May 2009

# GEARTECHNOLOGY

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The Journal of Gear Manufacturing

25 YEARS 1984-2009

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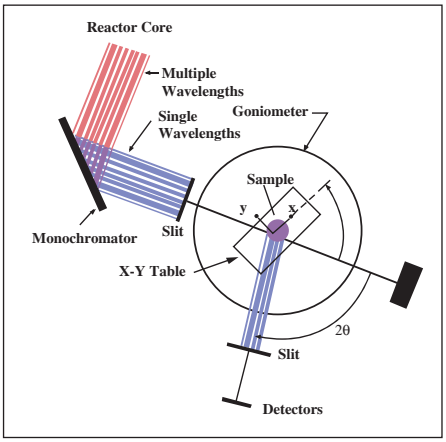
# CONTENTS

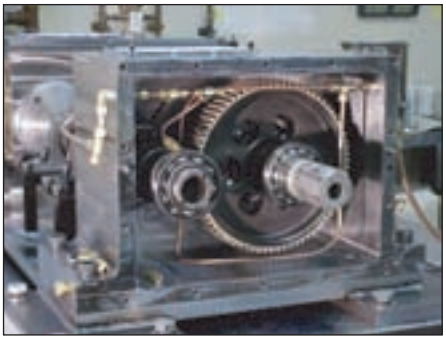
## FEATURES

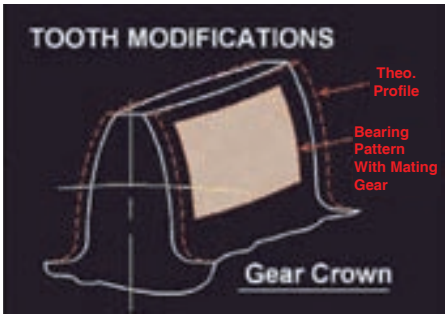


## TECHNICAL ARTICLES





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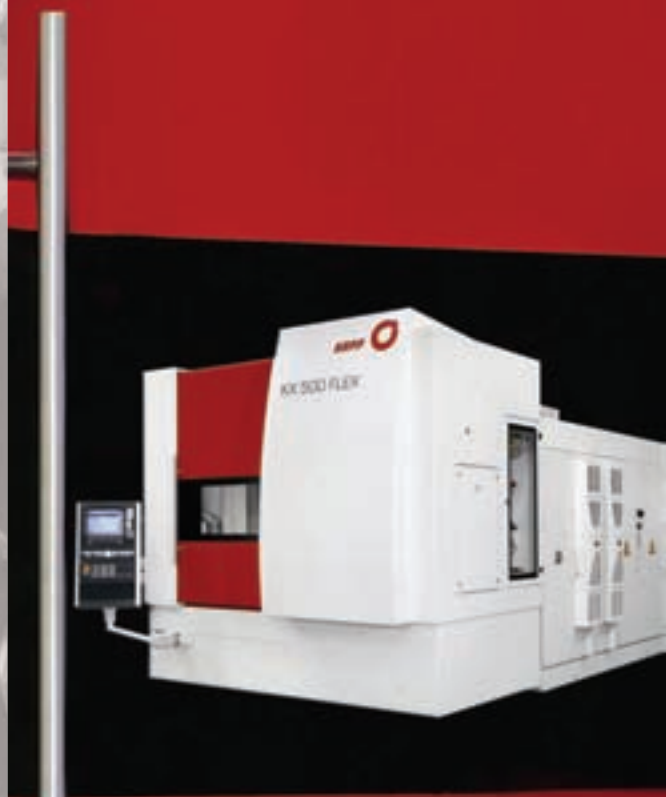

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# CONTENTS

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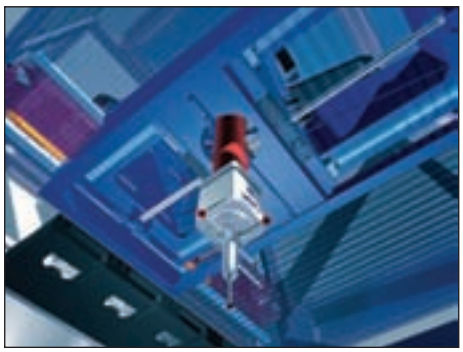

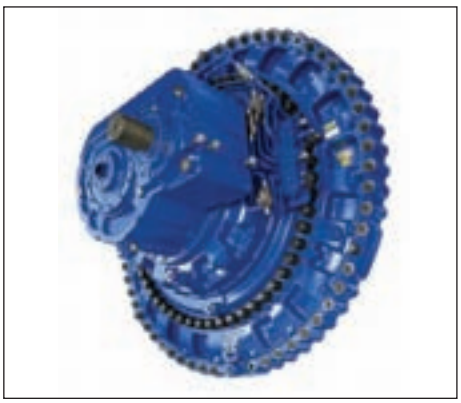

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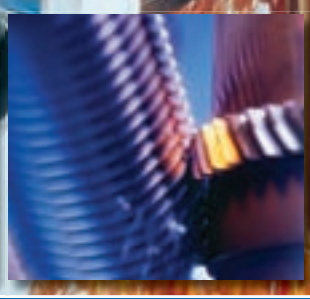

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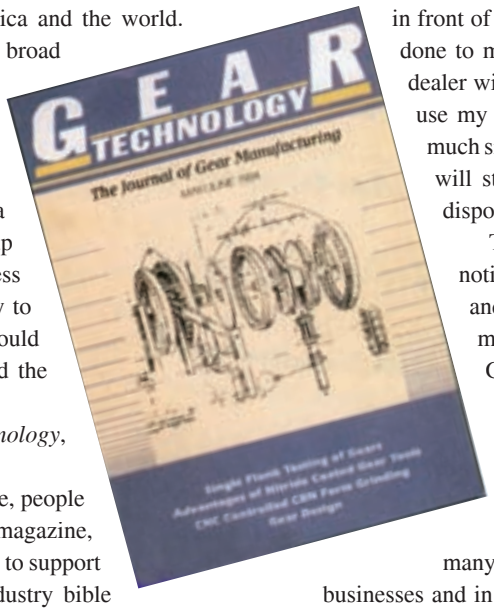
# Crossroads and Transitions
## Part I

Twenty-five years ago, America was just coming out of the worst recession since the Great Depression. The overall economy was mired in bank failures and the savings and loan crisis. Like most sectors of the economy, manufacturing suffered. Closed factories and the resulting manufacturing unemployment were the skid marks left by a manufacturing industry that had come screeching to a halt.

It was a time of transition for America and the world. Computers were beginning to make a broad impact on our lives—with the PC coming into our homes and NC and CNC machine tools beginning to replace older mechanical models in our factories.




During that same period, I was at a turning point in my career. I had grown up in the machine tool business and had success serving the gear industry, but I was ready to do something else—something that would make a lasting difference both to me and the industry I had become a part of.

So, in May 1984, I launched *Gear Technology*, the Journal of Gear Manufacturing.

There were many naysayers at the time, people who said it was the wrong time to launch a magazine, people who said the industry was too small to support its own publication (at that time, the industry bible was still the 200-plus page *American Machinist*). But fortunately we had our supporters, too, including many of you—both readers and advertisers—who have been with us since that very first issue.

Happy 25th anniversary, *Gear Technology*. We've come a long way.

But here we are, in May 2009, and I can't help but notice the similarities between now and then. Some of them are obvious, like the current economic difficulties and troubles among our nation's financial institutions. Other similarities you may not know about.

I find myself, once again, at a turning point in my career. Many of you are probably aware that in addition to my role as publisher and editor-in-chief of *Gear Technology*, I have also been the president of Cadillac Machinery, a worldwide dealer specializing in second-hand gear machinery. We've decided to close Cadillac Machinery and on May 12, we'll sell at auction the company's extensive stock of machinery and tooling.

But don't get the idea that I'm moving to Florida to play shuffleboard the rest of my life. Let me make it very clear—only Cadillac Machinery is retiring. I'm not. I'm not going anywhere. In fact, I feel much like I did 25 years ago, when I launched *Gear Technology*. The next phase of my life is approaching, and I'm ready to face it. Moreover, I'm energized by all the possibilities in front of me and how I can build on what I've already done to make this next transition. After 45 years as a dealer with a large inventory and warehouse, I plan to use my knowledge and contacts to begin something much simpler, requiring less responsibility, but which will still allow me to help the gear industry buy, dispose of and appraise its used gear equipment.

The close readers among you will have noticed that this editorial is titled "Crossroads and Transitions, Part I." That's because I have more to tell you about the future of Michael Goldstein and *Gear Technology*, as well as some of the things we have in store for you. Unfortunately, Part II of the story will have to wait until next issue.

But I will leave you with this thought: Through the last 25 years, there have been many ups and downs, both in the economy, in my businesses and in my personal life. But through that time, one thing has remained constant—and that is my dedication to making *Gear Technology* the best possible information resource for the worldwide gear industry that it can be. That will never change.

Here's to another 25 years.

Michael Goldstein,
Publisher & Editor-in-Chief

P.S. You can always reach me at *publisher@geartechnology.com*, but those of you who knew me through my role at Cadillac Machinery may wish to contact me at my new e-mail address: *michael@goldsteingearmachinery.com* or online at *www.goldsteingearmachinery.com*.

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# The Gear Vanity Plate Hall of Fame


ADDENDUM

Honk if You Love Gears

Alberta GEARS Wild Rose Country

*Dear Addendum Team:*

*Firstly, may I congratulate you on your publication, which I have had the pleasure of reading for many years. I am a "time-served" gear cutter by trade, and I have had a good career involving gear manufacture and production.*

*My interest in gearing was the reason my wife surprised me many years ago with a birthday present of a personal license plate, GEARS, for my vehicle. I think my second vehicle will be "DPCPMOD," a good fit for the allowable 7 letters.*

*It would be interesting to see if any others have any innovative places to advertise their interest/involvement in this fine art.*

*Many thanks for an excellent product.*

*Best wishes,*
*Alan Bailey, Alpek Machine Works, Calgary, AB*

Alan, we like the way you think, so we're pleased to announce the establishment of the Gear Vanity Plate Hall of Fame. It's sort of like the Rock & Roll Hall of Fame, only way cooler. In order to be inducted, all you have to do is send us a photo of your plate, tell us who you are and where you live.

You drive around advertising your love of gears. We're giving you the opportunity to advertise it to the world. Inductees into the Gear Vanity Plate Hall of Fame will be publicized in a future issue of *Gear Technology*. Even more importantly, the submission materials will be permanently enshrined in the Gear Vanity Plate Hall of Fame (as soon as we find a suitable location and clear all the required building permits).

Recognizing the global appeal of gearing, our goal is to have as many U.S. states, Canadian provinces and countries represented as possible. So if you have a gear-related vanity plate, please consider submitting it for this prestigious honor.

**Submit your entry today to addendum@geartechnology.com**

80 GEARTECHNOLOGY | March/April 2009 | www.geartechnology.com

Last issue's Addendum column introduced the "Gear Vanity Plate Hall of Fame," and we're pleased to announce that we have received a number of nominations for inductees.

The editors had prepared a nicely laid out presentation for this page. Unfortunately, some unidentified members of the Addendum Team snuck in and rearranged all the photos. Now we don't know which plate belongs to which inductee. Maybe you can help…

**The Inductees**

A. Michael Insabella, President, State Tool Gear Co.
B. Kash Chadha, Sales Engineer, Cadillac Machinery Co., Inc.
C. Mike Goza, Senior Program Director, Forest City Gear
D. Dwight Smith, President, Cole Manufacturing Systems
E. Dean Engelhardt, President, Engelhardt Gear
F. Michael Goldstein, Publisher & Editor-in-Chief, Gear Technology

1. 


2. 


3. 


4. 


5. 


6. 


**Answers:**
1-E, 2-D, 3-F, 4-B, 5-A, 6-C

# Race to the Finish:

## KOEPFER UPS THE ANTE ON HIGH-SPEED HOBBING

The Koepfer 160 gear hobbing machine is well-suited to manufacture steering pinions with an eight-axis control system and high speeds on both the work and cutter spindles.

Just eight or 10 years ago, most machines required around 20 seconds to machine armature shafts, but the Koepfer 160 has achieved this in eight seconds for a number of years. Koepfer has managed to cut machining time even further—to six seconds—with an optional workpiece loading capability, which will be offered as a modification to the machine's long-bed version. An extra two seconds per armature shaft goes a long way in terms of the millions of them produced every year.

"The K 160 is designed as a fully automatic machine and is setting new standards, which is partially due to its ingenious loading concept," says Armin Wacker, VP of sales and marketing for Koepfer GmbH in Germany.

The integral gantry loader with rotating twin-gripper allows for shortest loading and unloading times.

"Our K 160 already gives us the fastest manufacturing time for shafts in the world," Wacker says. "The new concept, in which the workpieces are literally 'shot' through the spindle, almost completely eliminates idle/changeover times. It allows us to reduce the machining time for a shaft by yet another two seconds. In other words, we have made the leap from eight to six seconds."

The preexisting model has been redesigned to offer increased workpiece length, and the material handling system now allows much heavier parts. The new concept also includes a new shifting hob head with a maximum hob shift of 160 mm. Programming is now simpler with a full color touch panel, 1 MB of memory and a BWO control that includes conversational dialogue. The BWO is a CNC control commercially available in Germany, and it offers some unique, technical electronic capabilities not readily available on some other controls. New software includes dialogue programming facility, which is an operator friendly, interactive programming for the CNC control.

"What that means is the operator simply answers a series of questions, presented in the computer format with supporting graphics," explains Dennis Gimpert, president of Koepfer America. "And by answering those questions there will be sufficient information for the CNC control to write a traditional CNC program automatically. That is fairly typical today in contemporary controls. When it started 25 years ago or so, this wasn't available on CNC controls and the operator would have to write a block program—it's almost like machine language, so he would have to have a level of expertise to do that. But today, an operator, if he can read a blueprint, can 'program the machine' and the machine writes the program for

The K160 manufactures steering pinions by soft pre-hobbing and hard finish-hobbing (skiving) of the gearing.

him, the true executable program."

The combined software and drive technology upgrades allow for a degree of precision that previously was only possible with grinding. This makes the K 160 appropriate for machining components with special safety requirements, such as those used in the aerospace industry. The K 160 has a work spindle speed of 1,000 rpm and a maximum cutting spindle speed of 5,000 rpm, which can be increased to 12,000 rpm. Wacker explains the benefits of the increased speed.

"On the one hand, we are not maxing out any of our machines, as we not only want to, but must, ensure they always suit the prevailing customer requirements. On the other hand, tooling manufacturers have—over the last few years—made enormous strides with, for example, coating processes. The much greater wear resistance of today's tool alloys allows us to increase spindle speeds and cutting speeds. 5,000 rpm is already pretty fast, but we have to be able to increase that when necessary."

With the standard work spindle speed, users can create armature shafts with four teeth using a 24 mm hob at a cutting speed of 300 m/min. The maximum workpiece length for the standard version of the K 160 is 300 mm, and it has a maximum hobbing length of 200 mm. The long-bed version of the K 160, which is available with the new modifications, has a maximum hobbing length of 480 mm and a maximum workpiece length of 600 mm.

Various Koepfer automation systems are available. They include the integrated gantry loader with flexible workpiece magazines, chain loader and conveyor belt storage section. Another system features a rotating twin-gripper, which provides the shortest loading and unloading times. A high-capacity redistributing storage system is an option that enables the machine to be run a number of hours and is quick to reset; this accommodates both gears and shaft- or pinion-type components.

Workpieces can be loaded diagonally with a metering hopper that features multiple feeder rails. Another option is an auxiliary tool that can be used for deburring operations, as a vibration dampener, a holder for the sensor that enables the automatic timing of workpieces with hardened gear teeth or for special purpose applications such as live deburring tools. For milling single- and multiple-start worms, an optional worm milling attachment can be fitted to the standard hob head.

"Blowing our own horn is not part of our strategy, but in the K 160, we have the world's fastest shaft hobbing machine," Wacker says. "And with the new concept, we shall improve on it even more."

Armin Wacker

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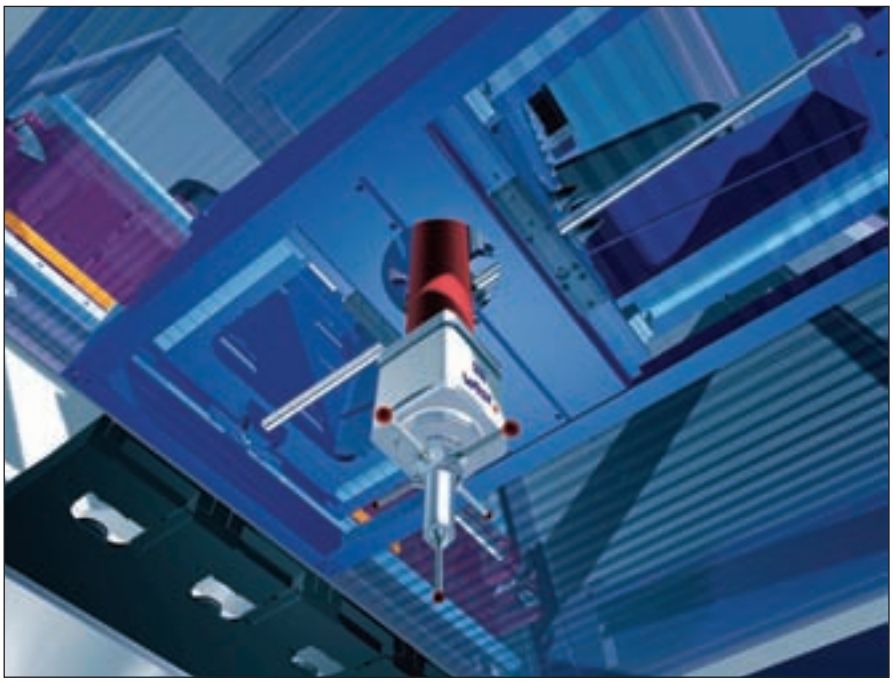
# Gage Max Measuring Technology

## A GOOD FIT FOR LINDE



Digital view into GageMax encapsulated 3D Box and VAST XT sensor (courtesy Carl Zeiss).

Linde Material Handling (LMH), a global manufacturer of forklifts and industrial equipment, originally measured gears with dedicated gear measuring machines. In order to measure the whole gearbox housing on the CMM as well as the gears on the gear checker, the company had to use two machines. Recently, LMH began using its GageMax CMM from Carl Zeiss for measuring gears. With GageMax, the company found a flexible production measuring center that was able to evaluate both parts.

"We have had dedicated measuring machines and therefore are able to compare the capabilities of each machine," says Katja Bleifuss, department of quality assurance at LMH. "With GageMax and *GEAR PRO* software, we are able to perform geometry and gear measurements directly in the production area."

With the addition of the *GEAR PRO* software package, CMMs can be used not only for geometrical parts but also for gears, which makes it a more versatile tool for the customer.

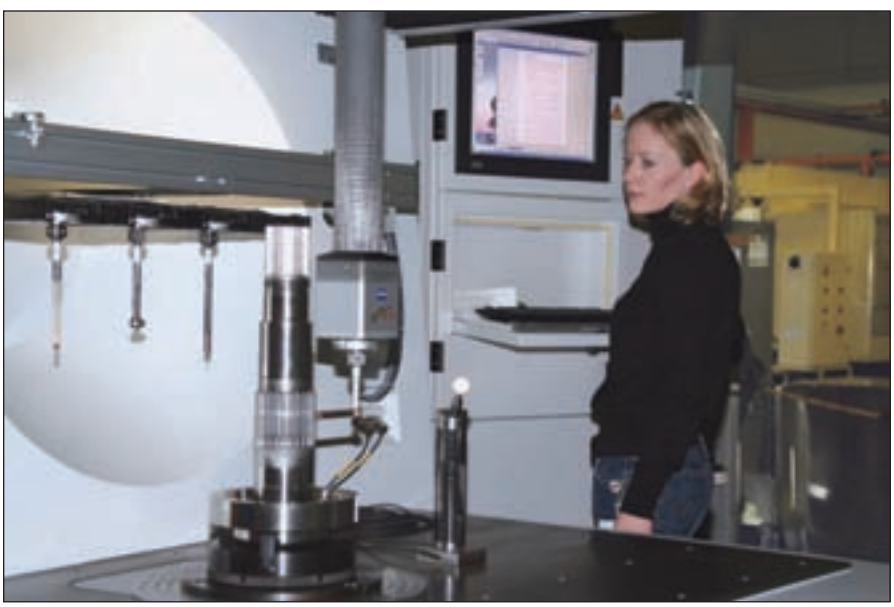
"GageMax brings this technology from the measuring lab to the factory floor and adds a big time benefit to the production control process. Now our customer has a tool for getting reliable measuring results for both geometrical parts and all kinds of gears directly in his production line and at ambient temperature—a real shortcut in the control cycle," says Roman Gross, Application Technology, Carl Zeiss.

The *GEAR PRO* software package in combination with GageMax can work under nearly any environmental conditions you might find in modern production, according to Gross.

"This measuring technology is not influenced by environmental factors, such as dirt, heat, cold, vibrations, etc. It is more flexible than dedicated gear measuring equipment in regards to set-up, alignment and size of the workpieces," Bleifuss says.

"GageMax can measure the whole range of parts that is normally checked in the quality lab directly in the production environment. Together with *GEAR PRO* software and eventually an integrated rotary table, it becomes a flexible inline gauging device for all gearbox manufactures," Gross says.

At LMH, the production runs in three shifts; therefore measuring equipment



Katja Bleifuss measures a drive shaft on the shop floor with GageMax (courtesy Carl Zeiss).

must work around the clock. This places special requirements on CMMs and software. Production demands that disruptions are carefully documented. These documents show that the measuring equipment is reliable and has not caused any failures in production.

Quality management is vital at LMH, where measurement results are stored on a centralized server. Employees are responsible for the global quality assurance of the gears and each individual knows the various requirements.

"The user interface can be set up—with images, drawings, etc.—to allow inexperienced users to easily start the measuring programs that have been created offline using CAD models by quality personnel," Bleifuss says.

Gross says that customers in aerospace, automotive and wind energy are all acting globally and want to run the same production process whether they're in North America, Europe, India, China or wherever else the parts are manufactured.

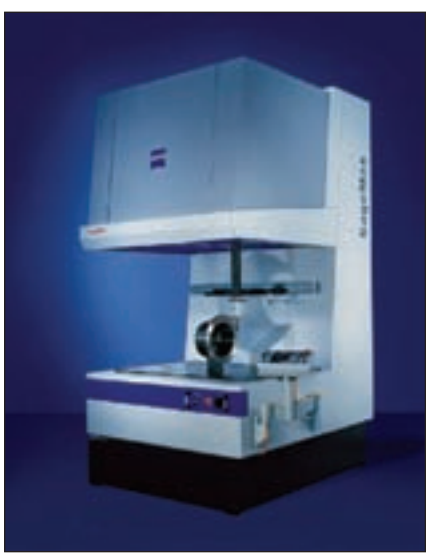
"They want the same quality controls, so they expect the same service and reaction time all over the world. These requirements cannot be fulfilled by a small, regionally organized company," Gross says.

LMH has been quite pleased since turning to Carl Zeiss for its gear measuring technology.

"The hardware and software from Carl Zeiss is very flexible, and the company offers customer-specific solutions. Accuracy and speed of the machines is comparable to our dedicated gear measuring machines. If there are any suggestions or ideas, we communicate these to Carl Zeiss right away," Bleifuss says.

"Some of our other customers—

continued



GageMax offers lower life cycle costs and higher productivity, according to the manufacturer (courtesy Carl Zeiss).

Magna, ZF, Delphi, VW and Ferrari—like this concept as it allows measurement of both housings and gears on one machine directly on the factory floor without losing time for transport to the measuring lab," Gross says.

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# James Engineering

## DEVELOPS REPEATABLE DEBURRING SETUP WITH MAX SYSTEM

In 2007, James Engineering focused on two major problems facing the deburring industry. The first involved parts that required more than four operations in a given cycle. The second involved the elimination of part scrap due to non-repeatable setups.

"In the past, the only solution available at the time was to use multiple machines to achieve the desired

**The MAX System from James Engineering offers Bi-Plane Tooling Technology (courtesy James Engineering).**

throughput," says James Richards, CEO of James Engineering. "The obvious issue with this is the excessive cost of purchasing, manning and running additional machines along with the tedious process of reconfiguring the tooling."

While the issue of non-repeatable setups may not seem as obvious, many shops have labor practices that allow operators to leverage the significant investment it makes in training its operators on specialized equipment. As operators either switch jobs or leave a company, they take their machine setup expertise with them, exponentially increasing the chance of parts being scrapped on a regular basis.

"Scrapping of the parts can be a major expense in the wind energy, aerospace, marine and construction industries, where large industrial parts are the norm," Richards says.

The obvious answer to the problem was to step up to a full CNC control system.

"CNCs offer precise and repeatable paths and positions. Problem is, the

existing machines require significant training and can be cost prohibitive," Richards says.

From the perspective of a tool builder who is required to engineer deburr machines with both a high level of functionality and at a reasonable price, employing a straight CNC just wasn't the answer.

"After exploring many different options, I gathered five veteran programmers together and expressed my vision for a new operating architecture," Richards says, "one that acts like a CNC control that was simple, intuitive, didn't require significant training to operate, could process multiple parts under multiple conditions and would virtually eliminate the hassle of repeat setups."

Following eight months of designing and testing, the result of the exercise is a new machine called the MAX System. The standard MAX System can service up to 23 different parts, each part can have up to 125 operations and there can be one to four tools working concurrently doing sequential operations on a single part during the cycle.

According to Richards, a customer would open the front door, insert the part and press the start button. Once the cycle is over, the part could be removed and replaced with a different part. This is precisely what James Engineering has done with the MAX System, without the cost of a full CNC controller.

"For the end user that utilizes repeatable parts processing, the MAX System would arrive with all of the parts setup preset into the machine," Richards says. "The end user would only need a new setup if they added a new part to the machine, which takes approximately 10 to 20 minutes depending on the number of operations required. Like a CNC, memory is stored forever, virtually eliminating the issues of part scrap and trained operator dependency."

The MAX System's new tool layout provides two advantages—a larger work envelope with a smaller machine footprint, and the bulk of the tool axes has been removed from the harsh environment. James Engineering has named this Bi-Plane Tooling technology. This technology is a proprietary, patented, gantry-type system using modular components.

The MAX System is capable of utilizing all four basic types of tooling including grinding media, rotary files, mill cutters and brushing media abrasives. It also has automatic wear

continued

compensation for each head that it uses. The working pressure applied to the appropriate tool head is also controlled.

"Roughly 90 percent of the deburring industry, even some job shops, do repeat parts manufacturing," Richards says. "In essence, the same group of parts is processed the same way, over and over again. If this is your process, you want a simple machine to operate that requires virtually no training and minimal to no setup."

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# Precision-Length Machine

## BRINGS SUB-MICRON MEASUREMENT TO SHOP FLOORS

The Mahr Federal Linear 100 is a high precision, universal length measuring instrument for quick internal and external measurements from the shop floor. With a direct measuring range up to 50 mm and an application range up to 100 mm, the Linear 100 adapts to new measurement jobs. Complex measuring tasks, such as measuring the dimension over two balls on gear ODs, are achieved by the machine's ability to measure lengths and diameters.

"The Linear 100 is a solution to the demand for precision length measurement on the shop floor," says George Schuetz, director of precision gages at Mahr. "It is the ideal shop tool when the measuring

requirements go beyond the capabilities of the typical comparative gage. With its fundamentally sound measuring principle and high accuracy readout, in the correct environment the Linear 100 can put sub-micron measurements directly into the hands of the precision machinist."

Features of the Linear 100 include an adjustable 76 x 76 mm (3 x 3 in) measuring table for modifying part position while measuring ODs, and a 4 to 40 oz adjustable measuring force stays constant over the measuring range. A 100 mm x 185 mm (4 x 7.3 in) worktable is responsible for accurate ID measurement. The measuring system is based on the ABBE principle, which determines whether the measuring arm and reference are in line to eliminate cosine errors.

Remastering is unnecessary while performing internal/external measurement and combined internal/external measurement. Measuring anvils are simple to interchange, so part measuring is more flexible. A solid cast body minimizes stresses and twisting error, and the Linear 100 has a digital display that allows users to select ID/OD results and preset values. An RS-232 interface helps transfer output data to PCs, and optional software enables users to move measured values to Windows programs like Excel.

**For more information:**

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*www.mahr.com*

# Solid Carbide

## END MILLS DEVOUR ALUMINUM

The Alu-Jet-Cut Solid Carbide End Mills, from Emuge Corp., are designed for large-volume machining of aluminum and developed along with major aircraft manufacturers. They provide material removal in monolithic airframe structural components

continued

manufacturing, where up to 95 percent of a solid block of material's weight is removed. They demonstrate twice the rate of removal of comparable carbide end mills, according to Emuge's press release.

"The Alu-Jet-Cut end mills were developed with one intention: to devour aluminum," says Stephen Jean, milling products manager at Emuge Corp. "By incorporating a series of specialized features into one tool, we can present


a tooling solution capable of doubling throughput as quickly and simply as the next tool-change."

The end mills are capable of cutting speeds greater than 3,000 surface feet per minute, and they resist vibrations due to a wear-resistant carbide substrate. A chip conveyor controls chip size and directional flow, which increases chip evacuation capacity and allows for stable operation with full radial engagement at one times diameter depth of cut. The result is 650 cubic inches per minute material removal rates.

Aluminum build-up along the cutting edges is reduced by a polishing process that achieves a higher quality surface. Combined with the shear velocity the tool operates at, the surface reduces the period of heat transfer from chip to tool by as much as 60 percent of other carbide end mills.

The Alu-Jet-Cut end mills come in a variety of corner radii, roughing and finishing designs. Roughing cutters are available with three flutes and finishing cutters with three and four flutes. They are suitable for minimum quantity lubrication.

**For more information:**
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*www.emuge.com*

# Sheffield

## MOVING BRIDGE CMM SUPPORTS VARIOUS SENSORS

The Pioneer Plus coordinate measuring machine from Sheffield Measurement, a subsidiary of Hexagon Metrology, features scalable options that include non-contact scanning capabilities and multiple sensor support. Powered by *PC-DMIS* software, the Pioneer Plus offers flexibility and accuracy for applications in aerospace, automotive, job shops and others.

A range of sensors are supported, and several types can be combined in a single system. One of the supported sensors is the ScanShark 4Vix line laser scanning probe, which collects data at 23,000 points per second and can quickly acquire data from geometrically complex parts. The scanner is lightweight and includes software filters for ambient lighting situations and surface finishes from chrome to glossy black; spray-on coating is unnecessary.

Also supported is the CMM-V vision sensor, which measures large and small parts without contact. It can measure hole diameters, edge contours and miniature features that a touch-trigger stylus can't define easily. The sensor operates as an extra supported probe inside the *PC-DMIS* software, so contact and vision features are programmed and inspected in one program.

The high-accuracy LSP-X1

continued

analog scanning probe head is the best fit for gear measuring, according to Bill Fetter, director of marketing and communications for Hexagon Metrology. It features all standard probing modes from single point probing and self-centering to continuous high-speed scanning for form and profile measuring.

"The LSP-X1 sensor supports continuous touch analog scanning for three-dimensional gears, and the CMM-V could be used for geometry of gears that have a relatively loose specification and are mainly two-dimensional, such as plastic gears," Fetter says. "The advantage of using a CMM-V would be you could quickly inspect a large quantity of small gears laid out on a table. The fact that you can combine both sensors on the same machine with the same software means you have a much more flexible system because you have a CMM that can inspect other things besides gears (think gearboxes), plus the ability to check gears. This capability can deliver a better return on investment than a single-purpose gear checking machine."

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*info@sheffieldmeasurement.com*
*www.sheffieldmeasurement.com*



# World's Largest Neidlein Face Driver Installed

LMC Workholding recently installed what the company says is the world's largest Neidlein face driver at TST Inc.

in Ontario, Canada. The specialty FSB 85 face driver can hold parts up to 40 inches in diameter, 210 inches long and weighing more than 20,000 pounds. It will be used to machine bar stock into billets for aerospace and defense applications. The face driver will be held by an older model lathe with manual tailstock and manual chuck.

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*www.lmcworkholding.com*

# Modular Vacuum Furnace

## CONFORMS TO GLOBAL POWER STANDARDS

The Titan production-line vacuum furnace from Ipsen, Inc. is a self-contained, highly mobile, skid-mounted system that features fast utility hookups allowing installation in a single day. With a globally certified chamber, the Titan conforms to most global power standards. It can be purchased, leased for tax advantages or rented for a minimum three-month period.

The control system supports 15 languages, switches between imperial and metric measurement units, provides real-time data acquisition, trending and archiving and stores up to 1,000 recipes. Recipe suggestions are made based on

continued

metallurgical needs by the interactive program generation feature of the expert controls option. The Titan was designed so that two units fit comfortably in one overseas container.

**For more information:**

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*www.ipsenusa.com*




# Programmable Laser Tool Verification, Breakage Control System

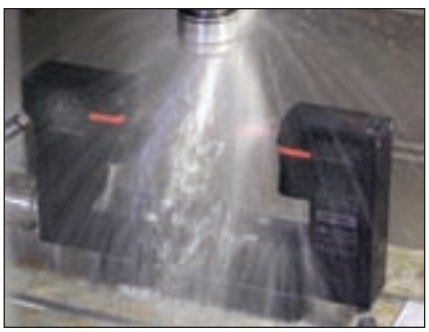
## HANDLES TOUGHEST CONDITIONS

The Mida Laser 75P non-contact programmable tool setting system is designed to perform under the harshest conditions. It features a patented protection system with air tunnel effect, integrated microprocessor for best performance under coolant, active drip rejection filter and enhanced noise reduction with double filtering technology.

Using the programmable feature, the system adapts to the tool type under verification, to the same rotation speed as used during machining and to the requested measuring cycle. The Mida Laser 75P unit is available with a collimated or focused laser beam. The focused model is necessary for verification of cutting edge integrity and length measurements of chisel or rounded nose tools, or for tools with a

diameter less than 1 mm.

The Mida Laser 75P uses an RS232 serial communication port for exchanging data during the measuring cycle to increase accuracy and repeatability results in harsh conditions, retrofit more simply without an M-code and to facilitate correct installation check and troubleshooting. This is in addition to the system's standard parallel I/O.



Uses of the Mida Laser 75P include tool identification, tool breakage detection, pre-setting of unknown tools, tool dynamic length and diameter measurement, tool wear compensation, tool cutting edge profile integrity verification and machine axis thermal drift compensation.

**For more information:**

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# Honing Tools

## LAST FIVE TIMES LONGER

The MMT superabrasive and diamond honing tools from Sunnen are factory-qualified to produce micron-level accuracy, and they are custom designed for fast metal removal and long life. High-volume, precise honing is achieved with minimum burr condition. The MMT tools can be used for demanding parts, such as pinion gears, fuel injector barrels, piston pumps, cartridge valves and gun barrels.

The body and feed wedge of the tools are precision machined from hardened tool steel. According to Sunnen, they typically last five times longer than conventional tools and reduce per-part cost by 30 percent. Accuracies of 0.0006 mm are achieved for diameter, roundness, straightness and taper. The

continued

MMT metal-bond honing mandrels are available for bore sizes 4 to 65 mm (0.157–2.56 inches), and larger sizes are available for special orders.

The MMT tools are custom made for every application with a unique part number based on width, length, expansion angle, number of stones and placement of stones. Options include one- to 12-stone versions for metal-bond diamond or CBN superabrasives. The honing stones are held in place by retention springs, and there is no need for truing because a factory verification

allows the tools to produce parts right out of the box.

The MMT honing stones can be replaced under the Sunnen precision reload program or the field reload program. Precision reloads for high-tolerance honing are brought back to the factory, and the stones are fitted to the stone slots, cylindrically ground to specification and returned to customers. The field reloads are installed by customers as a drop-in replacement, so the assembly is designed to have clearance to the stone slot, and they are appropriate for honing applications with tolerances in the 0.008 mm (0.0003 inches) or greater range, such as pinion gears or connecting rods.

**For more information:**
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St. Louis, MO 63143-2793
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The wind market is gaining momentum in India much like it has around the world (courtesy of Suzlon Wind Energy).

# What Now? What Next?

## ECONOMIC SLOWDOWN RAISES QUESTIONS FOR INDIAN GEAR MARKET

Matthew Jaster, Associate Editor

In 2006-2007, the industrial sector in India was praised for its manufacturing growth and global potential in Asia. Increased building capacity, technological advancements and a thriving domestic market predicted a bright future for India's industrial economy. A growing middle class meant more manufacturing projects resulting in a greater need for gears.

What a difference a couple of years make.

Today, the global economic slowdown is affecting Indian gear companies with varying degrees and consequences. The automobile industry is in sharp decline, energy demands are constantly increasing and skilled workers are hard to find, let alone keep— struggles that mirror other manufacturing sectors around the world.

The focus on expansion has been silenced by companies simply trying to sustain business. It's not all doom and gloom, but 2009 appears to be far removed from the original expectations of the Indian manufacturing community.

Companies like Dee Kay Gears, Prakash Gears, Anil CNC & Gears and Mahindra Sar Transmission need to address numerous problems to ensure future growth for India's industrial base. Plans include expanding the customer base, focusing on alternative energy markets, improving lead times and recruiting more experienced help.

Gurpal Sachdev, director of Dee Kay Gears in Mumbai, India, summed it up best when discussing the various challenges facing the Indian gear industry.

"Many improvements need to be made," Sachdev says, "but investing in power and infrastructure will be the key to India's success."

continued

In a January report by the Prime Minister's Economic Advisory Council entitled, "Review of the Economy 2008-2009," the growth forecast in India was trimmed to 7.1 percent in 2009 after posting a 9 percent growth rate between 2007-2008.

The estimated growth in manufacturing alone was 12.1 percent in 2006. As of January 2009, the number stands at just 4 percent. According to the Advisory Council, these numbers have dropped significantly due to the declining sales of automobiles and heavy machinery vehicles.

The massive decline in the automobile and industrial sectors were largely due to the rollback of mining, steel and cement projects and the sudden rise in interest rates, according to Sachdev at Dee Kay. Meanwhile, the agriculture, energy, machine tools and tractor industries have been steadily improving.

Prakash Gears, a manufacturer of spur, helical, bevel and worm gears located in the Coimbatore district in Tamil Nadu, India, has been manufacturing gears since 1984.

"We've had around a 20 percent decline in sales due to the economic slowdown," says S. Surulivel, a partner at Prakash. "Our plan is to expand our sales network to other countries as well as other industries like wind."

Improvements to CNC machines in India have given Prakash Gears the opportunity to prosper in the Indian gear industry. New machine technologies and a growing interest in the alternative energy market will help prepare the company for future business.

Unlike other gear companies, lead times have not been altered by the recent slowdown, according to Surulivel.

"We've been able to outsource some of our components and get things done in a quicker period of time since the economic slowdown," Surulivel says.

In other areas of the country, lead time is a growing concern.

"Lead time is so important right now and can affect the survival of anybody," says Kaushik Damani, head of business development at Mahindra Sar Transmission Pvt. Ltd. "One must spend a good amount of effort to ensure improvements."

Founded in 1987, Mahindra Sar has been a manufacturer of gears and other transmission components in Rajkot, an engineering hub in India that boasts highly skilled workers and a labor-friendly environment.

Damani says the Indian gear industry needs to better prepare itself for economic downturns as fluctuating fuel and material costs have created plenty of confusion throughout the supply chain.

"The cost of materials has become a greater issue in 2009, and needs to be handled carefully and transparently," Damani says. "Our main concerns are cost fluctuations in steel and fuel, liquidity of inventory and sustainability."

"Material cost will always be a concern for us," Surulivel adds. "We always face the threat of China as an exporter who is always cheaper than us by 15 percent in overall cost. The raw material cost here compared to China is 15 percent more."

Anil CNC & Gears, a manufacturer of spur and helical gears, spiral and straight bevel gears, worm shafts and spline shafts, saw a minor drop in business due to economic inactivity, but it has recently begun to pick up.

"Our business was affected by 30 to 40 percent for a short period of time," says CEO B.K. Nataraju. "Since then, we've been participating in government tenders, getting subsidies, etc."

While the slowdown affected Indian companies differently, a common theme across the country is an emphasis on power requirements and the alternative energy market.

"We need to develop more generating plants to ensure adequate power, keeping in mind our target requirements for the next 20 years," Surulivel says.

Whether working in a rural or urban area, energy needs will greatly influence India's industrial capabilities in the future, notes Sachdev at Dee Kay.

"Energy costs are currently one of our greatest challenges. There is a tremendous shortage of power even in

Komatsu Ltd., a producer of large dump trucks for mining projects, has seen business increase since opening its second production base in India

developed cities like Delhi, Mumbai and Calcutta," Sachdev says.

Along with retaining power, Sachdev sees a growing influence on business in the alternative energy market. As business in the automotive and special machine industries waned, many companies began to establish an emphasis in alternative energy, specifically wind.

"There is a global awareness to be less dependent on conventional energy means," Sachdev says. "This is the future that is encouraged globally. We would like to get more involved in this market, but we need the knowhow."

"This market is growing so fast," Surulivel says. "Prakash Gears has only a small presence in wind, and we need to enter into the market much more."

In order to make the most of the alternative energy marketplace, companies must take a closer look at machine technology and get more support from the government.

"Machine improvements have been made," Surulivel says, "but the country needs to become fully modernized by using CNC machines in almost all operations of gear making."

Nataraju at Anil has not seen any new developments in gear technology in India, but believes improvements in the field of gear grinding would be beneficial. Damani at Mahindra Sar cites higher accuracy and upgrades in equipment in machining and special processes as highlights of the Indian gear industry.

Still, Damani believes many problems need to be addressed to protect the industry in the future. "The country itself needs to prepare to turn challenges into opportunities in this present situation of uncertainty," Damani says.

Nataraju agrees that India needs to take more responsibility on the home front during such hardships.

"The Indian government has to reduce the amount of importing and realize that Indians are capable of taking on all the various challenges here at home. This way, the manufacturing sector will sustain during the economic struggles," Nataraju says.

Damani at Mahindra Sar adds, "The government needs to take steps to boost the domestic market as the export market is not going to improve in the short/medium term."

Because its export business took some heat in 2008, companies like Mahindra Sar compensated these losses by acquiring new customers and new business in segments like agriculture, off-highway and wind applications.

Much like the United States, India is having a difficult time finding and

continued

keeping skilled workers to help serve these new business ventures—an issue affecting the global gear industry.

Due to the declination of the economy, Anil CNC was forced to cut down the workforce in other areas in order to keep its skilled workers on staff.

"Our biggest operational challenge is cost reduction," Nataraju says. "By cutting down the employees (mainly unskilled), we have full utilization of the skills of existing employees, but there is always a great need for skilled help."

Skilled labor is in high demand in India regardless of the economic situation, but many companies can't hire right now simply because they lack the spending power.

"We've cut production down by 20 percent, so we're not hiring more workers," Surulivel says.

Keeping the workers they have is another challenge. Workers that have the necessary skills and qualifications for highly skilled manufacturing positions can come and go as they please, moving around as demands increase. This has led to many career changes.

"Job jumping is a major concern," Sachdev says.

Tata Motors hopes to boost India's automotive market with its electric Ace platform of vehicles (courtesy of Tata Group).

Construction and highway projects in Mumbai are target growth areas for Indian manufacturers (courtesy of Asif Akbar).

It becomes even a greater challenge to build the most effective workforce when the numbers of engineering and manufacturing prospects just aren't there.

"Because of the information and technology boom, many youngsters are choosing these fields over engineering in India," Sachdev says. "This has created a tremendous shortage of the kind of skilled help we need."

The World Education News and Reviews website (*www.wes.org*) posted a report on India's educational troubles in the engineering sector in January 2007.

The report lists several factors on why engineering students as well as the educational system overall has had problems developing highly skilled workers:

- Too many institutions due to unregulated growth, especially in private sector.
- Educational institutions are proliferating in geographical pockets, leading to oversupply in some markets and shortages in others.
- There are not enough qualified faculty members, and not nearly enough doctorates coming through the system.
- Weak quality assurance structures, especially accreditation procedures.
- Lack of cooperation between industry and the classroom.
- High levels of unemployment and underemployment among engineering students.
- Graduate rate is far exceeding the economy's growth rate.
- Colleges are not meeting the manpower skill requirements for many industries.
- Rising tuition fees at many private colleges.

Due to many of these factors, a company like Prakash Gears couldn't get the skilled help it needed when resources were available.

"We've faced many problems in the availability of skilled labor at competitive cost of wages," Surulivel says. "However, while there is a migration of skilled workers in our

continued


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With question marks surrounding engineering and manufacturing education, financial accountability and government assistance to the industrial complex, India's challenges remain global. China, Europe and the United States are facing the same difficulties. The future of the global gear market will depend on saving resources, changing policies and stabilizing manufacturing and industrial segments around the world.

By most accounts, the global gear industry will survive these setbacks with alternative energy projects or new business models. When business is slow and the economy falters, many take the opportunity to look at innovations and benchmark new technologies. Now is as good a time as any to bolster R&D, look at lean and green technologies and reexamine business plans.

Most of the individuals participating in this article have begun to see some positive signs heading into the summer of 2009.

"The gear industry must not be so bad at the moment," Damani says. "We're not expecting any negative growth at Mahindra Sar."

Surulivel adds, "Business is good and steadily growing. There is still large potential throughout the world for India's gear industry."

For others, 2010 can't get here fast enough.

"It's difficult for us to sustain in 2009," Nataraju at Anil says. "It's a zero investment year."

Hoping to put the global economic slowdown behind them, gear companies wait to see what the future holds for industrial India.

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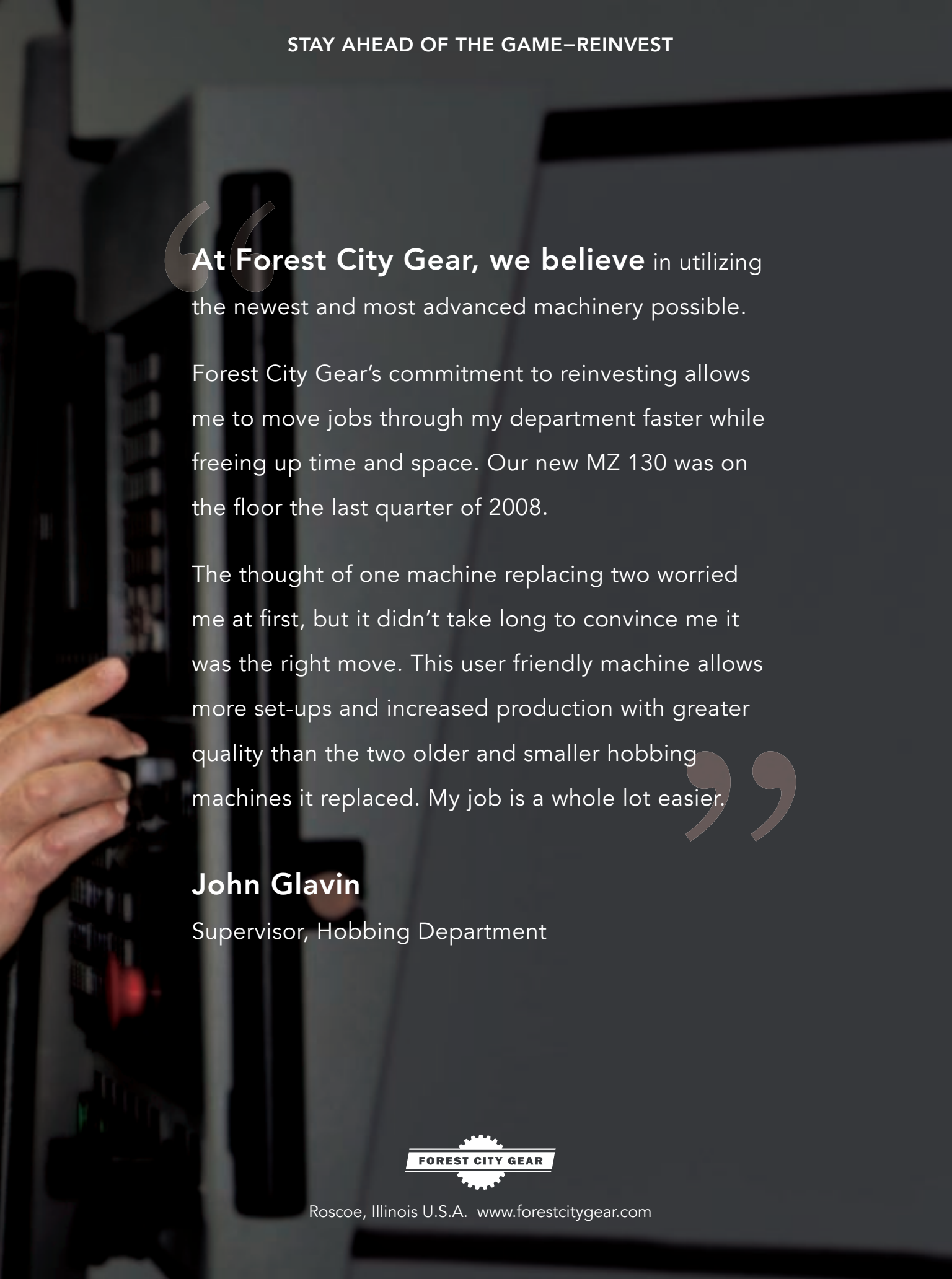

**At Forest City Gear, we believe** in utilizing the newest and most advanced machinery possible.

Forest City Gear's commitment to reinvesting allows me to move jobs through my department faster while freeing up time and space. Our new MZ 130 was on the floor the last quarter of 2008.

The thought of one machine replacing two worried me at first, but it didn't take long to convince me it was the right move. This user friendly machine allows more set-ups and increased production with greater quality than the two older and smaller hobbing machines it replaced. My job is a whole lot easier.

**John Glavin**

Supervisor, Hobbing Department

FOREST CITY GEAR

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# In-Situ Measurement of Stresses in Carburized Gears via Neutron Diffraction

R.A. Le Master, B.L. Boggs, J.R. Bunn and J.V. Kolwyck



**Management Summary**

This paper presents the results of research directed at measuring the total stress in a pair of statically loaded and carburized spur gears. Measurements were made to examine the change in total stress as a function of externally applied load and depth below the surface. The measurements were made using the new Neutron Residual Stress Mapping Facility (NRSF2) instrument at Oak Ridge National Laboratory. A Static Load Application Device (SLAD) was developed to load the gear pair while mounted on the NRSF2 instrument. The paper includes a summary of various methods that are used to determine $d_0$ and a discussion of their applicability to carburized gears. The possibility of determining $d_0$ using ψ-tilt methods is discussed and results are presented for $d_0$ variation through the carburized layer determined using the $\sin^2\psi$ method.

## Introduction

The total stress in an operating gear comprises two types: 1) externally induced stresses associated with the transmission of power, and 2) residual stresses associated with the heat treatment and machining of the tooth profiles. It is the combined effect of these two stress types that contributes to the life of a gear.

Stresses in metallic components can be measured using X-ray and neutron diffraction methods. Historically, these methods have been used to measure only residual stresses. X-ray and neutron diffraction methods involve measuring the interplanar spacing (d-spacing) of atoms in the crystal lattice using diffractometers that measure the position of the diffraction maxima, which is converted to d-spacing using Bragg's Law. The measured d-spacing is the average value for a group of grains suitably oriented within an irradiated surface area or volume. The change in d-spacing between stressed and unstressed states allows the determination of strains and, consequently, stresses.

In recent years, there has been interest in using neutron diffraction methods to measure the in-situ stresses in operating equipment. It is hypothesized that the penetrating feature of neutrons will allow the measurement of operating stresses inside mechanical components—which would not be possible via X-ray methods. A specific goal of this research was to determine the degree to which neutron diffraction can be used to measure the total stress in meshed carburized gears that are under static load. Considering statically-loaded-but-meshed gears as a first step would allow the effects of the near-surface chemistry, phases and microstructures to be isolated from dynamically induced phenomena.

## Neutron Diffraction

Neutron diffraction is an experimental method used to study the structure of crystalline materials. Neutron diffraction instruments include a source capable of generating a stream of neutrons, or beam. This beam is directed at a sample, and the intensity of the scattered neutrons is measured using detectors. Variations of the intensity at different angular positions around the sample provide information about its crystal structure.

There are two primary types of neutron sources—nuclear reactors and spallation. The research presented in this report was conducted using the NRSF2 instrument that receives neutrons from the High-Flux Isotope Reactor (HIFR). HIFR is located at the Oak Ridge National Laboratory in Oak Ridge, TN.

Figure 1 presents a schematic of the NRSF2 instrument that traces the neutron beam from the reactor to the six position-sensitive detectors (PSDs). The beam leaving the reactor core contains many wavelengths, and a deformable Si crystal monochromator is used to obtain one of six possible wavelengths. A wavelength of 1.54 angstroms associated with the Si 422 plane was used for most of this research.

The single wavelength beam leaving the monochromator passes through a snout containing slits. The slits create a rectangular opening that control the incident beam width and height. The beam leaving the slits passes through the sample

that diffracts a fraction of the incident neutrons. When the beam encounters grains within the sample that have their lattice planes oriented in a particular direction, the beam will diffract and cause a peak in the measured intensity.

The scattering angle at which the peak will occur is governed by Bragg's Law:

$$\lambda = 2d \sin \theta \quad (1)$$

where $\lambda$ is the wavelength of the incident beam measured in angstroms, $d$ is the lattice spacing between the atoms in the diffracting plane measured in angstroms, and $\theta$ is the diffraction angle (Figs. 2 and 3) in either degrees or radians. The d-spacing is obtained by rewriting Equation 1 as:

$$d = \frac{\lambda}{2 \sin \theta} \quad (2)$$

The diffraction angle is determined by fitting a curve to the detector intensity data. The location of the peak intensity defines the diffraction angle. The wavelength of the radiation leaving the monochromator enables the calculation of the d-spacing using Equation 2.

### In-Situ Strain Measurement

***Static load application device (SLAD)***. SLAD was designed to hold and statically load the two gears used in these experiments. SLAD was also designed to be compatible with the NRSF2 instrument. The SLAD contains two major sub-assemblies—1) a loading fixture (Figs. 2a and 2b) and 2) a pump sub-assembly (Fig. 3). The two sub-assemblies are connected by a 10-foot-long hydraulic hose. A static torque is applied to the test gear using a hydraulic cylinder. This torque is transferred from the test gear to a mating gear that is prevented from rotating by a single tooth rack. The orientation of the test gear in the SLAD was designed so that the principal direction of the bending stress at the critical cross section was horizontal. This enabled the alignment of SLAD with the incident and diffracted beams that also lie in the horizontal plane. The gears are also positioned so that the contact point is at the worst load radius.

SLAD was designed to induce a 140 ksi bending stress at the critical cross section in the fillet region of the tooth. By using the equations at the bottom of Table 1, it was determined that this stress occurs at a hydraulic cylinder pressure of approximately 1,400 psi. The bending stress and associated strain for each of the pressures used in the tests are shown in Table 1. The 140 ksi- maximum stress level was chosen because the compressive, residual stresses of this magnitude— measured on the surface of the gears using x-ray diffraction (Ref. 1)—would be approximately balanced out and the resulting stress would be near zero.

***Experimental setup***. The experiment was designed to measure d-spacing in three orthogonal directions using the SLAD and NRSF2 instruments. The measurement of d-spacing in three orthogonal directions required mounting the

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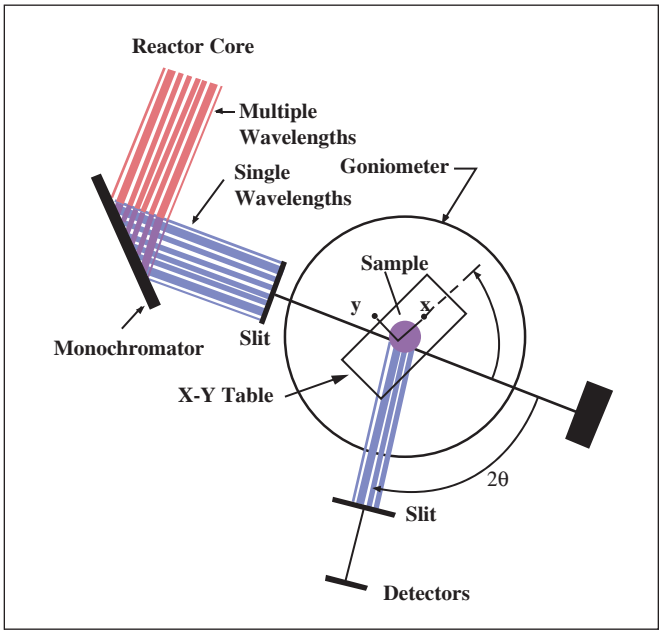


Figure 1—NRSF2 neutron beam schematic.

Figure 2a—SLAD load fixture showing the two mating gears.

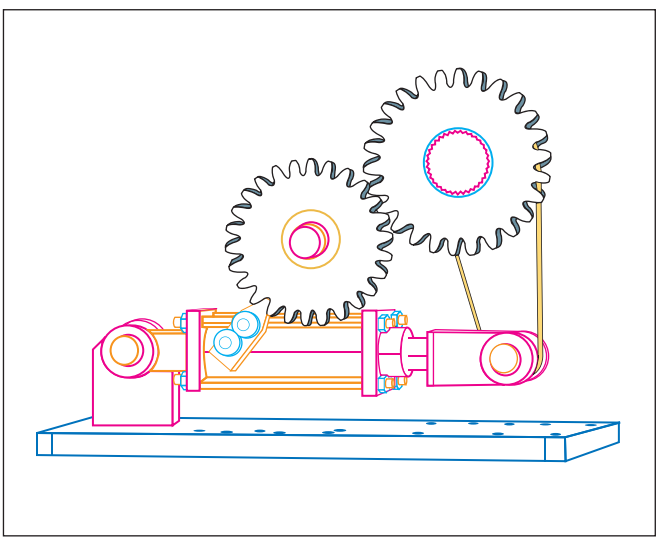

Figure 2b—CAD rendering of SLAD showing the hydraulic cylinder and torque arm used to load the gears.

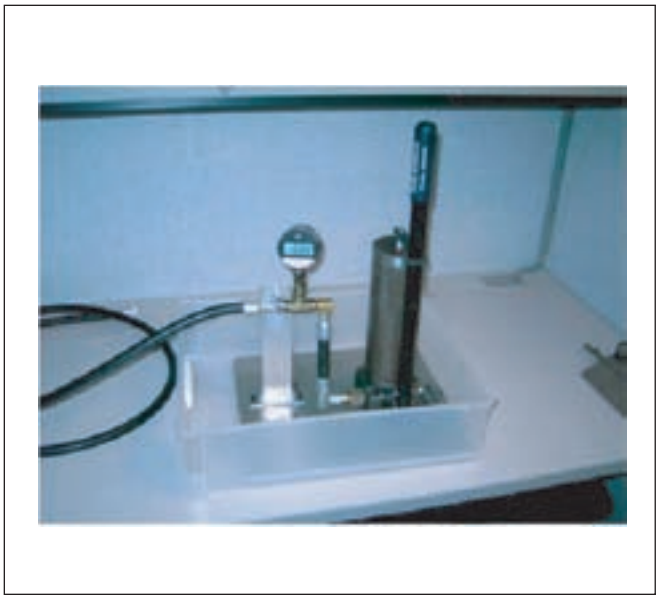

Figure 3—Manually operational hydraulic pump used to load gears (plastic container is for spill containment).

**Table 1—Critical bending stress and strain.**

| Cylinder pressure, psi | Torque, in-lb | Transverse tooth force, $W_t$, lb | Peak bending stress, $\sigma_b$ | Peak bending strain $\varepsilon_b$ |
|---|---|---|---|---|
| 116 | 2,640 | 845 | 11.9 | 410 |
| 340 | 7,740 | 2,480 | 34.8 | 1,200 |
| 625 | 14,200 | 4,540 | 63.7 | 2,200 |
| 883 | 20,100 | 6,430 | 90.2 | 3,110 |
| 1,136 | 25,900 | 8,290 | 116.0 | 4,000 |
| 1,387 | 31,600 | 10,100 | 142.0 | 4,900 |

$$\sigma_b = \frac{W_t P_d}{F J} \qquad J = 0.38$$

$F = 0.75$ in;

$P_d = 4$ teeth/in

$$\varepsilon_b = \frac{\sigma_b}{E} \qquad E = 29 \times 10^6 \text{ psi}$$

**Table 2—D-spacing for longitudinal strain component vs. measurement depth and hydraulic cylinder pressure.**

| Depth, mm | Average pressure, psi | | | | | |
|---|---|---|---|---|---|---|
| | 116 | 340 | 625 | 883 | 1136 | 1387 |
| | d-spacing (A) | | | | | |
| 0.08 | 1.16925 | 1.17093 | 1.17111 | 1.17231 | 1.17246 | 1.17280 |
| 0.25 | 1.16997 | 1.17040 | 1.17228 | 1.17245 | 1.17320 | 1.17298 |
| 0.50 | 1.17052 | 1.17157 | 1.17190 | 1.17272 | 1.17273 | 1.17287 |
| 0.75 | 1.17081 | 1.17182 | 1.17262 | 1.17239 | 1.17256 | 1.17289 |
| 1.00 | 1.17106 | 1.17193 | 1.17196 | 1.17249 | 1.17251 | 1.17299 |
| 1.25 | 1.17113 | 1.17196 | 1.17223 | 1.17251 | 1.17298 | 1.17297 |
| 1.50 | 1.17138 | 1.17181 | 1.17211 | 1.17257 | 1.17280 | 1.17278 |
| 1.75 | 1.17156 | 1.17192 | 1.17218 | 1.17249 | 1.17279 | 1.17283 |
| 2.00 | 1.17169 | 1.17218 | 1.17225 | 1.17252 | 1.17233 | 1.17271 |

**Table 3—D-spacing for lateral strain component vs. measurement depth and hydraulic cylinder pressure.**

| Depth, mm | Average pressure, psi | | | | | |
|---|---|---|---|---|---|---|
| | 119 | 363 | 619 | 894 | 1125 | 1389 |
| | d-spacing (A) | | | | | |
| 0.08 | 1.17063 | 1.17078 | 1.17097 | 1.17092 | 1.17118 | 1.17171 |
| 0.25 | 1.17118 | 1.17082 | 1.17102 | 1.17131 | 1.17103 | 1.17107 |
| 0.50 | 1.17132 | 1.17131 | 1.17105 | 1.17090 | 1.17085 | 1.17102 |
| 0.75 | 1.17132 | 1.17117 | 1.17112 | 1.17117 | 1.17101 | 1.17106 |
| 1.00 | 1.17145 | 1.17121 | 1.17136 | 1.17135 | 1.17134 | 1.17129 |
| 1.25 | 1.17140 | 1.17164 | 1.17164 | 1.17158 | 1.17154 | 1.17155 |
| 1.50 | 1.17182 | 1.17168 | 1.17171 | 1.17172 | 1.17168 | 1.17163 |
| 1.75 | 1.17169 | 1.17178 | 1.17166 | 1.17163 | 1.17163 | 1.17158 |
| 2.00 | 1.17170 | 1.17170 | 1.17163 | 1.17155 | 1.17160 | 1.17153 |

| Table 4—D-spacing for normal strain component vs. measurement depth and hydraulic cylinder pressure. | | | | | | |
|---|---|---|---|---|---|---|
| Depth, mm | Average pressure, psi | | | | | |
| | 104 | 359 | 614 | 868 | 1182 | 1352 |
| | d-spacing (A) | | | | | |
| 0.00 | 1.17264 | 1.16929 | 1.16903 | 1.16903 | 1.1927 | 1.16905 |
| 0.25 | 1.17195 | 1.16920 | 1.16900 | 1.16900 | 1.16953 | 1.16891 |
| 0.50 | 1.17196 | 1.16929 | 1.16899 | 1.16889 | 1.16947 | 1.16925 |
| 0.75 | 1.17205 | 1.16905 | 1.16892 | 1.16892 | 1.16941 | 1.16923 |
| 1.00 | 1.17178 | 1.16944 | 1.16903 | 1.16903 | 1.16975 | 1.16931 |
| 1.25 | 1.17178 | 1.16893 | 1.16921 | 1.16921 | 1.16955 | 1.16918 |
| 1.50 | 1.17185 | 1.16916 | 1.16925 | 1.16925 | 1.16969 | 1.16925 |
| 1.75 | 1.17146 | 1.16914 | 1.16935 | 1.16935 | 1.16957 | 1.16925 |
| 2.00 | 1.17183 | 1.16917 | 1.16943 | 1.16943 | 1.16958 | 1.16934 |

SLAD on the NRSF2 instrument in three orientations.

- The first orientation was chosen to measure the d-spacing for the longitudinal strain component at the location of the critical bending stress in the fillet area. A 3 × 0.3 × 3 mm slit arrangement was used.
- The second orientation was achieved by rotating the Ω-axis of the NRSF2 instrument by 90°. This orientation was used to measure the d-spacing for the lateral strain component at the critical bending stress location. The same slit arrangement was used.
- The third orientation was orthogonal to the first two orientations and was achieved by physically rotating the SLAD by 90°. This orientation was used to measure the d-spacing for the normal strain component at the bending stress location. A "hanging slit" configuration was required with the lateral and normal directions to avoid interference issues between the NRSF2 instrument and the SLAD.

The d-spacing measurements were taken at nine depths—0.08; 0.25; 0.50; 0.75; 1.00; 1.25; 1.50; 1.75; and 2.00 mm—in each orientation, and at six hydraulic cylinder pressures of approximately 100; 360; 620; 880; 1,140; and 1,400 psi. The actual pressures used in each orientation were slightly different due to the inability to achieve a precise pressure using the manually operated pump.

***Experimental data.*** Measured d-spacing for the longitudinal, lateral and normal directions at various pressures and depths is summarized in Tables 2, 3 and 4. All of the measurements were taken near the center of the tooth (8.5 mm in from the side of the gear). Figures 4, 5, and 6 show all of the d-spacing for a particular direction versus depth on a single graph.

***SLAD data analysis***. The effect of increasing the tooth load by an external source on d-spacing for the longitudinal strain component is clearly seen in Figure 4. At the lowest load level (116 psi cylinder pressure), the presence of the compressive residual stress state is evident. The d-spacing is smallest near the surface where the compressive residual stress is highest. The d-spacing increases as the measurement depth

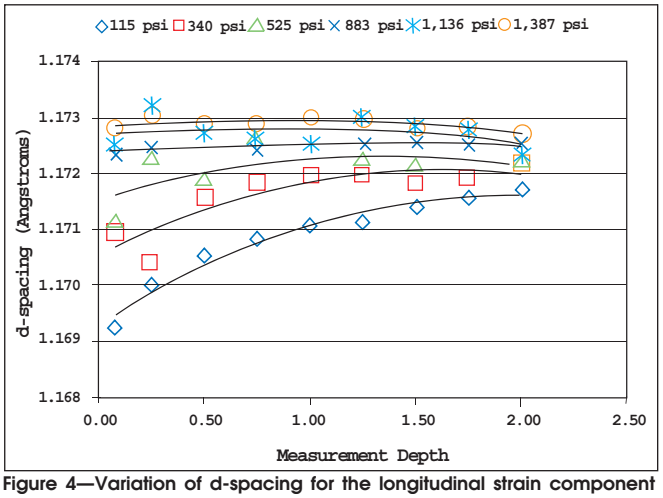


**Figure 4—Variation of d-spacing for the longitudinal strain component with depth at different test pressures.**

inside the carburized layer increases. This corresponds to a decreasing compressive stress state with increasing distance from the surface. As the tooth load is increased, the d-spacing increases—which is expected from the combination of a compressive residual stress and tensile stress resulting from the external load.

The SLAD device was designed to create a total stress of zero at the critical stress location on the fillet, at a pressure of 1,400 psi. The data shown in Figure 4 suggests that this was accomplished. At 116 psi, the compressive d-spacing gradient is clearly seen. In contrast—at a hydraulic cylinder pressure of 1,387 psi—the d-spacing gradient is nearly zero. The canceling of the d-spacing gradient as the cylinder pressure is increased is consistent with the compressive residual stress on the surface of 140 ksi, as measured using x-ray diffraction. It also shows that the AGMA tooth-bending equation given as,

$$\sigma = \frac{W_t P_t}{FJ} \tag{3}$$

where $W_t$ is the transverse component of the contact force, $P_d$ is the diametral pitch, $F$ is the face width, and $J$ is the bending geometry factor (0.38 for the gears used in this test), gave accurate results. Further increases in hydraulic cylinder

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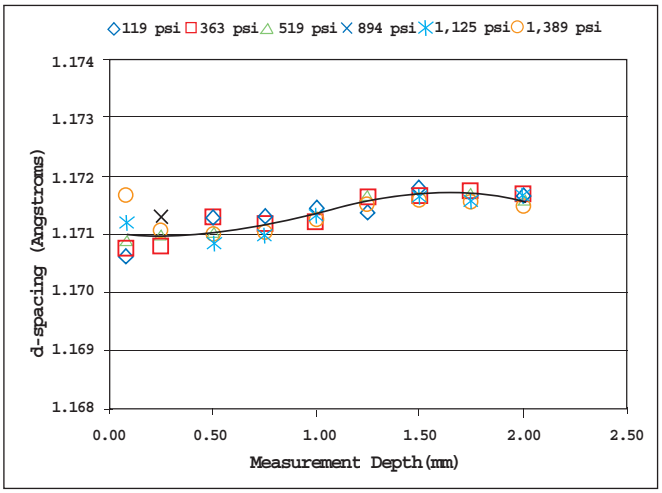


**Figure 5—Variation of d-spacing for the lateral strain component, with depth at different test pressures.**

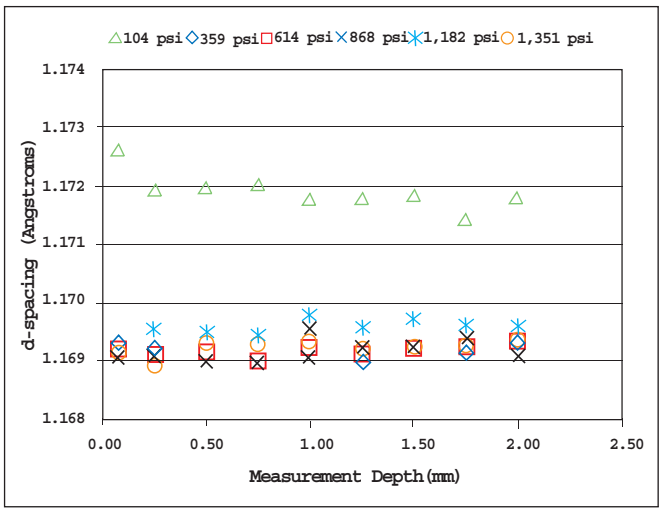


**Figure 6—Variation of d-spacing for the normal strain component, with depth at different test pressures.**

pressure result in higher d-spacing on the surface.

The effect of increasing tooth load on the d-spacing for the lateral strain components is not pronounced. The d-spacing data for the lateral direction is nearly the same for all pressures, and a single line can be fit to all of the data (Fig. 5). The measurements for all three strain components were made on a plane parallel to the sides of the gear and bisecting the center of the gear teeth. This plane is a plane of symmetry for the lateral direction and a state of plane strain exists. This condition leads to the lateral strains being zero for all pressures. At the location where the measurements were made, the total stresses (residual and externally induced) depend only on the residual stresses. This would not be expected if measurements were made off of the plane of symmetry. As one moves farther away from the plane of symmetry—i.e., closer to either side—it is expected that a condition approaching plane stress would be observed. This variation in the lateral strain/stress component across the width of a tooth is seen in finite element analyses.

There was no effect of increasing the tooth load on the d-spacing for the normal strain component (Fig. 6). All of the data can be fit closely with a single—almost horizontal—line. One data set is offset from the others. This offset is thought to be due to possible movement of one of the hanging slits. The normal stress component is zero at the surface, and one would expect that the normal strain component would be a function only of Poisson ratio effects. The d-spacing for the normal strain component was not expected to change much, but it was expected that Poisson ratio effects would show a scaled variation of the data from the longitudinal direction.

***Strain calculations***. The calculation of strains using d-spacing data is accomplished using the equation:

$$\varepsilon = \frac{d-d_0}{d_0} \tag{4}$$

where $d$ is the d-spacing measured in one of three mutually orthogonal directions, and $d_0$ is the strain-free d-spacing. Carbon, phase and microstructure gradients within the carburized surface layer will cause $d_0$ to vary through the thickness. As pointed out by Withers (Ref. 2), "Even slight changes in composition can bring about large changes in lattice spacing." Withers also discusses a variety of methods that can be used to determine $d_0$. These include powders, cubes, combs and $\sin^2\psi$ methods.

The measurement of $d_0$ and its variation within the carburized layer is not trivial. Two attempts to measure the variation of $d_0$ in the carburized layer using $\sin^2\psi$ methods are documented in Reference 3. In both cases, the measurements were inconsistent and confidence in the $d_0$ results was low. Another attempt to measure the variation of $d_0$ in a carburized layer by other methods was also unsuccessful (Ref. 4). Since we were unsuccessful in measuring $d_0$, no computed strain results are reported.

***Stress calculations***. Although strains were not computed due to the inability to determine $d_0$, the method by which stresses could be computed is presented for completeness. The conversion of strains to stresses requires a constitutive equation that relates stress to strain. The material in the core of the gear (outside of the carburized region) can be described as a homogeneous, isotropic material. However, the material *within* the carburized region is not homogeneous and the degree of isotropy is unknown. The macroscopic properties (Young's modulus, $E$, and Poisson's ratio, $v$) of hardened, high-carbon steel are close to those of a low-carbon, unhardened steel. Therefore, it is reasonable to assume that even though the material in the carburized region is not homogeneous at the microscopic scale, the macroscopic properties $E$ and $v$ do not vary significantly.

The form of the constitutive equation for either an isotropic or orthotropic material is shown as

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{23} \\ \sigma_{13} \end{Bmatrix} = \begin{bmatrix} C_{1111} & C_{1122} & C_{1133} & 0 & 0 & 0 \\ C_{1122} & C_{2222} & C_{2233} & 0 & 0 & 0 \\ C_{1133} & C_{2233} & C_{3333} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{1212} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{2323} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{1313} \end{bmatrix} \begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \varepsilon_{12} \\ \varepsilon_{23} \\ \varepsilon_{13} \end{Bmatrix} \tag{5}$$

This equation shows no coupling between the normal and shear strains. Since neither the degree of isotropy nor the orthotropic material constants are known, the equations for an isotropic material would normally be used to convert the measured strains to stresses. Equation 5 can be simplified to Equation 6 if only stresses normal to the orthogonal surfaces are of interest. This equation is not limited to principal strain or stress components, and can be used for any set of orthogonal stresses and strains.

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \end{Bmatrix} = \begin{bmatrix} C_{1111} & C_{1122} & C_{1133} \\ C_{1122} & C_{2222} & C_{2233} \\ C_{1133} & C_{2233} & C_{3333} \end{bmatrix} \begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \end{Bmatrix} \quad (6)$$

***Design and neutron diffraction experimental issues.*** Most of the challenges faced in using SLAD were associated with avoiding interferences with the NRSF2 instrument. Several iterations were made during the design of SLAD to minimize beam attenuation. Windows were cut and bearing mounting plates were moved to achieve the best design. Future attempts at in-situ measurements of total stresses should consider the design of slit-mounting hardware that is specific to the loading device.

An accumulator should also be incorporated into the hydraulic loading system to enable more precise load control and to eliminate drift in hydraulic pressure over time. During the experiments, the pressures were observed to drift by as much as ± 3% during the five- to six-hour data acquisition period. On occasion, the variation in pressure was observed to follow temperature changes in the HIFR beam room. At higher cylinder pressures, the pressure is thought to have decreased slightly due to relaxation of the stresses in the many tapped holes in the aluminum plates making up the SLAD.

## Conclusions

The primary objective was to measure the total stress in a pair of statically loaded, carburized gears. The total stresses comprise both residual stresses and those due to the external loading. SLAD was designed to load two carburized spur gears while positioned in the NRSF2 instrument. SLAD and the NRSF2 were successfully used to measure the d-spacing at various depths and tooth loads. The d-spacing data very clearly shows the change in d-spacing as a function of depth and pressure for the longitudinal strain component. The d-spacing at low tooth loads shows characteristics consistent with a compressive, residual stress state. Increasing the tooth load created tensile stresses that negated the effects of the residual stress. The d-spacing associated with the lateral and normal strain components was not sensitive to a change in tooth load. This result would not be expected for d-spacing associated with the lateral strain component at points off the plane of symmetry that were used in this experiment.

Attempts to measure the variation of the strain-free d-spacing ($d_0$) using the $\sin^2\psi$ method were unsuccessful and prevented the calculation of strains and stresses from the d-spacing data.

The SLAD experiments demonstrated the ability to measure the change in total d-spacing resulting from residual and externally induced stresses using neutron diffraction. The near- surface d-spacing data obtained from the NRSF2 and SLAD was consistent with x-ray diffraction data. The data also was consistent with the AGMA bending stress equation that was used during the design of the SLAD.

continued


## Acknowledgments

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# Repair via Isotropic Superfinishing of Aircraft Transmission Gears

Dr. Suren B. Rao


## Management Summary

The objective of this paper is to demonstrate that transmission gears of rotary-wing aircraft, which are typically scrapped due to minor foreign object damage (FOD) and grey staining, can be repaired and re-used with significant cost avoidance. The isotropic superfinishing (ISF) process is used to repair the gear by removing surface damage. It has been demonstrated in this project that this surface damage can be removed while maintaining OEM specifications on gear size, geometry and metallurgy. Further, scrap CH-46 mix box spur pinions, repaired by the ISF process, were subjected to gear tooth strength and durability testing, and their performance compared with or exceeded that of new spur pinions procured from an approved Navy vendor. This clearly demonstrates the feasibility of the repair and re-use of precision transmission gears.


### Background

The CH-46 Sea Knight aircraft is a medium-lift helicopter in the U.S. Marine Corps. It serves as the "workhorse" of the Corps for troop deployment. From a maintenance perspective, the Navy Depot at Cherry Point (NADEP CP), the Marine Corp's only aircraft depot, scraps many CH-46 transmission gears. Prominent among them is the "mix" gear box collector gear, P/N A02D2066, and its mates, the spur pinion gears, P/N A02D2065, shown in Figure 1. Also frequently scrapped have been the sun gears, P/N 107D2256-7, in the main transmission, and input pinion gears, P/N A02D2059-3, in the "mix" gearbox. Primary reasons for scrapping these gears are minor FOD or contact fatigue damage, usually termed as gray staining (also sometimes referred to as micropitting). The criterion for scrapping the gear is surface damage that snags a sharp scriber when it is traversed over the damage. Annual procurement costs on these four part numbers alone are in the range of several million dollars at Cherry Point. Analysis of the scrap gears indicated a potential greater than 50% for repair and re-use of these gears—with significant cost avoidance.

The primary focus of this effort was to demonstrate that safe re-use of scrap gears that are currently discarded would have significant reduction on sustainment costs. From an operational perspective, several additional issues are also of relevance. They are: the operational lives of gears, vibration levels in the gear mesh pair and the heat losses in gear meshes in a transmission of a helicopter—all of which could benefit from the improved surface finish generated by the superfinishing process. An increase in operational lives and reduction in vibration levels—which would attenuate the occurrence of clutch raceway failure—would directly impact CH-46 sustainment costs. Further, heat losses in gear meshes in a transmission have to be absorbed by additional lubrication oil and onboard lubricant cooling systems. The additional lubricant and the cooling systems required for this purpose add weight to the aircraft and subtract from the payload. Reduction in heat loss in gear meshes would favorably impact aircraft payload.

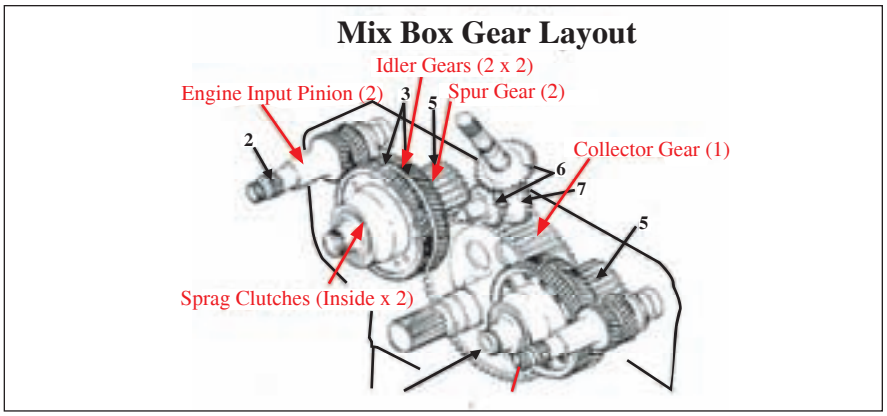


Figure 1—CH-46 mix gearbox.

### Technical Approach

As mentioned, the primary causes of a gear being scrapped are FOD (Fig. 2, circled in red) and gray staining (Fig. 3). The effort to demonstrate the feasibility of gear repair was conducted in two major phases. In the first phase, scrap gears from Cherry Point were analyzed for damage, superfinished by the ISF process and then inspected for dimension, geometry and metallurgy. In the second phase, test hardware for traditional gear tooth strength and durability testing was designed and fabricated for the spur pinion (P/N A02D2065). This included a single-tooth fatigue fixture (Fig. 4).

For dynamic tests, the spur pinion and collector gear pair were considered, and a power recirculating test rig was designed and fabricated (Fig. 5). New

spur pinions were procured from the approved Navy vendor and sufficient quantities of the scrap spur pinions were repaired by the ISF process. A detailed test plan was defined and presented to the Navy. With test hardware, both the new and repaired pinions were evaluated for single-tooth bending fatigue, contact fatigue and scoring resistance, as per the approved test plan.

## Results

The repaired gears (scrap gears that had been superfinished to remove surface damage) were inspected for dimension, geometry and metallurgical integrity. The tooth thickness was smaller than before by the amount of material removed, but still well within the tolerance. The lead, profile and index error were relatively unchanged after superfinishing, and were found to be within OEM specifications. Some of the gears were sectioned, mounted and examined for hardness, hardness profile, retained austenite and residual stress. The repaired gears met all OEM specifications on these parameters. The microstructure of the repaired gears was also examined, and no deleterious impact on the microstructure due to the ISF process was observed. The surface roughness of the repaired gears was generally in the 4–6 µin. $R_A$, while the ground gears generally had a surface roughness in excess of 16 µin. $R_A$.

The repaired and new gears were then subjected to bending fatigue, contact fatigue and scoring resistance tests, as per the approved test plan. Standard statistical analysis was also conducted on the collected data to establish the results on a firm basis. In all three tests, the repaired gears met or exceeded the performance of the new gears. Further, the repaired gears—due to their superior surface finish—operated at about 20–30°F cooler than the new gears, as measured by the out-of-mesh oil temperature in the power recirculating test rig.

## Conclusion

This project has clearly established that a significant subset of gears that are considered scrap—because of surface damage such as FOD or gray staining—can be repaired and used with significant savings in cost. Consider that the lead times for fabrication of new replacement aircraft gears have, in many instances, extended into the 12–18 months timeframe. Consequently, utilizing scrap gears has the potential of minimizing aircraft downtime and increasing aircraft availability.

While this effort was focused on CH-46 gears, the repair and reuse is applicable to transmission gears of all fixed-wing and rotary-wing aircraft. The implementation of this process will, however, require the approval and acceptance of the aircraft manufacturer. This acceptance and approval is being pursued.


## Acknowledgment

*This project was supported by the U.S. Navy Manufacturing Technology Program through the Institute for Manufacturing and Sustainment Technologies (iMAST) at the Applied Research Laboratory of The Pennsylvania State University.*



**Suren B. Rao** *is a senior scientist at the Applied Research Laboratory of The Pennsylvania State University and managing director of the Gear Research Institute. He holds a doctorate from the University of Wisconsin-Madison, a master's from McMaster University-Canada and a bachelor's from Bangalore University-India, all in mechanical engineering. He has a wealth of experience in manufacturing research in academia, industry and government, of which about 25 years have been focused on mechanical power transmission components and systems. He has authored many papers in refereed journals, conference proceedings and several book chapters. He also holds several patents in the field of gear manufacturing and is a member of the ASME, the AGMA and NAMRI/SME.*


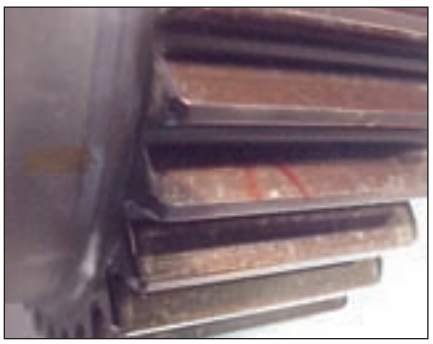

Figure 2—FOD on spur pinion.

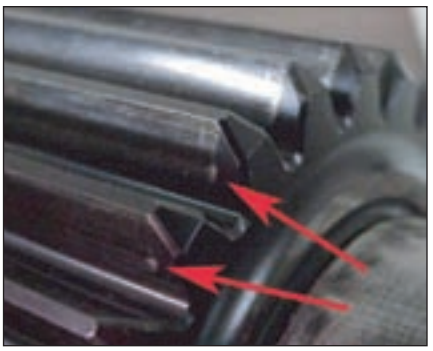

Figure 3—Gray staining on gear teeth.

Figure 4—Single-tooth fatigue fixture.

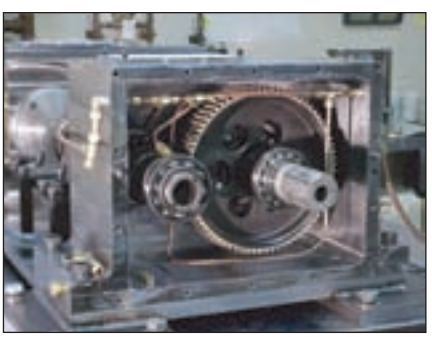

Figure 5—Power recirculating test rig.

# Gear Up Your Quality Control

## RoboScan – automatic Barkhausen Noise inspection system for gears – from small car transmission gears to large windmill gears

RoboScan system greatly improves grinding quality control of gears and reduces labor time and cost. The system provides grinding inspection based on Barkhausen Noise with minimum operator involvement. Gears are loaded into the system, and the robot takes care of the measurements. Many different surfaces can be measured effectively as the robot selects and uses a variety of sensors automatically. All results are documented on a PC and displayed on the monitor.

**SOLUTIONS AND INSTRUMENTS FOR**

- Automated grinding burn detection systems
- Automated heat treat defect detection
- X-ray diffraction and Electronic speckle pattern interferometry (ESPI) for residual stress measurements
- X-ray diffraction for retained austenite measurements

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# How Are You Dealing with the Bias Error in Your Helical Gears?

J. Lange

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**Management Summary**

This paper initially defines bias error—the "twisted tooth phenomenon." Using illustrations, we explain that bias error is a by-product of applying conventional, radial crowning methods to produced crowned leads on helical gears. The methods considered are gears that are finished, shaped, shaved, form and generated ground. The paper explains why bias error occurs in these methods and offers techniques used to limit/eliminate bias error. Sometimes, there may be a possibility to apply two methods to eliminate bias error. In those cases, the pros/cons of these methods will be reviewed. Profile and lead inspection charts will be used to detail bias error and the ability to eliminate it.

The paper details the simultaneous interpolation of multiple axes in the gear manufacturing machine to achieve the elimination of bias error. It also explains that the CNC machine software can be used to predict bias error. Equally important, the software can be used to create an "engineered bias correction" to increase the load-carrying capacity of an existing gear set.

## Introduction

Bias error or correction (a.k.a. "the twisted tooth error" and topological correction) was understood and addressed in the mid 1970s. It was not used by designers to increase a transmission's gear load capacity and noise reduction but, rather, in a manufacturing process to finish automatic transmission gears to a quality level similar to a shaved-finished quality. The finish-rolling process required the use of dies that required bias error correction. Without bias correction, the rolling dies and the working pressure of the process would produce errors similar to bias. The bias correction process was applied to a finishing tool. However, there was little chance to apply bias correction economically to conventional gearing.

The push in almost every gearing field is to increase durability and load-carrying capacity, and to reduce noise level for a given gear set. It is common to hear of the need for higher power density, more torque capability, a quieter gear box, longer life and so on. From the aerospace industry, it might be twisted around a bit (pun intended). They want a smaller, lighter gear set, but with the same load-carrying capacity. Dealing with the loss of involute contact ratio and tooth face width bearing pattern contact—due to bias error—in turn reduces the load-carrying capacity of a given gear set. So addressing that just might make it possible to meet the demands of higher power

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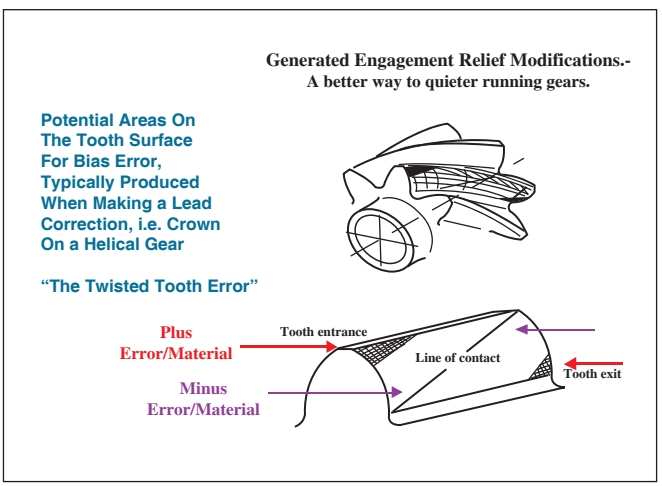


Figure 1—Line of action contact.

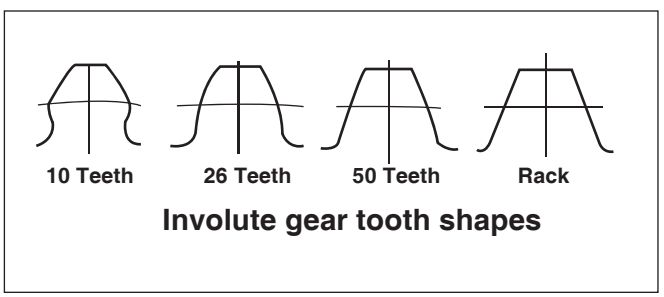


Figure 2—Curvature of the involute gear tooth shapes.

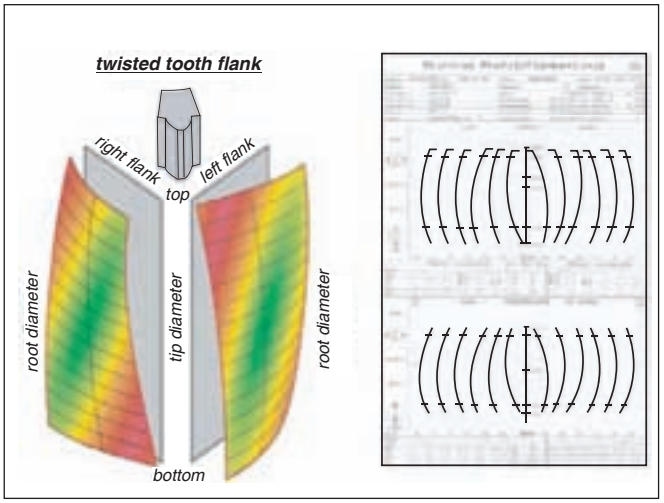


Figure 3—Amount of bias, $s_{\alpha}$.

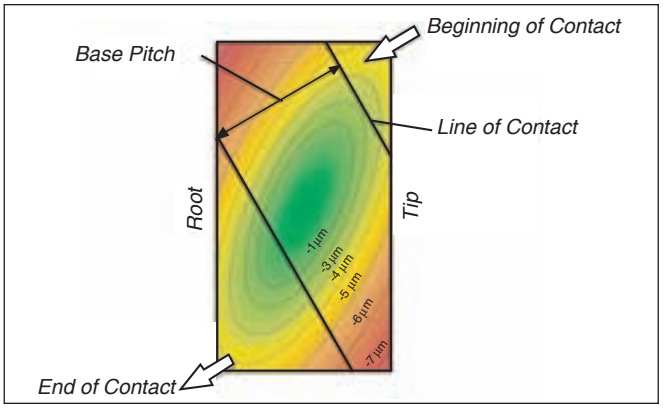


Figure 4—Flank topography.

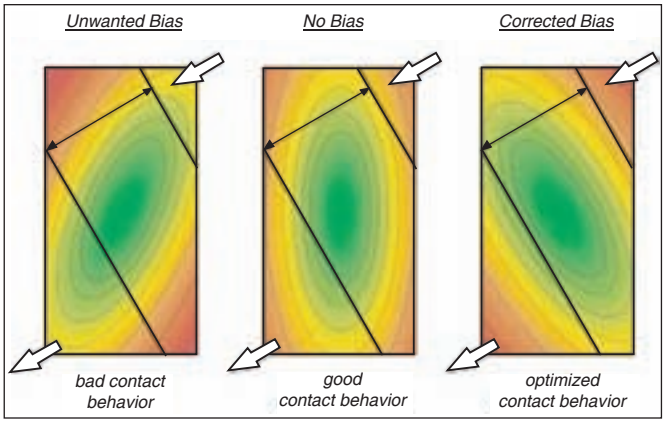


Figure 5—Impact of bias on tooth contact.

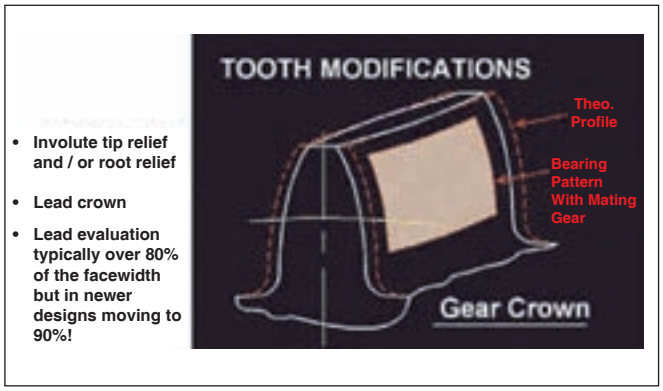


Figure 6—Load distribution: Because of varying load, tooth and gear blank/shaft bending under severe loading, there is a need to create gear tooth modifications.

density without an entire redesign of the gear set.

## Discussion

Bias error is a non-uniform profile and lead geometry across the face width of a helical gear. "The twisted tooth" appears as if one end of a gear tooth was rotated clockwise and the other end counterclockwise. It is the direct result of making a lead crown correction using the conventional method of the radial displacement of the tool (cutting or otherwise) as it moves along the face width of the gear. Pinions—the lower number of teeth component in a gear set—are more prone to "inherit" this unique manufacturing error. The pinion, being the smaller gear component, is more apt to deflect under heavy loads. That deflection occurs in the lead and involute planes. It is ironic that gear designers, in an effort to maintain a reasonable face contact pattern at peak loads, specify lead crowns that in reality can have an adverse affect. There is a need to understand that a lead crown correction with bias error compensation will achieve the goals of the designers.

The contributing factors creating bias error and those increasing the amount of bias error are:

- The helical aspect relates the line of action contact pattern of two helical gears in mesh (Fig. 1);
- The pinion is the gear normally modified, and it has the highest degree of tooth curvature. The higher the tooth curvature—lower number of teeth—the greater the potential for bias error (Fig. 2);
- The coarser the module/DP, the greater the bias;
- The higher the helix angle, the greater the bias;
- The larger the face width, the greater the bias;
- The higher the amount of lead crown correction, the greater the bias.

Figures 3, 4 and 5 illustrate bias error and a corrected bias error. The red section of the plotted tooth represents unwanted plus error; yellow signifies the transition zone to the beginning of tooth contact; and green, the ideal tooth geometry along the line of contact.

## What Does a Gear Designer Consider, and How Does Bias Error Affect Those Decisions?

Three significant factors figure into the load-carrying capacity rating and noise of a gear set:

1. ***Involute contact ratio***: A theoretical calculation of an average number of teeth in contact as mating gears roll in mesh—two or greater is desirable;

2. ***Load distribution***: Distributed across the face width of the gear, which at the same time, can affect the involute contact ratio negatively if the two gears in mesh are not contacting each other along the designated face width, normally 80% or more when under load (Fig. 6);

In the finished gear, plus error needs to be avoided. If not, high contact stress could lead to tooth pitting in those areas of plus error.

So to deal with it, the designer will need to define the amount of bias error being dealt with (Fig. 7). Once the designer is informed as to the amount of bias, a decision can be made to either reduce the crown to reduce the bias, or discuss with manufacturing engineering the ability to eliminate it. It may be

that prototypes need to be made and inspected for bias error. See Figures 8–11 for examples of bias error evaluation methods.

Now the amount of bias error has been defined. The next step is to approach the gear designers and describe the errors that were caused when creating the specified crown correction. It may be necessary to show the following schematics illustrating how the lead crown was created. Point out the plus error issue. In addition, inquire if the crown is required on both flanks and if the root diameter changed in relation to the crown is desirable or required. The significance of these

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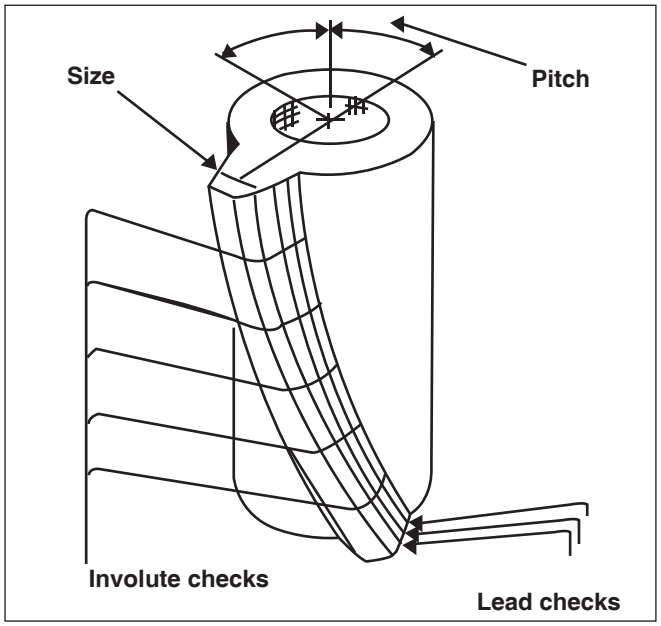


Figure 7—Inspecting for bias lead and involute measurements of a single tooth.

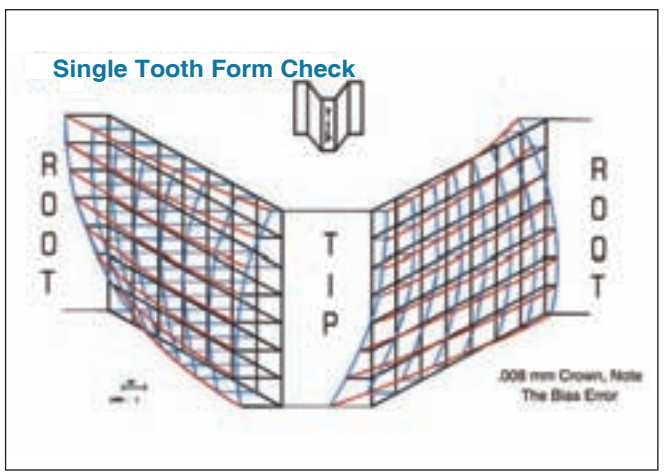


Figure 8—Single tooth with bias error.

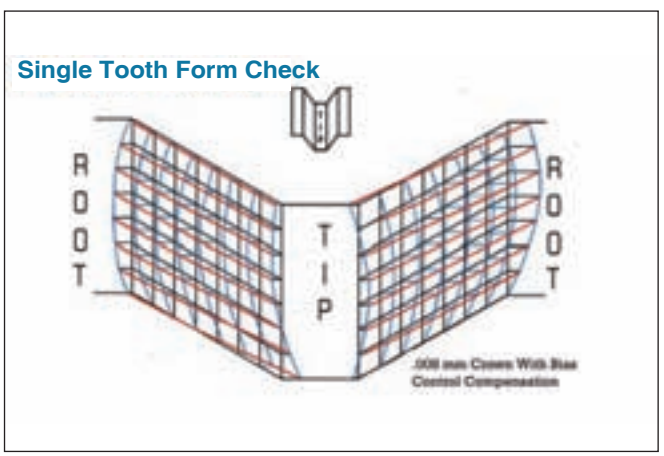


Figure 9—Single tooth without bias error.

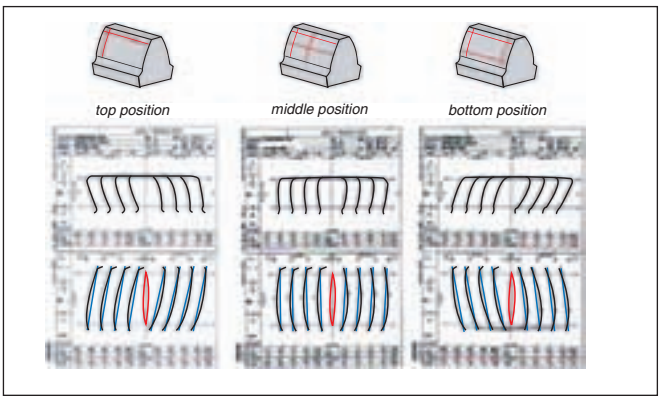


Figure 10—Typical four-teeth inspection technique with bias error.

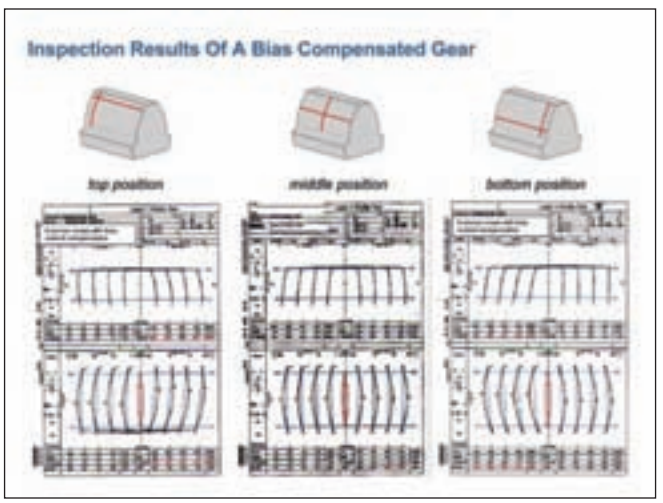


Figure 11—Typical four-teeth inspection technique with bias correction.

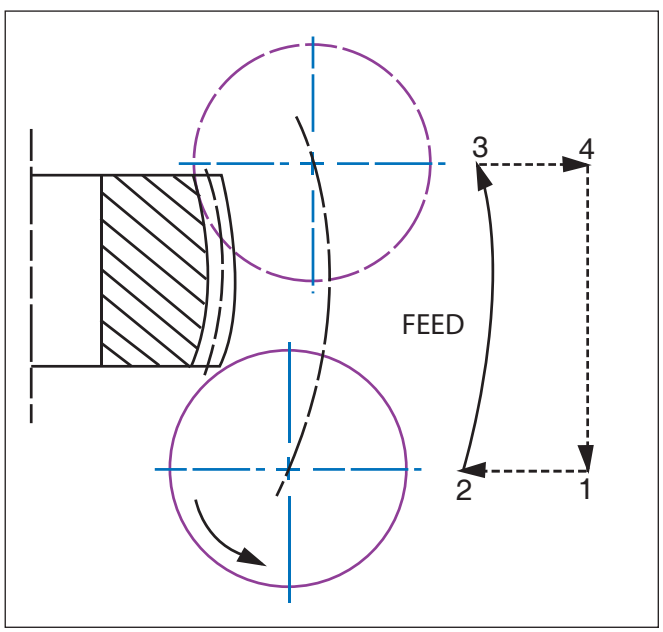


Figure 12—Traditional method for lead crown correction with a circular tool. Traditional path of hob, threaded wheel grinding and form grinding tools. This method of crowning will create bias error.

answers will become apparent a bit later in this discussion.

### Methods to Make a Lead Crown Correction

Form grinding will be used as a means to demonstrate how the kinematics of creating a lead crown creates a bias error. See Figures 12–20.

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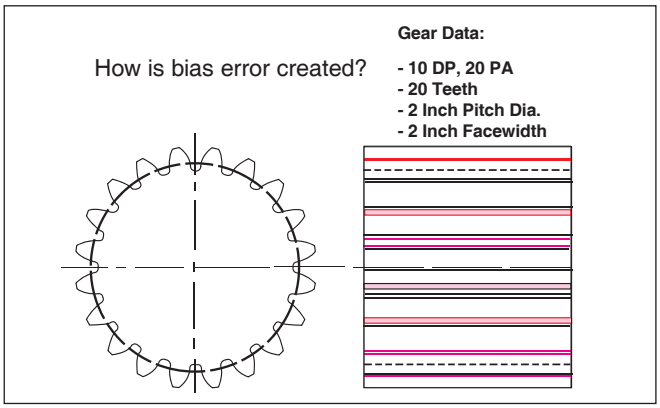



Figure 13—Form grinding example.

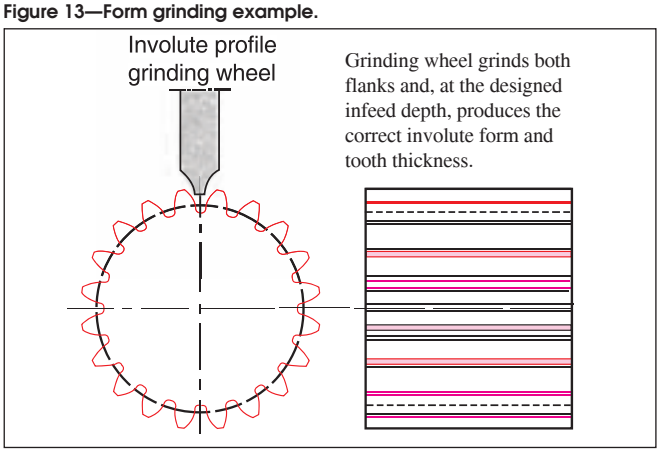



Figure 14—Form grinding method.

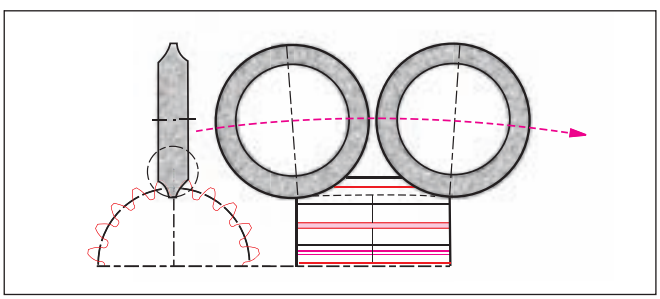


Figure 15—Form grinding wheel path for a convex crown. Form grinding wheel path required to create a symmetrical lead crown using the conventional crowning technique of radial displacement of the grinding wheel, relative to Z axis position along the gear face width.

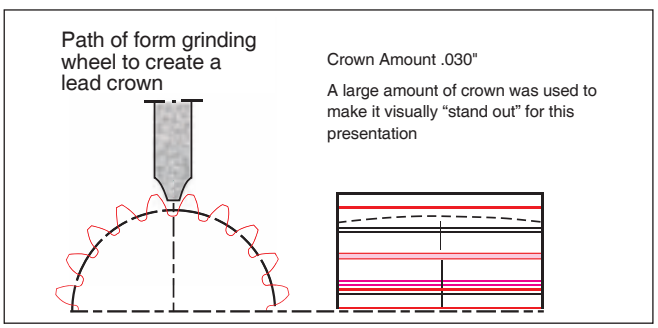



Figure 16—Tool path for a 0.030" crown per flank.

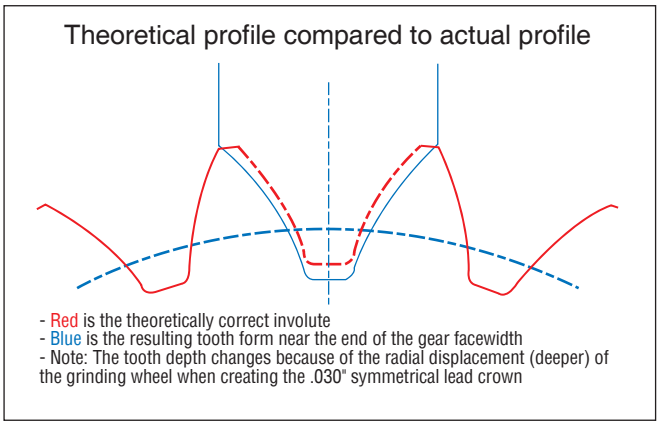



Figure 17—Involute profile "radial shift" resulting in involute errors when creating a 0.030" crown. (Note: A 0.030" crown is inordinately large, but that was done for visual effect.)

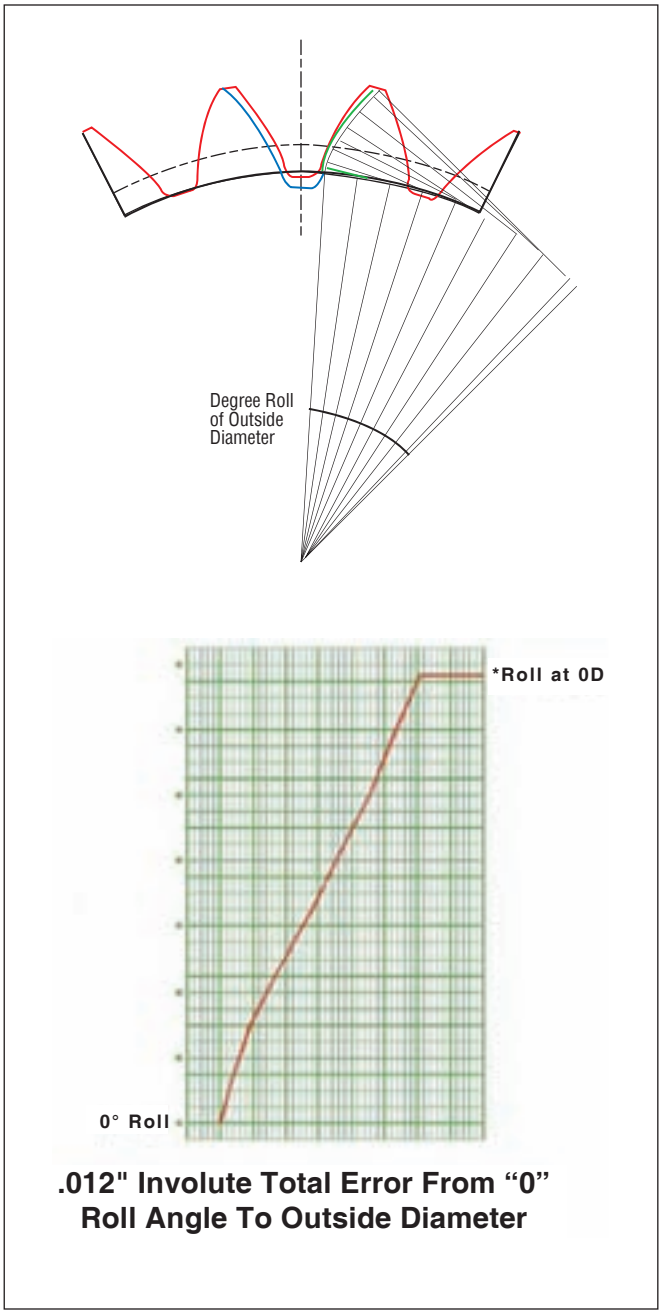



Figure 18—Lead slope error as the result of 0.030" crown.

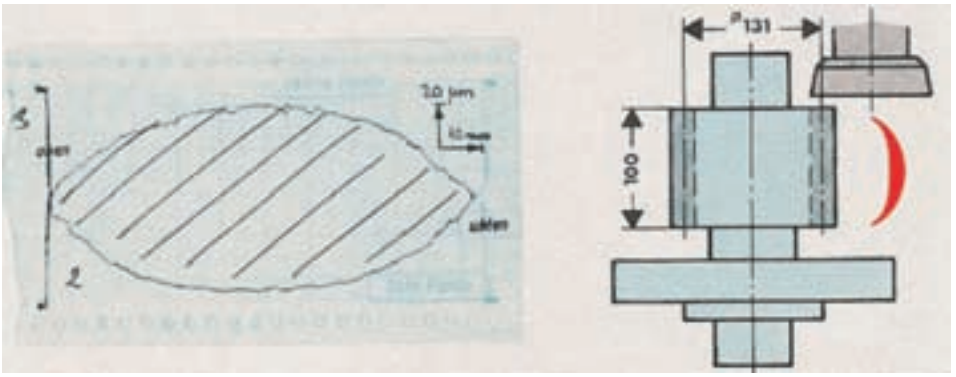
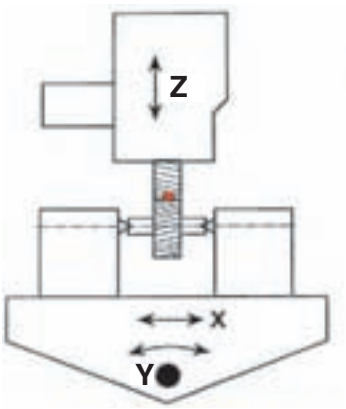



Figure 19—Shaping method for lead correction. The gear shaping process creating a lead crown with a radial position change of the path of the shaper cutter as it passes along the face width of the gear. This method of crowning will create bias error.




"Rocking Table" Design
- Varying Center Point

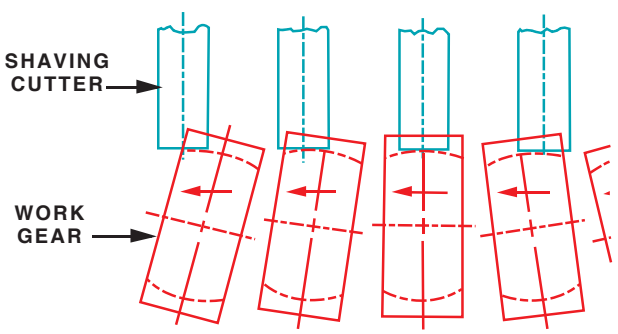
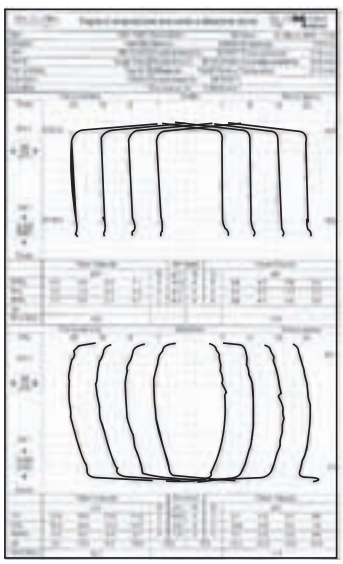



Figure 20—Shaving a lead crown correction by "rocking" the gear. In the shaving process, the crowned lead created by changing the center distance between the shave cutter and gear as the contact point moves right to left as the work side "rocks up and down." This method of creating a crowned lead will produce bias error. Note: Plunge shaving and honing having the lead crowned correction dressed into the shave cutter and hone stone, and, consequently, will not produce bias error. The Gleason Hurth Honing machine has the ability to make bias error correction using four axes of motion. It "knows" where the center point of contact is at all times and controls its position/motion to produce bias error correction.



Gear Data
30 Teeth, 7.25 DP, 30.9 Helix
5.05" OD, 1.05" Width

*GEAR SHAPING PROCESS*

*Electronic Guide*
*Lead Correction*
*Example*

*Flank Correction Results*

*Asymmetrical Slope*
*LF .0167 RF .0011 mm*

*Symmetrical Crown*
*LF .010 RF .0105 mm*

Figure 21—Lead crown correction made with a CNC guide.

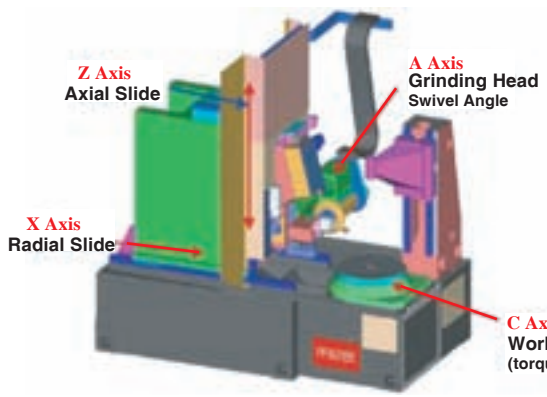
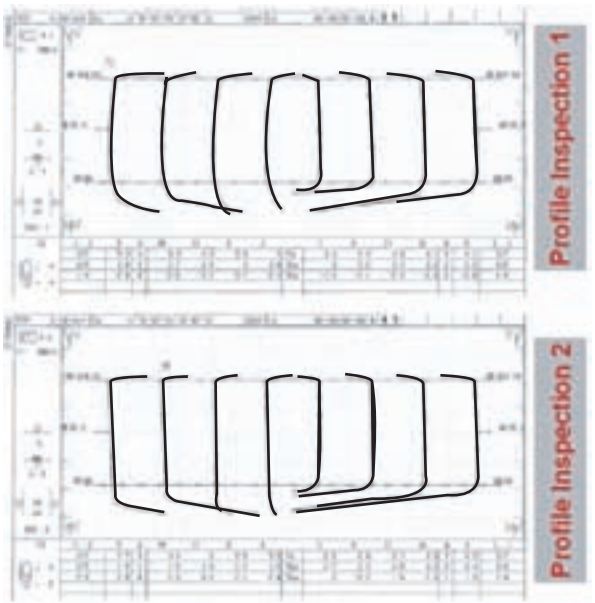



Figure 22—Axes being interpolated when making bias error correction (X, Y, A and C, depending on Z position). Multi-axes gear grinding machine interpolating 5 axes of motion to eliminate bias error when creating a lead crown grinding two flanks.




Profile charts

Figure 23—Dual-flank grinding without producing bias error.

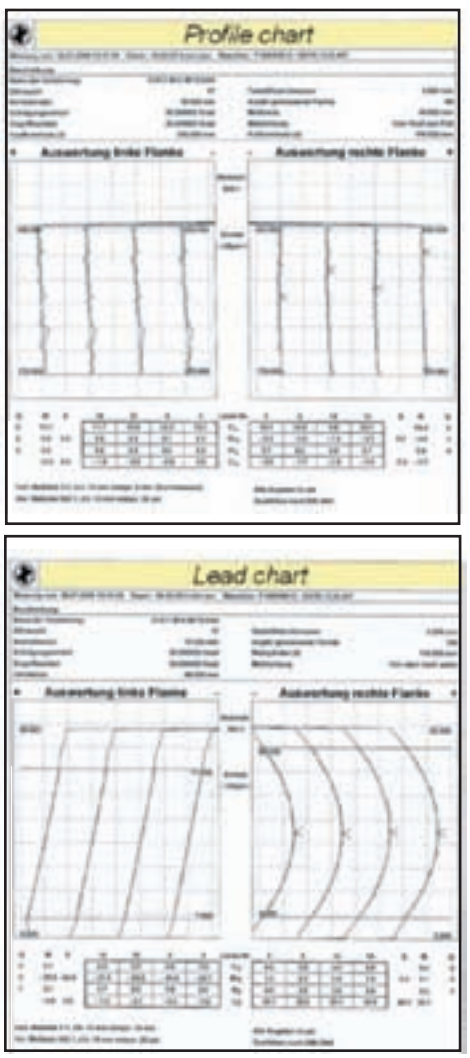


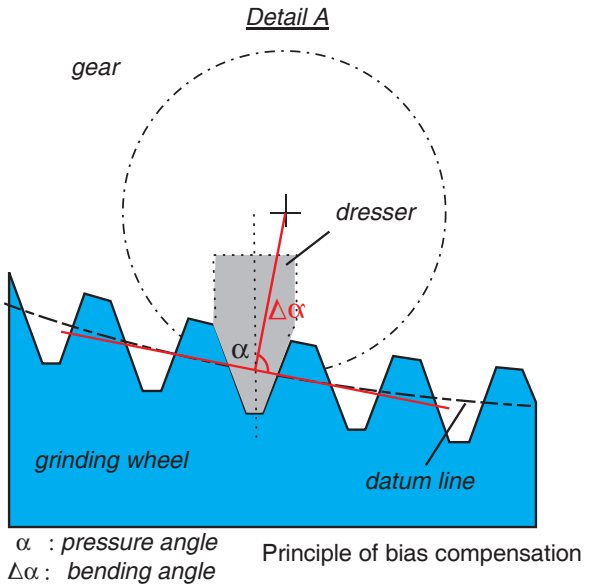

Figure 24—Dual-flank grinding without producing bias error.

**How to Deal with Unwanted Bias Error—**
**How Not to Make Bias Error**

- Do not make a lead crown correction using the traditional, radial displacement of the tool or workpiece. This may not be practical, as the gear manufacturing equipment in use in a plant most likely has no other method of making a lead crown.
- An important point about a machine's CNC capability with special software and various CNC-controlled axes needs to be known: If the machine can cut a part cutting only one flank at a time, it may be possible to use the worktable rotation or another rotary axis to make a lead crown, and not cause bias error. This one-flank finishing process applies to form grinding and shaping. The gear designer should be asked if it is really necessary for both flanks' lead to have a lead crown correction. If yes, then two finishing passes are required to make this gear, and more cycle time is required. This single-flank crowning method does not change the root diameter. One could actually consider if making a crowned lead without a root diameter change, might you have a stronger tooth?
- If finished hobbed, there is nothing that can be done. Bias error will occur.
- If finished shaped, bias error will occur, unless the machine has a CNC guide capability and special software. Then the finish cutting method is to cut a flank at a time, making a right-hand helical until mid-face, and then a left-hand helical. It would be the opposite for the other flank. One would think that this crown cutting method would make a lead correction that would look like a chevron. This is not the case; see the example lead chart made on a Gleason/Pfauter gear shaping machine with an electronic guide and special software (Fig. 21). Note the intentional asymmetrical and symmetrical lead corrections.
- If a shaved part, use only the plunge shaving process. Plunge shaving will not create bias error. This is not practical if the part has a face width larger than 2" (50 mm), and/or if the pitch is coarser than 6 DP (4.23 module). With the parallel and diagonal shaving method, a bias error is created when making a lead crown correction.
- If grinding, you need to do the following:

1. ***Form grinding***: Use the single-flank grinding process with work spindle rotation—not "X"radial axis displacement—as the grinding wheel moves along the face width of the part. If both flanks require a crown, then an additional finishing pass is needed. Or, if the machine has a very special software and multi-axes interpolation motion capability, then a dual-flank grinding process can be done, thus saving an enormous amount of time. See

continued



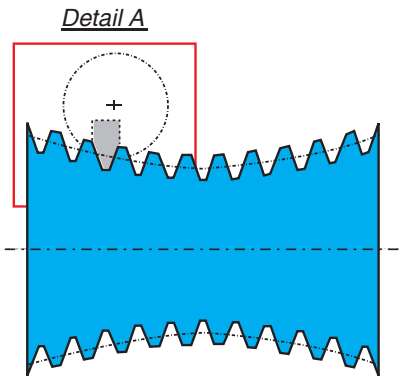




Figure 25—Special dressing technology applied to the grinding wheel to eliminate bias error when making a lead crown.

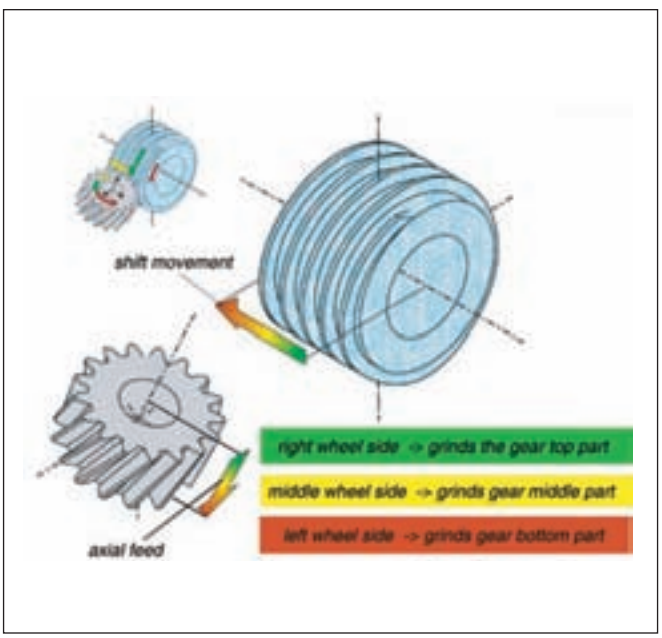
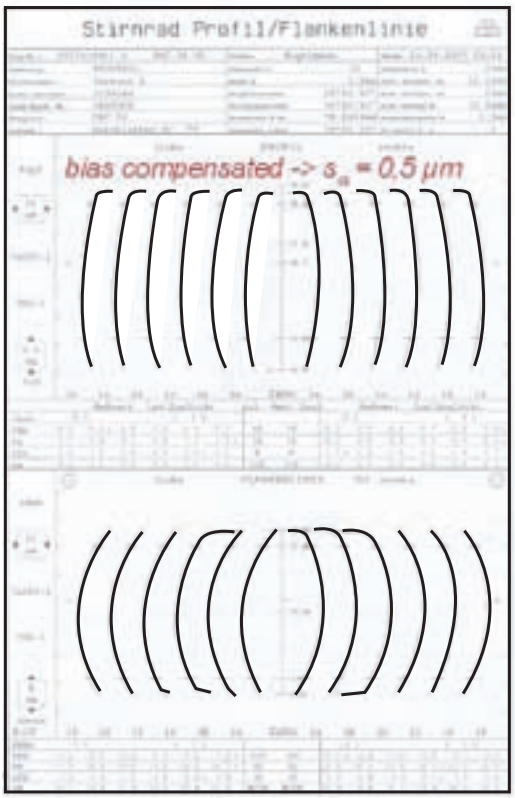



Figure 26—Special dressing technology and shifting strategy to eliminate bias error when making a lead crown.

## Results of Bias Modification / Compensation



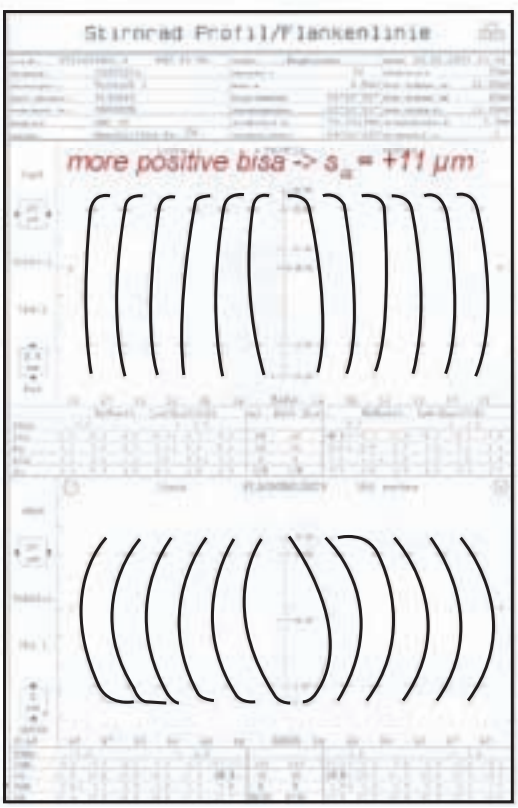




Figure 27—Threaded wheel grinding with lead crown correction and no bias error.

Figures 22–24 for an example of a Gleason/Pfauter CNC grinder using patented software producing bias error correction and, in the second example, totally different lead correction. Knowing the contact point of the grinding wheel at all times is paramount to this successful and unique lead correction technique.

2. ***Threaded wheel grinding*** Special, patented software and machine dressing capability are applied to create on the grinding wheel different geometric proportions over its length. This is an example of a Gleason software solution to eliminate bias error or to make a bias correction (Figs. 25–27).

## Conclusion

Gear designers and manufacturing engineers need to know that it is now possible to make lead crown corrections without creating bias error. They need to use this knowledge along with processes to create a face load distribution over the typical 80%, which many gear designers consider for their designs. Why not even 90%, when the designer is forced to continue to use an existing gear box at higher-rated load capacity? Designers may even rethink bias error and consider using this ability to manipulate bias values into a bias correction.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**John M. Lange** *is a product manager for The Gleason Works. Active in gear manufacturing since graduating with his bachelor's degree in 1970, he is a past chairman of the AGMA Gear Manufacturing Committee and the AGMA Metrification Committee. Lange's papers have been published by Gear Technology magazine and the SME, and has authored two sections in the SAE's 1990 Gear Design, Manufacturing*


## Author's Note

***Just to be clear****…At the close of this presentation, the reader is left with the impression that the latest gear manufacturing machine technology for controlling bias/twist is used only to prevent bias error; or—as termed in this paper—bias* compensation.

*Bias compensation serves to help in achieving a designer's original goal—to have a lead crown correction that would hopefully create a uniform load distribution across the face width of the gear at peak loads.*

*It was also originally stated that the future would see designers using this unique machine technology of multiple CNC axes of interpolation to make a bias correction in combination with a crown correction for the ultimate load distribution.*

*After the 2008 AGMA Fall Technical Meeting, conversations with several gear designers indicated that they do, in fact, have current designs with bias correction requirements.*

*A particular example was the need to create a bias correction of 0.003–0.004 mm for an engine balance shaft gear. The bias correction was implemented using the plunge shaving process. (You can imagine the challenge of grinding a tightly controlled bias correction into the plunge shaving cutter's lead and involute.)*

*Recently, we have seen four examples of part prints—from four different companies—requiring hard gear finishing with bias correction. These are automotive transmission parts that would most likely use the threaded-wheel-grinding process for three of the parts, and honing for the fourth. Honing is required because it is a pinion shaft with a 20-tooth gear next to a 37-tooth gear with a distance between the two of only 7 mm. The bias correction amounts for these four parts ranged from 0.005 mm to as much as 0.020 mm.*

*It would appear that an understanding by gear designers of this bias correction capability is gaining currency. One can then perhaps anticipate the next question for a future technical paper—How does a designer determine the amount of bias correction being specified?*

—John Lange.

May, 2009

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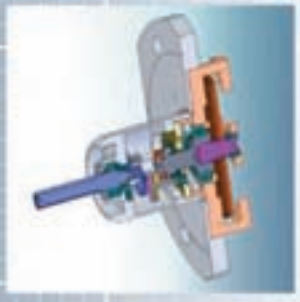

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# Gears, Motors and Controls Expo 2009—

## PROMISES INDUSTRIAL GROWTH IN INDIA

Photo courtesy of Tom Calendera.

As India looks to recover from the global economic slowdown, the trade show circuit in Asia has been hit with budget concerns and attendance issues. Although many 2009 Asian trade shows have been postponed or outright cancelled, others plan to carry on in an effort to create more opportunities for the industrial and manufacturing sector.

The Gears, Motors and Controls Expo 2009 (GMC) is scheduled to take place at the Chennai Convention Center in Chennai, India May 14-17 to bring together buyers and sellers of gears, motors and control equipment and promote industrial manufacturing in India.

Organized by Conventions & Fairs (India) Pvt. Ltd., GMC 2009 is designed to encompass developments in these fields and bring together key corporations to discuss the future of Indian manufacturing.

According to the expo's website (*www.gmconline.in*), industrial corporations and consulting companies continue to remain upbeat about India's economic forecasts despite recent reports. To sustain economic growth, the country is focused on rapid development and massive infrastructure projects in 2009 and 2010. Industry observers say the market is currently shifting toward heavy manufacturing in the region.

Because of these factors, many exhibitors believe GMC 2009 will be a great focal point for managers, engineers, buyers and quality control personnel in industries from defense and agriculture to automotive and construction to help jumpstart India's industrial economy.

Some of the products at GMC 2009 will include AC/DC motors, stepper motors, electric motors, motor accessories, geared motors, servo drives and motion controllers; motor starters, internal combustion engines, hydraulic motors, pneumatic motors, turbines, right angle gearboxes, worm gearboxes, rack and pinion gears, spur gears, hydro-mechanical equipment, helical and bevel helical gearboxes; roller chain sprockets and switchgears.

GMC 2009 will be held in conjunction with the Pumps, Valves and Compressors Expo 2009. The exhibition is supported by the All India Electric Motor Manufacturers Association and the All India Association of Industries. Media Partners include *Engineering Review*, Tender World Newspapers Group, Product Finder, Trade India, India Mart, Kompass, Project Vendor and Tender Tiger.

The Chennai Trade Center is a state-of-the-art exhibition complex that offers four halls, an auditorium that seats 1,000, storage and warehouse facilities, banquet halls and restaurants and snack bars. The center is in close proximity to both the airport and train station near Chennai.

Organizers at Conventions & Fairs (India) Pvt. Ltd. have been involved in trade shows for 17 years in India and hope to build on their reputation with GMC 2009. The success of the show, according to organizers, will rely heavily on the future business that it will create.

According to B&K Securities, an Indian investment firm, the country is a key growth market as there is a discernible trend in shifting the base of heavy manufacturing to the region. Fluid power is an integral component in the capital goods business, and given the increasing demand and robust environment, the prospects of this industry look promising. For more information on GMC 2009, visit *www.gmconline.in* or contact *conventions@mtnl.net.in*.

Photo courtesy of Asif Akbar.

# CALENDAR

**June 3–5—Advanced Gear Design and Theory.** UWM School of Continuing Education, Milwaukee, WI. This advanced course for experienced designers will address topics key to the application of gears in today's products with an emphasis on proper selection, design application and use, as opposed to fabrication. The curriculum outline addresses manufacturing methods and considerations; inspection and quality control; materials and heat treatment; drawing data requirements, specifications and formats; basics of load capacity rating: theory, practice and reality; and lubrication types and methods. Knowledge of geometry, trigonometry and elementary algebra is required. The course is part of the continuing education program at the University of Wisconsin—Milwaukee and is taught by Raymond Drago, chief engineer for Drive Systems Technology, Inc., a mechanical power transmission consulting firm. For more information, contact Murali Vedula, program director, at (414) 227-3121 or *mvedula@uwm.edu*, or contact Debra O'Neill, program assistant at (414) 227-3100, or *oneill@uwm.edu*.

**June 16–18—Western Manufacturing Technology Show.** Northlands Park–AgriCom, Edmonton, Alberta, Canada. Held every two years in Alberta's capital, Western Manufacturing Technology Show (WMTS) is a showcase for manufacturers of products ranging from machine tools, welding equipment, design engineering and plant maintenance to process control and automation. This event is a major forum for manufacturing professionals from Edmonton and the surrounding area to source machinery, equipment, supplies and services for all aspects of their operations. WMTS helps industry professionals address production challenges and pinpoint new opportunities. It offers an opportunity to view a wide range of product lines and locate suppliers for products and services that can help their businesses. For more information, contact *canadasales@sme.org* or call (888) 322-7333.

**June 28–July 1—International Conference on Powder Metallurgy and Particulate Materials.** The Mirage Hotel, Las Vegas. The latest PM products, raw materials and process equipment will be on display at the trade exhibition portion of this annual PM conference. Other events include the annual state of the PM industry special session, keynote address, award presentations for outstanding PM parts, products and service to the PM industry. Experts from around the world will deliver more than 200 technical presentations in 46 sessions and six special interest programs. Technical sessions will cover advanced gear processing, advanced powder production techniques, nanostructured materials, thermal management materials, functionally gradient materials, biomedical applications in powder injection molding in addition to trends in metal powders, PM processing equipment and PM parts making. For more information, visit *www.mpif.org* or call (609) 452-7700.

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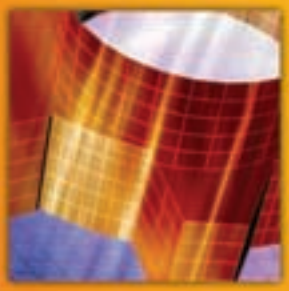

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**GLOBAL BUSINESS SOLUTIONS!** The U.S. Department of Commerce chose Gear Expo 2009 to participate in the International Buyer's Program so you can share ideas and solutions with your counterparts from around the globe.

**QUALITY EDUCATION!** Check www.gearexpo.com often as we post the full education line-up, including AGMA's Fall Technical Meeting, plus seminars from several well-known associations.

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# Addition of Robot Blasting Cell

## ENABLES SHOT PEENING DEMONSTRATION

Steve Donohue (left), vice president of sales & marketing, pictured with Steve Byrnes (right), president of Guyson, announce the expansion of the company's engineering test laboratory to include a robotic pressure-blast system.

Guyson Corporation expanded its engineering test laboratory with the purchase of a robotic blast system to sustain application development work on customers' automated blasting projects and Guyson's contract finishing and surface preparation services.

"The investment, together with our advanced CAD/CAM-based software for off-line robot motion programming, will extend our lead in supplying engineered-to-order robotic blast systems to manufacturers of medical, aerospace and other components that require the highest degree of precision and repeatability in surface treatment," said Steve Byrnes, president of Guyson, to employees while unveiling the equipment.

The robot blasting cell enables the test lab to perform on-demand demonstrations of robotic surface finishing and shot peening processes. The programmed process routine for a particular component can be stored, recalled and repeated precisely anytime. A rotary table pressure-blast cabinet and a six-axis robot that manipulates the blast nozzle make up the system. The blasting cell constantly maintains a specified offset, angle of impingement and surface speed while following contours of complex-shaped components.

Guyson is making the cell available for certain contract finishing work, and the company hopes it will promote process development in partnership with customers. "Many of our customers are in regulated industries or have rigid quality systems requirements; for example, shot peening of aerospace components to stringent specifications such as AMS-2432 to meet NADCAP AC-7117 audit criteria, or medical components processed in accordance with FDA guidelines in an ISO-13485 certified operation," says Steve Donohue, vice president of sales and marketing. "A fully functioning robotic blasting cell enables us to assist our partners with blast process validation, the elimination of non-conformities and the achievement of repeatable Six Sigma quality."

# Gear Technology

## RECOGNIZED BY BOEING FOR EXCELLENCE

The Silver Performance of Excellence Award was presented to Gear Technology of Newport Beach, CA by Boeing.

"We are proud to recognize the performance excellence of our suppliers, who have demonstrated that they are the best in the Boeing supply base," says Steve Schaffer, Boeing enterprise leader of supplier management and vice president and general manager of supplier management for Boeing Commercial Airplanes.

The annual award is based on product quality and delivery metrics over a twelve-month period and is given to a handful of worldwide suppliers. "Boeing is committed to developing, rewarding and retaining our top-performing suppliers who share our focus on first-time quality and on-time delivery," Schaffer says. "These high-level certifications represent our ongoing commitment to superior product quality, customer value and personal customer service."

Gear Technology manufactures gears for aerospace, military and commercial manufacturers around the world since 1986. The company was also recently awarded ISO 9001:2000 and AS9100B:2004 quality certifications by the International Standards Authority registrar. "Our integrated manufacturing processes, including sophisticated job tracking systems, ensures products are produced with careful attention to the most intricate engineering detail and product specifications," says Tom Marino, president of Gear Technology. "The company also offers gear blanking, engineering consultation and sophisticated inventory management services."

# MIM Materials Standard Released

An addendum to the 2007 edition of MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts," has been released. The additions include low-alloy steel specifications, a new MIM standardized material designation code, information, property data, chemical composition and data tables (both inch–pound and SI units) for the MIM-4140 quenched-and-tempered material.

The standard is posted on the MPIF website, at *www.mpif.org/Pubs/35_addenda.asp?linkid=81*, as a free-access document until it is included in the next printed edition of the standard publication. The pdf may be copied and sent to design engineers and others who specify MIM parts.

# Kapp

## TAPS NORTHEAST SALES REP


Dwight Smith

Dwight Smith, of Cole Manufacturing Systems, Inc., was awarded a contract to exclusively represent Kapp and Niles products in New York, Michigan, Indiana, Northern Ohio, Pennsylvania and New Jersey. He previously worked with Kapp from 2001 to 2006.

Smith has a range of experience in gear manufacturing, metrology, analysis and project management. Since 1989, he has developed and presented gear training sessions, and he served as chairman of the AGMA handbook committee.

"We are delighted that Dwight has re-joined our sales team," says Bill Miller, vice president of sales at Kapp Technologies. "He is recognized and valued for his years of experience selling gear manufacturing machinery and metrology instruments as well as serving the American Gear Manufacturing Association in multiple capacities. He is a professional who enthusiastically commits himself to excellence in customer service."

# AMT

## SEEKING NEW LEADERSHIP

Following the resignation of Robert K. Simpson as president, the Association for Manufacturing Technology is pursuing new leadership. Simpson joined AMT in May 2008 and will be pursuing other interests.

"In these critical economic times, we are seeking a leader who will continue to guide AMT on its mission of serving our members' needs and supporting the interests of the manufacturing technology community as a whole," says Ronald F. Schildge, AMT chairman and president of Transmares Corporation. "The focus now for the AMT board of directors is to identify the president who will lead us to provide what our members need as they weather this global economic crisis, and who will continue to position AMT and its members to emerge even stronger."

The interim AMT senior staff is in cooperation with the board of directors in overseeing ongoing programs and day-to-day operation. The board of directors is in the process of searching for a replacement president and hopes to name one shortly. "On behalf of the AMT Board of Directors, we would like to thank Bob for his service to AMT and the manufacturing technology industry," Schildge says. "We wish him well in his future endeavors."

# PM Association

## NAMES PRESIDENT

Richard Pfingstler, president of Atlas Pressed Metals in DuBois, PA, has been appointed president of the Powder Metallurgy Parts Association (PMPA), which is a member of the Metal Powder Industries Federation (MPIF) and represents major international manufacturers of

continued

Richard Pfingstler

precision metal parts made from metal powders.

Pfingstler has served on the MPIF finance committee and the PMPA board of directors. He is a CPA and earned his bachelor's degree in accounting from Gannon University. He is the principal owner of Atlas, which he first joined in 1980. The PMPA engages in market development, statistics, government relations, materials standards, professional education, industry safety and health, e-learning and technology transfer.

"The association serves to promote the wider use of PM parts and improve the quality of our products," Pfingstler says. "It is the champion of the industry rather than one company."

# Skills Certification System

## TARGETS HIGH UNEMPLOYMENT, UNFILLED MANUFACTURING JOBS

The Society of Manufacturing Engineers (SME) is partnering with the National Association of Manufacturers (NAM) and The Manufacturing Institute to create a skills certification system aimed at helping U.S. workers succeed in manufacturing jobs. The Manufacturing Skills Certification System will provide skills assessments, standardized curriculum requirements and portable credentials identified by manufacturers to assure them that new hires and existing employees have the core academic and workforce competencies required.

"At a time when millions of Americans face unemployment, manufacturing jobs with excellent salaries—and across all skill levels and sectors—are unfilled because of the lack of qualified applications," says John Engler, president and CEO of NAM. "Tough economic times call for clear pathways to skills in demand."

The Manufacturing Institute, a nonprofit subsidiary of NAM, is establishing and operating the system, which is

based on the ACT National Career Readiness Certificate and includes certification programs required by various industry groups for entry level positions. Higher levels of practitioners are reinforced by the SME certifications for manufacturing engineers and for manufacturing technologists.

"SME has long been a proponent of building a high-skilled workforce using outcome-based assessments," says Mark C. Tomlinson, SME's executive director and general manager. "This system provides the framework to make it happen."

# Hansen

## DELIVERS FIRST GEARBOX FROM CHINESE FACILITY

Hansen Transmissions announced the delivery of the first gearbox manufactured in the new facility in the Beichen Hi-tech Industrial Park, Tianjin, China. The delivery occurs six months after construction began on the 250,000 $m^2$ assembly and test facility, and it will be deployed in a 2.1 MW Suzlon turbine. The Tianjin facility is modeled after Hansen's facility in Lommel, Belgium and will use the same manufacturing machines and processes.

"The delivery of this first gearbox from our Chinese

continued

facility, on time and on budget, represents another milestone for Hansen," says Ivan Brems, CEO. "The facility in China will add to Hansen's capabilities to supply high quality products in Belgium, India and China."

## Marposs

### BUYS PROCESS MONITORING SUPPLIER

Marposs S.p.A. acquired ARTIS Gesellschaft für angewandte Messtechnik GmbH, a developer, manufacturer and supplier of in-process tool, process and machine condition monitoring systems as well as adaptive control apparatus. The German company's products are used by manufacturers of machine tools in aerospace, automotive, heavy equipment and other capital goods industries.

"Working with Marposs represents a perfect opportunity for rolling out ARTIS' products on a broader geographic scale via Marposs' global distribution network," says Hans-Georg Conrady, managing director of ARTIS. "I am looking forward to working with Marposs over the coming years to further grow the business, which I have been part of since 1992."

"ARTIS offers cutting-edge solutions with large potential to be used in additional applications and by current and future Marposs customers on a global basis," says Stefano Possati, president of Marposs. "Our goal is to grow in a solid and continued way both in our traditional and new markets. Purchasing quality companies with products that are complementary to those of Marposs is a tool that we will continue using, in addition to our strong activity in research and development inside the company."

## Sandvik Coromant

### SUPPLIES PURDUE ENGINEERING LAB

In a recent collaboration with Purdue University's School of Engineering Education, Sandvik Coromant has supplied

From left to right: Sandvik Coromant's Greg Wilson, Tim Taylor of Haas Automation, Jeff Huddleston and Eric Holloway of Purdue, and Mike Verkamp and Darrall Erb, both of Sandvik Coromant.

tooling solutions and services to the school's Ideas to Innovation (I2I) Learning Laboratory. The new, state-of-the-art lab is also a Haas Technical Education Center, and it will provide hands-on design experience to almost 1,700 first-year engineering students.

The partnership includes Purdue faculty and staff, Haas Automation and Quality Mill Supply, and Indiana-based industrial distributor. Sandvik is developing curriculum-based training in addition to providing tools to the lab.

"I2I is a collaborative, experiential learning environment that engages students by allowing them to develop and refine engineering skills for the real world," says Eric Holloway, director of instructional labs at Purdue. "Through our collaboration with Sandvik Coromant, students can become well versed in cutting tools and the solutions that will best enable them to take concept-level projects to the manufacturing stage."

The lab has seven studios specializing in design, demonstration, prototyping, electronics, fabrication, artisan and innovation. After planning, students can build, test and refine prototypes with a variety of machine tools. The I2I lab also features a 120-student classroom, 3-D rapid prototyping printers and a Microsoft Surface interactive multi-touch table.

Purdue will receive ongoing technical support in the machining labs, printed training aids, tooling software and live in-class presentations from Sandvik engineers as part of the partnership. Engineering faculty and staff will receive free training at Sandvik Coromant's metal cutting technology seminars.

"Sandvik Coromant was eager to collaborate with Purdue University in the development of the I2I Learning Laboratory," says Mike Verkamp, Midwest zone manager for Sandvik. "Educating tomorrow's engineering and technology workforce in advanced metal cutting practices will serve as a critical function to growing our nation's manufacturing

continued

economy, and through this collaboration, we will be able to aid in the recruitment, education and development of nearly 1,700 engineers each year."

# Zeiss APPOINTS SALES VP

Andrew Sisler

Andrew Sisler has been appointed vice president of sales for Carl Zeiss. He will lead the business efforts and new business development in North America.

"I am excited that Andy has joined the Carl Zeiss team," says Greg Lee, president and CEO of Carl Zeiss IMT. "He brings more than 20 years of distribution and technology leadership experience to Carl Zeiss and will help us continue to grow our already strong presence in North America. His vast experience as a sales executive in B2B is another stronghold for Carl Zeiss in addition to his team-oriented approach and competitive drive."

Sisler was previously vice president of sales and marketing for CRST Van Expedited, and he held various leadership positions at Bandag, Inc., including vice president of sales and support in addition to president of Bandag, Canada Ltd.

"I am very proud to be joining the Carl Zeiss team and being part of a successful, global company that is known for its long history of developing leading edge technologies and products," Sisler says. "I am very enthusiastic about the products and look forward to contributing to the success of Carl Zeiss."

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## SERVICE



## HEAT TREATING

## GEAR MANUFACTURING



## HELP WANTED



# Building a Better Mousetrap

## Mouse in the house? Forest City Gear has the answer with the *Better Forest City Gear Mousetrap*.

At its location in Roscoe, IL, the Forest City Gear facility is surrounded by wildlife splendor. Fruit trees, nature walks and the occasional cute and furry animal sighting create an unlikely landscape for a manufacturing site. Of course, cavorting with the cute and furry does have its drawbacks.

Prior to the company's adoption of lean and 5S initiatives, Forest City Gear employees would find the occasional renegade rodent scurrying across the manufacturing floor.

"Desiring the need to rid ourselves of the wee beasties, my set-up guys utilized some leftover gears to create the *Better Forest City Gear Mousetrap*," says Fred Young, CEO.

Set-up "technicians" Kent Blatchford and John Schwable, along with Gear Lab "sleuth" and mousing "expert" Amy Chiodini, carefully engineered the mousetrap in the hopes of ridding the facility of any uninvited guests.

After months of rigorous testing and research, the mousetrap was put to work on the floor at Forest City Gear. In a strange turn of events, the *Better Forest City Gear Mousetrap* (patent pending) recently lured a suspicious looking rodent that appeared to be assembled from other gearing type products (pictured right).

This either proves the theory that gears truly are an intrinsic part of our everyday lives or that certain people over at Forest City have too much time on their hands!

Regardless, the Addendum staff is not here to judge.

If a mouse is not caught in the deathly grip of the *Better Forest City Gear Mousetrap*, Young and his engineering team have other options for the furry trespassers.

"We bait the trap with peanut butter so if it misses, they die of salmonella."

Are you currently cooking up your own personal gear gadgets? Briefly discuss your latest invention with us in an e-mail and send it to *addendum@geartechnology.com*. We'll post some of your technological advancements in a future issue.

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