gear TECHNOLOGY®

JAN/FEB 2013

BIG-GEAR NDT
Too Big to Fail?

Job Shop Lean Debuts

Agma Gear School's Basics and Beyond
On-Site and on the Air!

TECHNICAL

Finding Harmony in Parts Balancing

Big Gear Manufacturing and Metallurgy

Large Pinions for Open Gears

Ask the Expert:
Taking the Measure of Involute Masters

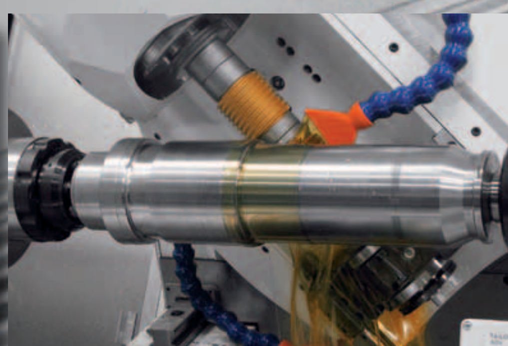
NEW! BACK TO BASICS

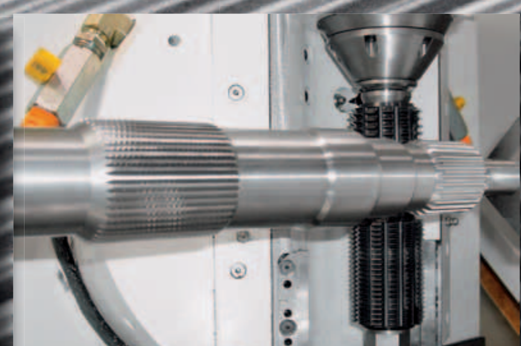
The Involute Curve

www.geartechnology.com

THE JOURNAL OF GEAR MANUFACTURING

Long spline and gear shaft hobbing





The Bourn & Koch 400H CNC horizontal hobbing machine is a 7-axis CNC machine that can hob spur gears, helical gears, splines and threads on cylindrical blanks or shafts.
Its powerful, direct drive work spindle and extremely stable, steel-polymer composite components make it ideal for manufacturing large and heavy shaft parts up to 406 mm in diameter and 6.4 module. Shaft lengths up to 76” or longer can be processed by the extended bed versions.
All axes’ movements are supported by high-precision ball screws and linear roller ways, resulting in very fast setups and precise part machining. The through-hole, work spindle drive allows clamping of shaft parts that exceed the actual work area limitations.

SAMPUTENSILI

Phone: 847-649-1450
5200 Prairie Stone Pkwy. • Ste. 100 • Hoffman Estates • IL 60192


BK 400 H
BOURN&KOCH

gear TECHNOLOGY

contents

JAN/FEB 2013

30

38

26

features

technical

Vol. 30, No. 1 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, July and December by Randall Publications LLC, 1840 Jarvis Avenue, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). Randall Publications makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1840 Jarvis Avenue, Elk Grove Village, IL, 60007.

gear TECHNOLOGY

Vol. 30, No. 1

departments

Cover Photo courtesy of Rexnord Gear Group

THE GEAR INDUSTRY'S INFORMATION SOURCE

www.geartechnology.com

Complete Back Issue Archive

The complete archive of back issues of *Gear Technology*—from 1984 through 2012—is now available online. You can browse the archive issue-by-issue or search by subject or keyword. Now, finding technical articles on gear-related subjects is as easy as 1-2-3

1. Click on "Magazine" at the top of any page on the site
2. Type a subject or keyword in the search box at the top of any page on the site

For Related Articles Search

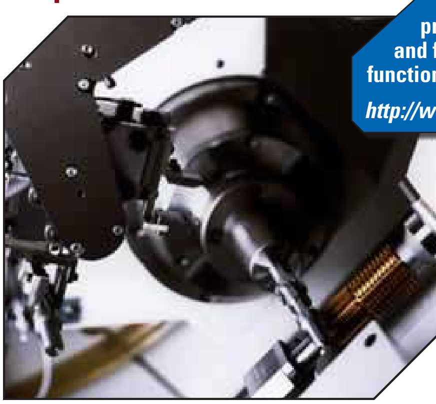
Search Term

at **www.geartechnology.com**

3. Look for this symbol throughout each issue of *Gear Technology* for relevant keywords that will lead you to related articles from our archive.

Throughout the site you'll find keywords that will take you to lists of related articles

Koepfer K Series



From chucked to shaft parts, small series to mass production, the Koepfer K series offers high quality and flexibility in gear cutting. Check out its many functions here:

http://www.geartechnology.com/videos/Koepfer-K-Series

Gear Train

Our new gear education and training department (Page 30) will explore the gear schools, seminars and educational opportunities available to the industry. It will also discuss how companies are finding and retaining skill workers. Submit gear education/training article ideas to wrs@geartechnology.com.

GT Newsletter

Upcoming newsletter topics for Gear Technology include Gear Finishing (March), Gear Shaping (April) and Chamfering/Deburring (May). Submit relevant article ideas on these topics to wrs@geartechnology.com.

Stay Connected

Follow us on Twitter
twitter.com/#!/Gear_Technology

Connect with us on LinkedIn
www.linkedin.com/groups/Gear-Technology-Magazine-3893880

Subscribe Online
www.geartechnology.com/subscribe.htm

gear TECHNOLOGY

RANDALL PUBLICATIONS LLC
1840 JARVIS AVENUE
ELK GROVE VILLAGE, IL 60007

(847) 437-6604
FAX: (847) 437-6618

EDITORIAL

Publisher & Editor-in-Chief
Michael Goldstein
publisher@geartechnology.com

Managing Editor
Randy Stott
wrs@geartechnology.com

Senior Editor
Jack McGuinn
jmcguinn@geartechnology.com

Associate Editor
Matthew Jaster
mjaster@geartechnology.com

Editorial Consultant
Paul R. Goldstein

Technical Editors
William (Bill) Bradley
Robert Errichello
Octave Labath, P.E.
Joseph Mihelick
Charles D. Schultz, P.E.
Robert E. Smith

DESIGN

Art Director
David Ropinski
dropinski@geartechnology.com

ADVERTISING

Advertising Sales Manager
Dave Friedman
dave@geartechnology.com

Materials Coordinator
Dorothy Fiandaca
dee@randallpublications.com

CIRCULATION

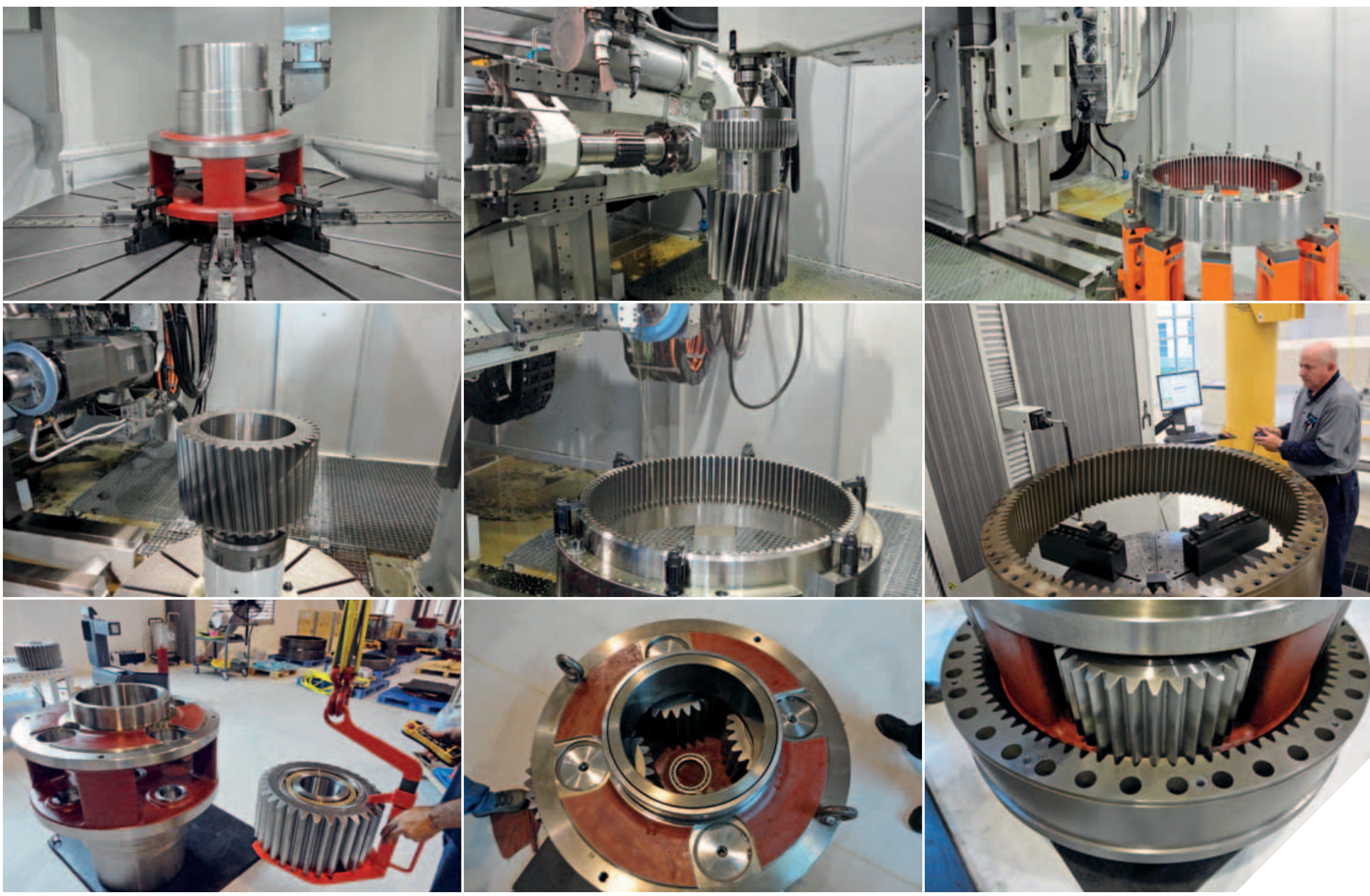
Circulation Manager
Carol Tratar
subscribe@geartechnology.com

RANDALL STAFF

President
Michael Goldstein

Accounting
Luann Harrold

BPA WORLDWIDE



Looking Back, *Looking Forward*

Publisher & Editor-in-Chief
Michael Goldstein

For 29 years, Gear Technology has provided an unparalleled collection of knowledge on the art and science of gears—encompassing a depth and breadth of expertise you can't find anywhere else.

I've been exploring that collection a lot lately, because—for the first time ever—our complete archive of articles and back issues is now available to subscribers online. I founded *Gear Technology*—first and foremost—as an educational magazine. Our mission has always been to bring the best technical content to the engineers and manufacturers who needed it. The archive furthers that mission by making our past content more easily accessible.

And there's a lot of value there. Many of our oldest articles are as relevant today as they were when first published. For example, in our very first issue we published "Advantages of Titanium Nitride Coated Gear Tools" by Peter W. Kelly of Barber-Colman. The economics of that article are just as valid today as they were in 1984, when most didn't know what TiN coating was or why they should pay such a large premium for it. That's just one example. You can learn much about gear design, manufacturing, inspection or heat treating by studying our articles and back issues.

We've tagged each article with keywords to help you find exactly what you're looking for. We completely scrapped our old search engine and built a new one—tying into those keywords and emphasizing the extremely important technical content that you won't find anywhere else.

So if you're new to gearing and you want to learn more, go to the site and type "basics" into the search box. Need more specific results? Try something like "hobbing basics" or "inspection basics." You'll find plenty of excellent articles to get you started.

But the archive isn't just for newbies. Even the experienced gear engineer can find important, relevant technical information this way. Try searching for "tip relief" or "profile modification" and you'll see what I mean. Want to know more about gear rating? Try something like "ISO 6336." The archives have something for everybody.

Most importantly, none of this valuable information costs you anything. That's right; it's absolutely FREE, as long as you're a subscriber to the magazine (which is also free). By the way, if your magazine arrived with a subscription card attached to the cover, that means you *aren't* a current subscriber, and you need to fill out the form.

But our mission isn't just about looking backwards. It's also about looking forward, and exploring ways we can broaden our scope, deepen our coverage of the industry, be of more interest and bring even more value to you, our reader. With this issue, we've introduced some great new features and departments. The first of those is "Back-to-Basics," which takes the place of "Addendum" on our back page. Although we've had a lot of fun producing Addendum, we've decided to give you something more practical and closer to our core mission. With Back-to-Basics, we'll provide you with a brief introduction to a particular gear-related topic, along with a list of additional resources where you can learn more.

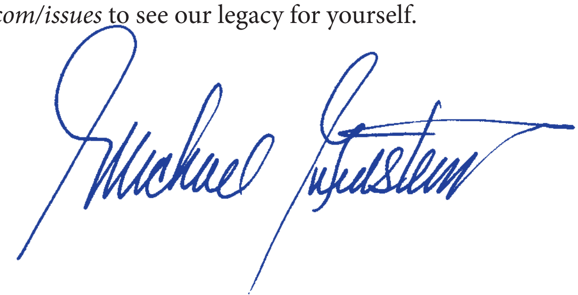
"Gear Train" is a new regular feature that explores gear training and education, including an in-depth look at gear schools, seminars and other opportunities. You'll also learn what other companies are doing to find and retain skilled labor. "Job Shop Lean" is a new column that takes you, step-by-step, through an actual lean transformation in a job shop environment. Think of it as our own little reality series.

Of course, none of our changes will ever distract us from the heart and core of *Gear Technology*—our technical content. "Ask the Expert" will continue to provide you with practical, hands-on experience of experts in the field. We'll also continue to rely on our technical editors—Bill Bradley, Robert Errichello, Octave Labath, Joseph Mihelick, Charles D. Schultz and Robert E. Smith. Their combined hundreds of years of experience helps us choose the best articles and make sure they're the most relevant, accurate and up-to-date as possible. I would also like to thank Dan Thurman, who has recently retired from our roster of technical editors. His many years of service to the gear industry—and to *Gear Technology*—have been invaluable.

As you probably know, we employ more staff editors than a typical magazine of our size. Together, our in-house staff editors have more than 100 years of combined gear industry and overall manufacturing experience, which is unique in our industry, enabling *Gear Technology* to write and edit with the insight and accuracy you've come to expect.

In fact, in October, *Gear Technology* was recognized by Niche Media in an article entitled "Gear Technology - Content Kings!" The article cited the size of our experienced editorial staff and our focus on content as the key reasons for our success.

I couldn't agree more. Visit our archives at *www.geartechnology.com/issues* to see our legacy for yourself.

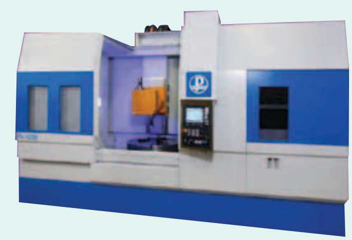


New name.
New opportunities.

GMTA (German Machine Tools of America) is the new face for what used to be American Wera. What hasn't changed is that we remain your source for the world's foremost machine technology--with more options than ever. From Gear Scudding®, to gear honing, gear grinding, polygon milling, turning, multi-functional machining and shaft straightening, we deliver practical, robust, cost-efficient solutions from a single machine to a complete system.

Profilator GmbH
Modular machines designed for gear Scudding®, tooth pointing, and polygon milling.

MAE-Goetzen GmbH
Shaft straightening machinery and railroad wheelset assembly presses.



Pittler T&S GmbH
Application-specific lathe technology for single or multi-task operations from 20mm to 6000 mm.

Praewema Honing Machines
SynchroFine line of high-performance hard gear honing machines for critical gearbox applications.

WMZ GmbH
Precision center-drive turning machines and modular automation solutions with reduced cycle times.

Praewema Gear Grinding Machines
SynchroFine line of high-performance hard gear grinding machines for coarse pitch applications.

Call us...let us show you what we can do for you.

GMTA
German Machine Tools of America

4630 Freedom Drive • Ann Arbor, MI 48108 • 734.973.7800 • fax 734.973.3053 • www.gmtamerica.com

CMM Gear Inspection

MITUTOYO OFFERS CAPABLE, AFFORDABLE AND FLEXIBLE GEAR INSPECTION OPTION

Gear inspection has long been considered a highly specialized, expensive and difficult part of the gear manufacturing process, requiring a wide variety of complicated gages, testers, dedicated CNC equipment and highly trained experts.

But if you want to make good gears, you need to have all that stuff, right?

Well, maybe not, says John Fox, senior CMM software application engineer for Mitutoyo America Corporation. According to Fox, the time may be right to consider a CMM for your gear inspection needs.

"We have many customers that are using a CMM for gear measurement, production and setup," Fox says. "Customers including Honda, Kawasaki, Hitachi, Molon Motors, etc. use the CMM to measure purchased gears. And there are high-precision gear companies such as Gear Manufacturers Inc. that incorporate our higher-accuracy CMM for setup and some production."

A lower price tag is one of the main reasons to consider CMMs over conventional dedicated gear inspection equipment, Fox says. A single piece of today's sophisticated, fully programmable, fully automated dedicated gear-checking equipment, limited to a single gear size range (gears up to 15" diameter, for example) plus software, might cost twice as much as a CMM machine equipped with a rotary table, high-speed scanning probe head and gear-checking software, Fox says.

Of course, exact prices for either type of system depend on options and machine size, but a smaller-sized Mitutoyo CNC coordinate measuring machine starts out around $55,000, Fox says. Adding in Mitutoyo's *GEARPAK* software for cylindrical gears adds about $11,000. *GEARPAK* for bevel gears adds about $9,000. *GEARPAK* for worm gears adds another $10,000. So for around $85,000, you can get a Mitutoyo CMM capable of inspecting cylindrical, bevel and worm gears. Dedicated gear inspection systems have been known to cost as much as four times that amount, Fox says.

The type of CMM used to measure gears depends mostly on the part's size and weight. When measuring large gears—those with diameters of more than a meter or which are extremely heavy—a high-precision, horizontal-arm CMM with a rotary table would be required. This style of CMM is generally used for inspecting large-scale gears such as those used in ship and heavy equipment powertrains, turbine gearing, and gears used in nuclear and thermal power plants and wind turbines. Inspection of large-scale gears is easier to perform with this style of CMM due to its open-access structure.

On the other hand, bridge CMMs are usually the right machine for measuring small or medium-size gears. Two styles of bridge-type CMM are available. One has a fixed table with moving bridge, and the other has a moving table with a fixed bridge. This second style of CMM offers greater accuracy. Some models of bridge CMMs have quite large capacities, overcoming the need for a horizontal arm machine.

In addition to replacing dedicated gear inspection equipment, CMMs can also replace many of the smaller, hand-held and functional gages often used in gear inspection. "Hand-held gauges are subject to operator interpretation," Fox says. "Repeatability between operators using manual inspection methods is lower. Speed of measurement is certainly slower. Written reporting is open to incorrect values being recorded. An automated CMM can be measuring parts, while the operator continues to produce parts. Once the CMM program is proven out, you know you will get good accuracy, repeatability and reporting."

In some cases the CMM can even be placed right on the shop floor, alongside production machines.

"The two major enemies for a CMM are rapid and dramatic temperature changes, and vibration," Fox says. "Even when on a shop floor, if the temperature is somewhat stable there is no major noticeable error. Mitutoyo equipment has temperature sensors on each scale. Therefore proper compensation is made for temperature fluctuations. Mitutoyo has many customers that place the CMMs on the shop floor and are very pleased with the repeatability and accuracy obtained. Mitutoyo manufactures a specif-

ic CMM, the Strato, which is made for use on a shop floor. The Strato scales incorporate non-expanding glass scales; the ways are completely protected with covers and bellows and active vibration dampening using auto leveling air spring units."

Those who might have considered CMMs in the past should definitely take another look, Fox says.

"In the past 5-10 years, Mitutoyo CMMs have become much more precise with the incorporation of high-performance controllers, greater scanning technology, minimizing internal heat generation, faster servo drive mechanisms with accelerations of up to 2.598 mm/sec^2," Fox says.

With regard to precision, Mitutoyo makes both high-accuracy CMMs as well as commodity-level equipment. The commodity-level machines allow a maximum permissible error (MPE_E) of 1.7+3L/1,000 microns, while Mitutoyo's mid-range and high-accuracy machines allow 0.9+2.5L/1,000 microns and 0.6+1.5L/1,000 microns, respectively.

"It is because of the accuracy at the mid-range and high end that Mitutoyo CMMs are very well suited for the extremely tight tolerances required for gear measurement," Fox says.

"One thing to be aware of is Mitutoyo manufactures every component that is used in all Mitutoyo equipment, including all of our CMMs," Fox says. "We have excellent control over the quality of the components that go into our CMMs. This enables Mitutoyo CMMs to have the longest meantime between failure, which is from 25,000 to 30,000 hours."

Some of the key ingredients to Mitutoyo machines' accuracy include machine construction and precision components. "The Y axis is cut and ground from the same piece of granite as the plate," Fox says. "The Y axis will never change because of this, unlike CMM manufacturers that use a separate piece of granite that is glued and attached by lag bolts. In addition, Mitutoyo has always produced the best scales, which have very minimal to no expansion. Mitutoyo incorporates temperature compensation on each scale."

Beyond the precision and accuracy of the machines, one of the keys to accurate gear measurement—whether on a CMM or a dedicated machine—is the software, Fox says. For example, calculation of whether an involute curve is correct based on data points extracted during measurement requires the use of high-level mathematical formulas and sophisticated algorithms. *GEARPAK* is very exact in these calculations, Fox says, and Mitutoyo has received certification of the algorithms from Physikalisch-Technische Bundesanstalt (PTB), Germany's highest national technical certification authority.

In order to achieve certification of the software, Mitutoyo had to provide PTB with *GEARPAK* calculations based on data points supplied by PTB. The range of calculations included complex gear flank evaluation for gear tooth profile and flank line; tooth profile deviations, such as slope and form; profile crowning; tip and root relief data; helix slope and form deviations; crowning of the flank line; a variety of end relief data, including modifications of curvatures and reliefs; gear pitch; tooth thickness; tooth spacing; dimension over wires, or balls; displacement dimensions; and tip and root diameters including concentricity, or runout. The results were sent back to PTB where they were compared with the correct results. In order to receive PTB Certification the results of test data must be less than 0.1 µm (0.0001 mm or 0.000004») from the PTB's reference values.

Mitutoyo's *GEARPAK* software for bevel gears supports Gleason geometry straight bevel, spiral bevel and hypoid gears. The *GEARPAK* for worm gears module supports ZA, ZN, ZI and ZK tooth forms, as well as single- or multi-start worms.

The *GEARPAK* software is incorporated with Mitutoyo's *MCOSMOS* software package (*Mitutoyo Controlled Open System for Modular Operation Support*). By combining intuitive icon-based programming with the ability to import native CAD models, *MCOSMOS* enables even novice users to easily import part and fixture models and "virtually" place them in the volume of their specific CMM. *MCOSMOS* graphically defines the CMM, racks, probes, and even styli. Selected graphically, all measurement points are clearly displayed on a 3-D graphic view which can be rotated, zoomed, or panned to any convenient viewpoint. Animation enables offline running of a workpiece before ever placing it on the CMM, thus providing machine volume verification and collision avoidance. Then, *MCOSMOS* enables users to choose various software modules to analyze measurement results, to document and present results, and to archive the data in practical structures. Furthermore, *MCOSMOS* integrates with networked systems for in-line process control applications as well as to enable true enterprise-wide functionality.

The other attractive feature of CMMs for gear inspection is that they can easily be used to inspect other features, Fox says. By incorporating high-level software, CMMs can measure virtually any type of geometry. For example, airfoils, compressor scrolls or turbine blade geometry can be inspected with the appropriate software. In addition, "the ability to incorporate components such as vision probes using edge detection technology and laser line scanning probes have made CMMs much more flexible and powerful," Fox says.

For more information:
Mitutoyo America Corporation
965 Corporate Blvd.
Aurora, IL 60502
Phone: (888) 648-8869
Fax: (630) 978-3501
www.mitutoyo.com

Progress in Gear Milling

BY AARON HABECK, MARKETING PROJECT MANAGER, SANDVIK COROMANT US

Sandvik Offers Latest Tool Technologies

In addition to volume gear manufacturing on dedicated machines, gear teeth are increasingly being machined as features on various components, as well as gear wheels in smaller batches. Whatever the application, gear milling should perform as well as other metal cutting operations, where technology has moved on considerably. The conventional scene—i.e., specialized production of gear milling using high-speed steel hobs or cutters at moderate speeds, bathed in oil—is changing. Such are the pressures of competition.

Machining centers and multitask machines are increasingly players in this scene, putting gear teeth on wheels and multi-feature components while providing new opportunities. Just like more traditional, dedicated gear cutting machines, these newcomers to the gear industry achieve maximum efficiency. Newly developed, indexable-insert technology is now providing new means to change gears in the machining process.

Progress in tool technology. Manufacturing gears, whether in the form of a gear wheel or a component with gear elements, is a machining-intensive process, therefore efficiency is key to cost effectiveness. High-speed steel (HSS) has for some time been the dominant tool material for gear cutting; however, it is being replaced by cemented-carbide. Most machining areas are today dominated by modern indexable-insert technology based on cemented-carbide cutting edges. This is complemented by solid-carbide tooling, particularly when size makes inserts impractical. The hot hardness difference between HSS and cemented-carbide is consider-

able, determining the difference in performance.

Indexable-insert tools have been used in gear cutting for some time, but overall the technology did not provide the performance advantages or meet the precision demands that are possible today. Gear manufacturers tend to hold on to the solid HSS cutters because it remains a secure, accurate and reliable process. However, HSS is a cutting tool material over 100 years old with a limited development scope. Although it has undergone considerable development as a cutting tool material, it is inherently limited in standing up to the machining temperature and wear-loads that are expected from a modern tool. Today, there is no reason why tools should be the limiting factor in raising productivity and achieving lower machining costs in gear cutting. Generally, the tool life of a modern cemented-carbide insert is five times that of an HSS edge—and at more than 2.5 times the cutting speed as HSS.

Precision—the final hurdle. Recent advancements in indexable-insert technology have overcome the accuracy and tolerance maintenance questions that detractors once cited. This has been an area where ground HSS cutters excelled and held their own—until now. Gear milling with modern, dedicated indexable-insert tooling is achieving results within even closer tolerance classes, according to DIN.

Standards for new indexable-insert tools are Class B-guaranteed, with most criteria holding A–some even AA ratings. Quality on the machined gear wheel is usually at 9, and often even 8. In addition, minimal tool run-out contributes to longer tool life and the elimination of step tendencies on the machined surface. The machined gear profiles are uniformly close to the required finished form while small and even machining allowances for any subsequent operations are achieved. Ground indication surfaces on cutters also make for easy and clear set-up control in machine.

Speed makes the difference. The main advantages that the specially developed indexable-insert technology has provided include metal removal rates in roughing and finishing large volumes of gear profiles, along with the flexibility to improve the economics of small-to medium-volume machining. Efficient and easy tool handling is important in gear milling because of the number of inserts to be indexed. Some tools use clamps instead of screws, which allow accurate changing of inserts within

10–15 seconds. Secure, stable insert seats provide reliable performance and are user-friendly.

The recently introduced insert technology for gear milling is partly based on advances in other machining areas. Along with extensive area-dedicated development, this has contributed to a new generation of gear milling tools. This creates a comprehensive program of tools for modules 3–30, disc cutters and hobs along with new machining methods.

New cutting edges. Gear milling is performed with robust disc-type cutters and the process is characterized by interrupted cutting action. In addition to thermal variations on the cutting edge, mechanical interruptions require a suitable balance of hardness and toughness to provide durability and strength for high cutting data. The degree of toughness needed from the tool material is determined by shape and geometry, in addition to entering and exit conditions. However, in gear milling, the demands for edge toughness are influenced also by the relatively small radial depths of cut in combination with the large tool diameters.

Dry machining, without any coolant application, is the preferred method with indexable- insert milling tools and today's high machining rates. It is difficult for even high amounts of coolant to have much effect at the cutting edge, most of which is vaporized. Any remaining coolant will marginally cool the insert as it goes in and out of the cut. Thermal variations are thus amplified, which has more of a negative effect on the insert than with heat. Coolants in gear machining are very much inherited from the use of high-speed steel tooling or the need to reduce heat in the component. However, gear milling with cemented carbide can stand up to high temperatures—eliminating the need for coolant. When applied correctly, there is minimal heat transferred to the component.

In gear hobbing, however, the process is quite different—often involving over 100 cutting edges in a single tool. It is a relatively smooth machining process with continuous cuts, varying in both chip thickness and cutting-force direction. Hobs are designed to provide high precision. HSS hobs normally allow around 50–100 m/min (165–330 SFM) in cutting speed, necessitating coolant. Cemented-carbide hobs, on the other hand, work well at 250–300 m/min

(820–985 SFM)—with or without coolant.

The tool material makes the difference. A modern coated insert grade has the capability to provide high security at the temperatures generated by high cutting speeds and feeds. However, many grades function well in both dry and wet conditions if or when the coolant is necessary for chip evacuation and maintaining component temperature for keeping within dimensional tolerances. When it comes to milling normalized case-hardening steels, the advantage of cemented-carbide inserts is particularly highlighted in the form of higher productivity. For tempered steels a marked extension of tool life at higher cutting data will be the main advantage.

In materials harder than 300 HB, the possible cutting speed with indexable carbide tooling is usually five times higher than with traditional HSS tooling. Important success factors of indexable-inserts in gear milling are those of geometry and manufacturing. Edge geometry and edge preparation are important combination factors with insert grades for achieving the best solution. Establishing the right microgeometry in the form of lands, chamfers and edge rounding decisively affect the strength of the cutting edge and its durability. This has a direct influence on cutting data capability, security and, very importantly, the predictability of quality consistency. Well-developed insert geometry will also provide good chip forming, which is important for evacuation and handling. Finally, the macro- and microgeometry and position of the cutting edge in the tool will not alter, as occurs when an HSS cutter is reground.

A good location is decisive. There are a great number of large inserts in a gear milling cutter where the position of one cutting edge affects the others during a cut. If these positions vary too much, they can negatively affect machining performance (cutting forces) and the capability to achieve the right quality level. In this context the insert location, tool manufacturing techniques and precision insert tolerances are crucial to achieving solutions in a marketplace

where quality demands are escalating constantly.

Machine tools and tool holding are also crucial to success. This is where the modern, and especially stable, machines from companies like Höfler, in combination with Coromant Capto as the spindle-tool interface, provide the basis for full utilization of the new indexable-insert technology for gear milling.

The new indexable-insert technology is increasingly used for both disc cutters and hobs. It's also used on specialized machinery through new methods such as uP-Gear Technology and the InvoMilling process, where gear milling can perform very efficiently in multitask machines and five-axis machining centers. This new technology is supported by local and global specialist teams dedicated to gear milling, involving design, application and commercial backing.

The focus has been on the development of a new generation of tools, machining methods and tool manufacturing with full control of all technology and support involved. The result, that which was deemed unthinkable in gear milling less than two years ago, is now a practical reality, available broadly for reviving gear milling performance.

New methods open up new possibilities. In addition to a new generation in tooling, the development of methods for gear milling has resulted in the uP-Gear Technology for bevel gear machining, as used on Gleason Heller five-axis machines. These machines are equipped with user-friendly software and a tool set suitable for the application, providing a new, flexible, productive and cost- efficient solution. The machining time is short compared to an end milling process. Moreover, the actual machine cost is no higher than a traditional five-axis machine as the tool cost is much lower than using dedicated bevel-gear tools. Also, the number of steps needed with this method is reduced thanks to the versatility of the process.

Another unique, new method development is the InvoMilling method for machining centers and multi-task machines: a combination of slot- and turn-milling. It enables the machining of gears with any module and helix angle, both involute and non-involute profiles. Through collaboration with machine tool makers DMG/Mori Seiki, a user-friendly interface in the CNC-control of the machine makes gear-milling easy to perform in a vast number of applications. Previously, most were only possible to do on special-purpose machines.

For more information:

Sandvik Coromant
1702 Nevins Road
Fair Lawn, NJ 07410
Phone: (800) SANDVIK
www.sandvik.coromant.com/us

LMT Fette

FOCUSES ON LARGE GEAR EFFICIENCY

The market for large gear wheels is growing – in a great variety of industries: wind turbines, construction vehicles and ships need transmission systems that use large gear wheels to move very large masses. The gearing experts at LMT Fette know exactly what kind of challenge is involved in producing these components. LMT gear cutters and hobs offer considerable advantages also and especially in demanding finishing applications. In 2012, according to forecasts by the World Wind Energy Association, installed wind power capacity worldwide increased by over 16 percent. By the end of the year, wind turbines will be able to generate up to 273,000 megawatts of electricity. (In comparison, the output of all the world's operating nuclear power plants currently totals nearly 390,000 megawatts.) And this boom is continuing: green electricity's share of the global energy mix is rapidly increasing. However, other industries that rely on large gears are also booming. For example, according to the German Association of the Automotive Industry (VDA), the global market for heavy commercial vehicles will grow by five percent this year.

What impact is this dynamic growth having on the production of the gears used in wind turbines, large commercial vehicles, building equipment and mining technology? "Requirements in many sectors have increased massively," explains Thomas Falk, who is responsible for gear cutting at LMT Tools. "Wind turbine engineering makes that especially clear. These installations are not only getting larger and larger, but they also have to be able to work longer without breakdowns. That naturally also applies to transmission systems and gears." As a result, very special attention is being paid to cutting processes. It is important here not only to machine components swiftly and efficiently, but also to achieve the highest possible surface quality during the finishing process. "When it comes to very large gear elements, machining quality and tolerances also and especially play a great role," confirms Falk. "Ultimately

they are responsible for the efficiency of the overall transmission system."

The machining is carried out using hobs or gear cutters—each with indexable inserts. Both types of tools can be used for both roughing and finishing. The choice depends on batch size or the required number of cogs. "This is where customers benefit from LMT's extensive range of tools and our pool of knowledge and experience. We can provide very exact advice when, for example, the blueprint of the component is available and the customer's operating conditions are known. We can then develop the most efficient tool solution," explains Falk.

The great benefits of LMT tools then become evident in practical use. On the one hand, the standardized and readily available range of indexable inserts and standardized tool bodies keep costs low for users. On the other, LMT specialists have developed innovations that guarantee quantum leaps in machining performance. Examples of this include the new LCP35H cutting material and the new range of sizes for gear cutters:

LMT developers combined an extremely tough, ultra-fine grain carbide with the wear-resistant Nanotherm coating for the LCP35H. This combination significantly boosts performance in wet machining, for example, and prevents the formation of fractures. This increases the operating life of the indexable insert and also makes the process extremely reliable. The new gear cutters with standardized indexable inserts for roughing stand out because of their very smooth cut in practical operation. LMT Fette designs the desired tooth flank contour to meet customers' requirements. This gives rise to powerful roughing and finishing tools that guarantee the highly cost-effective production of gear wheels.

"Overall, we can provide appropriate tool solutions for all applications in the large gear sector. We are a technology leader here — especially when it comes to perfect surface qualities and the lowest possible machining tolerances. This combination is giving us major opportunities in an increasingly important market," Falk sums up the enormous potential opening up for LMT Fette.

For more information:
LMT USA Inc.
1081 S. Northpoint Blvd.
Waukegan, IL 60085
Phone: (847) 6933 270
www.lmtusa.com

Zoller

OFFERS INSPECTION FOR HOB CUTTERS

Gear cutting is a challenging task. Only perfect and re-sharpened tools can guarantee correct workpieces, short setup times and low downtimes of expensive gear cutting machines. Complete documentation and logging are fundamental requirements. The measurement and inspection of hob cutters has remained the domain of highly complex and extremely expensive measuring systems. Tactile sensors are in wide-spread use, requiring especially trained operators and considerable time. High costs and supply bottlenecks are the result.

With it's new *hobCheck* Zoller now offers a quantum leap for the measurement of hobs: the first truly shop floor compatible and at the same time economical specialist for the overall measurement of hob cutters. Zoller combines image processing technology with a measuring sensor, a swiveling optic carrier and six CNC-driven axes to provide distortion-free complete measurement of hobs. This gives the user an exact replica of the tooth profile on the cutting edge.

The user-friendly software *pilot 3.0* offers a simple operation by displaying the desired parameters according to DIN 3968. The calculation of the quality classes and graphic logging is fully automated. The link to esco, the standard software for hobs, avoids duplicate data entry, saves time and guarantees an error-free measured result taking current parameters into account.

These include concentricity and runout, deviations in the shape and position of the cutting face, of the cutting edge, tooth thickness and flute direction. The quality class is assigned automatically and marked appropriately in the protocol.

The *hobCheck* not only solves the challenge of measuring hobs economically with high precision, but also

includes all the standard functions of a measuring machine. The complete measurement of standard and special tools (drills, step drills, form cutters and milling cutters) is possible without any difficulties. This is a distinct added value, especially for re-sharpening businesses.

For more information:
Zoller Inc.
3753 Plaza Drive, Ste. 1
Ann Arbor, Michigan 48108
Phone: (734) 332-4851
www.zoller-usa.com

Drake Manufacturing

CO-EXHIBITS WITH VMT AT IMTEX 2013

Drake Manufacturing Services of Warren, Ohio, with its representatives, VMT Technologies India, displayed a high accuracy work head and linear motor demonstration unit in its booth at IMTEX. The unit helped visitors visualize the technologies used in Drake machines. The display featured Drake's high-accuracy work head and the various components of the linear motor platform including linear motor and magnets, rails, and roller cars and 8-million count Heidenhain encoders. Linear motor drives mean no drive train windup, backlash, or lead error due to aging ball screws, couplings, or bearing blocks. Drake also demonstrated its built-in *Part Smart* programming and menu screens on a Fanuc CNC control system. With Drake's *Part Smart* menus, no programming knowledge is required. The *Part Smart* approach allows users to run parts and change-over jobs with menu-driven ease. In conjunction with IMTEX, Jim Vosmik, Drake's president, presented, "The Latest Developments in Fine Pitch Thread Grinding" on January 23 at the International Seminar on Machining Technologies (ISMT). Attendees learned about the latest developments in wheel, machine, and dressing design for fine-pitch thread grinding. Drake has many machine installations in India and throughout Asia including thread grinders, ball screw grinders and profile gear grinders for a variety of applications. Local Indian sales, service and support is handled by VMT Technologies-Bangalore.

For more information:
Drake Manufacturing Services, Inc.
4371 North Leavitt Road
Warren, OH 44485
Phone: (330) 847-7291
www.drakemfg.com

Coord3

LAUNCHES UNIVERSAL CMM TO NORTH AMERICAN MARKET

Earlier this year, Coord3 launched its all new 'Universal' line of CMM machines at the Control Expo show in Stuttgart, Germany. Now, Coord3 Metrology LLC, headquartered in Wixom, Michigan is introducing the new European-manufactured 'Universal CMMs' to the North American market.

Coord3 CEO Angelo Muscarella states "since taking the company into private ownership three years ago, we have focused on rebuilding our international distribution and engineering growth in the large CMM market segment. With the introduction of the Coord3 Universal bridge CMM, we focus the company into the highly competitive vertical bridge CMM market at a time when all of our major competitors are supplying an increasing array of cost-focused Chinese manufactured CMM units. The Universal CMM applies our 'design-for-manufacture' focus that dramatically reduces CMM assembly and calibration times and allows Coord3 to not only compete in global markets against low-cost China manufacturing operations, but also allows Coord3 to double our CMM manufacturing capacity, with a negligible increase in factory space or workforce."

The Universal CMMs utilize a high-technology alloy, moving frame design that provides the benchmark for dynamics and measuring accuracy performance. This design overcomes the issues associated with operating traditional granite CMM structures, in the typical, less than perfect, CMM operating environments. In addition, the Universal CMM introduces a wireless CMM thermal compensation system of both machine and part, allowing the measuring system to automatically and dynamically compensate for changes in the CMM operating environment. This system allows the CMM to perform with stated measuring accuracy between 16 and 26 degrees C. Gold-plated 0.1 µm measuring scales are free-floating in support tracks, eliminating any CMM structural changes from influencing its measuring accuracy.

The Coord3 Universal CMMs provide a highly rigid structural coordinate measuring platform, allowing the use of point-to-point, analog contact scanning and laser scanning sensors, making it suitable for full five-axis and gear measuring applications.

Universal CMMs have a very efficient design in terms of machine complexity, which improves long-term reliability and ultimately cost of CMM ownership. The Coord3 Universal CMMs have an isostatic design for each axis that provides optimum machine geometrical alignment in the construction of the machine, which ultimately benefits the ability to make accurate field calibrations. Universal has a monolithic base-plate, with integral inverted dovetail guide-way, and a generous 90 mm (3.5 in.) × 90 mm (3.5 in.) Z Ram section. Direct axis drives, using toothed drive belts, provide the vibration-free motion with zero hysteresis.

Universal CMMs can also be equipped with an optional SZP (Safety Zone Protection System), which uses laser scanners to monitor the defined protection zone when the CMM is in high speed automatic measuring mode. SZP reduces the CMM speed upon infringement of the safety zone by an operator and automatically returns the CMM to its full measuring speed, only after the zone infringement has been cleared. The SZP system allows safe use of the CMM in a production, shop-floor and fully-automated applications.

The higher accuracy nano technology (NT) version of the Universal CMM that uses a silicon carbide Z ram and enhanced measuring scale system to provide higher speed enhanced scanning accuracy offering a 0.3 μm reduction in measuring uncertainty.

The Coord3 Universal CMM family of machines is currently available with measuring strokes for the X-axis of 1,500 mm, 2,000 mm, 2,500 mm and 3,000 mm; Y-axis of 1,000 and 1,500 mm; and Z-axis of 900 and 1,000 mm.

For more information:
Coord3 Metrology LLC.
48861 West Road
Wixom, MI 48393
Phone: (248) 397-5490
www.coord3.com

Sunnen
INTRODUCES NEW HONING FEATURES

Sunnen Products introduces new servomotor and drive technology under the hood of its three primary vertical honing platforms, bringing additional capabilities, speed, accuracy and safety to the machines. As a result, the company's existing SV-1000, SV-400 and SV-500 models are being replaced with the SV-2000, SV-2400 and SV-2500 series of machines that feature the same outward appearance as the predecessor models.

The various new models have upgraded capabilities such as selectable tool-

feed, constant crosshatch and faster automatic bore detection for reduced cycle times. The SV-2000 and SV-2400 machines are already in production, while remaining SV-400 and 500 models will be replaced later this year. The range of machines can process bores ID's from 3 mm to 300 mm, typically found in parts such as fuel injectors, piston pumps, gun barrels, hydraulic components, engine/compressor cylinders, diesel cylinder liners, landing gear and similar.

All of the new models now include a 7.5 kW (10 hp) servo spindle. The new SV-2000 platform offers a new choice of controlled-force or controlled-rate tool feed. Controlled-rate allows automatic tool feed in increments as fine as 0.1 μm (0.000010"). Controlled-force tool feed monitors force in the tool feed system. It feeds the abrasive at the highest rate possible for part conditions, ensuring shortest cycle times and longer abrasive life. The new SV-2400 platform now includes selectable “constant spindle load” and controlled-rate tool feed as standard. Other new capabilities on the upgraded models include whole-bore, constant crosshatch angle. Constant crosshatch eliminates the “flattening” of the crosshatch angle at stroke-reversal points, a feature required by some engine manufacturers and MilSpec parts.

The new drive technology also enables the machines to be setup to hone only on the pull stroke, or easily produce custom profiled and tapered bores. All the new platforms include safe-drive technology that monitors all safety devices on the machine with a separate PLC, which stops or limits the speed of the drives if triggered.

For more information:
Sunnen Products Company
7910 Manchester Road
St. Louis, MO 63143
Phone: (314) 781-2100
www.sunnen.com

Mahr Federal

DISPLAYS MEASURING SYSTEM AT MD&M WEST

Mahr Federal will be featuring the MarSurfR XR 1, an economical, mobile, PC based surface measuring system, at MD&M WEST, February 12-14, 2013, at the Anaheim Convention Center, Anaheim, CA, Booth #2885. With the MarSurfR XR 1 surface measuring system, Mahr has bridged the gap between portable surface measuring devices and larger, full-featured, PC-based surface measurement and evaluation systems. The MarSurf XR 1 combines the skidded and skidless drive units of Mahr’s portable M-Series instruments, with its MarWin evaluation software. The new XR 1 provides an affordable entry into the world of modern, PC-based measurement and evaluation systems, including compliance with all International Standards, diverse evaluation methods, extensive documentation, large storage capacity, data export and import, as well as networking and other benefits.

The MarSurf XR 1 is suitable for use either in the measurement lab or on the shop floor, and provides over 80 parameters for R, P, W profiles according to current DIN, ISO, JIS, ASME and MOTIF Standards. The system can utilize both the MarSurf RD 18 drive unit with skidded probe and the MarSurf SD 26 drive unit with skidless probe, and virtually any number of drive units can be connected to the evaluation unit via Bluetooth or cable. Measuring units can be used alone in different orientations, in combination with various accessories, or mounted on measuring stands. Measurements can be initiated either by touch screen on a PC or manually on the drive units.

Mahr Federal will also feature their line of Dimensionair air gaging products for orthopedic and other non-contact applications. Air gaging is a proven, highly precise and accurate way of measuring bores and tapers often found in orthopedic implants. It is quick and easy to use, requiring little skill on the part of the operator, and is highly adaptable to measuring special features for both dimensional and geometric tolerances.

For more information:
Mahr Federal Inc.
1144 Eddy Street
Providence, RI 02905
Phone: (401) 784-3100
www.mahr.com

Ingersoll Cutting Tools

SWITCHES TO OELHELD'S SINTOGRIND

To advance its grinding capabilities and improve the working environment, Ingersoll Cutting Tools has switched to SintoGrind IG, a synthetic based grinding fluid, to ensure reliable high quality and improved performance. Since their first cutting tool patent in 1889, Ingersoll has strived to provide innovative and productive metal removal solutions on the market including indexable carbide end mills and on-edge insert configurations. Bob Arndt, manager of carbide manufacturing in Rockford, Illinois says, "We take great pride in producing a quality product supported by superior service to our customers." The Rockford plant is a significant U.S. manufacturer of industrial tungsten carbide high feed inserts for the automotive, aerospace and agricultural industries. "We have invested heavily in leading edge CNC equipment to retain our quality edge and delivery promise. The key to manufacturing a good tool," Arndt says, "is in controlling the grinding process through a variation of principals. Our tools need to have a long life which starts with a clean, chip free cutting edge. Therefore, close monitoring of the grinding speeds/feeds, grinding wheel and especially the grinding fluid is critical. Synthetic grinding fluids developed and produced by oelheld U.S., Inc. coupled with a clever and smart filtration system exactly meet the demands of Ingersoll Cutting Tools." With the install of a fine filtration system and switching over to SintoGrind IG, a super high performance synthetic grinding fluid, new benchmarks have been set in carbide production at Ingersoll.

For more information:
Ingersoll Cutting Tools
845 S. Lyford Rd.
Rockford, IL. 61108
Phone: (815) 387-6600
www.ingersoll-imc.com

Oelheld U.S. Inc.
1760 Britannia Drive Unit 1
Elgin, Illinois 60124
Phone: (847) 531-8501
www.oelheld.com

Rex-Cut

OFFERS COTTON FIBER ABRASIVE WHEELS

A line of Type 27 cotton-fiber abrasive wheels that can remove filet welds on stainless steel and aluminum and produce food-grade finishes in one-step is available from Rex-Cut Abrasives of Fall River, Massachusetts. Rex-Cut Type 27 Cotton Fiber Grinding Wheels feature multiple layers of cotton fiber that are impregnated with aluminum oxide grains and then pressed and bonded together. Suitable for removing filet welds on stainless steel and aluminum, they constantly reveal fresh abrasives to provide smooth controlled grinding action and can grind with both the side and face. Available in 4½", 5", and 7" sizes, 3⁄16" and ¼" thick, with A36 or A54 grit sizes, and a GFX latex bond, Rex-Cut Type 27 Cotton Fiber Grinding Wheels provide finishes that are two to three grit sizes finer than comparable wheels and are non-loading on aluminum, claims the firm. Optional 5⁄8"-11 throw away adapters are offered. Rex-Cut Type 27 Cotton Fiber Grinding Wheels are priced from $7.37, depending upon size and quantity. A price list is available upon request.

For more information:
Rex-Cut Products, Inc.
960 Airport Road
P.O. Box 2109
Fall River, MA 02722
Phone: (800) 225-8182
www.rexcut.com

JOB SHOP LEAN

Editor's Note: This is the first article in an eight-part "reality" series on implementing continuous improvement at Hoerbiger Corporation. Throughout 2013, Dr. Shahrukh Irani will report on his progress applying the job shop lean strategies he developed during his time at The Ohio State University. These lean methods focus on high-mix, low-volume, small-to-medium enterprises and can easily be applied to most gear manufacturing operations.

Dr. Shahrukh Irani, Director IE Research, at Hoerbiger Corporation of America

The Idea Factory

If an organization decides to embark on its *lean journey*, its leaders should be prepared to embark on a *never-ending journey*. Toyota Motor Corporation is the unquestionable poster child of companies that have made continuous improvement an effective and self-sustaining business strategy. At Hoerbiger Corporation of America, located in Houston, Texas, we manufacture a wide range of components and systems for reciprocating compressors. Our R&D teams develop technologies that extend component life and improve overall machinery performance. Product manufacturing is strictly controlled—from procurement and testing of raw materials to installation and testing at our customer sites.

In the United States, we have manufacturing facilities in Pompano Beach, Florida, and Houston, Texas. In addition, we have nine other production facilities spread across the globe in cities like Vienna (Austria), Shanghai (China), Pune (India) and Zandov (Czechoslovakia). Here in the United States, our range of metallic and non-metallic products include: capacity control, monitoring systems, compressor valves, piston rings and rider bands, rod packing, pistons and piston rods, and check valves. Accordingly, we serve many markets, e.g.: OEMs, oil and petrochemical refining, natural gas, refrigeration, cryogenic and industrial air and gas markets.

In our Houston facility (which occupies 63,000 square feet and employs about 125 people) we machine both metallic and non-metallic components, and do some final assembly also. We are loosely organized into five machining cells and two molding departments that produce the bushings supplied to the machining cells.

Through the coming months, Job Shop Lean will discuss a range of projects undertaken and experience gained as I and many of my colleagues throw ourselves into learning, failing, trying, succeeding, innovating and celebrating every little success. To every reader of *Gear Technology*, I can sincerely say one thing: What you will read is exactly what happens in our Houston, Texas, facility because it takes considerable efforts from everybody to bring every project to fruition. To gain each success, there will be many failures, frustrations and setbacks along the way.

If Every Team Could Implement One Idea Every Week

We began our continuous improvement journey simply by asking each employee on the shop floor to come up with an idea that they would like to see implemented, or could just implement themselves. Our previous plant manager Keith Farnham, had initiated a weekly all-hands meeting with the shop employees at 7:00 a.m. every Friday. He organized the employees on both shifts into teams and appointed a leader for each team. These teams are basically the employees who work in the five machining cells (quick response, CNC packings, power rings, piston rings, manual packings), molding cells (cold compression molding, hot compression molding) and support departments (quality, maintenance, shipping, receiving).

Now, I am a former academic and could be forgiven for doing a simple calculation. If every week, each team in each shift implemented one good idea, this would result in 22 improvements being made every week. Assuming approximately 50 working weeks in the year, we could have *1,100* improvements that could impact our core business goals (workplace safety, job satisfaction, speed of customer service, waste reduction and sales).

It helps to have a CEO (Don York) who walks to your office instead of phoning or e-mailing you to come to his. Whenever he walks through the facility, he uses his time on the floor to guide and offer suggestions to employees in the areas that he visits. York did not demand that I develop and administer a cookie-cutter lean assessment tool to kick off our journey.

The very first improvement idea that was offered by a shop employee concerned safety. Ly Nguyen from the quick response cell demonstrated how loading/unloading heavy parts on an engine lathe could lead to an accident. That resulted in immediate attention to bringing in handling equipment for parts loading/unloading.

Our supervisors, such as Charlotte Pett (shipping), Leonel Salinas (molding), Greg Oakley and Ziggy Skora (machining), also deserve much credit. A continuous improvement program often loses steam because it gets mired in housekeeping projects. Rather than lapse into that comfort zone, our supervisors ask their teams to extend themselves and select challenging projects after the initial housekeeping projects get done. Their message could be summed up as follows, "Just give it a shot. Let me handle the fallout if you fail. Okay?"

We Also Leverage The Time And Talent Of Our Engineers

Conventional wisdom says to let all continuous improvement work be thought about and implemented only by the employees themselves. Otherwise, the improvements will not be accepted or the solutions will be implemented in half-hearted fashion at best. That is not the case in our company. Sometimes the project is technically demanding, and involves IT, data mining or other "engineering skills." Take the case of implementing a project to assess if our workforce was ready for the introduction of computer-aided shop scheduling and order tracking. That was right down the alley of Paul Mittendorff, director of manufacturing systems. With the assistance of one of our planners, Russell Irvine, Mittendorff helped to implement the software in one of our cells. Meanwhile, the cell team did its own workplace improvement projects.

Now consider Shalini Gonnabathula, our continuous improvement engineer, who has an M.S. degree in industrial engineering. It helps to have a details-oriented IE like her to do the methods analysis and time studies that have produced accurate time standards for our ERP system. The time studies she has done have helped cost accounting, scheduling and level loading of our production plans.

Finally, I hope that you will take inspiration from the work that was done for us by Thomas Leskowschek, an undergraduate intern from Austria who is studying for his B.S. in industrial management in the Department of Industrial Management at the FH-Joanneum University of Applied Sciences. Together, we assisted several employees with their continuous improvement projects. In addition, during the four months that he was with us, we did a slew of interconnected technical projects that sought to improve the space utilization and workflows in the shipping department. Thomas brought to Hoerbiger a great work ethic and solid, integrated engineering training. Hoerbiger matched that by giving him valuable on-the-job training by involving him in a variety of meaningful projects where he was mentored by experienced senior personnel.

Recognizing The Smallest Efforts

We do our best to recognize initiative while refraining from scoring employee projects. Take the case of Luong Dam, a machinist in the manual packings cell. He took so much pride in doing housekeeping improvements while his milling machines remained in cut. Talk about eliminating the wastes of waiting and operator motion!

The shipping department contained plenty of dead or slow-moving inventory prior to lean implementation (all photos courtesy of Hoerbiger Corporation).

BEFORE

Then there is our ebullient receptionist, Keri Walker. One day over lunch she got to talking with Charlotte Pett about the projects they were doing in the shipping department. That was reason enough for Walker to clean and spruce up the supplies closet in a couple of days. Now she has posted instructions on the door of that closet to prevent it from becoming a dumping ground for others.

We Seek The Movers And Shakers In Our Workforce

One of the best continuous improvement projects is that of Juan Nunez in shipping. The first half-hour stand-up meeting that we had with that team yielded a popular grouse from the employees, "We do not have space. It is too crowded in here!" The intern and I did a 5-Why's brainstorming session with them. A color-coded map of the department layout showed that several areas were "locked out" by racks carrying dead or slow-moving inventory. In one case, two steel racks along the wall carried incomplete orders waiting for one or more parts to get done so they could be packaged and shipped. Nunez came in on a Saturday, emptied an outside rack that had dead inventory, then moved these incomplete kits out of the department. He then categorized the kits and labeled every location that carried an incomplete order. What next? He has kicked the ball back into our court. We will log onto our ERP system and document why each kit is incomplete. So this is how our employees work with our industrial/manufacturing engineers whenever the need arises.

We Are Lucky To Have In-House Lean Experts

Leonel Salinas, supervisor of both molding departments, is a prime example of an individual who demonstrates the potential to become our eventual in-house sensei. He has both a B.S. and an M.S. in manufacturing engineering from the University of Texas – Pan American, along with a prior stint at Siemens where he learned to implement lean. In walking past his areas, you will see considerable evidence that lean has taken root; i.e., they are clean and organized. He does weekly production huddles with his people in both departments to address issues; I have often seen him assisting his employees. He has acknowledged their projects and recommended them for Employee Achievement Awards. In fact, I challenged him to pursue the next level of improvement opportunities since they have already plucked many of the low-hanging fruits in both departments. As the work in this department involves considerable heavy loading/unloading work, he allows rest breaks that outside observers would consider to be slacking off.

A Team Leader Who Puts Team Before Self

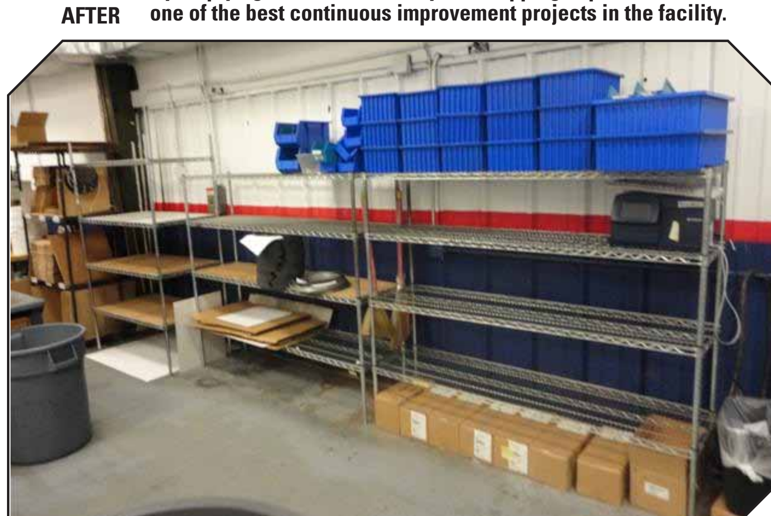
James "Rojo" Bowen is the team leader for the hot compression molding (HCM) cell. He "drank the lean Koolaid" when it was "served to him" by his supervisor, Salinas. I got to work closely with Rojo because we were put on the Tiger Team that our CEO asked to be formed to drive continuous improvement into the ranks of our workforce. You will be inspired to hear Rojo talk about the importance of lean because he has seen the impact in his department! So I decided to cite him for an Employee Achievement Award. At that time, I did not know that he had already won the Employee of the Year Award for 2010. I requested him to swing by my office and provide additional details about his lean projects so I could complete my citation. Okay, so he comes to my office, settles into a chair and then did what we know is core to the Toyota culture: humility and team before self. Rojo asked me to include EVERYBODY in his department in the citation for Employee Achievement Award because "I could not have done what I did without all of them contributing". Yes sir, the molding departments are where lean is thriving here in HCA-TX and from there it will spread to the rest of our facility. Count on that!

We Also Do the "Big Bang" Improvement Projects

Even as the dozens of small quick-and-easy improvement ideas of our employees are being implemented, we are also doing a

AFTER

By emptying the dead inventory, the shipping department now boasts one of the best continuous improvement projects in the facility.



few "Big Bang" improvement projects. There is no better example than the complete revamping of the receiving department. This was done by Anthony Herrell, materials manager, Andrew Reynolds, warehouse and inventory supervisor, and department personnel, including Willie Christopher, Linh Nguyen and Thomas Tubes. Similarly, a computerized scheduling and order tracking system has been implemented in one of our manufacturing cells. It serves as a pilot to assess the pros and cons to a full-blown implementation of the same system to manage our entire facility. Each of these projects will be described in detail in a future column.

A Humble Start To Our Lean Journey

In their article "Swarm Intelligence: A Whole New Way to Think About Business" (*Harvard Business Review*, May 2001, 106-114), Eric Bonabeau and Christopher Meyer state that even an ant colony collectively executes and completes challenging tasks because of three characteristics:

- Flexibility (the colony can adapt to a changing environment)
- Robustness (even when one or more individuals fail, the group can still perform its tasks)
- Self-Organization (activities are neither centrally controlled nor locally supervised)

In a similar vein, we at Hoerbiger Corporation decided to first and foremost have ***all of our shop employees*** undertake continuous improvement projects of ***their*** choice; we have not imposed any constraints or expectations on them. Rather, we have allowed them to choose *what* to improve, *where* to improve, *how much* to improve, etc. Perhaps the only "higher level" involvement that management had was to have them work in teams that are associated with a manufacturing cell or department. That will ensure that even though we have embarked on just the first leg of our lean journey, future projects will impact clusters of value streams based on part families (or an entire segement of the product mix).

Since September 2012, **Dr. Shahrukh Irani** has been the director of industrial engineering research at Hoerbiger Corporation of America (www.hoerbiger.com). Previously, he was an associate professor in the Department of Integrated Systems Engineering at The Ohio State University. His research there focused on the development of new IE methods to adapt and scale lean for use by high-mix, low-volume SME's (small and medium enterprises). His research group created PFAST (Production Flow Analysis and Simplification Toolkit)— a software tool for material flow analysis and facility layout to implement lean in job shops. Irani subsequently received the Outstanding Faculty Award for excellence in teaching from the graduating classes of 2002—2006, and 2009. In 2002, he received the Charles E. MacQuigg Student Award for Outstanding Teaching from the College Of Engineering. He served as the director of the facilities planning and design division of the Institute of Industrial Engineers for 1999-2001 and 2001-2003. He is the editor of the Handbook of Cellular Manufacturing Systems (1999, John Wiley). In 1996, he was voted Young Engineer of the Year by the Minnesota Federation of Engineering Societies and the Minneapolis Chapter of the Institute of Industrial Engineers.

The "Gear Gods" Help Those That Help Themselves

AGMA delivers with online and on-demand gear training

By Jack McGuinn, Senior Editor

(Editors' Note: With the following article Gear Technology begins its enhanced coverage of gear training and education programs. From teens to twenty-somethings to bucket-listers—gearing/engineering programs around the country are fighting the good fight in their efforts to coach up both aspiring and veteran gearheads. Watch this space in every issue as we showcase these schools and associations.)

It makes sense to begin our newly expanded coverage of education with the American Gear Manufacturers Association's (AGMA) longtime commitment to the industry and its members via their comprehensive gear schools and an assortment of on-demand or real-time, face-to-face seminars on specific gear issues. In all cases the classes and seminars—onsite, online, video format—are taught by veteran gear industry players; i.e., gear business owners, OEM executives, highly talented engineers, full-time educators and CEO s among them.

To obtain the most up-to-date information regarding all AGMA training we turned to Jan Alfieri, AGMA education manager.

"We have a number of great online training opportunities that run the gamut: from 90-minute webinars to 15-hour video courses offered in one-hour segments," Alfieri says. "The webinars are offered live throughout the year and are then archived for purchase later if you missed one. Many companies encourage employees to attend the live sessions as a group, and they also purchase the archived event for a company training library.

"Through generous support from the AGMA Foundation, we have recorded two of our most popular live courses, taught by two of our most revered gear experts—*Detailed Gear Design*, taught by Ray Drago, P.E. (*gear-doc@att.net*), and *Gear Failure Analysis*, taught by Bob Errichello (*geartech@mt.net*). Students can get the experience of the course through one-hour-segment videos and supporting training documents.

"We also offer three self-paced courses that are free to employees of member companies (a savings of $295 per person, per course.) These begin with *Fundamentals of Gearing* (which provides a nice foundation for anyone in a company) and then become a bit more advanced *with (Gear Manufacturing) Hobbing and Parallel Gear Inspection.*)"

It is obvious in visiting the AGMA website (*www.agma.org*) that there is no shortage of training modules and seminars available—for AGMA members and non-members—there for the "taking" whenever you're ready and class schedules allow. We'll focus here on just a sampling—some new—of the many learning opportunities.

Arguably the most significant news regarding AGMA's gear school is that two of the most popular—and important—classes offered are now available both online and in video format. We're talking about Drago's *Detailed Gear Design* and Errichello's *Gear Failure Analysis*. If you went through the college experience you can liken the keen interest in these courses and their teachers to those presented by revered professors teaching, for example, Film 101 or *The Kinsey Report*. And so it is there is always a waiting list to sign up for *Gear Failure Analysis* (*Ed's note: See page 84 for information on Ray Drago's Gearbox CSI event in March*).

Gear Failure Analysis

Errichello employs the latest industry tools and methods; i.e.—lectures, slide presentations and Q&A sessions—to impart a straightforward yet comprehensive understanding of why gears fail. Errichello possesses Bachelor's and Master's Degrees in mechanical engineering and a Master of Engineering degree in structural dynamics. He has over 40 years of experience, has authored some 60 articles—many appearing in *Gear Technology*—and is a recipient of AGMA's prestigious Lifetime Achievement Award.

According to Errichello, students will learn the causes of gear failure and how to proactively prevent it. (Avoiding gear failure can save tens of thousands of dollars—or much more—in

Among the new AGMA learning options available are Ray Drago's Detailed Gear Design as well as other on-demand online and video format presentations (courtesy R. Drago).

repair, downtime and or liability costs; think of a high-volume assembly line going down or a gear-related HVAC system failure in, for example, a hospital.) With that in mind, Errichello presents and explains the various types of gear failure, such as overload, bending fatigue, Hertzian fatigue, wear, scuffing and cracking. As well, the typical—and atypical—causes of these failures are presented, along with suggestions on how to avoid or correct them.

"We teach a gear failure analysis seminar and get a diverse student base from many different industries, not just the gear industry," Errichello says. "Consequently, many don't have an engineering background in gears. We find that their interest in gear failures piques their interest to know more about gear design and inspires them to take other courses to increase their knowledge in all aspects of gear design."

Indeed, the course does indeed provide his students a leg up in finding—or retaining—employment in whatever industry they work. If, say, a student is a factory maintenance manager, you can bet that gears and gear drives—and their failure—are in play.

"Yes, most of our students work in industries that have gear failure problems, Errichello says. "Gear failure analysis is a unique skill that helps secure employment."

And while Errichello readily admits that students taking his course are not going to "graduate" as gear experts, the program's success speaks for itself. And how that affects potential job opportunities is a relative scenario.

"That (securing employment or promotion) depends on the circumstances of the employer. Some companies are willing to train on-the-job; others want entry-level people to have some gear experience. Our training in general failure analysis is a good background for students to learn about gears in general."


Bob Errichello, Gear Failure Analysis instructor with Corny, a fondly remembered "best friend." (courtesy B. Errichello).

Who benefits from this course: Attendees from an array of industries and job functions will gain an understanding of how to solve everyday problems—whether you are a gear engineer, user, researcher, maintenance technician, lubricant expert or manager.

And to get a head start on the learning experience, Alfieri advises that students would be wise to visit AGMA's archived webinar that addresses metallurgy of gear materials, presented by Dr. Phil Terry, AGMA chairman/Technical Division Executive Committee. This webinar is highly recommended for those with no training in metallurgy.

Upon completing the course: Students get to keep their course manual as a permanent reference and guide for failure analysis. It offers over 100 color photos, dozens of illustrations, a textbook and failure atlas. And perhaps most important, students completing the course and successfully completing a short quiz will receive a certificate for completion of 10 hours of advanced training.

Detailed Gear Design

Another waiting-list-only attraction is taught by longtime, indefatigable gear expert Ray Drago, chief engineer for Drive Systems Technology and a man of respect in the gear world. Drago presents this in-person (also online and video) course in 15 one-hour modules, along with supporting training documents. *Detailed Gear Design* teaches students about gear design and then challenges them with carefully crafted scenarios they are likely to face in their jobs and demonstrates practical application of optimization methods.

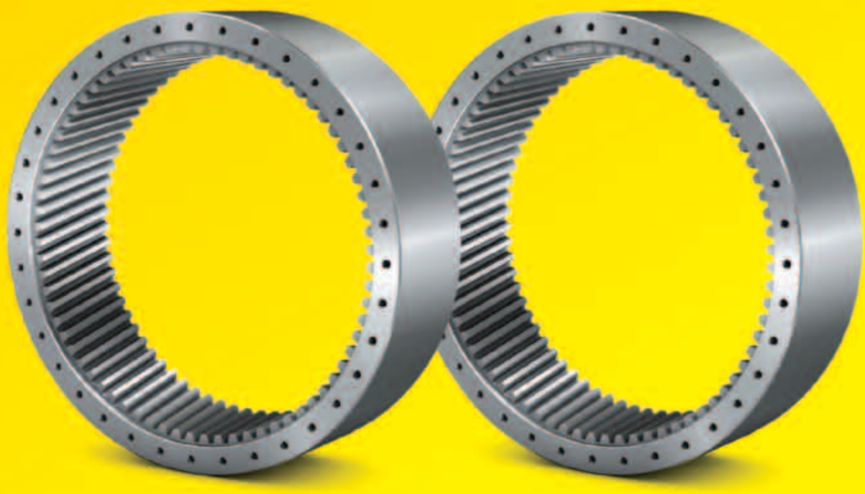
As with Errichello's gear failure module, Drago's *Detailed Gear Design* course is as timely as ever. That's because gearbox applications have proliferated in a great number of new applications. And, of course, that means there exists an ever-greater need for engineers to design them.

Drago concurs regarding gearbox growth.

"Yes, this is certainly true. Gears and gearboxes are omnipresent in a huge number of devices and industries. At this very moment, for example, the (Drive Systems Technology) team is working on gearbox applications, including a 'future' space vehicle; coal and iron ore conveyor systems; helicopter gearbox manufacturing development; three very large, high-horsepower steel mill systems; a SAG mill; a fishing reel; pulper systems for paper processing; an automotive drive improvement; a crane drive; coal and cement mill drives; among a host of others.

"This extreme variety of applications affects our training approach in a very direct way. We start every class by advising our seminar participants that, regardless of application, similar gearbox technology can be successfully applied. That is not to say that all gear systems are the same. Rather, the underlying principles are similar across many applications. For exam-

Ray Drago, Detailed Gear Design and Gearbox CSI instructor, firmly believes that recruitment of tomorrow's engineers should begin in the earliest grade levels.



ple, we are now working on two non-lubricated gear systems; one of them uses gears much less than one inch in pitch diameter, with a diametral pitch over 60, while the other involves a gear more than 12 feet in pitch diameter with a diametral pitch less than 1.0! In both cases, we apply the very same principles to minimize wear rate. It is this commonality that we try to convey to our seminar participants. I refer to this as adding to the seminar participants' gear technology 'bag of tricks.'"

Given that gearbox design is a very complex process requiring critical knowledge of gears and how they work, you'd reasonably think course attendees meet that standard.

Better think again.

"Our seminars are attended by folks with an extremely wide variety of backgrounds and we are occasionally completely surprised," says Drago. "One participant several years ago is particularly memorable. She was a woman whose age I guessed (correctly) as close to 70. I spoke with her at various breaks and finally asked what her job was and how she came to attend this particular seminar. She told me that she was a secretary at an old family-run, gear-related company and was not an engineer at all. She said that she was about to retire and her very long-term employer wanted to do something special for her.

"To her boss's surprise, she asked to attend this seminar so that she could finally understand what 'all her men' were talking about! Realistically, the fact that the seminar was held at the Sheraton Sand Key Resort in Clearwater Beach, Florida probably played into her request too.

"Over many years we have had a truly broad range of participants—from veteran gear engineers looking to update their skill and knowledge base to complete 'newbies' and even some still in college. In addition, we have folks who were not engineers at all, including purchasing agents, maintenance technicians—particularly for our *Gearbox CSI* seminar) and company executives who wish to gain a better understanding of the technology that is the basis of their various companies (*Please note:* Gearbox CSI *is another "hot-ticket" course, see page 84 for information*).

Listening to Drago, one gets it that the man is also a born entertainer. While the online and video versions of his instruction are all of equal technical value, the added, in-person human touch is always welcomed.

Continuing with his live events, "We have also modified our seminars for on-site presentation to special audiences. For example, we have been asked to present a seminar on the gearbox technology considerations required to enter the wind turbine gearbox arena at the national engineering and sales meeting of a major company, and another to present a summary of the 'state of the art' of gear system technology at a research and technology center for one of the major auto makers.

"Further, to address a broad need in the industry, we developed a seminar entitled *'Steel Mill Gearing Technology—A Practical Treatment for Engineers, Technicians, Managers and the Skilled Trades.'* As the name implies, attendees include all levels of involvement—from upper management to line-level millwrights and similar trades. The intent is to provide all involved—from top to bottom—with a reasonable understanding of the importance of gearing in the operation of a steel mill (or any other primary processing industry)."

Who benefits from this course: Gear engineers, gear designers, application engineers, people who are responsible for interpreting gear designs, technicians and managers will come away with a better understanding of all aspects of gear design. The majority of the course material is presented through qualitative descriptions, practical examples, illustrations and demonstrations, which require basic mathematical and engineering skills. However, some familiarity with gear design and application will enhance overall understanding of the material.

Upon completing this course students will: See improvement in their gear designs; better understand gear rating theory and analysis methods; investigate differences in stress states among various surface durability failure modes; discuss time- dependent and time-independent failure modes related to tooth design; use computer- generated graphics to examine mesh action and tooth interaction; and gain new insight into the concepts presented through illustrations and demonstrations.

Fundamentals of Gearing/Gear Manufacturing

Presented by Dwight Smith (*gearguy1@colemfgsystems.com*; CEO Cole Manufacturing Systems, Inc.), along with Pete Grossi and Allen Bird, these online-only, ABCs of gearing courses provide a comprehensive overview of the industry. The basic course teaches students to set up machines for maximum efficiency, to inspect gears accurately, and to understand basic gearing. Although the basic course is designed primarily for newer employees with at least six months experience in setup or machine operation, it has proved beneficial to quality control managers, sales representatives, management, and executives.

In case you might be wondering, even though the course is basic in nature, you probably won't be seeing any "off-the-street" people attending the class.

"Although no one would be refused," says Smith, "I don't see it happening. This is specific and technical training, and, so far, 100 percent of the participants in my classes are engaged in the gear industry at some level."

"Walk-ons" notwithstanding, make no mistake: this "basic" course is for many attendees a gateway to the appreciation and understanding of an industry where, in many instances, quot-

Instructors (including front, left—Dwight Smith) and students alike at the AGMA Gear School at Chicago's Daley College (courtesy D. Smith).


The stock market report.
Stock news that's good? You bet: STOCK GROUND TOOTH Spiral Bevel Gears from the industry leader.
• Arrow Gear offers the broadest range of STOCK GROUND TOOTH Spiral Bevel Gears.
• Up to 16 inch dia., lapped and NOW!! GROUND TOOTH in stock for IMMEDIATE DELIVERY.
• Visit ARROWGEAR.COM for your stock gear solutions.
Now that's good news!
ARROW GEAR COMPANY
© 2010 Arrow Gear Company
www.arrowgear.com
630.969.7640

ing the old gospel standard, "99-and-a-half won't do." In short, precision rules.

"The training evolved from a perceived need," says Smith. "I was involved in the sales and support of gear metrology systems, and customers frequently asked for information regarding what the inspection charts showed. It became clear that there was a void in the gear education arena, so I developed the Gear Basics seminars. This led to the involvement with the AGMA Basic School.

"Perhaps the concept most beneficial from the training is an understanding and appreciation for the function of gears, and the requirement for accuracy. The ability to apply knowledge of the inspection results to solving manufacturing problems is a valuable product of the class as well."

The course begins with a little history of gearing and proceeds through the topics of:

- Gearing and nomenclature
- Principles of inspection
- Gear manufacturing methods
- Hobbing and shaping

Also helping in making these courses worthwhile are:

Steve Janke and Brelie Gear Co., Inc., who provide gear blanks especially for these classes. And Process Equipment Company (PECo), who generously loans out an ND 300 checker for use at all in-person classes.

There's simply no substitute for hands-on experience with the tools of the trade (courtesy D. Smith).

Who benefits from these courses: Primarily for those with at least 6 months' experience in setup or machine operation. However, past students have included executives, sales representatives and quality control managers.

Upon completing this course students will: Learn basic skills on manual machines; everything that students learn is valid and adaptable with CNC equipment commonly in use. By using manual machines, students can see the interaction between the cutting tool and the workpiece, thus better understanding the process and the physics of making a gear.

For more information—locations for upcoming live seminars; pricing; course availability; PC requirements and more—on all AGMA training opportunities and course formats, contact:

Jan Alfieri, Education Manager, American Gear Manufacturers Association, 1001 N. Fairfax Street/5th Floor, Alexandria, VA 22314-1587, Phone: (703) 838–0055, Fax: (703) 684–0242, alfieri@agma.org, *www.agma.org*

WINTERTHUR WENDT Slip Naxos

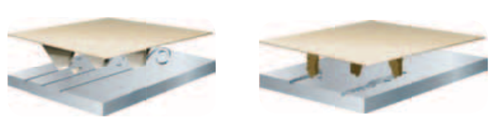
Now part of 3M

Introducing 3M™ Cubitron™ II Gear Grinding Wheels

Precision grain shape is the key to superior performance.

- Drastically reduces risk of burning
- Reduced grinding time
- Less wheel dressing
- Longer wheel life
- Consistent grinding performance

CUBITRON II



3M™ Cubitron™ II vs. Conventional

3M, Winterthur, Wendt and Slip Naxos are brands recognized and trusted worldwide for reliable quality and precision abrasive product used in industries that manufacture precision parts and components for automotive engines and transmissions, oil and gas drilling, cutting tools, aircraft and land based turbines and many others.

Now, 3M offers you today's most innovative portfolio of advanced abrasive technologies to help you achieve the next level of manufacturing precision and productivity.

Proven performance in Single Rib Gear Grinding.

For more information, call 1-866-279-1288 ext 1725

3M

A Hippocratic Oath for the Big-Gear Industry: Do No Destructive Testing

Jack McGuinn, Senior Editor

It is often said: "If it ain't broke, don't fix it."

And, in paraphrase of that old bromide regarding very LARGE gears—if it ain't tested, don't use it.

A too-clever-by-half way to introduce an article on non-destructive testing, perhaps, but you get the point—when outsize gear applications are in play—from bridges to boats to buses—two considerations are paramount: safety and do-re-mi. Which, by the way, makes perfect sense. After all, in most cases, the bigger the gear, the bigger the cost to make it. And as for personal safety—who in his right mind wants to step up and try to put a price on *that*?

So let us stipulate that big gears require very hands-on, meticulous, in-process procedures. But watch those hands!—a light touch is in fact required for these brawny beasts.

Non-destructive testing—NDT—has existed, in one form or another, since the mid-nineteenth century. Witness: 1854, Hartford, Connecticut—a boiler at the Fales & Gay Gray Car Works explodes, killing 21 people and seriously injuring 50. Within a decade, that state passes a law requiring annual inspection (in this case visual inspection) of boilers.

Jump ahead another 40 years or so and we find one Wilhelm Conrad Roentgen discovering X-ray technology. And, in his first published paper on the subject (1895), what does Herr Roentgen propose for the new technology's first application?—flaw detection. Not human flaws mind you—such as, for example,

A very pricey investment such as the behemoth ring gear seen here requires ASNT-certified testing (courtesy Rexnord Gear Group).

broken bones or cancerous tumors; rather—for identifying crack initiation in very heavy—and costly—steel railroad parts. Truly, "the squeaky wheel gets the grease" every time.

Make one more leap—to the 20th century—and we find that "Non-destructive testing, either by sound waves or magnetic fields, goes back to the late 1990s with the issuance of the first edition of American Society for Testing and Materials (ASTM) A609 for ultrasonic inspection and E709 for wet magnetic particle inspections," says Frank Uherek, principal engineer Rexnord Gear Group in Milwaukee, WI.

Ironically enough, however, we find that "Many of today's latest technical innovations come from the medical industry," says Israel Vasquez, an independent quality systems and NDT Level 3 consultant for more than 20 years, and principal owner of NDT specialists Vastek Consulting. In this instance he is speaking for Chicago-based Overton Gear, a longtime client. "The use of NDT on parts, components and materials is very much related to the procedures used by today's medical practitioners.

"The basic principles behind NDT are to examine materials, components and/or parts for characteristics (that are) detrimental to their use (i.e., defects), by methods that will not induce physical (and costly) changes (damage) to the item being inspected. When we have a medical examination, it is a form of nondestructive examination. After all, the objective (find physical imperfections), principles (do no harm to the patient), and examination methods are comparable.

"The NDT community uses radiographic inspection (and now computer and digital radiography), and the medical industry has radiology, computer-aided tomography (CAT scan) and digital radiology. We have magnetic particle inspection, and the medical industry has magnetic resonance. We have ultrasonic inspection (UT), and they have ultrascan, etc."

What types of big-gear applications require the most testing, you ask?

"The amount of testing required is a function of the economic risk of failure of the part in service and the level of experience of the supplier of the machined blank," says Uherek. "Manufacturing processes with a high level of control requires less testing than unique, one-off products."

"The primary purpose for the use of NDT is safety," says Vasquez. "Which is why the aerospace (military and commercial) and nuclear industries require the most NDT. Just about every structural or engine component of an aircraft, missile or ship undergoes some form of NDT, at the raw material source (for inherent imperfections), the machining company (for manufacturing induced defects), and during the life of the vehicle (for service induced defects). Nuclear facilities undergo initial inspections during installation, and periodic inspections for obvious reasons."

And while N.K. Chinnusamy, president of Roscoe, Illinois-based Excel Gear, Inc. agrees that such testing is typically performed on "Parts that are used in critical applications which require reliability," he adds that "(the gear) will have to pass inspection for hardness, burns, cracks, UT or X-ray testing for inclusions, porosity or discontinuity."

OK—better to be safe than sorry rules the day—thank God. But to what degree is NDT obligatory? Is the need for it typically customer- or, say, government-driven?

It's negotiable.

"The amount of required inspections is always subject to contract discussions between the buyer and seller," Uherek says. "AGMA 6014 for large gears requires NDT for Grade-2 materials only. Grade-1 material, having lower power capacities, does not have this requirement.

"Only if an organization has overall design control over the product can they omit NDT altogether," says Vasquez. "Even so, (that) would not be prudent, and (not testing) is very risky. NDT is a 'special process' that—by definition—is an activity conducted on a component, part or material that cannot be measured, monitored or verified until after the resulting product has been used or delivered. The purpose of NDT is to examine materials, components, and/or parts for defects by methods which will not induce physical changes to the item being inspected, and in most cases is a requirement specified in a manufacturing specification, drawing, or contract by the buyer or end user.

"Some pro-active companies choose to conduct NDT not only during 'final' inspection (100 percent) but also as an 'in-process' inspection on a sampling basis to monitor manufacturing operations. There are too many recorded cases where NDT was conducted incorrectly for which discrepant product had to be returned to the manufacturer or had to be discarded. Imagine if NDT hadn't been conducted at all."

Adds Chinnusamy, "Customers can waive any NDT requirement if they deem it is not required for that particular job. But manufacturers cannot skip NDT requirements without customer approval, which will be cause for rejection."

When working large, NDT benefits from economies of scale carrying the day, i.e.—portable testing equipment. One can now bring Mohammed to the mountain, so to speak.

"In most cases the equipment is portable so that the testing equipment can be brought to the part," says Uherek. "At Rexnord, we use a mixture of in-house equipment and selected third-party inspection houses that come on site to perform the inspection. Sending parts out is typically only required for radiographic (X-ray) inspections."

"NDT can be conducted in-house, by either the product manufacturer's personnel or by contracted personnel," says Vasquez. "In the first case, the manufacturer will have to have the appropriate equipment, materials and trained personnel. If contracted personnel are utilized, they will bring the necessary equipment/materials with them. Or, as an alternate, the product can be sent to an independent NDT laboratory for inspection."Speaking of "trained personnel," what skills are needed for conducting NDT?

"One needs to be certified by the American Society for Nondestructive Testing (ASNT)—SNT–TC-1A—and take periodic tests to maintain certification," Uherek says.

Adds Vasquez, "Typically, the employer's program will require three levels of qualification and subsequent certification. A Level I may be the person(s) conducting the pre-cleaning, processing and post-cleaning of the product. The Level II may conduct the same functions—including the actual inspection (acceptance/rejection) of the product. A Level III is the person responsible for the employer's certification program, NDT training, audits, NDT procedure writing and approval of NDT-related documents. All three levels require documented, formal (classroom) training, on-the-job (OJT) training for experience, visual acuity examinations, and qualification examinations consisting of general (method), specific and practical examinations in order for one to be certified."

And, says Chinnusamy, "Personnel should be trained to certify any NDT process; Level I or II certification is required to certify any NDT."

Indeed, if NDT is conducted by the manufacturer, Vasquez says that "Employees will have to have the proper NDT training and be qualified and certified by the employer. Contracted personnel are also required to have the same (credentials), except they are certified by their employers. NDT-knowledgeable auditors may be from the end-user's (the buyer) organization, or from a third-party agency—such as A2LA, Nadcap, L-A-B, etc.—and contracted by the manufacturer or the buyer for registration or accreditation purposes."

When a gear maker—or buyer—hears buzz (buzz kill, in some cases) words like "registration," "accreditation "or "standards"—global considerations come into play. Such as, to what extent is NDT being conducted internationally? Are corners being cut in some places? ASNT standards adhered to?

Uherek points out: "The basic NDT method and criteria are ASTM standards. They are referenced in both AGMA and ISO gear rating standards, and so have worldwide acceptance in their use."

Concurring, Vasquez states that "I would say that (NDT) is relatively consistent. Where the proper NDT equipment and certified personnel are available, most facilities are conducting NDT as prescribed. In the aerospace and nuclear industries, all NDT facilities are continually audited to ensure that the organizations are meeting the specified requirements and are not cutting corners."

NDT Testing Methods

Ultrasonic testing. Most ultrasonic testing concentrates on the interior of the component. The most common method is to use a transducer to send ultrasonic vibrations through the test object. The transducer converts electrical signals—sent from an oscilloscope—into ultrasonic vibrations. Interior defects show up in the sound waves reflected back to the transducer. The transducer converts the sound energy back to an electrical signal for display on the oscilloscope. Examining a weld or component can be quick and economical, but the skill of the inspector, coupled with the expense of his training and equipment, can be limiting factors.

Eddy current testing. Eddy current testing uses an alternating magnetic field to induce small electric currents in the component being examined. These currents are affected by surface or slightly sub-surface abnormalities in the components. Defect indications appear on the instrument CRT. Eddy current testing is limited to conductive materials. Care must be taken to avoid false indications due to part geometry or permeability variations (ferromagnetic materials).

Magnetic particle examination. The magnetic particle examination technique detects surface and sub-surface indications. While providing a magnetizing force over a test area of the component, the inspector sprays a suspension of colorized iron fillings—either dry or wet fluorescent—within the magnetized area. The iron fillings align themselves along the artificial magnetic field created by any defects. The process is simple to use and some methods do not require extensive training.

Liquid penetrant testing. Penetrants detect surface flaws by permeating cracks or pores. A small amount of penetrant is applied to a test area. Alter a specified dwell time has elapsed, the penetrant is removed from the surface. A blotter-like developer is applied over the test surface. The developer draws any excess penetrant from the defects. The penetrant is either a color that contrasts strongly against the component background or it is fluorescent. Although simple to use, penetrants can miss defects if the surface is not adequately cleaned or the flaw is obstructed with smeared metal.

Radiographic testing. Radiography employs X-rays or gamma rays to penetrate the test object. It displays a permanent picture of the test object's interior on radiographic film. Radiographic limitations include the need for adequate component geometry, strict security of the test area and time to develop and interpret the test film. Radiographic examiners require extensive training.

ACRONYM Soup De-Coded

Following are "translations" of the various acronyms used in the NDT story.

ASNT American Society for Non-Destructive Testing

A2LA American Association for Laboratory Accreditation

Grade-2 Material Low-to-medium carbon steel, as rated by ISO, SAE and ASTM

MPI Magnetic particle inspection

NDT, Level III Level III NDT technicians are capable of establishing techniques and procedures; interpreting codes, standards, and specifications; and designating the particular nondestructive testing methods, techniques and procedures to be used. They must also have knowledge of materials, fabrication and product technology. Level III technicians are responsible for training and examining Level I and Level II's. Usually Level III technicians are in administration, supervision or management positions, or are owners of a testing laboratory. Some Level III technicians also become consultants.

SNT TC 1A A personnel qualification and certification in NDT (2011) that provides guidelines for employers to establish in-house certification programs for the qualification and certification of non-destructive testing personnel. Since 1966, employers have used this industry-valued document as the general framework for their NDT certification programs.

Nadcap Nadcap is the leading, worldwide cooperative program of major companies designed to manage a cost- effective consensus approach to special processes and products and provide continual improvement within the aerospace industry.

UT Ultrasonic inspection

(Editors' Note: Those with a particular interest in NDT will want to be sure to check out two of this issue's three Technical Articles on pgs. 58 and 66.)

Taking a somewhat dimmer view, Chinnusamy offers an emphatic "No; it (compliance) depends upon the manufacturer. If the manufacturer can get by with cutting corners, they may try to do it."

Expanding on his previous comment regarding "certified personnel," Vasquez references the dilemma that gear makers everywhere are grappling with: "The biggest problem worldwide—including the U.S.—is in finding qualified personnel, especially at the Level III rank."

Indeed, consider alloys for a moment; their use in big gears requires, at minimum, conversant knowledge of metallurgy—especially for the most critical applications. And keep in mind: these are real—and real expensive—gears being tested, not oops—throw-away-and- let's-try-another-one prototypes.

Speaking of challenges, our contributors were asked which big-gear applications—bridges, rail, mining, etc.—present the most challenges?

For Vasquez it is "A gear which has been assembled and cannot be disassembled prior to inspection is the biggest challenge. When conducting the inspection, most NDT methods or techniques require access to all surfaces requiring inspection. Surface finish (or cleanliness) also has an impact on NDT feasibility."

"Chinnasumay cites the customer's requirement. "Large gears are normally loaded heavily and tooth breakage will be the main concern in some applications. Even small gears for aerospace and military applications will require more stringent inspection than some large gears. Not all heat treating companies are qualified to heat treat gears for aerospace and military."

And then there is the "size matters" challenge inherent with NDT; just thinking of the logistics involved gives one a headache.

For example, says Uherek, "Larger gears take more time to test due to surface area that needs to be examined. In-shop examinations allow for the area to be tested to be presented at a comfortable work height and in proper lighting to conduct the test."

"(It depends) on which NDT method is required or specified," Vasquez explains. "Conventional NDT equipment cannot be used for the larger gears in most cases. These gears may have to be lifted when 100 percent inspections of all surfaces are required, and they cannot be accommodated on magnetic particle inspection benches or fit in penetrant inspection tanks, dryers or inspection booths. When ultrasonic inspection is required, both sides may have to be accessible; therefore lifting equipment has to be available, and there is a much larger area which may require scanning."

Chinnusamy agrees that size-wise, NDT is no picnic. "Yes, because of size itself. To check for burns the gear must be dipped into nitric acid solution. MPI inspection has to be done one section at time, which is time consuming; and there are chances for error. Inspecting sizes and quality of large gears is very difficult.

As for working with those "black science" alloys, "There are limitations in each NDT method," Vasquez admits. "(And this) is why the appropriate NDT method or technique has to be selected by knowledgeable personnel—in most cases, a Level III. Austenitic steels cannot be magnetic particle-inspected since they are essentially non-magnetic. Porous metals cannot be inspected by the liquid penetrant method, since they entrap the penetrant and may interfere with the interpretation process. Some metals may be too dense for X-ray equipment with limited penetrating ability."

For Related Articles Search
nondestructive
at **www.geartechnology.com**

For more information

Overton Gear Chicago
2823 West Fullerton Avenue
Chicago, IL 60612
Phone: (773) 638-0508
Fax: (773) 638-7161
oc-gear.com

Rexnord Corp.
Motion & Control
4701 West Greenfield Avenue
Milwaukee, WI 53214-5310
Phone: (414) 643-3000
Fax: (414) 643-3078

Isn't it time for America to return to its winning game plan?

Manufacturing is what made America the world's unrivalled economic superpower. To solve our many economic challenges, we must look again to manufacturing. We must return America to the forefront of *exporting products* to the world market and *importing national wealth*.

Citizens for American Manufacturing (CAM) is striving for this goal. The mission of **CAM** is to promote manufacturing's critical role in our nation's economic health and unite the many voices of American citizens now calling on all levels of government to help restore American manufacturing.

Solving this crisis is vital for our country now and for our children's future. But we can't do this alone. For more information on how you can get involved, please visit our Website at **www.CamUsaNow.com.**

Doing nothing is not an option!

We are asking for your support and your tax deductible financial contribution.

A Message from CAM's Board of Directors

Joseph Arvin - Arrow Gear Company • Greg Bedalov - Choose DuPage • Ken Clingen - Clingen Callow & McLean
Ted Englehart - Cambridge Ventures, L.P. • Sid Firstman - IIT Research Institute (R)
Michael Goldstein - Gear Technology Magazine • Judith La Marche - La Marche Manufacturing Company
Scot McConachie - McConachie Insurance • Melissa Newton - MoneyBasics U
Scott Newton - APEX Media Solutions • Fred Young - Forest City Gear

Restoring America Through A Strong Industrial Base

CAM
Citizens for American Manufacturing

www.CamUsaNow.com

Citizens for American Manufacturing is a non-partisan, Illinois-based 501(c)(3) non-profit corporation.


Need High-Quality Gears
For Off-Highway Applications?
Child's Play...At Forest City Gear
Construction, mining and agricultural vehicles and equipment are pushing into some pretty out-of-the-way places these days. Vital components like gears are expected to operate smoothly, quietly and around the clock in the harshest environments – and reliability is paramount. Forest City Gear is pushing into new frontiers as well – like helping develop and manufacture large gears for some of the leaders in these industries.
Let's have some fun together. Visit:
www.forestcitygear.com.
FOREST CITY GEAR
11715 Main Street, Roscoe, IL 61073
815-623-2168
FOREST CITY GEAR

GOT A GEAR QUESTION?

Ask the Expert!

Welcome back to *Gear Technology*'s Ask the Expert!—our popular regular feature intended to help designers, specifiers, quality assurance and inspection personnel in addressing some of the more complex, troublesome gearing challenges that never cease to materialize—whether on the drafting table or the shop floor. Simply email your question—along with your name, job title and company name (if you wish to remain anonymous, no problem)—to: *jmcguinn@geartechnology.com;* or submit your question by visiting *geartechnology.com*.

QUESTION

Measurement of Involute Master

I am a calibration technician that has been saddled with finding how to measure some involute masters.

I have a print for them, but it only references, doesn't tolerance.

Am I to assume that the dimensions listed on the print are not important and therefore not necessary to measure? Or am I just looking at an improper print?

I am very new to gears, and am having some difficulty understanding them to this point.

Figure 1 115 mm base circle diameter involute artifact (courtesy Robert E. Smith).

Figure 2 Internal gear artifact (courtesy Robert E. Smith).

Response from Robert E. Smith, Robert E. Smith & Co., Inc.

To begin, the term "involute master" can be taken two ways.

There are involute *masters* that are actually just one flank of an involute tooth shape; this is probably the most common type. These are used to calibrate and determine the uncertainty of analytical type gear measuring instruments.

There are also involute *master gears*; these are actual, complete gears—made to very high accuracy—for double-flank and single-flank composite testing.

Point one. The involute master described in No. 1 above can be made from a drawing that only specifies the geometry— not the accuracy tolerances. It is not important that they be made to a specified tolerance or accuracy grade; it is only important to measure what it actually *is* and to what uncertainty. After it is made, it has to be measured by either an accredited laboratory or by an analytical-type instrument that has been certified with traceability to a national gear metrology laboratory.

In recent years, we have created our national gear metrology capability at the Oak Ridge Metrology Center, at the Y-12 National Security Complex. Artifacts of involute, helix, pitch, etc. are measured here with an uncertainty of less than 36 millionths of an inch (0.9 microns). One can have artifacts measured and certified at the Y1-2 Lab or by other labs that have been accredited by traceability to the National Laboratory.

For Related Articles Search
involute master
at www.geartechnology.com

In the process of setting up our National Gear metrology capability, an AGMA-directed committee wrote new standards for the calibration of gear measuring instruments. These later were submitted to the ISO standards association as a work project on international standards. This evolved into the creation of ISO 18653–2003 as the international standard for the calibration of gear artifacts and gear measuring instruments. It is also available as an identical document: ANSI/AGMA/ISO 18653–A06.

Point two: Involute master gears—as described above—are complete gears of a specific DP and design to mate with a product gear being manufactured. These are used in a rolling-type gear tester for the measurement of double-flank or single-flank composite deviations.

Standards have also been written that describe the procedure for calibration of these master gears. The current document is ANSI/AGMA 2015–2–A06; it describes the tolerances for various grade levels of master gear accuracy. These can be measured by analytical-type gear instruments or by composite measurements when running against a qualified "grand" master gear.

It is highly recommended that the questioner obtain these calibration standards before trying to do any calibration activity on gear artifacts or master gears. It is also very important to understand the concept and application of "uncertainty" when doing a calibration. This is well-described in the ANSI/AGMA/ISO18653–A06 standard; in fact, the end-user of the artifacts should be well aware of the effect of uncertainty on their final product tolerances in manufacturing.

Figure 3 Helix (lead) artifact (courtesy Bruce Cox).

Robert E. Smith
Robert E. Smith & Co., Inc.

Gear industry consultant **Robert E. Smith**—R. E. Smith & Co., Inc. (resmith.co@worldnet.att.net; gearman@resmithcoinc.com)—possesses a half-century of hands-on experience and knowledge. A 1998 recipient of AGMA's E.P. McConnell Award, Smith'sdistinguished career includes almost 40 years at Gleason Corp. in a variety of important positions, including stints as gear methods and new product engineer. Smith is a longtime AGMA member and currently serves on its Gear Accuracy and Calibration (chairman/ISO delegate) committees. Educator (Rochester Institute of Technology) and prolific author, Smith also finds time—since 1991—to serve as a valued Technical Editor for Gear Technology.

Response from Steven Lindley, Rexnord Gear Group

Without seeing your print, I am going to make the assumption that you have an involute master gear and desire to do an analytical check (involute, helix and pitch) of the master gear. There are two very helpful sources on master gears. AGMA 2000-A88 *Gear Classification and Inspection Handbook,* Section 8 (inch), Section 8M (metric) and AGMA 2015-2-A06 "Accuracy Classification System: Radial Measurements for Cylindrical Gears, Annex A," have very detailed information on master gears. Even if what you have is an involute master artifact, the artifact is based on some type of gear geometry with a specified number of teeth, diametral pitch or module, pressure angle, helix angle and tooth thickness. This is basic information that would be required to calculate the base circle diameter.

Your drawing may give some type of master gear class code that will drive the tolerances. AGMA 2000-A88 uses Master Gear Class 1, 2, 3, 4 and 5. AGMA 2015-2-A06 uses only two classes of master gear—M1T and M2T; each of these standards has tolerance tables based on the class of master gear. There are also formulas in these documents

For Related Articles Search
master gears
at www.geartechnology.com

to calculate the tolerances. The drawing should have at minimum module or diametral pitch, pressure angle, number of teeth, helix angle, hand of helix angle and tooth thickness. The drawing may also have listed a test radius and a base diameter. All of these are important dimensions for the inspection of the gear.

Two other documents that have pertinent information about master gears are AGMA ISO 10064-5-A06: Code of Inspection Practice, Part 5: Recommendations Relative to Evaluation of Gear Measuring Instruments, and ANSI/AGMA ISO 18653-A06 Gears: Evaluation of Instruments for the Measurement of Individual Gears. Each of these documents will give guidance and some methods on master artifacts and machines to measure such artifacts. Dependent upon how in-depth you wish to go, there are also calculations for measurement uncertainty and different methods and practice.

Steven Lindley
Rexnord Gear Group

Steven Lindley is a gear engineer for Rexnord Gear Group and current chairman of the AGMA Gear Accuracy Committee.

Response from Bruce Cox, Bruce Cox Engineering

Gear artifact measurements are defined in the standard ANSI/AGMA ISO 18653—Gears: Gear Evaluations of Instruments of the Measurement of Individual Gears—and the parameters measured on gear artifacts are defined in the standard ISO 1328: Cylindrical Gears: ISO System of Flank Tolerance Classification, Part 1: Definitions and Allowable Values of Deviations Relevant to Flanks of Gear Teeth. Unfortunately, the ISO 1328 standard is still being revised at this time. The types of gear artifacts are helix (lead), involute, pitch, run-out and tooth thickness. Artifacts may be workpiece-like—such as an accurate gear (*see photos*).


Figure 4 Master gear artifact (courtesy Robert E. Smith).

Basically, what are measured are the datums, such as centers, journals, or the bore to establish the centerline of the gear artifact. Next, width of the feature to be measured is established to set the coordinate system in the center of the artifact. A point on the feature is measured to set the rotation of the coordinate system to zero. Finally, the feature is measured on the artifact and the deviation from the nominal value is recorded.

In the case of the involute artifact, a series of points are taken in the center of the tooth shape from the root to the tip and compared to the nominal point values defined from the base circle diameter marked on the artifact and plotted on a graph of roll length vs. deviation. From this plot you can calculate the total, slope and form deviation. These values can be compared to the calibrated values of the artifact to help determine your measurement uncertainty for this feature.

For Related Articles Search
artifact
at www.geartechnology.com

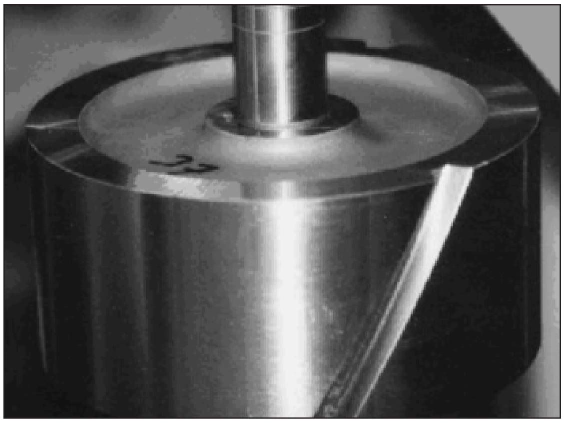


Figure 5 Tooth thickness artifact (courtesy Bruce Cox).

In the case of the helix artifact, the measurements are from the bottom of the tooth to the top at the pitch diameter along each flank. The deviations from the nominal values are plotted and compared to calibrated values in the same way as in the involute artifact.

In the case of the pitch/run-out artifact, the pitch measurements are one point at the center of each gear tooth flank at the pitch diameter referenced to the first tooth. Index deviation is the difference between each measured circular arc position on each tooth flank and the theoretical circular arc position from the first tooth flank measured. Pitch deviation is the difference in circular arc position of each successive tooth flank. The total-pitch deviation (maximum minus the minimum) and the single-pitch deviations are recorded and compared to calibrated values. Run-out is the axial distance from the center of the artifact to the center of a ball contacting both tooth flanks at the same time. The total run-out deviation and the single run-out deviations for each tooth gap are recorded.

In the case of the tooth thickness artifact, the circular arc width across the tooth or the tooth gap is measured at the pitch diameter—usually at the top, bottom and middle of the artifact.

The master gear artifact combines the features of all of the above artifacts.

Bruce Cox

Bruce Cox owns and operates Bruce Cox Engineering *(bcoxengineering.com)*. He is the former technical manager of the Oak Ridge Metrology Center at the Y-12 National Security Complex in Oak Ridge, Tennessee.

OVERTON**CHICAGO**GEAR

PROCESS-DRIVEN PRECISION

IT'S WHAT'S INSIDE THAT COUNTS

In no other industry are gears subjected to the harsh conditions and extreme shock loads as they are in mining. At Overton Chicago Gear, we know how critical it is to keep mining operations running smoothly. We keep the mining industry in motion with precision spur, helical and internal gears and a bevel gear capacity that is virtually unrivaled worldwide. Because it's what's on the inside that counts.

125 years of precision gears
for the most demanding gear applications.

Chicago • Addison • Lombard

(630) 543-9570 | www.oc-gear.com | sales@oc-gear.com

Balancing: Smoke and Mirrors No Longer

Robin Hines Mifsud

By virtue of collected anecdotal accounts, equations and problem solving, balancing is discussed as more math and common sense, and less smoke and mirrors.

Introduction

In the late 1970s a balancing machine salesman visited a customer who had just purchased a new balancer from the salesman's competitor. The plant manager said they were very happy with their automatic balancing machine and offered to show it to the salesman. The manager walked the salesman out on the floor and the two of them watched the operator and balancer in action.

The operator placed a part on the balancer and closed the door. The balancer spun the part; stopped; welded on a weight; spun up again; stopped; and displayed "good part." The operator removed the balanced part, put in a new part, and closed the door. The balancer spun up the part; stopped; welded on a weight; spun up again; stopped; and displayed "good part." This scenario was repeated several more times as the salesman and the manager watched.

The manager commented, "We just love our new machine. All day long it balances parts by welding on weights and puts out good parts." The salesman suggested having the operator place a "balanced part" back in the balancer again—just to see what would happen. So the operator placed the previously balanced part back in the balancer again and closed the door. The balancer spun up the part; stopped; welded on a second weight; spun up again; stopped; and displayed "good part." The manager had the operator take another previously "balanced part" and put it into the balancer again. Again, the balancer spun up the part; welded on another weight; spun up again; and displayed "good part." Suddenly the manager was not so happy with his balancing machine. It had become clear: this machine was not balancing the parts at all. What they in fact actually had was an expensive welding machine to weld weights on their parts.

Balancing: Shedding Some Light

Production managers who have just added a new balancer to their shop or production line often ask, "How do I know if my part is balanced?" This question is usually asked after the person has had some basic training in balancing and has started balancing some parts. They quickly realize that, visually, there is no measurable difference between a "balanced" part and an "imbalanced" part. They can see that the "balanced" part has some holes (or other correction) and the "imbalanced" part has no holes (or other correction.) The balancing machine says, "good part," but they still feel a need to ask, "How do I know if the part is *really* balanced; and, "What if the balancer is wrong?" I will attempt to answer these questions in the pages that follow, such that "If you can fog a mirror, you can probably understand balancing."

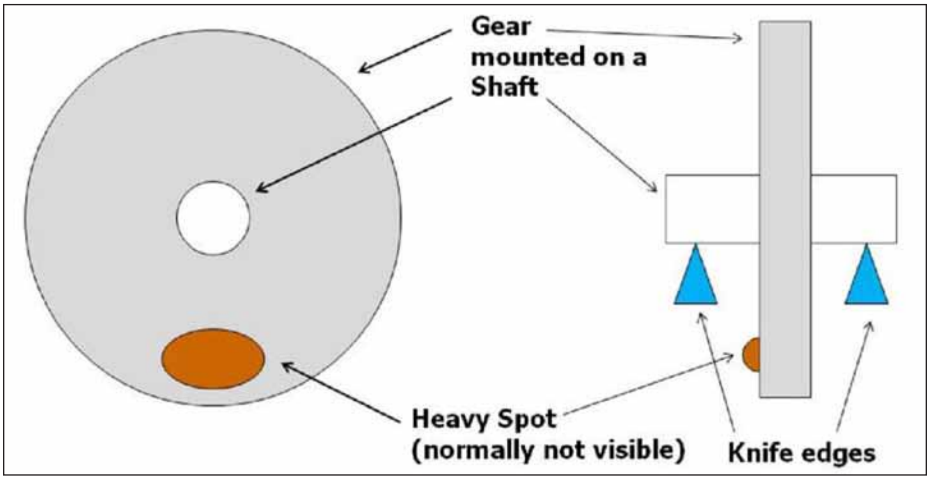


Figure 1 Part with imbalance.

Basic Balancing Principals

The simplest form of imbalance is called "force imbalance," "static imbalance" or "single-plane imbalance." These are all words for the same thing. If you take an imbalanced gear, mount it on a shaft and set it between two knife edges, the heavy spot will roll to the bottom. When this part is spun up and the heavy spot is spinning around, the forces generated by that heavy spot pull the gear in the same direction, similar to spinning a stone on a string. The forces caused by the imbalance increase or decrease as the square of the change in the rotational speed. Imbalance is usually measured and specified in units of ounce–inches, gram–centimeters or gram–millimeters. Roughly, 1 oz–in = 72 g–cm, or 720 g–mm (Figs. 1 and 2).

Single-plane imbalance. The equation for calculating the amount of single plane imbalance is:

$$\text{imbalance} = \text{mass (or weight)} \times \text{radius}$$

This is the mass of the heavy spot multiplied by the gear radius to the center of the heavy spot.

Using oil-based modeling clay, shape and weigh a one-gram piece. Add the one-gram mass of clay to a balanced gear so the clay is located at a radius of 200 mm. The gear now has an imbalance of:

$$\text{imbalance} = 1\text{ g} \times 200\text{ mm} = 200\text{ g–mm}; (0.035\text{ oz} \times 8\text{ in} = 0.28\text{ oz–in})$$

Reflecting on Balancing Machines

The following is a very brief synopsis of balancing machines, past and present:

Balancing ways. A gear assembly (or a gear mounted on a shaft) is placed on two knife edges. The heavy side rolls to the bottom to show the imbalance.

Bubble balancers. The axis of the part is held vertically and loosely. The part does not rotate and a bubble is used to show the location of the imbalance or heavy spot.

Soft-suspension balancing machines. Hold the part suspended on a fine wire. The part is spun at high speeds (above the resonant frequency of the suspension) and the machine measures the displacement.

Parts of different weights require a different calibration; parts with large initial imbalance must be balanced in steps at gradually increasing speeds.

Hard-suspension balancing machines. Hold the part on a stiff suspension; the part is spun at relatively low speeds (below the resonant frequency) and the machine measures the force caused by the imbalance. Calibration is the same for the full range of part weights. This suspension readily allows for on-machine correction; even parts with large amounts of imbalance can be balanced on the first spin. Non-rotating balancing machines with a hard suspension use what is called a stiff pivot.

Forces generated by the imbalance — smokescreen. To calculate the amount of force caused by imbalance in a rotating object, use the following equation:

$$F_{unb} = 1.77\ (\text{rpm}/1{,}000)\ 2\ (\text{oz–in})$$

or,

$$F_{unb} = 127.41(\text{rpm}/1{,}000)\ 2 \times (\text{g–cm})$$

where:

F_{unb} is the centrifugal force generated by imbalance in a rotating object—in pounds

oz–in is the amount of imbalance in the residual heavy spot—in ounce–inches

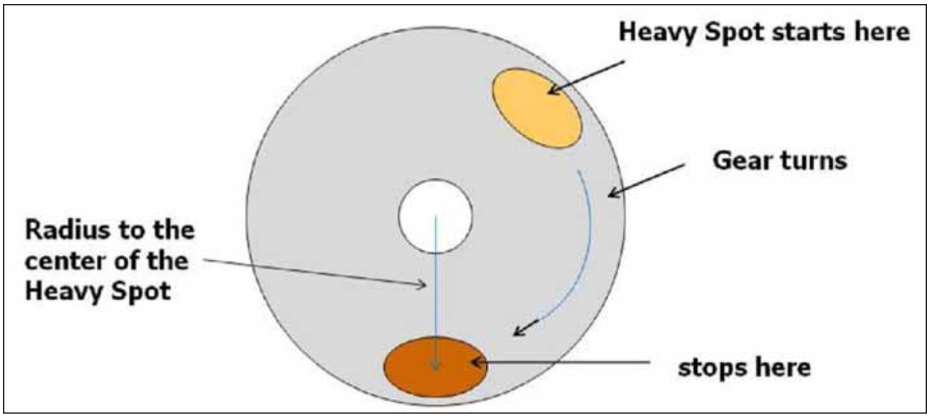


Figure 2 Part with imbalance.

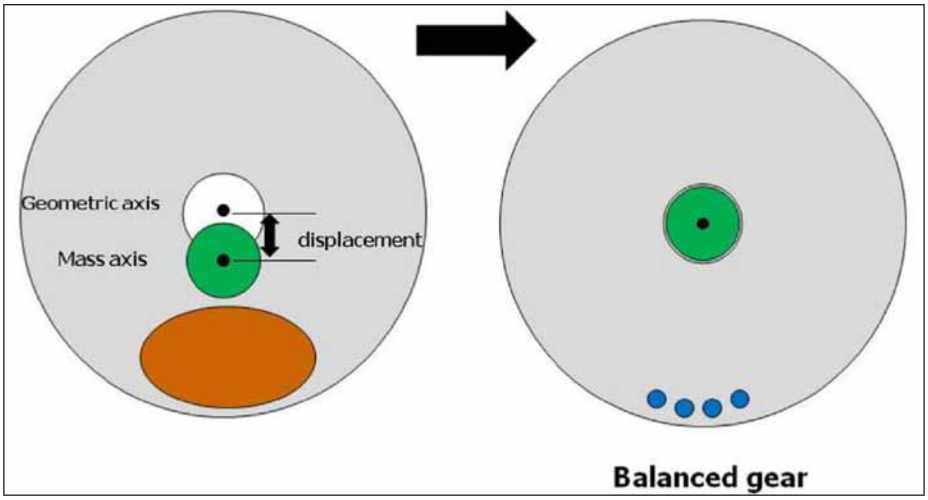


Figure 3 Balancing is alignment: mass axis to geometric axis.

In a gear assembly operating at 1,500 rpm with 1 oz–in of imbalance:

$$F_{unb} = 1.77\ (\text{rpm}/1{,}000)\ 2\ (\text{oz–in}) = 1.77 \times (1{,}500/1{,}000)\ 2 \times 1\text{ oz–in} = 4\text{ lb force}$$

In a gear assembly with 4× the amount of imbalance, the force is 4× larger:

$$F_{unb} = 1.77\ (\text{rpm}/1{,}000)\ 2\ (\text{oz–in}) = 1.77 \times (1{,}500/1{,}000)\ 2 \times 4\text{ oz–in} = 16\text{ lb force}$$

In the first gear assembly, operating at 4× the original speed, the force is 16× larger:

$$F_{unb} = 1.77\ (\text{rpm}/1{,}000)\ 2\ (\text{oz–in}) = 1.77 \times (6{,}000/1{,}000)\ 2 \times 1\text{ oz–in} = 64\text{ lb force}$$

The problems caused by the imbalance are relative to the overall weight, age and use of the gear assembly.

Displacement = distance between geometric axis and mass axis. On a balanced gear the geometric axis and mass axis are the same. The geometric axis is the axis determined during manufacture; it is the center of the shaft that the gear is mounted upon. The mass axis is the line or axis that the gear will naturally rotate around if it is tossed up into the air and spun (Fig. 3).

If you add some mass to the gear on one side, the center of mass—or mass axis of the gear—shifts in the direction of the added mass. The distance between the mass axis and the geometric axis is called "displacement."

$$\text{displacement} = \text{amount of imbalance/total mass (or weight)}$$

To calculate the displacement, take the amount of imbalance, i.e.: 200 g–mm, and divide it by the total mass of the gear or gear assembly, i.e.: 50 kg or 50,000 g.

$$\text{displacement} = 200\text{ g–mm}/50{,}000\text{ g} = 0.004\text{ mm of displacement}$$

$$0.28\text{ oz–in }/1{,}764\text{ oz} = 0.00016''\ (1.6 \times 10^{-4})\text{ of displacement}$$

Balancing = adalignment of geometric axis and mass axis. Gears may be balanced by adding weight 180° from the heavy spot; by welding; riveting; adding epoxy putty; etc. (Fig. 4). When we balance the gear from the above example, we remove material at the angle of the heavy spot—either by drilling, milling or grind-

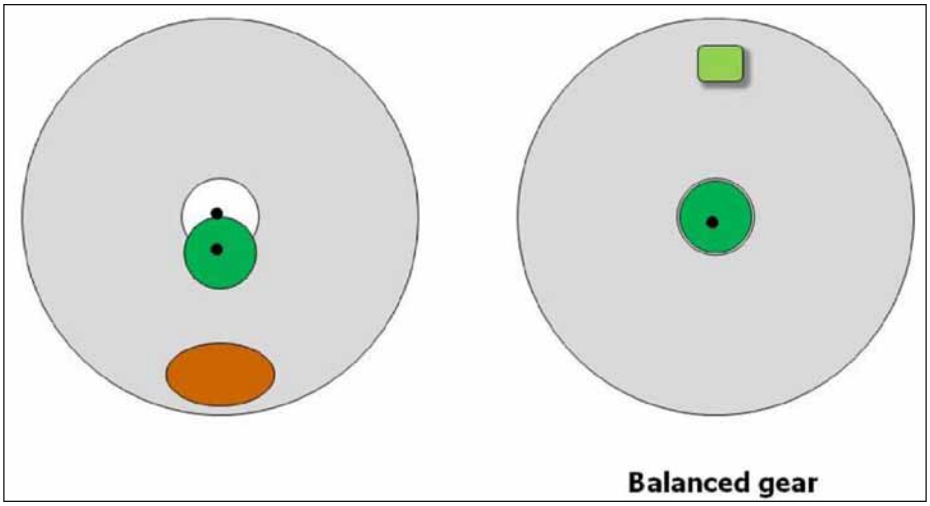


Figure 4 Welding on a weight to correct imbalance.

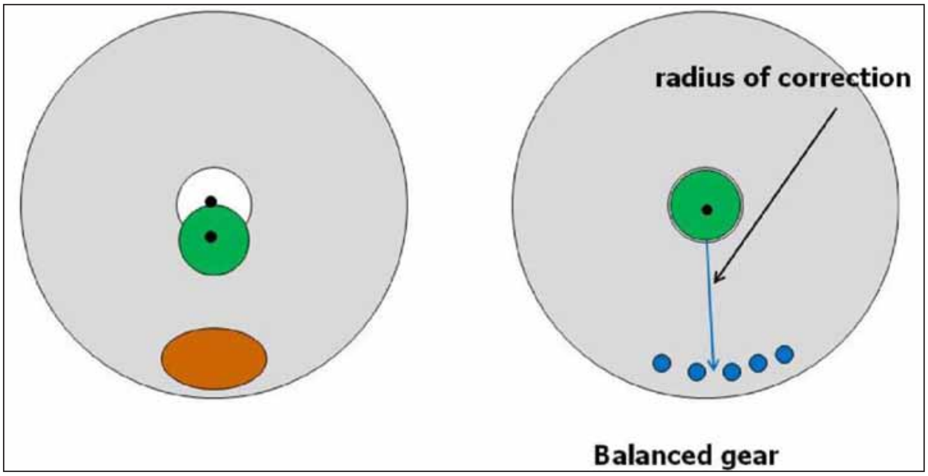


Figure 5 Drilling holes to correct imbalance.

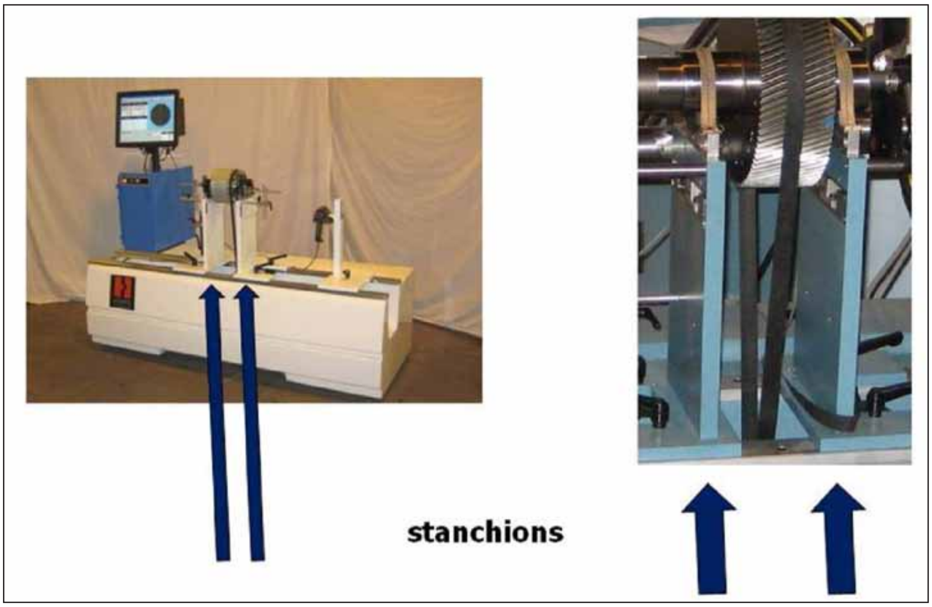


Figure 6 Cradle-style balancer with two stanchions to support the part.

ing. If we precisely remove one gram of mass, at a radius of 200 mm and at the angle of the heavy spot, the mass axis and geometric axis are realigned and the gear is "balanced" (Fig. 5). We could also remove two grams at a 100 mm radius or 20 grams at a 10 mm radius. The smallest corrections for imbalance are made as close to the outer diameter of the part as possible.

Balance tolerance. One method of setting a balance tolerance is using the API equation:

balance tolerance = 4W/N = 4 × weight-in-pounds-per-stanchion/rpm

Using a 50,000g (110 lb) gear assembly that rotates at 5,000 rpm in use:

4 × 55 lb/5,000 rpm = 0.044 oz–in / stanchion = 32 g–mm/stanchion

It is important to note that although the rpm is used in the equation to determine the amount of imbalance, this does not mean the part must be spun at 5,000 rpm to measure it. Some balancers do not spin at all; rather, they measure the weight on all sides of the geometric center of the part.

imbalance = (1 g × 32 mm)/stanchion × 2 stanchions = 64 g–mm = 0.088 oz–in.

The gear assembly will have 64 g–mm of imbalance, whether it is sitting still or spinning at 100 rpm, 3,500 rpm or 10,000 rpm. The forces caused by the imbalance will be vastly different, but the amount of imbalance remains the same. It is important to list the rpm assumed for a particular balance tolerance. The balance tolerance is often listed as 32 g–mm at 5,000 rpm. Again, the 5,000 rpm is specifying the *operating* speed—*not* the balancing speed. If in use the part spins faster or slower than 5,000 rpm, a different balance tolerance should be calculated.

The only reason to balance at the operating speed is if parts or components of the assembly swing out or shift at a higher speed. Many turbines and combines have blades or hammers that shift outward as the part is spun up to the operating speed, so they should be balanced at that speed. When components are shifting at different speeds, the imbalance is also changing. For ultra-precision balancing, replicating the operating temperature and pressure for the part in use should be considered (Fig. 6).

Two-plane imbalance. In the case of two gears mounted on a shaft, one gear may have imbalance—caused by a heavy spot at one angle—and the second gear may have a different amount of imbalance at a different angle. This is variously called "dynamic imbalance," "two-plane imbalance" or "a combination of couple imbalance and force imbalance." In this case the mass axis and geometric axis are no longer parallel, but skewed. To correct the imbalance, the heavy spot on each gear will need to be removed.

As the two correction planes are moved closer together, along the geometric axis, the amount of correction required increases to infinity. The smallest corrections are made closest to the part's outer diameter, with the correction planes the farthest apart (Fig. 7).

Importance—or not—of small variations. If a balanced gear with a mass of 50 Kg (110 lb) is mounted on a balanced shaft and the clearance, or eccentricity, is such that the gear is held off center by 0.00006" (or 6×10^{-5} inch), it will put the assembly in imbalance:

$$110 \text{ lb} \times 16 \text{ oz/lb} \times 6 \times 10^{-5} = 0.106 \text{ oz–in } (63 \text{ g–mm}), 0.053 \text{ oz–in/stanchion}$$

Compare this to our balance tolerance of 0.04 oz–in/stanchion. The assembly is out of tolerance—not because of any imbalance in the gear but because the gear is held off center in the assembly. The shaft may have run-out (TIR) or clearance of 0.00012" (1.2×10^{-4}) – or 0.003 mm.

Don't let your time spent balancing be wasted. It is inefficient to balance components to tight tolerances unless part dimensions, clearance and run-out are held to equally tight tolerances in the final assembly. Where possible, it is often best to balance the full assembly in its own bearings, either radial or preloaded axial (Figs. 8 and 9).

Problem solving: production line gears–mirror images. When balancing gears in a production environment it is important to continually monitor the final balanced product. Are they actually balanced? Is the machine still calibrated and set up correctly? And how do you know? To confirm that "balanced" gears are actually balanced, one should take five or 10 from each lot back to the balancer and run the following tests:

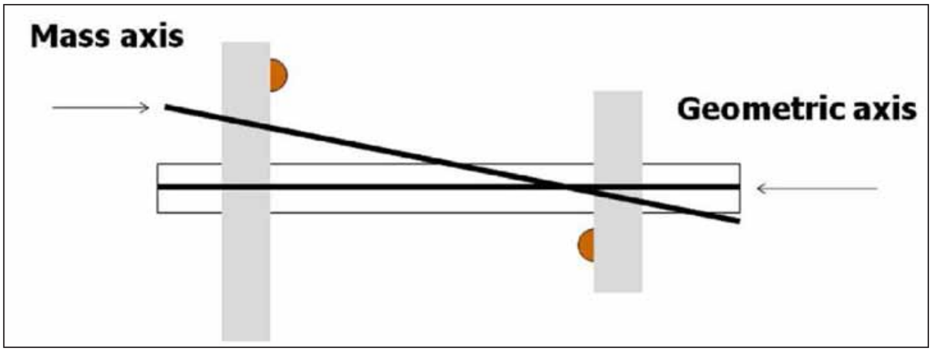


Figure 7 Two-plane imbalance.

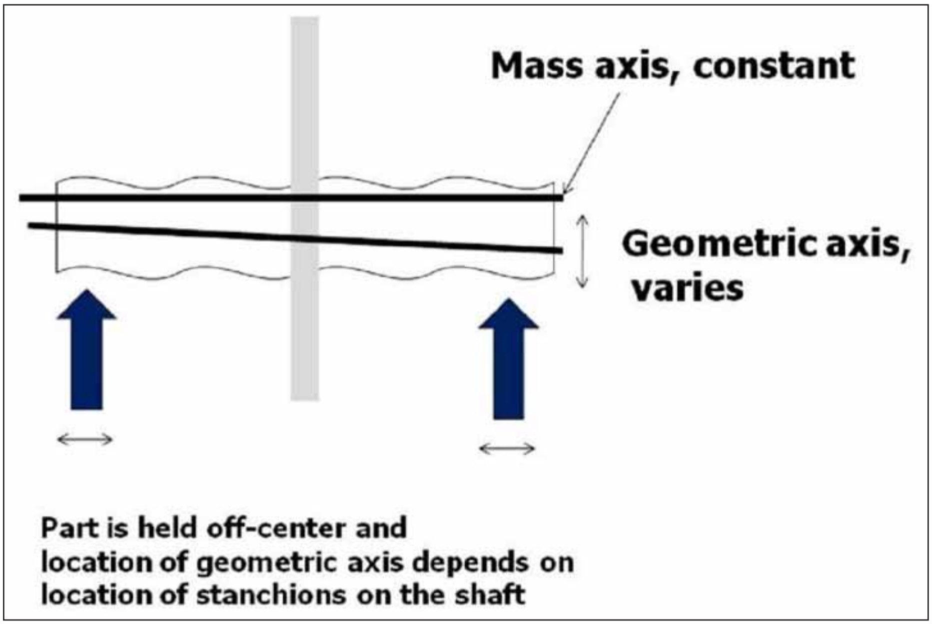


Figure 8 Small variations (exaggerated view).

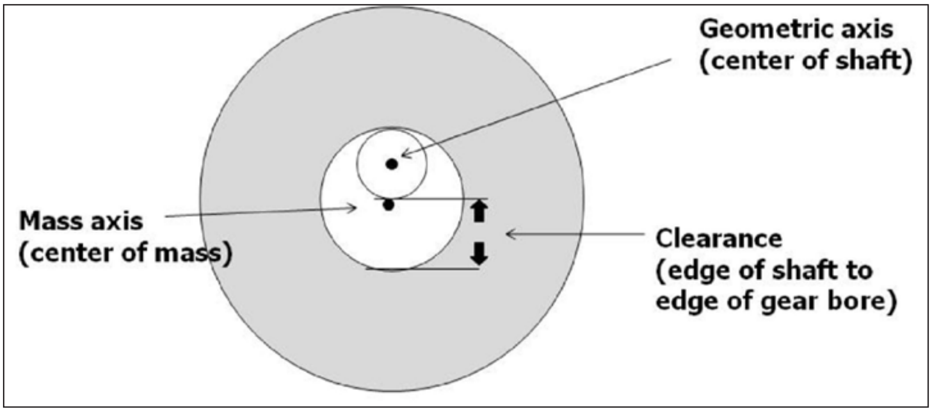


Figure 9 Small variations (exaggerated view).

- Measure imbalance. Is it below tolerance?
- Turn the part 180° on the tooling and measure imbalance again. Is it still below tolerance?
- Measure each of the parts in this manner; if they are not all clearly below tolerance, you should run the entire lot through the balancer again. Lesson learned: check early and often until you gain confidence in the balancer.
- Add a test weight—to either the spindle or a master part. Is the balancer calibrated? Does the balancer display the amount of imbalance expected for the test weight?
- Check the rest of the set-up related to your part and correction method.

It is important to keep scrap parts from getting accidentally mixed in with the good parts. There are many standard balancing machine features available to help with this, including:

- Password required to remove scrap parts from the balancer
- Locked scrap bins
- Ink marking only good parts or only scrap parts
- Automatic transfer of parts to conveyors for good or scrap parts

Problem solving: gear assembly—blowing smoke. When balancing gears that will be assembled later, it makes sense to balance the assembly as well. Even though the individual gears and shaft are balanced, the final assembly may have imbalance due to clearance and run-out. (See "Importance—or not—of small variations" above) To test that the gears or assemblies are truly balanced you can use the list given in "production line gears" = measure, turn 180° to measure again, and test calibration.

Sometimes a gear assembly is balanced, the machine setup is changed, and another part or assembly is balanced; then the setup is changed again and the first assembly is put back into the balancer. The readings may be quite different; why? (See again, "Importance of Small Variations.") When you are reading fine levels of imbalance, small changes can make a big difference. If the balancer bearings locate in one location on the shaft one time and another location the next—and there is run-out in the shaft—the geometric centerline changes in turn as do the imbalance readings. For this reason it is often best to balance the assembly in its own bearings—radial or preloaded axial.

Other causes of vibration: smoking guns. Sometime, even though an automobile or other assembly is "completely balanced," there is still vibration. Some possible causes are:

- Misalignment
- Reciprocating masses
- Worn bearings
- RPM is higher than expected and tolerances weren't set correctly
- Components were balanced but assemblies were not
- Components were balanced on surfaces that are "close" but not the actual mounting surfaces
- Resonance
- Vibration that is caused by imbalance always increases with an increase in the rotational speed. Thus any vibration that comes and goes as the rpm is increased is not caused by imbalance.

Conclusions

- Balancing is heavily math-based; when imbalance readings change or unexpected vibration occurs, get down to the basics of balancing and do the math.
- Most balancing machines can't tell if you have added weight to the part, changed parts, or if it is the same part; all they can do is measure and display the imbalance.
- There is a reason for the change and it can usually be calculated.

References

1. *Balance Information Guide*. Hines Industries, Inc., Ann Arbor, MI 2004.
2. "Balancing Requirements of Rigid Rotors." IRD Balancing, Louisville, KY, Rev. 2, March 2009.
3. *Basic Balancing Theory.* American Hofmann, Lynchburg, VA.
4. "Understanding Balance Tolerances." Schenck Trebel Corp, Deer Park, NY.


Working at her family-owned company—Ann Arbor, MI-based Hines Industries, Inc. *(www.hinesindustries.com)*—**Robin Hines Mifsud** has gained more than 17 years' experience in the parts balancing industry. Having earned BS and MBA degrees, Hines Mifsud has held a variety of positions at the company, including—machinist; assembling, calibrating and servicing equipment; managing a balancing service; and the marketing and selling of machinery for the last 11 years. She presented the preceding paper at last year's AGMA Technical Conference.


LIGHT YEARS AHEAD
IT'S THE DAWN OF A NEW ERA FOR GEAR MANUFACTURING.
AND SCHAFER IS LEADING THE WAY.

Gear Material Selection and Construction for Large Gears

Frank C. Uherek

A road map is presented listing critical considerations and optimal use of materials and methods in the construction of large gears.

Introduction

The purpose of any gear mesh is to transmit rotary motion and torque from one location to another at a consistent rate. Various rating practices from AGMA, ISO and others go into great detail about the tooth proportions, accuracy requirements, material selection and cutting methods to produce a tooth that satisfies the requirements of the application. However, standards do not provide all the information necessary to ensure the torque at the gear tooth is actually moved to the piece of driven equipment, i.e.—gear blank design. In most enclosed drive applications, a disk of the same face with a bore and keyway is sufficient. Yet, in the realm of large gears—defined as three meters (10 feet) in diameter and above—a solid blank fulfills the design engineer's maxim of making the part difficult to manufacture and impossible to install. Blank design needs to be driven by the application and the range of materials available to ensure that sufficient stress capacity is available at the teeth—as well as the ability to connect with the driven equipment. This paper covers these issues in a specific area of use: gearing for cylindrical grinding mills and kilns.

Background

Grinding mill and kiln services are unusual installations for gearing when compared to traditional enclosed gear drive installations, yet these applications have been utilized for more than 85 years. The grinding process—more accurately, a tumbling process—uses horizontal rotating cylinders that contain the material to be broken, potentially augmented by grinding media. The material moves up the wall of the drum until gravity overcomes centrifugal forces; it then drops to the bottom of the drum to collide with the remaining material. This breaks up the particles and reduces their size. Kilns rotate at far slower speeds to enable even firing of their contents. Power required for this process ranges from 75 to 18,000 kW (100 to 24,000 hp)—in either single- or dual-motor configurations.

In this type of application, the pinion is mounted on pillow blocks driven by a low-speed motor or a motor and enclosed gear drive. For mill applications the gear is mounted on the mill using a flange bolted connection (Fig. 1). For a kiln, various types of spring plates are used; both the center distance and alignment are adjustable, either by shimming the pillow blocks or moving the mill. Lubricant is typically either high-viscosity oil (1,260 cSt @100° C) sprayed on the gear in 15-minute intervals, or a lower viscosity oil or grease product sprayed on the pinion every few minutes. Alternately, lubrication can be applied by continuous spray or dip immersion methods.

Gear sizes can range up to 14 meters (46 feet) in diameter, with face widths approaching 1.2 meters (50 inches). Typical tooth sizes range from 20- to 40-module (1.25 DP to 0.64 DP). Single-stage reduction gears range from 8:1 to as much as 20:1. Gear materials are typically through- hardened cast steel, fabricated rolled steel or spheroidal graphitic iron. Pinions are carburized, induction-hardened or through-hardened steels. For small installations, either a one- or two-piece design is used with the split joints located in the root of a tooth. Four- and six-piece designs are also utilized when weight or pouring capacity becomes an issue.

Figure 1 Grinding mill installation.

Structure Requirements

Based on the application, these gears need to have large bores to accommodate the mill or kiln shell. This enables use of reduction ratios not normally thought of as reasonable (i.e., 8:1 to 20:1) in a single stage. The gears are bolted to the mill through a flange connection or mounted on tangential spring plates to allow for thermal growth (Fig. 2).

The next step is to connect the bore of the gear to the teeth; this is done by either using a "box,"—also known as a delta- or Y-shape—or T-shape structure (Fig. 3).

A typical ring gear has a series of windows cut into the material for handling and weight considerations (Fig. 4).

Over time, design rules have been developed to address the material shape distribution of the various elements of the ring gear structure. Rexnord has over 5,000 gears in service with design lives exceeding 25 years that confirm these rules and calculations reflect field requirements. The purpose of the structure is to provide stability at the tooth location to ensure the assumptions made at the rating phase of gear development are supported by the actual blank design. Annex C of ANSI/AGMA 6014–A06 discusses the following considerations for blank design:

- Reduction of strength rating by moving the location of bending fatigue failure into the gear rim from the tooth root (K_{Bm} factor)
- Effect of rim deflection on the load distribution factor K_m
- Influence of the mating element on load distribution factor K_m
- Definition of dynamic alignment techniques to achieve correct mesh patterns

Rim thickness is a significant parameter in the design. There is a minimum value of the thickness specified by the rating standards to ensure any bending strength failure of teeth would travel through the base of the tooth and not through the rim of the blank. Based on field experience, AGMA 6014 suggests designs having a backup ratio $mB > 1.0$

$$m_B = \frac{t_R}{h_t} \quad (1)$$

where:

m_B is back-up ratio
t_R is gear rim thickness below the tooth root, in.
h_t is gear tooth whole depth, in.

This avoids the need to derate the gear to move the failure mode to a more conventional area. Other standards, such as ANSI/AGMA 2001–D04, feel a value of 1.2 is more appropriate. A point of debate is what is considered the inside rim of a gear. Conservative thinking would require that any missing material below the tooth root is the start of the inside rim diameter. Many designs feature a groove in the side of the gear for mounting of a dust shield. This groove is located to generate a backup ratio of ~ 0.6– to 0.80. The loss of support, typically 13 mm (0.5 inch) is not considered significant when working with face widths of 380 to

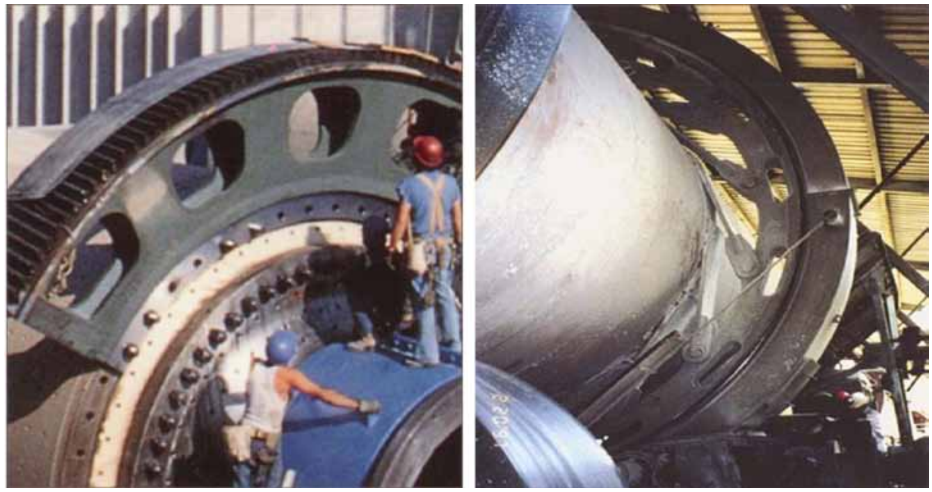


Figure 2 Flange mounting and spring mounting options.

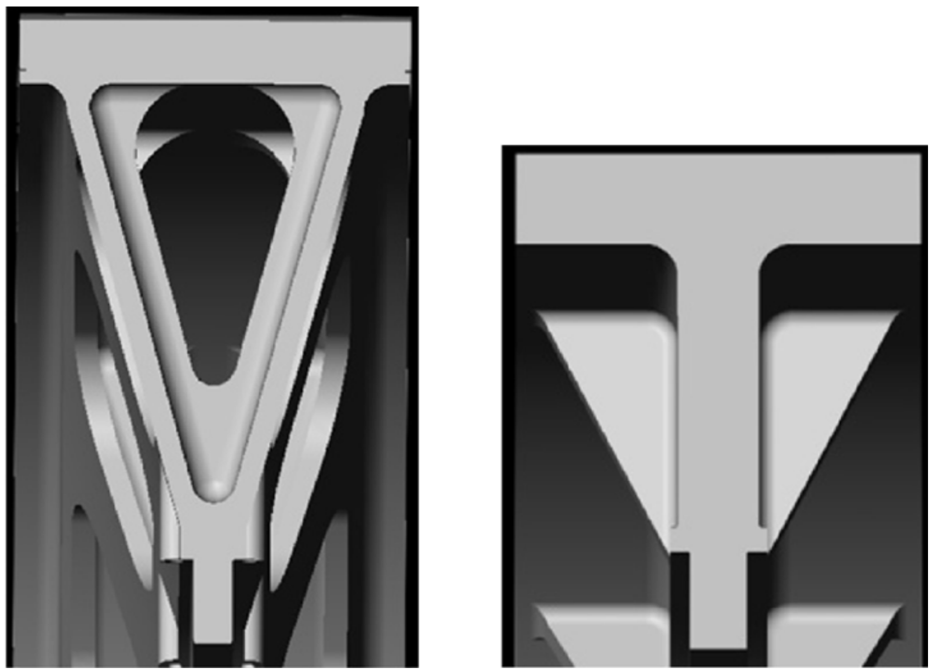


Figure 3 Box/Y/delta and tee shape cross section.

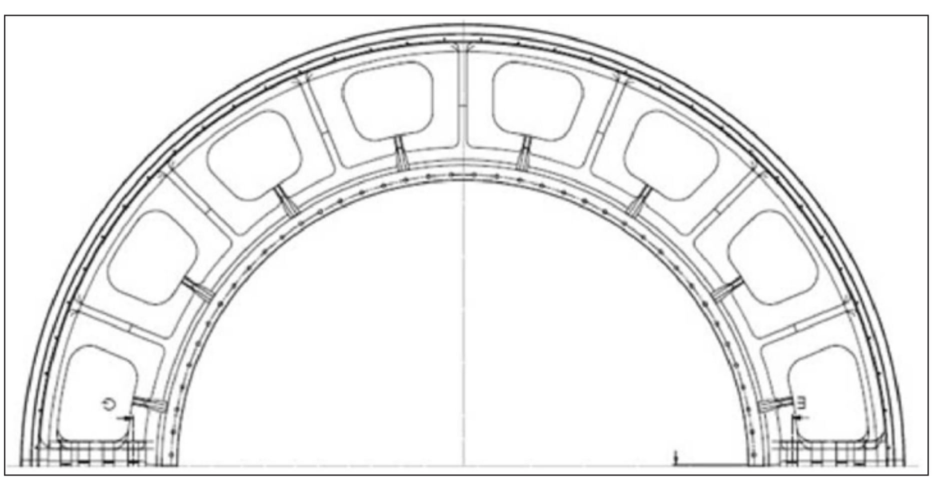


Figure 4 Side view of ring gear.

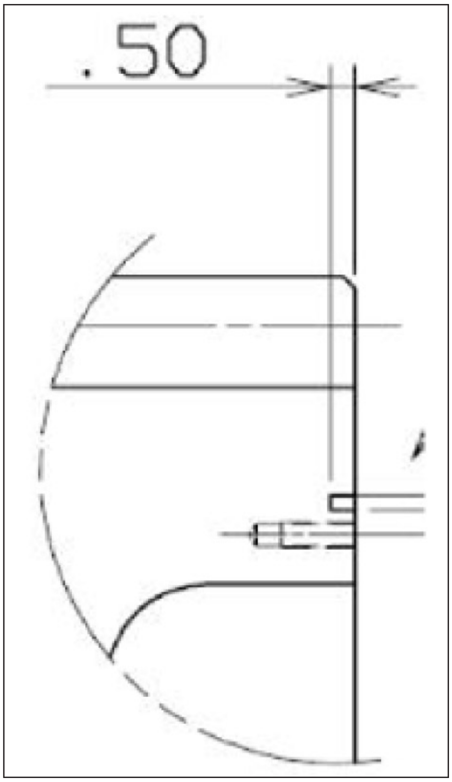


Figure 5 Locations of dust guard groove and indicating band.

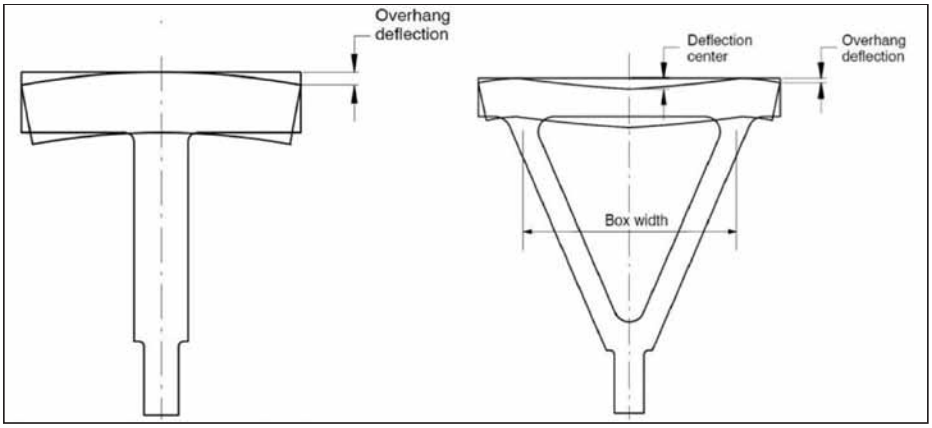


Figure 6 Overhang deflection modes.

1,015 mm (15 to 40 inches). The next loss of material underneath the tooth root is an indicating band typically turned on the inside of the rim diameter to facilitate installation (Fig. 5). This loss of support is typically 25 mm (1 inch) wide. Finally there is the true inside rim diameter that is typically 13 mm (0.5 inch) beyond this value. Reasonable design practice tends to use the machined indicating band as the location of the inside diameter for the purposes of determining a value for the rim thickness factor, *K*Bm.

Since 60 percent of the weight—and, therefore, cost— is tied to rim size and thickness, optimization pays large dividends. A start point for rim thickness values are a backup ratio of 1.10 for box section gears and 1.25 for tee section gears. As gears move toward finer pitches (i.e., $< 25\ m_n, > 1.0$ DP) what tends to drive rim thickness is the tapped hole beneath the guard groove for support of the external dust guard. At larger modules, deflection tends to be the controlling factor.

Achieving calculated values of load distribution, K_m, is a function of tooth generation accuracy and rim support. Based on the rating practice, these types of gears are typically A9 to A7 (Q8 to Q10) for helix accuracy. Typical verification methods are a helix check of the pinion and a contact check with the gear to confirm mesh compatibility. One typical deflection source comes from face movement away from the pinion either in the center portion of box Y rims or the end portions of T rims.

Two other deflection modes are rim deflection and face deflection (Fig. 6). Rim deflection occurs when the rim sags between the arms of the gear. Face deflection arises when the entire gear bends from the mounting flange due to thrust force of the teeth. A good design practice is to limit maximum deflections of these three modes to be less than 25 µm (0.001 inches).

The other two parameters affecting K_m are influence of the mating element and dynamic alignment techniques to achieve correct mesh patterns. These are beyond the scope of this paper.

When designing large gear blanks, the major factors to be considered are:

- Load
- Face width
- Rim thickness
- Stiffener spacing and number of windows
- Window size
- Support web thickness
- Material

Loading on these blanks comes from three sources: the amount of power being transmitted though mesh, handling as horizontal rings during manufacturing, and handling as vertical segments or semi rings during installation.

Typically the requirement for maintaining tooth alignment is the chief driver for dimensional selection. Wider face widths tend to require additional rim thickness to manage overhang deflection. For cast steel designs, the crossover point between tee and box Y section designs is 760 mm (30 inches) of face width. In a specific example, a 6,250 kW ball mill gear at 16.76 rpm output speed has a required rim thickness value of 210 mm (8.26 in) in a tee configuration whereas the box Y gear has 165 mm (6.51 in). This reduces the overall weight of the gear to 61,600 kg (135,700 lbs.) in a box Y configuration but 67,500 kg (148,700 lbs.) as a tee configuration.

Fabricated steel and ductile iron designs cannot take advantage of a box Y design due to cost of construction and material flow during the production process and as a result will have thicker rims with these face widths.

As noted above, rim thickness is driven mainly by requirements for failure through the tooth root and not the blank. Locations of customer supplied guarding and deflection also drive this parameter.

The number of stiffeners is a function of the web height of the gear (i.e., distance between the bore and the inside rim diameter), the number of windows, and the amount of helix angle of the gear to prevent face deflection. For gears of tight cross section (< 150 mm, 6.0 inches) they may not be needed due to the stiffness of the web and are not practical from the construction standpoint. As the diameter of the gear increases, the distance between stiffeners becomes a greater influence factor on rim deflection over the windows in the blank. To provide adequate support, stiffeners should be placed ~1 m (40 inches) apart for tee designs and 1.2 m (50 inches) for box Y designs. This allows for a reasonable balance between deflection and rim thickness. This will also drive the number of windows between the stiffeners.

Window sizing is a parameter that is more critical for cast steel and ductile iron designs than for fabricated gears. All three gears share the same need for windows from the standpoint of openings for lifting slings and chains. Since the window is a sunk cost for a fabricated design in that the web plate is sold by weight and window cutouts are unlikely to be used in other portions of the fabrication, the size of the window should be dictated by handling only. Whereas for cast designs, material usage can be optimized allowing for larger windows having a weight savings. In addition, they are necessary to support the top portion of the mold during pouring. From the deflection standpoint, window size plays a role in supporting the rim between stiffeners. In bending deflection, the moment of inertia is in direct proportion to width but a cubic function of height. Therefore, when dealing with rim deflections issues, lowering the window outside diameter to stiffen the web and therefore reduce the deflection may be a better use of material than adding thickness to the rim area.

Support webs come in two types for these gears. Box width for cast steel gears is a function of allowing sufficient space for the split joint hardware as well as stiffness to manage sag between the side supports. Web width for tee sections adds stiffness and transmits torque between the rim and the bore of the gear. In both cases, thickness and location are driven by rim deflection considerations.

Material is the last parameter to consider in gear blank design and has a significant impact on cost. An advantage of fabricated designs includes the ability to assemble gears with high alloy at the tooth locations, necessary for torque transmission, while using a lower grade alloy for the structure of the blank. This cost savings may be offset by the welding assembly cost. Contrary to fabricated gears, cast gears are constructed of uniform isotropic material, avoiding any issues with performance variation as a function of alloy. Optimizing window size is an option cast gears can utilize to offset a portion of the material cost.

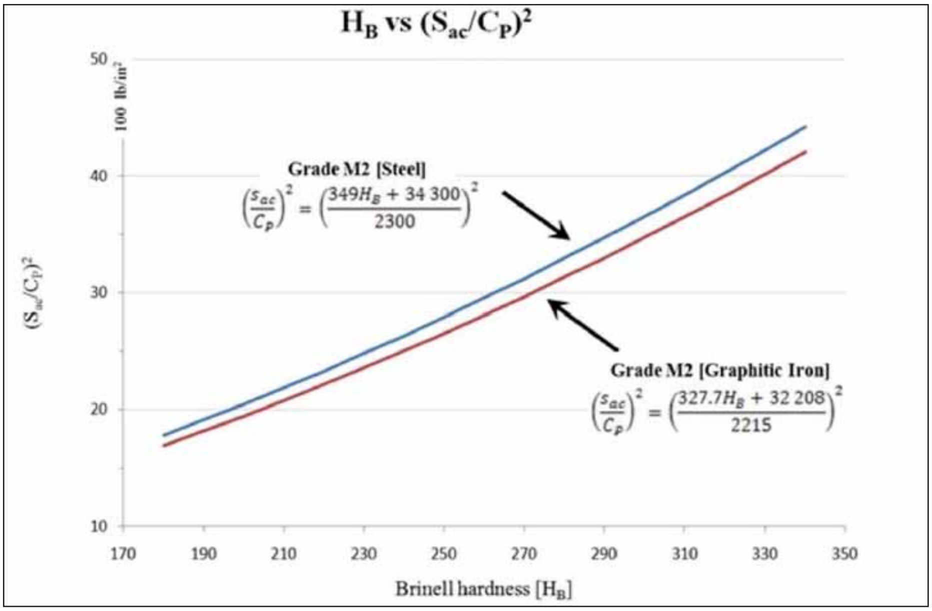


Figure 7 Comparison of material related factors for pitting resistance.

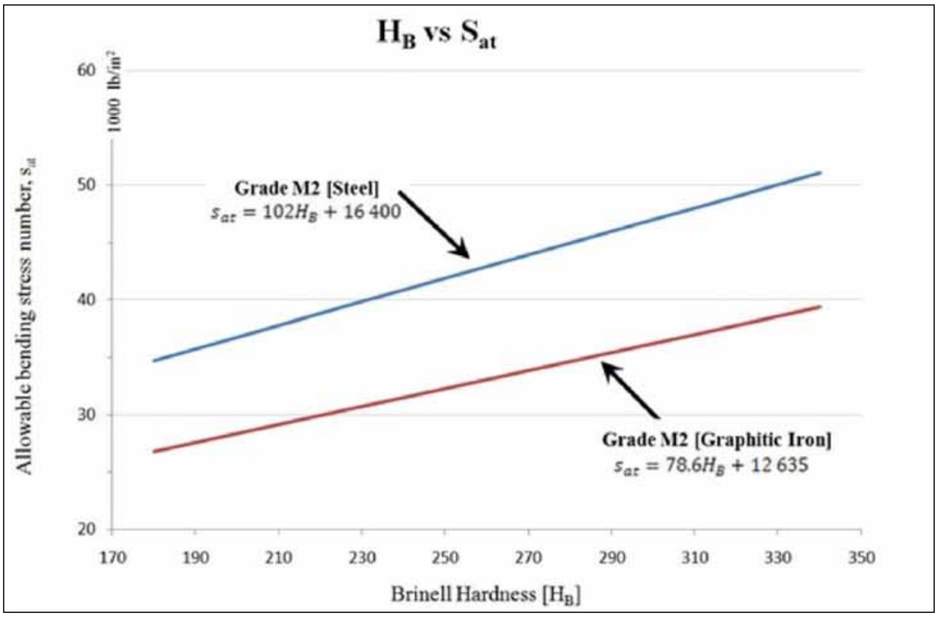


Figure 8 Comparison of material related factors for bending strength.

Rim Material Choices

The selection of rim material is driven by the blank manufacture method. For large gear design there are currently two choices in use today: fabricated and cast structures. Steel can be used in both options, while ductile iron is only available as a cast option.

Fabricated structures consist of a rolled rim SAE 1045 or rolled ring forging SAE4340 plate that is welded to an ASTM A36 web plate with stiffeners. Design hardness is 180 HBW for the 1045 material and up to 265 HBW for 4340 plate.

Cast steel is the traditional material used for large gear blank designs. Typically proprietary alloys are used to enable sufficient hardenability through the rim area to ensure design hardness at the root diameter. Design hardness ranges from 180 HBW to 335 HBW.

Ductile iron is an alternate cast material; it offers similar weight optimization attributes as cast steel, with the additional benefit of absorbing noise vibration due to the precipitated graphite particles. As noted below, this comes at the cost of reduced power capacity. Design hardness ranges from 180 HBW to 335 HBW.

From the power capacity standpoint, there is no difference in allowable transmitted power between fabricated and cast steel gears of the same hardness. But the same *cannot* be said for ductile iron.

Due to the lower values of the modulus of elasticity, Poisson's ratio and different fatigue life performance in contact and bending stress, the power capacity of a ductile iron gear is typically lower than the same gear made from fabricated or cast steel. Pitting resistance changes by 5 percent in this case (Fig. 7).

A larger difference occurs in bending strength, resulting in a 23 percent difference in power capacity (Fig. 8). These values are based on the rating formulas in AGMA 6014 using grade-two material. Grade-one material requires less material certification and therefore has lower power capacity. Other standards may indicate a different comparison.

Typical service factors for grinding mills require higher values for bending strength than pitting resistance. Kilns at 1.5 rpm output speed require values of 1.00 and 1.75 for C_{sf} and K_{sf}, respectively. Ball and SAG mills require 1.75 and 2.50, respectively in higher power applications (> 3,350 kW or 4,500 hp). When using ductile iron gears in these applications, the reduction in bending strength requires either wider face widths or larger modules (coarser pitches).

Another consideration is the yield strength of the material. Figure 9 illustrates that ductile iron has ~ 60 to 70 percent of the yield strength of its steel counterpart for the same material hardness.

This becomes an issue when reviewing the performance of mill gears in low cycle inching or maintenance drive usage when the number of load cycles is expected to be less than 10,000. For cycles greater than 10,000, there is no fatigue life performance difference between steel and ductile iron, per AGMA 6014.

Construction Considerations

Each of the three methods of ring gear fabrication offers significant benefits, as well as noteworthy disadvantages that can be used as a guideline for the selection process.

The initial consideration is the client interface dimensions, as gear designers have little control over the bore of the gear and the connection interface to the structure. For applications that feature a gear reducer in addition to the gear set, the distribution-of-ratio between the gear drive and the final-stage reduction will have a significant impact on cost. An initial conjecture is to wrap the gear as closely as possible around the mill or kiln, and place the remaining ratio in the gear drive—based on the assumption that a carburized-hardened and ground enclosed drive is more cost efficient in torque-transmittal capabilities than the open set. This needs to be balanced by the loss in efficiency if a multiple-stage reduction drive is necessary for the ratio required. If one is using a line of catalog gear drives, the steps in torque transmittal capacity as a function of unit size will also drive the selection. The final consideration is the overall cost of providing torque to the mill or kiln in terms of selecting a low-speed (200 rpm) motor and directly connecting it to the mill pinion in place of a higher speed motor (1,170–740 rpm) and including a gear drive in the train. It is best to advise the gear supplier of either the direct-driven or reducer-driven option and let them work out the most cost-efficient solution to size the gear/gear drive combination. Forcing a mill pinion speed in a reducer drivetrain or selecting too fast of a motor speed can lead to low-cost items—such as input shaft bearings in the gear drive—constraining the entire design of the drivetrain. An example of this is the combination of high- power (over 5,000 kW or 6,700 hp) high-speed motors with L10 bearing requirements greater than the design amount, based on the service factor of the drive. Requesting 100,000 hours of L10 life with a 2.0 service factor that implies 50,000 hours of life requires the drive designer to increase the size of the input shaft bearings to achieve the life requirement. This may lead to an increase in drive size to achieve the L10 life requested. Not allowing the ratio in the drive to increase to use more of the excess torque capacity of the gear drive by slowing down the pinion speed causes an uneven distribution of torque between the drive and the gear set—thus increasing costs.

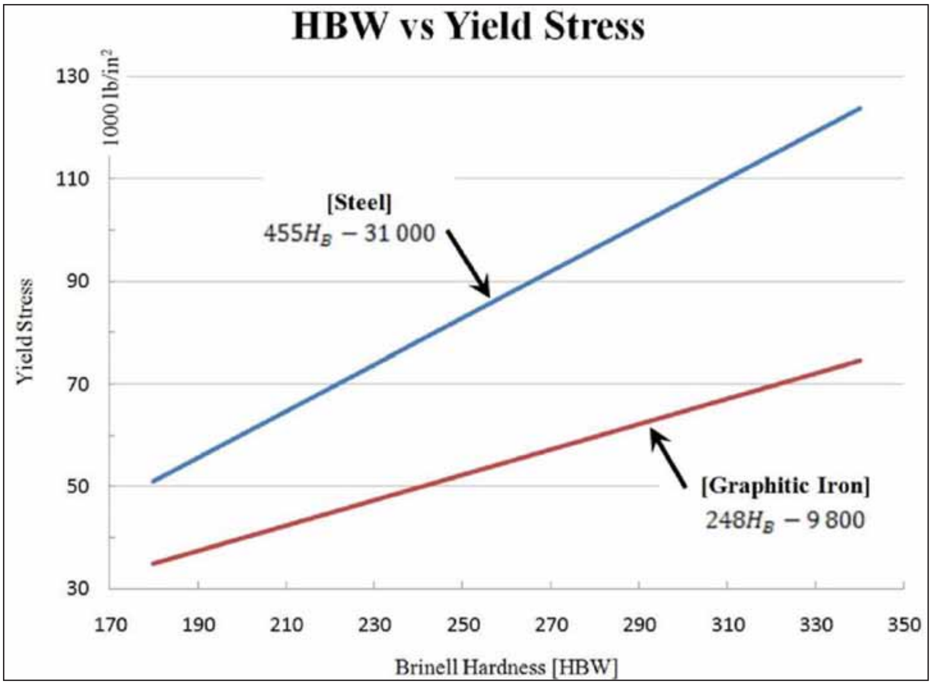


Figure 9 Comparison of material related factors for yield strength.

Cast Ductile Iron

The next consideration is to select the material for construction. When designing with ductile iron, the first consideration, as noted above, is the reduced bending strength rating. This will tend to drive the design to larger modules that require greater rim thickness due to the requirements of the rim thickness factor, K_B; having a thicker rim will also help in controlling overhang deflection of the rim. Having a modulus of elasticity ~ 11 percent less than steel will result in ductile iron moving more under the same load. To control this, rim and web sections tend to be larger than on a comparable-sized steel gear. For successful casting, abrupt section size changes should be avoided with this material due to solidification dynamics. In addition, to achieve uniform cooling, mold chills are required in the rim and bore area; this tends to prevent adoption of the box Y design for these types of gears. With the use of a T section, the pattern cost of a ductile iron gear is reduced.

Steel Gears

The next option in material is the use of steel for the rim material. This eliminates the loss of rating present in ductile iron designs. Therefore, the choice between fabrication and cast steel designs is dependent on material performance issues, construction options, lead time and cost.

Material performance of wrought versus cast steels. Wrought rim material consists of a steel plate that is rolled into a ring shape. Rolled metal develops and retains a fiber-like grain structure aligned in the principal direction of working. These fibers are the result of the elongation of the microstructure constituents of the metal in the direction of working. Due to the directionality, the mechanical properties of the plate are not uniform in the three principle directions of longitudinal, long transverse and short transverse—causing anisotropic performance. Variations in property performance are attributed to this elongation, as well as the stress concentration effect of loading normal to the major axis of an essentially elliptical void.

Cast rim material is poured into its final shape by the molding process. On a microstructure level, there are no directional property variations in the material since the micro-discontinuities generally have no preferred orientation. This random orientation allows for isotropic performance, avoiding changes in material performance based on load direction.

Construction options. Fabricated gears, in some applications, can reduce costs, since no pattern is required. Manufacturers may be limited by the ability to obtain a rolled, forged ring for the rim of the gear as well as oven or furnace capacity to stress relieve the gear after welding.

For fabricated gear blanks, the process starts with flame cutting of the rim plate material to required width. After stress relieving, the plate is rolled to shape and stress-relieved again. The center portion of the gear is also flame-cut and stress-relieved prior to welding to the rim material. The various parts of the gear are then welded, stress-relieved and, finally, the assembly is normalized and tempered to specified hardness. The large number of stress-relieving operations is necessary to prevent subsequent movement during machining and in-service operations. Selection of the proper weld rod material—typically heat-treatable electrodes—and pre-heat temperatures are necessary to ensure a successful fabrication. Pedersen (Ref. 9) indicates that it is well known that welded joints have low fatigue strength compared to the base material. This is mainly caused by local stress concentrations due to the presence of notches and high-tensile, residual stresses. Notches occur both because of the geometry of the joint and weld imperfections, such as undercuts and slag inclusions. Tensile-residual stresses arise from the contraction of the weld metal during cooling and solidification. Therefore, on mill gears, the weld joint tends to fail first from fatigue, given no installation, alignment or lubrication issues are present.

Generally speaking, castings are versatile and economical. The casting process utilizes the liquid metal's ability to flow into extremely complex shapes—even those with internal pockets and external projections. As a result castings produce a seamless, one-piece component that offers uniform strength and toughness. For cast gear blanks, the process starts with the construction of the pattern to make the casting. After pouring, the blank is allowed to cool in the mold. The risers and casting gate system are then removed and the remaining sand is cleaned off the blank. Magnetic particle inspection is conducted to indicate areas needing process welding. After process welding—preferably with heat-treatable electrode material—and a final magnetic particle inspection—the piece is normalized and tempered to achieve specification hardness. The location and volume of risers are critical to achieve a casting free of macro-porosity. Based on solidification rates, the risers feed additional material while cooling and collect slag and other material impurities. It is critical to have this impure material out of the tooth rim location to ensure uniform performance.

Lead time. A mill gear, whether constructed as a cast structure or fabricated rim, is a product that requires weeks of manufacturing before the client receives the end product. The main factor that determines the lead time is the construction process of the blank. For a cast gear these include building a pattern, melting and pouring the raw material, and solidification and extraction of the gear; this takes about 14 to 16 weeks for a cast gear. Since a fabricated gear is shaped from rolled steel plate, the construction time is shortened compared to a cast design—assuming stocked plate material. A fabricated blank must be hot- or cold-rolled from flat plate and then welded into shape; these two processes usually take about three to four weeks. Beyond construction of the blank, the rest of the gear manufacturing—milling, boring, turning, tooth cutting and drilling—is the same, regardless of blank construction. Construction time of the blank, whether cast or fabricated, seems to be minimal compared to the overall process from start to finish that historically tends to average around 50 weeks.

Due to the need for rapid response for field issues, some business interruption policies require either storage of the blank pattern to reduce turnaround time for replacement, or having a spare blank available for tooth cutting. Transportation and storage costs need to be reviewed when this option is selected.

Cost. Fabricated gears have a perceived cost advantage over castings due to the lack of pattern construction. Molding cost is not an issue since all steel starts out as cast in either ingot or melt form. Specification for plate steel must include low sulfur requirements to avoid issues with rim laminations. Cast designs must be produced with sufficient pouring capacity for manufacturing both the gear and filling the required risers to ensure material integrity at the rim, split joint and bore flange of the gear. Sixty to 65 percent of the steel used in the pouring of a mill gear is consumed in the riser and gating system. This is recycled for the next gear so this additional material is not considered part of the gear cost.

To identify a crossover point between the three options, a selection of sets was developed and the gear blanks were priced reflecting the three types of mate-

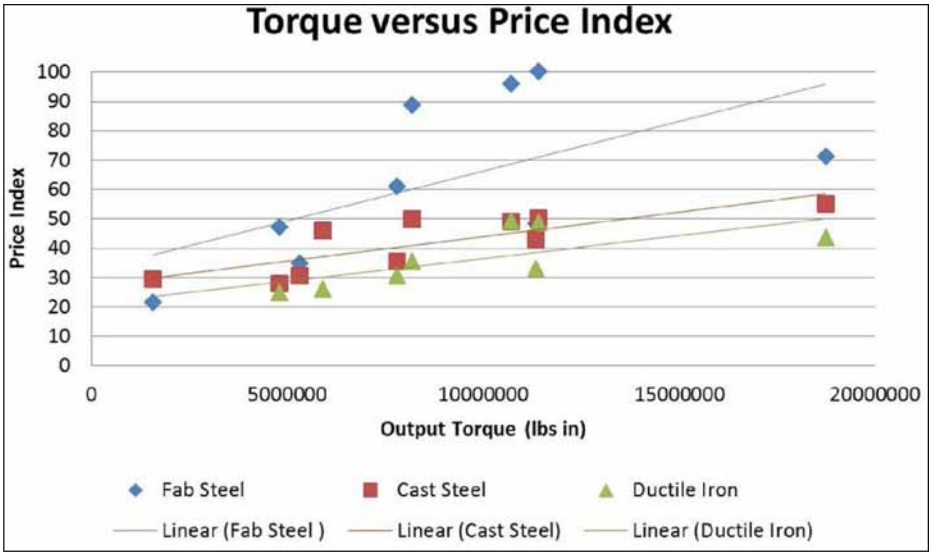


Figure 10 **Cost comparison of blank construction as a function of torque.**

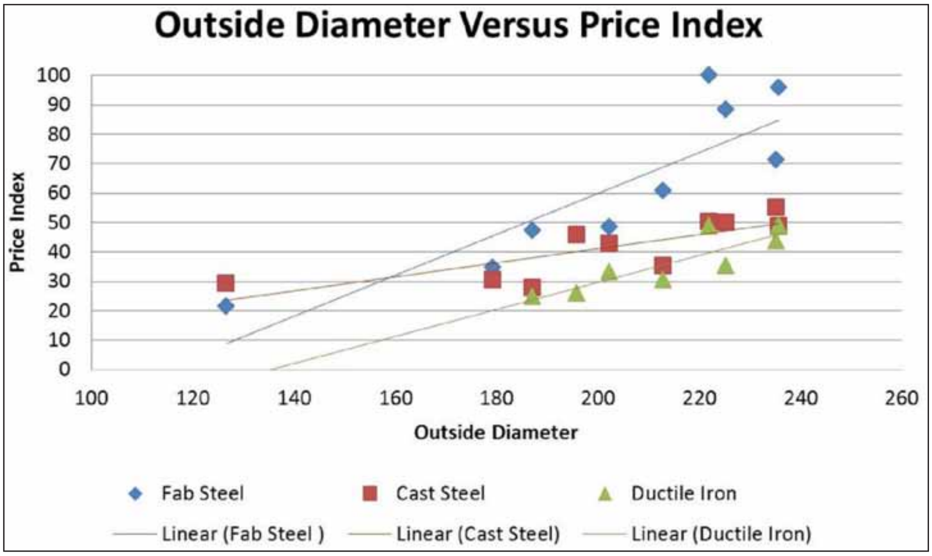


Figure 11 **Cost comparison of blank construction as a function of diameter.**

rial. The price index is normalized to the most expensive blank at 100; the results are plotted in Figure 10.

Looking at the data as a function of outside diameter (Fig. 11) illustrates a crossover point of ~4 m (160 inches), where cast steel gears overcome the pattern cost. As gears become larger the ability to shape the material to match loading requirements begins to pay significant dividends.

Conclusions

There are a variety of options for manufacturing methods for large gear designs. Fabricated steel, cast steel and ductile iron designs offer advantages as a function of output torque requirements. Voice-of-the-client data indicates that the key drivers in selection are lead time and cost, based on the expectation that high quality and compliance to specification are provided. Based on that, we see a transition from fabricated to cast designs at about 4 m in diameter; further work is required on the influence of bore size and hardness on cost. Ensuring that good design and material selection criteria are followed, each material type and construction method has its place in providing torque transmission for the application.

Acknowledgments. *The author would like to thank Jacob Higgins and colleagues of Rexnord/Falk for providing significant research assistance and editing efforts for this paper.*

References

1. ANSI/AGMA 6014–A06: Gear Power Rating for Cylindrical Shell and Trunnion-Supported Equipment.
2. ANSI/AGMA 2001–D04: Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth.
3. Blair, Malcom and Raymond Monroe. "Steel Fabrications vs. Castings," Steel Founders Society of America, *MetalCasting Design.com.*
4. Cahala, Glen and Tim Zwirlein. "Ring Gear Materials," The Falk Corporation, 991001 April 2000.
5. Carpenter, G.F. "Fatigue and Fracture Properties of Cast Steels," *ASM Handbook*, S.W. Becker, Vol. 19, (S. l.); ASM International, 1996, 656–58, "Print, Fatigue and Fracture."
6. Lynch, Alban and Chester Rowland. *The History of Grinding*, Littleton: Society for Mining, Metallurgy and Exploration, 2005.
7. O'Rourke, Robert. "Cast Iron: A Solid Choice for Reducing Gear Noise," ***Gear Technology,*** September 1999.
8. O'Rourke, Robert. "The Details of Ductile Iron," *Gear Solutions,* May 2004.
9. Pedersen, M, M., O.O. Mouristen, M.R. Hansen, J.G. Andersen and J. Wenderby. "Comparison of Post-Weld Treatment of High-Strength-Steel-Welded Joints in Medium Cycle Fatigue," International Institute of Welding, XIII–2272–09.
10. Rexnord Industries. "Evaluating Casting vs. Forging vs. Fabricating Technology," *Rexnord.com.*
11. Rhody, William. "Influence of Gear Manufacturer Method," *Motion System Design,* March 1993.
12. James, A. Rossow/Wyman–Gordon Company, "Closed-Die Forgings"; *ASM Handbook.* "Properties and Selection: Irons, Steels, and High-Performance Alloys," Materials Park, OH, ASM International, 1990, 342–44.
13. Uherek, Frank. "Development of a Gear Rating Standard: A Case Study of AGMA 6014–A06," 06FTM05, American Gear Manufacturers Association, 2006.

Frank C. Uherek is principal engineer/mill products for Rexnord Geared Products in Milwaukee WI. He received both a BSME (1981) and MBA (1985) from the Illinois Institute of Technology. Over 32 years, he has held various positions in design engineering and quality management, covering enclosed drives, wind turbine drives and open gearing for mill and kiln applications. He has served on numerous AGMA technical committees, including as vice chairman (and editor) of the Helical Gear Rating Committee, and received the AGMA TDEC award in 1997. In 2011, Uherek received the AGMA Distinguished Service Award for his work in developing AGMA gear rating standards.


A "Large Gear" manufacturing company with high quality, unbeatable prices and quick deliveries is no longer light years away.
Griffin Gear
Employee Owned
MAAG ZURICH
Manufacturers of Industrial Gears since 1967
With the capabilities to machine and cut gears ranging in size from one-half inch to twenty feet in diameter, we have the largest selection of equipment and tooling (including metric) required for highly customized jobs.
We also have a complete gear box rebuild shop for all your reducer needs
Member of
AGMA
Mailing Address
PO Box 202
Roebuck, SC 29376
Shipping Address
131 Rail Road Street
Roebuck, SC 29376
Call toll free 800.423.7506
Email: sales@griffingear.com
www.griffingear.com
Scan to see our new video.

Large Pinions for Open Gears: The Increase of Single Mesh Load

Michel Pasquier and Fabrice Wavelet

This paper introduces mandatory improvements in design, manufacturing and inspection—from material elaboration to final machining—with special focus upon today's large and powerful gearing.

Introduction

This paper is based on the fact that mining mills are becoming more and more powerful—up to 8,500 kW per pinion. Then the pinions have to grow to meet the single-mesh power increase and, consequently, conventional manufacturing and inspections reach their limits. Therefore the methods that have been used successfully for years must improve. Indeed, most customers have already acknowledged this need in the requirements of their technical specifications.

Starting from rough material and ending with final inspections, the intent of this paper is to introduce the needed technical improvements in manufacturing and inspection of large pinions to achieve the required transmitted power and the related service factors, as defined by worldwide consensus standard ANSI/AGMA 6014–A06.

Gear Rating According to ANSI/AGMA 6014–A06

The rating principle of a large pinion in an open gear set—according to ANSI/AGMA 6014–A06—is defined by its possibility to transmit a certain power, considering a certain safety factor—both in terms of bending strength and pitting resistance.

ANSI/AGMA 6014–A06, Equation 14:

$$P_a = \text{the lesser of } \frac{P_{acm}}{C_{SF}} \text{ and } \frac{P_{atm}}{K_{SF}}$$

where:

P_a is transmissible power
C_{SF} is safety factor for pitting resistance
K_{SF} is safety factor for bending strength

Considering now ANSI/AGMA 6014–A06 formulas to determine P_{acm} and P_{atm}:

$$P_{acm} = \frac{\pi n_p F}{396{,}000} \frac{I}{K_{vm} K_m} \left(\frac{d s_{ac} Z_N C_H}{C_p} \right) \quad (1)$$

$$P_{atm} = \frac{\pi n_p d}{396{,}000 K_{vm}} \frac{F}{P_d} \frac{J s_{at} Y_N}{K_m K_{Bm}} \quad (2)$$

Circled above are the parameters having the most influence on the final results:

K_{vm} (dynamic factor) and K_m (load distribution) are directly related to tooth accuracy

S_{ac} (pitting fatigue limit) and S_{at} (bending fatigue limit) are purely dependent upon material

Their definition and actual results condition the service life. In other words, the control of the manufacturing and inspection parameters that make these criteria are of the most importance.

Material

Material is of great importance to service life, but is also of great importance in terms of design. Let's consider an open gear set designed to transmit a power of 7,000 kW (9,387 hp) using a steel pinion, case-hardened:

- Grade M1 (low quality): $K_{SF} = 2.77$; $C_{SF} = 2.21$
- Grade M2 (best quality): $K_{SF} = 3.10$; $C_{SF} = 3.02$

In the case of large pinions, achieving the required mechanical properties throughout the entire part is a challenge. Thus perfect control of the manufacturing process and quality assurance—from ingot casting to final heat treated forging (including case-hardening)—is mandatory, which is the central reason that the M2 material is chosen.

Rough material. The pinions are manufactured from forged parts, themselves coming from an ingot. The ingot casting requires high technical skill to achieve both the metallurgical requirements (mechanical properties, homogeneity, etc.) and other parameters known for their influence on the behavior of the part in service (cleanliness, compactness. etc.).

Ingot casting. Some of the key parameters in respect to fatigue behavior of the parts are obtained from the casting and will not change afterward, e.g.:

- ***Soundness*** is the absence of macro-defects like porosities or cracks
- ***Cleanliness*** is the absence of endogen, non-metallic inclusions and segregation
- ***Homogeneity of microstructure*** through the entire thickness
- ***Uniformity of secondary structure*** (grain, etc.)
- ***Chemical composition*** is an adequate and controlled quantity of alloy elements such as manganese, chromium, nickel, copper, molybdenum and vanadium

The following is a review of the parameters:

Segregation. Even though it is not a standard requirement, the first point relevant to the solidification process is the segregation. Segregations are a localized over-abundance of alloying

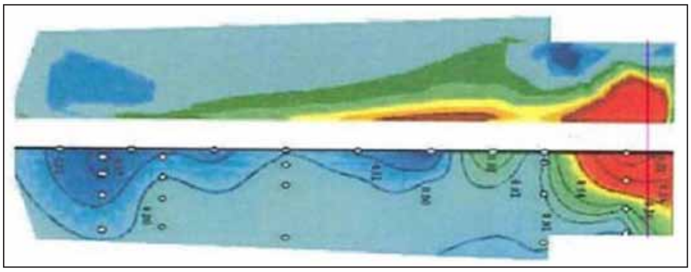


Figure 1—Computer simulation of segregation.

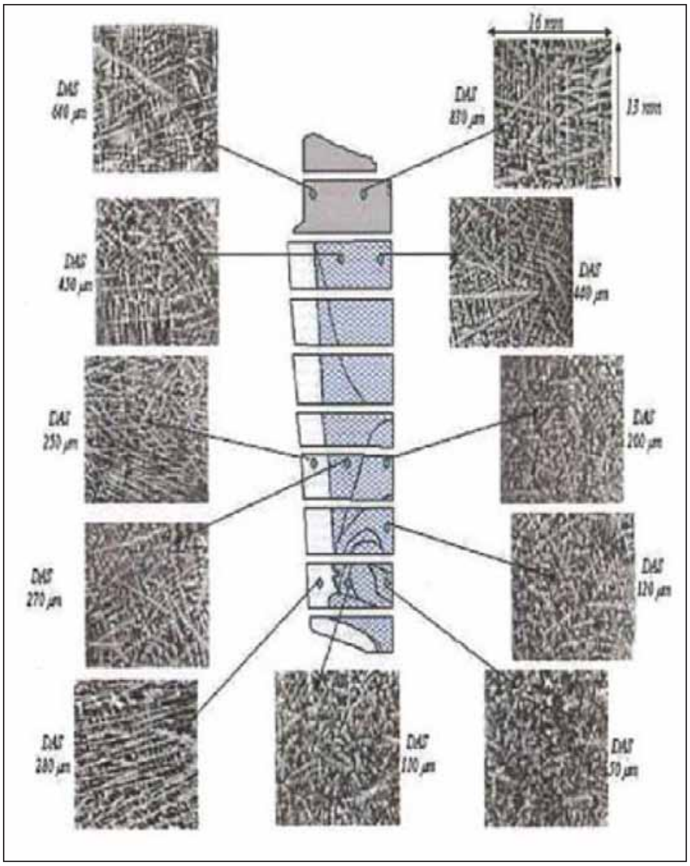


Figure 2—Actual segregation in ingot.

Figure 3—Sudden breakage due to hydrogen embrittlement.

Figure 4—Magnification of hydrogen burst in the broken surface.

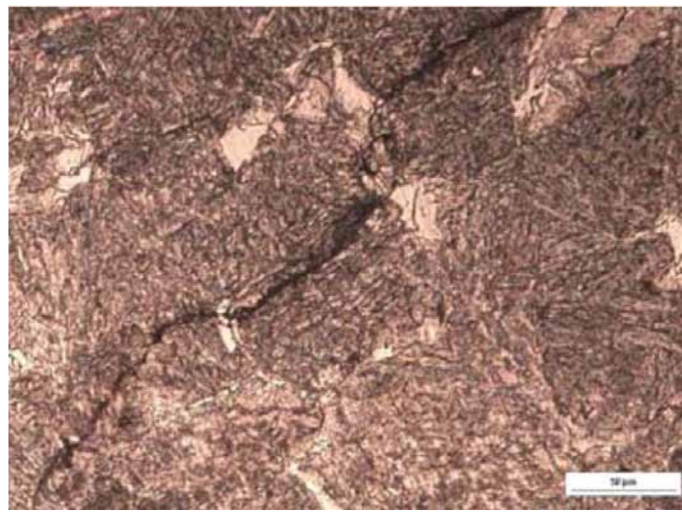


Figure 5—Free hydrogen influence—microcrack formed during forging.

elements, implying a decline in mechanical and fatigue properties that may lead to shrinkages. As heat treatment cannot erase such segregations, it must be avoided. With technology development and solidification knowledge, solidification can be more accurately computer simulated. Some ingots have very low levels of segregations, even for large castings (Figs. 1 and 2).

Cleanliness. Cleanliness is at the top of metallurgical standard requirements for obvious reasons; i.e., cleanliness is related to non-metallic inclusions—even though they are needed to initiate solidification and to obtain a thin and homogeneous structure. A local concentration of these elements will lead to buried defects. A definition of the acceptance criteria is then needed, but the problem is that cleanliness can be stated according to several different standards for different results. For example: in ANSI/AGMA 6014–A06 the cleanliness requirement is according to ASTM866 or AMS 2301. ISO 6336 refers to ISO 4967. Sometimes, steel manufacturers rate cleanliness in accordance with DIN 50 602, Method K. Are we then to consider only ANSI/AGMA 6014–A06 cleanliness requirements for steel pinions meant for the teeth area (Table 5, Note 2), while case-carburized pinions have different requirements (Table 7, Item 4)?

The multiplicity of standards, and of course their respective acceptance criteria, makes it almost impossible to determine an appropriate content for the different kinds of non-metallic inclusions (sulphides, aluminas, silicates and oxides). For the large parts we are talking about, cleanliness shall be achieved throughout the complete thickness.

H2 content. Even though it has long been evident that free hydrogen content is of the greatest importance, none of the existing rating standards defines a maximum content. Free hydrogen may have a dramatic effect on the part, whether at the manufacturing stage or during service. As the hydrogen content increases, the internal gas pressure increases at an exponential rate. Combined with inherent material dislocations and atomic diffusion (embrittlement is a very complicated process), hydro-

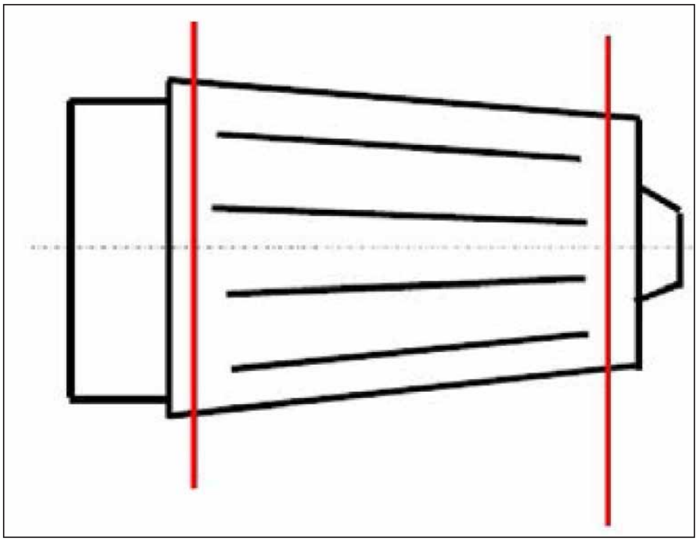


Figure 6—Ingot location of head and foot cuts.

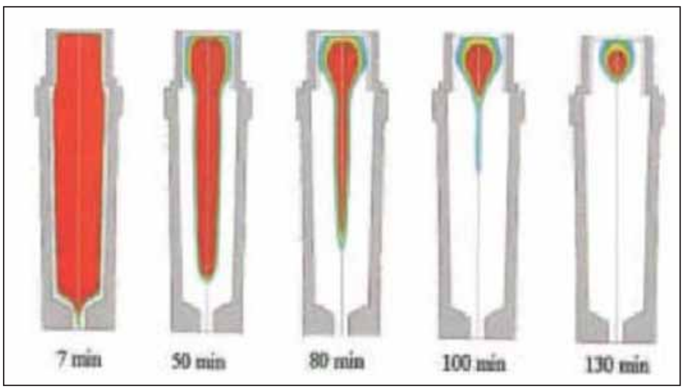


Figure 7—Computer simulation of cooling.

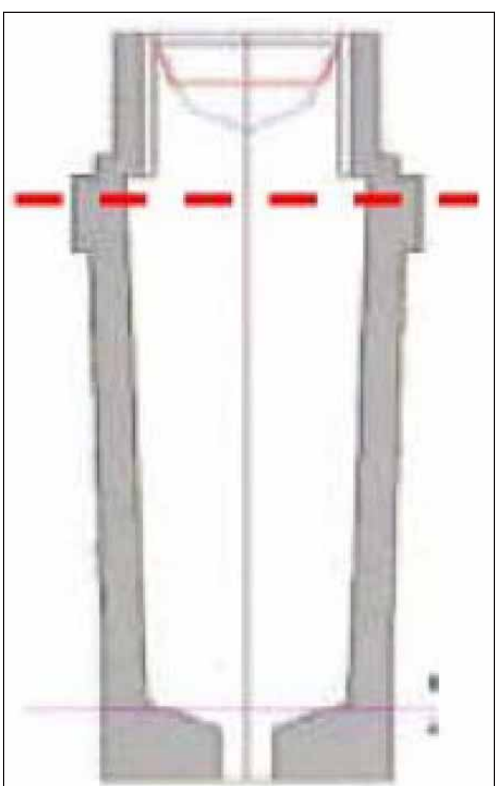


Figure 8—Location of the porosities in the ingot.

gen may lead to severe damage. A well-known effect of that, and probably the most typical, is a sudden break while efforts undergone by the part are very low (Figs. 3–4). Another effect can occur during ingot casting or at the forging stage. Figure 5 shows a crack that occurred during forging, generated by hydrogen embrittlement in a bainitic structure.

The origin can be summarized as follows:

Steel Ingot →Dendrites → Segregations + Free H2 → Embrittlement →Cracking

A solution to avoid such embrittlement is to maintain a low level of free hydrogen. This can be achieved with a vacuum degas process. By today's standards, 2 ppm of H_2 is a limit commonly reached and guarantees a minimum risk of embrittlement. But, naturally, then comes the question of the measurement of free hydrogen in such small amounts. Whatever the equipment used, the hydrogen content is better tested in the hot top (ingot casting) rather than via ladle analyses.

Forging. The second important step concerning rough material is forging; the ingot is cut head and foot (Fig. 6).

The key point is the location where the initial piece is taken from the ingot. Figure 7 explains the cooling process of the ingot and the final location of porosities (in the top). If the initial piece is taken close to the head of the ingot, it should be carefully checked that the head cut is enough to remove all porosities (Fig. 8). An example of defect found in a large pinion forging is shown in Figure 9. Small cracks or very small cracks were observed in the core of the forged part. The origin of the defect can be ascribed to the location of the initial piece close to the top of the ingot (last solidification area), where important areas of porosity are present (Fig. 10).

Under constraints (thermal, mechanical), porosities turn into cracks. By avoiding this area of last solidification when cut, the ingot is absolutely needed to obtain a quality product. For forgings, it is expected to achieve a certain reduction ratio (commonly 3:1). What does this mean for pinions, and specifically for large parts in the teeth area? Reduction ratio means the difference in terms of diameters between the ingot and the wrought piece. Forging reduction induces a compactness improvement and a structure orientation that are both good for mechanical properties.

Considering the volume represented by a large pinion, and the increased influence of segregations, porosities, hydrogen, etc., and due to its size, the use of wrought product with a high reduction ratio is obviously of more importance for small pinions.

Inspection

ANSI/AGMA 6014–A06, as well as the customer's technical specifications, often include some inspection requirements and acceptance criteria for the abovementioned key parameters. Whatever they are, the most difficult inspection regards internal material soundness through ultrasonic (UT) inspection and its related acceptance criteria.

ANSI/AGMA 6014–A06 (Tables 5 and 7) give both test conditions ("For pinions, above UT applies in radial direction, 360 degrees around, and axially from both ends") as well as acceptance criteria. The concern comes with the ultrasonic inspection that is to be repeated after carburization (for case-carburized pinion)—i.e., anything different from the initial test is to be recorded, which is quite imprecise and difficult in practice.

For this reason some specific requirements for through-hardened and case-carburized pinions have been developed in recent years. This includes both test methods and highly stringent acceptance criteria, based on the fact that with products being bigger and more powerful, any single problem could lead to dramatic effects. Concerning through-hardened pinions, only one test is carried out at the rough-machining stage. For case-carburized pinions, two inspections are carried out: 1) at the rough machining stage; and 2) after case-carburizing and final grinding.

UT inspection is done on machined surfaces with a surface finishes equal to Ra 6.3 μm (160 micro-inches) or less, which is even better than required in ANSI/AGMA 6014–A06. Inspection is performed by either using reflection on calibration blocs (AVG method) or the DGS/CAD method (automatic calibration); straight-beam probes of two MHz or less are used. 100% of the pinion's volume is tested in the radial direction on the major diameters; in addition, the pinion is inspected lengthwise from each shaft end. This last test provides a good idea of the material quality—even if this is not part of the acceptance criteria. Using a 2 MHz probe, shoot from one shaft end; should you:

- Obtain one back-wall echo with a loss less than 30% = what's expected
- Obtain two back-wall echoes in the same conditions = good forging
- Obtain three back-wall echoes = excellent forging

Even though more restrictive acceptance criteria have been defined, the available feedback does not conclude whether these requirements are correct or perhaps even too conservative.

A well-known method common in the medical field is now currently under development for industrial applications—phased-array ultrasonics (PAUT). This new technology, applied to steel forgings, may bring a new level of interpretation for expertise purposes (Figs. 11 and 12).

Phased array probes typically consist of a transducer assembly containing from 16 to as many as 256 small elements that can each be pulsed separately. In its most basic sense, a PAUT system uses the wave physics principle of phasing. A certain volume of the part is swept individually by each ultrasonic element, with a very brief delay between each. Electronic interpretation of the signal provides 2-D mapping of the section tested.

As far as the strength and integrity of forgings are concerned, the PAUT method provides new levels of information and visualization as compared to common UT inspection. Yet, it remains an ultrasonic technology, meaning phased-array ultrasonics will still imply different directions of shooting to determine the exact volume of a buried indication. The accuracy and visualization introduced by this continuously improving technology—coupled with the possibilities and limits extant in today's electronics—render PAUT a significant inspection tool upgrade over traditional UT.

Microstructure:

Through-hardened steels. Through-hardening is the most common treatment for the heavy parts discussed here; hardness requirements are 340–400 HB. Nevertheless, quenching in an adequate bath and tempering must also be conducted in order to ensure that the required microstructure is achieved in the core of

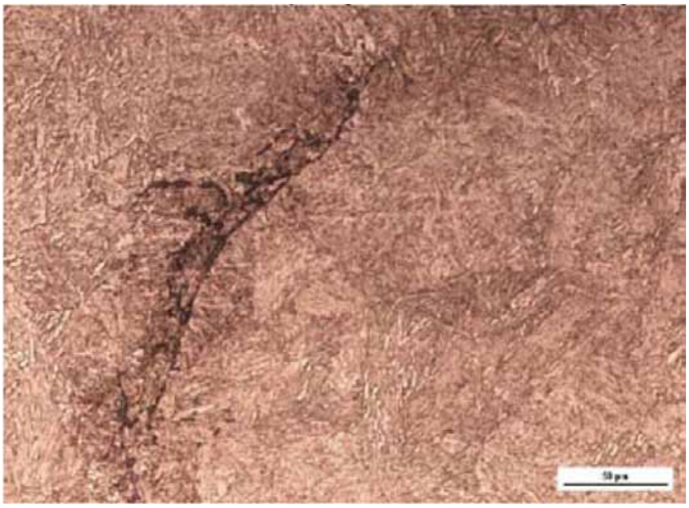


Figure 9—Crack in a forged part formed from a porosity.

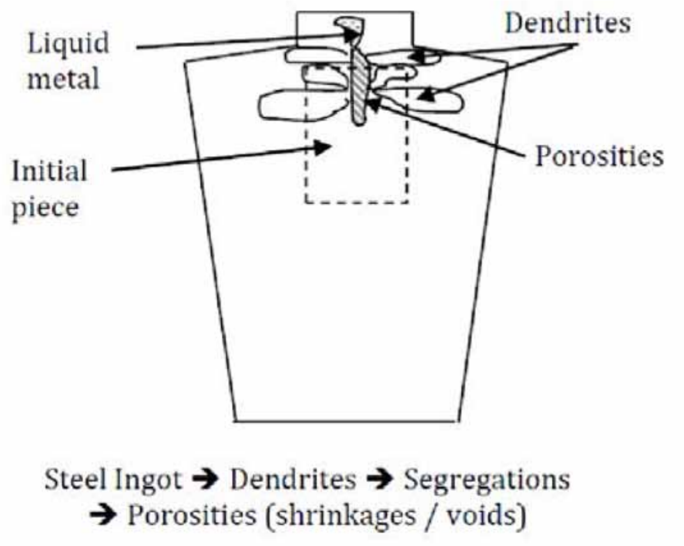


Figure 10—Example of initial part location of a failed forged.

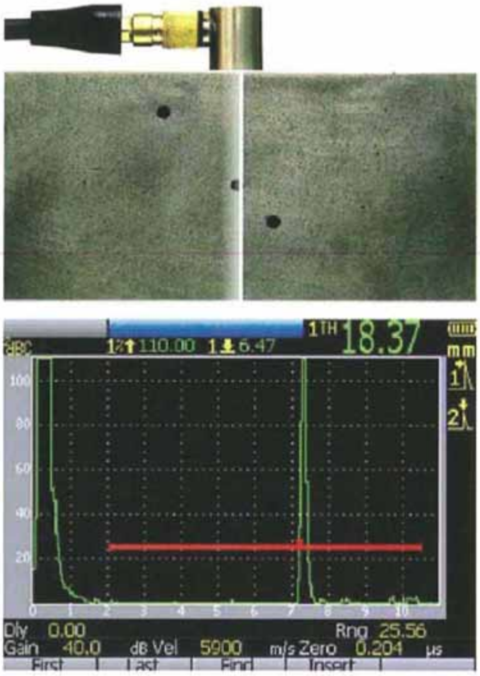


Figure 11—UT inspection—basic principle.

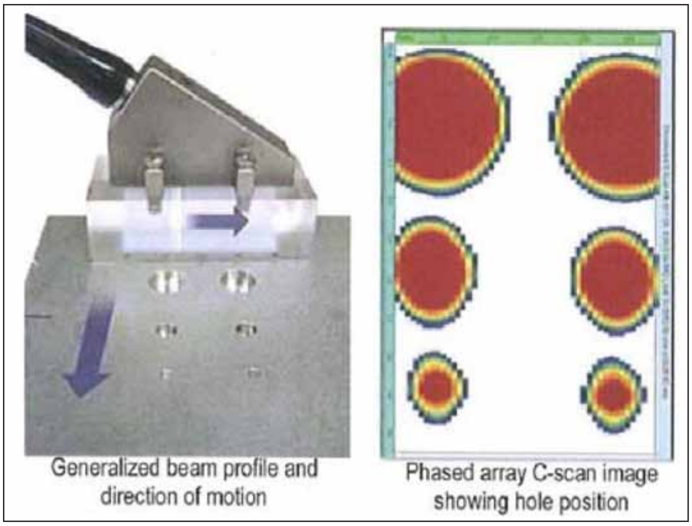


Figure 12—Phased array inspection—basic principles.

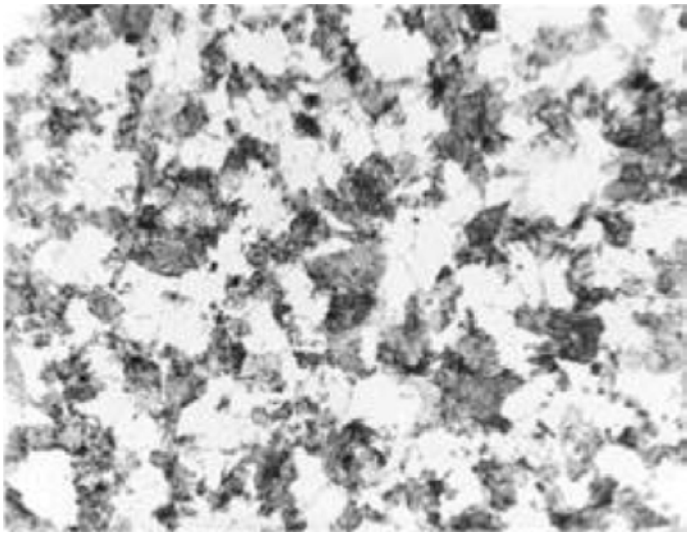


Figure 13—Case carburized steels—+TH initial microstructure.

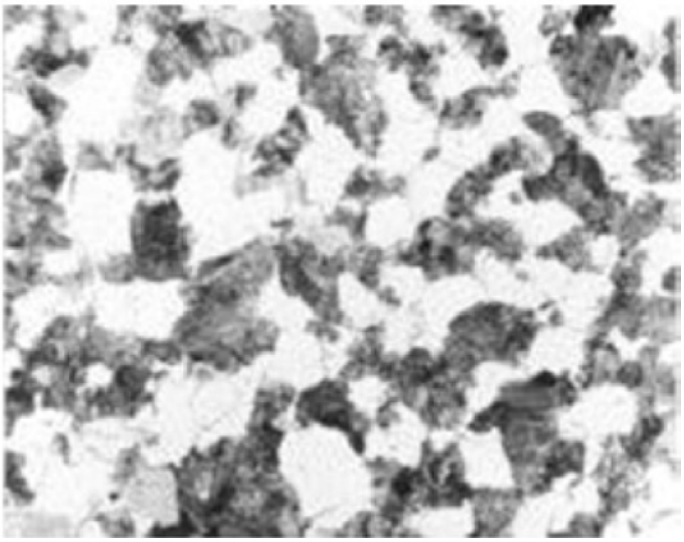


Figure 14—Case carburized steels—+FP initial microstructure.

the part. And even if bainitic structure is required (for very large parts), a given amount of martensite and/or residual austenite is acceptable in the core—where the stress in service is very low.

Case-hardened steels:

The initial microstructure of case-hardened steel is of the greatest importance in respect to final distortion after case carburizing and quenching. It is related to delivery conditions as defined in EN 10084 (although current American standards do not list a corresponding material, and mainly use 18 CrNiMo 7–6). The most common microstructures are:

Annealed with a range of hardness: (+TH). It is a softening treatment according to EN 10052. The intent is to reduce the hardness of the material to a given range (around 200 HB). The annealing process is:

Austenitization to a temperature slightly above AC3 for a 18CrNiMo 7–6 steel

Slow cooling

The resulting microstructure is composed of ferrite and pearlite; but other microstructure elements, such as bainite, can be found as well. Structure is inhomogeneous (Fig. 13) and thus generates final deformations after case-carburizing, which cannot be monitored.

Treated to achieve a ferritic/pearlitic structure with a range of hardness—(+FP): From an historical point of view, it is the bainite— or "Behandelt auf Ferrit–Perlit Gefüge (BG)" treatment cycle, according to DIN. A typical BG cycle for 18CrNiMo 7—6 is:

- Normalization at 930°C (1,700°F)—(holding time: 1 min/mm [1 min/0.04"] +1h30)
- Austenitization at 840°C (1,540°F) followed with oil or polymer quenching
- Tempering at about 650°C (1,200°F): (holding time 2 min/mm [2 min/0.04"] +2h)
- Hardness: around 180 HB

The ferritic/pearlitic structure is homogeneous (a so-called "checkerboard" structure; Fig. 14) and provides good results in respect to residual deformations post case- carburizing.

Even if such a structure is not defined in EN 10084, strategic parts can be requested with an initial microstructure—"Quenched and Tempered," +QT. Generally, it is bainitic quenching followed by tempering. The bainitic structure is more homogeneous and, despite the case-carburizing temperature being above AC3 and the initial microstructure being withdrawn, residual deformations are minor and homogeneous.

Manufacturing

One of the simplest ways to increase power transmitted through mesh is to enhance the tooth accuracy level. With a gear set of AGMA Q8–Q10 (gear – pinion) from a few years ago, the gearing now requires AGMA Q10–Q12. These modifications allow a substantial gain on the dynamic factor, although only gear accuracy is considered in the calculations through ANSI/AGMA 6014–A06 (K_{vm}; see Equations 1 and 3). Specifying enhanced accuracy levels in the drawing is one thing; meeting them on the shop floor is another story.

Machining

Cutting. Although the CNC machine offers a high accuracy, pinion accuracy (lead, pitch, profile mainly depends on the tool itself. In terms of cutting, errors transmitted by the machine compared to errors given by the tools have an influence from 1 to 10. Of course, the cutting mode (single index vs. hobbing) introduces a different set of deviation, some more pronounced on pitch for single index and others more pronounced on lead for hobbing, to make it simple.

Different processes are available to prepare pinions to be ground with different benefits and disadvantages:

- Small pinions (i.e., 19 teeth, 25.4 module) can be fully turned and cut on the same machine, a five-axis CNC machining center. Since the shaft and teeth are geometrically related, only one set-up is required. This avoids lack of accuracy during each setting on every machine. Moreover, the reference axis is kept all along the manufacturing, improving greatly the overall accuracy. In the other hand, machining of the teeth is done with conventional milling tools. Specific hobs or inserts are not required in those conditions. With such a machine, geometry of the teeth is as accurate as on gear cutting or gear grinding machines (Figure 15 and Figure 16).
- Large pinions (i.e., 19 teeth, 33.866 module) still have to go through a traditional process, where turning and cutting are separated. Today's pinion sizes and the wanted level of accuracy (AGMA Q12), however, impose the use of carbide tools. Good points are the cutting of hard materials (over 340 HB), the longevity (one set of inserts for the complete cutting), and of course, the quickness of cutting. The disadvantages are a restricted number of suppliers, the cost of such tools, which are mainly made on demand, and the fact that with each pinion being different, it requires the purchase of individual sets of inserts every time.

Grinding

After case carburizing, quenching and tempering, a large amount of distortions is present. Their anticipation during the rough machining process is a key point to guarantee the final tooth thickness combined with the required carburized layer thickness. The final tooth geometry, because of the hardened surface, imposes a need for tooth grinding. The most efficient process is form grinding (Figs. 17 and 18).

Load distribution over the face width is a key point in service, and with even more importance being placed on the increase of mill power, efficient grinding becomes more and more needed. Case carburized pinions are going through grinding as a normal process. It has to be pointed out that the grinding process is only flank grinding to avoid removal of compressive residual stresses in the root filet and to avoid surface tempering.

The benefits on through hardened pinions are also significant, especially when considering tooth corrections (on lead and/or profile). These corrections are planned to compensate elastic deformations to achieve the best possible load distribution during meshing. Such tooth modifications can only be addressed through a grinding process. In mining applications, with gearing designed according to ANSI/AGMA 6014—A06, such a correction is not taken into account and gives unrealistic longitudinal load distribution.

Figure 15—Pinion milling on multi multi-axes machine.

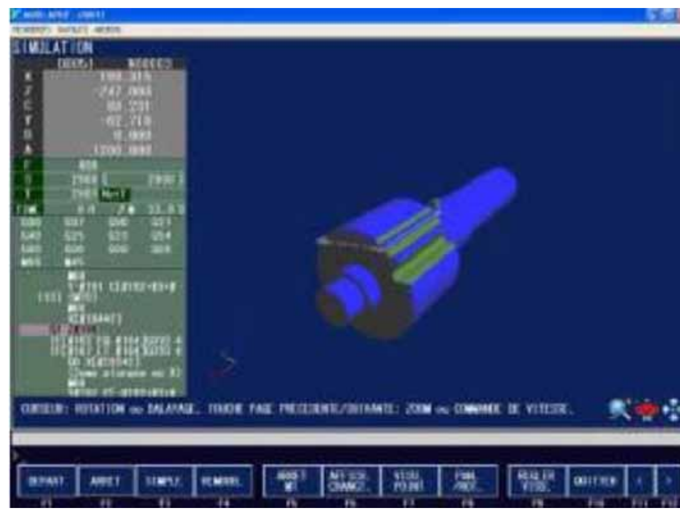


Figure 16—Pinion milling—CN software.

Figure 17—Large CNC form grinding machine.

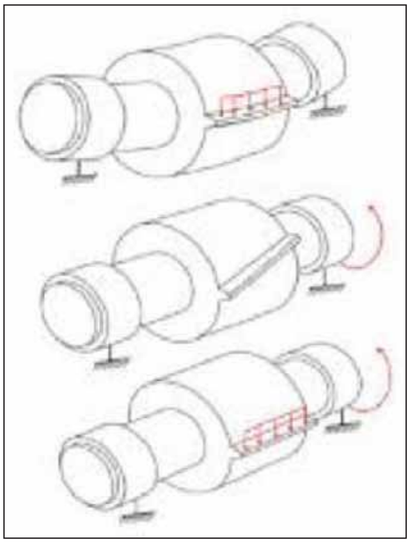


Figure 18—Computer simulation of torsional and bending deformation.

Figure 19—CNC gear measuring machine for heavy parts.

Inspection

Tooth geometry. Since the quality level is considered in the calculation of several factors in ANSI/AGMA 6014—A06, the geometry of the pinion teeth has to be verified to make sure that the service factors are actually achieved. This can be done either on heavy gear measuring machines, on the gear cutting machines or gear grinding machines.

Part size and weight makes the calibration of measuring devices difficult—there are no comparable "reference laboratories" and "reference masters" available. The calibration chain cannot be the same as for small parts. An inter comparison procedure has to be developed to accurately check the geometry of the teeth, with enough repeatability and reliability. On the other hand, because surface finish is of great influence on fatigue properties, the measurement of surface conditions, for both through hardened and case carburized pinions, requires high tech measuring apparatus (Figure 19).

Internal structure. Tooth internal fatigue fracture, TIFF, is a gear failure mode based on fatigue, not related to contact or bending failure mechanisms. Neither ANSI/AGMA 6014—A06 nor ANSI/AGMA 2001—D04 includes an assessment method for determining the susceptibility of gear failure under this mode, although it is known that some pinions have failed under loads which were below the predicted range of the rating procedure. In a TIFF failure, the crack initiates beneath the flank surface and propagates via fatigue modes both into the body of the tooth and towards the tooth surface. The result is a complete tooth break (Figs. 20, 21 and 22).

This kind of damage can occur on a case carburized pinion (Figure 23) after several thousand operating hours. The aim of ultrasonic inspection is to detect internal discontinuities as early as possible, and to check changes in the buried indications (if any) through the manufacturing by repeat inspection. UT inspection is performed on finish machined surfaces with a surface finish equal to Ra 6.3 μm or less (160 micro inches):

- 100% of the pinion's volume has to be tested using a straight beam probe
- In addition, pinion is inspected lengthwise from each shaft end.
- Inspection is carried out using straight beam probes with a frequency of 2 MHz or less.

Figure 20—Example of fatigue fracture initiated from involute part of the profile.

Figure 21—Magnification of one edge of the broken surface.

Figure 22—Magnification of the opposite edge of the broken surface.

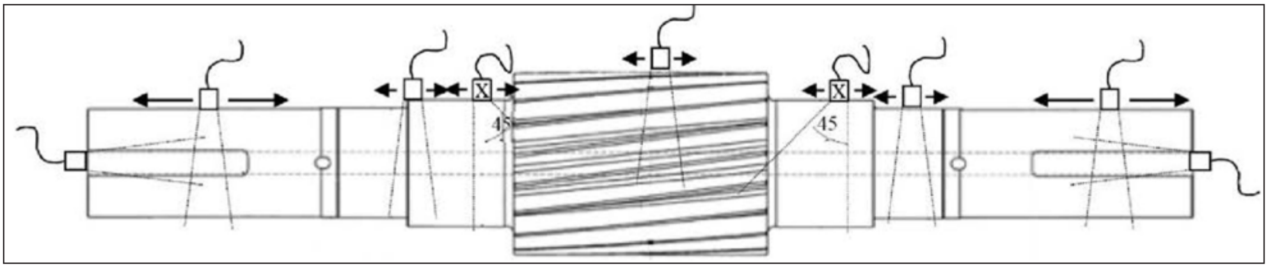


Figure 23—UT inspection: location of inspection areas and type of waves used.

- Inspection is completed with angle beam probes 45°, frequency 2 MHz or less, where a back-wall echo cannot be maintained.

Another method can be used—high frequency surface inspection using a straight beam probe of 8 MHz. The calibration procedure is rather complex. A calibration bloc made of the same material that has undergone the same heat treatments has to be used. A flat bottom hole of 1 mm is then drilled in this reference piece (Figure 24). With such a high frequency, the close surface can be checked on few millimeters in depth, i.e., just below the case depth or at the maximum shear stress depth.

Case-hardened layer. According to most standards, the case-hardened layer as well as the case depth, is verified on a coupon which undergoes all the heat treatments of the part itself. However, the coupon standard dimensions are not related to tooth dimensions, and thus the obtained results can be subject to discussion. To avoid such a discussion, a procedure was developed internally for the inspection of the case hardened layer and case depth, on the part itself. After final grinding, a sample is cut from one tooth edge, and due to case hardening deformations, this is where the maximum of the case hardened layer has been ground (Fig. 25).

Measurement of the case depth is made by a laboratory microhardness machine on a polished sample. All hardness marks should be aligned perpendicular to the flank within a 5 mm wide strip. The case depth corresponds to the depth where 550 HV1 is reached (Fig. 26).

A nital etching is then performed, and the actual microstructure of the case-hardened layer can be studied. As the surface of the teeth has been enriched with carbon and then quenched and tempered, this case- hardened layer should be made of tempered martensite. At the same time, presence of any carbide networks is checked as such a concentration can lead to an unexpected service failure (Fig. 27).

Grinding damages. As far as case carburized gears are concerned, the grinding process may involve local overheating leading to heavy damages called grinding burns. In case carburized pinions, structure is typically made of martensite and bainite. The main structure of the carburized layer is martensite, and is very sensitive to quick heating and cooling. With such a phenomenon generated by the grinding wheel, it may appear cracked should the grinding wheel be worn or should a lack of lubrication arise (Fig. 28).

One method to check grinding burns is given in ANSI/AGMA 2007—C00. This method has demonstrated the first disadvantage to using hazardous products, such as nitric acid and alcohol, even if water can be used as an alternative to alcohol. The second disadvantage is that the procedure must be carefully followed to

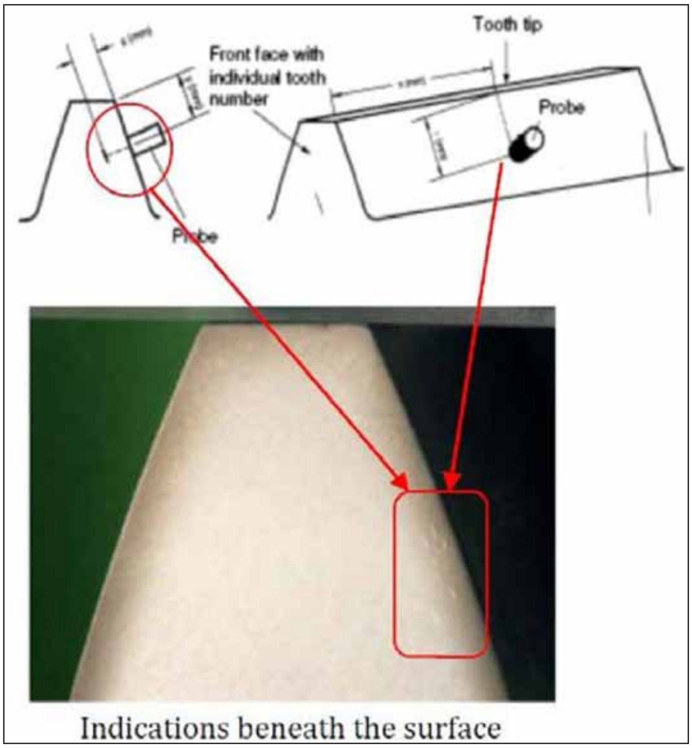


Figure 24—UT inspection procedure for inspection of subsurface defects.

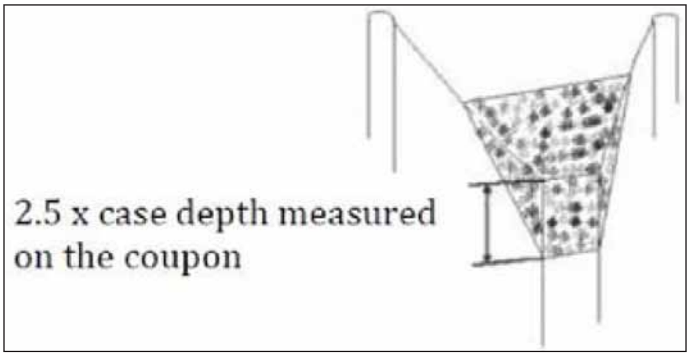


Figure 25—Sampling on an actual gear tooth for case-hardened layer inspection.

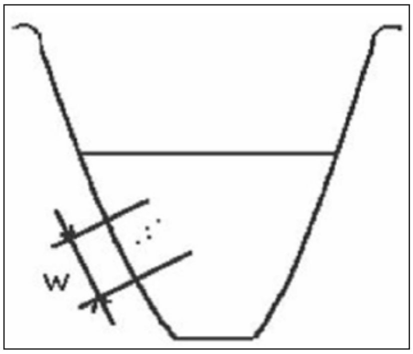


Figure 26—Case depth procedure of measurement on a sampling taken from a tooth.

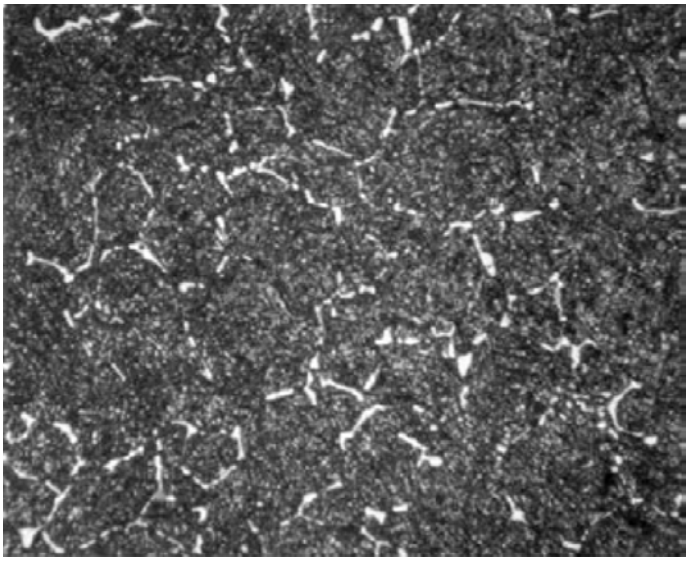


Figure 27—Case-carburized layer with carbide network.

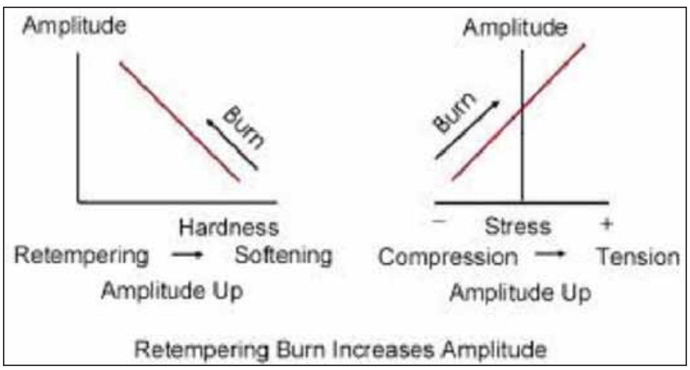


Figure 28—Grinding damage: re-tempering grinding burn.

	BN-method	Temper Etch
Nondestructive	Yes	No
Use of Chemicals	No	Yes
Automated	Yes	No
Objective	Yes	No
Quantitative	Yes	No
Reliable	Yes	No
Evaluation Through Coatings	Yes	No
Danger of Hydrogen Embrittlement	No	Yes
Influenced by Both Stress and Microstructure	Yes	No

Figure 29—Barkhausen noise vs. nital etching.

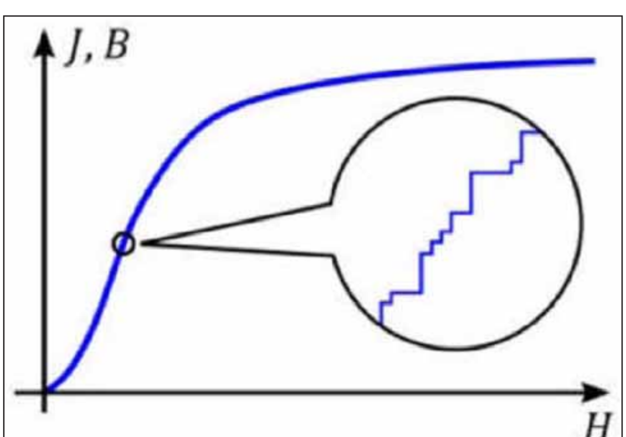


Figure 30—Effect of applied magnetic field in ferromagnetic material magnetic field changes—hysteresis.

avoid hydrogen embrittlement. The third disadvantage is the subjective interpretation of the "grey color." An alternative nondestructive method has been developed recently, Barkhausen noise inspection, BNA. Figure 29 is a comparison chart showing the advantages and disadvantages of the two methods.

Barkhausen was a German scientist who proved that magnetism not only affects atoms in a ferromagnetic material, but in fact the structural domains of it (called Weiss domains). In other words, a ferromagnetic material can be considered as an assembly of multiple magnets. Barkhausen also proved that magnetic changes in ferromagnetic materials are not continuous but tiny and steep, and related to discrete changes in size and orientation of each individual Weiss domain; the combination of all these changes gives magnetic hysteresis (Fig. 30).

When an alternative magnetic field is applied to the ferromagnetic material, these domains are forced to be reorganized in a direction relative to the applied magnetic field and their primary orientation. The constant reorganization generated by the alternative magnetic field induces a current. This is the so called Barkhausen noise. The induced current is then measurable, and typical of a specific material. The Barkhausen noise is dependent on several parameters, among which surface defects, residual stress, dislocations and hardness all play a role (at different levels). The higher the hardness, the lower the Barkhausen noise.

When applied to NDT, the Barkhausen effect allows detection of surface or near surface defects by the measurement of magnetic field perturbations. This measurement can either be acoustic or inductive (Fig. 31).

Over the past 15 years, this method has been successfully adapted to the search of overheated areas and grinding burns on ground pinions. Since it is comparatively a nondestructive test, calibration is the most difficult point. Barkhausen noise is dependent on chemical composition, hardness, dislocations, and residual stress. Of course, no calibrated samples are available for such large part application. In order to develop a dedicated process for such large case carburized pinion, a "library" of test samples of smaller size has been created. These samples are all made of the same material (18CrNiMo 7—6 according to EN 10084) and their sizes and carburized layer depth have been recorded to extract their influence from the Barkausen noise equation.

Meshing. Once the gear and pinion have been manufactured and inspected, now comes the moment to check how they work together. The mesh test is probably the easiest way to do so, but result interpretation is not as easy as one would think. This test can be carried out in three manners:

1. On the gear cutting machine, GCM;
2. Pinion on the ground, gear rolling over;
3. Gear on the ground, pinion rolling over.

The choice of test type is related to safety conditions, keeping in mind that the safer test is on the GCM. Results obtained through the three different methods are relatively equivalent, but testing on the GCM allows backlash adjustment, just like on site. However, it should be remembered that the mesh tests are done with no load, as opposed to what is done on site. This means shop mesh test and site mesh test can present some differences in terms of contact.

One of the key points is blue application. Contact of the gearing set obtained from the mesh test will mainly depend on blue thickness (or in other words, the capacity of the blue to fulfill gaps into the mating surface), and a little bit of the applied pressure (which is nothing compared to the load in service). Figure 32 illustrates the influence of blue thickness (same gear, same pinion for the 3 pair of prints):

As it can be seen, a very thin line of contact is legible when 5 mm of blue have been applied, a larger surface of contact is obtained with 10 mm (100% contact on the face width and 20% over the active profile), and 20 mm of blue gives a perfect contact (100% over face width and profile). What is also shown in Figure 32 is that 20 mm of blue were sufficient to fill the gaps between the gear tooth surface and the pinion tooth surface. In this case, lead tolerance of the gear and the pinion is 80 mm. This could lead to gaps between the two mating surface up to 160 mm, and will not authorize blue transfer. The roll test will then fail even though the gear and pinion are within tolerances. Summarily, the shop contact test is the most conservative test a gear set can undergo. If it passes the test, the gear set will work perfectly for years (at the ultimate condition, and assuming that site set-up is done correctly; but this is another story).

A correct interpretation of shop contacts can tell a lot about the way the gear and pinion have been cut, and if the gear cutting machine is reliable and functional. Years of tests have led us to write a guide of contact interpretation. The knowledge obtained from that study has been turned into machine and method improvements with the final goal to obtain the best meshing possible for the gear set. This parameter is so important today with the increase of mill power that these tests are conducted on every gear set.

Conclusion

Since mining mills become much more powerful, the pinion has to transmit more and more power through a single mesh and naturally becomes bigger and bigger. Whatever the size is, acceptance criteria remains unchanged. For such heavy parts, this means that the requirements are more stringent and imply the use of unconventional methods to meet with them. There is no longer a single part which is manufactured and inspected with a "rough" process. Related to the size increase, this article tries to show parameters to focus on and propose some acceptance criteria for both rough material as well as machining. These new criteria imply a "pull-up" of machine and inspection technologies to get more and more "high-tech" products capable of transmitting more power in a conventional manner (gear and pinion). The future is promising a lot in regards to these topics.

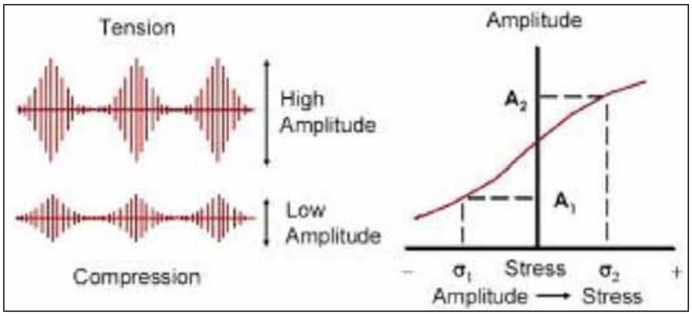


Figure 31—Effect of stress.

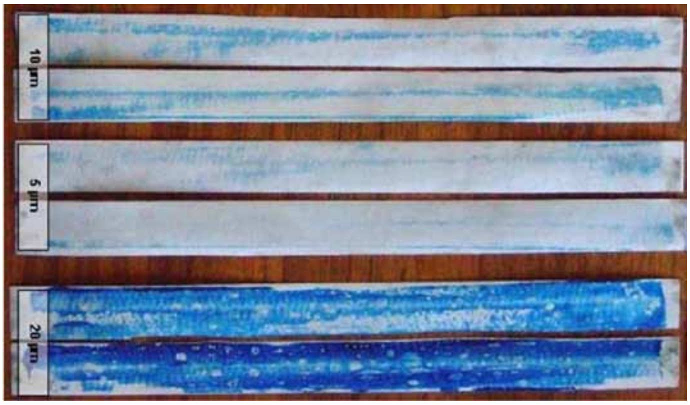


Figure 32—Influence of blue thickness on contact pattern record.

References

1. AGMA 218.01. "Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth."
2. ANSI/AGMA 2001—D04. "Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth."
3. AGMA 2000—A88. *Gear Classification and Inspection Handbook.*
4. ANSI/AGMA 6014—A06. *Gear Power Rating for Cylindrical Shell and Trunnion-Supported Equipment.*
5. Drago, R.J. and R.J. Cunningham. "*Hydrogen and Internal Residual Stress Gear Failures—Some Failure Analysis and Case Study,*" FTM 08FTM13.
6. "Tooth Interior Fatigue Fracture (TIFF)," Presented by the U.K. Delegation at the November 4, 2011 Plenary Meeting of ISO TC60 (ISO TC60/N1043).
7. Appolaire, B. "Prise en Compte Dumouvement des Cristaux Equiaxes dans Lamodélisation de la Solidification des Lingots d'Acier Coulés en Fonderie," Thèse INPL, 1999.
8. Appolaire, B. and H. Colombeau. "Modélisation de la Formation Demacroségrégations et Desmicrostructures Induites par la Sédimentation de Cristaux Équiaxes Pendant la Solidification de Gros Lingots d'Acier," Communication au Congrès Matériaux, Tours, 2002.
9. Jaouen O. "Modélisation Tridimensionnelle par Eléments finis pour l'Analyse Thermo Mécanique du Refroidissement des Pièces Coulées," Thèse de l'Ecole Supérieure des Mines de Paris, 1998.
10. Vannier I. *Modélisation de la solidification des ingots d'Acier,* Thèse NPL, 1995.
11. Wavelet, F. Roll "Test Result Interpretation, Ferry Capitain."
12. Pokorny A. and J. Pokorny. *Inclusion Non Métalliques dans les Aciers*, TI M220, 20 AGMA 12FTM14.
13. Bosson, J.C. Analyse de L'hydrogène dans les Aciers, TI M262.
14. Meyer, A., FILENGRENE, une Solution pour le Fraisage des Engrenages, JTM—INSA Lyon, 2011.
15. Stresstech. "Barkhausen Noise Analysis," Tool for Quality Control.
16. Olympus. "Phased Array Testing—Basic Theory for Industrial Applications," NDT field guide.

Michel Pasquier began his career in gearing upon graduation from the Ecole Supérieure de l'Energie et des Matériaux d'Orléans. In 1990 he took work in the automotive industry, focusing on automatic gearboxes for heavy vehicles and special differentials based on planetary gears. He joined CETIM in 1991, where until 2002 he resolved gear unit failures and worked with mechanical-related industries in the design of mechanical power transmissions. He moved to CMD Engrenages et Réducteurs in 2002 (to present) as technical support manager. Pasquier has served on the French delegation for ISO TC 60 (gears) and is a member of AGMA Committee 7e (6014).

Fabrice Wavelet is a metallurgist engineer who has since 1996 worked at Ferry Capitain, a CIF company, and as project manager/quality control since 2000. In 2003 he was charged with the technical supervision of production of all Ferry Capitain mining parts, which he also does for other CIF sister companies. Wavelet also lends technical expertise to other areas of the company, including R&D projects, non-destructive testing, material development and specification writing. In 2010 Wavelet and co-author Pasquier served on Committee 7e for revision of AGMA–6014.

H-D Advanced Manufacturing

ACQUIRES OVERTON CHICAGO GEAR

Hicks Equity Partners and The Riverside Company recently announced that they have partnered with Christopher DiSantis to establish H-D Advanced Manufacturing Company (H-D), a holding company that will specialize in a wide variety of heavy-duty, precision-engineered industrial components. Simultaneously, they announced that H-D has acquired Overton Chicago Gear Corporation (Overton), a manufacturer and distributor of large, custom, mission-critical gears and gearboxes.

DiSantis, age 41, is an accomplished manufacturing executive who previously served as CEO and president of Latrobe Specialty Metals, a former portfolio company of Hicks. Prior to Latrobe, DiSantis served as president and COO of Hawk Corporation, a former portfolio company of Weinberg Capital Group, which is also an investor in H-D. The formation of H-D again pairs DiSantis and Dale Mikus, the former CFO of Latrobe, who will serve as CFO of H-D.

Thomas O. Hicks, chairman and CEO of Hicks Equity Partners, said, "The formation of H-D Advanced Manufacturing, with Overton as its foundation, provides an excellent opportunity to create value in the high-precision manufacturing sector. We are very pleased to partner with Riverside in building H-D behind the leadership of Chris DiSantis and Dale Mikus, with whom we have worked successfully in the past, and the management team of Overton. Under this leadership team, we believe H-D is very well positioned to be at the forefront of what we see as a resurgence of U.S. manufacturing."

"Riverside specializes in acquiring middle market companies and providing them with resources that enable them to thrive," said Riverside Partner Tim Gosline. "H-D's acquisition strategy fits squarely with that of Riverside, and we look forward to working with H-D and Overton's management to make this investment a success."

"H-D Advanced Manufacturing is going to build a first class manufacturing company that serves as a strategic supplier to the world's leading industrial companies, both big and small," said DiSantis. "I can't think of a better company than Overton Chicago Gear to serve as H-D's first acquisition. I look forward to selectively adding other manufacturers of high-quality industrial components to the H-D team and to executing our business strategy."

With a history dating to 1888, Overton manufactures large, high-precision gears that are designed to meet a wide range of requirements for the most challenging applications in the oil and gas, minerals and mining, rail, renewable energy, power generation and infrastructure industries. Customers in these industries require high-precision gears and gearboxes that are durable and reliable enough to withstand harsh operating environments. Overton designs and manufactures custom gears in a wide variety of profiles, including herringbone, bevel, helical, spur and double enveloping worm gears, as well as gearboxes. The company employs more than 200 people at three manufacturing facilities in the Chicago area.

Overton will continue to be led by CEO Louis Ertel. "This transaction is an excellent outcome for our employee stock owners, and I would like to personally thank them for their hard work and dedication to make this transaction possible," Ertel said. "As part of H-D Advanced Manufacturing, Overton will be better positioned to build on the strong growth and success it has achieved over the last ten years through added financial strength and management expertise."

As previously announced, Mikus will serve as the CFO of H-D. Mikus has more than 30 years of financial management experience, including over a decade with PWC, and has held senior financial positions for several large corporations. In addition, Ron Weinberg, chairman of Weinberg Capital Group, will serve as a director of H-D Advanced Manufacturing.

Hicks and Riverside are actively seeking additional acquisition opportunities for H-D Advanced Manufacturing in the gearing industry and within other heavy duty, high-precision manufacturing sectors. PNC Business Credit and Babson Capital provided financing for the acquisition of Overton. KPMG, Akin Gump Strauss Hauer & Feld and Jones Day advised Hicks and Riverside on the investment.

Mitutoyo Corporation

BREAKS GROUND ON NEW CORPORATE HEADQUARTERS

Mitutoyo America Corporation recently announced the groundbreaking for a new corporate headquarters building located at 945 Corporate Boulevard in Aurora, Illinois. The 159,300 square-foot, multi-million-dollar facility will include a state-of-the-art M3 Solution Center offering the ability to provide interactive product demonstrations; an A2LA Accredited Calibration Lab, supported by fully staffed field service and repair departments; abundant warehouse space necessary for timely distribution of product, parts and accessories; an educational facility (Mitutoyo Institute of Metrology), for all training and instructive metrology resources; and free flowing office areas to encourage inter-departmental collaboration and communication.

"Our goal is to provide high-tech, best-in-class metrology services and solutions to our customers and their subsidiaries. The new facility will accommodate all the departments at Mitutoyo so everyone functions cohesively as one all-encompassing team to meet the needs of our customers," states Shigeyuki Sasaki, president, Mitutoyo America Corporation.

To assist with the funding for the new construction, Mitutoyo turned to the City of Aurora and a newly approved Tax Increment Financing (TIF) district. This district was developed to stimulate economic development, enhance community vitality through creative growth solutions and provide incentives to corporations to attract private development. Without the support from the City of Aurora and funding through this TIF district, the new headquarters building would not have been pragmatic for Mitutoyo. The new facility is expected to open in the fall of 2013, which coincides with the celebration of Mitutoyo America Corporation's 50th Anniversary.

Sandvik Coromant

BREAKS GROUND ON FACILITY IN NEW JERSEY

Sandvik, and its tooling division, Sandvik Coromant, broke ground Friday, Dec. 3, 2012, on a location neighboring its current U.S. headquarters in Fair Lawn, New Jersey. The new facility will serve as Sandvik's U.S. head office and a hub for Sandvik Coromant's Market Area Americas, a strategic geographical alignment dedicated to increasing synergies between the USA, Canada, Mexico, Argentina, Brazil, Chile and Latin America.

"We're proud to reaffirm our roots in New Jersey," said Johan Israelsson, president, Sandvik Coromant, Market Area Americas. "Superstorm Sandy dealt a blow to many in this state, but we're not going anywhere. Our new facility will keep Sandvik Coromant headquartered in the same community we've been in for 57 years."

The groundbreaking kicked off the construction of the 108,000 square-foot, state-of-the-art facility that will be designed to meet Leadership in Energy and Environment Design (LEED) standards. The contemporary 'green' design, energy efficient facility will provide general office space, a Productivity Center and an Aerospace Application Center (AAC).

Serving customers throughout the metalworking field within all major industries, the new Sandvik Coromant Productivity Center will have the capacity to help manufacturers maximize their metal cutting operations by offering a balance of theory-based training courses, technical seminars and hands-on machining demonstrations. In addition, the Productivity Center will be staffed with training specialists and machining experts that will educate customers in methods for improving efficiency and productivity in metal cutting.

Sandvik Coromant will also continue its commitment to aerospace with the new AAC at the facility. This state-of-the-art center will focus on projects for machining composite materials or in high temperature and titanium alloys for aero frame structural parts and engine components. The aim is to concentrate specifically on customers who are interested in readdressing their current processes.

A dedicated team of industry specialists will support the customer projects and training at the AAC, which will be fully equipped with the latest machines to develop the most productive processes for aerospace customers.

Both the Productivity Center and Aerospace Application Center will focus on helping American manufacturers maximize their productivity and profitability through understanding and application of the latest technologies in cutting tools, machine tools and machining processes.

Star Cutter Company

RECEIVES ISO REGISTRATION

Star SU recently announced that Star Cutter has received a Certificate of Registration for ISO-9001:2008. Star Cutter was registered to the ISO-9001:1994 in January of 1998 and remained registered to the updated ISO-9001 Standards through May, 2009. The company has now received its registration and re-certification after assessment of the company's quality management system and found it to be compliant with ISO-9001:2008 by third party registrar, NSF-ISR based in Ann Arbor, Michigan. The scope of registration is for the manufacture of precision gear cutting tools, round tools, deep-hole drills and solid carbide tools; special tungsten

carbide preforms, extruded product and machine tools. The Certificate of Registration represents a company-wide accomplishment achieved by all Star SU and Star Cutter Company locations including Hoffman Estates, Illinois; Farmington Hills, Michigan; East Tawas, Michigan; Elk Rapids, Michigan; Lewiston, Michigan; Ossineke, Michigan and Queretaro, Mexico. For more information, visit *www.star-su.com*.

Carl Zeiss

APPOINTS INDUSTRIAL METROLOGY GROUP PRESIDENT

Carl Zeiss announces the appointment of **Michael Kirchner** as the new president for the Industrial Metrology group in North America effective January 1, 2013. Kirchner succeeds Greg Lee, who retired after more than 30 years of leadership. Prior to this role, Kirchner had successfully established a manufacturing operation for Carl Zeiss Shanghai Co. Ltd. where he was general manager for over eight years. In 2012, he also helped implement manufacturing in India, lending his supply chain and process expertise.

Kirchner began his career with Carl Zeiss Industrial Metrology as an intern in New York, where he first met his predecessor, Greg Lee. Working his way through the company, Kirchner has held various management positions with increasing responsibility. These positions included product manager, regional sales manager, area sales manager, customer care manager and vice president of service in North America prior to his last role as general manager for manufacturing in China.

"I am pleased and grateful that Michael Kirchner is succeeding me and leading IMT into the future. I have known and worked alongside Michael for many of the last 26 years and I couldn't think of a more qualified and deserving leader to take my place," Lee said. For more information, visit *www.zeiss.com/metrology*.

AFC-Holcroft

NAMES DISLER PRESIDENT AND CEO

AFC-Holcroft recently named **William Disler** as president and CEO, effective December, 2012. In his new position as president and CEO of AFC-Holcroft, Disler will report to Gary Dawson, former president and CEO of AFC-Holcroft, who retains his role as president of the Atmosphere Group, which provides management services to AFC-Holcroft and other affiliated companies. Disler was previously executive vice president of sales and engineering at AFC-Holcroft, having joined the company in 2005. He has been involved in the heat treatment equipment industry since 1987, starting his tenure as an electrical engineer with the Holcroft Company, after graduating from Lawrence Technological University with a BSEE degree. During his 20+ year career, he has held multiple positions, including manager of advanced control systems and Far East operations manager. His experience includes extensive international involvement, including living in Asia for more than two years coordinating furnace co-builds with multiple customers and travel throughout more than 25 countries around the world while supporting sales, engineering and manufacturing activities. For more information, visit *www.afc-holcroft.com*.

Cleaning Technologies Group

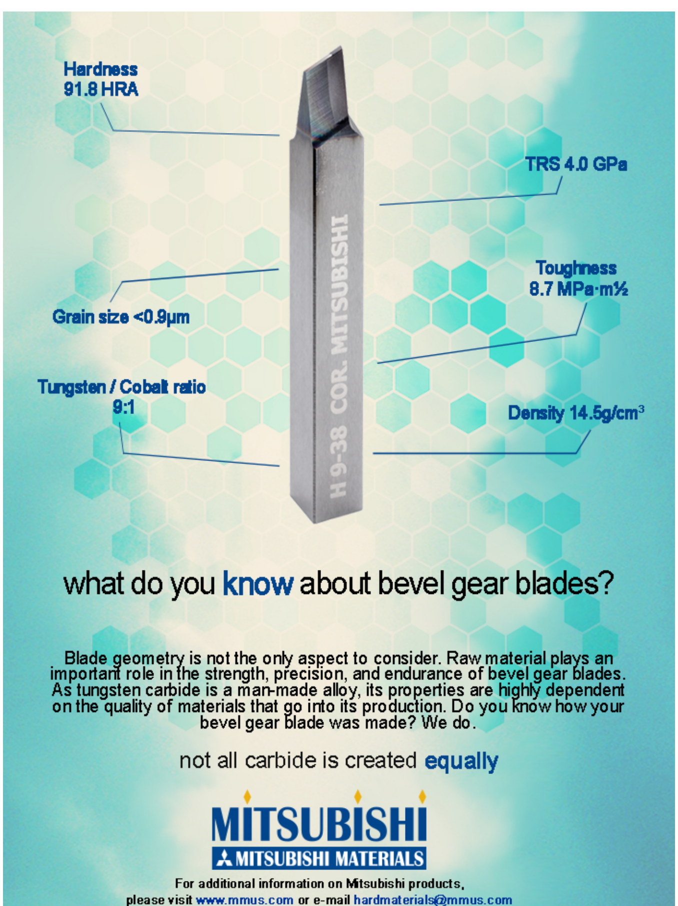
HIRES DAVE MELTON AS MARKETING MANAGER

Dave Melton has joined Cleaning Technologies Group, LLC as the marketing manager. Melton will provide marketing support for Cleaning Technologies Group by developing and executing marketing activities to build global awareness for the Ransohoff, Blackstone-NEY Ultrasonics, and CTG Asia product lines. “We are confident that with his extensive global machine tool marketing experience Dave will be an asset to our organization and will play a key role in our push to gain global market share,” says Chris Whittaker, vice president of sales and marketing CTG, LLC. Melton brings more than 25 years of marketing experience in the machine tool industry serving as marketing manager for companies including Gleason Corporation in Rochester, New York and Makino Inc. in Mason, Ohio. Melton holds an Associate’s Degree in Business from Cincinnati State and currently resides in Cincinnati, Ohio with his family. For more information, visit *www.ctgclean.com*.

Solar Atmospheres

NAMES REGIONAL SALES MANAGER

Solar Atmospheres of Western PA has named **John (Jack) Giacobbi** as their new regional sales manager. Giacobbi will manage established accounts and develop new business in the Mid-West U.S. territory. He previously held a position with similar responsibilities as an account manager at Bodycote in Rochester, NY. “The expansion of our sales team further strengthens our ability to meet the needs of our customers,” noted Robert Hill, SAWPA president. “Jack’s comprehensive understanding of heat treating sales



and processing will help us connect with new customers and improve our client service. As an award-winning salesperson with a proven track record, we are confident that Jack will make a valuable contribution to our continued success." Giacobbi holds a BA in Business Administration from Columbia College. For more information, visit *www.solaratm.com*.

Dontyne Systems

ESTABLISHES NORTH AMERICAN SUPPORT FACILITY

Dontyne Systems, supplier of gear design software and systems, has recently established a North American support facility. Dr. Michael Fish, co-director of the Newcastle U.K. based developer of tools to optimize gear production, announced the opening of the Cincinnati, Ohio based facility effective December 15, 2012. The support office will be managed by Mr. Rich Easley and support the company's business throughout North America. Dr. Fish stated "Continued growth of our installed customer base, combined with increasing product interest, has made this expansion necessary. Rich has nearly 30 years' experience in engineering design, project management and customer support. His team in the U.S. will provide excellent support to Dontyne's North American growth." The Dontyne North American office may be contacted by telephone at 513-679-0313 or email at *namerica@dontynesystems.com*.

Norton Abrasives

ANNOUNCES BRAND STANDARDS PROGRAM

NORTON
SAINT-GOBAIN

Norton Abrasives, a brand of Saint-Gobain Abrasives, has announced the introduction of a new global Norton brand standards program. The standards will unify branding efforts worldwide to facilitate a cohesive, impactful image for the Norton brand and Norton sub-brands, for quicker association to the brand assets and the best products for cutting, grinding, sanding and polishing applications. The new global identity program includes the Norton parallelogram logo that is now endorsed with the Saint-Gobain parent organization and a structure that ties the Norton brand with all of the technology-leading sub brands, including Norton Quantum, Norton Blaze and Norton Paradigm.

"With the changing face of communication, it is imperative that we ensure every touch point with our brand is consistent so as we reach people globally, the brand is uniformly identifiable," said David Long, director of marketing and strategy at Norton Abrasives. "As the industry leader, it is important to maintain this cohesive strategy so that our customers immediately associate our brand with the high level of product performance and technical expertise they are familiar with, no matter where they are located. With our new brand standards, we have a clear strategy on how we visually present ourselves in our literature, web activities, media, advertising, packaging and all other marketing collateral," commented Long.

In the new standards, Norton Abrasives is complementing their most valuable visual asset, the Norton brand logo, with the introduction of the Norton "Mark." The Mark is an iconic element that ties the shape of the Norton logo parallelogram with a contemporary graphic treatment to provide a quick brand reference for packaging, promotional wear and web sites/apps."The Norton 'Mark' will be used as an additional symbol of our guarantee to deliver leading innovation, engineering and service to the broad spectrum of end users of our abrasive products. This program will roll out globally throughout 2013," according to Long.

Ipsen

HIRES VP OF SALES

Ipsen USA is pleased to welcome **Art Tsubaki** to the Ipsen USA Team as vice president of sales. Reporting to Geoffrey Somary, Ipsen USA CEO, Tsubaki will be responsible for all Ipsen USA sales and service, while globally supporting vacuum products strategic business unit. Tsubaki held various leadership roles in multiple industries before joining Ipsen. Within these various roles, he was tasked with improving corporate and brand strategy, product development, product management and market execution. He also achieved Six Sigma certification, which will allow him to contribute to Ipsen's existing lean manufacturing and continuous improvement efforts. Tsubaki has also held executive roles at DICKEY-john Corporation, Textron (Greenlee) and Uniden America Corporation, as well as roles at large corporations, namely SPX and Motorola. He holds five U.S. patents in different industries. Tsubaki earned a Bachelor of Science degree in Business Administration and a Bachelor of Arts degree in East Asian Languages and Cultures from the University of Kansas. He also attended Northwestern University's Kellogg School of Management where he completed an MBA in Marketing and Strategy. As a Japan Ministry of Education (Monbusho) Scholarship recipient, Tsubaki attended Osaka University of Foreign Studies in Japan. With his experience leading global teams and executing strategy, paired with his proven ability to drive results in an innovative way, his insights and initiatives will be instrumental in continuing Ipsen's growth. For more information, visit *www.ipsenusa.com*

March 5–6—The 2nd International VDI Conference: Maintenance of Wind Turbines.

Hamburg, Germany. Wind turbines have an expected service life of some 20 years. However, manufacturers' liability mostly covers only the initial two to five years of operation. But systems will age, so operators must be prepared to ensure technical support for maintenance needed in their wind turbines. A foresighted service and maintenance concept is one of the major success factors governing system availability of a high level in any machinery and plant. The conference will focus on issues like which promising maintenance concepts are available and what are their associated costs and risks. Experts will highlight major mechanisms causing structural damage or difficulties in the operation of wind power plants. Expert presenters will come from various renowned companies to report on the maintenance of electrical components and systems in wind turbines, present a comparative study on concepts for offshore maintenance, and demonstrate asset integrity management. For more information, *www.vdi.de/maintenance*.

March 5–8—The MFG Meeting (Manufacturing for Growth). Hilton Waikoloa Village, Waikoloa, Hawaii. The MFG Meeting (Manufacturing For Growth) brings together a broad spectrum of manufacturing business owners and top industry executives for a 4-day forum on how we can work together to restore manufacturing to its rightful place as an engine that drives the U.S. economy. Jointly produced by three major industry trade groups, this groundbreaking event tackles the issues that affect the entire realm of manufacturing and provides a forum for a conversation that can't be found at any event presented from a single sector's perspective. For more information, visit *www.themfgmeeting.com*.

March 12–14—Gearbox CSI:Forensic Analysis of Gear and Braking Failures. Hyatt Regency Baltimore, on the Inner Harbor, Baltimore, Maryland. Determining the cause of a failure in a gearbox is like a "whodunnit" mystery. What caused the failure: The bearings, a gear, the lubrication or a shaft problem? Where do you start, and how can you tell? Instructors Raymond Drago and Joseph Lenski, Jr., from Drive Systems Technology, Inc., will help gear designers gain a better understanding of various types of gears and bearings. Learn about the limitation and capabilities of rolling element bearings and the gears that they support so you can properly apply the best gear-bearing combination to any gearbox, whether simple or complex. A certificate will be awarded upon completion of the seminar. For more information, visit *www.agma.org*.

March 20–21—Gear Forum International 2013.

Parma Exhibition Center, Parma, Italy. Opinion leaders, international buyers of gears and gear suppliers will meet in order to speak about issues regarding the future of gears including expectations and solutions. The event is coordinated by an international steering committee chaired by Prof. Carlo Gorla of Mechanical Department of Politecnico di Milano, technical director of the magazine *Organi di Trasmissione*, and composed by leading experts of the gear sector, that will discuss topics including research trends, standards, present and future trends in the United States, worm gear performance, software and simulation for gears and automotive power transmission efficiency. Speakers include Prof. Dr. Ing. Karsten Stahl, director of Technische Universität Munchen; Charlie Fischer, vice president-technical division of the American Gear Manufacturers Association (AGMA); Michael Goldstein, publisher and editor-in-chief of *Gear Technology* magazine; Michel Octrue, president of CETIM Centre Technique des Industries Mécaniques; Dr. Ulrich Kissling, technical director – purchase manager of Kisssoft; and Andrea Piazza, transmission and hybrid design and testing department manager, Fiat Power Train. The event will be held within MECSPE, the international fair on technologies in the mechanical and subcontracting sectors. For more information, visit *www.senaf.it/MECSPE/home/117.*

April 8–12—Hannover Messe 2013. Hannover Fairgrounds, Hannover, Germany. The world's leading trade show for industrial technology returns in 2013 with a full lineup of trade shows under the banner "Integrated Industry." The 11 co-located shows include Industrial Automation; Motion, Drive and Automation; Energy; Wind; MobiliTec; Digital Factory; ComVac; Industrial Supply; Surface Technology; IndustrialGreen Tec and Research and Technology. Russia is the official partner country in 2013. Discover new perspectives on energy, automation and industrial supply and engineering topics as well as a broad range of events and displays affecting the global industrial market today. Other Hannover highlights include Metropolitan Solutions, TectoYou, Job and Career Market and Energy Efficiency in Industrial Processes. For more information, visit *www.hannovermesse.de*.

April 29–May 2—Gear Dynamics and Gear Noise Short Course. Gear Dynamics and Gear Noise Research Laboratory. The Ohio State University, Columbus, Ohio. For more than 33 years, this course has been offered as a tool to engineers and technicians involved in the analysis, manufacture, design, specification or utilization of simple and complex gear systems. Industries that find this course helpful include the automotive, transportation, wind-energy, process machinery, aircraft, appliance, general manufacturing and all gear manufacturers. The course material is covered in such a way that the fundamentals of gearing, gear dynamics, noise analysis and measurements are covered. This makes the course appropriate to the gear designer with little knowledge of noise analysis as well as to the noise specialist with little prior knowledge of gears. Course attendees are asked to present a brief synopsis of problems they have encountered or of a procedure they have used for gear noise analysis and reduction. Possible approaches to solve each problem are discussed. For more information, visit *www.gearlab.org*.

Unlock the Archive

The complete set of back issues of *Gear Technology* is available online--but ONLY if you're a subscriber. Make sure you have access by filling out the form!

gear TECHNOLOGY®

1

☐ **YES** I want to receive/continue to receive ***Gear Technology*** FREE**!**

☐ No thank you.

Name:______________________________ JobTitle/Position: ____________________
(print)

Signature ______________________________________ Date: _______________
(required)

2 → E-mail ____
(So we can notify you when the online edition is available)

SAVE a TREE!
☐ I ONLY want the digital edition
(e-mail required)

3 → Please update your contact information or attach you business cards here. (No Staples)

Address: ____

____

____

City: ____

State/Province: _______________ ZIP/Postal Code: ____________

Country: ____

Telephone: ____________________ Fax: ____________________

E-mail: ____

Website: ____

4 → What is your primary JOB FUNCTION (check ONLY one)

- ❑ Corporate Executive (B)
- ❑ Manufacturing Production Management (C)
- ❑ Manufacturing Production Department (D)
- ❑ Manufacturing Engineering Management (E)
- ❑ Manufacturing Engineering Department (F)
- ❑ Product Design, R&D Management (H)
- ❑ Product Design, R&D Department (I)
- ❑ Purchasing (L)
- ❑ Marketing, Sales or Communications (M)
- ❑ Quality Control Management (P)
- ❑ Quality Control Department (Q)
- ❑ Other (Please describe) (N)

____

5 → How are YOU involved with gears (check all that apply)?

- ☐ My company MAKES gears (20)
- ☐ My company BUYS gears (22)
- ☐ I DESIGN gears (23)
- ☐ I am a SUPPLIER to the GEAR INDUSTRY (please specify product or service) (24)

____

DIGITAL SUBSCRIPTIONS

- ❑ **YES,** I want to be notified each issue when Gear Technology is available online
- ❑ **YES,** I would like to receive Gear Technology's monthly e-mail newsletter
- ❑ **YES,** I would like to receive Gear Technology's monthly e-mail Product Alerts
- ❑ **YES,** I would like to receive 3rd-party e-mails from Gear Technology's advertisers and partners
- ❑ **YES,** I would like to receive subscription renewal notices by e-mail
- ❑ **No,** I do not wish to be contacted by e-mail.

FAX TO 1-847-437-6618 or
VISIT US ONLINE AT
www.geartechnology.com/subscribe.htm

CORRECTION

In the November/December 2012 issue of *Gear Technology*, John Walter was incorrectly identified as John 'Walters' in the article "If We Only Had a Crystal Ball." *Gear Technology* regrets the error.

—The Editors

NEXT ISSUE

Focus on
HEAT TREATING

Be a part of the discussion by contacting our editors:

Randy Stott, Managing Editor
wrs@geartechnology.com

Jack McGuinn, Senior Editor
jmcguinn@geartechnology.com

Matt Jaster, Associate Editor
mjaster@geartechnology.com

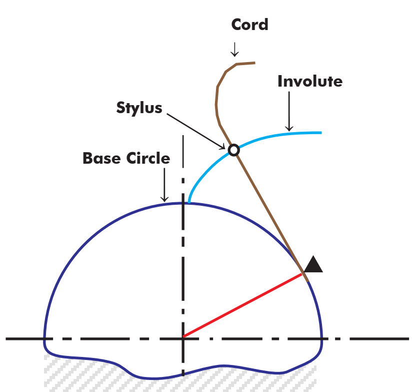
The Involute Curve

Editor's Note: You've been asking for it and here it is: Back To Basics! Need brushing up on your gear "vocabulary"? Need a bevel gear refresher? Metrology? Watch this space regularly for all of this and more. If it's basically gears, you'll find it here. And don't forget to send us your questions—any questions (there are no stupid ones, correct?)—for whatever gear issue you need coaching-up on. Send your questions to: geartechnology.com.

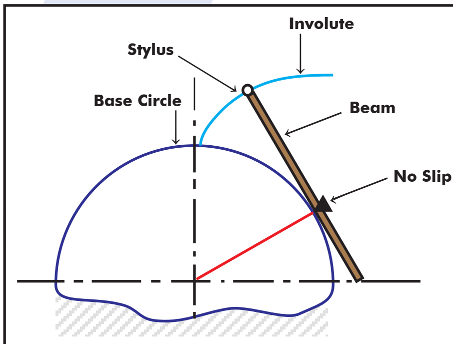
Although gears can be manufactured using a wide variety of profiles, the involute curve is the most commonly used. An involute curve is generated by a point moving in a definite relationship to a circle, called the base circle.

Two principles are used in mechanical involute generation. Figures 1a and 1b show the principle of the fixed base circle. In this method the base circle and the drawing plane in which the involutes are traced remain fixed.

The simplest way to generate an involute curve is to unwrap a taut cord from a fixed cylinder or circle (the base circle), as illustrated in Figure 1a. The involute path is traced by an imaginary point on the cord as it unwinds from the circumference of the base circle. Similarly, the involute can be generated by a rolling beam, as shown in Figure 1b. In this case, the involute is traced by an imaginary point at the end of the beam.



(a) Cord Method (fixed base circle)



(b) Rolling Beam Method (fixed base circle)

The second principle, that of the revolving base circle, is used in generating involute teeth by hobbing, shaping, shaving and other finishing processes (Fig. 1c). In this case, the drawing plan in which the involutes are traced is attached to the revolving base circle.

Properties of the Involute

A perpendicular to the involute surface is always tangent to the base circle.

The length of such a tangent is the radius of curvature of the involute at that point. The center is always located on the base circle.

For any involute, there is only one base circle.

For any base circle, there is a family of equivalent involutes, infinite in number, each with a different starting point.

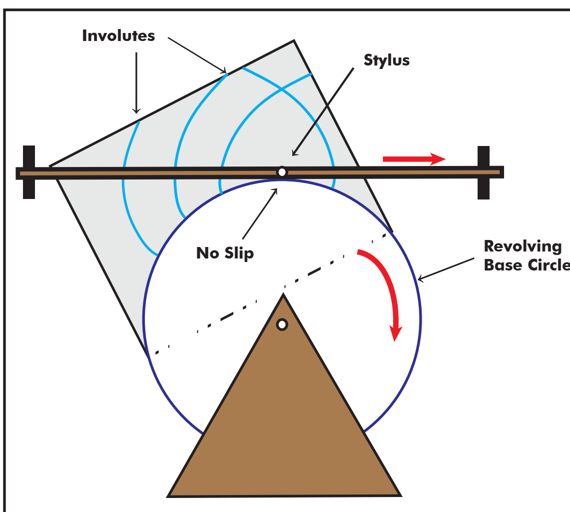
The radius of curvature of an involute surface is equal to the length of the tangent to the base circle.

Involutes to different base circles are geometrically similar; that is, corresponding angles are equal, while corresponding lines, curves or circular sections are in the ratio of the base circle radii. Geometric similarity explains why the teeth of a large gear can mesh properly with those of a small gear.

When the radius of the base circle approaches infinity, the involute becomes a straight line.

Involutes in Contact

Mathematically, the involute is a continuous, differentiable curve; that is, it has only one tangent and only one normal at each point. Thus, two involutes in contact (back-to-back) have one common tangent and one common normal. This common normal, furthermore, is a common tangent to the base circles. Since this normal for all positions intersects the centerline at a fixed point, conjugate motion is assured. When two involute gear teeth move in contact, there is a positive drive imparted to the two shafts passing through the base circle centers, thus ensuring shaft speeds proportional to the base circle diameters. This is equivalent to a positive drive imparted by an inextensible connecting cord as it winds onto one base circle and unwinds from the other. It is analogous to two pulleys with a crossed belt arrangement. Note that the surfaces of both involutes at the point of contact are moving in the same direction.



(c) Revolving Base Circle Method. The beam and base circle roll with each other without slip

Where Can I Learn More?

The material in this Back-to-Basics Brief was adapted primarily from two sources:

"Spur Gear Fundamentals," an article by Uffe Hindhede, which appeared in the January/February 1989 issue of *Gear Technology*, and "Involutometry," an article by Harlan W. Van Gerpen and C. Kent Reece, which appeared in the September/October 1988 issue of *Gear Technology*.

Power Skiving – A Milestone in Gear Manufacturing

CIMT **Beijing, China** - 22.-27. April 2013
Hall E2 Booth 805

Power Skiving – KLINGELNBERG Presents its Latest Innovation

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

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

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

Extended Product Range – With the addition of the Hofler gear manufacturing technology for cylindrical gears, the Klingelnberg Group expanded its product portfolio and strengthening its position as a single-source system supplier.

www.klingelnberg.com www.hofler.com

KLINGELNBERG