GEAR TECHNOLOGY

MARCH/APRIL 2004
The Journal of Gear Manufacturing
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HEAT TRATING

- Heat Treating News
- Low Pressure Carburizing/High Pressure Gas Quenching
- Influence of Materials and Geometry
- NEW! Heat Treating Classifieds

ALSO IN THIS ISSUE

- Precise, Uniform End Chamfering
- New ANSI/AGMA Accuracy Standard

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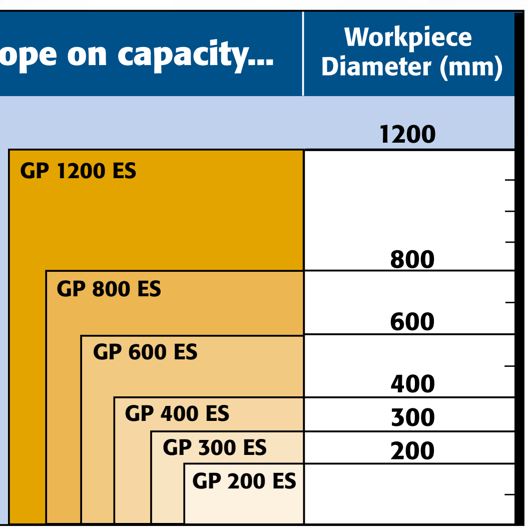

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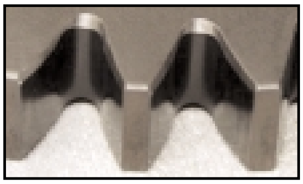
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Hope Springs Eternal

As I write this editorial, much of America seems frozen solid. It snowed again here in Chicago yesterday, and last night the wind chill was –30ºF (–34ºC). It's been cold like this for more than a week, and the forecasters are predicting more of the same. After a while, such a deep freeze can be depressing.

Except I know that Spring is coming.

For several years now, the American economy—in fact, much of the whole world—has also been in a deep freeze, and that, too, can be depressing.

Except I know that Spring is coming.

Signs of an economic thaw have been developing for some time. According the the U.S. Bureau of Economic Analysis, U.S. real gross domestic product has increased for nine consecutive quarters. GDP growth in the fourth quarter of 2003 was at an annualized rate of 4.0%.

Unemployment, although still fairly high at 5.7%, is at its lowest level since October 2002, and it declined in each of the last three months of 2003.

Even manufacturing seems to be gaining momentum. The Purchasing Managers' Index (PMI) released by the Institute for Supply Management has been at 50 or above every month since May 2003. A reading above 50 generally means that the manufacturing economy is expanding. In January, the index was at 63.6, its highest level in more than 20 years.

"Manufacturing is in a definite recovery with six months of month-over-month growth at this point," said Norbert J. Ore, chairman of the Manufacturing Business Survey Committee, in the institute's January 2004 *Report on Business*.

Other manufacturing indicators are also on the rise, such as the quarterly Business Conditions Index (BCI), prepared by the Tooling & Manufacturing Association, a non-profit organization whose members include 1,500 precision manufacturers and their suppliers in the Chicago area. The January 2004 report put the BCI at 38, placing business conditions between "Fair" (25) and "Good" (50). Although 38 is still considered weak based on past ratings, the index hasn't registered this high since the first quarter of 2001. It is also a vast improvement over the third quarter's mark of 28.

With all of these positive trends, it's easy to get excited about where we're headed. But it's also important to note that most of the statistics available are broad aggregates, taking into account many industries that are unrelated to gear manufacturing.

Some of you may be wondering when all this increased activity is going to show up as orders and cash flow in your own company. I realize that many of you may still be struggling, and that my telling you that things are heating up is a little like consoling a man in the street with no jacket when you tell him that instead of 30 below, tomorrow's temperature is only going to be 20 below.

But it *is* getting better. The more gear manufacturers I talk to, the more I hear that they are getting busier. A few I know are doing quite well. Cutting tool people also tell me they are seeing increases in their business, which means more teeth are being cut.

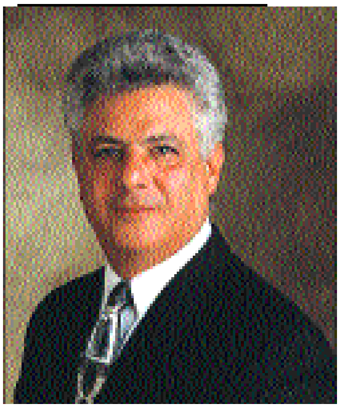
We'll know things have turned around definitively when the machine tool market picks up. That will signal that manufacturing companies are investing again. So far, machine tool sales are spotty, at best, and well below its levels from the mid- to late 1990s.

Through November 2003, machine tool consumption was down 8% versus the same period in 2002, according to the Machine Tool Consumption Report, compiled by AMT—The Association for Manufacturing Technology and the American Machine Tool Distributors Association (AMTDA). However, the November numbers themselves are up significantly compared to October 2003.

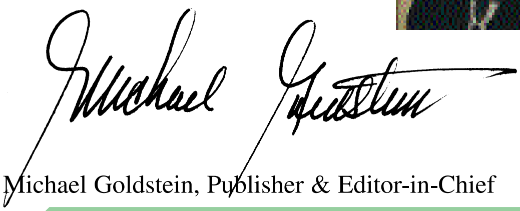
One economic variable helping American manufacturers right now is the weakness of the U.S. dollar. As the dollar weakens, goods from American manufacturers are becoming more affordable overseas than they've been in a long time, making American-made products more competitive than we previously thought.

But a weak dollar cuts both ways. Many of the suppliers to the gear industry—including machine tool and cutting tool manufacturers—are outside the United States. While U.S. exported goods are getting cheaper, many imported goods will become more expensive in the near future. Right now, the machine tool importers are pre-buying machinery and hedging currencies to keep price increases to a minimum, but they can only keep this up for so long. Eventually, their sales prices have to go up, too. (Thinking about buying a machine tool? Now might be the time!)

It may seem like your business is operating in a solid block of ice right now, but take heart, because Spring is coming. We're all anxious for business to pick up, but sometimes Mother Nature—and the economy—have a way of taking their own sweet time. Just remember that in the history of the world, there hasn't been a winter yet—nor an economic downturn—that hasn't turned itself around.



Yeah, it's been cold for a long time, but today, finally, the sun is shining. Outside my window, I can see drips from ice melting off the eaves. Although I can't yet see or smell the flowers, I know the bulbs are down there, getting ready to sprout.



Michael Goldstein, Publisher & Editor-in-Chief

P.S.—Want more info?
The following websites might prove useful:

The Institute for Supply Management
www.ISM.ws

The U.S. Bureau of Economic Analysis
www.bea.gov

The White House Economic Statistics Briefing Room
www.whitehouse.gov/fsbr/esbr.html

The Tooling and Manufacturing Association
www.tmanet.com

The American Machine Tool Distributors Association
www.amtda.org

AMT—The Association for Manufacturing Technology
www.mfgtech.org

TECHNICAL CALENDAR

March 9—Symposium on Advanced Surface Engineering for Gears. Crowne Plaza at Detroit Metro Airport, Romulus, MI. Attendees will learn about new material processes for gears, including heat treating, coating and superfinishing, and will discuss needs in automotive, aerospace and heavy equipment industries. $335 for ASM/GRI/AGMA members, $355 for non-members. For more information, contact ASM by telephone at (800) 336-5152 or on the Internet at *www.asminternational.org*.

March 16—Heat Treating & Hardening of Gears. Holiday Inn City Centre, Chicago, IL. Sponsored by the Society of Manufacturing Engineers, topics include specific microstructures and mechanical results, performance successes, quality control methodologies, and guidelines for preferred procedure. $495 for SME members, $695 for non-members. For more information, contact the SME by telephone at (313) 425-3098 or on the Internet at *www.sme.org*.

March 16–18—Reducing Costs Through Traditional and Alternative Deburring & Surface Finishing Methods. Holiday Inn City Centre, Chicago, IL. Anyone involved in component finishing is encouraged to listen to expert presentations on various buffing, brushing, and belting processes to deburr, generate radius and improve microfinish on edges and surfaces for functional requirements. $845 for SME members, $945 for non-members. For more information, contact the SME by telephone at (313) 271-1500 ext. 3109 or by e-mail at *lwalsh@sme.org*.

March 17–18—Basic Gear Design and Manufacturing and Tabletop Exhibits: Everything You Always Wanted to Know About Gears But Were Afraid to Ask. Holiday Inn City Centre, Chicago, IL. A review of the fundamentals as well as basic gear design concepts. $795 for SME members, $995 for non-members. For more information, contact the SME by telephone at (313) 425-3098 or on the Internet at *www.sme.org*.

March 17–19—Fundamentals of Gear Design. School of Continuing Education. University of Wisconsin-Milwaukee. Recently updated and expanded to cover history, basic gear tooth nomenclature, types of gears, gear arrangements, theory of gear tooth action and failure modes and prevention. All attendees should have knowledge of geometry, trigonometry and elementary algebra. $1,095. For more information, contact the university by telephone at (414) 227-3121 or by e-mail at *mvedula@uwm.edu*.

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Gears of Gold

Gear buyers don't usually ask about karats, but the team at SKF's Industrial Transmission Division thought a new approach would add luster to their concept gearbox.

The 18k Golden Gearbox from SKF is a conceptual project designed to demonstrate the company's competence in the industrial transmission market. SKF is not actually in the gearbox market, but the company created a prototype that's a 250 mm size gearbox with the power of a 280 mm gearbox and a service life of more than 50,000 hours.

This gearbox is just a showpiece, but the bearings, oil seals, engineering and monitoring systems are for sale. Sandro Chervatin, an engineer at SKF's Industrial Transmission Segment, explains the connection between the 18k and the marketing of its components and services: "Compactness is often a target for standard catalogue gearboxes. It leads to decreased manufacturing costs, which is an advantage from the viewpoint of the gearbox manufacturer. It also allows a higher power output in a smaller space," he says.

To calculate the power rating, a stressing load cycle was created with start-ups every 60 seconds and a life requirement of 50 hours. The resulting equivalent power rating is approximately 70 hp with a service factor of about two due to the stressing conditions. Therefore, the gearbox's official power rating stands at 150 hp.

The extra long life span is due to several components of the interior design, including the new nitrillic compound used in the lubricant, which was specially created for the 18k.

The gearbox is typical of one that might be used in steel mills or cranes or in the pulp and paper industries. The 18k weighs 15–20 percent less than comparable gearboxes of the same size with 12–25 percent less volume, according to Chervatin. The gearbox is also engineered for zero unplanned downtime during its service life because of its monitoring system.

All of the internal gears have been completely re-engineered. The Centro Ricerche FIAT, a partner in the gear optimization process located in Turina, Italy, applied an automotive approach to the gear design starting from the SKF inputs on actual shaft deflections.

A gleaming gearbox from SKF, Exxon and Fiat.

***Welcome to* Revolutions, *the column that brings you the latest, most up-to-date and easy-to-read information about the people and technology of the gear industry.* Revolutions *welcomes your submissions. Please send them to* Gear Technology, *P.O. Box 1426, Elk Grove Village, IL 60009, fax (847) 437-6618 or send an e-mail message to* hazelton@geartechnology.com.**

The redesigning extends even into the oil, which has been reformulated to match the gearbox requirements.

SKF worked in cooperation with Exxon Mobil to develop the latest mix of the oil. The joint effort set the criteria for an optimized oil selection that considered all the possible side effects for lubricating conditions.

With its mechatronic sensors, this product can provide a complete overview of the gearbox running system every hour of every day. Six online performance sensors do this by reporting constantly on speed, acceleration, torque, axial movement, temperature, humidity and lubrication conditions.

SKF was able to use in-house expertise in creating the 18k. The computer calculation system BEAST and Orpheus, the company's simulation system, both were instrumental in projecting the gearbox's capabilities.

The design includes nine of the company's premier bearings, including four Explorer spherical roller bearings, three Explorer cylindrical roller bearings, and two Explorer angular contact ball bearings. Other components include new standard roller shaft seals, five accelerometers, two position sensors, a temperature sensor, a torque sensor and a speed sensor.

The exterior is an SKF original as well. Chervatin explains, though, that it's just paint, not actual gold: "SKF is a profitable company today, but we still don't think of using real gold to build products."

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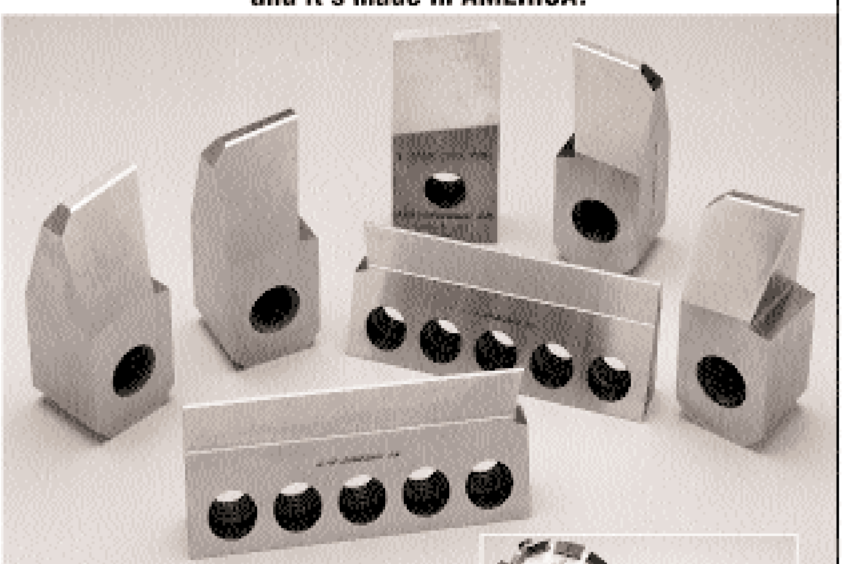

Process Equipment's Virtual ND430

In early December, Brian Slone of Process Equipment Co. loaded a 3,500-pound gear inspection machine into his car for an out-of-state sales trip. The machine didn't weigh down his trunk, though; his tires didn't scrape the tops of his wheel wells.

Slone didn't even put the machine in his trunk; he didn't need that much space. He just tossed it onto his passenger seat.

All this easy loading and storage was possible because of virtuality.

On Slone's passenger seat was his laptop computer. At the potential customer's plant, Slone would use his laptop to connect to the Internet for viewing access to an ND430 Next Dimension® gear measurement system, set up in Process Equipment's plant in Tipp City, Ohio.

With connection and access, Slone would be ready for the gear inspection machine to be put through its paces for the customer in a virtual demo.

"It's like taking a 3,500-pound machine in the trunk of your car," says Slone, business unit manager for Process Equipment's metrology systems division, which includes gear inspection machines.

The virtual demo is Process Equipment's new means for promoting the ND430 system.

With one of the customer's personal

Through the Internet, Process Equipment Co. can provide a virtual demo to a potential customer in another state of an ND430 gear measurement system in Ohio. And the possible reach of virtual demos? "Anywhere in the world," says Process Equipment's Brian Slone.

computers, a salesman goes to his division's website and uses a password-protected system to connect to a live Web camera in the division's metrology lab. He also boots up the ND430 gear application software on his own laptop.

The salesman then pulls up ND430 command screens on his laptop so the customer can see how data is entered and inspection routines are run. With his own computer, the customer can also see the inspection machine run the routines.

The salesman isn't actually operating the gear inspection machine, though. His command screens are exactly like the machine's, but they're stand-ins. While he enters data and runs routines, a lab technician in Tipp City mirrors the salesman, entering the same data, running the same routines on the screens that actually control the ND430.

"He's a virtual operator," Slone says of the salesman.

The demo allows the customer to see setup and inspection of his own gears or Process Equipment's sample gears. For example, he can see an inspection probe's calibration procedure, can see the steps and motions the machine goes through. And he can see the ND430 inspect index, profile and helix (lead).

A live camera lets customers see what the inspection probe is doing better than a static photo does.

"It just gives them a better understanding of how our system operates," Slone says. "Seeing the machine in motion answers questions that are difficult to answer over the phone or with a brochure."

If Process Equipment is measuring the customer's gear, the lab technician can e-mail the inspection results to the customer during the demo. If Process Equipment is measuring its own gear, then the salesman can pull up previously generated results on his laptop to show to the customer and can tell the customer what steps to take to analyze the data.

Besides demonstration, Process Equipment can also place tooling right in front of the camera, so the remote customer can see different probe configurations.

But the customer needs to have a fast Internet connection, like a T1 line. Slone says a slow connection creates a problem: "The picture can be a little choppy."

Process Equipment started offering the demo in the summer of '03 and featured it in the fall at Gear Expo. The company has given several virtual demos, mostly to potential customers in the United States, but also to foreign customers. Process Equipment uses virtual demos only for the ND430.

With gear manufacturers scattered around the world, the virtual demo may someday establish itself alongside traditional means of demonstration: the trade show and the visit to the manufacturer's plant.

In line with that idea, Process Equipment still encourages potential ND430 customers to visit its plant, but it understands that many potential customers have tightened their travel budgets because of the economic slowdown.

Slone himself describes the virtual demos as "more of a complement" to plant visits than a substitute for them.

Still, he sees the Internet as offering additional possibilities for communicating with customers—"This is just the beginning." ⚙

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Web: ***www.gearinspection.com***

HOT STUFF

HEAT TREATING NEWS

NEWS AND NOTES...Ajax Tocco Magnethermic has invested £2 million in the U.K. market to establish Ajax Tocco International Ltd., with new facilities built in Saltley, Birmingham. The company is also opening a new service center in Le Roeulx, Belgium. **Surface Combustion Inc.** has received an order for a Super Allcase batch integral quench furnace line from National Metal Processing, located in Richmond, KY. **SECO/Warwick** has received an order for a new double-chamber vacuum carburizing furnace from the Randolph Austin Co., which plans to use the furnace for producing high-performance gears in its Manchaca, TX, facility. **ALD Vacuum Technologies** has received an order for a six-chamber ModulTherm vacuum furnace from the Stackpole Automotive Gear Division. The **Hi TecMetal Group** has announced the appointment of Chandni Dighe as strategic business unit manager of the company's Cincinnati-based Hydro-Vac division.

New Rotary Hearth Oven from Grieve

The No. 815 from Grieve is a 500°F electric rotary hearth oven that is designed to preheat gears.

This unit features an aluminized steel interior and exterior and 4" insulated oven walls.

According to the company's press release, the hearth oven is driven by a 1/4 hp motor through a gear reducer with a torque limiting device. The hearth indexes one position each time the loading door is opened or closed.

Two 2000 CFM, 2 hp recirculating blowers provide a vertical downward airflow over the workload. Special safety equipment includes a manual reset excess temperature controller, separate heating element control contactors and powered exhauster and a purge timer.

For more information, contact the Grieve Corp. of Round Lake, IL, by telephone at (847) 546-8225 or at *www.grievecorp.com*.

New Hires at Inductoheat

Steve Fillip was promoted to director of aftermarket sales for Inductoheat Inc.

His new responsibilities include overseeing the aftermarket sales support team, providing customers with spare parts and service and designing, building and repairing coils.

According to the company's press release, Fillip has worked within the Inductotherm group for the past 17 years as materials control manager, director of operations, and vice president of manufacturing.

Kathy Coburn was recently appointed as the new aftermarket sales coordinator.

Her new responsibilities include spare parts sales, customer relations and support of the recently renovated coil department, which includes fabricating new coils, prototype coil work and coil repair.

According to the company's press release, she has worked for the past five years as an engineering coordinator at Inductoheat. The company, located in Madison Heights, MI, is a designer and manufacturer of induction heating equipment.

New Metal Treating Institute President

Harvey Dominy was elected president of the Metal Treating Institute, an international trade association representing the corporate heat treat industry.

According to the association press

HEAT TREATING EVENTS

March 8–11—Furnaces and Atmosphere for Today's Technology. Holiday Inn Express, Meadville, PA. A basic primer on heat treating, equipment application, operation and maintenance along with key topics in continuous and batch systems. $375. Contact SECO/Warwick Corp. by telephone at (814) 332-8437 or on the Internet at *www.secowarwick.com*.

March 9—Symposium on Advanced Surface Engineering for Gears. Crowne Plaza at Detroit Metro Airport, Romulus, MI. Attendees will learn about new gear material processes, including heat treating, coating and superfinishing. $335 for ASM/GRI/AGMA members, $355 for non-members. Contact ASM by telephone at (800) 336-5152 or at *www.asminternational.org*.

March 16 – 18—Abar-U. Ipsen International Facility, Rockford, IL. This beginning or refresher course in the area of heat treating equipment focuses on the fundamentals of pumping systems and pumps as well as step-by-step procedures for vacuum furnace equipment maintenance. $595. Offered bi-monthly, the next session is scheduled for May 11–13. For more information, contact Ipsen International by telephone at (815) 332-4941 or on the Internet at *www.abaripsen.com*.

April 21–25—Best Practices for a Heat Treat Business. Renaissance Wailea Beach Resort, Maui, Hawaii. Itinerary includes a keynote breakfast, general sessions and the MTI Iron Ore Golf Classic. Member registration fee is $575. For more information, contact Metal Treating Institute at *www.metaltreat.com*

release, Dominy served at international and local levels in all elected offices of the institute. He has worked in the heat treat industry since age 14.

The association also elected several members to its board of trustees. Roger Jones of Solar Atmospheres Inc. was elected international vice president/president-elect. Norman Graves of National Metal Processing was re-elected as treasurer.

Paulo Now Ford Preferred Supplier

The St. Louis, MO, facility of Paulo Products Co. was awarded preferred supplier status, the highest rating that can be achieved by a tier supplier, by Ford Motor Co.

According to the company's press release, the award recognizes Paulo's sustained level of heat treating and customer service excellence. Paulo's Murfreesboro, TN, plant also has received the Ford status.

Paulo Products provides engineered solutions in heat treating, brazing and metal finishing. Paulo St. Louis specializes in production heat treating of batch and continuous furnaces, vacuum heat treating and black oxide finishing.

Precision Batch Oven from Pyromaitre

The Pyro Try Out oven from Pyromaitre is a batch version of its in-line, continuous, high-output P106HE.

The furnace has been updated with

Gear Hardening Line from Inductoheat

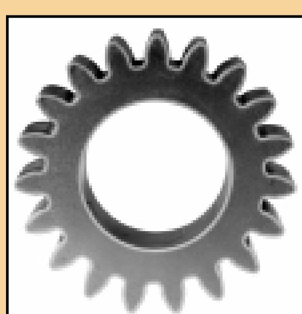
Three distinct technologies for heat treating gears are available from Inductoheat. The single frequency, variable frequency and simulataneous dual frequency lines are all suitable for use in gearing applications.

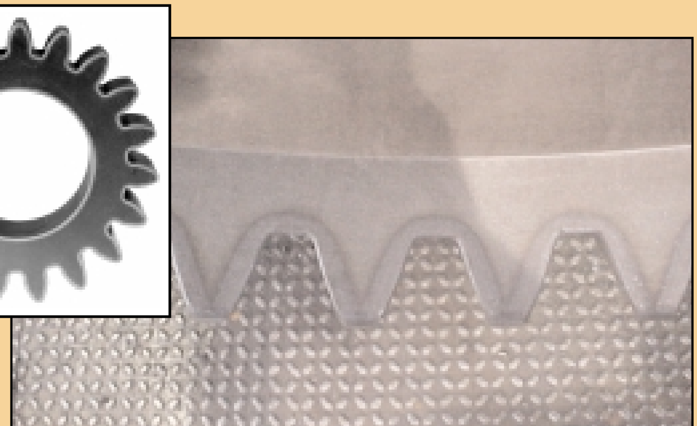
According to the company's press release, single frequency gear hardening for high volume dedicated applications allows for manual tuning while the variable frequency operates with push-button tuning. This technology matches frequency to a diametrical pitch.

The simultaneous dual frequency induction gear hardening process can be integrated into new or existing manufacturing lines as a work cell.

By mixing the medium and high frequencies combined with a high power output, a shorter heating cycle can be achieved. The microstructure of a hardened area can be improved with minimal effect on material core properties. This line can eliminate the need for final machining since diametrical specifications are unaffected after hardening.

For more information, contact Inductoheat of Madison Heights, MI, by telephone at (248) 585-9393 or on the Internet at *www.inductoheat.com.*





The Pyro Try Out oven from Pyromaitre is used for stress relieving spiral bevel ring gears.

simulation software that can calculate operating cost. The software automatically selects stress relief temperature as a function of cycle time according to the particular alloy, and prevents use of a temperature so high that it could negatively impact hardness.

According to the company's pres release, the software generates two temperature curves, called core and surface, that are based on alloy thermal conductivity, wire diameter, cycle time and temperature.

The oven is designed for applications such as stress relieving ring gears, valve springs, half shafts and sickle blades.

For more information, contact Pyromaitre of St. Nicholas, Quebec, by telephone at (418) 831-2576 or on the Internet at *www.pyromaitre.com*.

New High Temp Pyrometer from Ircon

The Modline 5 standalone temperature thermometer was designed for temperature measurement in industries like induction heating, steel and gas.

Among its features are a total system health check diagnostic mechanism, a match function that allows users to input process temperature and automatically adjust emissivity, and a dirty window detector to check for build-up.

According to the company's press release, temperatures can range from 482°F (250°C) to 5,432°F (3,000°C). Operating wavelengths vary from 1.5 to 1.6 and 0.85 to 1.1. For the two-color version, wavelengths are 1.05.

For more information, contact Ircon of Niles, IL, by telephone at (847) 967-5151 or on the Internet at *www.ircon.com*

Bodycote Earns NADCAP Registration

Bodycote Thermal Processing announced the registration of its Fort Worth, TX, facility to NADCAP.

According to the company's press release, this increases the number of Bodycote plants with NADCAP accrediting to 18. Most recently, Bodycote's Wooford, U.K., plant became the first subcontract heat treatment facility in the country to gain NADCAP approval.

This registration is in addition to the Fort Worth plant's existing ISO 9002:2000 accreditation.

Bodycote Fort Worth specializes in various conventional brazing, batch atmosphere, deep pit, vacuum, aluminum, titanium and copper treatments.

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Hobbing Precise, Uniform End Chamfers

Brian W. Cluff

Management Summary

Machining a measurably precise and consistent uniform chamfer on the end faces of cylindrical gear teeth has never been a satisfactory or cost effective process. For manufacturers of aerospace gears, with critical functional and blueprint specifications, width and uniformity of the chamfered end faces has been a cost driver.

A recently developed chamfer hob design (patent pending) has produced a practical hob cutter that can chamfer gear teeth end faces uniformly to a measurably consistent, precise tolerance.

Its developers say the tool is cost effective because the process can be performed sequentially within a normal CNC hobbing machine cutting cycle. It does not require a special machine with its associated capital and maintenance costs for a subsequent operation.

The seemingly simple process of placing a uniform chamfer on the face ends of spur and helical gears, at least for the aerospace industry, has never been a satisfactory or cost effective process. High precision aerospace gears requiring uniform end chamfers have a manufacturing rejection rate, for some producers, as high as 30%. The more critical the function of the gear, the more stringent the requirement for a measurable, uniform chamfer.

Despite the numerous advances in gear production technology, the methods of gear tooth chamfering have remained relatively unchanged. Hand chamfering is still prevalent in gear shops around the world. Grinding, machining, filing, wire brushing or buffing the end faces of each gear tooth constitute the conventional technologies to produce some kind of chamfer.

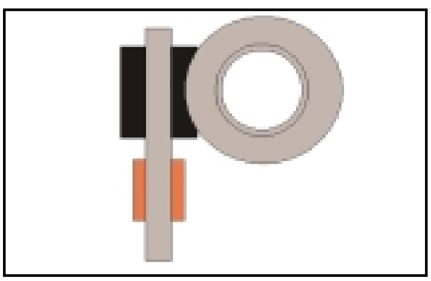

Figure 1—Teeth are hobbed into a gear in a normal cycle.

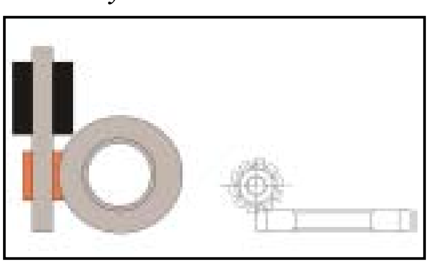

Figure 2—Chamfer hob shifts into cutting position. Hob slide moves to position hob above workpiece and feeds radially to depth.

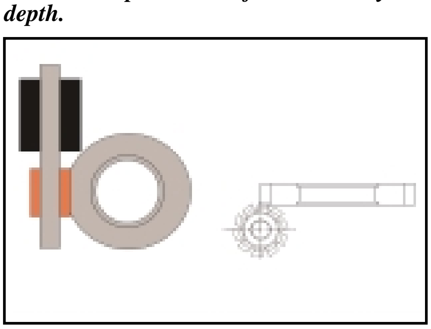

Figure 3—Hob slide retracts hob from depth at top position, moves to bottom face of part, positions hob, and radially feeds to depth, completing the chamfering cycle.

Many gear manufacturers use conventional automated deburring and chamfering machines from companies like Redin Corp., Mutschler & Sons Inc., James Engineering, Gratomat-Rausch GmbH, Chamfermatic Inc., Hurth (a unit of Gleason Corp.), Samputensili S.p.A. and others. Some aerospace gear producers use expensive CNC multi-axis milling machines to produce chamfers on their high precision gears when the drawing specification dictates a precise, measurable, uniform chamfer.

When gears are hobbed or shaped, the end faces of the gear are very sharp. These sharp edges require, in most processes, an edge break or slight chamfer to remove any burrs. Conventional chamfer production machines adequately break the edges and remove the burrs, but they cannot produce a repeatable, uniform, measurably accurate chamfer from the outside diameter (tip), down the flank of the gear tooth into the root radius and up the adjacent tooth flank. CNC machining centers can achieve this type of precise chamfer, but not without individual programming of each gear geometry on an expensive capital asset.

In precision aerospace gearing, chamfer non-uniformity, steps or divots can result in stress risers. These stress risers can lead to cracks and gear failure. Consequently, width and uniformity of the chamfered area is critical.

A recently developed, patent-pending design has produced a hob cutter that can chamfer gear teeth uniformly. Although chamfering hobs are used in the industry for edge break on one flank of a gear tooth, no designs have been previously available to create a precise, measurable, uniform chamfer from tip to trochoid.

The new hob's chamfering technique is relatively simple. It is used in conjunction with standard tooth hobbing and is performed on the same CNC hobbing machine sequentially within the hobbing operation. In the work cycle, the workholding fixturing necessarily is designed to accommodate the clearances required by the chamfering hob.

The technique is illustrated in Figures 1–3.

Brian W. Cluff

is vice president of sales & application engineering for Star-SU LLC, located in Hoffman Estates, Illinois, U.S.A. He's the author/editor of seven editions of Gear Process Dynamics *and has written more than 30 technical papers on gear processing. For many years, he was also a speaker at AGMA, ASME and SME gear manufacturing conferences.*

For gears cut with a two-cut hobbing cycle, it is possible after the first hobbing cut to shift the chamfer hob into position and hob a slightly oversized chamfer on one end of the workpiece. After completing the finish cut with the tooth cutting hob, the chamfer hob chamfers the other end of the workpiece with a correctly sized chamfer.

The application of the chamfer hob often involves an engineering interference study to be certain that both the cutting hob and the chamfer hob can fit on the same hob arbor without workpiece interference. In addition, because the chamfer hob requires a different radial position inside the root diameter of the workpiece, the workholding fixturing has to be designed to allow clearances not normally associated with standard gear tooth axial hobbing.

The benefits of the process are numerous, such as cost per part (see Table 1). Also, since it is incorporated into the tooth hobbing operation of the workpiece, there

Figure 4—View of gear teeth with uniform chamfer as produced by chamfer hob.

Figure 5—Chamfer hob shown with workpiece.

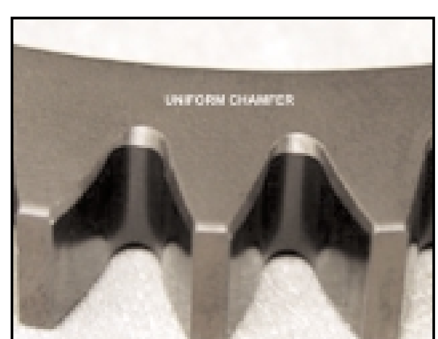

Figure 6—Uniform chamfer as produced by chamfer hob.

Table 1—Price-per-part comparison of conventional chamfering methods and hob chamfering for obtaining a uniform chamfer of 0.015"–0.030" on a gear of 10 DP, 7.5" diameter.	
Chamfer Process for Aerospace Gear	**Typical Price-per-Part Total Costs**
CNC Milling	$70.00
Hand Grinding	$65.00
Deburring Machines	$12.25
Hob Chamfering	$2.50

are no additional setup costs for a separate operation. The chamfer is uniform and is machined to precise tolerances as specified by the blueprint. Typically, the operation takes less than one minute per side. It is certainly less time consuming than hand grinding or CNC milling. Dependent on pitch and number of teeth, some chamfering hob designs have a range of teeth they can chamfer. For more precision applications, though, a dedicated chamfer hob is needed.

The hob chamfering technique is also suitable for tooth rounding, bullet nosing and one-side chamfering, which is used for Bendix starter gears.

As the requirements for higher quality and lower cost continue to push manufacturing, the hob chamfering technique offers higher quality at lower cost, increasing profitability for gear manufacturers. ✪

This chamfering hob design is available exclusively from Star-SU LLC. For more information, contact Star-SU via:
Phone: (847) 649-1450
Fax: (847) 649-0112
E-mail: *sales@star-su.com*
Web: *www.star-su.com*

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New ANSI/AGMA Accuracy Standards for Gears

Edward Lawson

Management Summary

AGMA has started to replace its 2000-A88 standard for gear accuracy with a new series of documents based largely on ISO standards. The first of the replacement AGMA standards have been published with the remainder coming in about a year. After serving as a default accuracy specification for U.S. commerce in gear products for several decades, the material in AGMA 2000-A88 is now considered outdated and in need of comprehensive revision.

Important changes include reversal of the accuracy grade system (larger grade numbers now mean larger tolerances), introduction of tolerances based on ISO 1328, new line-fit methods of analyzing helix (lead) and profile test traces, and the inclusion of single-flank composite testing as an optional alternative method of qualifying gears. Enhanced descriptions of required measurement methods are provided to reduce ambiguity and the associated potential for controversy.

Underlying these changes is the important transition from reliance upon local standards, such as AGMA, DIN, JIS, BGA, etc., to international adoption of ISO standards, which are now positioned to become the default specifications for global commerce in gear products.

Time for a Change

For many years, the U.S. system of gear accuracy tolerances has been provided by AGMA 2000-A88, *Gear Classification and Inspection Handbook*. This document has been commonly used for gear accuracy specifications in contractual agreements for vendor-supplied gears. Also, it has often been used as the basis of internal company gear tolerance systems.

The material within AGMA 2000-A88 has been carried forward without substantial change for nearly 40 years. It is widely considered to be outdated and in need of comprehensive revision, particularly with respect to the following issues:

1.) Lead tolerances in 2000-A88 are substantially larger than those found in other national gear accuracy standards.

2.) The standard lacks tolerances for cumulative pitch (a.k.a. index) deviations.

3.) The K-shaped tolerance band method provided in 2000-A88 for control of involute profile and helix (a.k.a. lead or tooth alignment) deviations is less desirable than line-fit tolerance methods found in other national gear accuracy standards.

Recognizing that the standard was overdue for revision, the AGMA Inspection Handbook Committee developed a new suite of replacement documents. The first three of these new standards was published about a year ago. After the remaining documents are published in about a year, AGMA 2000-A88 will be withdrawn. Consequently, it is very important to understand the coming changes.

The ISO Connection

In recent years, AGMA technical standards development has increasingly focused upon achieving harmony with ISO gear standards. The AGMA Technical Division Executive Committee (TDEC) now requires technical committees to consider adoption of relevant ISO standards, wherever possible, instead of writing new AGMA documents. Also, it is required that all new standards produced by AGMA committees be in SI (metric) units of measure.

These changes are seen by the AGMA as an important element in its increasing emphasis on assuring the competitiveness of the U.S. gear industry in the rapidly evolving world marketplace. With make/buy decisions becoming an increasingly prevalent issue for gear product users, selection of a genuinely international gear accuracy standard is increasingly attractive.

Given the international makeup of ISO standards writing committees, their documents are viewed as inherently global in nature. The importance of ISO gear standards is expected to increase substantially in coming years. An example of the potential power of ISO standards can be seen in the widespread adoption of ISO 9000 standards.

Accordingly, existing ISO gear accuracy standards and technical reports were used as starting templates, along with selected material from current AGMA standards, in the development of the new ANSI/AGMA standards. Also, AGMA hopes that much of the new material in its new accuracy standards will gain acceptance for inclusion in the next-generation ISO standards.

Organization of Material

AGMA 2000-A88 combined all of the material for measuring and tolerancing gears in a single document. The new AGMA accuracy standards segregate the material into four main documents, following the organization of the analogous ISO documents.

Topics are divided according to tangential (single-flank) vs. radial (double-flank) considerations. Additionally, material is presented in either:
1.) a standard limited to definitions, the tolerance system, and required related information; or
2.) an information sheet containing measuring methods and other helpful information (referred to as a technical report in ISO).

The existing ISO and new AGMA gear accuracy documents correlate as shown in Figure 1.

Current Status of New Standards

In late 2002, the new tangential accuracy standard ANSI/AGMA 2015-1-A01, *Accuracy Classification System—Tangential Measurements for Cylindrical Gears*, was published. It provides the tolerance system for profile, helix, pitch (single and cumulative), and single-flank composite deviations.

In early 2003, the associated tangential accuracy information sheet AGMA 915-1-A02, *Inspection Practices—Part 1: Cylindrical Gears—Tangential Measurements,* was published. It provides the required measurement methods and supplementary guidance.

In mid-2003, an additional document, Supplemental Tables for AGMA 2015/915-1-A02, *Accuracy Classification System—Tangential Measurement Tolerance Tables for Cylindrical Gears,* was published. Since 2015-1 tolerances are provided in the form of equations, many users were asking for a set of tables, which are more convenient for quick reference. However, it must be noted that most tolerance equations are non-linear, so interpolation between table values will not produce accurate tolerance values.

A tolerance calculation program for ANSI/AGMA 2015-1-A01 has also been produced that provides a quick, easy way to accurately determine tolerances for a given gear. It is available free in the members-only section of the AGMA website.

The Inspection and Handbook Committee is currently developing a new standard, ANSI/AGMA 2015-2-AXX, and associated information sheet, AGMA 915-2-AXX, pertaining to radial (primarily double-flank composite) accuracy specifications.

Once the radial accuracy documents are published, the AGMA intends to withdraw AGMA

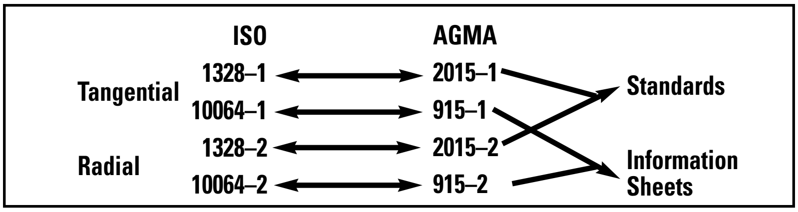

Figure 1—Correlation of existing ISO and new AGMA gear accuracy documents.

2000-A88 as an active standard. It will, however, continue to be available for sale for the foreseeable future.

The New Accuracy Grade System

AGMA 2000-A88 includes 13 quality classes numbered Q3 through Q15, in order of increasing precision. ANSI/AGMA 2015-1-A01 provides 10 accuracy grades numbered A2 through A11, in order of *decreasing* precision. In other words, the smaller the accuracy grade number in the new standard, the smaller the tolerances. While this is the opposite of the structure of 2000-A88, it follows the convention of all other major gear accuracy standards.

This difference inevitably raises questions as to how one can compare tolerance grades between old and new AGMA standards. It is never really valid to compare accuracy grades from one standard to another. The old "apples & oranges" analogy inevitably applies, owing primarily to the differences in test analysis methods and tolerance curves. This having been said, it can be recognized that a rough approximation can often be made of the relationship between accuracy grades provided by different standards.

For comparison of the old AGMA (2000-A88) to the new ANSI/AGMA (2015-1-A01, etc.) standards, use of the "magic number" 17 is suggested. By this method, the tolerance grade of a given standard can be subtracted from 17 to produce a roughly corresponding accuracy grade for the other standard. For example, an AGMA 2000-A88 class Q10 could be considered roughly equivalent to a grade A7 in ANSI/AGMA 2015-1-A01.

Continuing a concept developed for the ANSI/AGMA 2009-A99 bevel gear accuracy standard, required measuring methods in ANSI/AGMA 2015-1-A01 are determined by the specified accuracy grade. This involves first segregating accuracy grades into three groups, generally termed low (A10–A11), medium (A6–A9), and high (A2–A5) accuracy. Each group then has a list of required accuracy parameters to be met for qualification of the gear.

As accuracy increases, the list of required parameters grows. This is not unlike AGMA 2000-A88, which for lower classes required only

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is director of metrology at M&M Precision Systems Corp. of Dayton, Ohio. He's the chairman of the AGMA Inspection and Handbook Committee and convener of ISO TC 60, WG 2 for gear accuracy. He's also chairman of the AGMA Technical Division Executive Committee (TDEC) and a member of the AGMA board of directors.

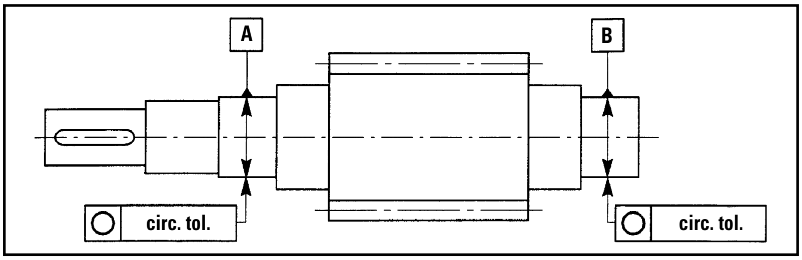

Figure 2—Guidance for proper specification of gear datum axis is provided in AGMA 915-3-A99.

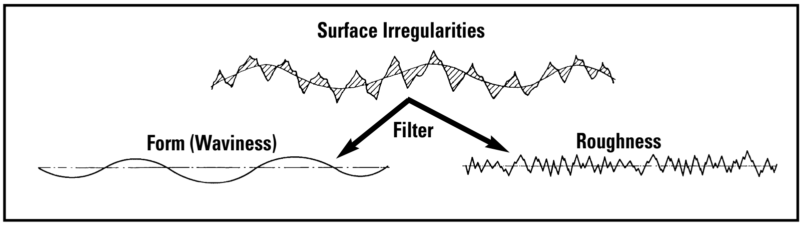

Figure 3—Low-pass filtering is required to segregate and remove high-frequency surface finish effects.

pitch and runout.

Included in the low accuracy group are only single pitch, total cumulative pitch, and tooth thickness parameters. The medium accuracy group adds total helix and total profile parameters. The high accuracy group additionally requires slope and form parameters for helix and profile. Functional/composite methods are offered as optional alternatives.

The Tolerance Structure

The tolerance structure of the new ANSI/AGMA standards is very similar to those provided in the ISO standards.

One point of significant deviation occurs in the case of single pitch and total cumulative pitch tolerances applied to gears at or below 400 mm in diameter. In these cases, the tolerance curves have been straightened to avoid the excessive slope of the ISO tolerance curve at smaller diameters.

While the tolerances in ANSI/AGMA 2015-1-A01 are based on ISO 1328 formulas, they are implemented in a significantly different manner. ISO tolerance formulas require entry of gear parameters (including module, diameter, and face width) as the geometric mean of the associated table range limits rather than as the actual values. The result is a tolerance identical to that listed in the tolerance table. A proper plot of ISO tolerance curves therefore looks like a series of stair steps rather than a continuous curve.

ANSI/AGMA 2015-1-A01 specifies entry of *actual* gear parameter values, thereby producing a smooth tolerance curve. This is the same method specified in AGMA 2000-A88.

Another way to look at this is to say that, according to ISO the standard tolerances are provided in tables with formulas offered to permit their calculation (by tortured means), while according to ANSI/AGMA the standard tolerances are provided by formulas with tables offered for convenient approximations.

The stepping factor is the factor by which tolerances increase with each increase in accuracy grade number. The stepping factor for both AGMA 2000-A88 and ANSI/AGMA 2015-1-A01 (and also ISO 1328) is the square root of 2 or approximately 1.4, thereby providing a 40% change in tolerance from grade to grade. So, for example, if a grade A5 tolerance for a given gear was 10 µm, the same gear with a grade A6 specification would have a tolerance 1.4 times larger, or 14 µm.

It is generally agreed that the new ISO-based ANSI/AGMA 2015-1-A01 tolerance system achieves significantly better internal coherence than its predecessor, AGMA 2000-A88. The relatively tighter lead tolerances included in the new system are an important contributor to this improvement. ANSI/AGMA 2015-1-A01 tolerances correlate very well with those found in other major national standards.

As is the case with all major gear accuracy standards except AGMA 2000-A88, ANSI/AGMA 2015-1-A01 includes tolerances on total cumulative pitch.

The new ANSI/AGMA 2015-1-A01 standard is limited as to scope of application. The overall limitations apply as follows:

number of teeth	$5 \le z \le 1{,}000$ or $10{,}000/m_n$ (whichever is less)
pitch diameter	5 mm $\le D \le$ 10,000 mm
normal module	$0.5 \le m_n \le 50$
face width	4 mm $\le b \le$ 1,000 mm
helix angle	$\beta \le 45°$

Additionally, scope-of-application limitations are specified for the individual tolerance parameters.

These scope limits of ANSI/AGMA 2015-1-A01 are generally equivalent to those specified in AGMA 2000-A88. Notable exceptions to this generality include the extension of elemental tolerances to finer pitches and lower accuracy grades and the inclusion of face widths up to one meter.

Profile and Helix Analysis

The AGMA 2000-A88 standard specifies tolerances for profile test results using a particular K-shaped tolerance band. For a gear to be considered acceptable, each profile test trace must fit within this specified tolerance band, which applies to the full active, unmodified portion of the gear tooth.

The K-shaped band applies the full tolerance at the extreme ends but tapers to provide only 50% tolerance at the middle. The same method is applied to tolerances for helix (tooth alignment) deviations.

There are three significant limitations to the band-fit method of tolerancing profile or helix traces.

The first is that any trace that fits in the band is acceptable and any trace that fails to fit in the band is rejected. It is easy to visualize examples of test traces fitting within a K-shaped band that would not be acceptable for use in given applications and vice versa.

The second limitation of band tolerancing is that any band infers a nominal that may not be the desired nominal. Consider the AGMA band, which infers a nominal situated midway between the maximum and minimum limits of the tolerance band (as is the case for all band tolerances of whatever shape). This inferred nominal is convex by 25% of the tolerance due to the K-shape of the band. However, this is clearly in opposition to the intent of the standard, which applies only to unmodified forms.

The third and possibly the most significant limitation of the band method of tolerancing is that it only serves as a go/no go observation of gear quality. Ideally, gear measurement operations serve to provide data for process control as well as sorting accepted from rejected workpieces. Band analysis provides no variable data to consider statistically or by other analytical means.

The new ANSI/AGMA 2015-1-A01 standard uses a fundamentally different analysis method commonly referred to as line-fit analysis. A key characteristic of this method is the specification of a design profile or helix. This permits the gear engineer to unambiguously specify the shape that he considers ideal for the application at hand. In the absence of such a specification, the standard defaults to an unmodified involute or helix.

Three tolerance parameters are specified for profile and helix analysis: total deviation, slope deviation, and form deviation. Total deviation analysis is only required for medium and high accuracy specified gears. Slope and form deviation analysis is also required for high accuracy gears.

Slope deviation represents the tilt deviation of the test trace, exclusive of its form (or shape) deviation. Form deviation represents the shape deviation, exclusive of its slope (or tilt) deviation. Total deviation represents the combined net effects of both the slope and form deviations of the test trace.

In contrast with the AGMA 2000-A88 go/no go method of band-fit analysis, the ANSI/AGMA 2015-1-A01 line-fit methods produce variables that can be applied to observation of process performance.

Slope deviations of profile or helix are given a plus or minus polarity. In the ANSI/AGMA 2015-1-A01 standard, profile slope is considered plus when the trend corresponds with a decrease in pressure angle (increase in base diameter). Helix slope in this standard is considered plus when the helix angle is increased (decrease in lead).

Reduced Ambiguity

It is unfortunately common for gear accuracy standards to inadequately address important metrology issues that can have substantial influence upon measurement test results and associated accept/reject decisions. ANSI/AGMA 2015-1-A01 and AGMA 915-1-A02 have been written to minimize such ambiguities and associated confusion and controversy.

First on this list is the obligation to specify the datum axis of the given gear, without which the nominal geometry of the gear teeth cannot be defined. Commonly, this is based upon bearing surfaces that establish the gear's axis of rotation in assembly. Reference is made to information sheet AGMA 915-3-A99, which provides detailed guidance concerning proper specification of the datum axis (see Fig. 2).

The ANSI/AGMA 2015-1-A01 standard specifies a tolerance diameter, which is the probe contact diameter during helix and pitch testing. It is also required information for proper management of direction of measurement issues.

Profile and helix traces are usually low-pass filtered to remove the effects of surface roughness before presentation and analysis, as shown in Figure 3. It is not common for the filtering method or the filter cutoff (the dividing line between wavelengths that are kept and those that are discarded) to be specified. ANSI/AGMA 2015-1-A01 recommends use of the digital Gaussian filter. Filter cutoffs are specified for both profile and helix test traces.

Minimum density of digital data is required for proper implementation of the specified profile and helix filter cutoffs. ANSI/AGMA 2015-1-A01 also specifies minimum measurement data densities to assure that proper digital filtering can be achieved.

ANSI/AGMA 2015-1-A01 does not specify the direction of measurement probe deflection during testing, but requires that it be known. This

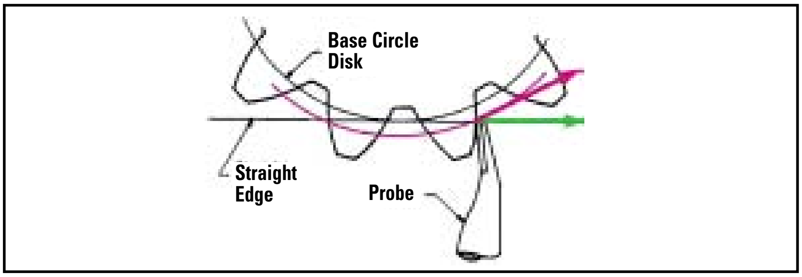

Figure 4—Direction of measurement can affect measurement results and accept/reject decisions.

Master Gear Grades	Required for	Test Gear Grades
Grade 2	→	Grades 4–5
Grade 3	→	Grades 6–7
Grade 4	→	Grades 8 and higher

Figure 5—Recommended master gear accuracy grades for given test gear accuracy grades.

measurement direction is needed for proper application of data corrections that may be required prior to reporting results and comparison to tolerances (see Fig. 4).

ANSI/AGMA 2015-1-A01 does specify a direction of tolerancing for each accuracy parameter. Measurements made or reported in other directions must be adjusted to the specified direction of tolerancing before comparison to tolerances and determination of gear conformance.

Measurement Process Calibration

Calibration is the process of evaluating the limits of validity of data coming from a given measurement process. Gear measurement processes are usually calibrated using master gear artifacts. Without current calibration reports issued by an accredited laboratory stating the measurement uncertainty of the calibration measurement process, master artifacts are of no value for measurement process calibration, measurement uncertainty estimation, or establishment of traceability.

The ANSI/AGMA 2015-1-A01 standard recommends periodic verification of elemental gear measuring instruments, according to standard calibration procedures, such as those provided in ANSI/AGMA 2110-A94 (for involute profile), ANSI/AGMA 2113-A97 (for helix), and ANSI/AGMA 2114-A98 (for pitch and runout). Further, determination of measurement process uncertainty is recommended.

Master Gears

Master gears are required for single- and double-flank composite action testing. They are subject to wear and damage and must be recalibrated periodically. Master gear calibration reports are required by ANSI/AGMA 2015-1-A01 to include statements of measurement conditions and the measurement uncertainty for each parameter reported.

For accuracy tolerance purposes, master gears are simply defined in ANSI/AGMA 2015-1-A01 as those meeting accuracy grade 4 and better. Minimum master gear accuracy grades are recommended for test gear accuracy grades, as shown in Figure 5.

Properly calibrated master gears can provide an attractive reference for calibration of elemental gear measuring instruments, instead of special purpose reference artifact fixtures. When such master gear reference artifacts are very similar to subsequent pieces to be tested by the measurement process, resulting measurement uncertainty may be significantly reduced.

Single-Flank Composite Action Testing

New tolerances for total and tooth-to-tooth single-flank composite deviation along with associated support material are provided in ANSI/AGMA 2015-1-A01. It is listed as an acceptable alternative method for qualification of gear accuracy.

This standard requires removal of the effects of eccentricity before analysis of tooth-to-tooth single-flank composite deviations.

Conclusion

It is important to understand the fundamental changes coming with the new AGMA standards. Given the approaching withdrawal of AGMA 2000-A88, an increasing number of gears will be specified according to the replacement documents.

It is possibly more important to understand the increasing AGMA focus on ISO standards development. It appears that, in coming days, ISO documents will provide the default specifications for global commerce in gear products.

Review of the progressive revisions incorporated into the new AGMA standards should provide valuable insight into important trends in gear accuracy specifications.

Low Pressure Carburizing with High Pressure Gas Quenching

Herwig Altena and Franz Schrank

Low pressure carburizing offers, on account of technological advancements, an alternative to conventional gas carburization of gear parts for the automotive industry. The requirement of reduced grinding operations and costs causes demands for reduced distortion and carburization without surface oxidation, which can only be fulfilled by means of vacuum technology.

A low pressure carburizing (LPC) method is presented that is distinguished by a high mass flow density of carbon at the beginning of the process. Along with a higher carburization temperature, cycle times can be reduced significantly. The incorporation of low pressure carburizing systems in production lines is an attractive proposition, in particular when used in connection with high pressure gas quenching, which produces bright, oil-free surfaces.

With regards to high pressure gas quenching, the most stringent requirements on environmental protection are met. Furthermore the distortion of critical parts may be reduced in many applications.

The principles of the process technology and their applications will be discussed. Furthermore a new continuous LPC system with high pressure gas quenching will be presented. The system allows a throughput capacity of more than 700 kg/hr. gross weight. The design of the quenching chamber was optimized by means of finite element simulation of the gas flow pattern, leading to an enhanced quenching rate and to improved core hardness of heavy gear parts.

Management Summary

High demands for cost-effectiveness and improved product quality can be achieved via a new low pressure carburizing process with high pressure gas quenching. Up to 50% of the heat treatment time can be saved. Furthermore, the distortion of the gear parts could be reduced because of gas quenching, and grinding costs could be saved. This article gives an overview of the principles of the process technology and the required furnace technology. Also, some examples of practical applications are presented.

Introduction

Conventional gas carburization already has a firm place as a thermochemical treatment process; carburization has become virtually indispensable in many industrial sectors, in particular in the car industry. Thanks to further development in the field of technology, gas carburization has reached a stage that guarantees good reproduction of results when appropriate checks and maintenance are carried out. However, this process is bound by certain limits, in particular where environmentally friendly methods and an oxide-free surface are required.

Recent years have seen a remarkable increase of interest shown in carburization using vacuum systems. Low pressure carburization has undergone major developments compared with its initial position around 20 years ago, and it has now achieved industrial maturity. Numerous older papers deal with low pressure carburizing (Refs. 1–4), at a pressure range between 200 and 500 millibars by the use of methane as carburizing gas. Due to a complete change of process parameters and carburizing gas, we are now able to present a reproducible and consistent process with very uniform results.

The advantages of low pressure carburization over gas carburization are not only the creation of a surface entirely free of oxide and the method's environmental friendliness, but also an improvement in deformation behavior achieved by combining carburization with gas quenching, a reduction in batch times by increasing the carburization temperature, lower gas and energy consumption and the prevention of soot to a large extent.

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Carburizing temperature	900–1,050°C
Carburizing pressure	1–30 millibar
Carburizing gas	Propane (acetylene)
Duration of treatment	10 min.–20 hr.
Carburizing depth	0.2–3 mm

Figure 1—Process parameters.

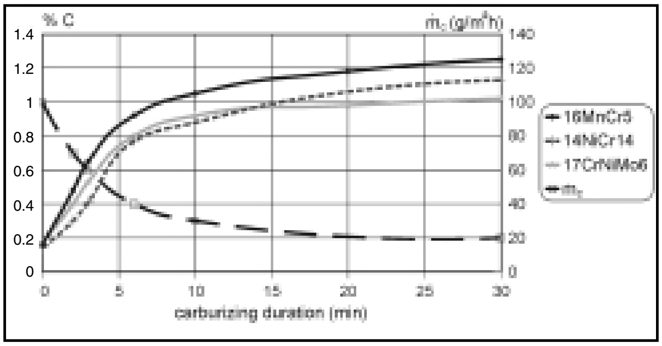

Figure 2—Surface content of carbon vs. carburizing duration.

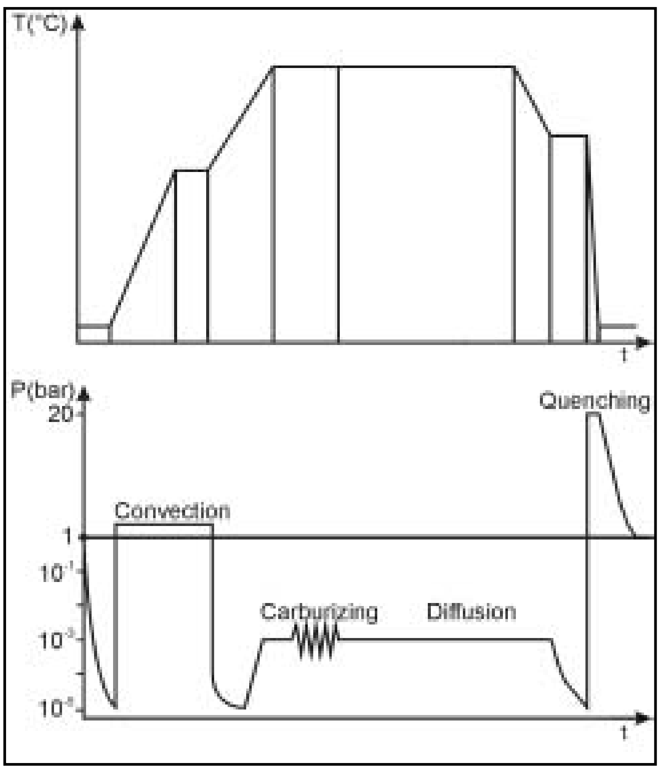

Figure 3—Process flow schematic.

10% coarse grain	18CrNi8	16MnCr5	17CrNiMo6	20MnCr5
900°C	> 8 hr.	> 8 hr.	> 8 hr.	> 8 hr.
940°C	4 hr.	> 8 hr.	> 8 hr.	> 8 hr.
980°C	1 hr.	4 hr.	4–8 hr.	> 8 hr.
1,020°C	5 min.	5 min.	15 min.	15 min.

Figure 4—Grain growth vs. carburizing temperature and duration (after V. Schüler, Ref. 7).

Mass Transfer and Reaction Mechanism

The process parameters for low pressure carburization are summarized in Figure 1. In general, the pressure range used is less than 30 millibars with sequences of pressure changing (gas inlet with intermediate evacuating). These sequences of pressure changes allow a much better uniformity of carburization in drilled holes as well as blind holes, due to the fact that the transfer of fresh reaction gas is much easier.

Propane is used in general as process gas in low pressure carburizing. In contrast to gas carburization, no oxygen-containing reaction gases are used in vacuum systems, and therefore carbon potential control cannot be carried out in low pressure carburizing. The most important parameter in this case is the carbon mass flow density (m_c), which is defined as the quantity of carbon introduced into the material per unit of surface and time. This parameter allows a direct comparison with gas carburization (Ref. 5).

The reaction ratio of the propane thermal decomposition, which proceeds favorably on the hot surface of the charge, has been determined in a single chamber furnace with an average load (surface of the charge, approximately 2.5 m^2) and 3 millibar gas pressure. The results proved a better reaction ratio with rising carburizing temperature and a decreasing amount of propane, which can be explained by the longer stay in the furnace. In total, 40–60% of the theoretically available carbon was deposited (Ref. 6).

In addition to methane, there arise ethylene and acetylene as intermediate products of the decomposition reaction, which are responsible for the carburizing reaction and can be used as process gases as well. The uniformity in carburizing of long blind holes and transitory drilled holes can be improved by using acetylene. Methane at all examined temperatures cracked less than 3% and is not relevant for low pressure carburizing when working in millibar range. To achieve sufficient methane thermal decomposition, the CH_4 partial pressure must be increased to more than 300 millibar. At more than 300 millibar, soot could develop in the LPC system.

To minimize the carburizing time, the process allows a high carbon mass flow of m_c = 100 (–200) g/m^2hr. Therefore, in only a few minutes, a surface carbon content of more than 1% is achievable (see Fig. 2). Also, a dynamic balance between the carbon supply and the diffusion speed into the basic material can be created by reducing the carbon mass flow. This reduction can be achieved by reducing the amount of the process gas flow during carburizing.

Figure 3 shows a typical process procedure in a single chamber vacuum furnace with the process steps: heating up, low pressure carburizing (pulsed), diffusion, reducing to hardening temperature and gas quenching. The carburizing can be simulated by a diffusion calculation program. Practical test results have been used to confirm the accuracy of simulation programs and as input to revise the simulation and refine the process parameters.

By modifying the carburizing time and the diffusion time, the necessary surface carbon content and hardening depth can be adjusted.

Diffusion

By implementing vacuum technology, the increase of carburizing temperature can be applied without any limitations caused by the furnace. (In contrast, atmospheric furnaces usually have a maximum temperature of 950°C for continuous systems and chamber furnaces a maximum temperature of 1,000°C.) However an increase in carburization temperature may not be possible depending on steel quality and other metallurgical factors.

Detailed tests performed by V. Schüler (Ref. 7) on standard fine-grain stabilized rods have shown that if the aluminum and nitrogen levels of the steels are sufficiently high, a carburization temperature of 980°C at a holding time of 4–8 hours will not lead to grain coarsening. The maximum admissible share of grain coarsening is limited to 10% (see Fig. 4). This gives the possibility of achieving effective hardening depths of 1.4–2 mm by direct hardening without intermediate isothermal annealing.

If the carburizing temperature is increased to 1,020°C, the maximum holding time is then limited to 15 minutes, which does not seem sensible (hardening depths of ~0.45 mm). Isothermal annealing followed by austenitizing leads to an extension of the process time, which can only be compensated at carburizing depths of more than 1.4 mm and temperatures of 1,020°C.

Quenching

The quenching is achieved with 10–20 bar nitrogen or helium, depending on the use of the materials, the maximum wall thickness of the workpieces, their geometry, the desired case and core hardness and the design of the furnace (single chamber or multi-chamber furnaces; see the next section: **Design of Systems**)

Substituting oil quenching with high pressure gas quenching guarantees not only a better surface quality, but also—in general—an improvement of the distortion. In addition, gas quenching spares one cleaning process as well as post-finishing costs, due to a reduction of the grinding allowances (Ref. 8). The demand for oxide-free carburizing only makes sense in combination with minimized distortion. By saving on post-finishing costs, one cleaning process and reduced disposal costs, low pressure carburizing represents an economical alternative to conventional gas carburizing.

Design of Systems

Low pressure carburization in general can be commonly realized in conventional single chamber vacuum furnaces, which can be adapted with gas distribution equipment for the process gas, special graphite insulators for the electrical power supply of the heating and some further technical adaptations. For achieving sufficient quenching speed in a single chamber furnace, the use of pressures up to 20 bar and helium or hydrogen as quenching gas is recommended.

The preferred furnace technology allows 10–20 bar N_2 quenching with a cold quenching chamber, achieving sufficient quenching rates for a great deal of different workpieces and materials. The transport of the charge between the two chambers is executed according to the well proven roller hearth principle, allowing quick transportation of the charges with a minimum of vibration (Fig. 5).

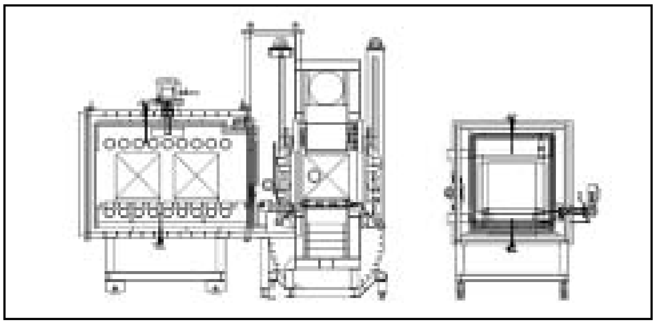

Figure 5—Schematic for two-chamber vacuum furnace.

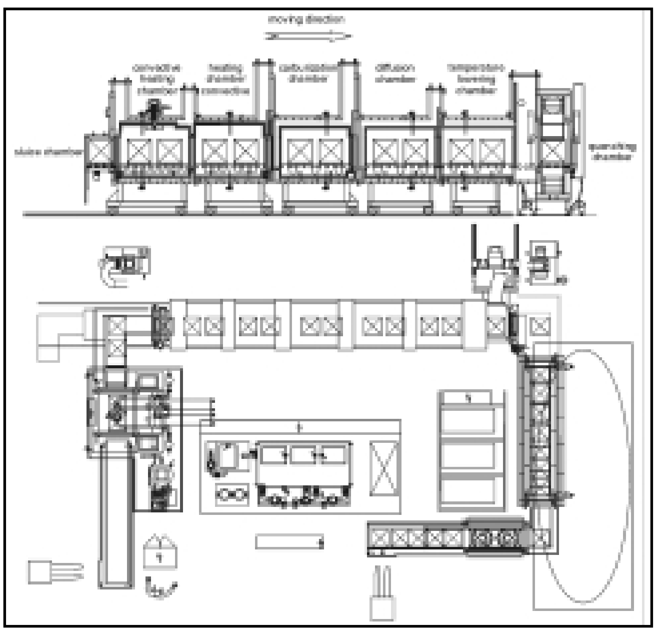

Figure 6—Schematic for low-pressure carburizing system.

Figure 7—Continuous low-pressure carburizing system.

For higher capacities, as required by the car industry, continuous, multi-chamber furnaces are mainly used for low pressure carburizing. These furnaces include a sluice chamber, a heating chamber (which allows convective heating with 1–2 bar nitrogen), one to two carburizing chambers, two to three diffusion chambers (which permits decreasing to hardening temperature) and a quenching chamber (which can be used as a sluice to unload the charge after quenching). Figure 6 presents a scheme for a continuous low pressure carburizing system. Figure 7 shows an overview of the entire LPC system.

The cold quenching chamber allows efficient quenching of numerous case hardening materials of different shapes and wall thicknesses. A cooling pressure of 10–20 bar nitrogen is sufficient to achieve core hardness for gears as demanded in the car industry. For high quenching rates, helium quenching in combination with a helium recycling unit can be achieved, too.

Carburizing Results

Uniformity. The uniformity of low pressure carburizing over the complete charge proved to be the main problem in the pressure range of a few 100 millibar, as observed in thorough tests by Chatterjee-Fischer (Ref. 1).

Reducing the pressure to only a few millibar as well as sequences of pressure changing (gas inlet with intermediate, short evacuating phases) have changed the conditions totally. The uniformity of the carburizing was examined on a test charge of 300 kg (rods $30^{\varnothing}$ x 500 mm, total load with a surface of 5 m^2).

Figure 8 shows the carbon profile of five turned test samples, which have been distributed in the complete charge chamber and carburized for three hours at 930°C. The case depth at 0.35% C was in the range of 0.80–0.85 mm.

Workpiece geometry. The efficiency of the process for carburizing in drilled holes as well as blind holes was examined on a test sample ($40^{\varnothing}$ x 100 mm) and the hardness profile was measured at different positions. Under the chosen geometrical conditions, the carburizing results were very uniform in both holes (see Fig. 9). Figure 10 shows etched microsections of workpieces (pistons and nozzles) also having a large number of drilled holes and a few blind holes. The workpieces were carburized to an effective hardness depth of 1–1.2 mm. The carburizing result for all the holes was very uniform. On the two microsection probes illustrating different geometry gears, a very high uniformity of carburizing has been achieved at the tips, flanks and roots of the teeth.

The use of acetylene leads to a further improvement of uniformity in carburizing very long blind holes and transitory drilled holes. Even critical components, such as pump noses and injection nozzles, can be treated to uniform results in spite of complex geometry and high charging density.

Application examples: gears and gear shafts. Depending on the geometry of the gear, the module and the required case depth, occasional minor deviations occurred regarding the hardness profile on the tips and bases of the teeth. Figure 11 shows a drive pinion and a ring gear made of 16MnCr5 (~SAE

5115), which have been carburized to an effective case depth of 0.6 mm at 625 HV. The uniformity of the carburizing on the tips, flanks and bases of the pinion teeth can be seen from the hardness profile in Figure 12. The surface carbon content was approximately 0.73%.

The minor differences in the hardening procedure can be referred as well to the higher carbon availability in the tooth base at low pressure carburizing, as to the minor differences in quenching velocity from the top of the tooth to the throat of the tooth.

Some other examples are shown in Figures 13 and 14 of gears and synchronized rings, which have been carburized in vacuum furnaces. Remarkable once again is the very good uniformity of carburizing of the tips and the bases of the teeth of synchronized rings and the very uniform results even at carburizing depths of only 0.3 mm (see Fig. 15). The carburizing was achieved at 930°C and the total time for carburizing and diffusion amounted to 8 minutes.

How densely gear shafts for the car industry have been loaded for low pressure carburizing is shown in Figure 16. Even with this dense load, uniform carburizing results have been achieved.

The improved quenching capacity of modern low pressure carburizing systems with a separate quenching chamber also makes possible the case hardening of solid components of truck-gear production. Numerous satisfactory treatment results of massive shafts (15–25 kg/piece) and synchronized rings (up to 6 kg/piece) extend the range of application of the process and indicate new operation areas.

Application examples: sintered materials. Sintered materials showing a residual porosity cause difficulties in gas carburizing processes due to the fact that the large surface of the pore channels allows full carburizing in very short time. On the contrary, low pressure carburizing has an advantage in that the carburizing is confined to the surface of the workpiece, if the size of the pores is a great deal less than 100 µm.

In this case, the length/diameter correlation is usually far beyond 15 and the LPC process does not allow carburizing of these very thin "blind holes" because fresh process gas does not penetrate into the pores. Furthermore, the very short processing times of LPC (just some minutes) can be controlled much better than normal gas carburizing processing of sintered parts.

Gears made of Sint D30 with a diameter of 10 mm were carburized. A case depth of 0.25 mm was required to avoid full carburizing of the teeth.

The carburizing was achieved with propane, at a pressure of 3 millibar, at 930°C and with a carburization time of 6 minutes.

To improve process security and uniformity in carburization, the process can be effective at temperatures of 850–900°C while prolonging the carburizing duration. The process control and gas absorption is adapted to the specific workpiece.

Summary

Low pressure carburizing offers, on account of technological advancements, an alternative to conventional gas carburiza-

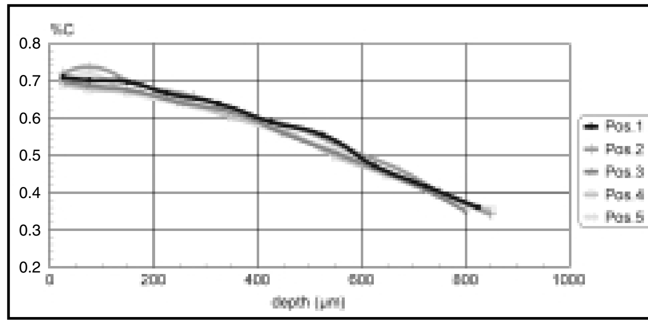

Figure 8—Carbon profile for 300 kg batch.

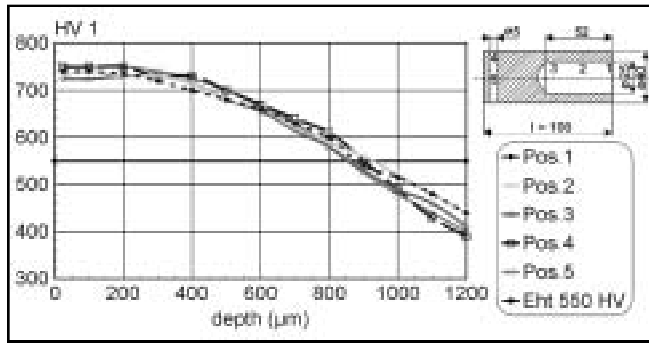

Figure 9—Hardness profile of 16NCD13 test piece.

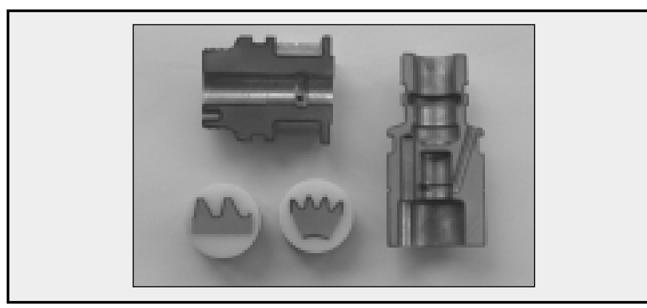

Figure 10—Micrographs.

Figure 11—Ring gear and drive pinion.

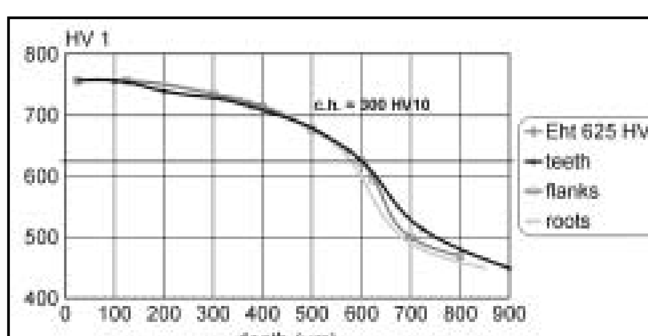

Figure 12—Hardness profile 16MnCr5 gear shaft.

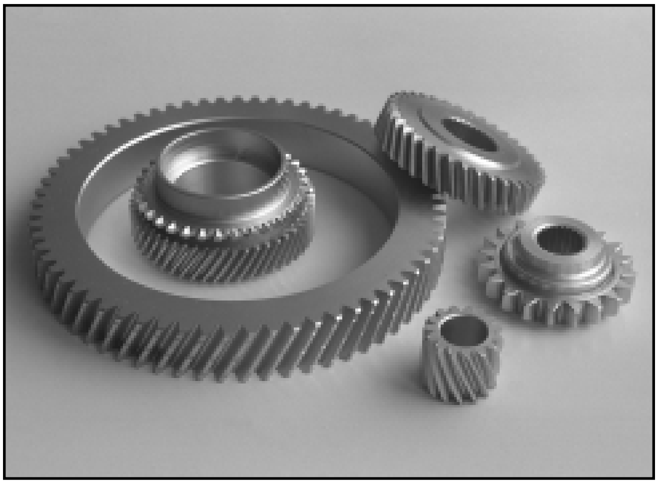

Figure 13—Various gear wheels.

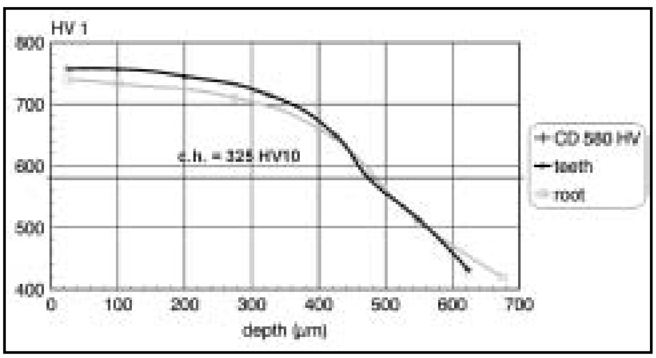

Figure 14—Hardness profile of 16MnCr5 gear wheel.

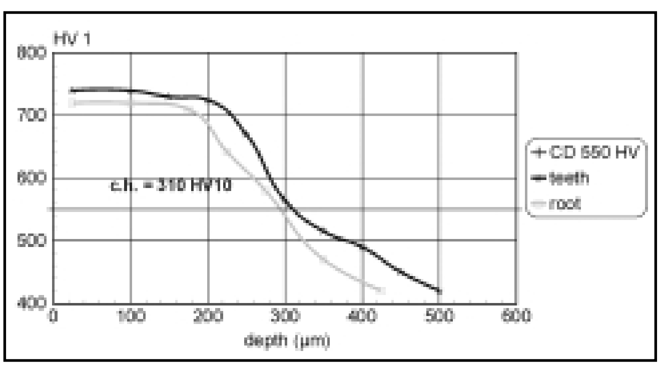

Figure 15—Hardness profile of smaller 16MnCr5 gear wheel.

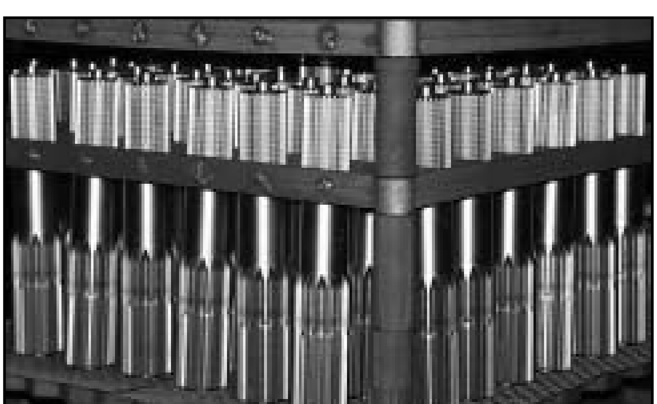

Figure 16—Load density of gear shafts.

tion. Apart from the oxidation-free surface of the charge, the process distinguishes itself by a short process time, higher process temperatures and the additional possibility of using high pressure gas quenching. Problems like the formation of soot or lack of uniformity of low pressure carburizing have been eliminated by optimizing the furnace technology as well as the process parameters. A calculation program allows complete control of the carburizing process with a very good correspondence to practical results.

The incorporation of vacuum systems in production lines is an attractive proposition given the relatively short treatment times involved, in particular when used in connection with high pressure gas quenching, which produces bright, oil-free surfaces. If oil quenching is not used, it is possible to satisfy the most stringent requirements of environmental protection regulations. In addition, gas quenching frequently reduces deformation of components, which may considerably cut the costs of further processing. In this connection, the demand of carburizing without surface oxidation has a new importance, too.

Low pressure carburizing can be achieved in one chamber, but two- and multi-chamber systems are preferable. For quenching, nitrogen or helium under 10–20 bar pressure is used. For continuous systems, gas cleaning and recovery is also possible.

Higher capacities as required by the car industry can be achieved in continuous furnaces with separate chambers for heating, carburizing, diffusion and quenching. Such systems can achieve net-throughput rates of 500 to 1,000 kg/hr., depending on the carburizing temperature and the required effective hardening depth. ⚙

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Gear Heat Treatment: The Influence of Materials and Geometry

Daniel H. Herring

Types of Gears

Gears play an essential role in the performance of the products that we rely on in our everyday lives. When we think about gears, we generally separate them into two categories: motion-carrying and power transmission. Motion-carrying gears are generally non-ferrous or plastics, while load bearing power transmission gears are usually manufactured from iron and steel. These gears (Fig. 1) are intended for heavy-duty service applications and will be the focus of the discussion that follows.

How Do Gears Fail?

The stresses that occur when the gears are in use and their surfaces in mesh must be carefully considered. To understand gear performance as it relates to materials (properties and heat treatment), the critical failure modes must be taken into account:

- Bending fatigue (root fillet cracks)
- Macropitting (pitch line surface degradation)
- Subcase fatigue (sub-surface fatigue failure)

Bending fatigue is caused by a load, applied along "the line of action," which generates stress gradients in the root fillets of the teeth. How these stress gradients react with the inherent strength gradients in part determines the fatigue life of the tooth (Ref. 1). The mode of failure tends to be in the form of crack propagation typically at the root fillet.

Macropitting can occur on the tooth surfaces, where the combination of pressure and sliding forces is the highest. Lubrication and surface finish can either promote or prevent macropitting. Where sliding is present and the coefficient of friction is high, the applied stress reaches a maximum at the surface and can exceed the material strength.

Subcase fatigue failure is another mechanism that can occur at the active profile face in that the applied stress level falls off gradually and can, therefore, approach or exceed the critical fatigue strength of the material. For case hardened parts, subcase fatigue usually occurs close to the case-core interface and cracking at the interface can be prevented by selecting, for a given material, the proper case depth and core hardness (that is, strength gradient) (Ref. 2).

Influence of Materials

Gears under load are subject to gradient stresses both on the active flank and at the root fillet. Properly selected materials and heat treatments will produce strength gradients that are adequate to withstand the stress gradients and provide an acceptable margin of safety.

Management Summary

Gear designs are evolving at an ever accelerating rate, and gear manufacturers need to better understand how the choice of materials and heat treating methods can optimize mechanical properties, balance overall cost and extend service life.

This article focuses on these issues as well as presents an example from the automotive racing industry, where enhanced fatigue performance and reduced incidents of failure can be directly related to the design and control of materials, especially alloying element additions and selection of a complementary heat treatment process (low pressure/vacuum carburizing) with optimized process parameters.

In all gears, the choice of material must be made only after review of the performance demanded by the application. Material choice must be a balance between overall cost and required service life. Key design considerations require an analysis of the type of applied load, whether gradual or instantaneous, and the desired mechanical properties, such as bending fatigue strength or wear resistance. The required

Figure 1—Fire truck transmission gears. (Photograph courtesy of Twin Disc Inc.)

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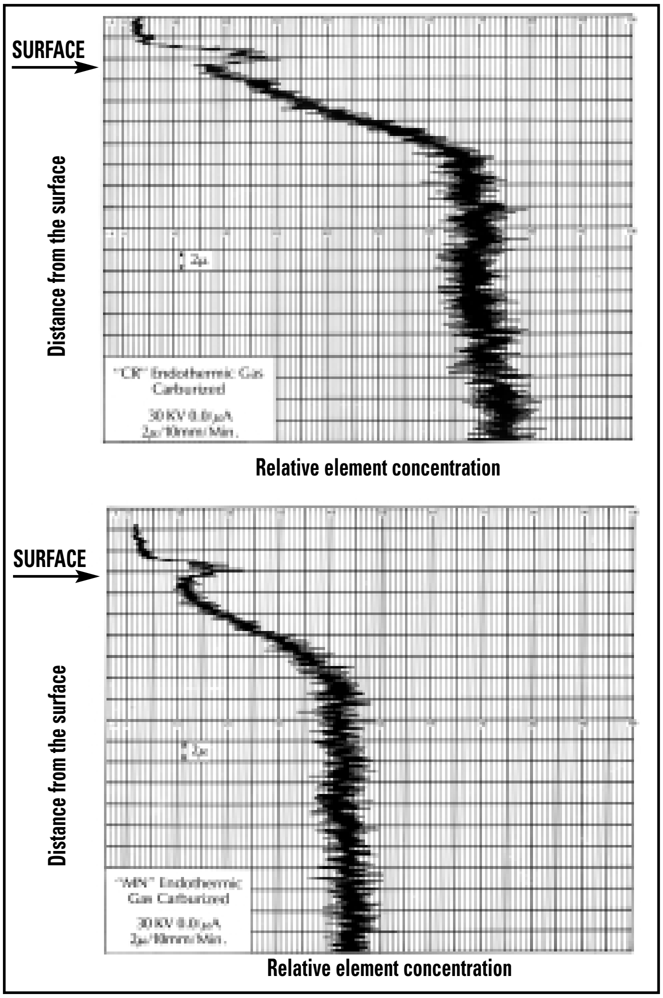


Figure 2—EDS analysis of atmosphere carburized gear surface oxidation effect for chromium (top) and manganese (bottom). Reading each scan from bottom to top, the specimen gear's surface is where the scan moves abruptly to the right.

Table 1—Available Gear Materials for Industrial Applications. (Ref. 3)

Typical Gear Materials (U.S. & European)	Gear Design Type	Typical Industrial Applications
(US) G3000, D5506, M5003, 1020, 1045, 1050, 1117, 1118, 1144, 4027, 4028, 4118, 4140, 4142, 4145, 4150, 4320, 4340, 4620, 4817, 4820, 5120, 5130, 5140, 5150, 8620, 8625, 8622, 8626, 8822, 9310 (European) 20NiCrMo2, 16MnCrB5, 20CrMo2, 17CrNiMo6, 20MoCr4, 18MnCrB5, 20CrMo4, 20MnCr5, 18NiCrMo5, 18MnCrMoB5, 27MnCr5, 27CrMo4, 23MnCrMo5	Face, Helical, Helical crossed-axis, Herringbone, Hypoid, Internal, Miter, Spiral/Straight Bevel, Skew Bevel, Spur, Spur rack and pinion, Worm, Zerol®	Differentials (automotive & heavy truck), Drives (industrial, tractor-accessory), Engines (heavy truck), Equipment (earth moving, farming, mining, paper/steel mill), Starters (automotive), Transmissions (aerospace, automotive, heavy truck, helicopter, marine, off-highway, tractor)

mechanical properties will define core strength and heat treating requirements. Manufacturing economics play an important role as well.

Each area in the gear tooth profile sees different service demands. For example, in the root area, good surface hardness and high residual compressive stress are desired to improve bending fatigue life. On the active flank, a combination of high hardness and adequate subsurface strength are necessary for adequate resistance to macropitting and subcase fatigue.

For example, some of the factors that influence fatigue strength are:

- Hardness Distribution
    - Case Hardness
    - Case Depth
    - Core Hardness
- Microstructure
    - Retained Austenite Percentage
    - Grain Size
    - Carbide Size, Type, and Distribution
    - Non-martensitic Phases
    - Intergranular Toughness
- Design and Manufacturing
    - Residual Compressive Stress
    - Surface Finish and Geometry

Although material cost represents only a small percentage (≈ 10%) of the total cost to manufacture a typical gear, material selection (Table 1) must be a perfect combination of raw material cost and performance capability.

Knowledge of the function of each of the alloying elements present in the material and their effect on the physical properties of the alloy is critical in material selection. Properties to be balanced by material selection include tensile, yield and impact strength, as well as elongation (Ref. 4).

Core Hardness. Core hardness is most strongly influenced by molybdenum and manganese. Chromium has a moderate effect and nickel a weak effect. Core hardenability is strongly influenced by quench temperature. For example, when quenching from 925ºC (1,700ºF) molybdenum has a notably stronger hardenability influence than any other element. Quenching from 830ºC (1,525ºF) reduces the effectiveness of molybdenum to a level that is more similar to the effect of manganese and chromium, with the effect of nickel remaining weak.

Susceptibility to bainite formation in the carburized case is strongly reduced by both molybdenum and chromium. Although manganese is the most cost effective element where core hardenability is concerned, high percentages of this element can create problems such as control of hardenability bandwidth (Ref. 5).

Surface Oxidation. Manganese and chromium are susceptible to oxidation in atmosphere carburizing, as is silicon (Ref. 6). Oxidation results in alloy depletion, which can be quantified by use of energy-dispersive X-ray spectroscopy (EDS). The technique separates and detects X-rays of specific energy levels that can be displayed as a line scan (Fig. 2) of relative element concentration (x-axis) as a function of distance from the surface (y-axis). In the case of manganese, the depletion results in lower hardenability and the formation of non-martensitic phases at the surface. Chromium loss contributes to difficulties with the formation of carbides in the case.

Shallow depths of surface oxidation appear to have no significant effect on fatigue properties, provided that the surface transforms to martensite (Ref. 7). Severe oxidation—which removes significant amounts of alloying elements from the austenite—lowers hardenability and allows other non-martensitic phases (pearlite and other decomposition products) to form. The formation of these phases reduces surface compressive stresses or results in surface tensile stresses and, therefore, is detrimental to fatigue (Ref. 8).

Influence of Part Geometry

Gear tooth profile, contact ratio, and pressure angle for a given application are critical in the proper selection of gearing for optimal use. The proper choice of heat treatment and surface treatment produce the strength and finish requirements necessary to perform the intended function.

Equally necessary to achieve high strength at the surface of the root fillet radius is a sound microstructure with material of high hardness.

Dimensional changes (growth, shrinkage, warpage) due to heat treatment cycle (heating and cooling) are a function of material selection, part geometry, manufacturing methods and equipment, and heat treatment process and cycles. Today, emphasis is placed on reducing the number of post heat treatment operations and, as such, heat treatment methods must be optimized.

Influence of Heat Treatment Method

Residual stresses are additive with applied stress. Compressive residual stresses are desired as they oppose the applied, repetitive, and undesirable tensile stress that causes fatigue failure.

The greater the magnitude and depth of the compressive stress, the greater the ability to improve fatigue properties. A high compressive stress value at the surface helps the component resist crack initiation. The deeper the compressive layer, the greater the resistance to crack growth for longer periods of time.

Carburizing remains one of the most effective ways of producing beneficial compressive stress on the part surface. And of all the carburizing processes, low pressure/vacuum carburizing has emerged as the most effective (Ref. 9).

Low Pressure/Vacuum Carburizing. The development of carburizing steels specifically designed to take advantage of low pressure/vacuum carburizing methods in combination with high pressure gas quenching technology is one example of the promise of materials engineering for the future. The key to

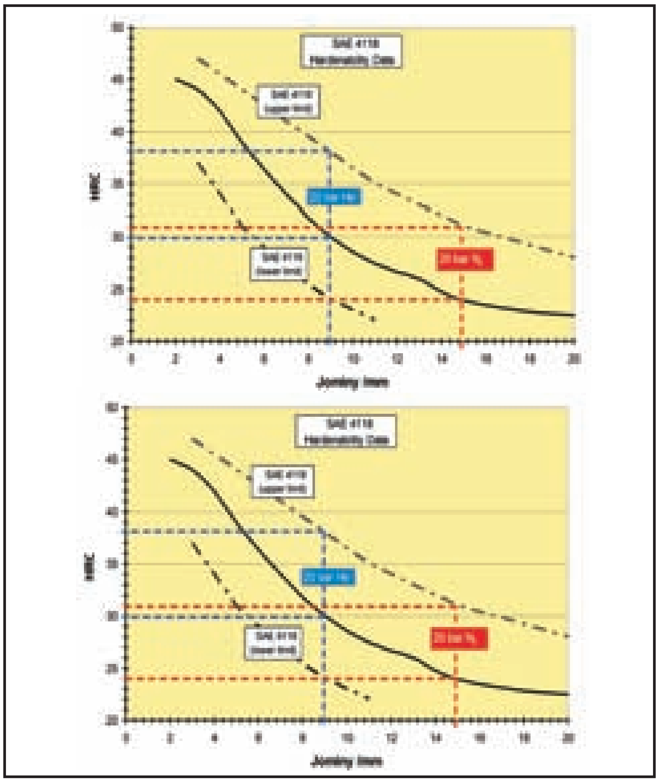


Figure 3—Influence of hardenability on gas quench properties.

Figure 4—Racing transmission gear (AISI 9310).

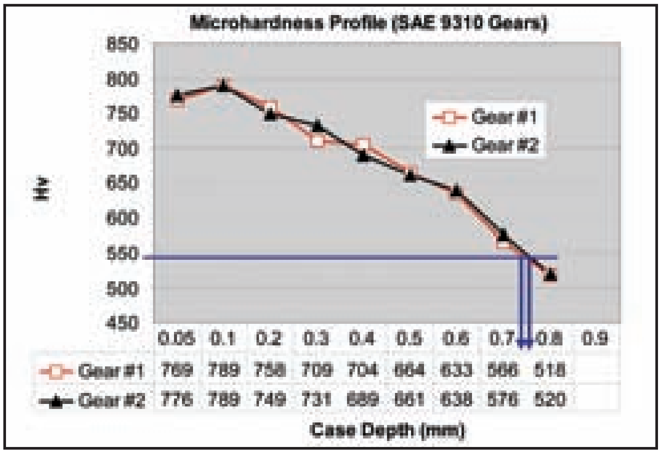


Figure 5—Gear effective case depth.

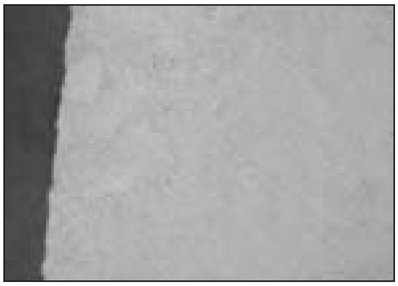


Figure 6—Gear microstructure (500X, 2% Nital)

Table 2—Gear Carburizing Requirements.

Items	Specifications
Part Description	Gear
Material	SAE 9310 Alloy Steel
Heat Treat Process	Carburizing
Effective Case Depth	0.025"–0.035" (0.63 mm–0.89 mm)
Carburized Surface Hardness	HRC 61.0 min.
Other Targets	No carbides, carbide networking or retained austenite
Quench	Nitrogen, 14 bar

Table 3—Shaft Carburizing Requirements.

Items	Specifications
Part Description	Main Shaft
Material	SAE 4820
Surface Condition	Clean (aqueous washing)
Heat Treat Process	Carburizing
Effective Case Depth	0.040"–0.050"
Carburized Surface Hardness	HRC 58–62
Other Targets	No carbides, carbide networking or retained austenite
Quench	Nitrogen, 18 bar

Figure 7—Racing transmission main shaft (AISI 4820).

these new steels will be their balance of material cost (targeting 10–25% of today's large quantity alloys) and performance (e.g. high hardenability and high toughness). In addition, using high pressure gas quenching to minimize part distortion reduces manufacturing cost. Considerable materials research is also underway to shorten cycle times by the use of high temperature carburizing methods. Micro-alloy additions of aluminum, niobium, and titanium have shown great promise (Ref. 10).

Other aspects, such as the tendency toward the formation of carbides and bainite in the case as discussed, must be taken into account. Generally speaking, low hardenability steels can be used for small gears, whereas higher hardenability is required for larger size gears. Since quench rate is also involved, there can be considerable variation. The more rapid the quench, the lower the hardenability required. However, where a particular heat of steel falls within its hardenability band is a factor that should not be ignored. For example, in high pressure gas quenching, this fact may dictate different types of quench gases and different gas pressures to achieve similar properties (Fig. 3).

A focus of this research has been to understand the effects of various alloying elements on core and case hardenability. Since base chemistry hardenability governs the capability of developing core and gradient strengths in the medium carbon portion of a carburized case and the lower carbon core region, understanding the relative magnitude of the major alloy element (manganese, nickel, chromium, and molybdenum) is very important. Case hardenability governs the capability of steel to develop sufficient hardness and microstructure in the high carbon surface. In general, performance life of carburized gears is dependent on surface microstructure, carbon content, strength gradient, residual stress and steel cleanliness (Ref. 11).

Racing transmission components (gears and shafts) can be used to illustrate the results that can be achieved by optimizing the heat treat process for a selected material (Ref. 12). These components are subjected to severe service duty and as such require the best achievable microstructure and properties.

Typical gears (Fig. 4) are processed as shown in Table 2.

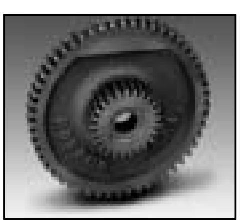
Checked gears showed uniform surface hardness that ranged from 64.2–64.7 HRC (as quenched). The effective case depth (Fig. 5) was measured as 0.75 mm (0.030") at 550 HV 0.5 (52.5 HRC). Carburized case microstructure (Fig. 6) revealed a uniform martensitic structure with no surface or intergranular oxidation, carbides, or retained austenite.

Main shafts (Fig. 7) in loads of 310 kg (690 lbs.) are processed to achieve the specifications called out in Table 3.

The shafts showed uniform surface hardness that ranged from 61.2–62.2 HRC after quench, deep freeze, and temper. The core hardness is 44.2–44.7 HRC. Parts were clean with a uniform total case depth of 1.32 mm (0.052") at 550 HV 0.5 (52.5 HRC).

Conclusion

Enhanced fatigue performance and reduced incidents of fail-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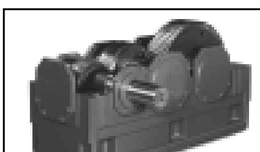
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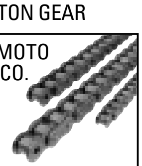
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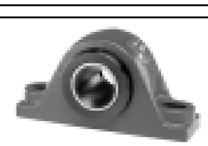
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ures can be directly related to the design and control of materials, especially alloying element additions and the selection of a complementary heat treatment process with optimized cycle parameters to produce a fine martensitic microstructure in combination with a minimization or elimination of surface oxidation.

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Founder/President of Parker Industries Dies

George Parker, founder and president of Parker Industries, Inc. died Dec. 22.

Born in England, he worked at Drummonds and Sykes, both gear machine manufacturers. He became a director at Sykes' office in Canada before moving to the U.S. He first was in sales at Quaker City Gear and then started Parker Industries, which sells gear tools.

Parker Industries covers all of North America and has tools for various required gear or spline specification. The company will continue.

Induction Heating Inventor Dies

Nicholas Ross, 80, owner of I.H.C. Consulting and a 40-year employee of Ajax Magnethermic Corp. of Warren, OH, died of respiratory failure.

In 1986, Ross created I.H.C. Consulting, which performs induction heating and electrical engineering consultations for Boeing Aviation, Barmet Steel, Ajax Magnethermic and other leading galvanizing companies. Prior to that, he was Ajax Magnethermic's director of research and development since the mid-1940s.

Among his most notable accomplishments is the invention of "The Ross Coil," an induction heating system with a 210-megawatt induction heater for wide steel rectangular slabs.

Ross held three patents related to induction galvannealing in steel making. Many of today's automobiles use large percentages of galvanneal steel.

He also wrote the book *Rules of Thumb for Induction Heating* and served as a consultant for the government during the Three Mile Island nuclear crisis.

Ross is survived by his wife, Jane; his son, Nick V. Ross III; his daughter, Stella Camuso; and a granddaughter.

Balzers Announces New President, Sales Appointments

Kent Cornell was appointed president of Balzers Inc. He has worked at ESEC, a sister company, for the past 17 years, most recently as vice president and general manager.

The sales department is also announcing new hires. Matt Collins, who will be the company's product manager for punching, forming and stamping, has 12 years of industry experience. Dwayne Douglas will work with new coatings for plastic molding as product manager for molds and dies. He has been with the company since 1995. Finally, Victor Johnston and Randy Bartholomew were named applications engineers. Both are responsible for customer service, sales and technical support.

New Managers at Philadelphia Gear

Philadelphia Gear Corp. has reorganized its service center management team in two of its regional maintenance facilities.

Tony Tartaglio was named general manager of the Western service center. Tartaglio has been with Philadelphia Gear for 30 years and will have operational control of Philadelphia Gear's facility in Lynwood, CA. Nel Mitchel will take over Tartaglio's former job as Western regional sales manager. Mitchel has more than 10 years of experience in industrial equipment repair, most recently as solutions account manager for SKF USA.

In addition, Barry Hall was appointed general manager of the Midwest service center.

AMT Elects Officers, Directors

AMT–The Association for Manufacturing Technology has elected its 2004 officers and directors.

Chairman of the board is R.J. Weskamp of Wes-Tech Inc. David J. Burns of Gleason Corp. is the new first vice chairman and J. Patrick Ervin of Hardinge Inc. was elected secretary.

The new board members are Ronald Schildge of Transmares Corp., Douglas K. Woods of Liberty Precision Industries and J. Patrick Ervin.

Longtime General Broach Manager Retires

Robert Roseliep, general manager of the machine tool division of General Broach, is retiring after 51 years with the company. S. David Graham will replace him.

According to the company's press release, Roseliep began his career at the company as a shipping clerk and then progressed through positions including broach tool designer, broach fixture designer, broach machine designer, chief engineer and vice president of engineering.

He was named president and CEO in 1977. In 1986, Roseliep and Raymond Eklund bought the company and its affiliates. Two years later, Roseliep bought out Eklund to become the sole owner. In 1991, he sold the company to Utica Enterprises and was retained as general manager of the machine tool division.

New President at Fairfield

Gary Lehman was appointed president and CEO of Fairfield Manufacturing Co. Inc.

Lehman was managing director and co-founder of the Cannelton Group, a consulting firm that specializes in strategic and operational assistance to manufacturing companies.

Prior to that, he was president of Phillips Lighting Electronics of North America. According to Fairfield's press release, he has 20 years of management experience with Federal Mogul, TRW, Deere and Co. and Allen Bradley.

Fairfield Manufacturing of Lafayette, IN, designs and manufactures custom gears and gear sets, power transmission assemblies and planetary drives.

New Calibration Facility for Gear Metrology Lab

Rob Frazer of the University of Newcastle-upon-Tyne, along with P. Mancasola and Gunther Mikoleizig of Klingelnberg GmbH, published a new paper outlining the calibration and measurement uncertainty requirements of the U.K. gear industry at the ASME 2003 Design Engineering Technical Conference.

Titled "A New Calibration Facility for the UK's National Gear Metrology Laboratory" (DETC2003/PTG-48106), the paper outlines initial tests on the performance of a new Klingelnberg P65 Gear Measuring Centre selected by the U.K.'s National Gear Metrology Lab as the platform for improving the country's gear calibration.

ITW Workholding Acquires Forkardt

ITW Workholding of Troy, MI, acquired Forkardt International Ltd. and plans to combine their sales channels, engineering and product lines.

Forkardt International, with subsidiaries in France, Great Britain, Germany, Italy, Switzerland and the United States, designs and manufactures custom and standard workholding products.

According to ITW's press release, any European subsidiaries will continue to operate under the Forkardt name as part of the ITW Workholding Group. Also included in the acquisition is the Kalamazoo, MI-based Buck Forkardt USA operation, which will continue to serve the general business segment of ITW Workholding.

New Engineer at Process Equipment

Brian Everson has joined Process Equipment Co. of Tipp City, OH, as a software engineer in the metrology system. Among his new responsibilities will be working as a member of the Next Dimension® gear measurement system software development team.

Prior to this, Everson worked for M&M Precision Systems Corp. for 17 years in a variety of technical positions.

Nachi Appoints Regional Sales Manager

Nachi Machining Technology Co. has announced the appointment of David Petrimoulx to the position of regional sales manager in the Southeastern United States. Petrimoulx relocated to Charlotte, NC in February and will be responsible for all sales in North and South Carolina, Georgia, Florida, parts of Tennessee and Virginia.

Petrimoulx has been with Nachi for 25 years, beginning his career as a machine operator and broach grinder. He has held various sales and engineering positions within the company, and most recently he was manager of the forming rack division.

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Products for the Gear Industry

New Hobbing Machine from Gleason

The P 90 from Gleason Corp. is a horizontal hobber that has twice the cutter drive output and 20% more capacity than the P 60.

According to the company's press release, this machine has a capacity for gears as large as 100 mm in diameter. It uses high-speed, direct-drive spindles for the hob head and work spindle.

In addition, this gear hobber has a fully integrated gantry loader system with buffer storage. The system is easily adaptable to different part types.

Although it was originally designed for dry hobbing, the machine can accommodate a range of wet or dry cutting conditions with carbide and high-speed-steel hobs. Other uses include worm milling and special profile grinding. With a compatible deburring station, these capabilities are available as well.

The P 60 was designed to conserve floor space and has a footprint of 3.5 square meters. It contains a CNC controller with a Windows-based software interface.

For more information, contact Gleason Corp. of Rochester, NY, on the Internet at *www.gleason.com.*

New Gear Grinding Machine from Kapp

The new KX300P gear grinding machine from Kapp Technologies utilizes two different grinding processes and two different tool concepts for each process.

It can use either a discontinuous form grinding process or a continuous generating grinding process along with non-dressable, electroplated CBN tools or dressable tools.

According to the company's press release, many combinations of processes and tool concepts are possible for roughing and finishing.

The machine features spindle integrated balancing of the grinding tool and on-board gear inspection. It can be used to grind gear shafts since it is equipped with a tailstock. Also, the company offers a custom-designed automatic loading system as an integral part of the concept.

For more information, contact Kapp Technologies of Boulder, CO, by telephone at (303) 938-9737 or on the Internet at *www.kapp-usa.com.*

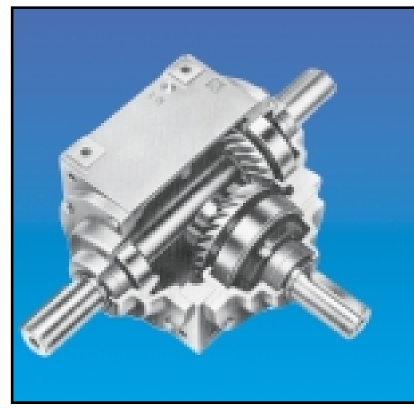
New Gearhead from Danaher Motion

The Micron EverTRUE continuous duty planetary gearhead from Danaher Motion is specifically designed to last at least 30,000 hours while running 24 hours a day, seven days a week.

According to the company's press release, this planetary gearhead is specifically engineered to handle duty cycles at high speeds with no dwells and can run at 95% efficiency.

Available in 100, 140 and 180 mm frame sizes, the ratios range from 4:1 to 100:1. With a precision specification of 4 arc-min of backlash, the product can run at low operating temperatures.

For more information, contact Danaher Linear Motion Systems of Mayfield Heights, OH, by telephone at (440) 995-3200.



Bevel Gearboxes by Andantex

The ANGLgear bevel gearboxes from Andantex USA transmit rotary motion to right angles.

Units are available in a variety of metric or inch-sized diameters and mounting surfaces. The boxes contain hardened bevel gears, double-sealed ball bearings and type 416 stainless steel enclosed in cast aluminum housings.

According to the company's press release, Andantex will modify any unit to user specifications and will design and produce custom applications.

For more information, contact Andantex USA by telephone at (800) 713-6170 or on the Internet at *www.andantex.com.*

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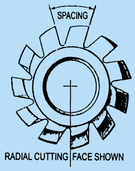

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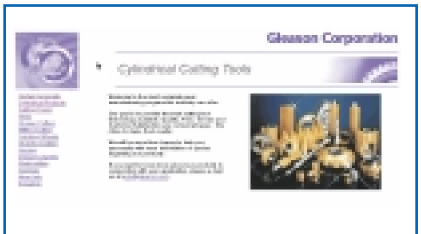

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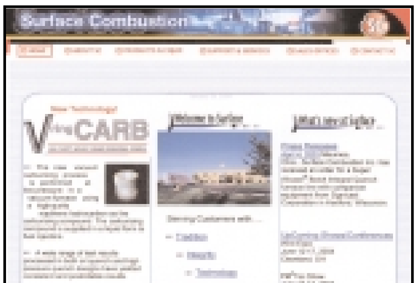

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ANCHORS WEIGH

Spiral bevel gear manufacturers—pay attention. There may be a whole new segment of the market that nobody has tapped into. This kind of marketing venture doesn't require travel to Third World countries, expensive machines or additional employee training.

Fred Young, president of Forest City Gear in Roscoe, Illinois, discovered this new market on a fly-fishing trip on the White River in Arkansas last year. His group was aboard a johnboat, a 16–20' boat with a special motor to move up and down the river. The group found a spot in the middle of the White River that was filled with trout, and the captain tossed out a weight to keep the boat in place—but instead of a normal anchor, he was using an old, rusty spiral bevel gear!

"It worked because the shape of the beveled teeth could grip the bottom of the river," Young explains.

It seemed funny to Young that a spiral bevel gear, which usually costs thousands, could be cast into the water and effectively used as an anchor.

As random as this was, it wasn't the only gear-related instance on this vacation. A couple days later, the ship docked in Cotter, Arizona, the trout capital of the world.

Young and the other fishermen were browsing around the riverfront shopping district, looking in windows, when he came across the first-ever boutique for his friends in the gear industry. "White River Gear" seemed the perfect spot to get an off-the-rack gear without taking too much time away from the fishing trip. Sadly, there were no worm gears inside, only actual worms to dangle from the end of a fishing pole.

Ever the entrepreneur, the whole day started the wheels turning in Young's head about the gear business venture possibilities there. For instance, located very close to the gear shop is The Lodge and Fly Shoppe above Rim Shoals at the White River. Maybe this could be a possible site for an engineering conference facility? Stocked with an open bar, the Lodge and Fly Shoppe could be a great spot to unwind after a trade show…

Taking that idea even further, Young jokes that this town in the Ozarks might be a good spot to transfer his company someday:

"I don't know if any (*Gear Technology*) reader happens to be the store owner, since, as an addicted fly fisherman, this strikes me as the perfect merger or acquisition candidate for Forest City Gear."

Fred Young models 2004's coolest gear accessory.

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