be judged is along the line of action in a base tangent direction, and not along the tolerance or inspection circle, as specified in the AGMA standard. The single-pitch deviation in the standard provides no such line-of-action spacing measurement. For gears in which eccentricity is the dominant accuracy deviation, the value of the currently reported single-pitch deviation comes only from the magnitude of eccentricity and the total number of teeth in the gear. To receive the benefit of single-pitch deviation

measurements, the measurement must be moved from the tolerance circle to the base tangent direction. This may be done by a change in the measurement procedure itself or by the use of software which takes the eccentricity information found from the cumulative pitch data and makes the required translation.

It is possible that any influence of eccentricity deviation may be accompanied by other, more local geometry accuracy deviations, such as an out-of-round condition. This would certainly influence the pitch deviation data. At first thought, it may be considered that extracting the once-per-gear rotation sine curve data would simply reveal any out-of-round condition. However, the out–of-round influence may be accompanied by a local pressure angle deviation condition—enough to distort the cumulative pitch deviation data and so distort the results of such an attempt at further tooth shape analysis. Additional research on this subject may be needed to find a superior method for showing, and measuring, any out-of-round condition.

Not included in the gear accuracy set of measurements, but often supplied by elemental gear inspection software, is a set of tooth thickness data calculated from the common index measurements of both sets of tooth flanks. Again, if eccentricity is the dominant accuracy deviation, these tooth thickness values, one for each tooth, will follow their own sine wave shape. Averaging this data is considered a useful measurement of tooth thickness along an equivalent gear tooth ring circle diameter. As long as there are no other "local" tooth accuracy deviations, the averaging process may be considered valid. If there are such local deviations, averaging will obscure any data revealing their presence—a case of "throwing out the baby with the bath water."

Profile, total, slope, and form. All these measurements are made in the profile inspection process. Three or four teeth are selected, with their tooth number intervals being equal, or nearly equal. At each of the teeth, the gear is slowly rotated about its datum axis while the probe contacting the tooth flank moves in a base tangent direction, starting near the tooth fillet and proceeding to the tip round or chamfer (Fig. 4).

If the base circle of the ring of gear teeth is ideally centered at this datum axis, and if the shape of the tooth flank is an involute curve generated from this base circle, the shape of the measurement plots will be straight lines parallel to the plotted horizontal axis. If the other conditions are met, but the generating base circle differs in diameter from that specified for the gear, the plots will still be straight lines, but at some other consistent slope.

However, if the datum axis is displaced from that of the generating base circle, i.e.—when eccentricity is a dominant accuracy deviation—the plots will no longer be straight lines, but rather small portions of sine curves, with each portion starting along the sine curve according to a phase relation defined by the tooth's position around the circle of gear teeth (Fig. 5). If extended, the amplitude of the sine curve will be determined by the eccentricity as defined by the equations in Reference 6. Also, the extent of each portion of sine wave will be defined by the roll angle interval along the tooth profile examined during the profile measurement. If the gear has more teeth, this roll angle interval is likely to be small and each trace will consist of a smaller portion of a full (360°) sine wave.

When confronted by such a set of profile traces, with its variation from tooth to tooth of crown and hollow and variation of profile slope, and without appropriate training, it would be difficult for the observer to make sense of these profile traces. Not recognizing the role of eccentricity would leave the observer searching unsuccessfully for a manufacturing process which could produce such profile deviations. The AGMA standards would be improved by supplying the needed training.

Clause 7.6 (Ref. 1), and repeated here in Figure 6, shows such traces caused by eccentricity, not as sinusoidal curves with their apparent crowns and hollows but, misleadingly, as straight lines of distributed, varying slopes. There is also no reference relating these varying slopes to the degree of eccentricity.

The AGMA standards define methods of quantitatively evaluating measurement traces in three different ways (Ref. 2):

continued

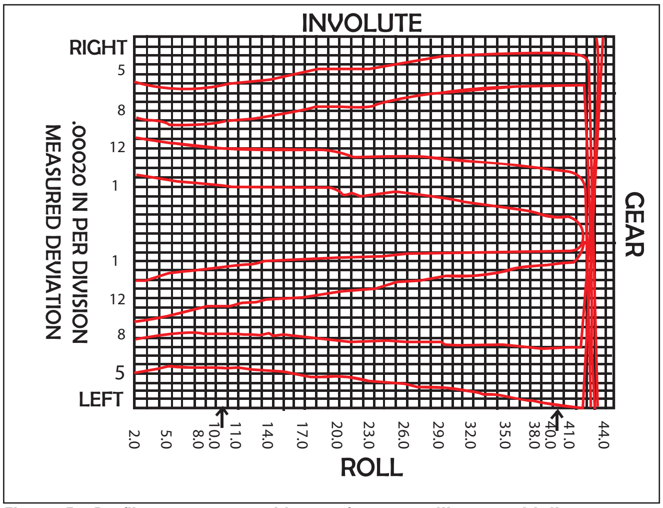

Figure 5—Profile measurement traces for gear with eccentricity.

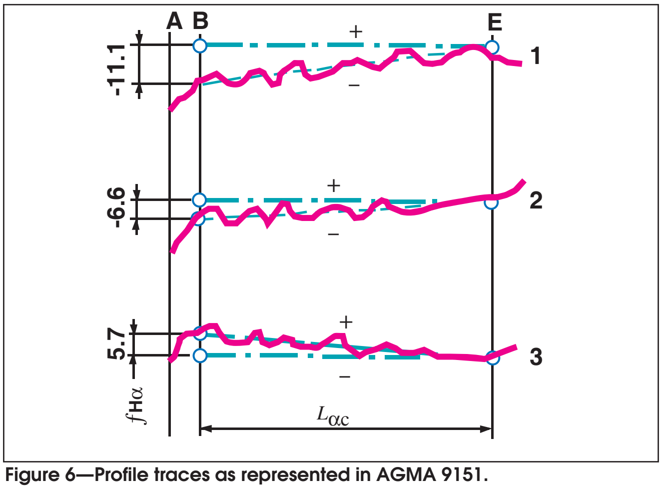

Figure 6—Profile traces as represented in AGMA 9151.

1) Total profile deviation is the full range of the profile curve or, if the profile has been modified by design, the full range between limit lines defined by the profile design modification.

2) Profile form deviation is the range of the profile curve as defined by limit lines matched to the mean profile line, curved if necessary.

3) Profile slope deviation is the range of the profile curve as defined by limit lines located where the mean profile line intersects the beginning and end of the active profile curve, with this mean profile line adapted to any design modifications.

Such evaluations make no attempt at explaining the possible role of eccentricity in the various measurement traces. Nor do they explain how the traces might change if the role of eccentricity was removed. They simply give quantitative values to be used in establishing the quality classification of the gears producing such traces.

Although not specified as having a role in defining gear accuracy, Reference 1 suggests averaging the data from all the (three or four) profile traces for each flank as a means of removing the effect of eccentricity and providing a clearer indication of the effective profile deviation. This suggestion creates two issues:

1) The reader is guided to two different methods for evaluating the quality of the gear—one by following the individual traces as the basis for accepting or rejecting the gear, the method of commercial significance; or, two, by examining the averaged data as a truer indication of gear quality.

2) While the averaging process can produce a valid result as long as all teeth are subject to the same quality influences, with eccentricity, for example, meeting this requirement as would a consistent profile slope deviation. However, if there are local differences in quality influences as, for example, in out-of-round gears, the averaging would likely obscure critical profile information. Cautions in using averaging where not appropriate are not included in the standard.

The most direct way of dealing with the complicating effects of eccentricity on profile measurements is, probably, by adding a separate set of profile trace plots. This second set would simply show the profile traces with the effects of eccentricity removed. The current set of data, actually composite measurements, would be transformed into two true, elemental measurements—eccentricity and true tooth profile traces. Such profile traces could then be further analyzed into their own set of elemental tooth accuracy deviations, such as pressure angle, crown and hollow, waviness and others. The process of enhanced profile analysis could be accomplished by added software features or by remeasuring the tooth profiles with a changed "datum" reference.

Helix: total, slope, form. These measurements are made in the lead inspection process. Three or four teeth are selected, with their tooth number intervals being equal, or nearly equal. For spur gears at each of the teeth, taking one set of flanks at a time, the gear is fixed against rotation while the measuring probe travels axially. For helical gears, the gear is slowly rotated while the measuring probe travels axially at a relative rate according to its specified helix angle (at the measurement diameter) or corresponding value of lead (Fig. 7). The probe readings may show end-effects, such as end chamfers, but these readings are normally excluded from measurement data analysis.

The AGMA standard, as part of its Gear Accuracy Classification System, evaluates the resulting lead traces into total, slope and form helix values by methods similar to those specified for involute traces (Ref. 1).

Eccentricity plays no significant role in helix measurements for spur gears. The traces may show the effects of crown and hollow, slope patterns and other such accuracy deviations. The slope patterns can be further analyzed into other elemental deviations such as taper or axial run out. This further analysis is not specified in AGMA standards, nor are tolerances assigned to them.

For helical gears, however, eccentricity does play a role in the lead traces produced. Aside from the kinds of accuracy deviations described for spur gears, eccentricity—without the introduction of corrections—will show curves corresponding to segments of sine waves (Fig. 8). The phase shift of individual segments will be determined by the interval of tooth numbers. If fully extended, the resulting sine curves will show amplitudes based on the eccentricity and the helix angle. The length of each sine curve will derive from the relationship of the gear's inspection face width to the gear's lead, as determined from its design specifications. If the face width, for example, equals the gear lead, the sine curves will extend for a full cycle of 360°. The treatment in the AGMA standard (Ref. 1) of the influence of eccentricity on helical gear measurement traces is as limited as it is for tooth profile measurement traces. Figure 9 shows a similar, simplified version of the resulting traces. What is also lacking for helical traces is a set derived with the effect of eccentricity removed. This would reveal the true nature of the remaining helix deviations, including those that readily appear for spur gear traces in which eccentricity plays no role.

Hidden run out. This type of accuracy deviation results from some form of a two-step manufacturing process. In the first step, the ring of gear teeth is manufactured by any process that leaves it eccentric to the datum axis. In the second step, the tooth flanks are reworked while maintaining the original, angular positions of the tooth spaces and keeping constant the new space widths along the datum pitch circle. An example of this second step process is a gear shaving process in which the shaving cutter takes on angular positions that largely follow the original tooth spaces. These tooth spaces positions have now become eccentric relative to the datum axis. Other examples may be found in certain roll forming processes, one of which is "tooth surface densification" of P/M gears in a set-up that centers the reworked gear on its datum axis.

Hidden run out is discussed briefly in Reference 3 and described in detail in Reference 7. It deserves special mention here because its presence is not readily revealed, or evaluated, in the standard "elemental" inspection processes. In the pitch deviation measurements, it appears simply as an eccentric gear, with only a hint of its special character. This hint appears in its unique phase relationship between the sine waves generated for the two flanks.

Another method of identification can be found through a special set of additional calculations using data from the cumulative pitch deviation measurements. As noted above, tooth thickness values are often calculated from this data. For the simple presence of eccentricity, these will vary as if they were points on a sine wave. This will also appear with hidden run out. However, if a second set of calculations is made of the space widths, the hidden run out is revealed, since these space width results will now be essentially constant around the gear.

The effect of hidden run out on gear performance is better revealed if the pitch measurements are made along the line of action, as recommended earlier. It is these pitch measurements, whether for simple eccentricity or hidden run out, that should be used to define gear accuracy. To determine the manufacturing process which requires correction, simple eccentricity or hidden run out, further analysis of the two sets of measurements may be needed.

Conclusion

It is proposed here that the benefits of elemental inspection would be extended by some limited additions or changes in the measurement processes and subsequent data analysis. Also important, these changes should include the presentation of results, whose content is currently determined by AGMA standards.

In summary, the changes are:

- Measure and report pitch deviations along a base tangent line, in place of along the inspection circle;
- Add plots of profile and lead measurements from which any effect of eccentricity has been removed;
- Treat the new measurements as true, elemental deviations without the role of eccentricity acting to produce composite deviations;
- Report eccentricity, amplitude and direction, as determined from the selected set of measurements, with the possible imposition of a tolerance.

These changes would increase the value of modern gear accuracy measuring equipment to those that have purchased them and continue to use them. They also open up the opportunity for the AGMA gear accuracy committee to lead the industry in their application.

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7. Smith, R.E. and I. Laskin. "Detection of Hidden Run Out," 95FTM1.

Irving Laskin, *a consultant in gear technology specializing in fine-pitch gearing and a* Gear Technology *technical editor, received in 2008 the AGMA Lifetime Achievement Award for his long career in the gear industry. The award is given to a member of the industry who demonstrates vision and leadership, sharing knowledge and experience for the advancement of the gear community. Laskin has been involved in AGMA's technical committees for more than 25 years, serving as chairman of the Fine Pitch Gearing, Plastics Gearing and Powder Metallurgy Gearing Committees; Laskin was also a member of AGMA's Technical Division Executive Committee. He played a pivotal role in establishing the plastics and powder metallurgy segments of the industry within AGMA, and he has been instrumental in recruiting many companies to become members.*

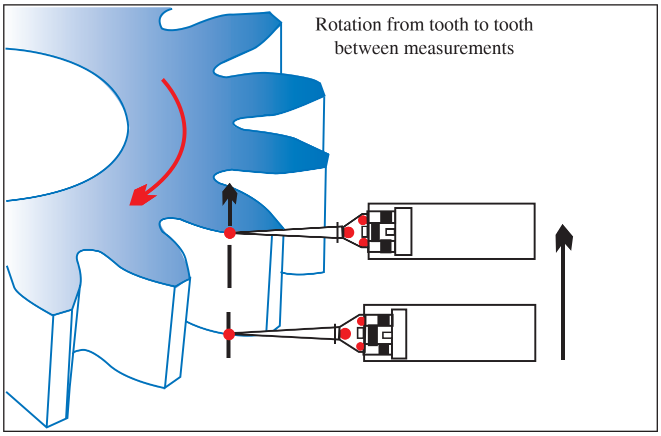

Figure 7—Measurement of helix (or lead) deviations.

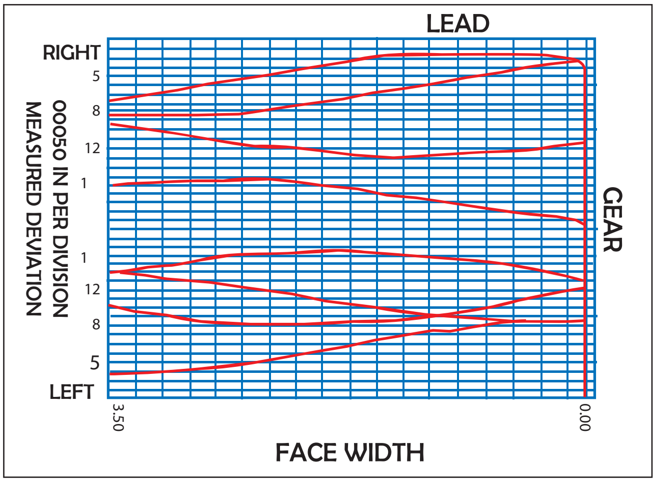

Figure 8—Helix measurement traces of gear with dominant eccentricity.

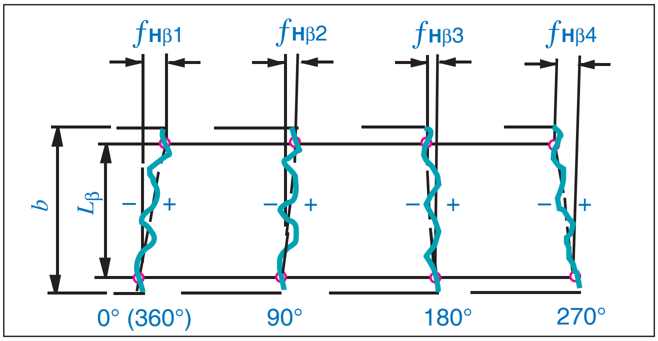

Figure 9—Helix traces for a helical gear as represented in AGMA 9151.

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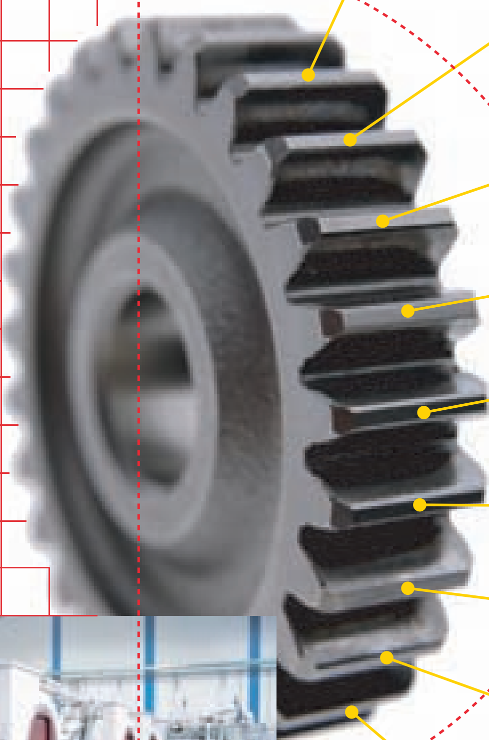

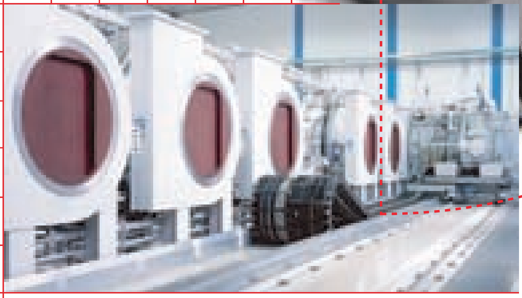

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The Effect of Manufacturing Microgeometry Variations on the Load Distribution Factor and on Gear Contact and Root Stresses

Dr. D.R. Houser

Management Summary

Traditionally, gear rating procedures consider manufacturing accuracy in the application of the dynamic factor, but only indirectly through the load distribution are such errors in the calculation of stresses used in the durability and gear strength equations. This paper discusses how accuracy affects the calculation of stresses and then uses both statistical design of experiments and Monte Carlo simulation techniques to quantify the effects of different manufacturing and assembly errors on root and contact stresses. Manufacturing deviations to be considered include profile, lead slopes and curvatures, as well as misalignment. The effects of spacing errors, runout and center distance variation will also be discussed.

Introduction

Gear rating formulas have numerous design factors that are intended to create realistic evaluations of the stress levels encountered by a gear pair. The dynamic factor, however, is the only factor that has manufacturing accuracy directly included in its evaluation. This paper discusses most of the other factors in the AGMA rating procedure (Ref. 1) that might be influenced by manufacturing accuracy and then uses load distribution analysis to assess the effects of profile, lead and spacing deviations on root stresses, contact stresses and load distribution factors. The dynamic factor has received ample study in the past (Ref. 27), so it will not be further investigated here. As part of the presented analysis, a procedure is provided for obtaining an acceptable microgeometry design that is relatively insensitive to manufacturing deviations and misalignment.

Manufacturing Accuracy Definitions

Prior to looking at the factors that affect tooth stresses, what is meant in this paper as "manufacturing accuracy" will be defined. In this context, manufacturing accuracy encompasses all factors in manufacturing or assembly that change the microgeometries and hence the load sharing of a tooth pair. The AGMA accuracy classification standard (Ref. 8) uses its quality number system to define quality levels for profiles, leads, runout and spacing. The accuracy of housings, bearings and support shafting, geometry changes to the surface and root geometries and variables such as center distance, backlash, outside diameter and tooth thickness are not included, but are occasionally discussed. Also not included are deviations that are measured through composite and single flank tests. However, these deviations result from the elemental variations that are considered.

Provided below is a brief discussion of factors affecting the tooth microgeometry that are studied in this paper.

Lead deviations and misalignment. These are discussed together since they have similar effects on the load distribution across the tooth face width. The effects of lead deviations, which essentially shift the load to one end of the tooth, have been discussed in many papers (Refs. 9–14). Misalignment that is at right angles to the normal contacting plane is an additive to lead slope deviation, so in this paper these effects for both the gear and pinion will be lumped together into a single variation. The AGMA accuracy standard (Ref. 8) recognizes that there are potentially two types of lead deviations—one of the linear type and the second being a curvature deviation. The linear slope deviation may be added to misalignment, while the curvature deviation is treated as a deviation in the specified lead crown.

Profile deviations. Profile deviations are often thought of as deviations of the tooth form from a true involute. But, in loaded teeth operating at the gear pair's rated load, profile modifications in the form of tip and root relief are desirable

continued

variations from a perfect involute. Hence, profile deviations are thought of as deviations from the specified profile shape. Again, the AGMA accuracy standard allows one to specify deviations in terms of slope and curvature. Profile deviations tend to affect tooth-to-tooth load sharing across the profile of the tooth pair.

Bias deviation. Although not spelled out in AGMA standards, this type of deviation, which is essentially a twisting of the tooth form, is identified by performing multiple profile and/or lead measurements on each measured tooth. This type of deviation, which commonly occurs when gears are finished by screw type generation grinding, also affects load sharing.

Spacing deviations. Tooth-to tooth spacing deviations may affect dynamics, but have a greater effect on tooth-to-tooth load sharing (Ref. 15). In this paper, AGMA quality number values are used and these load sharing effects are analyzed.

Runout deviations. Runou tresults from eccentricities in both the manufacture and the assembly of gears. The most common form of runout is radial runout, which manifests itself in terms of cyclic spacing deviations, cyclic changes in the profile slope and cyclic changes in the operating center distance and/or the effective outside diameter. The latter two effects slightly change the profile contact ratio of the gear pair. In the analysis of this paper, only the spacing deviation effect of profile runout is considered. Another form of runout commonly referred to as lead runout or lead wobble occurs in the face width direction. It is assumed that lead wobble effects are already included in the tolerance used for lead deviations, so no special analysis of lead wobble is performed in this paper.

AGMA rating equations. Since this study concentrates on the effects of manufacturing deviations on stresses, we first look at the current AGMA method for computing these stresses and discuss in general how each factor in these stress equations is affected by manufacturing deviations. The AGMA stress formulas (Ref. 1) for bending and durability are respectively given below.

Contact stress equation:

$$s_c = C_p \sqrt{W_t K_o K_v K_s \frac{K_m}{dF} \frac{C_f}{I}}$$

Tensile bending stress equation:

$$s_t = W_t K_o K_v K_s \frac{P_d}{F} \frac{K_m K_B}{J}$$

where,

s_c contact stress number, lb/in^2;
C_p elastic coefficient, [lb/in^2] $^{0.5}$;
W_t transmitted tangential load, lb;
K_m load distribution factor;
K_o overload factor;
K_v dynamic factor;
K_s size factor;
C_f surface condition factor for pitting resistance;
F net face width of narrowest member, in;
I geometry factor for pitting resistance;
d operating pitch diameter of pinion, in;
s_t tensile stress number, lb/in^2;
K_B rim thickness factor;
J geometry factor for bending strength;
P_d transverse diametral pitch, in^{-1}.

The factors that are unlikely to be affected much by manufacturing (deviations in materials are not considered in this paper) include the elastic coefficient, the overload factor and the size factor. As mentioned earlier, the dynamic factor has been studied extensively (Ref. 27) and is the only factor used in the above formulas that is currently based on gear quality. The load distribution factor certainly is affected by misalignment, profile and lead modifications. In a way, the current use of this factor does depend upon accuracy, but this use is not quantified in terms of the accuracy numbers. In the simulations of this paper, the load distribution factor is evaluated based on quality numbers. The surface condition factor is certainly affected by manufacturing, but also is not considered by AGMA in its accuracy definitions and will not be studied in this paper. Both geometry factors are subject to manufacturing tolerances, but again they are not quantified in the AGMA tolerance numbers, so will only be briefly discussed. The bending strength geometry factor is subject to changes in surface finish and shape imperfections in the root fillet region that could affect root stresses. For instance, this author once had some gears made in which the hob feed rate was varied and the teeth with the coarser feed rate were found to have lower lives based on single-tooth fatigue testing (Ref. 16). With regard to the surface durability geometry factor, it has been shown that the contact stress may increase significantly at locations on the tooth

Table 1—Helical Gear Geometry

	Pinion	Gear
Number of teeth	25	31
Normal diametral pitch (1/in)	8.598	
Normal pressure angle (deg)	23.45	
Helix angle (deg)	21.50	
Center distance (in)	3.50	
Face width (in)	1.25	1.25
Outside diameter (in)	3.360	4.110
Root diameter (in)	2.811	3.561
Standard pitch diameter, d_p (in)	3.125	3.875
Transverse tooth thickness at d_p (in)	0.1934	0.1934
Profile / face contact ratio	1.383/1.254	
Total contact ratio	2.637	
Pinion torque, lb-in	5000	

changes in the tooth form, an example being the radius of curvature change in the tip relief "break" region (Ref. 17). The rim thickness factor is subject to manufacturing to the extent that there are tolerances on the thickness value that could affect root stresses.

Baseline Microgeometry Selection

When studying microgeometry variations, one must first start with a baseline microgeometry. This, in essence, means to define the baseline profiles and leads of the design. Every gear designer has his own approach to establishing these parameters. Some designers might choose a profile so as to avoid corner tooth contact and tip interference; others might minimize transmission error and others may wish to minimize the effects of spacing deviations. When selecting lead variation, some designers use no lead crown; others select a standard amount of lead crown based on experience and still others might prefer end relief rather than lead crown. In this study, we shall use a load distribution simulation (Refs. 18–20) to select both the profile and lead modifications that will avoid corner contact and tip interference, and at the same time provide reasonable insensitivity to misalignment.

The basic gear geometry to be used in this paper is given in Table 1. The geometry is similar to one used in a previous study (Ref. 21) except that the root diameters have been adjusted slightly.

The procedure for coming up with an acceptable microgeometry is as follows:

Step 1. Identify the rough torque rating for the gear pair. For the sample gear set, we used an AGMA rating formula with approximate constants to come up with a torque rating of roughly 5,000 lb–in.

Step 2. Using this rating, a load distribution analysis with perfect involutes (shafts not included in the analysis) is performed. Figure 1 shows the load distribution at one contact position for the perfect involute analysis. One observes that there is significant contact at the tooth tips (tip interference) and at the entering corner of the tooth (corner contact). Figure 2 shows a composite plot of contact stresses that results from the analysis of many positions of contact. The stresses at the tip, root and corners are abnormally high due to the tip interference and corner contact, and also due to the fact that the radius used to compute the contact stress at the tip is much smaller than that along the tooth flank. Peak contact stresses are about 240 ksi in the corners, 200 ksi on the tip edge and 170–180 ksi in the tooth center. From Figure 3, which shows root stresses at five equally spaced locations along the root of the tooth, the peak pinion root stress is about 44 ksi. The root stresses of the gear were quite similar, so in all subsequent analyses we shall only observe the pinion root stresses.

Step 3. Identify the maximum tooth deflection, the value of which is then used as a guideline in selecting the values of tip and root relief. This deflection, which may be taken from the transmission error plot of Figure 4, is about 0.001 inch.

Step 4. For reference, determine at

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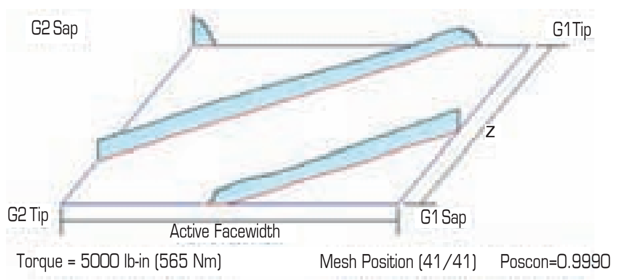

Figure 1—Load distribution of a perfect involute with 5,000 lb–in torque.

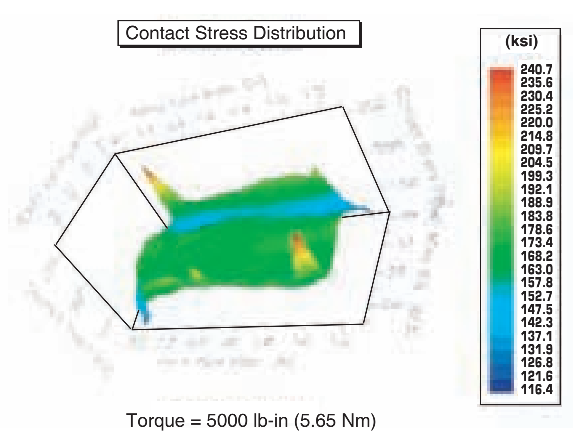

Figure 2—Contact stress distribution of a perfect involute with 5,000 lb–in torque.

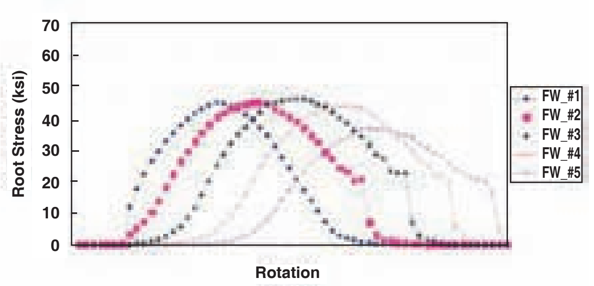

Figure 3—Pinion root stresses at five locations across the face width for a perfect involute with 5,000 lb–in torque.

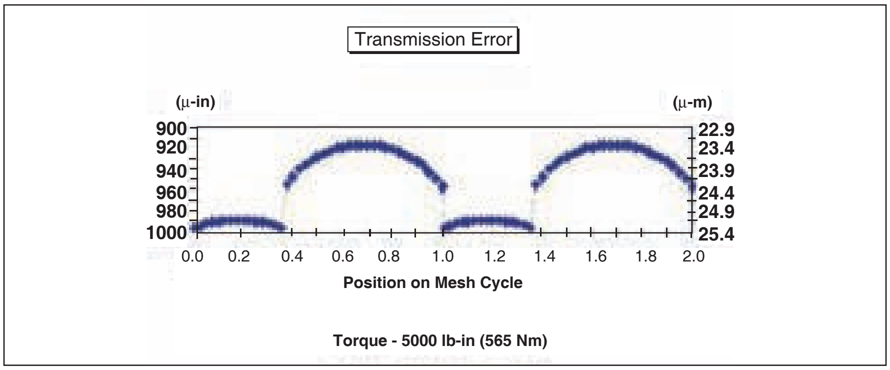

Figure 4—Transmission deviation of a perfect involute with 5,000 lb-in torque.

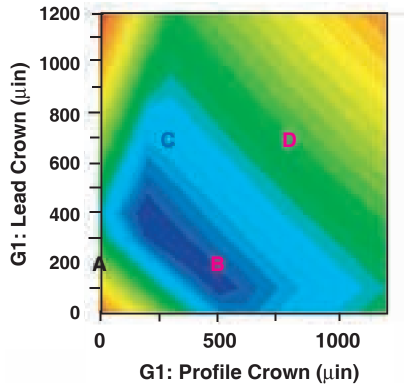

Figure 5—Effect of profile and lead crown on the peak contact stress at 5,000 lb-in torque. (A– 240 ksi; B–201 ksi; C–213 ksi; D–230 ksi)

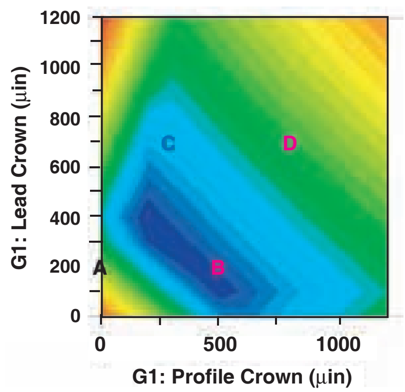

Figure 6—Effect of profile crown and lead crown on pinion root stress at 5,000 lb-in torque. (A–43 ksi; B–48 ksi; C–53 ksi; D–60 ksi)

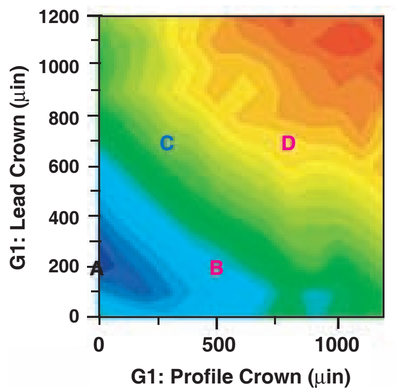

Figure 7—Effect of lead crown and profile crown on load distribution factor at 5,000 lb-in torque. (A–1.19; B–1.39; C–1.58; D–1.71)

the design load the effect of amplitude of tip relief and lead crowning on the major design parameters, namely—contact stress and root stress. For narrow face width helical gears, it has been found that both circular lead and circular profile modifications perform well in distributing the load and in reducing transmission error. Figure 5 shows the results of such an analysis for our gear pair when operating at a pinion torque of 5,000 in–lb.

Figure 5 is quite interesting since it shows the threshold modifications that are required in order to minimize both tip interference and corner contact stresses. The stresses at the lower left corner are abnormally high, due to the corner contact. As one increases the lead crown, these stresses drop, but soon the tip interference stresses dominate and any further increase of lead crown amplitude causes these stresses to increase. In order to totally minimize the tip interference stresses, one must apply tip relief. In this case, applying about 0.0005 in. of profile crown and about 0.0002 in. of lead crown provides a minimum contact stress of 201 ksi. As either the profile crown or the lead crown is further increased, one observes that the contact stress increases. This increase is essentially due to a focusing of the load closer to the center of the tooth.

Figure 6 shows that after a small initial amount of lead crown is applied, root stresses increase with increasing profile and lead crown. One observes that there is a slight conflict between the respective optimal microgeometries desired for root stresses and contact stresses. However, our final microgeometry is selected based on, first, insensitivity to misalignment, and second, insensitivity to all manufacturing deviations. So, at this time, this is not a big issue.

As a matter of interest, Figure 7 shows how the load distribution factor, K_m changes with microgeometry variation. The "optimum" microgeometry now has about 0.0002 in. of lead crown and no profile crown; at this condition, the load distribution factor is about 1.19. Any further misalignment or load shift the design load the effect of amplitude of tip relief and lead crowning on the major design parameters, namely—contact stress and root stress. For narrow face width helical gears, it has been found that both circular lead and circular profile modifications perform well in distributing the load and in reducing transmission error. Figure 5 shows the results of such an analysis for our gear pair when operating at a pinion torque of 5,000 in–lb.

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As a matter of interest, Figure 7 shows how the load distribution factor, K_m changes with microgeometry variation. The "optimum" microgeometry now has about 0.0002 in. of lead crown and no profile crown; at this condition, the load distribution factor is about 1.19. Any further misalignment or load shift due to shaft deflections is likely to increase this value. Also, note that this perfectly aligned load distribution factor increases as we increase either the lead crown or the profile crown.

Step 5. Determine candidate profile crowns and perform microgeometry simulation of the interaction between lead crown and misalignment. From Figures 5 and 6 we choose profile modifications from 0.0004 to 0.0007 in. For this paper, we are using two different AGMA quality numbers, Quality A6 and A8, respectively, for the evaluation of sensitivity to misalignment. The misalignment used is essentially the root sum square (RSS) value of the AGMA lead deviations of each part as

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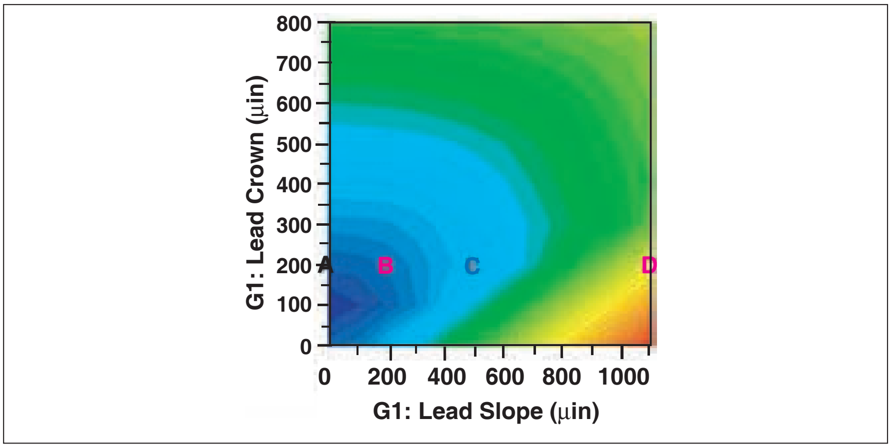

Figure 8—Interaction between misalignment and lead crown on the contact stresses with 0.0005 in. of profile crown. (A–200 ksi; B–201 ksi; C–208 ksi; D–234 ksi)

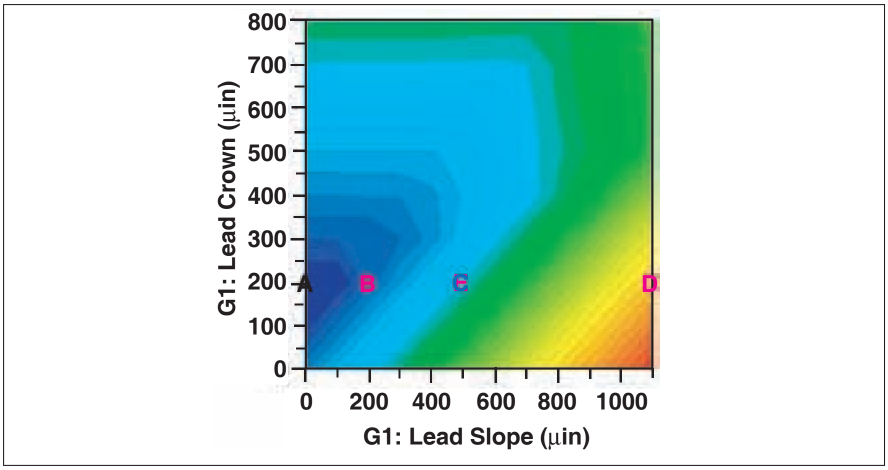

Figure 9—Interaction between misalignment and lead crown on pinion root stresses with 0.0005 in. of profile crown. (A–47 ksi; B–51 ksi; C–57 ksi; D–67 ksi)

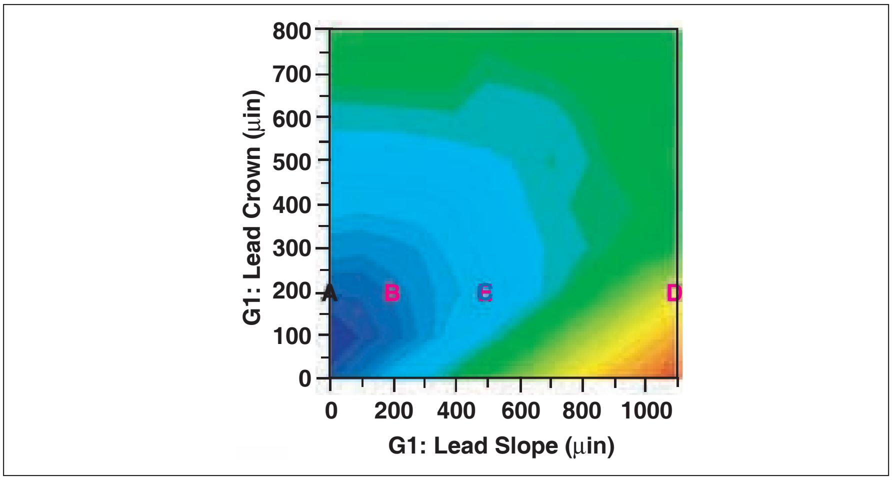

Figure 10—Interaction between misalignment and lead crown on load distribution factor with 0.0005 in. of profile crown. (A–1.41; B–1.44; C–1.53; D– 1.90)

Table 2—Standard deviation of robustness parameters		
	A6	A8
Profile slope (in)	0.000070	0.000140
Profile curvature (in)	0.000084	0.000170
Lead slope + misalignment (in)	0.000140	0.000370
Lead curvature (in)	0.000080	0.000160
Bias (in)	0.000040	0.000060

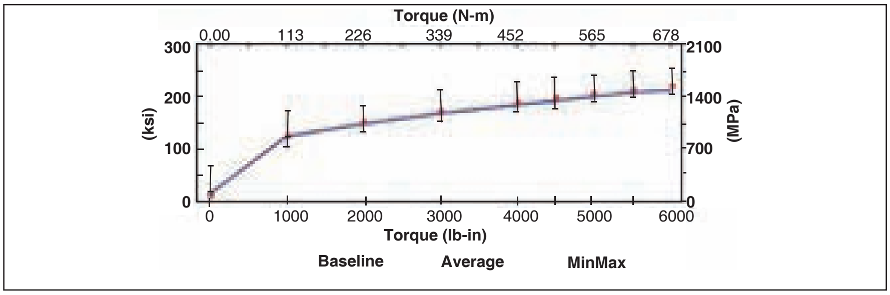

Figure 11—Peak contact stress using 100 random robustness analysis (profile crown = 0.0005 in.; lead crown = 0.0002 in.; quality = A8).

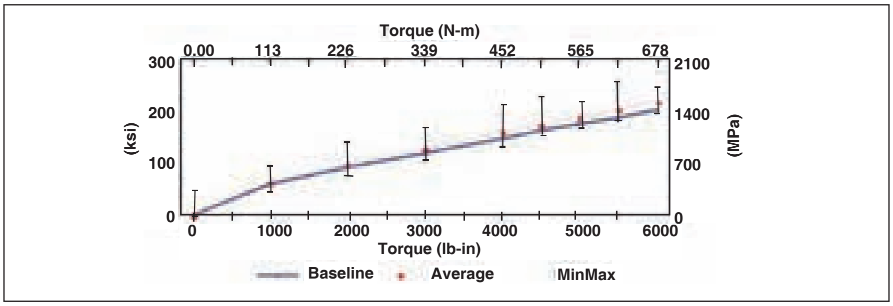

Figure 12— Pinion root stress using 100 random robustness analysis (profile crown= 0.0005 in.; lead crown = 0.0002 in.; quality = A8).

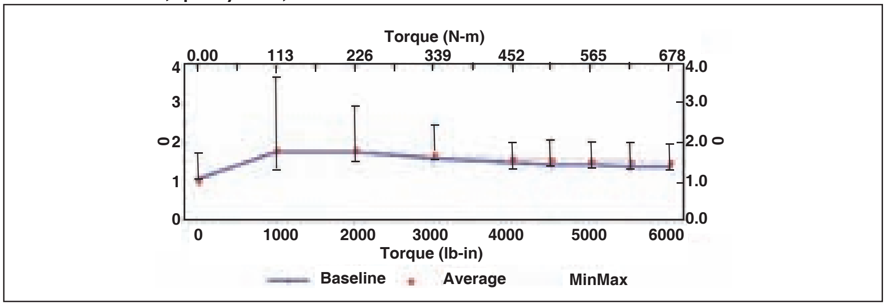

Figure 13— Load distribution factor using 100 random robustness analysis (profile crown = 0.0005 in.; lead crown = 0.0002 in.; quality = A8).

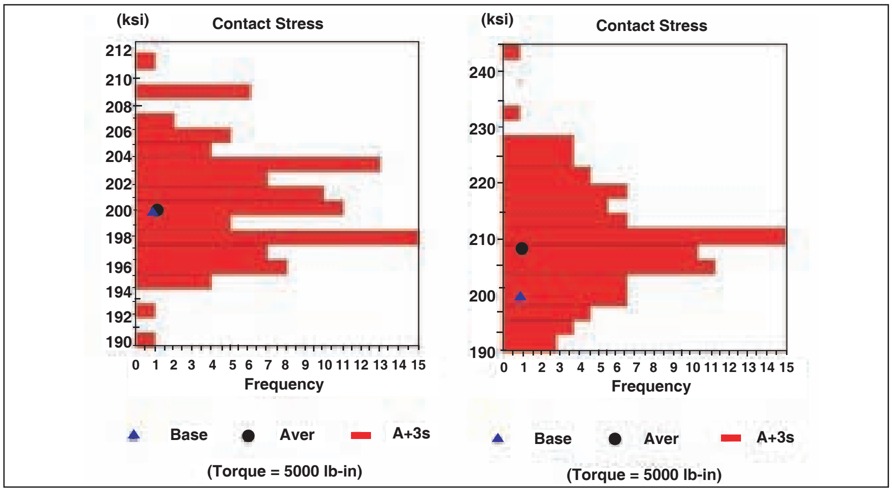

Figure 14—Frequency distribution of peak contact stress using random robustness analysis at 5,000 lb-in torque (profile crown = 0.0005 in.; lead crown = 0.0002 in. A6 on left, A8 on right).

0.0002 in., the load distribution factor of quality A6 gears at the maximum misalignment is 1.53, while the same factor for A8 quality gears is 1.90.

Robustness Analysis

A Monte Carlo type robustness analysis (Refs. 22–23) for quality A6 and A8 manufacturing deviations is performed next. In this analysis, one assumes that each manufacturing variable has a Gaussian distribution and each variable is randomly sampled from this distribution for each load distribution simulation. In this case, load distribution simulations of 100 randomly sampled sets of manufacturing variables are performed for each of the selected profile and lead crown combinations. Here, the standard deviations of each variable come from the AGMA accuracy standard (Ref. 8), but in practice, the manufacturer could establish these standard deviations through product audits. When using the AGMA tolerance values, the tolerance is assumed to be six standard deviations in width. A shaft misalignment tolerance must be added to the lead slope tolerance in order to account for misalignment. Since bias is not included in the AGMA tolerances, a relatively small bias value relative to the other factors was used in the simulation. Table 2 shows the standard deviations of the tolerance values that were used.

Figures 11–13 respectively show the effects of torque on the contact stresses, root stresses and load distribution factor for quality A8 gear pairs having 0.0005 in. of profile crown and 0.0002 in. of lead crown. The mean of the 100 robustness simulations is shown as the solid line; the baseline stress values are the dashed line; and the deviation bands indicate the maximum and minimum values at each of the loads. The deviation bands for each of the loads adjacent to the 5,000 lb–in load are roughly the same. This justifies using an estimate of the rated load in establishing deviation bands.

Figures 14–16 show, respectively, the distributions within the 5,000 lb-in. deviation band for the contact stresses, pinion root stresses and the load distribution factor for each of the quality levels. It is noted that the bands, as expected, are much wider for the lower quality level and the mean values also are higher for the lower quality level.

Tables 3 and 4 show summaries of the statistical data evaluations for the 5,000 lb–in. load. The first two columns provide the respective amplitudes of the profile and lead crowns in tenths of thousandths of an inch. The next three columns respectively show the mean contact stress, the standard deviation for that stress, and the value of the mean plus three standard deviations. The latter quantity is felt to provide an estimate of the expected maximum value of the worst-case combinations of gear accuracy deviations and provides a better number for making comparisons than does the true maximum value of the 100 runs. The next three columns provide similar data for the peak pinion bending stress, and the final three columns provide similar assessments of the load distribution factor.

Because of the danger of corner contact and tip interference, profile crowning was not reduced beneath 0.0004 in. However, if one wishes to totally avoid corner contact, the sum of the profile crown and lead crown must exceed 0.001 in. Also of interest is

continued

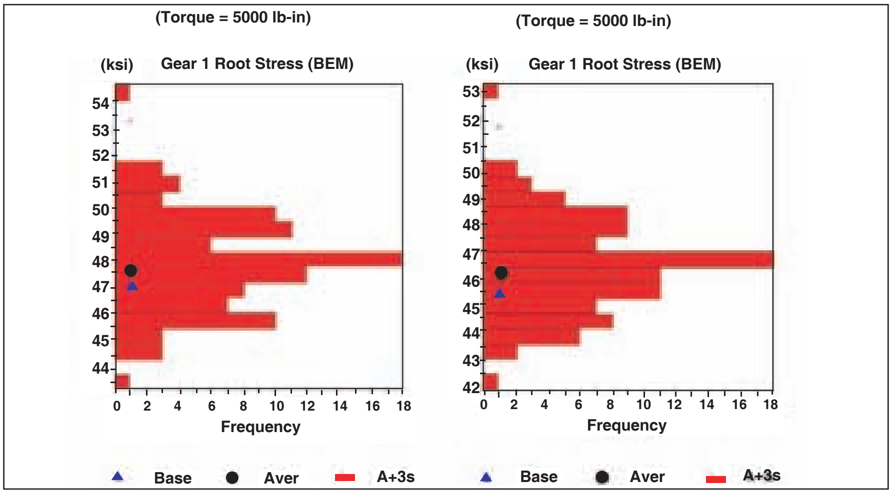

Figure 15—Frequency distribution of peak pinion root stress using random robustness analysis at 5,000 lb–in torque (profile crown = 0.0005 in.; lead crown = 0.0002 in. A6 on left, A 8 on right).

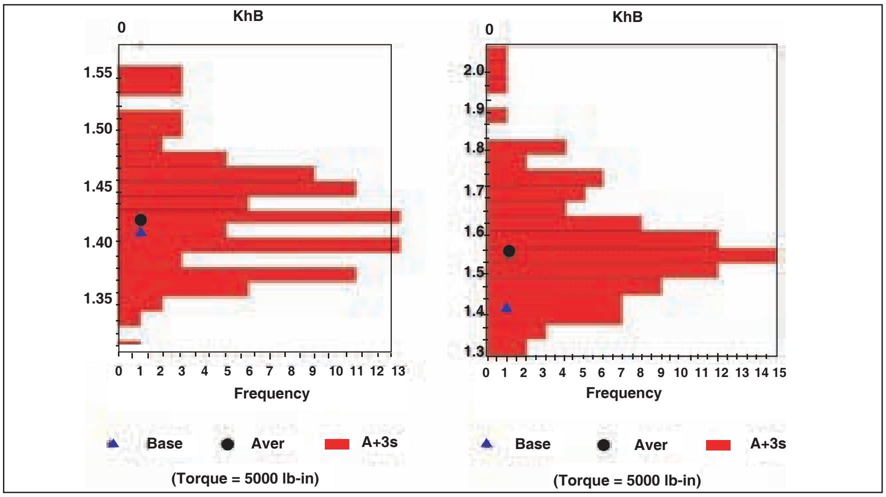

Figure 16—Frequency distribution of the load distribution factor using random robustness analysis at 5,000 lb–in torque (profile crown = 0.0005 in.; lead crown = 0.0002 in. A6 on left, A8 on right).

Table 3—Summary data for A6 quality
(P = profile crown, L=lead crown, both in tenths of thousandth of an inch; stresses in ksi)

P	L	s_c	s	s_c+3s	S_t	S	S_t+3s	K_m	S	K_m+3s
4	2	196	4.1	209	46.3	1.8	51.7	1.38	.05	1.54
4	3	199	4.9	214	46.8	1.8	52.2	1.41	.06	1.59
5	2	200	4.2	213	47.7	1.9	53.3	1.42	.05	1.57
5	4	206	5.1	222	49.6	2.0	55.7	1.51	.07	1.70
7	2	208	4.2	220	50.7	1.8	56.2	1.51	.05	1.66
9	0	222	6.5	241	56.0	2.9	64.6	1.67	.09	1.95
8	4	218	4.8	232	54.4	2.1	60.6	1.64	.06	1.81

Table 4—Summary data for A8 quality
(P = profile crown, L=lead crown, both in tenths of thousandth of an inch; stresses in ksi)

P	L	s_c	s	s_c+3s	S_t	S	S_t+3s	K_m	S	K_m+3s
4	3	204	8.2	228	48.9	3.5	59.3	1.51	.13	1.91
5	2	209	9.9	238	50.7	3.9	62.5	1.55	.15	1.98
5	3	207	8.1	232	50.3	3.5	60.9	1.53	.11	1.87
6	3	211	8.1	235	51.7	3.6	62.4	1.56	.10	1.87
9	0	233	13.5	274	58.6	5.3	74.5	1.81	.20	2.40
7	3	214	8.0	238	53.2	3.6	63.9	1.59	.10	1.88
8	4	219	8.1	243	55.0	3.5	65.6	1.64	.09	1.90

that the minimum transmission error is achieved when the sum of the profile and lead crown are equal to about 0.0009 in. The rows are oriented such that the sum of profile and lead crowns is lowest at the top and increases as one reads down the table.

Contact stress discussion. Much like Figure 5, the lower the sum of profile crown and lead crown, the lower the contact stress. For the A6 quality, the average contact stress was about equal to the baseline value; but for quality A8, the average was somewhat higher than the baseline level (seen from Figure 14). The standard deviations do not vary much with the selection of crowns, with the exception being the case that has zero lead crown. Here, the standard deviation was much greater than for the other modifications. The mean plus 3 standard deviation data indicates the worst case stress, and is probably the best column for comparing the different modifications. Here, we see that for the A6 quality, the P4L2 case has the lowest value and is followed quite closely by the P4L3 and P5L3 cases. The P4L3 case seems to be the best of the Quality A8 pairs, followed closely by the P5L3 case. Going from Quality A6 to A8 roughly doubles the standard deviation; the average stresses increase by 7-10 ksi and the maximum stresses increase about 20 ksi (10% of the mean stress). When taken from the baseline data, there is a peak stress increase of about 7% for the A6 quality and an increase of 14% for the A8 quality.

Pinion root stress. Again, the standard deviations are quite similar for all cases except the P9L0 case. For both quality levels, the "best" modifications are the same as those for the contact stresses. This occurrence is most fortunate since it avoids the need for a compromise to be made for these criteria. The percentage increases in root stresses from the baseline values of the A6 and A8 quality gears are 13.6% and 26%, respectively.

Load distribution factor. The best modifications for both quality levels are similar to those for the stress calculations. The percentage increases in the load distribution factors for the A6 and A8 quality levels are 12.4% and 34%, respectively.

Since the baseline gear was used to compute the percentages, the true percentage increases from the unmodified gears will be a bit higher. If the starting modifications are far afield from the "best" modifications—as occurs with the P9L0 case—it is likely that both the baseline stresses and the standard deviations will be greater than for the "best" cases. Hence, there is much to be gained by having "good" starting profile and lead modifications.

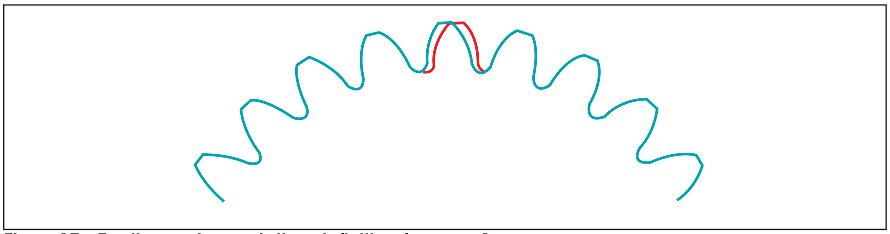

Figure17—Tooth spacing variation definition for case 1.

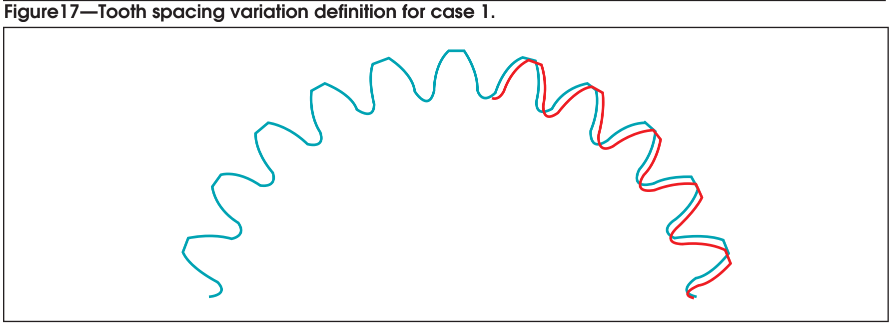

Figure 18—Tooth spacing variation definition for case 2.

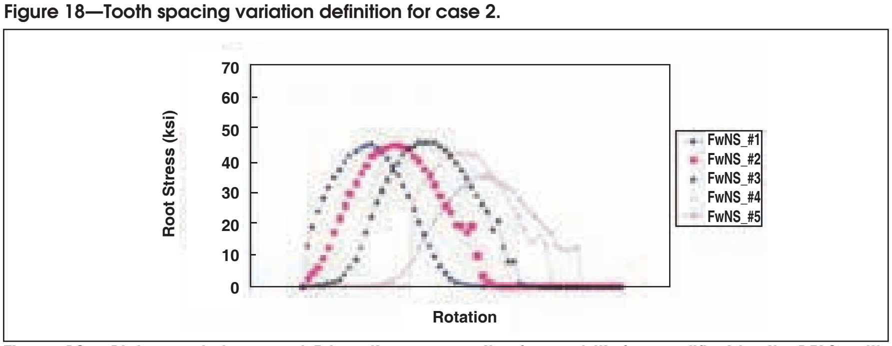

Figure 19— Pinion root stresses at 5 locations across the face width for modified teeth (P5L2) with 5,000 lb-in. torque (no spacing variations).

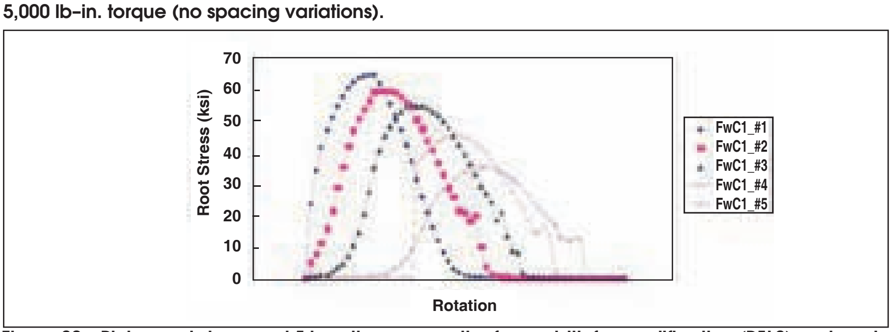

Figure 20—Pinion root stresses at 5 locations across the face width for modification (P5L2) and quality A8 spacing variation (case 1) with 5,000 lb-in. torque.

Table 5—Summary of pinion root stress using spacing deviation for the modified P5L2 helical gear pair.

	AGMA A8 0.000692 in (ksi)	AGMA A6 0.000346 in (ksi)
No spacing	45.03	
Spacing case 1 (+)	64.22	54.61
Spacing case 2 (+)	66.33	55.05
Spacing case 1 (-)	66.32	Not run
Spacing case 2 (-)	50.97	Not run

Spacing and Runout Deviations

Both of these deviations fall in the domain of the AGMA quality system, and so are evaluated using the load distribution analysis. A scheme for evaluating these deviations on both static and dynamic stresses has been performed (Ref. 15), and this method could in fact be superimposed upon the methodology described in this paper. Here, we shall only perform the static analysis. It is expected that one can simply superimpose the spacing and runout deviation effects with the lead and profile deviations, without introducing much error. So for now, we will only look at the spacing and runout deviation effects as separate cases.

Spacing Deviations. Here, we shall evaluate only the worst case tooth-to-tooth spacing deviation and will present results only for root stresses. There seem to be two possibilities for creating a worst-case scenario—the first being when only one tooth is mispositioned, and the second when many subsequent teeth are mispositioned by the deviation tolerance. Figure 17 shows the first case and Figure 18 shows the second case. In each case the position of the first tooth with an error may be positive (comes into contact early) or negative (comes into contact late). The negative condition is shown in the two figures.

These effects are simulated by essentially shifting the profiles either forward or backward, depending upon the sign of the deviation. For positive deviations, the tooth with the error comes into contact early and carries a disproportionate share of the load. The values of errors used are the sum of the square of the spacing deviations of the pinion and the gear, respectively.

Figure 19 shows the plots of root stresses for five locations across the face width (similar to Figure 3) for a modified gear tooth without spacing errors. Figure 20 shows the stresses after the addition of the spacing error, and one notes that the stresses at the edge of the tooth increase significantly. Table 5 summarizes the stress values for positive and negative errors for each case for both A6 and A8 accuracies. For quality A8 gears, the root stress increases about 45% for three of the four cases and for the A6 quality, the stress increase is still about 20%.

Runout deviations. In the simulations performed for this paper, AGMA radial runout was converted to tangential spacing errors using the tangent of the pressure angle. The runout was considered to be sinusoidal and a sinusoidal train of spacing errors was simulated. Values are not presented, but values were roughly equivalent to those of individual spacing errors of the "worst- case spacing" of the sinusoidal errors.

In converting radial runout to tangential spacing error, the following equation was used for each gear:

$$SE = \frac{f_{idT}}{2} \tan\,(\phi_t) \left(\frac{360}{N_T}\right) \qquad (3)$$

where,

SE peak effective spacing error

F_{idT} radial composite tolerance

ϕ_t transverse pressure angle

N_T number of teeth

Summary

An analysis procedure has been presented that accounts for manufacturing accuracies in evaluating contact stresses, root stresses and load distribution factors. The same procedure may be used for other design metrics such as film thickness, flash temperature and transmission error. The increases in stresses due to profile and lead deviations are certainly significant, being as high as 26% for the root stresses of the example quality A8 helical pinion. The load distribution factor increased 34% for the same pinion. Spacing variations provided even higher stress variation, with root stresses increasing by as much as 45% for the A8 spacing error. Although not shown, contact stresses and the load distribution factor also increase significantly when spacing errors are applied. Also presented in this paper is a procedure for selecting appropriate modifications that compensate for misalignment and avoid severe corner contact and tip interference. General conclusions are:

- Spacing deviations: They have a large effect on contact and root stresses, mainly due to transverse load sharing (up to 50%).
- Runout has a relatively small effect, but lower quality gears still may cause an increase in stresses.
- Microgeometry changes (profile, lead and misalignment deviations) significantly affect contact stresses (5–10%) and root stresses (10–25%).
- It is important to start a design with reasonable profile and lead modifications, since this reduces the variability in stresses due to inaccuracies.
- The best modifications do not totally eliminate corner contact or tip interference, but do reduce their effect. If one totally eliminates tip interference, stresses will be higher than those for the"best" modifications shown here.
- Although the increases in stress values due to manufacturing variability appear to be quite large relative to current rating practice, one could justify these effects as being part of the uncertainty that is part of the design factor of safety (difference between design allowable stresses and material property stresses) in the current rating practice.

Even though many manufacturing variables have been considered in this study, there are still numerous factors that are affected by manufacturing accuracy that will influence stress values. Several, such as tooth thickness, center distance variation, outside diameter variation and surface finish variation, have not been included and certainly have possibilities for future studies. Fortunately, many designers run min/max calculations for these parameters so they do in a way get considered in their evaluations.

Acknowledgements

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continued

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ASM

BRINGING THE HEAT TO GEAR EXPO

The Heat Treating Society Conference and Expo is expected to add 3,000 attendees and 100 exhibitors to Gear Expo.

Gear making and heat treating pair together like a fine cabernet and filet mignon. Now for the first time, the two industries are embracing this symbiotic relationship by co-locating their industry events this fall in Indianapolis. ASM International's 2009 Heat Treating Society Conference and Exposition and Gear Technology's favorite trade show, Gear Expo, are teaming up September 14–17 at the Indiana Convention Center in Indianapolis.

"We expect our combined attendance to provide unprecedented learning opportunities for leaders, innovators, suppliers and customers of both communities," says Rick Sisson, president of the ASM Heat Treating Society.

As North America's largest heat treating event, the 2009 Heat Treating Society Conference and Exposition typically takes place every two years; this is the 25th edition of the event.

In the past, the ASM show has partnered with other events of interest to its members, such as the Materials Science and Technology Conference and Exhibition, and shows organized by the Minerals, Metals and Materials Society, Association for Iron and Steel Technology and American Ceramic Society. "We look to partner with societies like AGMA whose members use heat treating as part of their larger technical focus," says Rego Giovanetti, communications officer for ASM International. "At the same time, a dynamic exposition like Gear Expo is going to be of great interest to the heat treating community, creating a win-win for both sponsoring societies."

In 2006, ASM Heat Treating Society executive director Thom Passek initiated discussions to bring the shows together with AGMA President Joe Franklin and Kurt Medert, former AGMA vice president, business management. "We are always looking for ways to provide a more valuable experience for our members—and in talking with them and our exhibitors and participants we found a very high level of interest in Gear Expo," Passek says. "We approached the AGMA about bringing our two shows together since the connection between gear manufacturing and heat treating is so strong. We both agreed that this was an opportunity to achieve a great deal of synergy, where someone attending one show could simply cross the aisle to learn about the other industry as well."

In addition to manufacturers demonstrating new furnaces and related equipment on the show floor, technical sessions and educational short courses will address topics that include applied energy, atmosphere technology, brazing, emerging heat treating technologies, quenching and cooling, vacuum technology, equipment innovations, global environmental issues, processes and applications.

"The short courses are optional (requiring an additional fee) and provide intensive instruction in a particular area of heat treating," Giovanetti says. "Call it a great way to strengthen your heat treating fundamentals and gain day-to-day knowledge that will benefit your heat treating operations. The conference sessions are more about new research, processes, applications or furnaces and equipment for higher quality, lower energy usage and emissions and improved productivity and profitability."

And, of course, gears will be a hot topic (pun intended). "Because of their importance in manufactured systems, the heat treatment of gears is always a major focus of our ASM technical sessions," Giovanetti says. "This year's co-location with Gear Expo has brought even greater focus on gears to our program. In fact, there are so many presentations involving heat treatment of gears, particularly for wind power generation applications, that we've themed our event 'Gear Up for the Winds of Change.'"

For more information, visit *www.asminternational.org/heattreat*

Attendance to Sigma Pool's first gear seminar of 2009 was up, and participants were eager to learn new technologies (courtesy of Sigma Pool).

Sigma Pool Encourages Collaboration at 2009 U.S. Gear Seminar

In the past, the coffee breaks and dinner events at Sigma Pool's gear seminars have often triggered future process development and product improvements. This was still the case during the 2009 installment where customers and suppliers talked shop inside and outside the banquet hall on the new market and technology challenges currently facing the gear industry.

Under the Sigma Pool name, Klingelnberg and Liebherr have worked together worldwide to communicate production, application and design know-how about gears and gear manufacturing processes to their customers since the beginning of the 1990s.

Sigma Pool recently wrapped up its first gear seminar of 2009, a two-day event that took place on June 16–17 at the Four Point Sheraton in Ann Arbor, Michigan with a focus on bevel gear and parallel axis technology.

Jan Klingelnberg, CEO of the Klingelnberg Group, introduced the event with "cautious optimism" noting that the industry must recover from an economic slowdown that has affected the global gear industry as a whole. Klingelnberg was pleased with the turnout for the first Sigma Pool gear seminar this year, citing the attendance numbers as a "positive sign that the gear industry will soon recover."

This is the 5th time Sigma Pool has offered gear makers in the United States a two-day event that covers all aspects of manufacturing and measuring of cylindrical and bevel gears. Apart from the fundamentals, the seminar focused on current trends and developments in gear manufacturing.

Dr.-Ing. Carsten Hünecke from Klingelnberg gave two presentations on

continued

day one focusing on modern production of straight bevel gears and Spirokon, a new manufacturing system for spiral bevel gears. Dr.-Ing. Oliver Winkel at Liebherr spoke twice on day two on the performance and flexibility of modern hobbing machines and the machining of large gears. Other topics included axle gear design, bevel measuring technology, roll testing technology and the generating and profile grinding of larger modules. Dr.-Ing. Hartmuth Müller, CTO of Klingelnberg, kept the question/answer sessions moving along after each presentation, allowing extra time for discussion and feedback from the attendees.

Rick Perri, engineering/purchasing at Superabrasives, Inc., felt the seminar was very informative and was interested in the presentation on spiral bevel grinding with Borazon.

"The data that was presented was done with one of our wheels and we wanted to see what the overall response would be. We are very encouraged to get more involved in the gear industry from the amount of questions that were asked."

"Working Together" is the general theme of the 2009 Sigma Pool gear seminars. The events will take place on three different continents and four different locations throughout the year. After the initial stop in Ann Arbor, the tour continues with a July 20–21 event in Chennai, India as well as a July 23–24 event in Pune, India. It continues October 29–30 in Sao Paulo, Brazil.

Keynote themes for future presentations include:

- New methods for bevel gear production—using modified mathematical models, spur-toothed bevel gears and the innovative Spirokon gear that can be dry-machined on Oerlikon milling machines.
- Enhancing productivity with alternative grinding abrasives—the vitrified-bonded CBN abrasives which have already proved their worth in external cylindrical grinding are now leading to significantly improved performances in the grinding of bevel gears.
- Grinding large gears cost-effectively—generation grinding, established for decades in the world of automotive gear production, is about to revolutionize the productivity of large module gear grinding.
- Gears for wind turbines—combined with tools using cemented carbide blades, stiff modern machine concepts open up new vistas in terms of high removal rates and minimum process times.
- Gear measuring machines can do more—modern measuring machines go beyond familiar geometry data, testing the complete part, including its surface roughness, and fully quantifying the form and position of all surfaces.
- Quality testing cylindrical gears—new methods enable gear metrology to move forward from pure geometry measurement to functional testing.

Sigma Pool will be on hand at Gear Expo in Indianapolis from September 14–17 and at EMO in Milan from Oct. 5–10. For more information on Sigma Pool's gear seminars, visit *www.sigma-pool.com*

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Jan Klingelnberg, CEO of the Klingelnberg Group, gives his opening remarks at Sigma Pool's U.S. Gear Seminar (courtesy of Sigma Pool).

July 27–29—Powder Metallurgy Basic Short Course. Penn Stater Conference Center Hotel, State College, PA. This three-day course is designed for users of PM parts and people starting out in the PM field looking for an introduction, looking to learn about recent developments in the industry or trying to broaden a PM background. Attendees will learn the history of PM, why it is viable, why use is so widespread, design points, production, injection molding, standards and the latest technologies. It is not required that attendees have a technical background. It is designed specifically for engineers, tool designers, product designers, metallurgists, technicians, QC personnel and more. For more information, visit *http://www.mpif.org/meetings/2009/2009_basic_sc.pdf* or call the MPIF at (609) 452-7700.

August 4–7—Center for Automotive Research Management Briefing Seminars. Grand Traverse Resort and Spa, Traverse City, MI. Leaders in the automotive and related industries convene in Traverse City every August to outline their future goals at the Center for Automotive Research (CAR) Management Briefing Seminars. This year, CAR anticipates a greater focus on the relationships between all stakeholders, including the federal government. Initial conference planning by the CAR team of researchers and conference managers is closely attuned to the industry and the economy as a whole. The realities of today dictate leaner budgets and staffing, and the 2009 program has been consolidated into a four-day event to reflect this. For more information, visit *www.cargroup.org*.

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

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

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

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

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

The grand opening ribbon cutting ceremony for Gleason Cutting Tools (Suzhou).

Gleason

OPENS SECOND CHINA PLANT

Gleason recently opened its second manufacturing facility in Suzhou Industrial Park for the production of cylindrical gear and bevel gear cutting tools. Gleason Cutting Tools (Suzhou) has begun full-scale production of hobs for spur and helical gear production and spiral bevel blades for bevel gear cutting systems.

"Gleason is not new to the fast-growing China market," says John J. Perrotti, president and CEO at Gleason. "In fact, no other manufacturer has imported to China the number of gear production machines and cutting tools as Gleason has over the last 30 years. Gleason continues to expand its presence in China to keep pace—locally—with growing demand for the most advanced machines and tooling."

The new facility complements Gleason Gear Technology (Suzhou) Co., Ltd. that first opened in October 2006.

"We now have the ability, unmatched by any other gear equipment manufacturer, to use the most modern local resources to meet the needs of our Chinese customers for greater access to the world's most advanced and productive gear manufacturing technologies," Perrotti says.

Among the investments made in the facility is a precision hob cell that includes advanced turning, wire EDM, grinding, hob sharpening and analytical inspection machines for 'one-stop' manufacturing of a wide variety of hob sizes and styles. This same cell concept is also being used for the production of spiral bevel blades for bevel gear cutting systems.

Woods

Elected AMT President

Douglas K. Woods

The Association for Manufacturing Technology's (AMT) board of directors has elected Douglas K. Woods president. Woods comes to AMT from Parlec, Inc., a company that specializes in tooling, workholding and presetting solutions. He was a member of AMT's board of directors from 2000–2008, serving as chairman from 2005–2006. Woods was also chairman of the committee for AMT's Custom Automated Systems Group.

"This is a fantastic opportunity for me to work at an association that promotes an industry I grew up in," Woods says. "I have a great deal of respect for the staff at AMT and look forward to working with the members."

Woods has worked at everything from small tool and die shops to multibillion-dollar machine tool corporations. His international experience and connection to a broad manufacturing base allow him a unique perspective on the needs of AMT members. "We are pleased that Doug has agreed to take on this challenge," says Ron Schildge, chairman of the AMT board of directors. "His experience and commitment to this industry will serve AMT and its members well in these challenging times."

Woods served as president of both Parlec, Inc. and Parlec International. He was president at Liberty Precision Industries, a company he joined in 1990, and served in executive positions with the automation systems divisions of Cross & Trecker and Gleason. He began his career at Alliance Automation System where he served his apprenticeship and went on to hold several management positions.

Woods has been involved in other manufacturing associations, including the National Tooling & Machining Association and the Rochester Tooling & Machining Association.

Philadelphia Gear

Hires Middle East Sales Engineer

R. K. Kumar

Philadelphia Gear Corporation has appointed R.K. Kumar as sales engineer for the United Arab Emirates. Kumar will be responsible for developing key accounts in the energy market and will handle daily customer relation activities. Kumar brings more than 15 years of experience in heavy industrial field work, sales and service of gas turbines and other related products. He was recently a customer support engineer with Sun Power Gen Systems and Services. He earned his bachelor's degree in mechanical engineering from the Institute of Engineers, Calcutta University in Calcutta, India.

"We are encouraged by the depth of global experience R.K. Kumar brings to the Philadelphia Gear Corporation sales team," says James Aston, Middle East Region sales director. "Our customers in the United Arab Emirates will benefit greatly from his varied skills developed in working with high-profile energy market companies throughout the Middle East."

AGMA

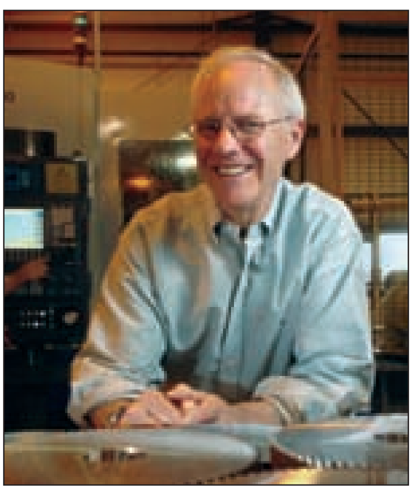
PUBLISHES BEVEL GEAR MEASUREMENT REPORT

AGMA recently announced the publication of a new ISO Technical Report for the gearing community. ISO/TR 10064-6, Code of inspection practice–Part 6: Bevel gear measurement methods, is designed to provide technical information regarding the measurement of unassembled bevel and hypoid gears and gear pairs. It is intended to permit the manufacturer and purchaser to conduct measuring procedures that are accurate and repeatable to a compatible degree with the tolerance grades in ANSI/AGMA ISO 17485. The paper was prepared by ISO TC 60/Working Group 2 with the input of leading U.S. experts from the AGMA Gear Accuracy Committee. It can be purchased in electronic format at *www.agma.org*.

Gear Research Institute

SHIFTS LEADERSHIP

Upon his retirement from the Gleason Corporation at the end of 2008, Gary Kimmet also stepped down from his role as president of the Gear Research Institute. "We wish Gary the very best in his retirement and thank him profusely for his long and selfless service to the institute," says Dr. Suren Rao, managing director. "As a good friend I have known since the 1980s, when I was in the industry, I will miss him, his support and his counsel."



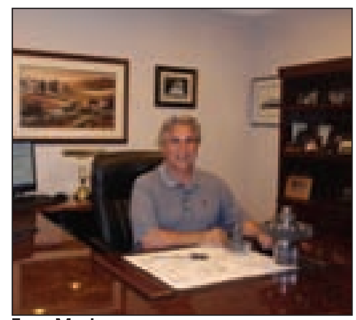
Sam Haines

Sam Haines of Gear Motions was elected president of the Gear Research Institute by the board of directors. Jack Masseth of Arvin Meritor was elected secretary and Al Swiglo of Northern Illinois University will continue as treasurer. Charlie Fischer, vice president of AGMA's technical division, was nominated by AGMA to the institute's board of directors as a replacement for Kimmet.

continued

Gear Technology

SIGNS AGREEMENT WITH TRIUMPH


Tom Marino

Gear Technology, a manufacturer of precision gears for aerospace, military and commercial industries, has signed a five-year manufacturing agreement with Triumph Gear Systems, a group company of Triumph Aerospace Systems, headquartered in Park City, Utah.

Terms and conditions of the agreement provide a mutual beneficial business relationship between our two companies, according to Tom Marino, president of Gear Technology.

"Gear Technology will be contract-manufacturing precision-quality machine gear products including shafts, splined rings, splined spacers and clutch plates for military V-22 Osprey Tilt-Rotor Aircraft," Marino says. "Our integrated manufacturing processes, including sophisticated job tracking systems, ensure products are produced with careful attention to the most intricate engineering detail and product specifications. The company also offers gear blanking, engineering consultation and sophisticated inventory management services."

MTConnect Institute

SEEKS MEMBERS

The newly established organization that seeks to promote manufacturing system interoperability seeks new members to assist in developing and promoting the standards and materials required to implement MTConnect.

The MTConnect Institute is open to any individual, company or organization interested in participating in MTConnect implementation. Four levels of membership are currently available including founding sponsor, institute partner, MTConnect Institute Technical Advisory Group (MTCTAG) member and registered member. Each level provides different benefits within the institute.

The development of MTConnect, an open, royalty-free standard, began in early 2007. It is a means of improving the ability to collect data across manufacturing technologies that address interoperability between controls, devices and software applications similar to what has been achieved in the information technology arena. MTConnect seeks to develop standardized communication protocols that will allow devices, equipment and systems to output data in a common format that can be read by another technology.

Partnership

BRINGS ACADEMIA AND INDUSTRY TOGETHER

LMS, an engineering innovation company, recently announced its partnership with the Australian Royal Melbourne Institute of Technology. Together, they have established the RMIT–LMS Centre of Expertise in NVH (Noise, Vibration and Hardness). The center will consist of education and research giving students at the institute an opportunity for internships at one of LMS International's worldwide offices.

"Establishing a strong partnership between LMS International and RMIT University provides a new way for industrial partners and universities to undertake joint research activities and develop a complementary expertise in a specialized area," says Aleksandar Subic, professor and head of the school of aerospace, mechanical and manufacturing engineering at RMIT.

The center will integrate LMS International's instrumentation, simulation and testing software with the university's expertise in NVH research, application and education. Laboratories will be set up for modal analysis, spectral testing and sound intensity measurements including an advanced, multi-channel acoustic camera for field mapping.

"We will be able to support the industry by offering regular technology updates as well as seminars for industry

continued

professionals and advanced graduate students," says Boris Marrone, LMS International area manager SEA/Pacific. "We are taking an important role by keeping the local industry up to speed with what is happening around the globe."

Adcole

PURCHASES KOMATSU-NTC

The Adcole Corporation has bought out Komatsu-NTC from their joint venture, Adcole Far East Ltd., in Tokyo. Terms of the deal were not disclosed though Komatsu is reportedly consolidating their business units. According to the company's press release, Adcole saw this as an opportunity to reinforce their relationship with Far East customers including Toyota, Nissan, Honda, Mazda, Mitsubishi, Mitsubishi Heavy, Yanmar Diesel, Hyundai, Kia, GM Daewoo and others. Adcole's measuring machines are used by engine manufacturers to help meet quality objectives in the gage room and on the shop floor.

"Despite the global recession and its impact on the automotive, trucking and heavy equipment industries, Adcole has chosen to buy out Komatsu-NTC to position ourselves for the economic recovery and our continued growth worldwide," says J. Brooks Reece, vice president.

ASTM International

APPROVES NEW STANDARDS

The American Society for Testing and Materials (ASTM) has recently approved two international standards for properties of sintered metallurgy products. The new standards, ASTM B962: Test Methods for Density of Compacted or Sintered Powder Metallurgy Products Using Archimedes' Principle, and ASTM B963: Test Methods for Oil Content, Oil-Impregnation, Efficiency, and Interconnected Porosity of Sintered Powder Metallurgy, are based on tests originally contained in ASTM B328, according to W. Brian James from the Hoeganaes Corporation.

The purpose of ASTM B962 is to provide the means, through use of Archimedes' principle, to determine the volume in order to calculate the density of complex three-dimensional shapes such as those formed and used in the powder metallurgy industry.

The results of the tests covered in ASTM B963 will be used for powder metallurgy quality control or compliance purposes.

Interested parties are invited to participate in the interlaboratory study that Subcommittee B09.04 is currently planning to determine the precision of the test methods. ASTM international standards can be purchased from customer service at (610)-832-9585 or by contacting *service@astm.org*. For more information, visit *www.astm.org*.

Northstar

SELLS SUBSIDIARY TO FOCUS ON GEAR PRODUCTION

The assets of Turbine Engine Service Group (TESG) of Stroud, OK, a subsidiary of Northstar Aerospace, Inc., was sold to Mint Turbines LLC. Gross proceeds of the deal were approximately $9.35 million, and the transaction included an estimated adjustment for working capital. Northstar intends to use net proceeds of the sale to reduce the Chicago-based company's outstanding debt obligations, which includes fulfilling a $7.5 million repayment due July 31.

TESG is a repair and overhaul business that specializes in Pratt & Whitney PT6 turboprop engines. TESG employs 43 people and generated more than $15 million of revenue in 2008. In November 2008, Northstar announced plans to divest the subsidiary as part of Northstar's larger strategy to concentrate its core business on manufacturing gears and transmissions for defense and commercial aerospace industry customers. Northstar's main products include helicopter gears and transmissions, accessory gearbox assemblies, rotorcraft drive systems and other machined and fabricated parts.

Glenn Hess, president and CEO of Northstar Aerospace, commented in a press release. "While we will miss our relationship with TESG, this transaction allows Northstar to focus on our core business, improve our balance sheet and satisfy our bank commitments."

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You Want It When!?

What do glam and avant garde rock star Brian Eno, AGMA and Seattle Gear Works have in common?

Admittedly, not much. But there is a connection of sorts.

In 1996, Eno was among a number of individuals credited with founding the Long Now Foundation, (*www.longnow.org*). No, it is not a cult. Rather, it was established "to develop the Clock and Library projects, as well as becoming the seed of a very long-term cultural institution. The Long Now Foundation hopes to provide a counterpoint to today's 'faster/cheaper' mindset and promote 'slower/better' thinking. We hope to creatively foster responsibility in the framework of the next 10,000 years."

According to the group's website, "Civilization is revving itself into a pathetically short attention span." As a result, a project was initiated by Long Now member and computer scientist Daniel Hillis, who lays claim to developing the "massive parallel" architecture for today's super computers. The project?—"I think it is time for us to start a long-term project that gets people thinking past the mental barrier of an ever-shortening future," says Hillis. "I would like to propose a large—think Stonehenge—mechanical clock, powered by seasonal temperature changes. It ticks once a year, bongs once a century, and the cuckoo comes out every millennium."

Known as the "10,000 Year Clock," Hillis and his group have hopes that the project, to be installed in the side of a mountain in eastern Nevada, "would do for thinking about time what the photographs of Earth from space have done for thinking about the environment."

Obviously, people with short attention spans would not be considered Long Now candidates. But many of us can relate to what Hillis is saying. Who hasn't wondered "where does the time go?" How can one possibly keep abreast of all the new technology in communications and elsewhere that seems to proliferate on a daily basis? What gear shop manager hasn't asked why customers always seem to need their order yesterday?

Perhaps in response to those questions, Seattle Gear Works (*www.thegearworks.com*) commissioned a gear art sculpture inspired by the 10,000 Year Clock. The work, created by Stuart Kendall of Seattle Solstice (*stuart@seattlesolstice.com*), an enclave of artists/engineers creating outsized works of art hewn from stone and other materials, incorporates gearing made of interwoven jade gear elements that form a rising arch topped off with the AGMA logo. Also incorporated are polished monel shafting and LED illumination, supported by a pedestal base of "timeless" granite. In addition, Kendall is involved in the creation of the 10,000 Year Clock's stone gears and the cavern in which the clock will be housed.

The sculpture was auctioned last March at the annual AGMA meeting in Orlando, FL, and the proceeds were used to create the Don McVittie Memorial Scholarship Fund in remembrance of Don's passing last year. The fund will help provide much needed support for the education of engineering students who are pursuing a career in the gear industry.

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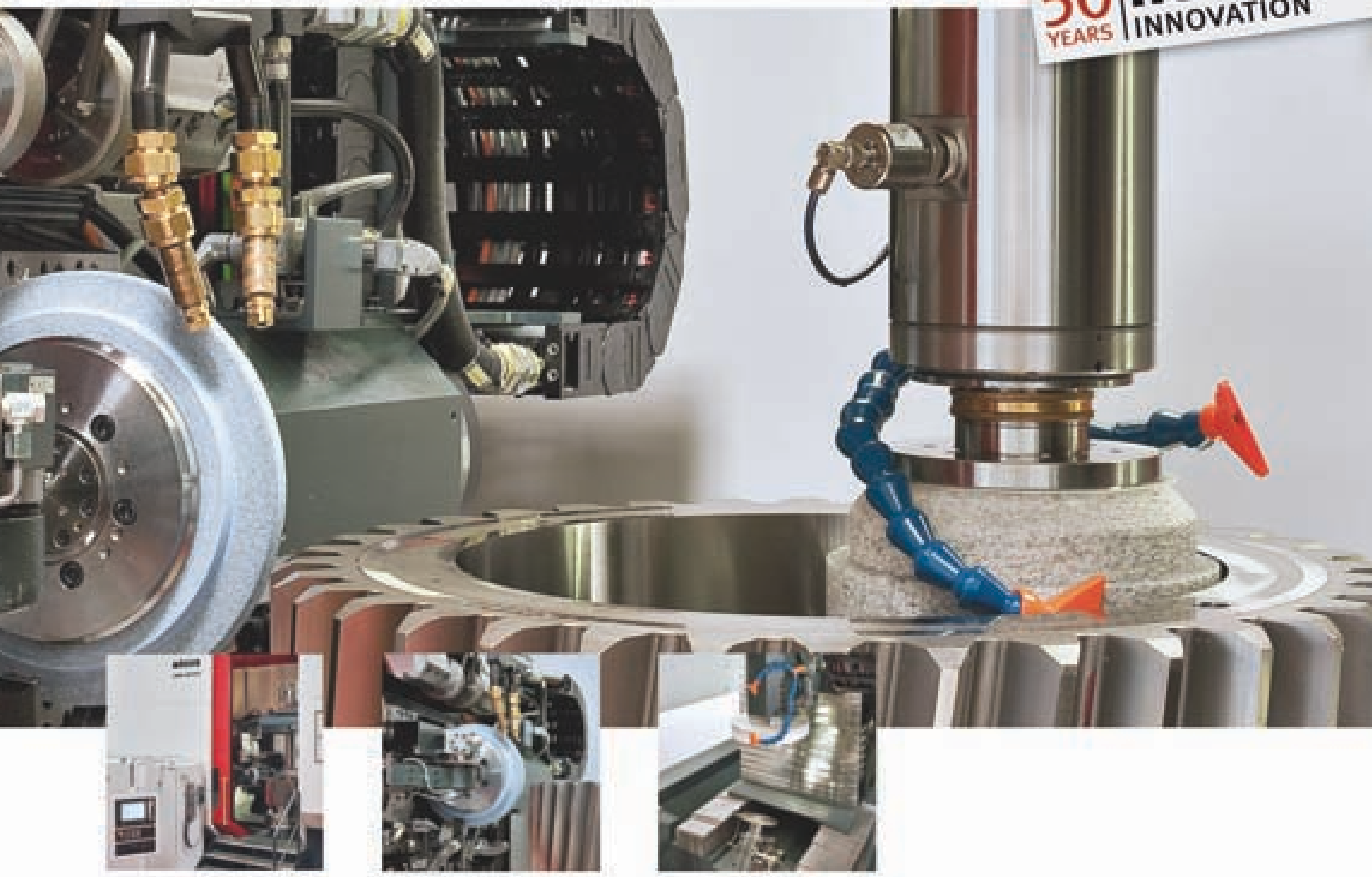

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