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NOV/DEC 2014

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GEAR TECHNOLOGY 30 YEARS 1984–2014

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The G 250 / G 450 can be easily equipped with various automation solutions

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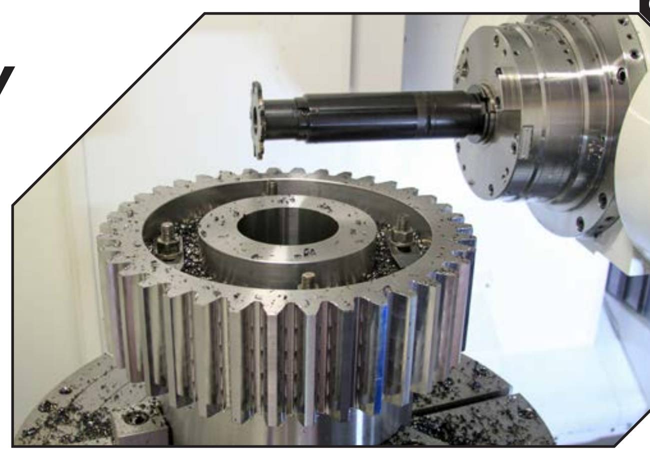

2014 STATE OF THE GEAR INDUSTRY ISSUE

features

technical

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departments

THE GEAR INDUSTRY'S INFORMATION SOURCE

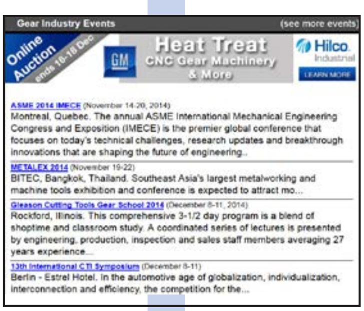
www.geartechnology.com

INDUSTRY 4.0

We're living in a time of rapid digitization, where computers and robots are performing tasks once deemed science fiction. The technology shifts signal another industrial revolution, and even though we are still in its very early stages, the pace of change is accelerating. The industry needs smarter, leaner and agile factories, where faster and reliable decision making and intelligent data stream management are prerequisites. In this video from Sandvik Coromant, Peter Evans and Martin Helgoson discuss the emerging trends of information technology in manufacturing. Visit *www.geartechnology.com* to watch the video.

Big Gear Inspection

Quick, accurate tooth thickness measurement for large-diameter gears is demonstrated in this video from Slone Gear. The gage is set to a master and then placed over several teeth. The Slone Gear software calculates the tooth thickness/dimension under pins. See how it's done at *www.geartechnology.com*.


Gear Industry Events (see more events)

Online Auction ends 16-18 Dec — GM Heat Treat CNC Gear Machinery & More — Hilco Industrial LEARN MORE

ASME 2014 IMECE (November 14-20, 2014)
Montreal, Quebec. The annual ASME International Mechanical Engineering Congress and Exposition (IMECE) is the premier global conference that focuses on today's technical challenges, research updates and breakthrough innovations that are shaping the future of engineering...

METALEX 2014 (November 19-22)
BITEC, Bangkok, Thailand. Southeast Asia's largest metalworking and machine tools exhibition and conference is expected to attract mo...

Gleason Cutting Tools Gear School 2014 (December 8-11, 2014)
Rockford, Illinois. This comprehensive 3-1/2 day program is a blend of shoptime and classroom study. A coordinated series of lectures is presented by engineering, production, inspection and sales staff members averaging 27 years experience...

13th International CTI Symposium (December 8-11)
Berlin - Estrel Hotel. In the automotive age of globalization, individualization, interconnection and efficiency, the competition for the...

Don't Miss Important Events

Want to know what's coming up that's relevant to the gear industry? Whether you're interested in technical conferences, seminars or the latest auctions of gear machinery and equipment, the Events section at geartechnology.com is the place to find out more information.

Buyers Guide

Even though the *printed* buyers guide is already produced (see page 36), the *online* buyers guide provides even more comprehensive information for those looking for information about the machines, tooling and services needed to manufacture gears. Visit *www.geartechnology.com* to contact any of the hundreds of companies who are suppliers to gear manufacturers. And if you're one of those suppliers, you can get listed in the Buyers Guide for free at *www.geartechnology.com/getlisted.php*.

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Step Right Up and Have Your Fortune Told

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Michael Goldstein

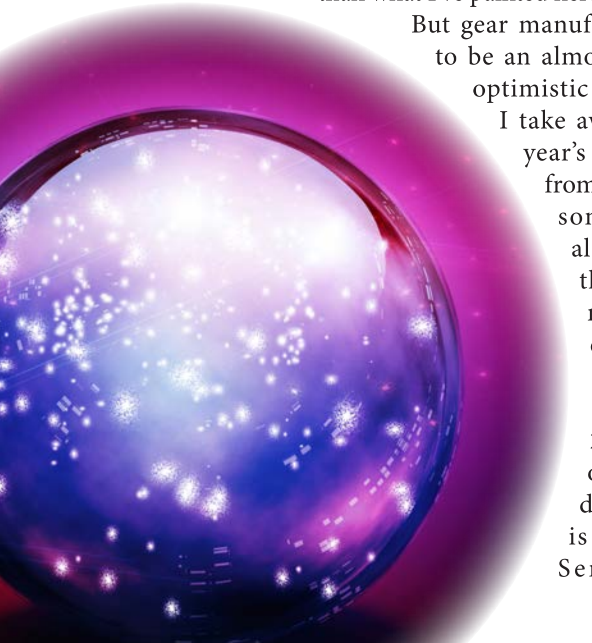
Most companies spend this time of year crystal ball gazing. Managers want to know the future so they can make projections, plan schedules, determine budgets and make major decisions that will ensure their success.

It would be nice if you could just put on your swami hat and know what was going to happen, but it doesn't work that way. The best you can do is identify what might happen, weigh the risks and costs of various outcomes and plan accordingly. The best planners often seem like fortune tellers, but they're not. They just have better information than everyone else.

As "The Gear Industry's Information Source," we try to do our part to help you stay well-informed. Our annual State-of-the-Gear-Industry survey is just one example (see page 28). Every year since 2006 we've surveyed gear manufacturers around the world to try to get an idea about current trends and future expectations. We're not statisticians, and we don't pretend to be, so we don't expect you to rely solely on this survey to plan your future. But more than 300 gear manufacturers participated, and their responses corroborate the other information we've seen. Call it reading tea leaves by consensus.

And the consensus among gear manufacturers is that 2014 was a pretty good year. Not a year where sales records were broken, but a decent year with modest growth and modest opportunities for more of the same. Not a great year, but not bad either. Gear manufacturers appear to be busy, with steady orders and prospects for work to continue.

Of course, the picture is a little bit different when you break down the numbers and delve into who is saying what. Gear manufacturers in North America are decidedly more optimistic than those in Europe, Asia or just about anywhere else. And naturally, the fortunes of manufacturers who are tied closely to specific industry sectors will follow those sectors more closely than gear manufacturing in general. So if you make gears for mining or construction equipment, your picture may be somewhat less rosy than what I've painted here.



But gear manufacturers seem to be an almost universally optimistic bunch. What I take away from this year's survey – and from my own personal, anecdotal evidence – is that most gear manufacturers expect 2015 to be a little bit better than 2014. Some of that anecdotal evidence is reflected in Senior Editor Jack McGuinn's article on page 22. Jack has interviewed a number of people across a broad spectrum of the industry so that we could share their opinions with you as well.

Like all of you, we here at *Gear Technology* rely on our predictions to make smart decisions for our business. In our case, we're optimistic about 2015, and we've made the decision to invest in our business by adding staff in order to make our products better learning and marketing resources for you.

Kirk Sturgulewski is our new online content manager. With more than a decade of experience in technical development and digital marketing, he is responsible for some of the improvements you'll be seeing very shortly in our e-mail newsletters, product alerts and other electronic communications. He's also working to make our websites more user friendly and accessible, so that no matter where you want access to our content – be it phone, tablet or desktop – the user experience will be smooth and intuitive. If you have any suggestions, you can contact Kirk via e-mail at *kirk@geartechnology.com*.

We've also hired Erik Schmidt as our new assistant editor. Erik will be responsible for developing our news sections both in print and online, so if you have industry news or new products to share with the gear industry, you can send them directly to *erik@geartechnology.com*. He'll help you get the word out. Erik will also be working on more in-depth feature articles, so if there are any subjects you think we should cover, we hope you will send him a note.

In addition, we're continuing to invest in making sure that *Gear Technology* can be found wherever there is relevant information related to the latest technology in gear manufacturing. Last issue you read about Jack McGuinn's trip to Lyon France to cover the International Conference on Gears. Last month we sent Managing Editor Randy Stott to the Gleason Works to attend the 5th WZL Gear Conference USA (see p. 100). We're also media sponsors of the CTI symposium on automotive transmissions being held in December in Berlin. If you go to the event, you'll find *Gear Technology* magazine there, too.

According to the best information available, the gear industry should have a strong 2015. We've made plans and investments accordingly. How about you?

Gleason

ANNOUNCES HIGH-SPEED GEAR SHAPER

Gleason Corporation has announced the introduction of the 100S Gear Shaping Machine.

The 100S is designed for small-face width gears, including spur and helical gears, both internal and external, as well as automotive synchro rings and tapered gears. It is a compact and robust machine requiring significantly reduced floor space. The 100S is easily moved, quickly installed and powered up.

Some of the significant features of the 100S include high productivity, with stroke rates up to 3,000 per minute, a static and dynamically stiff machine concept, aided by a twin-bearing crankshaft design and a fast clamping and unclamping system HSK 63 for high repeatability and manual activation for minimized weight.

The 100S is offered with standard dry machining cycle and an optional automatic adjustment of stroke position after re-sharpening of the shaper cutting tool. Optional wet machining is also available.

For more information:
Gleason Corporation
Phone: (585) 473-1000
www.gleason.com

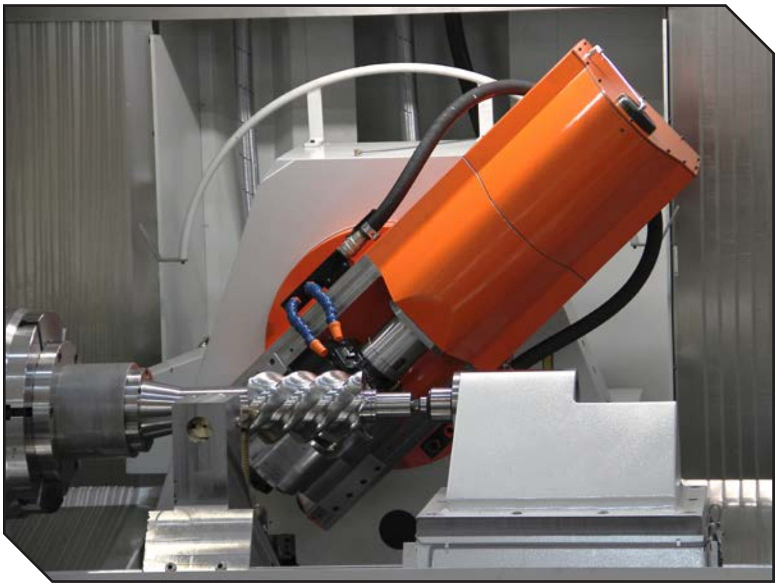
Koepfer America

INTRODUCES NEW 'H' SERIES HOBBING MACHINES

Koepfer America LLC introduced the CLC "H" series of heavy-duty horizontal gear hobbing machines to the North American gear manufacturing market. These machines offer a competitive and fully customizable solution for high-precision, CNC horizontal gear hobbing.

The CLC 260-H is rated at 7.874" (200 mm) diameter at 4 DP (module 6.0). Larger work pieces can be hobbed with a maximum swing of 20.472" (520 mm) diameter. The larger CLC 500-H is rated at 19.685" (500 mm) diameter at 0.847 DP (module 30.0) with a maximum swing diameter of 31.496" (800 mm).

Both machines can be built with different bed lengths to provide axial travel up to 118" (3000 mm), making either machine a flexible solution for shafts and pinions. Additionally, these machines have unique features, such as a large through-hole in the work spindle for extra-long work pieces.



These machines also have standard features such as high-speed, direct-drive torque motors for both the work and cutter spindles, Fanuc 31i numeric control, and optional skiving (carbide re-hobbing) capability with an integrated electronic timing probe. They are also equipped with a high-speed hob head that swivels ±45°. For high-helix worms or rotors, a special CLC 500-FR-H form milling machine is available.

The CLC "H" series provides North American gear manufacturers a new option for horizontal gear hobbing. These machines can be specially customized as needed to provide customers an optimal solution for their gear manufacturing needs.

For more information:
Koepfer America LLC
Phone: (847) 931-4121
www.koepferamerica.com

Mitsubishi Heavy Industries

DEVELOPS 'SUPER SKIVING SYSTEM' FOR HIGH-SPEED GEAR CUTTING

Mitsubishi Heavy Industries, Ltd. (MHI) has completed development of the "Mitsubishi Super Skiving System" for machining internal gears with high-speed precision.

This new system overcomes technical issues characteristic of conventional skiving by use of an MHI-developed, barrel-shaped, multiple cutting-edge rotary tool, enabling mass production of internal gears. In addition, longer tool life and shorter machining times will enable reductions in production costs. MHI is aiming to commence marketing of the new tool and skiving machine in April of 2015.

The "Super Skiving Cutter" was designed by applying skiving technology to MHI's barrel-shaped grinding wheel, developed for MHI's ZI20A gear-grinding machine, a machine designed for mass-production applications in 2009.

Skiving is a cutting technology whereby a pinion type cutter or other rotary tool is engaged with a workpiece at a crossed-axes angle, and synchronously rotated together.

At the points where the two contact, the effect of the crossed-axes angle generates a sliding velocity of the tool in the axial direction, resulting in high-speed machining. Use of a pinion cutter-type tool, however, typically makes the cutting (skiving) angle obtuse – a drawback that impedes improvements in cutting precision and also causes significant tool wear.

With MHI's newly developed tool, the adoption of a barrel shape averts interference with the workpiece and prevents the cutting angle from becoming obtuse. As a result, a large crossed-axes angle can be achieved, enabling the realization of cutting speeds and precision levels surpassing those of pinion-cutter type skiving.

The new MHI "Super Skiving System" was first exhibited at the 27th Japan International Machine Tool Fair (JIMTOF) held at Tokyo Big Sight from Oct. 30 through Nov. 4.

For more information:
Mitsubishi Heavy Industries, Ltd.
www.mhi-global.com

KISSsoft AG

ADDS BEVELOID GEARS MODULE

Beveloid gears have their own new module in the KISSsoft system (module ZH1). Sizing and dimensioning of beveloid gears have been implemented based on cylindrical gear standards, which also makes it possible to consider load spectra.

The usual flank modifications, such as helix angle modification or negative crowning, are still available to help optimize tooth contact in a 3D model.

Finally, the tooth contact can be verified using the graphical contact analysis method, and the models can be exported for various purposes, such as FE analysis, 5-axis milling, or output to a measurement grid.

For more information:
KISSsoft AG
Phone: +(41) 55 254 20 50
www.KISSsoft.AG

Oelheld

RELEASES CONTROXID 1642 RUST PROTECTION FLUID

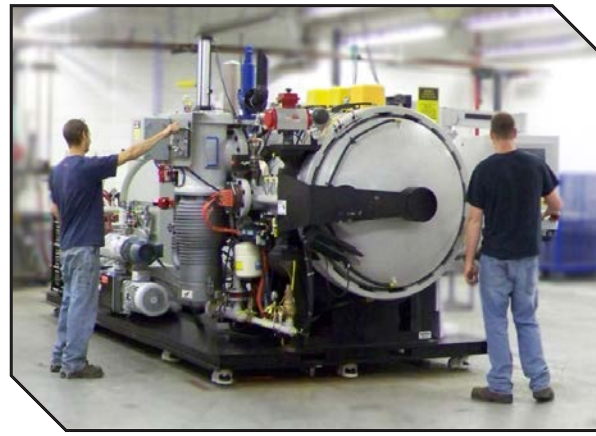
ControXid 1642 is a ready-to-use rust protection fluid for coolant circuits based on synthetic, water-soluble corrosion inhibitors. It is low-foam and affords reliable protection against corrosion as well as high resistance to fungal and bacterial contamination.

ControXid 1642 can be used for temporary corrosion protection during hydraulic tests, corrosion protection in coolant circuits and as a coolant for machine tool spindles. It is not caustic, does not contain nitrites, chromates, heavy metals, phosphates, chlorine compounds or amines. It protects ferrous metals (steel, cast iron) against corrosion and has no effect on aluminum alloys, other nonferrous metals or mineral oil-based sealing materials.

For more information:
Oeheld U.S., Inc.
Phone: (847) 531-8501 ext. 206
www.oelheld-us.com

Ipsen

SHIPS TITAN FURNACE BY AIR



As the world evolves, so do the ways products travel to customers.

Ipsen recently hit a new milestone, shipping their first Titan vacuum furnace by air. This Titan H2 with 2-bar quench was shipped to a company located near Shanghai, China as part of a collaborative 3D printer-furnace package. This company is part of the continuous casting industry, and it will use the Titan furnace to process printed steel part prototypes and assist in furthering the company's new research and development projects.

This thermal processing vacuum furnace was purchased as part of Ipsen's partnership with a global provider of 3D printing machines and printed products. Since the partnership began, several 3D printer-furnace packages have been sold to companies throughout Europe and North America; however, this was the first combination to be sold to a company in China.

The Titan vacuum furnace's journey began at Ipsen's Cherry Valley, Illinois facility, where it was assembled. During that time, the customer visited Ipsen's facility to receive hands-on installation and operation training. The furnace was then shipped to Kentucky's CVG Airport. From there, its modular and compact size allowed it to be loaded upon a plane and shipped to China.

Even though this is the Chinese company's first 3D printer and first vacuum furnace, Ipsen's global presence – including an office located nearby in Shanghai – gives them immediate access to support whenever necessary. Customers can also take advantage of Ipsen's Global Support Team, which facilitates on-site installation, training and start-up assistance.

Ipsen's Titan line is a self-contained, skid-mounted system that installs in just one day. Designed for ease of use, the Titan is designed for first-time heat treaters and experts alike. Titan's standardized and simple control system operates in 20-plus languages, meets global industry standards, switches easily between units of measure and stores up to 1,000 recipes. The Titan is able to handle a number of different processes, including annealing, hardening, brazing, sintering, tempering and more.

For more information:

Ipsen, Inc.
Phone: (815) 332-2679
www.ipsenusa.com

Dillon Mfg.

WILL FEATURE ITS HARD JAWS AT HOUSTEX

Dillon Manufacturing, Inc. announced that its hard jaws will be featured in Houstex booth #127.

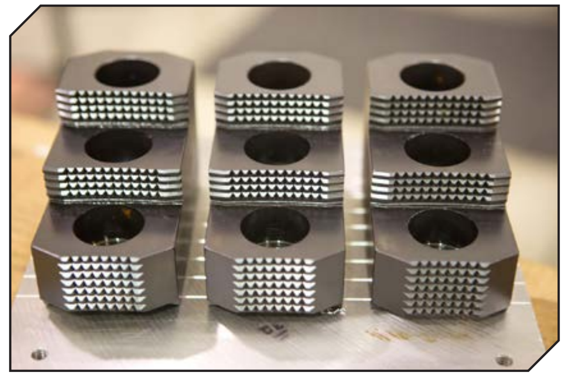
Hard jaws from Dillon Manufacturing, Inc. feature diamond-shaped serrations for increased pull-down effect, reducing part slippage and push back, especially when using a bar feeder.

Manufactured of 8620 steel, the jaws are case-hardened, surfaces ground and the jaws coated with black oxide for corrosion resistance.

They are available in different mounting configurations including serrated, T&G, Acme, and square serrated key types to fit all brands of chucks. Dillon chuck jaws have multiple radii for both inside and outside clamping.

Dillon also produces rough and semi-finished jaws for machinists. Various processes help reduce the amount of machining required by parts makers.

For more information:
Dillon Manufacturing, Inc.
Phone: (800) 428-1133
www.dillonmfg.com



Emuge Corp.

DEBUTS NEW SPEEDSYNCHRO TOOL HOLDER

Emuge Corp.'s new Speedsynchro tool holding solution features an integrated transmission of 1:4.412 for optimizing thread production on CNC machines with synchronous spindles. The integrated transmission is combined with Softsynchro minimum-length compensation to efficiently work with high-cutting speeds and a relatively low synchronous machine tool speed, compensating for synchronization errors during the threading process. The results are significant time and money savers, particularly in high-production tapping operations.

The new tool holder offers easy programming and up to 40 percent time savings due to significantly shortened thread production cycles resulting from the combined fast acceleration and cutting speeds facilitated by the integrated transmission. The time savings substantially increases the number of tapped holes achieved in a given operation and is especially effective in high-production tapping. Tool life and thread surface quality are both optimized.

Exact thread depths can be achieved with Speedsynchro, as it does not reverse the direction of rotation. Emuge Speedsynchro Tool Holder supports a maximum spindle speed of 2,000 RPM and a maximum tapping speed of 8,824 RPM. Cutting range is from M1 - M8, and an ER16 tool holder size is offered. Internal coolant capability is provided.

For more information:
Phone: (800) 323-3013
www.emuge.com

Seco Tools

TO SHOWCASE PRODUCTS AT TECMA 2015

At TECMA 2015, Seco Tools, LLC will showcase numerous cutting tool products that bring enhanced productivity to metalworking operations. Visitors to Seco stand 848 at the Expo Bancomer Santa Fé in Mexico City from March 3 to 6 will discover several new milling cutters, as well as the latest turning and threading solutions.

Seco will highlight several of its multi-edge cutters, which offer a lower cost per cutting edge. Featured will be the Square T4-08, Square 6 and R220.LN14 lines of square shoulder mills. Made for roughing and semi-finishing operations, Square T4-08 cutters feature four cutting edges and a tangential cutter design that brings surface finish to slotting, contouring and plunging applications. These cutters are available in the M08 and MD08 insert geometries as well as eight different grades.

Various mounting types include cylindrical, Weldon, arbor and Combimaster, and cutting diameters range from 15.875 millimeters to 63.5 millimeters, with a maximum cutting depth of 7.97 millimeters. Corner radii range from .406 millimeter s to 1.6 millimeters. Square 6 cutters employ trigonal inserts with six indexable cutting edges, lowering cost per edge. These cutters are available in two different insert sizes – Square 6-08 and Square 6-04 – to handle a wider range of cutting diameters and depths. All Square 6 inserts can be set to a true 90-degree cutting angle to create clean 90-degree walls and eliminate secondary operations. Inserts lock into place via a center screw placed in the same direction as cutting forces, and wiper flats optimize surface finishes.

Seco designed its new R220.LN14 line of square shoulder mills to bring increased value and performance to demanding applications that require large depths of cut. R220.LN14 provides four cutting edges with a 14 millimeter cutting edge length to reduce cost per edge. Negative rake, 7-millimeter thick inserts provide the robustness needed for heavy cuts up to 14 millimeter in

difficult materials, long-reach applications and less stable setups. The tools are suited for medium to heavy-duty applications requiring a 90-degree wall, and inserts are available in six grades to handle a variety of materials.

Face Milling

Seco will also showcase its new Double Octomill High Feed face mill with 16 cutting edges. Designed to increase metal removal rates in steel and cast iron applications, this face mill brings versatility, productivity and economy to both roughing and finishing operations, and is available in diameters from 80 millimeters to 60 millimeters. Seco offers three insert geometries, four grades, and three different pitch versions – normal, normal+ and close – for use with the Double Octomill High Feed so it can be applied across a wide range of materials. Grind location grooves on these inserts ensure they align between the edge and seat of each cutter body pocket, which allows the cutter to achieve tight tolerances.

General End Milling

Also in Seco's TECMA stand, Niagara Cutter will spotlight its new NS240R solid carbide long-flute end mill for general machining in aluminum, stainless steel and titanium – and especially those applications requiring fine surface finishing. The NS240R end mill reduces machining cycle times in square shoulder milling operations through its one-pass finishing capabilities, and produces tight-tolerance straight walls when cutting deep pockets. As standard, the NS240R provides 5xD depths of cut and come in diameters ranging from 6.35 millimeters to 31.75 millimeters and with various radii, including those specifically for aerospace applications.

Turning

Seco has added turning bars to this patented line of damped tooling that brings increased productivity results to a wide variety of long overhang machining operations. Featuring the company's new, patented GL connection, the same

Steadyline turning bar performs both rotating and static operations to increase versatility while helping to reduce overall tool costs. Available in 6xD, 8xD and 10xD, a range of types, including Seco-Capto C4, C5 and C6, and a broad selection of turning heads for CN, DN, WN, CC, DC, TC, TN and RN inserts as well as heads for Snap-Tap threading, Steadyline turning bars can handle a variety of applications and operations, including roughing, finishing, threading and grooving. In addition, these bars feature coolant supply channels for enhanced chip evacuation.

Threading

Seco will display its new Thread Chaser inserts that incorporate multitooth patterns to allow push and pull threading of O.D. and I.D. features with one or two passes. Through-coolant holes and chip formers direct high-pressure coolant to the cutting edge to optimize chip formation, provide efficient chip evacuation and extend tool life. These inserts provide value to manufacturers working with pipes and couplings made from a range of materials for the oil and gas industry.

For more information:
Seco Tools
Phone: +(46) 223 40000
www.secotools.com

Schunk

RELEASES EGS CLEANROOM GRIPPER

The EGS from Schunk is designed for the gripping of small- to medium-sized workpieces, with flexible force and high speed in clean environments, such as assembly, testing, laboratory and the pharmaceutical industry.

It is digitally activated by binary signals for easy start-up and integration in existing facilities and is quick to achieve the maximum number of cycles per minute. The EGS is sturdy, making it almost wear-free, while also supplying high-gripping forces for each cycle.

The EGS has autonomous gripping and swiveling, adjustable gripping force and freely adjustable angle of rotation. It is energy efficient due to the use of an electric powertrain, and is simple to use, with no programming costs.

For more information:
Schunk
Phone: (905) 712-2200
www.schunk.com

Ransohoff

INTRODUCES THE NEW GENERATION LEAN-JET RB-FLEX+ PARTS WASHER

Ransohoff, a division of Cleaning Technologies Group LLC, recently introduced its new generation Lean-Jet RB-Flex+ immersion cleaning system.

The Lean-Jet RB-Flex+ is a flexible and scalable platform that can be configured for a variety of parts and capacities from camshafts to locomotive engine blocks weighing over 20,000 pounds. The washer cleans using a triple-action batch cleaning process, which includes a washing and rinsing process of agitation, spray impingement, hydraulic purging through immersion and rotation and heated blow-off drying. Options such as clamp and flush, precision probes and manifolds or ultrasonics can be added if even more focused cleaning is required.

The Lean-Jet RB-Flex+ parts washer also features the latest Siemens programmable controller and operator interface screen. This controls platform boosts system flexibility for automation integration, process control and data logging while offering an intuitive user interface.

As with all of the Ransohoff Lean-Jet products, customer specific basket designs are available to accommodate larger parts.

For more information:
Cleaning Technologies Group, LLC
Phone: (513) 870-0100
www.ctgclean.com

Grieve

NO. 814 CABINET OVEN SUITED TO PLASTIC OR METAL

No. 814 is a 500 degree, electrically-heated cabinet oven from Grieve, currently used for various plastic and metal part heat treating operations at the customer's facility.

Workspace dimensions of the oven measure 22" W × 21" D × 85" H. 18 kW Nichrome wire tubular elements heat the oven chamber, while a 750 CFM, 3/4-HP recirculating blower provides a vertical downward airflow to the workload.

This Grieve cabinet oven features 4-inch insulated walls, aluminized steel exterior and interior, three integral metal shelves, plus all safety equipment required by NFPA Standard 86 for handling flammable solvents, including a powered forced exhauster, airflow safety switch and purge timer.

Other controls on No. 814 include a fused disconnect switch, digital temperature controller and manual reset excess temperature controller.

For more information:
The Grieve Corporation
Phone: (847) 546-8225
www.grievecorp.com

Liebherr

DEVELOPS MULTI-CUT STRATEGY GEAR HOBBING MACHINE

Liebherr has developed a gear hobbing machine that applies a multi-cut strategy including press deburring. Continual loading and press deburring occur in parallel during machining time.

Separate machine operations take place on two machine tables, each easily accessible and able to swivel 180 degrees. After the blank is locked in and tightened, it is swiveled and the first cut of the gear takes place on the first table, while on the second table the chamfer is produced by pressing. After another swivel, finishing takes place in order to eliminate the bulging that occurs as a result of pressing.

The finishing process is essential to this cycle; it is a stand-alone process not subject to crossover impacts generated by a parallel process on the neighboring table.

"We chose this strategy, since external mechanical encumbrances should be excluded during machining, especially during the precision finishing process," said Dr.-Ing. Hansjörg Geiser. "The quality of the components, of the flanks in particular, and the reliability of the process as a whole benefit from this."

For more information:
Liebherr
Phone: +49 (0) 831 786-3285
www.Liebherr.com

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MEMBER

ISO 9001:2000 CERTIFIED

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- Linear motor for the table slide, eliminating backlash
- Advanced worm and thread grinding for multiple worm types

get more information at http://lurenusa.com

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2015: MORE OF THE SAME

But no one's complaining

Jack McGuinn, Senior Editor

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state of the gear industry

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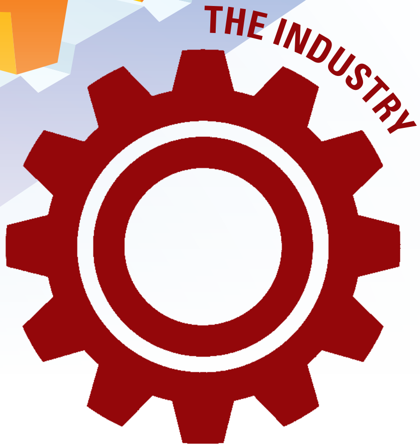


From a technological perspective, there typically aren't many EUREKA! breakthroughs in the "state of the gear industry" to report, and 2014 was really no different. (But there *were* improvements; please read further). On the dollar-and-cents side of the equation, however, most gear industry players should be reasonably content over how this past year shook out — and are at least guardedly optimistic about the next. Our yearly State-of-the-Gear-Industry Survey (Page 28) bears testament to that. What follows here are some insights from gear manufacturers, suppliers and other industry insiders — and their take on how things look for 2015. We'll follow that with snapshots of U.S. gear research (OSU GearLab); workforce stability (apprenticeship programs); and women in (gear) engineering.

That gearing is an industry with deep age lines is unquestioned; just one example: Gleason Corp. celebrates its 150th year in operation this June. But "still water runs deep," as the adage goes, so age notwithstanding, there is *always* something new going on in the world of gears, and 2014 was true to form. Technology improves and upgrades continue occurring in meaningful — if incremental — ways in various areas in the industry. Like, for instance, on the machinery side, as reported by **Al Finegan,** director of marketing for Gleason Corp. "(Our) industries are relatively mature, and technology advancements tend to be evolutionary, rather than revolutionary. With respect to gears, advances generally center about improvements in gear design, gear materials, tool materials, and processing." Star SU president **David Goodfellow** also cites small-yet-significant breakthroughs — particularly the "definite improvement in gear cutting tools, with the utilization of indexable, carbide tools for gear milling cutters and hob inserts, and the continued development in the power skiving process."

And in Milwaukee, **Kevin Zaba,** recently named Rexnord president of power transmission, says it's all about gear user demand for creating "more and more torque transmission from smaller gear drives." Zaba says this "trend" is creating a welcomed ripple effect that is "driving the development of innovative gear tooth coating and finishing techniques that haven't been required in the past." And "Rexnord is responding to those customer needs."

Looking at the Big Picture, it seems to be ever more difficult for gear industry manufacturers in particular to sustain their relevance in this New World Economy — especially given the ever-tougher demands of customers.

Goodfellow responds to that premise with "The biggest challenge is the continued improvement in accuracy and quality requirements, while still maintaining higher productivity values."

For AGMA president **Joe T. Franklin Jr.**, "Sustained relevance" comes from constantly challenging yourself as a manufacturer, con-

stantly insisting that your employees are well-trained and well-educated, making sure that your manufacturing equipment is capable of producing products your customers need and that relationships with your customers have reached an advanced stage where you truly are partners." Franklin adds that the process is aided by the industry's system of standards, created by industry volunteers.

At Rexnord, Zaba echoes the importance of standards "Rexnord's support of AGMA is steadfast and (in fact the company) participates in standards-writing committees with AGMA and ISO in order to shape the intent and use of standards and principles."

Closing this one out, Finegan's answer is classic, textbook Business & Marketing 101 in its clear-eyed understanding that, at the end of the day, it is all reduced to: Quit whining. The customer is always right. End of story. "Sustained innovation is the key to maintaining sustained relevance. Citing the imposition of tougher standards by governments or blaming customers for being more demanding will accomplish nothing. Customers can be demanding, but only because they too are subject to the same tougher standards and their customers are demanding. It's today's business world."

Of keen interest to many on the automotive side of gearing are impending stiffer, government-mandated curbs on CO_2 emissions. In 2012, the U.S. Department of Transportation and the EPA issued new rules for corporate average fuel economy (CAFE), which set much more stringent requirements for U.S. automobile manufacturers in terms of their vehicles' energy efficiency. These mandates have led to the design and manufacture of more and more complex transmissions. The result is that over the past few years, we've seen a steady increase in the number of gears in automobile transmissions, and that trend looks to continue.

"(Such) transmissions are already in North America and actively in use," says **David Zini,** GM gear system design and development/global technical specialist. "GM is aggressively rolling out 8-speed automatic

transmissions in the Corvette, Cadillac models, and Chevrolet Silverado and GMC Sierra full-size trucks (and) 9- and 10-speed automatics are in our future. GM is continuing to develop new technology for future applications that is optimal for CO_2 emissions."

"The biggest challenge is the continued improvement in accuracy and quality requirements, while still maintaining higher productivity values."

David Goodfellow, Star-SU

Franklin reveals that, "Based on the report presented by Brett Smith of the Center for Automotive Research to AGMA, the EPA and the automobile industry are moving aggressively to meet new standards that will require significant reductions in CO_2 emissions in coming years." He says a paradigm

> **"Customers can be demanding, but only because they too are subject to the same tougher standards and their customers are demanding. It's today's business world."**
> *Al Finegan, Gleason Corp.*

shift is in the offing for "those of us who (were looking) for ways to conserve energy resources by increasing miles-per-gallon."

Automobile transmissions with more gears means more gear manufacturing and continued work for the gear industry. By all accounts, the automobile industry has been a bright spot and should continue to drive gear industry growth. But this report would not be complete without a brief look ahead to Gear Expo 2015, convening in Detroit's Cobo Hall. So we asked about expectations.

"At the moment, the U.S. economy is reasonably healthy, and manufacturing is making a modest resurgence," allows Finegan. "That being said, Gear Expo is a highly focused show that serves a finite market, so one cannot expect off-the-chart attendance figures." Star SU's Goodfellow is looking "to see the same enthusiasm at next year's Gear Expo on the heels of strong automotive production."

As for the event's host, "AGMA has high expectations and, more importantly, so do our exhibitors," says Franklin. "At this point the show is 85% sold. We are developing an expanded education program that should appeal to both manufacturers and users of complete drivetrain systems." Venue-wise, "We have followed the (redevelopment) of the downtown area and are quite confident that visitors will be met by a friendly and safe city, (including) a revitalized Cobo Hall—with new management." Without prompting, Franklin candidly allows that "Detroit continues to have challenges… but if the (Cobo) success is any example, we should all have great optimism for the future of Detroit."

And speaking of optimism, it's time for the last BIG question—what to expect in 2015. *Spoiler Alert*: it's stay the course and keep on keeping on. In their own words:

Finegan: We expect to see some modest improvement in 2015, which is probably in line with the broader machine tool market and the economic projections for most major industrialized countries.

Goodfellow: We believe 2015 should show some improvement in other manufacturing sectors such as construction, truck and tractor and agriculture; 2014 was mainly driven by the U.S. automotive industry.

Zaba: We're anticipating market conditions in 2015 similar to this year. In 2014, we've seen increased market demand for more torque-dense drives and larger drives. We've also seen trends and interest regarding our product quality and reliability, services, and ease of doing business. One of our top-selling products, the Falk V-Class, is continuing to expand in size and scope while penetrating new markets and applications.

Zini: Better. Our gear manufacturing and supplier base is more streamlined than ever, and we're able to provide the best products we've ever made.

Citing recently received data from AGMA economic counsel IHS Economics Group, **Franklin** reports that "Demand for gears in the United States fell nearly 9% in 2013, and they (IHS) anticipate growth of slightly more than 1% this year.

"The good news is based on an analysis of customer industries, as well as the broader U.S. economy; they show demand for gearing in 2015 growing just under 6% and in 2016 approaching 7%.

"The industry sectors showing the greatest potential in the next two years include manufacturers of electrical generating equipment, machinery such as machine tools, material handling equipment, industrial machinery, aerospace, and construction. The only negatives in the next two years are for manufacturers of farm machinery in 2015, and railroad equipment in 2016. So, we should all sing along with Little Orphan Annie as we watch the sun come out tomorrow."

GEAR RESEARCH

Broadway hit musical references aside, forget for the time being all about a maturing industry or artifacts-in-amber inferences. For at The OSU GearLab—headed up by **Dr. Ahmet Kahraman**—things are popping—and have been for some time now; hardly a sign of an industry in total stasis. OEMs of various stripes continue beating a path to their door—dollars in hand—seeking answers, breakthroughs or improvements on any number of gear-related issues—some with far-reaching impact.

Consider again those government-mandated CO_2 reduction standards vis-à-vis multitudinous-gear vehicle transmissions. The OSU GearLab has certainly not been sitting on the sidelines. Indeed, "Gear and transmission efficiency have been a very significant portion of our research portfolio for the last decade," Kahraman affirmed.

"We have developed physics-based, mechanical power loss models for spur, helical and hypoid gears based on elastohydrodynamic lubrication theory. Some of these models are implemented in our *LDP* and *HAP* software programs, which allow our consortium sponsors to do such predictions. We complemented these models with spin loss models for gears and bearings. Combining all these models, we were able to develop manual- and dual-clutch transmission, planetary gearsets and rear-axle efficiency models for various companies. We also invested heavily on experimental studies of gear efficiency and developed extensive databases for model validation. (What's more), "we have published more than 20 journal articles on gear efficiency since 2010.

"GearLab is in a very healthy position; its growth has been steady and robust for the last 10 years," Kahraman confirmed, pointing to "more than 70 fee-paying members to our Gear Research Consortium, including most OEMs and first-tier suppliers from automotive, aerospace and heavy-vehicle industries."

The Lab's solo-sponsored research portfolio and its experimental research capabilities are flourishing as well, said Kahraman, citing its Pratt & Whitney Center of Excellence of Gearbox Technology partnership and the purchase of "a dozen state-of-the-art test set-ups, machines and measurement systems."

As for what's new in the GearLab's world? "I can't speak for the gear industry, but we invested significant effort to developing models to design and analyze spline joints to the levels of sophistication as gears. Our sponsors are very excited about our *Spline-LDP* software, as well as our second-generation spiral bevel and hypoid contact analysis model *HAP*."

In the January/February 2014 issue of *Gear Technology* we did a story on apprenticeship programs—or the lack of them—in the U.S. For decades apprenticeship programs were a reliable feeder component adding to the steady flow of qualified workers that kept the country's manufacturing houses humming. And then around the early 1970s—when it seems just about *everything* went to hell one way or another—poof!—no more apprenticeship programs. But they're coming back—at least in some parts of the country—especially the Pacific Northwest, i.e.—*aerospace country*. That's where the Aerospace Joint Apprenticeship Committee (AJAC), assisted by **Lisa Van Dyke,** marketing communications manager works the trenches daily in partnership with a consortium of willing and eager aerospace and other hi-tech-type manufacturers in recruiting and retaining candidates for what is surely one of the most successful apprenticeship programs in North America.

We asked her how are things going at AJAC since we last talked. After all, with what seems like boatloads of folks preparing for Mars colonization, aerospace must be hot and in need of even more trained workers.

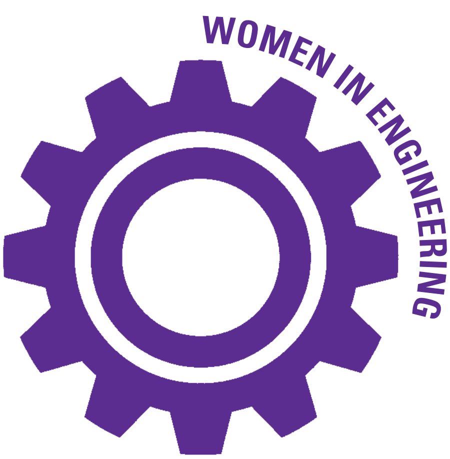
Indeed, "AJAC has sustained a 44% increase in the number of apprentices between 2013 and 2014," Van Dyke reports. "Likewise, the number of registered Training Agents (AJAC participating employers) increased by 54%, (highlighting) the booming demand for apprenticeship training in aerospace and manufacturing occupations across

Washington State." (Source: AJAC 2013-2014 Summary Report.)

Van Dyke adds, "There is (also) a strong interest at the federal level, (given the) surge in federal dollars (for) job-driven training." In fact the U.S. Department of Labor has ponied up $100 million in American Apprenticeship Grants (who knew?) to incentivize partnerships that facilitate getting more workers into apprenticeships.

Van Dyke believes that "This competition will help more Americans access this proven path to employment and the middle class, i.e.—*87% of apprentices* are employed after completing their programs, and the average starting wage for apprenticeship graduates is over $50,000." (*Source: AJAC 2013-2014 Summary Report*)

This, she says, dovetails with a simple fact of 21st century life that—proud mothers and fathers notwithstanding—a growing number of young people are starting to realize, i.e.—that "the four-year college degree is not the only path to a successful career after high school. They are learning that apprenticeship offers high school graduates an avenue to train for a career while earning a paycheck as well as a degree—but not racking up debt at the same time."



Women in engineering—unlike peace in our time—is not as rare an occurrence as you might think.

But women in *gearing*—now *there's* a subject that bears some scrutiny. Because let's face it: dating from whenever it was, exactly, that the first gearset was improvised—the fairer sex has definitely gotten the short end of the addendum.

But no longer—and we have two worthy representatives on record here to tell you why: **Robin Olson,** sustaining engineering manager/gear group, Rexnord Corp., and **Jane Muller** of Geartech.

Jane Muller's supervisory skills were developed at an early age, as a look at this job site clearly demonstrates.

Not unlike the boys on the block, both women had to know how things worked at an early age—regardless of their inspiration.

"My parents are the type of people who develop an interest in a topic and then seek to learn as much as they can about it," says Olson. "When I was young, there was always a Heathkit project or box of old radio parts somewhere in the house. In fact, my dad built our first computer—the Heathkit H89."

Muller "was always interested in how things work," copping to having "many non-traditional girl toys, including trains, cars, Legos, erector sets, and Lincoln logs. I wanted to take (high school) shop, drafting, or woodworking classes, but was not allowed."

In becoming an engineering gearhead, there was no dramatic epiphany, but more of an evolving. "I was convinced I wanted to program computers until I took physics as a junior in high school," Olson conceded. "That got me interested in forces, motion, and energy; I selected marine engineering as a (college) major.

As for Muller, she was a twenty-something working as an assistant in the occupational therapy department of a large hospital in San Francisco. With her learned mechanical skills a major asset, she "became the person who fixed equipment and created adaptive devices for patients." Having also "worked with amputees using then-state-of-the-art myo-electric prosthetics," one thing led to another—including a fateful conversation with a colleague—and "within weeks, I had applied to San Francisco State University (SFSU) and was accepted. I had no inkling of what I was getting into. The SFSU engineering department was a unique environment; there was a peak in enrollment of women in engineering at that time and there were many older re-entry students with very diverse backgrounds. I felt I had the support of other students and the instructors and staff. However, there were some instances of discrimination and inappropriate behavior, based on gender and ethnicity. For my part, I either handled these situations personally or worked my way around them.

"Trail blazers"—whatever the "trail"—are often in for a rough ride. Women breaking into male-dominated industries are often no exception, and do so at risk of humiliation and or failure if not given a fair shake to succeed. But not these two, apparently. Take workplace hazing, for example.

"If I have (been hazed), I've never noticed it," said Olson. As long as someone is willing to listen, learn, and contribute their ideas, gender hasn't been an issue."

While for Muller, "Working in geriatrics with mainly male patients, I believe that background, and my empathetic nature, have made working in a male-dominated field easier. (But) there have been a few instances of harassment during my work career. Some of these I handled myself by remaining professional and successfully defending myself with technical arguments. One instance, at a factory in Europe, was dealt with by the co-workers of the inappropriate person, and the matter was resolved to my satisfaction. In another instance, my employer stepped in and action was taken by the supervisor of the person involved. The matter was resolved to my satisfaction.

And what of job interviews? What were those like?

"They get easier with experience," says Olson. "I remember one where I was asked, "You have heard of thermodynamics, haven't you?" It was right after college and my resume was very thin."

I've been able to add some accomplishments since then.

It has been different for Muller—in a good way. "My work situation is, and

"That need for a mentor is continuous in a technical career; as we grow our experience, we seek out advice from others who have already had those experiences."

Robin Olson, Rexnord Corp

always has been, unique. I maintained contact with a few of (my) professors. I approached (former SFSU professor) (and longtime *Gear Technology* Technical Editor) Robert Errichello for advice on job hunting. At the time, he needed immediate part time help, so he hired me on a very temporary basis while I searched for a full-time job. That was > 30 years ago. Therefore, I was spared the stress of the job interview process.

Mentoring is a priceless form of on-the-job "coaching" that is hard enough to find today for even the sharpest young lad on the floor. With so few women in the gear world — in either the executive or hands-on part of the business — it has to be even tougher. Unless you get lucky; both of our subjects would be the first to say they got *damn* lucky.

Olson: "I am fortunate to have started my career at Falk. When I started, Falk had one female engineer and she had been with the company for around 30 years. I was hired as her understudy and the mentoring came with the job. My boss at the time, Mike Antosiewicz, also put me on projects that interacted with some great gear engineers at Falk and in AGMA — people like John Lisiecki and Don McVittie*. I asked a lot of questions and they were all willing to share their knowledge. That need for a mentor is continuous in a technical career; as we grow our experience, we seek out advice from others who have already had those experiences. (**The late Don McVittie was also a longtime Gear Technolgy Technical Editor*.)

"Friends and mentors are indispensable — while in school and during your career," says Muller. "Mentors inspire you to grow and continue learning. I would suggest looking for people who are eager to join group projects or are willing to volunteer for special projects. If you have a specific interest, find a person who is interested in that subject. Determine if they have a history of mentoring and talk with them."

And when asked if they'd recommend a career in mechanical engineering to their daughters, nieces, nephews — whomever — well, you know their answer.

"Yes, absolutely!" said Olson. "In order to innovate, we need to get young people interested in technology and make it rewarding for them to participate in engineering careers. My experience in engineering has been positive because previous generations of female engineers and scientists paved the way. I admire their perseverance and courage."

"I would never hesitate to recommend engineering as a career choice," Muller concurs. She in fact volunteers at a children's science museum where they hold annual women-oriented STEM events in all areas of science, technology, and mathematics. Muller led a session on gear failure analysis last year and "had a large turnout of interested girls. This year I'm planning to do a Geartech vendor table and hope to reach a larger cross-section of girls in a different venue."

2014 State of the Gear Industry

Reader Survey Results

Gear Technology's annual State-of-the-Gear-Industry survey polls gear manufacturers about the latest trends and opinions relating to the overall health of the gear industry.

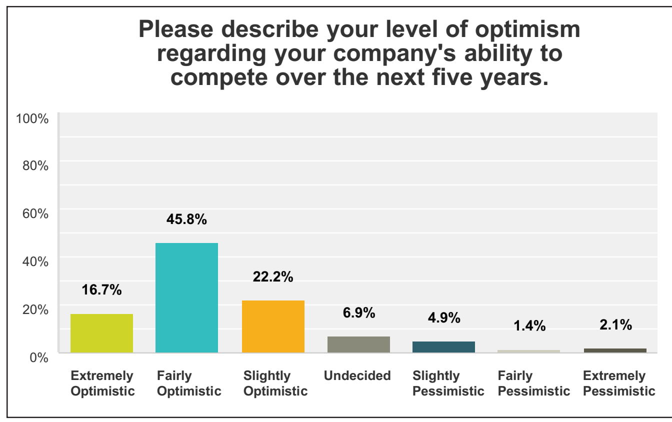
As in years past, the survey was conducted anonymously, with invitations sent by e-mail to gear manufacturing companies around the world.

More than 300 individuals responded to the online survey, answering questions about their manufacturing operations and current challenges facing their businesses. All of the responses included in these results come from individuals who work at locations where gears, splines, sprockets, worms and similar products are manufactured. They work for gear manufacturing job shops, captive shops at OEMs and end user locations.

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

Gear Industry Optimism – Depends on Where You Are

Over the past nine years, approximately 89% of respondents indicated some level of optimism regarding their companies' ability to compete. This year trended slightly downward, with only about 85% indicating optimism. However, there was a wide disparity in optimism depending on where the respondent was from. Within North America, optimism ranked slightly higher than average, at 90%. Outside North America, optimism was decidedly lower, at 80%.



Significant Challenges

Across the board, our respondents indicated pressure to meet customer demands for higher quality, reduced lead times and new products, all while struggling to maintain engineering and skilled production capacity.

"Improving quality and on time delivery ."

"Uncertainty of receiving planned orders."

"Fewer production people, more engineering capacity."

"Productivity and quality."

"New transmission implementation."

"Internal costs."

"To meet customers' increasing quality requirements."

"Market conditions."

"New product development ."

"Skilled labor and rising energy taxes/costs."

"Implement aerospace mentality."

"Skill for new products."

"Meet growing demand, diversify into more products."

"Shorten lead times."

"Volume increase through new products."

"Engineering ."

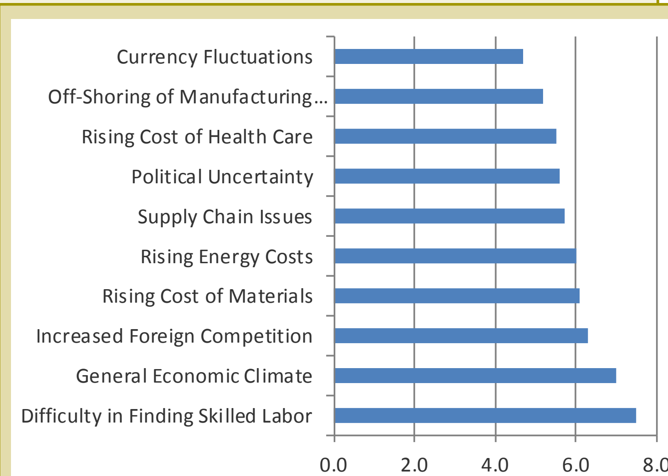
"Handling complexity."

"Technology upgrades and cost reductions."

"Create higher efficiency products, reduce development time to market, develop more modular products."

"Marketing to new customers."

"Develop new PM techniques."



Significance of each challenge was rated from 1-10, with 10 being the most significant. Average weighted values are represented here.

"Justifying investment for new equipment. Determining payback thresholds."

"New investments in updated technologies."

"Reduce lead times."

"Increasing capacity and capability."

"Introduction of new processes."

"Quality control."

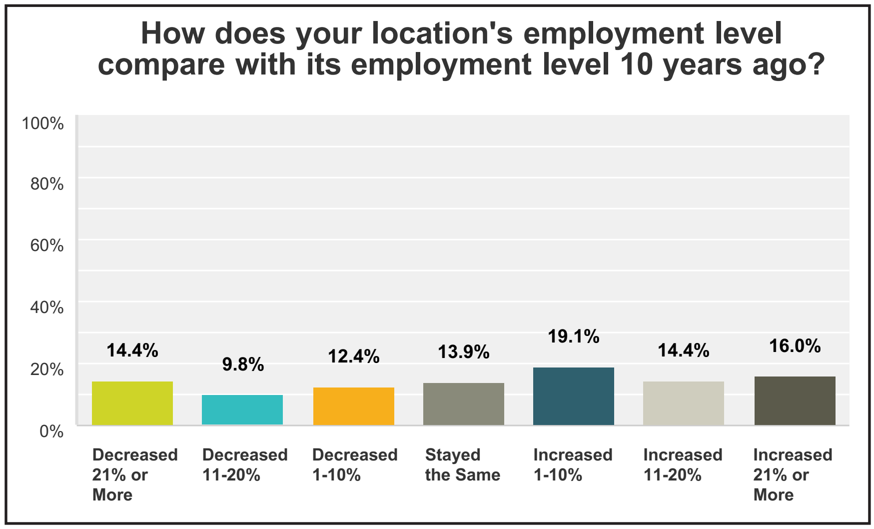
"Productivity."

"Increasing production while training new staff."

"Introducing two new gearbox lines."

Employment

Gear industry employment was very stable in 2014, with 40% of respondents indicating no change in their company's number of employees, and nearly equal numbers reporting increased (32.4%) and decreased (27.6%) employment. However, gear industry respondents have a fairly positive outlook toward 2015, with 87.5% indicating they believe that employment levels will either remain the same or increase.



Why Did Your Employment Level Increase?

"Expansion of manufacturing facility."

"Business picking up and new customers."

"Increase in volumes."

"Improved car sales require more automatic transmissions."

"Surge in demand and aftermarket parts."

"Business was slow in second quarter, but picked up in third and fourth quarters."

"Production demand increased."

"Large increase in new multi-year orders."

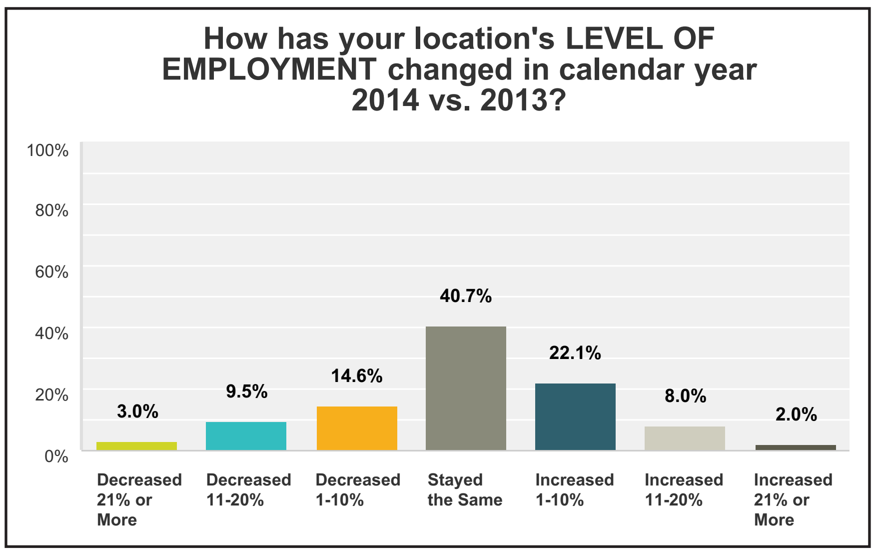
"Staff level was very low in 2013."

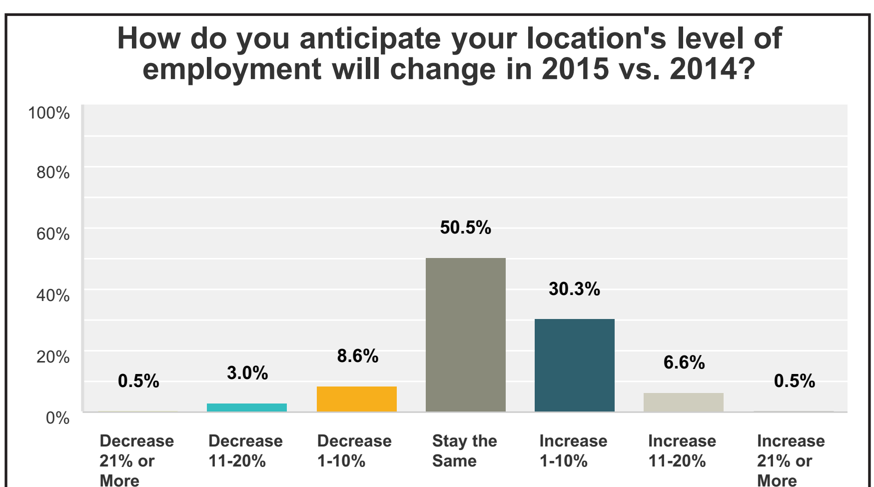
"Building for future growth."

"Increase in demand for natural gas fracking equipment."

"We were understaffed the previous year."

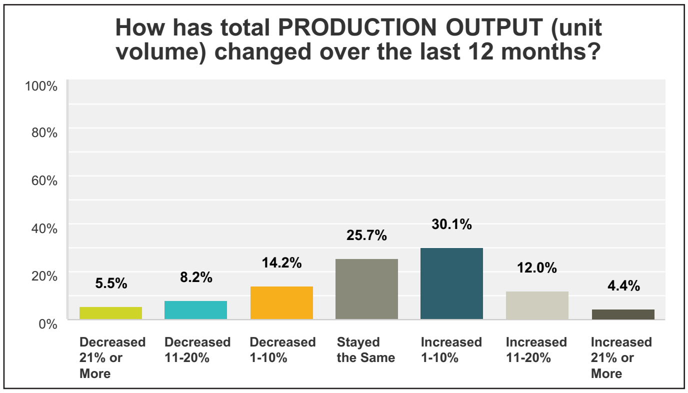
"Increased business from existing customers along with new business from new customers."

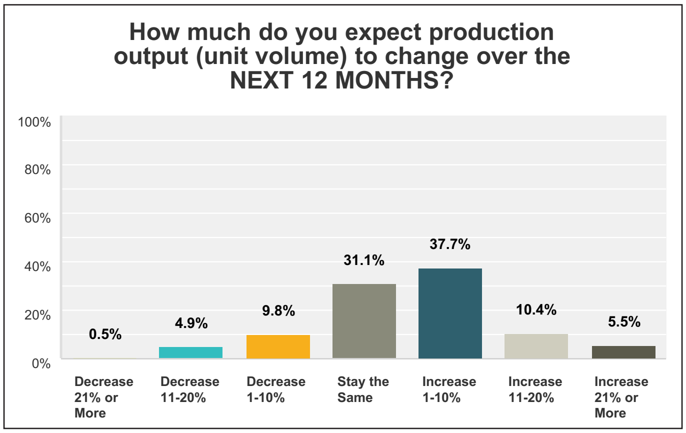




Production Output

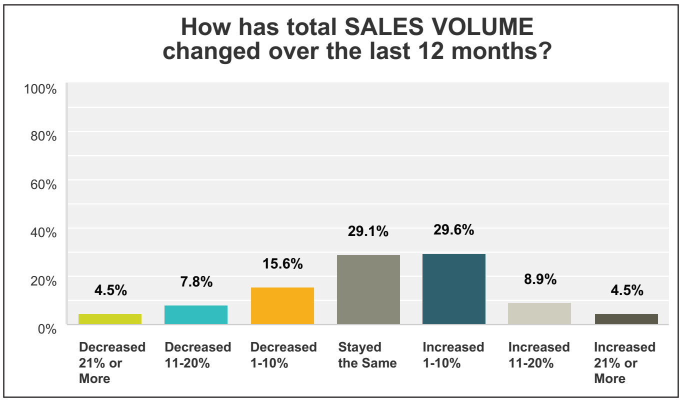
Most gear manufacturers (71.7%) either maintained or grew their production output in 2014, while 28.3% indicated a decrease in output this year. But the future looks a little bit brighter, with only 15.5% expecting decreased production in 2015, and more than half (54.2%) expecting increased production levels next year.

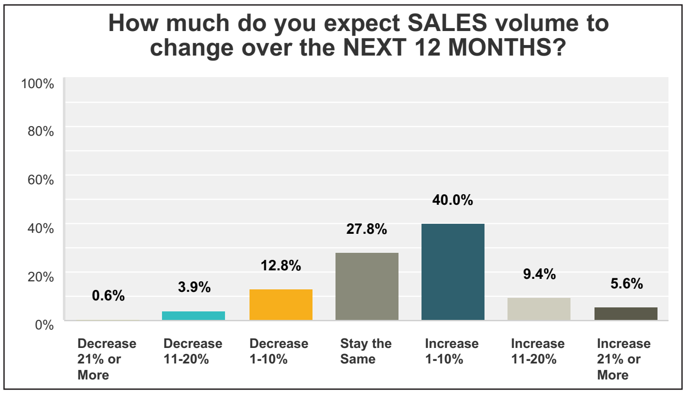




Sales Volume

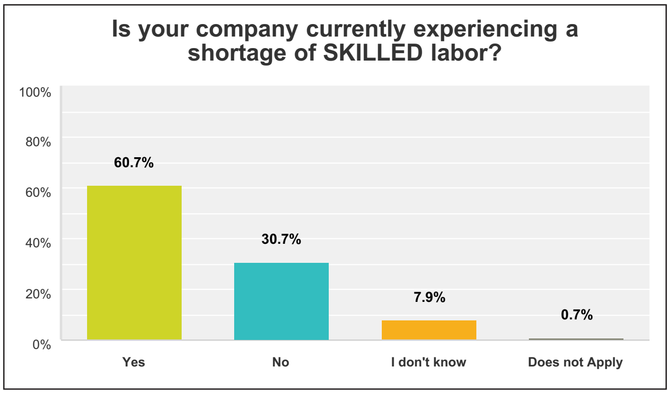
Gear manufacturers are even more optimistic with regards to sales volume than with employment or production levels. After a year that saw 42% of respondents experience increased sales, 55.8% are expecting an increase in sales for 2015.

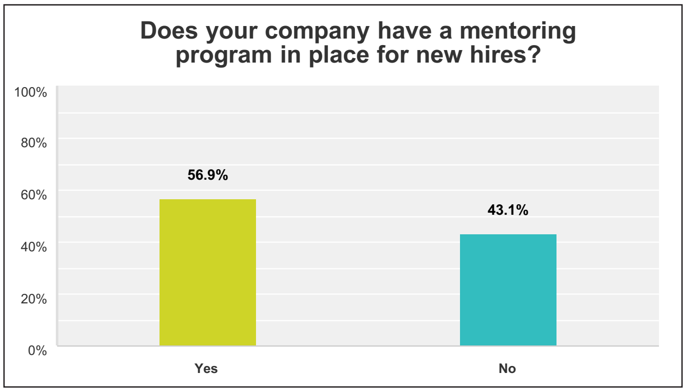




Skilled Labor

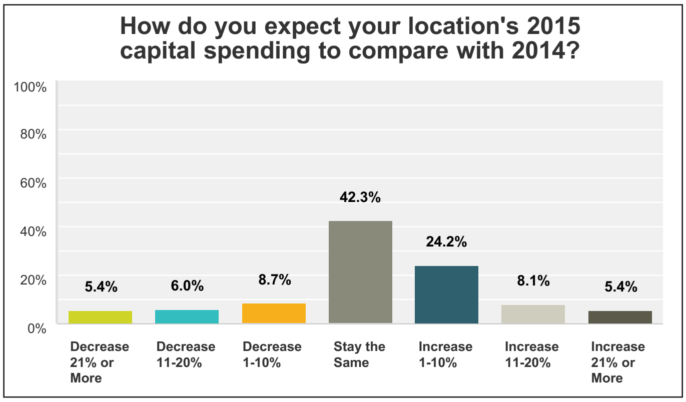
The difficulty in finding and keeping skilled labor remains one of the most significant challenges facing the gear industry. According to our respondents, the issue confronts gear manufacturers throughout their organizations, with shop floor and engineering workers the most difficult areas to fill. Although the majority of respondents (58.7%) reported a shortage of skilled labor, this number is lower than last year. 66% reported a shortage of skilled labor in 2013.

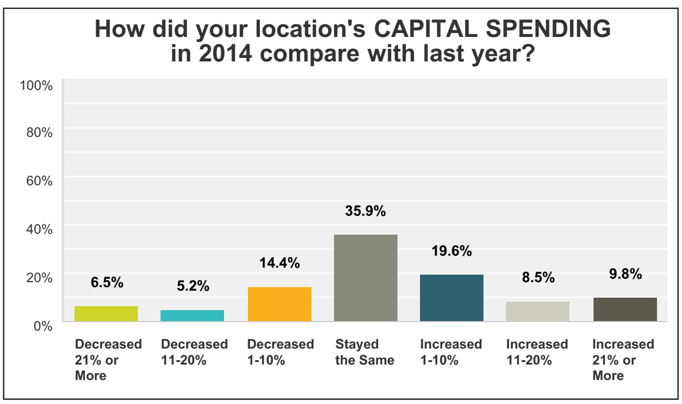


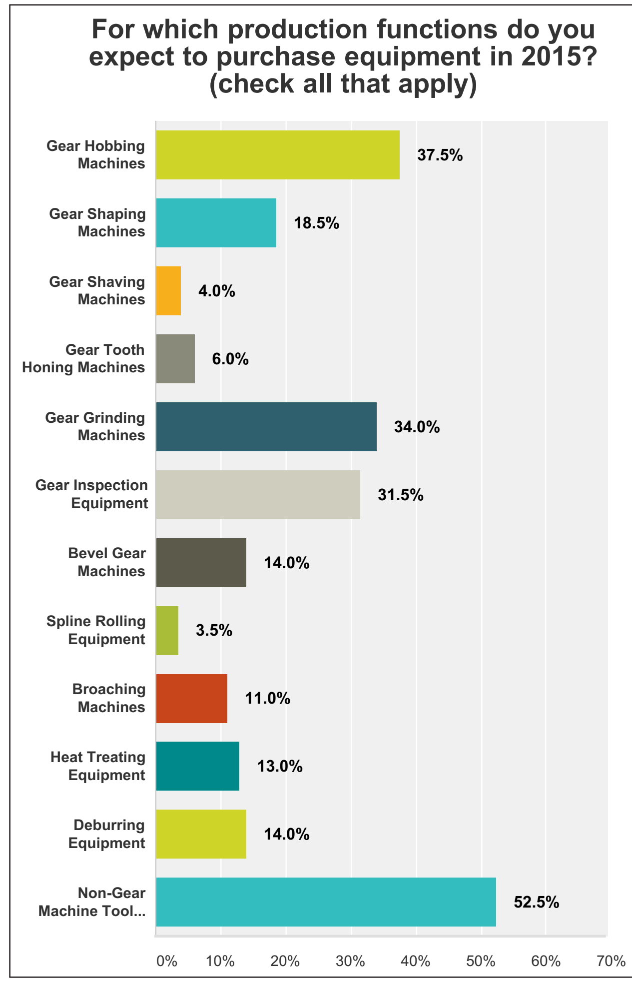


Capital Spending

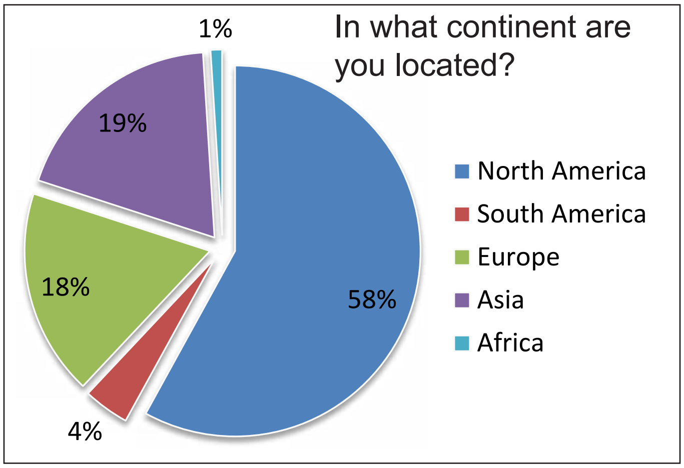
82% of respondents work at locations that spent more than $100,000 on capital equipment in 2014.
43% work at locations that spend more than $1 million.
26% of respondents' companies spent less than last year.
38% of respondents' companies spent more.
80% of respondents expect to spend the same as 2014 or more in 2015

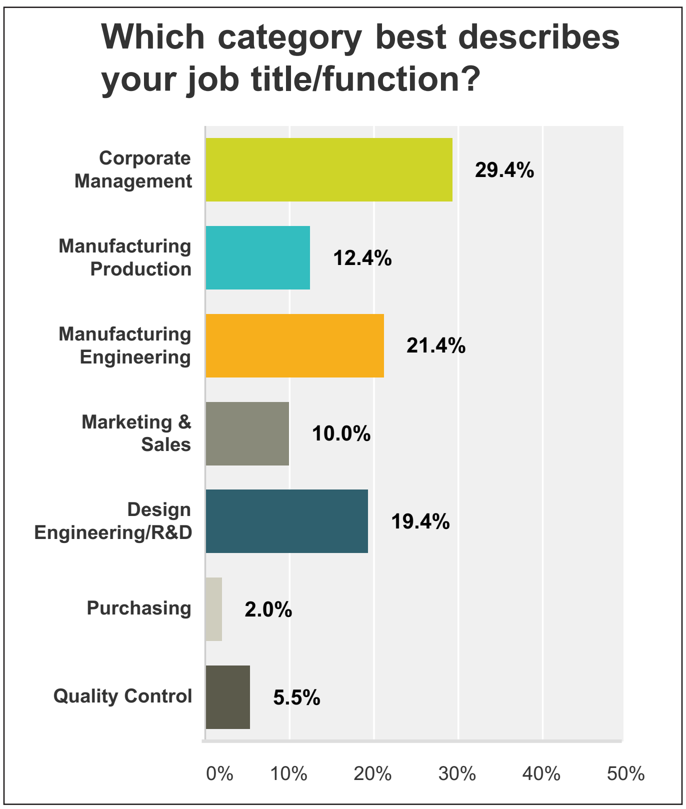


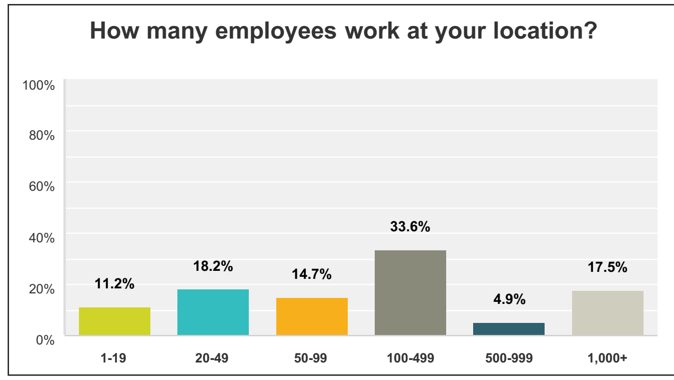


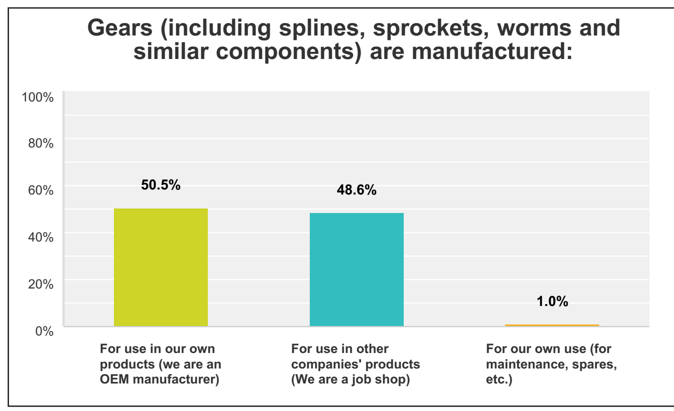


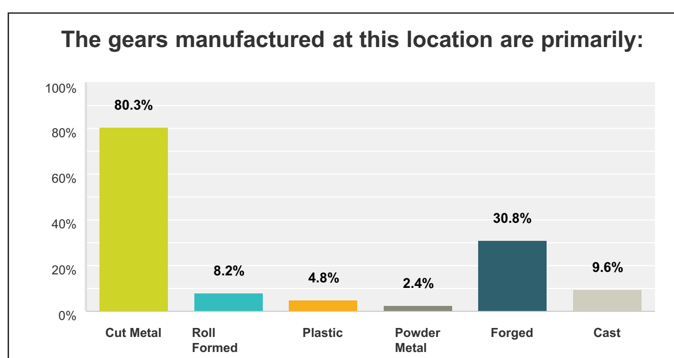
Demographics

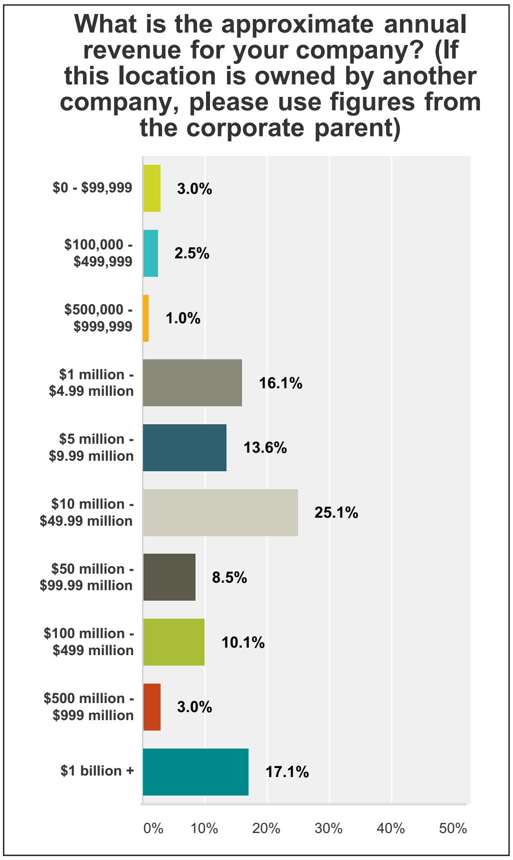


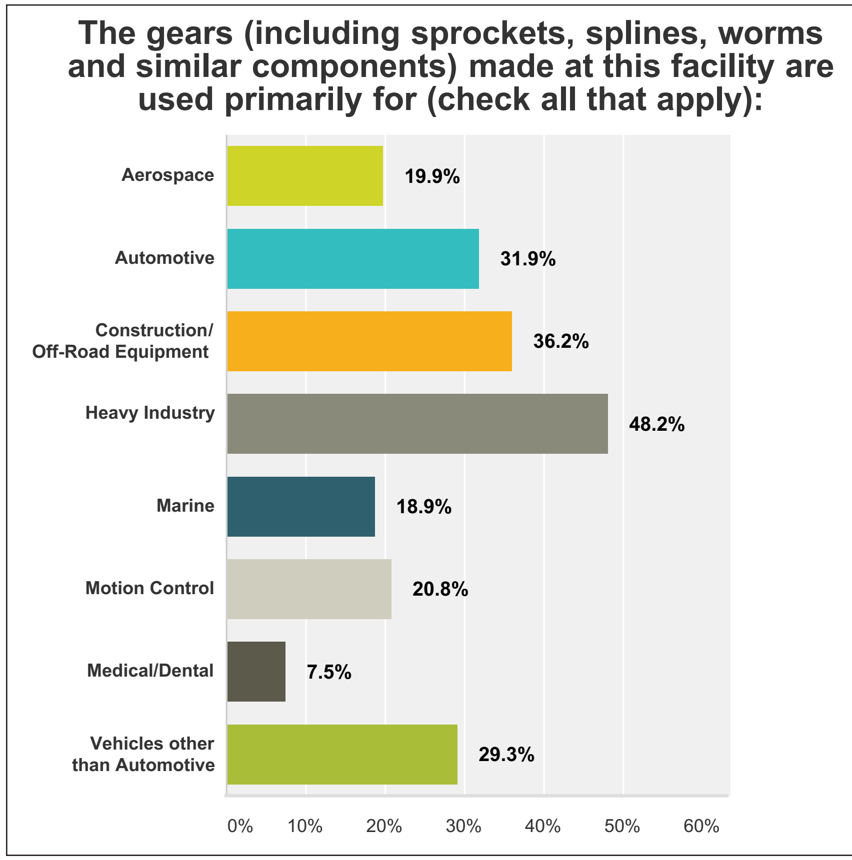









What is the approximate annual revenue for your company? (If this location is owned by another company, please use figures from the corporate parent)
$0 - $99,999
3.0%
$100,000 - $499,999
2.5%
$500,000 - $999,999
1.0%
$1 million - $4.99 million
16.1%
$5 million - $9.99 million
13.6%
$10 million - $49.99 million
25.1%
$50 million - $99.99 million
8.5%
$100 million - $499 million
10.1%
$500 million - $999 million
3.0%
$1 billion +
17.1%
0%
10%
20%
30%
40%
50%


The gears (including sprockets, splines, worms and similar components) made at this facility are used primarily for (check all that apply):
Aerospace
19.9%
Automotive
31.9%
Construction/ Off-Road Equipment
36.2%
Heavy Industry
48.2%
Marine
18.9%
Motion Control
20.8%
Medical/Dental
7.5%
Vehicles other than Automotive
29.3%
0%
10%
20%
30%
40%
50%
60%

About This Directory

The 2014 *Gear Technology* Buyers Guide was compiled to provide you with a handy resource containing the contact information for significant suppliers of machinery, tooling, supplies and services used in gear manufacturing.

Bold Listings throughout the Buyers Guide indicate that a company has an advertisement in this issue of Gear Technology.

But Wait! Where are the Gear Manufacturers Listed?

If you are looking for suppliers of gears, splines, sprockets, gear drives or other power transmission components, see our listing of this issue's power transmission component advertisers on page 51. In addition, you will find our comprehensive directory in the December 2013 issue of Power Transmission Engineering as well as in our online directory at *www.powertransmission.com.*

Handy Online Resources

The Gear Industry Buyers Guide – The listings printed here are just the basics. For a more comprehensive directory of products and services, please visit our website, where you'll find each of the categories here broken down into sub-categories: *www.geartechnology.com/dir/*

The Power Transmission Engineering Buyers Guide – The most comprehensive online directory of suppliers of gears, bearings, motors, clutches, couplings, gear drives and other mechanical power transmission components, broken down into sub-category by type of product manufactured: *www.powertransmission.com/directory/*

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How to Get Listed in the Buyers Guide

Although every effort has been made to ensure that this Buyers Guide is as comprehensive, complete and accurate as possible, some companies may have been inadvertently omitted. If you'd like to add your company to the directory, we welcome you. Please visit www.geartechnology.com/getlisted.php to fill out a short form with your company information and Buyers Guide categories. These listings will appear online at *www.geartechnology.com,* and those listed online will automatically appear in next year's printed Buyers Guide

CUTTING TOOLS

2L Inc.
300 Below, Inc.
A.L. Tooling cc
ANCA, Inc.
Accu-Cut Diamond Tool Co.
Acedes Gear Tools
Addison & Co. Ltd.
Advico
Ajax Tool Supply
Alliance Broach & Tool
Allied Machine & Engineering Corp.
American Broach & Machine Co.
American Gear Tools
Anderson Cook Inc.
Apex Broaching Systems
Apollo Broach, Inc.
Ash Gear & Supply
Banyan Global Technologies LLC

Broach Masters / Universal Gear Co. SEE OUR AD P17
1605 INDUSTRIAL DRIVE, AUBURN, CA 95603
Phone: (800) 563-3442
Fax: (530) 885-8157
sales@broachmasters.com
www.broachmasters.com

Broaching Machine Specialties
Canada Broach
Capital Tool Industries
Carbide Tool Services, Inc.
Carborundum Universal Ltd.
Ceramtec North America
Cold Forming Technology
Colonial Tool Group
Comco Inc.
Continental Diamond Tool Corporation
D.C. Morrison Company

DTR Corp. (formerly Dragon Precision Tools) SEE OUR AD P76
1865A HICKS ROAD
ROLLING MEADOWS, IL 60008
Phone: (847) 375-8892
Fax: (224) 220-1311
alex@dragon.co.kr
www.dragon.co.kr

Dathan Tool & Gauge Co. Ltd.
ESGI Tools Pvt. Ltd.
Eltool Corp.
Eltro Services, Inc.
Emuge Corp.
Engineered Tools Corp.
Fässler by Daetwyler Industries
Fangyuan Ringlike Forging & Flange Co., Ltd.
Federal Broach & Machine
Friedrich Gloor Ltd.
Fuji Machine America Corp.
Galaxy Sourcing Inc.
General Broach Company
German Machine Tools of America

Gleason Corporation SEE OUR AD P52-53
1000 UNIVERSITY AVENUE
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Fax: (585) 461-4348
sales@gleason.com
www.gleason.com

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1351 WINDSOR RD., LOVES PARK, IL 61111
Phone: (815) 877-8900
Fax: (815) 877-0264
gctc@gleason.com
www.gleason.com

Goldstein Gear Machinery LLC SEE OUR AD P102-103
1840 JARVIS AVENUE
ELK GROVE VILLAGE, IL 60007
Phone: (847) 437-6605
Fax: (847) 437-6618
michael@goldsteingearmachinery.com
www.goldsteingearmachinery.com

Great Lakes Gear Technologies, Inc.
Greg Allen Company
Guven Bronz Metal
Hanik Corporation
Hanro Tools Incorporation
HobSource Inc.
Huff Carbide Tool

Ingersoll Cutting Tools SEE OUR AD P43,45,47,49
845 S. LYFORD ROAD
ROCKFORD, IL 61108-2749
Phone: (815) 387-6600
Fax: (815) 387-6337
info@ingersoll-imc.com
www.ingersoll-imc.com

Inland Broaching and Tool Company
International Tool Machines (ITM)
Interstate Tool Corp.

J. Schneeberger Corp. SEE OUR AD P37,44,45
1380 GATEWAY DRIVE, UNIT #8
ELGIN, IL 60123
Phone: (847) 888-3498
Fax: (847) 888-3665
rolf@schneeberger-us.com
www.schneeberger-us.com

Kennametal Inc.
Khemka Broach & Spline Gauge
Kinefac Corporation

Klingelnberg AG SEE OUR AD BACK COVER
BINZMÜHLESTRASSE 171, CH-8050 ZURICH
SWITZERLAND
Phone: +(41) 44-2787979
Fax: +(41) 44-2781594
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www.klingelnberg.com

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www.klingelnberg.com

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GERMANY
Phone: +(49) 2192-810
Fax: +(49) 2192-81200
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www.klingelnberg.com

Knuth Machine Tools USA, Inc.
Koepfer America, LLC
LMT USA
Lalson Tools Corporation
Leistritz Corporation

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Fax: (734) 429-2294
info@liebherr.com
www.liebherr.com

Liebherr-Verzahntechnik GmbH SEE OUR AD P5
KAUFBEURER STRASSE 141, D-87437 KEMPTEN
GERMANY
Phone: +(49) 831-786-0
Fax: +(49) 831-7861279
info.lvt@liebherr.com
www.liebherr.com

Longevity Coatings

Luren Precision Chicago SEE OUR AD P21
707 REMINGTON RD., SUITE 1
SCHAUMBURG, IL 60173
Phone: (847) 882-1388
Fax: (847) 882-1933
sales@lurenusa.com
lurenusa.com

Machine Tool Solutions, Inc.
Maheen Enterprises
Maxwell Tools Co. USA
Maxwell Tools Company
Miller Broach

Mitsubishi Heavy Industries America SEE OUR AD P8
MACHINE TOOL DIVISION
46992 LIBERTY DRIVE, WIXOM, MI 48393
Phone: (248) 669-6136
Fax: (248) 669-0614
sales@mitsubishigearcenter.com
www.mitsubishigearcenter.com

Mitsubishi Materials USA
Modern Gearing
Mutschler Edge Technologies
Nachi America Inc.
Norton | Saint-Gobain
ORT Italia
Ohio Broach & Machine Co.
PDM Engineering Pvt. Ltd.
Parker Industries Inc.
Philadelphia Carbide Co.
Pioneer Broach Co.
Polygon Solutions
QC American
R.A. Heller
Razorform Tools
Roto-Flo / U.S. Gear Tools
Russell Holbrook & Henderson
S.S.Tools
SU (Shanghai) Machine & Tools Co., Ltd.
Saazor
Samputensili S.p.A.

Sandvik Coromant SEE OUR AD P75
1702 NEVINS ROAD, FAIR LAWN, NJ 07410
Phone: (201) 794-5000
Fax: (201) 794-5257
us.coromant@sandvik.com
www.sandvik.coromant.com/us

Schnyder SA SEE OUR AD P97
JAKOBSTRASSE 52, CH-2504 BIEL
SWITZERLAND
Phone: +(41)(32) 344-0406
Fax: +(41)(32) 344-0404
george.boon@schnyder.com
www.schnyder.com

Schunk Inc.
Seco Tools Inc.
Shape-Master Tool Company
Slater Tools Inc.
Slone Gear International, Inc
Star Cutter Co.

Star SU LLC SEE OUR AD IFC-1, 103
5200 PRAIRIE STONE PARKWAY, SUITE 100
HOFFMAN ESTATES, IL 60192
Phone: (847) 649-1450
Fax: (847) 649-0112
sales@star-su.com
www.star-su.com

Steelmans Broaches Pvt. Ltd.
Super Hobs & Broaches Pvt. Ltd.
Superabrasivi

TMFM LLC
TSA America, LLC
Tazz Broach & Machine, Inc.
Techcellence
Ty Miles Inc.
U.S. Equipment
U.S. Gear Tools
United Broach Company
United Tool Supply Ltd.
V W Broaching Service, Inc.
Vargus USA
Walter USA, LLC
Watkins Mfg. Inc.
West Michigan Spline, Inc.
Wolverine Broach Co., Inc.
Yash International
Yuvraj Tools & Forgings

GEAR BLANKS & RAW MATERIAL

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A. Finkl & Sons Co.
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Ajax Rolled Ring and Machine
Aksan Steel Forging

All Metals & Forge Group, LLC SEE OUR AD P14,37,38
75 LANE RD, FAIRFIELD, NJ 07004
Phone: (973) 276 5000
Fax: (973) 276 5050
laweiss@steelforge.com
www.steelforge.com

American Friction Welding
Anihas Castings
ArcVac ForgeCast Ltd.
Autoparts Solutions Pvt. Ltd.
Balaji Thermotech India Private Limited
Bhandari Precision Forgings Pvt. Ltd.
Bharat Forge Ltd.
Bohler High Performance Metals Pvt. Ltd.
Bohler-Uddeholm Corporation
Boltex Manufacturing
Brooker Bros. Forging Co.
C.E. Sweeney & Associates
Canton Drop Forge
Castalloy
Celanese
Clifford-Jacobs Forging
Concast Metal Products
Cornell Forge
Crucible Industries LLC
DECO Products Company LLLP
DSM Engineering Plastics
Dayton Forging and Heat Treating
DuPont
Dura-Bar
Earle M. Jorgensen Co.
ElectroHeat Induction
Ellwood City Forge
Erasteel Inc.

Excel Gear SEE OUR AD P11
11865 MAIN STREET, ROSCOE, IL 61073
Phone: (815) 623-3414
Fax: (815) 623-3314
Chinn@excelgear.com
www.excelgear.com

Fangyuan Ringlike Forging & Flange Co., Ltd.

Forging Solutions LLC
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Galaxy Sourcing Inc.
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Lalson Tools Corporation
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Lefere Forge
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Martin Tool & Forge
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Maxplus Enterprise
Maxwell Tools Co. USA

McInnes Rolled Rings SEE OUR AD P13,38
1533 EAST 12TH STREET, ERIE, PA 16511
Phone: (800) 569-1420 or (814) 459-4495
Fax: (814) 459-8443
sales@mcrings.com
mcinnesrolledrings.com

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Parag Casting Co.
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Presrite Corporation SEE OUR AD P51
3665 E. 78TH STREET, CLEVELAND, OH 44105
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Ralf Schaffer
Reade Advanced Materials
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Scot Forge
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Shree Krishna Auto Indsutries
Southwest Metal Products Ltd.
Spectrum Machine Inc.
Steuby Manufacturing Company, Inc.
Sunbelt-Turret Steel. Inc.
TimkenSteel Corporation
UMC - United Metals Co.
United Cast Bar, Inc.
Viking Forge
Walker Forge
Watkins Mfg. Inc.
Welland Forge
Willman Industries Inc.
Yarde Metals
Yash International

GEAR MACHINES

ANCA, Inc.
Abtex Corp.
Accu-Cut Diamond Tool Co.
Acme Manufacturing Co.
Advico
Allen Adams Shaper Services, Inc.
Alliance Broach & Tool
American Broach & Machine Co.
Anderson Cook Inc.
Apex Broaching Systems
Banyan Global Technologies LLC
Barber-Colman, Div of Bourn & Koch
Bates Technologies Inc.
Becker GearMeisters, Inc.
Bourn & Koch Inc.
Broaching Machine Specialties
C & B Machinery
Capital Tool Industries
Chamfermatic Inc.
Cleveland Deburring Machine Co.
Colonial Tool Group
Comco Inc.
D.C. Morrison Company
Danobat Machine Tool Co. Inc.
Donner+Pfister AG
Drake Manufacturing Services Co. Inc.
Dreamtec Consulting LLC
EMAG LLC
Electronics Inc.
Eltro Services, Inc.
Engineered Abrasives
Engis Corporation
Erwin Junker Machinery, Inc.
Fässler by Daetwyler Industries
FFG - MODUL
Federal Broach & Machine
Fellows Machine Tools
Felsomat USA Inc.
Fuji Machine America Corp.
Gear Consulting Group
Gearspect s.r.o.
General Broach Company
Georg Kesel GmbH & Co. KG
German Machine Tools of America

Gleason Corporation SEE OUR AD P52-53
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Phone: (585) 473-1000
Fax: (585) 461-4348
sales@gleason.com
www.gleason.com

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1351 WINDSOR RD., LOVES PARK, IL 61111
Phone: (815) 877-8900
Fax: (815) 877-0264
gctc@gleason.com
www.gleason.com

Goldstein Gear Machinery LLC SEE OUR AD P102-103
1840 JARVIS AVENUE
ELK GROVE VILLAGE, IL 60007
Phone: (847) 437-6605
Fax: (847) 437-6618
michael@goldsteingearmachinery.com
www.goldsteingearmachinery.com

Great Lakes Gear Technologies, Inc.
Greg Allen Company
Höfler - A Brand of Klingelnberg
Haas Multigrind LLC
Hamai Co. Ltd.
Hanik Corporation
Hanro Tools Incorporation

Hans-Juergen Geiger Maschinen-Vertrieb GmbH
JAMES-WATT-STRASSE 12, D-72555 METZINGEN
GERMANY
Phone: +(49) 7123-18040
Fax: +(49) 7123-18384
geiger@geiger-germany.com
www.geiger-germany.com
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Hartech
HOTA INDUSTRIAL MFG. CO. LTD
16 KEYA ROAD, DAYA TOWNSHIP
TAICHUNG 4281
TAIWAN ROC
Phone: +(886) 4-25604141
Fax: +(886) 4-25609591
www.hartech.com.tw
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Heller Machine Tools
IMEXSU Group
ITW Heartland
Index Corporation
International Tool Machines (ITM)
Involute Gear & Machine Company

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1380 GATEWAY DRIVE, UNIT #8
ELGIN, IL 60123
Phone: (847) 888-3498
Fax: (847) 888-3665
rolf@schneeberger-us.com
www.schneeberger-us.com
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JRM International, Inc
James Engineering
KGK International Corp.

Kapp Technologies
2870 WILDERNESS PLACE, BOULDER, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131
sales@kapp-usa.com
www.kapp-usa.com
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Khemka Broach & Spline Gauge
Kinefac Corporation

Klingelnberg AG
BINZMÜHLESTRASSE 171, CH-8050 ZURICH
SWITZERLAND
Phone: +(41) 44-2787979
Fax: +(41) 44-2781594
info@klingelnberg.com
www.klingelnberg.com
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118 E. MICHIGAN AVENUE, SUITE 200
SALINE, MI 48176
Phone: (734) 470-6278
Fax: (734) 316-2158
KLA.info@klingelnberg.com
www.klingelnberg.com
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GERMANY
Phone: +(49) 2192-810
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www.klingelnberg.com
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Lambda Technologies
Leistritz Corporation

Liebherr America
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Fax: (734) 429-2294
info@liebherr.com
www.liebherr.com
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KAUFBEURER STRASSE 141, D-87437 KEMPTEN
GERMANY
Phone: +(49) 831-786-0
Fax: +(49) 831-7861279
info.lvt@liebherr.com
www.liebherr.com
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707 REMINGTON RD., SUITE 1
SCHAUMBURG, IL 60173
Phone: (847) 882-1388
Fax: (847) 882-1933
sales@lurenusa.com
lurenusa.com
SEE OUR AD P21

MPT Manufacturing Process Technologies

Machine Tool Builders
7723 BURDEN ROAD
MACHESNEY PARK, IL 61115
Phone: (815) 636-7502
Fax: (815) 636-5912
aminer@machinetoolbuilders.com
www.machinetoolbuilders.com
SEE OUR AD P4

Mazak Corporation

Mitsubishi Heavy Industries America
MACHINE TOOL DIVISION
46992 LIBERTY DRIVE, WIXOM, MI 48393
Phone: (248) 669-6136
Fax: (248) 669-0614
sales@mitsubishigearcenter.com
www.mitsubishigearcenter.com
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Nachi America Inc.
Nagel Precision
Normac, Inc.
ORT Italia
Ohio Broach & Machine Co.
Okuma America Corporation
PTG Holroyd
Parker Industries Inc.
Pegard Productics Division HARO

Pentagear Products
12955 YORK DELTA DRIVE, SUITE 1
NORTH ROYALTON, OH 44133
Phone: (330) 421-0420
mnicholson@pentagear.com
pentagear.com
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Precision Finishing Inc.
Preco Inc.
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Redin Production Machine
Reishauer AG
Reishauer Corporation
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Russell Holbrook & Henderson
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SU (Shanghai) Machine & Tools Co., Ltd.
Saacke North America, LLC
Samputensili S.p.A.
SerWeMa GmbH & Co. KG
Sinto Surface Treatment
Slone Gear International, Inc
Star Cutter Co.

Star SU LLC
5200 PRAIRIE STONE PARKWAY, SUITE 100,
HOFFMAN ESTATES, IL 6019
Phone: (847) 649-1450
Fax: (847) 649-0112
sales@star-su.com
www.star-su.com
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Steelmans Broaches Pvt. Ltd.
Stenhoj Broaching Machines
Sunnen Products Company
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Surface Finishing Equipment Co.
Surplex GmbH
TECO Werkzeugmaschinen GmbH & Co.
Tazz Broach & Machine, Inc.
Tianjin No.1 Machine Tool Works
Toolink Engineering
Ty Miles Inc.
U.S. Equipment
U.S. Gear Tools
Ultramatic Equipment Co.
Vermont Machine Tool
WARDJet
West Michigan Spline, Inc.
Westminster Machine Tools Ltd.
Wheelabrator Group
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GRINDING WHEELS/ABRASIVE TOOLS

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3M Abrasives
3M CENTER, ST. PAUL, MN 55144-1000
Phone: (888) 364-3577
www.3m.com/Abrasives
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Ajax Tool Supply
Alliance Broach & Tool
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Bates Technologies Inc.
Brighton Laboratories
CGW - Camel Grinding Wheels
Carborundum Universal Ltd.
Cleveland Deburring Machine Co.
Comco Inc.
Continental Diamond Tool Corporation

DTR Corp. (formerly Dragon Precision Tools)
1865A HICKS ROAD
ROLLING MEADOWS, IL 60008
Phone: (847) 375-8892
Fax: (224) 220-1311
alex@dragon.co.kr
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Diamond Abrasive Products
Dianamic Abrasive Products Inc.
Dr. Kaiser Diamantwerkzeuge
ESGI Tools Pvt. Ltd.
Engis Corporation
Fässler by Daetwyler Industries
FFG - MODUL
Gear Resource Technologies Inc.

Gleason Corporation
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Hermes Abrasives Ltd.
Huff Carbide Tool
IMEXSU Group
Interstate Tool Corp.
Involute Gear & Machine Company

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ELGIN, IL 60123
Phone: (847) 888-3498
Fax: (847) 888-3665
rolf@schneeberger-us.com
www.schneeberger-us.com

JRM International, Inc

Kapp Technologies SEE OUR AD P3
2870 WILDERNESS PLACE, BOULDER, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131
sales@kapp-usa.com
www.kapp-usa.com

Klingelnberg AG SEE OUR AD BACK COVER
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SWITZERLAND
Phone: +(41) 44-2787979
Fax: +(41) 44-2781594
info@klingelnberg.com
www.klingelnberg.com

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SALINE, MI 48176
Phone: (734) 470-6278
Fax: (734) 316-2158
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www.klingelnberg.com

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GERMANY
Phone: +(49) 2192-810
Fax: +(49) 2192-81200
info@klingelnberg.com
www.klingelnberg.com

Knuth Machine Tools USA, Inc.
Koepfer America, LLC
Lambda Technologies

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Phone: (734) 429-7225
Fax: (734) 429-2294
info@liebherr.com
www.liebherr.com

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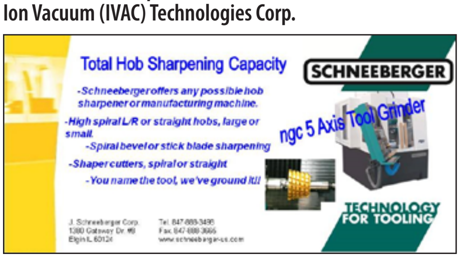

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Star SU LLC SEE OUR AD IFC-1, 103
5200 PRAIRIE STONE PARKWAY, SUITE 100
HOFFMAN ESTATES, IL 60192
Phone: (847) 649-1450
Fax: (847) 649-0112
sales@star-su.com
www.star-su.com

Stenhoj Broaching Machines
Stotz Gaging Co.
Studwell Engineering
Super Hobs & Broaches Pvt. Ltd.
Surplex GmbH
TECO Werkzeugmaschinen GmbH & Co.
Toolink Engineering
Toshiba Machine Co.
Tribo Surface Engineering LLC
Ty Miles Inc.
U.S. Equipment
Ultramatic Equipment Co.
United Grinding
Usach Technologies Inc.
VaporKote, Inc.
Vermont Machine Tool
View Micro-Metrology
Voelker Sensors, Inc.
WARDJet
Watkins Mfg. Inc.
West Michigan Spline, Inc.
Westminster Machine Tools Ltd.
Wheelabrator Group
Wolverine Broach Co., Inc.

RESOURCES

AGMA - American Gear Manufacturers Association
AMT - The Association For Manufacturing Technology
ASM International
American Bearing Manufacturers Association
American Chemical Technologies, Inc.
American Wind Energy Association
Banyan Global Technologies LLC
CTI – Car Training Institute
Drive Systems Technology, Inc.
Forging Industry Association
Gear Consulting Group

Gleason Corporation SEE OUR AD P52-53
1000 UNIVERSITY AVENUE
ROCHESTER, NY 14692-2970
Phone: (585) 473-1000
Fax: (585) 461-4348
sales@gleason.com
www.gleason.com

Gleason Cutting Tools Corporation SEE OUR AD P52-53
1351 WINDSOR RD., LOVES PARK, IL 61111
Phone: (815) 877-8900
Fax: (815) 877-0264
gctc@gleason.com
www.gleason.com

Hannover Fairs USA

Kapp Technologies SEE OUR AD P3
2870 WILDERNESS PLACE, BOULDER, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131
sales@kapp-usa.com
www.kapp-usa.com

Koepfer America, LLC

Liebherr America SEE OUR AD P5
1465 WOODLAND DR., SALINE, MI 48176
Phone: (734) 429-7225
Fax: (734) 429-2294
info@liebherr.com
www.liebherr.com

Lubrication Engineers
Metal Powder Industries Federation (MPIF)
Noria Corporation
R.E. Smith & Co., Inc.
Randall Publications LLC
Slone Gear International, Inc
Suresh Mehta Associates
The Herring Group Inc.
Thors LLC
VDI
Virgo Communications & Exhibitions Pvt Ltd.
West Michigan Spline, Inc.

ZRIME SEE OUR AD P27
NO. 81 SONGSHAN SOUTH ROAD
ZHENGZHOU HENAN 450052
CHINA
Phone: +(86) 371-67710564
Fax: +(86) 371-67710565
cheny@zrime.com.cn
www.zrime.com.cn

SERVICES

ATS - Advanced Technology Services
Acedes Gear Tools
Ajax Tocco Magnethermic Corp.
Aksan Steel Forging
Allen Adams Shaper Services, Inc.
American Broach & Machine Co.
Ampere Metal Finishing
Andec Mfg. Ltd.
Anthony Best Dynamics Ltd
Apex Broaching Systems
Apollo Broach, Inc.
Balaji Thermotech India Private Limited
Banyan Global Technologies LLC
Barber-Colman, Div of Bourn & Koch
Becker GearMeisters, Inc.

Beyta Gear Service SEE OUR AD P99
0N230 COUNTY FARM ROAD, WINFIELD, IL 60190
Phone: (630) 209-1652
chuck@beytagear.com
www.beytagear.com

Bill's Machine Repair
Borescopes-R-Us
Bourn & Koch Inc.

Broach Masters / Universal Gear Co. SEE OUR AD P17
1605 INDUSTRIAL DRIVE, AUBURN, CA 95603
Phone: (800) 563-3442
Fax: (530) 885-8157
sales@broachmasters.com
www.broachmasters.com

Broaching Technologies, LLC
Bruce Cox Engineering Corporation
Bryant Grinder
C & B Machinery
CNC Design Pty Ltd
Canada Broach
Capital Tool Industries
Carbide Tool Services, Inc.
Carl Zeiss Industrial Metrology LLC
Daubert Cromwell
Delta Inspection
Diehl Engineering Company, Inc. PS
Dixitech CNC
Drive Systems Technology, Inc.
EES Gear GmbH
EMAG LLC
East-Lind Heat Treat, Inc.
Eicher Engineering Solutions
ElectroHeat Induction
Electronics Inc.
Ellwood City Forge
Eltro Services, Inc.
Engineered Abrasives
Estudio Piña

Excel Gear SEE OUR AD P11
11865 MAIN STREET, ROSCOE, IL 61073
Phone: (815) 623-3414
Fax: (815) 623-3314
Chinn@excelgear.com
www.excelgear.com

Extremeion Hard Carbon
FPM HEAT TREATING
Framo Morat, Inc.
Frenco GmbH
Friedrich Gloor Ltd.
Furnaces, Ovens & Baths, Inc.
GMN USA LLC
GWJ Technology GmbH
Gear Consulting Group
Gear Consulting Services of Cincinnati LLC
General Magnaplate

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1000 UNIVERSITY AVENUE
ROCHESTER, NY 14692-2970
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www.gleason.com

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1351 WINDSOR RD., LOVES PARK, IL 61111
Phone: (815) 877-8900
Fax: (815) 877-0264
gctc@gleason.com
www.gleason.com

Great Lakes Gear Technologies, Inc.
Greg Allen Company
Grindal Company
HobSource Inc.
Hydrotex
IHI Ionbond Inc.
Impact Finishers

Index Technologies Inc. SEE OUR AD P103
5755 CANAL ROAD, VALLEY VIEW OHIO 44125
Phone: 216 642 5900
Fax: 216 642 8837
galllen@gallenco.com
www.gallenco.com

Industrial Metal Finishing, Inc
Inland Broaching and Tool Company
Involute Gear & Machine Company
Ion Vacuum (IVAC) Technologies Corp.
K+S Services, Inc.

KISSsoft AG SEE OUR AD P99
ROSENGARTENSTRASSE 4, CH-8608 BUBIKON
SWITZERLAND
Phone: +(41) 55-254-2050
Fax: +(41) 55-254-2051
info@kisssoft.ag
www.kisssoft.ch

Kinematics Manufacturing, Inc.
Kleiss Gears, Inc.

Klingelnberg America Inc. SEE OUR AD BACK COVER
118 E. MICHIGAN AVENUE, SUITE 200
SALINE, MI 48176
Phone: (734) 470-6278
Fax: (734) 316-2158
KLA.info@klingelnberg.com
www.klingelnberg.com

Koepfer America, LLC

Koro Sharpening Service SEE OUR AD P103
9530 85TH AVENUE NORTH
MAPLE GROVE, MN 55369
Phone: (763) 425-5247
Fax: (763) 425-5261
info@koroind.com
www.koroind.com

Lalson Tools Corporation
Laser Tools Co.

Liebherr-Verzahntechnik GmbH SEE OUR AD P5
KAUFBEURER STRASSE 141, D-87437 KEMPTEN
GERMANY
Phone: +(49) 831-786-0
Fax: +(49) 831-7861279
info.lvt@liebherr.com
www.liebherr.com

Longevity Coatings

Luren Precision Chicago SEE OUR AD P21
707 REMINGTON RD., SUITE 1
SCHAUMBURG, IL 60173
Phone: (847) 882-1388
Fax: (847) 882-1933
sales@lurenusa.com
lurenusa.com

MDM-Mecatronics
MESYS AG
MTI Systems, Inc.

Machine Tool Builders SEE OUR AD P4
7723 BURDEN ROAD
MACHESNEY PARK, IL 61115
Phone: (815) 636-7502
Fax: (815) 636-5912
aminer@machinetoolbuilders.com
www.machinetoolbuilders.com

Machine Tool Solutions, Inc.
Magnetic Inspection Laboratory
Maguire Technologies
Mahr Federal Inc.
Masternet Ltd.
Metal Improvement Company
Metallized Carbon Corporation
Metallurgical Processing, Inc.
MicroTek Finishing, LLC
Milburn Engineering, Inc.

Mitsubishi Heavy Industries America SEE OUR AD P8
MACHINE TOOL DIVISION
46992 LIBERTY DRIVE, WIXOM, MI 48393
Phone: (248) 669-6136
Fax: (248) 669-0614
sales@mitsubishigearcenter.com
www.mitsubishigearcenter.com

Mitsubishi Materials USA
Mitutoyo America Corporation
New England Gear
Noria Corporation
Oerlikon Balzers - PPD Division
Oerlikon Balzers USA
Peening Technologies
Precision Spindle & Accessories Inc.

Proto Manufacturing SEE OUR AD P12,43
12350 UNIVERSAL DRIVE
TAYLOR, MI 48180
Phone: 1 (313) 965-2900
Fax: 1 (734) 946-0974
info@protoxrd.com
www.protoxrd.com

Quality Reducer Service, Inc
R & P Metrology GmbH
R.E. Smith & Co., Inc.
REM Surface Engineering
Red Rover
Romax Technology
S.K. Gear Consulting
SWD Inc.
Samputensili S.p.A.
Seco/Warwick Europe S.A.
Sedlock Companies - Euskal Forgin
Slone Gear International, Inc
Smart Manufacturing Technology Ltd.
Springfield Metallurgical Services, Inc.
Star Cutter Co.

Star SU LLC SEE OUR AD IFC-1, 103
5200 PRAIRIE STONE PARKWAY, SUITE 100
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Stone Tucker Instruments Inc.
Sulzer
Superabrasivi
Superior Industrial Sharpening & Grinding
Suresh Mehta Associates
Surface Finishing Equipment Co.
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The Modal Shop
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Ty Miles Inc.
U.S. Equipment
Ultramatic Equipment Co.
United Tool Supply Ltd.
VFA Engineering Group
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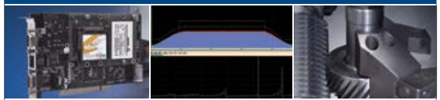
Vermont Machine Tool
WPC Treatment Co., Inc.
Welter Group
West Michigan Spline, Inc.

SOFTWARE

A.G. Davis - AA Gage
AKGears, LLC
ATS - Advanced Technology Services
Acme Manufacturing Co.
Andec Mfg. Ltd.
Anthony Best Dynamics Ltd



Artis/Brankamp Div. of Marposs SEE OUR AD P43,48
3300 CROSS CREEK PARKWAY
AUBURN HILLS, MI 48326
Phone: (248) 370-0404
Fax: (248) 370-0991
jorge.pena@us.marposs.com
www.artis.de

Ash Gear & Supply
Bourn & Koch Inc.

Broach Masters / Universal Gear Co. SEE OUR AD P17
1605 INDUSTRIAL DRIVE, AUBURN, CA 95603
Phone: (800) 563-3442
Fax: (530) 885-8157
sales@broachmasters.com
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CD-adapco
Carl Zeiss Industrial Metrology LLC
Community PC
Donner+Pfister AG
Dontyne Systems
Drake Manufacturing Services Co. Inc.
Drive Systems Technology, Inc.
Dynamic Systems
Eicher Engineering Solutions
Eltro Services, Inc.
Erwin Junker Machinery, Inc.
Estudio Piña
Euro-Tech Corporation

Excel Gear SEE OUR AD P11
11865 MAIN STREET, ROSCOE, IL 61073
Phone: (815) 623-3414
Fax: (815) 623-3314
Chinn@excelgear.com
www.excelgear.com

FARO Technologies, Inc.
FPM HEAT TREATING
FastCAM Inc.
Frenco GmbH
GWJ Technology GmbH
GearOffice

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Fax: (815) 877-0264
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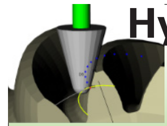
www.gleason.com

Great Lakes Gear Technologies, Inc.
Hanro Tools Incorporation
Heller Machine Tools
Hexagon Industriesoftware GmbH
Hexagon Metrology
HiTech e Soft
Hobbing.com / Planeta Inc.
ITI GmbH



Involute Simulation Softwares Inc. SEE OUR AD P48
10415 DU SUPERBE, QUEBEC QC G2B 2S1
CANADA
Phone: (418) 843-6828
hygears@hygears.com
www.hygears.com

KGK International Corp.

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info@kisssoft.ag
www.kisssoft.ch

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Fax: (815) 363-8832
dan.kondritz@kisssoft.com
www.kisssoft.com

Khemka Broach & Spline Gauge

Klingelnberg AG SEE OUR AD BACK COVER
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SWITZERLAND
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Fax: +(41) 44-2781594
info@klingelnberg.com
www.klingelnberg.com

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Fax: +(49) 2192-81200
info@klingelnberg.com
www.klingelnberg.com

Kollmorgen

Liebherr America SEE OUR AD P5
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Phone: (734) 429-7225
Fax: (734) 429-2294
info@liebherr.com
www.liebherr.com

MDM-Mecatronics
MESYS AG
MSC Software Corp.
MTI Systems, Inc.

Machine Tool Builders SEE OUR AD P4
7723 BURDEN ROAD
MACHESNEY PARK, IL 61115
Phone: (815) 636-7502
Fax: (815) 636-5912
aminer@machinetoolbuilders.com
www.machinetoolbuilders.com

Marposs Corporation
Mitutoyo America Corporation
Normac, Inc.
PTG Holroyd

Pentagear Products
SEE OUR AD P33
12955 YORK DELTA DRIVE, SUITE 1
NORTH ROYALTON, OH 44133
Phone: (330) 421-0420
mnicholson@pentagear.com
pentagear.com

Precision Gage Co., Inc.
Prime Technologies
Promess Inc.
Romax Technology
SU (Shanghai) Machine & Tools Co., Ltd.
Saazor
Scientific Forming Technologies Corp.
SerWeMa GmbH & Co. KG
Slone Gear International, Inc
Smart Manufacturing Technology Ltd.
Spring Technologies Inc.
Stotz Gaging Co.
Super Systems Inc.
Techcellence
Thermo-Calc Software Inc.
Universal Technical Systems, Inc.
Vermont Machine Tool
WARDJet
Waterloo Manufacturing Software
Web Gear Services Ltd.
Wenzel America
Yash International

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Advico
Ajax Tocco Magnethermic Corp.
Apex Auctions Inc.
CBI Industrial Asset Management bv
Cincinnati Industrial Auctioneers
Corporate Assets Inc.
Dixitech CNC
Fairfield Auctions

Gear Machinery Exchange
SEE OUR AD P102-103
1840 JARVIS AVENUE
ELK GROVE VILLAGE, IL 60007
Phone: (847) 437-6605
Fax: (847) 437-6618
www.gearmachineryexchange.com

Gibbs Machinery Company
GoIndustry DoveBid

Goldstein Gear Machinery LLC
SEE OUR AD P102-103
1840 JARVIS AVENUE
ELK GROVE VILLAGE, IL 60007
Phone: (847) 437-6605
Fax: (847) 437-6618
michael@goldsteingearmachinery.com
www.goldsteingearmachinery.com

Gray Machinery Company
Hilco Industrial
Koster Industries
Mohawk Machinery Inc.
PPL Group
U.S. Equipment
Used Machinery Sales LLC
West Michigan Spline, Inc.

WORKHOLDING & TOOLHOLDING

2L Inc.
A.G. Davis - AA Gage
Accu-Cut Diamond Tool Co.
Acme Manufacturing Co.
Acme Wire Products
American Broach & Machine Co.
Andec Mfg. Ltd.
Apex Broaching Systems
Ash Gear & Supply
Banyan Global Technologies LLC
Bourn & Koch Inc.

Broach Masters / Universal Gear Co.
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sales@broachmasters.com
www.broachmasters.com

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Cleveland Deburring Machine Co.
DT Technologies US
Dinanath
Dr. Kaiser Diamantwerkzeuge
Drewco Workholding
Emuge Corp.
Engineered Tools Corp.
Euro-Tech Corporation
Forkardt
Frenco GmbH
Fuji Machine America Corp.
Galaxy Sourcing Inc.
Gear Resource Technologies Inc.
Georg Kesel GmbH & Co. KG

Gleason Corporation
SEE OUR AD P52-53
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Fax: (585) 461-4348
sales@gleason.com
www.gleason.com

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1351 WINDSOR RD., LOVES PARK, IL 61111
Phone: (815) 877-8900
Fax: (815) 877-0264
gctc@gleason.com
www.gleason.com

Gleason Metrology Systems
SEE OUR AD P52-53
300 PROGRESS ROAD, DAYTON, OH 45449
Phone: (937) 859-8273
Fax: (937) 859-4452
gleason-metrology@gleason.com
www.Gleason.com

Great Lakes Gear Technologies, Inc.
Greg Allen Company

Hainbuch America
SEE OUR AD P23
W129 N10980 WASHINGTON DR.
GERMANTOWN, WI 53022
Phone: (414) 358-9550
Fax: (414) 358-9560
sales@hainbuchamerica.com
www.hainbuchamerica.com

Hanro Tools Incorporation
Hardinge Inc.
HobSource Inc.
Hydra-Lock Corporation
IMEXSU Group
Industrial Tools Corporation
Interstate Tool Corp.
JRM International, Inc
Kennametal Inc.
Kitagawa - NorthTech Workholding

Klingelnberg AG
SEE OUR AD BACK COVER
BINZMÜHLESTRASSE 171, CH-8050 ZURICH
SWITZERLAND
Phone: +(41) 44-2787979
Fax: +(41) 44-2781594
info@klingelnberg.com
www.klingelnberg.com

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KLA.info@klingelnberg.com
www.klingelnberg.com

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Phone: +(49) 2192-810
Fax: +(49) 2192-81200
info@klingelnberg.com
www.klingelnberg.com

Knuth Machine Tools USA, Inc.
LMC Workholding
Lyndex-Nikken

Machine Tool Builders
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MACHESNEY PARK, IL 61115
Phone: (815) 636-7502
Fax: (815) 636-5912
aminer@machinetoolbuilders.com
www.machinetoolbuilders.com

Machine Tool Solutions, Inc.
Miller Broach

Mitsubishi Heavy Industries America
SEE OUR AD P8
MACHINE TOOL DIVISION
46992 LIBERTY DRIVE, WIXOM, MI 48393
Phone: (248) 669-6136
Fax: (248) 669-0614
sales@mitsubishigearcenter.com
www.mitsubishigearcenter.com

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Northfield Precision Instrument Corp.
Ohio Broach & Machine Co.
P.G. Engineers
Parker Industries Inc.

Pentagear Products
SEE OUR AD P33
12955 YORK DELTA DRIVE, SUITE 1
NORTH ROYALTON, OH 44133
Phone: (330) 421-0420
mnicholson@pentagear.com
pentagear.com

Phase II
Pioneer Broach Co.
Polygon Solutions
Positrol
Precision Devices, Inc.
Precision Gage Co., Inc.
Precision Spindle & Accessories Inc.
Pro-Beam USA
QC American
Reska Spline Products Co.
Riten Industries, Inc.
Samchully Machinery Co., Ltd.
Schunk Inc.
Slater Tools Inc.
Slone Gear International, Inc
Speedgrip Chuck
Stace-Allen Chucks, Inc.

Star SU LLC
SEE OUR AD IFC-1, 103
5200 PRAIRIE STONE PARKWAY, SUITE 100
HOFFMAN ESTATES, IL 60192
Phone: (847) 649-1450
Fax: (847) 649-0112
sales@star-su.com
www.star-su.com

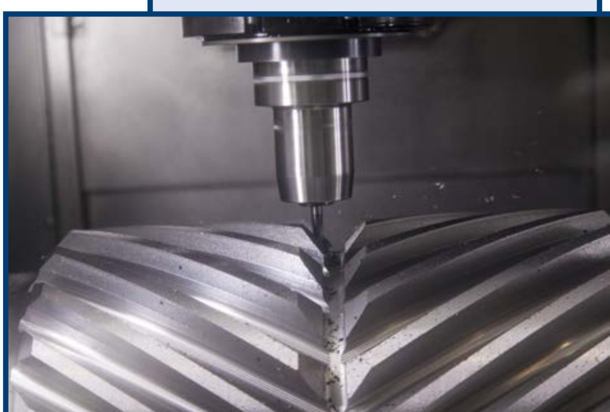
Steelmans Broaches Pvt. Ltd.
Stotz Gaging Co.
Superabrasivi
Tazz Broach & Machine, Inc.
Toolink Engineering
V W Broaching Service, Inc.

WAIT A MINUTE!

Where are the Gear Manufacturers?

A partial listing of gear manufacturers and other power transmission component suppliers can be found on page 72.

However, a comprehensive directory of mechanical power transmission components, will be featured in Power Transmission Engineering's buyers guide in the December issue.



Of course, you can always find the current listings of gear manufacturers online at *www.powertransmission.com*

2L Inc.
4 KANE INDUSTRIAL DRIVE, HUDSON, MA 01749
Phone: (978) 567-8867
Fax: (978) 562-8972
contact@2Linc.com
www.2Linc.com

300 Below, Inc.
2999 E. PARKWAY DR., DECATUR, IL 62526
Phone: (217) 520-3335
Fax: (217) 423-3075
ppaulin@300below.com
www.300below.com

3M Abrasives
SEE OUR AD P93
3M CENTER, ST. PAUL, MN 55144-1000
Phone: (888) 364-3577
www.3m.com/Abrasives

A. Finkl & Sons Co.
1355 E. 93RD ST., CHICAGO, IL 60619
Phone: (773) 975-2510
Fax: (773) 348-5347
www.finkl.com

A.G. Davis - AA Gage
6533 SIMS DR., STERLING HEIGHTS, MI 48313
Phone: (586) 977-9000
Fax: (586) 977-9190
inquire@agdavis.com
www.agdavis.com

A.L. Tooling cc
P.O.BOX 215, CAPE TOWN WC 7404
SOUTH AFRICA
Phone: +(27) 21-5112628
Fax: +(27) 21-5112656
altool@mweb.co.za
www.altooling.co.za

Aarna Lube Private Ltd.
F-204, DHEERAJ PRESIDENCY, M.G. RD., KANDIVALI-WEST
MUMBAI MAHARASTRA 400067
INDIA
Phone: +(91) 250-2464981
Fax: +(91) 250-2464985
sales@aarnalube.com
www.aarnalube.com

Abbott Furnace Company
1068 TROUT RUN RD., SAINT MARYS, PA 15857
Phone: (814) 781-6355
Fax: (814) 781-7334
dreardon@abbottfurnace.com
www.abbottfurnace.com

ABTech Inc.
126 MONADNOCK HIGHWAY, SWANZEY, NH 03446
Phone: (603) 358-6431
Fax: (603) 358-0196
mkeenan@abtechmfg.com
www.abtechmfg.com

Abtex Corp.
89 MAIN ST., DRESDEN, NY 14441
Phone: (315) 536-7403
Fax: (315) 536-0280
sales@abtex.com
www.abtex.com

Accu-Cut Diamond Tool Co.
4238 N. SAYRE, NORRIDGE, IL 60706
Phone: (708) 457-8800
Fax: (708) 457-8061
info@accucutdiamond.com
www.accucutdiamond.com

Accu-Temp Heat Treating
2400 RACINE ST., P.O. BOX 085299, RACINE, WI 53408
Phone: (262) 634-1905
Fax: (262) 634-9102
accutemp@accutempheat.com
www.accutempheat.com/

Accura Technics/EDAC Machinery
21 SPRING LN., FARMINGTON, CT 06032-3128
Phone: (800) 851-2654
Fax: (860) 677-7344
www.edacmachinery.com

Accurate Specialties Inc.
570 BLUEMOUND RD., WAUKESHA, WI 53188
Phone: (262) 547-5450
Fax: (262) 547-5892
www.accuratespecialties.com

Accurate Steel Treating, Inc.
10008 MILLER WAY, SOUTH GATE, GA 90280
Phone: (562) 927-6528
Fax: (562) 927-8591
mail@accuratesteeltreating.com
www.accuratesteeltreating.com

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ENGLAND
Phone: +44 (0)1635-524-252
Fax: +44 (0)1635-521-085
sales@acedes.co.uk
www.acedes.co.uk

Acme Manufacturing Co.
4240 N. ATLANTIC BLVD., AUBURN HILLS, MI 48326
Phone: (248) 393-7300
Fax: (248) 393-4060
carlsong@acmemfg.com
www.acmemfg.com

Acme Wire Products
7 BRD.WAY AVENUE EXTENSION, MYSTIC (STONINGTON),
CT 06355
Phone: (860) 572-0511
Fax: (860) 572-9456
info@acmewire.com
www.acmewire.com

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CORRECTIONS: SEPTEMBER-OCTOBER *GEAR TECHNOLOGY*

In what could be described as a journalistic version of "Murphy's Law" on steroids, we report the following errors — all affecting solely one entity: KISSsoft AG.

In the article, "Les Gears Lyonnaise," (p. 66), Ulrich Kissling (President, KiSSsoft AG) was misidentified as Stefan Beermann (CEO, KiSSsoft AG).

In the article, "Getting the Right Tools," several errors occurred in the chart found on Page 30.

One — the company name is graphically misrepresented at the top of the column; and two — several of the Yes/No responses in the KISSsoft column are incorrect (please see corrected version).

Gear Technology sincerely regrets the errors.

Software Article

Question	Vendor>	MITcalc	Dontyne	Excellent	Romax	KISSsoft	AGMA	PowerGear
1	Spur	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Helical	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Internal	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Eppicyclic	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Bevel	Yes	Yes	Future	Yes	Yes	Diff.Program	No
	Worm	Yes	Yes	Future	Future	Yes	No	No
2	AGMA	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	ISO	Yes	Yes	Yes	Yes	Yes	Yes	No
	DIN	Yes	Yes	Yes	Yes	Yes	No	No
	JIS	Yes	No	No	Partial	Yes	No	No
	BS	Yes	Yes	No	Partial	Yes	No	No
	API	Yes	Yes	No	Partial	Yes	Yes	No
3	Lubrication	Partial	Yes	Yes	Yes	Yes	No	Yes
4	Rack Coeff	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	matl & HT	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Miner's Rule	No	Yes	No	Yes	Yes	Yes	Yes
7	HPSTC, etc.	No	Yes	Yes	Yes	Yes	Yes	Yes
8	HCR OK?	No	Yes	No	Yes	Yes	No	Yes
9	Tooth Mods	No	Yes	Partial	Yes	Yes	No	Yes
10	Cm	Yes	Yes	Yes	Yes	Yes	No	Yes
11	Tooth Profiles?	Yes	Yes	No	Yes	Yes	Yes	Yes
12	Profile Export?	Yes	Yes	No	Yes	Yes	Yes	Yes
13	AGMA Tol?	No	Yes	Yes	No	Yes	Yes	Yes
14	Other Tol?	No	Yes	ISO, DIN	Partial	Yes	No	Yes
15	Span Measure?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
16	Ball or Pin?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Specify Pin Dia?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
17	PM Gears?	No	No	No	No	Yes	No	No
	Plastic Gears?	No	No	No	No	Yes	No	No
18	Geo Warnings?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
19	Warning Override?	Yes	Yes	Yes	Yes	Yes	No	Yes
20	Training Available?	No	Yes	Yes	Yes	Yes	Yes	Yes

Small-Module Gear Design

QUESTION

With small-module gear design, how does one define pressure angle and module? Which factor should we take into account?

Expert Response provided by Dr. Alex Kapelevich, AKGears, LLC *(www.akgears.com)*

Gears with a diametral pitch 20 and greater, or a module 1.25 millimeters and lower, are called fine-pitch or low-module gears. The design of these gears has its own specifics. A small tooth size makes fine-pitch gears more sensitive to manufacturing tolerances and operating conditions than the coarse-pitch gears.

Manufacturing tolerances include gear tolerances (tooth tip diameter, tooth thickness at the pitch diameter, and run-out); housing center distance tolerance; allowable gear axis misalignment; etc. Operating conditions may include the gear housing and shafts deflection under load; a temperature range resulting from gear drive component thermal expansion or shrinkage (especially for dissimilar materials); and a humidity range that affects some plastic components. All these factors should be taken into consideration for fine-pitch gear design.

For a given gear accuracy grade, the fine-pitch gear tolerances relative to the tooth size are much greater in comparison to coarse-pitch gears. For example, according to the AGMA 2000-A88 accuracy standard, the grade Q8 total composite tolerance (aka TTE) for a 0.3 millimeter module, 30-tooth gear is 0.036 millimeters, but for a 3.0 millimeter module, 30-tooth gear it is 0.110 millimeters. The gear size is increased by 10 times, but the TTE is increased only by 3 times. Another example: according to the ISO 1328-2 accuracy standard, the grade 8 runout tolerance for gears with a pitch diameter between 20 and 50 millimeters and module between 0.5 and 2.0 millimeters is 0.032 millimeters. The gear pitch diameter and tooth size (module) can vary 2.5 and 4 times, accordingly, but the run-out tolerance remains the same. This explains why the given tolerance for the gearbox housing center distance is easy to absorb by coarse-pitch gears, rather than the fine-pitch ones that could have a contact ratio below 1.0 — or even totally separated when the center distance is at its maximum value. A wide operating temperature range for dissimilar material gears and housing aggravates this problem. For example, steel fine-pitch gears inside an aluminum housing may properly work at ambient temperature, but at high operating temperature the center distance will be increased because of greater housing expansion, and fine-pitch gears could be separated. An opposite issue arises when fine-pitch plastic gears are in an aluminum housing. At cold temperature the fine-pitch plastic gears are getting smaller and could get separated; at high temperature they grow greater than the housing and could become jammed. Some gear polymers, like nylons, are also sensitive to humidity. They are smaller at dry conditions and grow with high humidity.

The following recommendations should be helpful for fine-pitch gear design:

Machined gears should be designed with reasonably high accuracy to minimize critical gear tolerances, like the tooth tip diameter, tooth thickness, and run-out tolerances. Unfortunately, this is not always possible with some gear-forming-fabrication technologies, such as powder metal processing and injection plastic molding.

When possible, minimize housing center distance tolerance and bearing or bushing gaps.

Maximize the gear tooth size. For example, replace the module 0.2 millimeter, 20-tooth gear with a module 0.4 millimter, 10-tooth gear. The mating gear number of teeth should be changed according to the required gear ratio; this will also increase gear tooth bending strength. For standard gears, the pp positive addendum modification (X-shift) should be applied to avoid a low number of tooth gear root fillet undercut.

The standard gear tooth proportions with 20 degree or 14.5 degree pressure

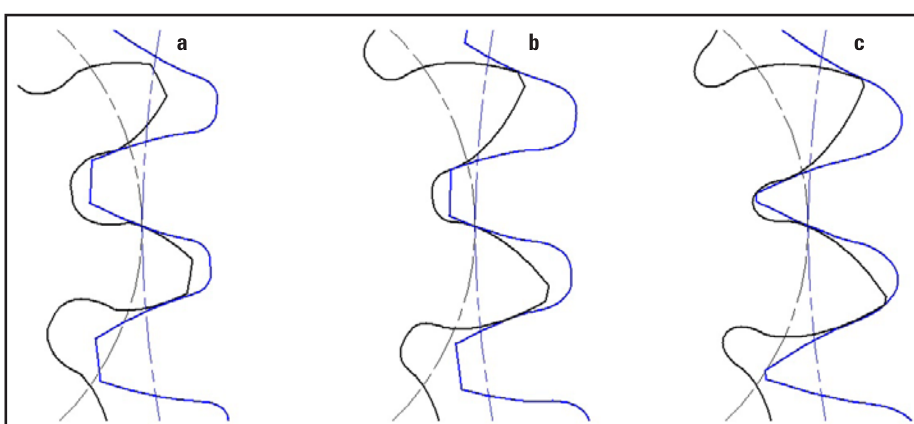
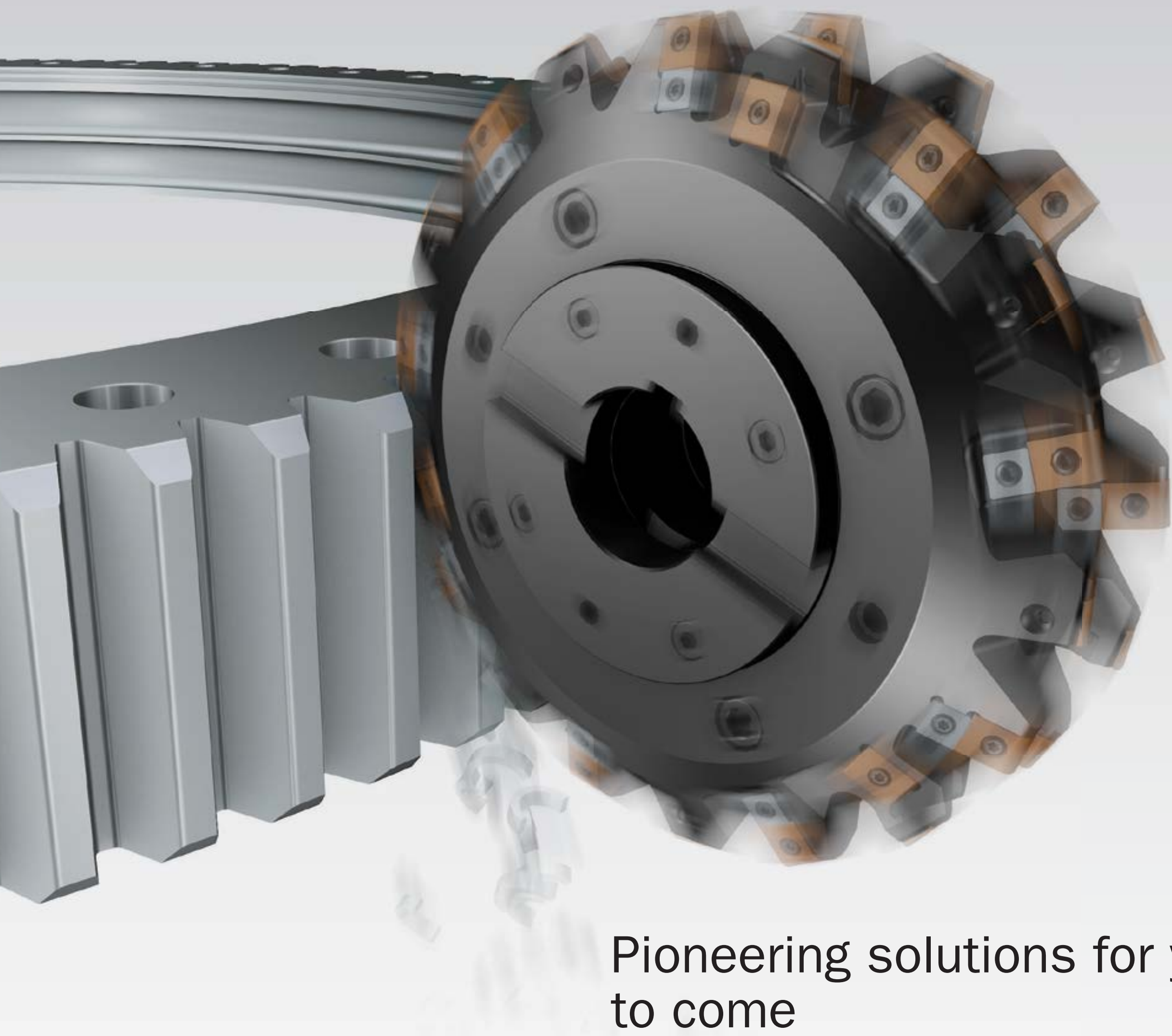


Figure 1 Gear meshes of 10 and 40 tooth gears; a – standard (pressure angle 20°, X-shifts 0 and 0, contact ratio 1.08), b – standard (pressure angle 20°, X-shifts +0.5 and -0.5, contact ratio 1.40), c – nonstandard (pressure angle 22.5°, contact ratio 1.70)



angles and addendum coefficient 1.0 work well for commercial-application, coarse-pitch gears. In many cases, however, they are not suitable for fine-pitch gears. An effective alternative for fine-pitch gears is the application of non-standard gear tooth proportions. Length of the effective involute profile should be increased to make the tooth as long as possible, just avoiding pointed tips. The root fillet should be formed accordingly, also avoiding interference. Long teeth are better suited to accommodate the center distance deviation at any tolerance combination. The recommended operating pressure angle range is 20-25 degrees; the tooth tip radii or chamfers should be minimized. Examples of standard gear meshes with and without addendum modification, and a non-standard gear mesh are shown in Figure 1.

When the gear design is done it should be verified by the tolerance and (if necessary) thermal analysis. Such analysis defines critical gear mesh parameters, minimum/maximum values of contact ratio, normal backlash, root radial clearance at extreme tolerance combinations and operating conditions. For example: with steel external gears and aluminum housing, the maximum contact ratio, and the minimum, normal backlash and root radial clearance values are achieved at minimum operating temperature, minimum center distance, maximum tooth thickness and tooth tip diameter, and when the maximum run-out reduces the effective center distance. Then the minimum contact ratio, and the maximum normal backlash and root radial clearance values are achieved at maximum operating temperature, maximum center distance, minimum tooth thickness and tooth tip diameter, and when the maximum run-out increases the effective center distance.

More details about nonstandard gear design and tolerance analysis can be found in Kapelevich's book, Direct Gear Design, *CRC Press, 2013.*.

Alex Kapelevich possesses more than 30 years of custom gear research and design experience, as well as over 100 successfully accomplished projects for a variety of gear applications. His company, AKGears, provides consulting services—from complete gear train design (for customers without sufficient gear expertise) to retouching (typically tooth and fillet profile optimization) of existing customers' designs — in the following specific areas: traditional or direct gear design; current design refinement; R&D; failure and testing analysis. The company provides gear drive design optimization for increased load capacity; size and weight reduction; noise and vibration reduction; higher gear efficiency; backlash minimization; increased lifetime; higher reliability; cost reduction; and gear ratio modification and adjustment. Kapelevich is the author of numerous technical publications and patents, and is a member of the AGMA Aerospace and Plastic Gearing Committees, SME, ASME and SAE International. He holds a Ph.D. in mechanical engineering from Moscow State Technical University and a Master Degree in mechanical engineering from the Moscow Aviation Institute.

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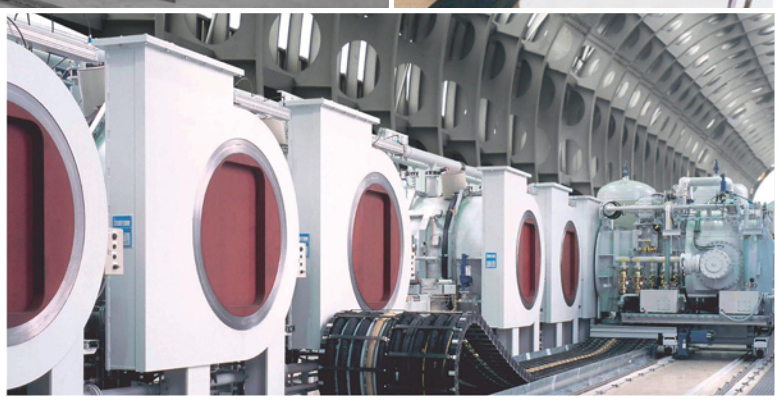
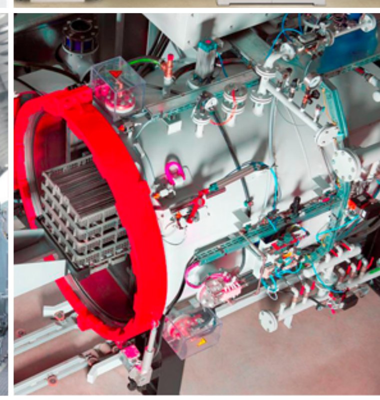

Application of Statistical Process Capability Indices in Gear Manufacturing

Yefim Kotlyar

This article discusses applications of statistical process capability indices (Cp and Cpk) for controlling the quality of tooth geometry characteristics, including profile and lead as defined by current AGMA-2015, ISO-1328, and DIN-3960 standards. It also addresses typical steps to improve manufacturing process capability for each of the tooth geometry characteristics when their respective capability indices point to an incapable process.

Introduction

The use of statistical analysis in today's world is omnipresent, inescapable, and vastly beneficial to many human endeavors; e.g. — medicine, weather prediction, government, finance, natural sciences, behavioral science, sports, insurance and — thanks in large part to Dr. W. Edwards Deming — the manufacturing industries. (*Ed.'s Note*: *Deming helped develop the sampling techniques still used by the Department of the Census and the Bureau of Labor Statistics. But were you aware: The original notions of Total Quality Management and continuous improvement trace back to a former Bell Telephone employee named Walter Shewhart. One of Deming's former teachers, he preached the importance of adapting management processes to create profitable situations for both businesses and consumers, promoting the utilization of his own creation — the statistical process control (SPC) control chart* Source: Wikipedia).

Manufacturers utilizing machining processes such as turning, milling and grinding have long embraced statistical process control (SPC) as a tool to understanding and quantifying their process capability, improving quality, and reducing cost.

Yet some gear manufacturers have only half-heartedly embraced SPC, and many use it only for features such as tooth thickness, diameters, or run-out. Taking full advantage of SPC tools to understand process capabilities and to control the quality of gear tooth profile and lead continues lagging behind.

Indeed — it is difficult to resist the temptation to offer some anecdotal explanations as to why SPC for tooth profile and lead characteristics remains underutilized.

Perhaps one reason is related to the proud history of gear manufacturers who learned how to precisely machine involute curves long before CNC cutting machines and CMM technology democratized the manufacture and inspection of complex shapes. Once upon a time, gear engineers had to create ingenious mechanical devices in order to precisely machine and measure involute curves. The slow acceptance of modern SPC tools for controlling profile and lead characteristics is somewhat reminiscent of the gear machine tools industry's adaptation of CNC in the 1980s — long after the turning and milling machine makers embraced CNC. The perception was that the earlier controls were neither precise nor fast enough to satisfy gear makers.

Another reason — at least here in the U.S. — is perhaps related to the nature of tolerance band specifications (K-chart) that was not easily conducive to a quantitative, and therefore statistical, analysis.

The final, and possibly least anecdotal, explanation for the reluctance to take full advantage of SPC tools is perhaps a seeming enormity and ambiguity of the task. Consider:

- How many and what specific profile and lead geometry characteristics should be analyzed? Should it be the total, slope, or form errors? Should it be a maximum error or a four-tooth-average?
- Are there differences between the analysis of the slope error and the form error?
- Data collection difficulties; not all inspection technologies have user-friendly means for collecting data automatically and in a format tailored for SPC analysis.
- A lingering concern that one needs to produce a significantly better-than-required quality in order to have a capable process. An informative (included for guidance only, and is not formally a part of the standard) Annex C of AGMA 2015-1-A01 has even attempted to quantify this concern.
- And finally, what should be done with the process capability analysis results? How does one use capability indices to improve quality and reduce scrap cost?

Whatever the reasons for not taking full advantage of modern statistical tools in gear manufacturing, this article is an attempt to address some of the above concerns and provide a few tips for utilization of the process capability indices to assess and, if necessary, improve the process capability for tooth geometry characteristics.

The strategy for improving the process capability is not unlike finding and addressing the root cause of a quality issue based on inspection of a single gear. As gear quality is affected by many overlapping contributing factors (machine, fixture, cutting tools, blanks, machining parameters, set-up, and inspection uncertainty), one needs to navigate all these factors to find and address the dominant contributor responsible for the quality issue. The advantage, however, is that statistical evaluation empowers engineers with the knowledge of multiple data points and a "big picture" perspective. In addition to the specific gear quality issues, engineers are possessed with the ability to know process quality as quantified by the capability indices that help in isolating those specific, contributing factors that require improvement.

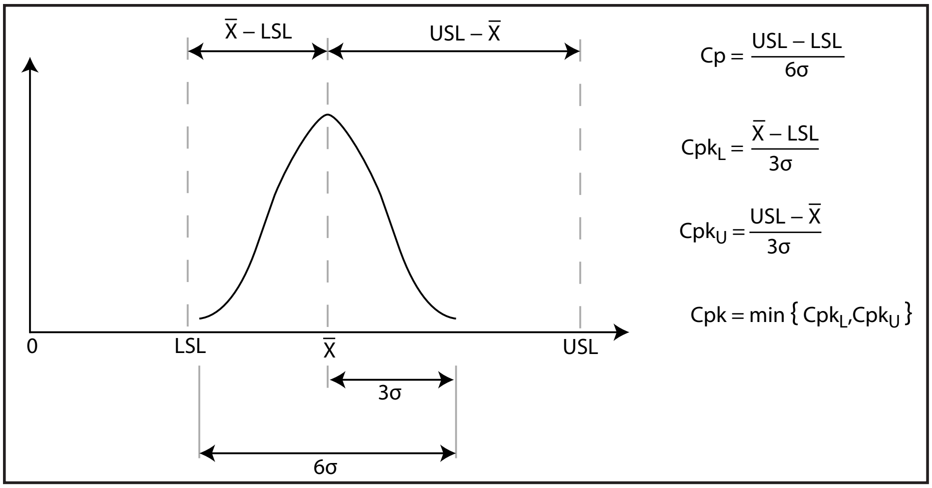

Figure 1 Cp and Cpk determination for a bi-lateral tolerance.

Basic Process Capability Terminology: Cp and Cpk

Space does not allow covering the basics or definitions of statistical terms. Nevertheless, below are just a few terms for a quick reference.

USL: Upper Specification Limit (upper tolerance)

LSL: Lower Specification Limit (lower tolerance)

***σ*:** Process standard deviation quantifies the data dispersion from the average. A lower σ indicates that the data points tend to be very close to the average, leading to improved process capability. In the absence of specialized software for SPC analysis, an approximation formula in *MS Excel* spreadsheet, "*stdev*" can be used. The sample size for evaluating the process capability is typically greater than 25.

6*σ: Statistical process variation – roughly 99.97% of the population will be within this range.

$\bar{X}$: Average of the measured sample population.

Cp – Capability Index. Cp = (USL-LSL)/(6*σ). This index is a measure of a potential process capability — a ratio between the tolerance range and the process variation. Cp value, however, does not reveal how well the process is centered in relation to the tolerance range.

Cpk: Capability Index that takes the centering of the process into account.

For a bilateral tolerance one needs to determine Cpk_L and Cpk_U and pick the smaller of the two. **Cpk**: min {Cpk_U, Cpk_L}; $Cpk_L = (USL - \bar{X})/(3*σ)$, $Cpk_U = (\bar{X} - LSL)/(3*σ)$ (Fig.1). Cpk > 1 provides a statistical assurance that the process is not only capable, but is also well-centered within the tolerance limits. In the case of a bilateral tolerance, both Cp and Cpk indices provide important insights into the process capability assessment.

For a unilateral tolerance, however, only a Cpk is used for the process assessment, as Cp may have no meaning. For a unilateral tolerance, Cpk is calculated only for the USL: $Cpk = (USL - \bar{X})/(3*σ)$ (Fig. 2).

Capability indices (Cp and Cpk) greater than unity are a minimum requirement for a capable process. Most companies, however, use more stringent requirements; e.g. — Cp and Cpk must be greater than 1.33, 1.67, or even 2.

Common cause variations are random and inherent to the process; these variations come from contributors such as machine, cutting tool, fixture, blanks, set-up, etc. when the quality of each contributor is in conformance with its respective tolerance limits.

Assignable cause variations are non-random and are usually greater than those induced by common causes. An assignable cause variation is frequently induced by the same contributors as common causes; i.e. — machine, cutting tool, fixture, blanks, etc. — when they are damaged, worn out, or, for whatever reason, are outside of their respective tolerance limits. For the process to be in control, all assignable cause variations must be found and eliminated (Ref. 1).

Preparations and Limitations

Prior to measuring gears, it is important to attain a high confidence level in the inspection process to ensure that reliable data are analyzed. Whenever possible, the inspection fixture should use the same gear datum as the gear cutting fixture. Calibration of the inspection machine and a GR&R (gage repeatability and reproducibility review) should be conducted to determine if the inspection process is compatible with the gear tolerances.

It is also important to note that for extremely precise gear tolerances, when a GR&R results in a P/T (precision/tolerance) ratio greater than 0.3, the measuring system is considered incompatible with the gear tolerances and therefore unacceptable for a process capability study. The P/T ratio shows how much of the gear tolerance would be "*eaten-up*"

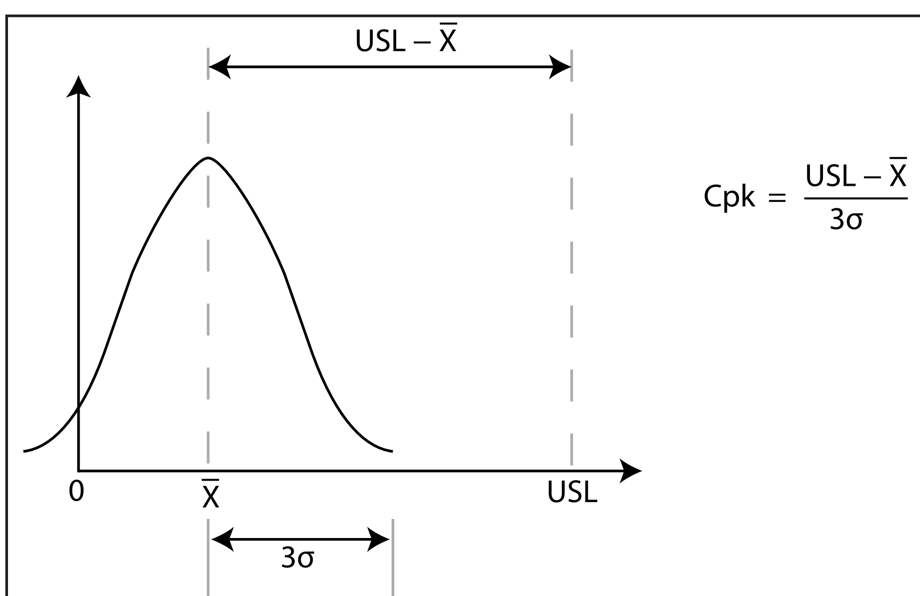

Figure 2 Cpk determination for a unilateral tolerance.

by the measuring system. Generally, a P/T ratio less than 0.1 indicates that the measuring system can reliably determine whether any given part meets the tolerance specification (Ref. 14).

A prudent practice is to study process capability for the blanks' datum features that are used for mounting gears in the gear cutting machine and inspection fixture. This will preempt and reduce some later work of investigating assignable causes if the process is found to be incapable.

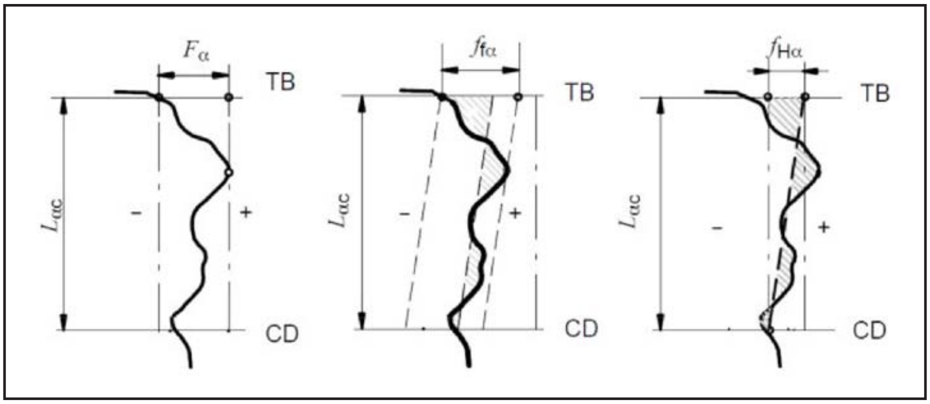

Figure 3 Total, slope, and form errors, AGMA 2015-1-A01.

Gear Characteristics: Typical Contributors to Their Process Capability

Since the introduction of AGMA 2015 standard in 2002, the three most widely used gear quality standards — ISO, DIN and AGMA — became conceptually the same. These three standards define tooth profile and tooth lead tolerances for total, slope, and form errors (Fig. 3).

Right and left flanks should be analyzed separately, as they may have different assignable causes for excessive errors and incapable processes.

For the process to be in control, all assignable causes must be found and eliminated (Ref. 1). To determine assignable causes, one must navigate multiple contributors to gear quality; i.e. — gear blanks; cutting/grinding machine; workholding fixture; cutting tool and its resharpening or dressing consistency; setup; cutting conditions; inspection equipment; and inspection fixture. In addition, each manufacturing system may have its own peculiarities, depending on the technology employed. Therefore the typical, assignable causes listed in this section should serve only as a starting point for developing a more comprehensive, customized list. Some hobbing-related examples follow below.

After determining the process capability indices (Cp and Cpk) — and finding out that the process is incapable — it would be prudent to start by investigating and addressing assignable root causes for a gear characteristic that has the worst capability index. Frequently, one assignable cause (for example, an excessive blank face run-out in relation to datum bore) adversely affects process capability indices of several gear characteristics.

Let's review one gear characteristic at a time:

Tooth Profile

Profile slope error, $f_{H\alpha}$. Figure 4 provides an illustration for calculating the profile slope average (mean) error (Ref. 9) and profile slope variation when three teeth are measured. Assignable causes for the slope average error and the slope variation are different. For example, a gear radial run-out may have a negligible effect on the slope average error, but a dramatic effect on the slope variation. It would therefore be prudent to analyze slope average error and slope variation separately, as it would make it easier to find assignable causes for each respective error.

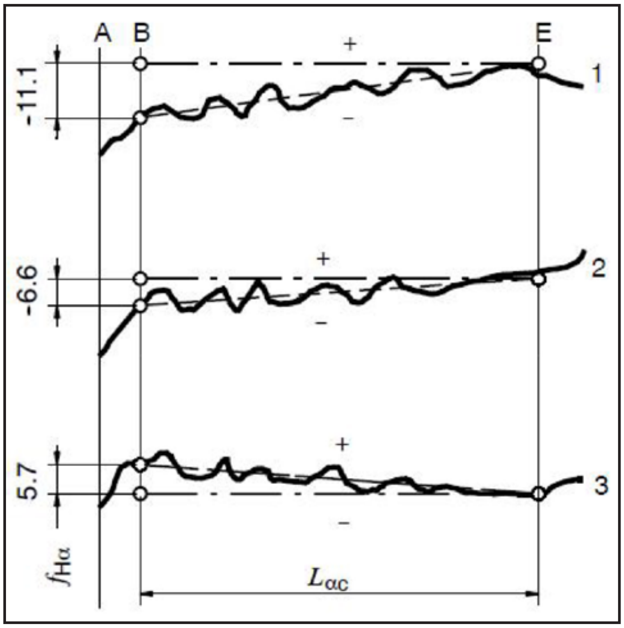

Figure 4 Average and Slope Variation — AGMA 915-1: average = (5.7+ (-6.6) + (-11.1)) / 3 = -4μm;variation = 5.7-(-11.1) = 16.8μm.

Profile slope average error, $f_{H\alpha m}$ (Ref. 9). The slope error averaged between four teeth spaced roughly 90° around the circumference can provide insights into a cutting tool; i.e. — hob, shaving cutter, or grinder dressing quality issues as they affect the process capability. The tooth profile slope average feature has a bilateral tolerance, therefore both Cp and Cpk should be determined. Table 1 covers different Cp and Cpk scenarios and provides some typical, assignable causes for an incapable process.

Profile slope variation. The slope variation between four teeth spaced roughly 90° around circumference can provide insights into fixture and blank quality, or other system contributors that create a radial run-out. The tooth slope variation is the difference between max/min slope errors as measured on four teeth of the same flank. Figure 4 shows an example for determining the slope variation error, as measured on three teeth. Note that the four-tooth measurement is a more reliable method for determining the slope variation error. If it is not defined on the drawing, the tolerance for the slope variation can be deduced from the slope tolerance. For example, if the slope tolerance is ±0.009 m, the slope variation tolerance is (0.009- [-0.009]) = 0.018mm (Table 2). Table 2 covers different Cp and Cpk scenarios, and provides some typical assignable ranges for an incapable process.

Profile form average error, $f_{f\alpha}$. Profile form error averaged between four teeth spaced roughly 90° around the circum-

Table 1 Profile Slope Average Error

Cp	Cpk	Tolerance example	Process assessment	Some typical assignable causes for an incapable process. Other assignable causes may exist depending on specifics of the machining technology.	Recommendations for improvements.
Cp>1	Cpk>1	±0.009mm	The process is capable and well centered.		Machine, fixture, blanks, cutting tool, & cutting conditions, inspection procedure are capable of making gears of specified quality.
Cp>1	Cpk<1	±0.009mm	The process is capable, but not well centered.	1. Hob rake error. 2. Hob profile error.	1. Re-sharpen the hob. 2. Re-profile the hob.
Cp<1	Cpk<1	±0.009mm	The process is incapable.	1. Hob cutter issues: exesssive wear, rake error, profile error, gash-to-gash index errror, thread-to-thread error, excessive cutter runout. 2. Gear blanks issues (excessive runout). 3. Workholding fixture misalignment or inadequate rigidity. 4. Inspection fixture issues. 5. Inspection process issues.	1. Increase shift frequency or distance, re-sharpen the hob to improve rake and index errors. Reprofile hob to reduce thread-to-thread and profile errors. Indicate the hob proof journals/faces to 0.005/0.007mm 2. Improve blanks face-to-bore runout, improve quality for the datum surface i.e bore size. Use the same datum for fixturing during cutting and inspection. 3. Increase clamping force, reduce radial/axial fixture runout. 4. If possible, use the same datum for inspection and workhollding to avoid runout between different datum. 5. Exclude tooth undercut and tip relief from the evaluation zone. Review if the inspection machine needs repair and GR&R.

Table 2 Profile Slope Variation

Cp	Cpk	Tolerance example	Process assessment	Some typical assignable causes for an incapable process. Other assignable causes may exist depending on specifics of machining technology.	Recommendations for improvements.
Not applicable	Cpk>1	0.009 - (-0.009) = 0.018mm	The process is capable.		Machine, fixture, blanks, cutting tool, & cutting conditions, inspection procedure are capable of making gears of specified quality.
	Cpk<1		The process is incapable.	1. Gear blanks radial runout. For high helix angle gears axial runout could also contribute to profile variation. 2. Workholding fixture misalignment. 3. Inadequate fixture rigidity. 4. Use of unqualified datum for gear inspection. 5. Contamination of mounting surfaces by cutting chips.	1. Improve the quality of datum surfaces i.e. bore size or bore-to-face runout, or shaft clamping diameter. 2. Reduce axial/radial fixture runout. 3. Increase clamping force. 4. If possible, use the same datum for inspection and workhollding to avoid runout between different datum. 5. Improve chip removal process by coolant flushing or other means.

Table 3 Profile Form Error

Cp	Cpk	Tolerance example	Process assessment	Some typical assignable causes for an incapable process. Other assignable causes may exist depending on specifics of the machining technology.	Recommendations for improvements.
Not applicable	Cpk>1	0.013mm	The process is capable.		Machine, fixture, blanks, cutting tool, & cutting conditions, inspection procedure are capable of making gears of specified quality.
	Cpk<1		The process is incapable.	1. Cutting tool issues. Hob runout, hob index error, thread-to-thread error in case of high helix gears and hunting ratio combination of gear teeth/cutter threads.Excessive cutter wear. Hob coating issues. Insufficient number of hob gashes. 2. Cutting conditions. Random gouges as a result of oil contamination. Excessive feed rate for high helix gears. 3. Inspection process issues. Cut-off lines do not exclude tip relief or undercut.	1. Indicate hob to reduce radial runout. Sharpen the hob to reduce index (gash-to-gash) error. Re-profile hob to reduce thread-to-thread error. Increase shift frequency or amount. Increase frequency of coating stripping prior application of new coating. Use hobs with larger number of gashes. 2. Use cleaner oil. Reduce feed rate in case of high helix angle gears. 3. Review evaluation cut-off lines and exclude tip relief and undercut from the profile evaluation zone.

Table 4 Helix/Lead Average Slope Error

Cp	Cpk	Tolerance example	Process assessment	Some typical assignable causes for an incapable process. Other assignable causes may exist depending on specifics of the machining technology.	Recommendations for improvements.
Cp>1	Cpk>1	±0.011mm	The process is capable and well centered.		Machine, fixture, blanks, cutting tool, & cutting conditions, inspection procedure are capable of making gears of specified quality.
Cp>1	Cpk<1	±0.011mm	The process is capable, but not well centered.	1. Machine program cutting angle needs readjustment. 2. Fixuture misalignment. 3. Machine tailstock/center misalignment.	1. Update cutting (or helix) angle based on the average slope arror. Angle adjustment amount = atan (average error/evaluation range) 2. Check and adust fixture alignment with the machine centerline. 3. Check and adust machine tailstock/center.
Cp<1	Cpk<1	±0.011mm	The process is incapable.	1-3. Same as above. 4. Workholding fixture issues: Excessive axial (and radial for high helix angle gear) runout. 5. Gear blanks issues: excessive axial runout and/or perpendicularity. 6. Cutting tool issues: thread-to-thread error for hunting ratio of gear teeth/hob threads. 7. Rigidity of machine or fixture, or workpiece are inadequate. 8. Inspection fixture: inspection fixture and workholding fixture use different datum causing excessive runout.	1-3. Same as above. 4. Indicate and reduce runout. 5. Improve blank quality. Blanks' datum surfaces should have a capable process. 6. Use hobs with improved thread-to-thread error. 7. Review system rigidity and make improvements. 8. If possible, use the same datum for inspection and workhollding to avoid runout between different datum.

Table 5 Helix/Lead Slope Variation

Cp	Cpk	Tolerance example	Process assessment	Some typical assignable causes for an incapable process. Other assignable causes may exist depending on specifics of the machining technology.	Recommendations for improvements.
Not applicable	Cpk>1	0.011-(-0.011) = 0.022	The process is capable.		Machine, fixture, blanks, cutting tool, & cutting conditions, inspection procedure are capable of making gears of specified quality.
	Cpk<1		The process is incapable.	1. Gear blanks axial runout. For high helix angle gears the radial runout could also contribute to lead slope variation. 2. Workholding fixture runout of datum surfaces. 3. Inspection fixture issues. Use of unqualified datum for workholding during inspection. 4. Hob thread-to-thread error when cutting gears with hunting ratio combination. 5. Contamination of mounting surfaces by cutting chips.	1. Improve the quality of datum surfaces i.e. bore size or bore-to-face runout, or shaft clamping diameter. 2. Indicate and reduce fixture axial and radial runout. 3. If possible, use the same datum for inspection and workhollding to avoid runout between different datum. 4. Reduce hob thread-to-thread error. 5. Improve chip removal process by coolant flushing or other means.

Table 6 Helix/Lead Form Error

Cp	Cpk	Tolerance example	Process assessment	Some typical assignable causes for an incapable process. Other assignable causes may exist depending on specifics of the machining technology.	Recommendations for improvements.
Not applicable	Cpk>1	0.013mm	The process is capable.		Machine, fixture, blanks, cutting tool, & cutting conditions, inspection procedure are capable of making gears of specified quality.
	Cpk<1		The process is incapable.	1. Machine rigidity: Looseness in cutter head or table spindle, worn bearings, worn ways. 2. Excessive feed rate. 3. Oil contamination causing gouges. 4. Excessive hob thread-to-thread error when cutting gears with hunting ratio combination of gear teeth and hob threads. 5. Inspection process issues. Cut-off lines do not exclude chamfers.	1. Machine repair is required. 2. Reduce feed rate. 3. Replace oil. 4. Reprofile the hob to reduce thread-to-thread error. 5. Review and adjust evaluation cutoff lines to exclude chamfers on both sides.

Table 7 Single Pitch Deviation

Cp	Cpk	Tolerance example	Process assessment	Some typical assignable causes for an incapable process. Other assignable causes may exist depending on specifics of the machining technology.	Recommendations for improvements.
Not applicable	Cpk>1		The process is capable.		Machine, fixture, blanks, cutting tool, & cutting conditions, inspection procedure are capable of making gears of specified quality.
	Cpk<1	0.015mm	The process is incapable.	1. Machine: Worn table, excessive backlash in the table wormgear, poor synchronization of hob spindle with machine table. 2. Excessive hob thread-to-thread error when cutting gears with non-hunting ratio combination of gear teeth and hob threads. 3. Oil contamination causing gouges.	1. Machine repair is required. 2. Reprofile the hob to reduce thread-to-thread error. 3. Replace oil.

Table 8 Cumulative Pitch Deviation

Cp	Cpk	Tolerance example	Process assessment	Some typical assignable causes for an incapable process. Other assignable causes may exist depending on specifics of the machining technology.	Recommendations for improvements.
Not applicable	Cpk>1	0.050mm	The process is capable.		Machine, fixture, blanks, cutting tool, & cutting conditions, inspection procedure are capable of making gears of specified quality.
	Cpk<1		The process is incapable.	1. Gear blanks radial runout. 2. Workholding fixture runout. 3. Inspection process issues. Use of unqualified datum for inspection.	1. Improve the quality of datum surfaces i.e. bore size or bore-to-face runout, or shaft clamping diameter. 2. Improve quality of the fixture. 3. If possible, use the same datum for inspection and workhollding to avoid runout between different datum.

ference can provide insights into cutting tool quality and cutting condition. One can study the max form error instead of an average. However, the author recommends evaluation of the profile form *average* error instead, as it would reduce the sometimes confusing effects of random small cutting blemishes/gouges, random inspection machine sensitivities to an external environment, or inspection machine filtering issues. Table 3 provides some typical assignable causes for an incapable process.

Profile total error, F_{α}. The total error could be regarded as the sum of its component errors, i.e. — slope and form. When the process is capable for the slope and form characteristics, it would typically be capable for total error as well. If the process is incapable for the total error, one could make improvements by studying and improving the process for the components of the total error — slope and form errors — starting with the worst of the two.

Tooth Lead

Lead slope error, $f_{H\beta}$. Like causes of profile slope error, assignable causes of lead slope average error and lead slope variation come from different contributors. Gear wobble (axial run-out), for example, may have only a slight effect on slope average error, but a *considerable* effect on slope variation. Therefore, it would be prudent to analyze lead slope average error and slope variation separately.

Lead slope average error, $f_{H\beta m}$. The slope error averaged between four teeth spaced roughly 90° around circumference can be affected by various factors such as machining parameters, fixture alignment, or machine tailstock alignment, and others. The tooth lead slope error is a bilateral tolerance, so both Cp and Cpk should be determined (Table 4).

Lead slope variation. The slope variation between four teeth spaced roughly 90° around circumference is affected mainly by fixture and blank quality. The slope variation is the difference between the max/min slope errors, as measured on four teeth of the same flank. This characteristic has a unilateral tolerance that, if not specified on the drawing, can be deduced from the slope error tolerance. For example, if the slope tolerance is ±0.009 m, the slope variation tolerance is (0.009- [-0.009]) = 0.018 m (Table 5).

Lead average form error, $f_{f\beta}$. Lead form error averaged between four teeth spaced roughly 90° around circumference is affected by machine and fixture rigidity, cutting condition, coolant quality, and other factors. One can study the max form error rather than an average. However, the author recommends evaluation of lead average form error, as it would reduce often confusing effects of random small cutting blemishes/gouges, random inspection machine sensitivities to an external environment, or inspection machine filtering issues (Table 6).

Lead total error, F_{β}. Like the profile total error, the lead total error could be regarded as the sum of its component errors — slope and form. When the process is capable for the slope and form errors, it is typically capable for the total error as well. If the process is incapable for the total error, one can make improvements by studying and improving the process for the components of the total error — slope and form errors — starting with the worst of the two.

Tooth Index

Single pitch deviation, f_{pt}. The single pitch deviation (sometimes referred to as pitch variation) is the difference between theoretical pitch and actual distance between two adjacent teeth. Earlier AGMA and DIN standards also discussed spacing variation, i.e. — the difference between two adjacent pitches. Both pitch deviation (variation) and spacing variation errors are frequently affected by the same contributors (Table 7).

Cumulate pitch deviation, F_p. Cumulative/total pitch deviation. (Table 8) provides some typical assignable causes for an incapable process. More often than not, radial run-out is the main culprit for excessive cumulative pitch deviation.

Tooth Thickness

Tooth thickness (or dimension over pins or span measurement) has a bilateral tolerance, so both Cp and Cpk should be determined; average tooth thickness should be analyzed to exclude the effects of run-out (Table 9).

Practical Applications and Recommendations

Figure 5 depicts a "real world" example of the multiple trial runs in the process to improve the capability of a tooth grinding operation, the goal being capability indices greater than 1.33. The first trial determined that the process was incapable — Cp and Cpk are mostly less than unity — (see red and yellow colors). This example shows that it took two additional trials to fully "de-bug" the process.

The process capability indices for gear characteristics, including profile and lead, can provide multiple benefits; a systematic approach to problem solving is just one of the benefits. Others include:

- Capability indices can qualify and quantify the capability of a new technology to consistently produce gears per required specifications.
- Capability indices can help compare and contrast capabilities of different technologies and/or processes.
- Capability indices can quantify existing processes that can help determine if a new technology is required.
- Processes that have capability indices greater than one can utilize a less-frequent inspection strategy, and therefore can benefit from improved efficiency and inspection cost reduction.
- When a quality issue arises, historical capability indices are powerful references that can help identify root causes with greater efficiency and confidence.
- Capability indices could also help more accurately predict the process cost — both fixed (machines) and variable (cutting tools).

Different gear cutting technologies have much in common. For example, an excessive gear blank "face-to-bore" run-out is the prime suspect for an assignable cause of an excessive lead slope variation,

Table 9 Tooth Thickness

Cp	Cpk	Tolerance example	Process assessment	Some typical assignable causes for an incapable process. Other assignable causes may exist depending on specifics of the machining technology.	Recommendations for improvements.
Cp>1	Cpk>1	±0.025mm	The process is capable and well centered.		Machine, fixture, blanks, cutting tool, & cutting conditions, inspection procedure are capable of making gears of specified quality.
Cp>1	Cpk<1	±0.025mm	The process is capable, but not well centered.	Setup issue.	Adjust the center distance between hob and workpiece accordingly.
Cp<1	Cpk<1	±0.025mm	The process is incapable.	1. Hob cutter issues: flute sharpening error, exesssive cutter wear. 2. Machine hob shift mechanism and hob axes have excessive parallelism error.	1. Resharpen the hob. Increase hob shift frequency or shift distance. 2. Reduce parallelism error between the hob axis and machine shifting mechanism.

Figure 5 Three sets of the Cp and Cpk indices show the progress of process improvement efforts.

		Trial 1				Trial 2				Trial 3			
Feature	Descripton	Meeting the spec	Fall-out /30 pcs	Cpk	Cp	Meeting the spec	Fall-out /30 pcs	Cpk	Cp	Meeting the spec	Fall-out /30 pcs	Cpk	Cp
1	Tooth Profile Total Average Error, right flank	No	5	0.36		Yes	0	1.68		Yes	0	6.17	
2	Tooth Profile Slope Average Error, right flank	Yes	0	0.68	1.26	Yes	0	0.66	0.69	Yes	0	2.38	3.54
3	Tooth Profile Form Average Error, right flank	No	3	0.43		Yes	0	5.22		Yes	0	7.41	
4	Tooth Lead Total Average Error, right flank	No	1	0.63		Yes	0	7.31		Yes	0	6.49	
5	Tooth Lead Slope Average Error, right flank	No	4	0.29	1.10	Yes	0	5.59	6.51	Yes	0	5.67	6.36
6	Tooth Lead Slope Variation, right flank	Yes	0	1.57		Yes	0	3.04		Yes	0	14.24	
7	Tooth Lead Form Average Error, right flank	Yes	0	1.45		Yes	0	16.45		Yes	0	24.72	
8	Tooth Lead Average Crown, right flank	No	18	-0.22	0.99	Yes	0	0.93	2.79	Yes	0	2.14	2.97
9	Adjacent Pitch Variation, right flank	Yes	0	1.06		Yes	0	1.81		Yes	0	3.94	
10	Adjacent Spacing Variation, right flank	No	2	0.57		Yes	0	2.06		Yes	0	3.22	
11	Cumulative Pitch, right flank	Yes	0	1.33		Yes	0	1.11		Yes	0	1.49	
12	Tooth Profile Total Average Error, left flank	No	2	0.51		Yes	0	3.25		Yes	0	6.42	
13	Tooth Profile Slope Average Error, left flank	Yes	0	0.69	0.72	Yes	0	0.84	1.16	Yes	0	1.92	1.98
14	Tooth Profile Form Average Error, left flank	No	5	0.28		Yes	0	5.20		Yes	0	6.13	
15	Tooth Lead Total Average Error, left flank	No	1	0.48		Yes	0	6.43		Yes	0	6.98	
16	Tooth Lead Slope Average Error, left flank	No	1	0.50	1.33	Yes	0	3.58	5.97	Yes	0	10.20	11.99
17	Tooth Lead Slope Variation, left flank	Yes	0	1.41		Yes	0	3.19		Yes	0	11.99	
18	Tooth Lead Form Average Error, left flank	Yes	0	1.28		Yes	0	16.45		Yes	0	5.15	
19	Tooth Lead Crown Average, left flank	No	29	-0.83	1.23	Yes	0	0.94	2.94	Yes	0	3.83	5.40
20	Adjacent Pitch Variation, left flank	Yes	0	0.81		Yes	0	3.10		Yes	0	4.00	
21	Adjacent Spacing Variation, left flank	No	5	0.23		Yes	0	2.50		Yes	0	4.22	
22	Cumulative Pitch, left flank	Yes	0	1.53		Yes	0	1.15		Yes	0	1.55	
23	Dimension Over Pins	Yes	0	0.59	0.60	Yes	0	0.29	0.54	Yes	0	1.32	2.06
24	Total Composite Error	No	1	0.62		Yes	0	0.80		Yes	0	1.41	
25	Tooth-to-tooth Composite Error	Yes	0	1.27		Yes	0	1.42		Yes	0	5.23	

regardless of whether the gear was produced on a grinding, hobbing, shaving or shaping machine.

However, every technology has its own peculiarities. For example, one needs to address a grinding wheel, a shaving cutter or a shaping cutter when a profile form error needs to be reduced on a grinding, shaving or shaping machine, respectively.

Once again, the (common and assignable) root causes and recommendations for improvements suggested in this article are just starting points that could be expanded and tailored for specific machines, fixture, blanks, cutting tools, set-ups, and experiences.

In rare cases it is possible that after all assignable causes are explored and eliminated, the process becomes in control — but remains incapable. Since both assignable and common causes derive from the same contributors (i.e. — machine, fixture, blanks, cutting tool, set-up, and cutting conditions), one could attempt to find a dominant common cause contributor(s) by following the same process as the one described above. After the dominant, common cause contributor is identified, one could attempt to improve the process by tightening the tolerances of that contributor. For example, one could tighten the tolerances of blanks, or workholding fixture, or use a higher-precision cutting tool, depending on what the dominant contributor is. But if improvement of the contributing factors is not possible, a different gear manufacturing process should be considered — or gear tolerances should be revisited.

In conclusion, customers continuously demand better quality, greater reliability, and lower cost. Application of process capability indices will not only support your process improvement efforts, but will also quantify the improvements with transparency and confidence.

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Yefim Kotlyar is a technical specialist at Navistar, responsible for the design and validation of gearing systems. His broad experience in the art of gearing includes the development of various gear cutting technologies, analytical inspections, and evaluation technologies for gears and hobs. Kotlyar has served on a number of AGMA technical committees, and he has authored numerous articles on gearing.

Fabrication of Directly Designed Gears with Symmetric and Asymmetric Teeth

Alexander L. Kapelevich and Yuriy V. Shekhtman

Introduction

When compared with the traditional gear design approach — based on pre-selected, typically standard generating rack parameters — the alternative Direct Gear Design (Ref.1) method provides certain advantages for custom, high-performance gear drives. Among them are increased load capacity; efficiency; length-of-service; reduced size and weight; noise/vibrations; and cost. However, the manufacture of such non-standard gears requires custom tooling and certain alterations of known gear fabrication processes.

This paper presents specifics of application main methods of gear fabrication, i.e. — form and generating machining (cutting and grinding); gear forming injection molding technology; net forging; powder metal (PM) processing; die casting; and wire EDM gear prototyping. It also describes tooling profile definition, dependent upon the selected gear fabrication method. It presents the Genetic Molding Solution technique for compensation of differential warpage and shrinkage for plastic injection molding tooling — that enables enhancement of gear accuracy and shortens the process development cycle.

Table 1 Main machining processes used for spur and helical gears

Type of process		Type of tooling
Form Machining	Cutting	Form disk or end mill cutter, broach, etc.
	Grinding	Grinding wheel
Generating Machining	Cutting	Hob, shaper cutter, rack cutter, shaver cutter
	Grinding	Grinding wheel
Contour Machining	CNC milling	Cylinder or ball mill cutter
	Wire-cut EDM	Wire
	Laser cutting	Laser beam
	Water Jet cutting	Water or water and abrasive media mixture stream

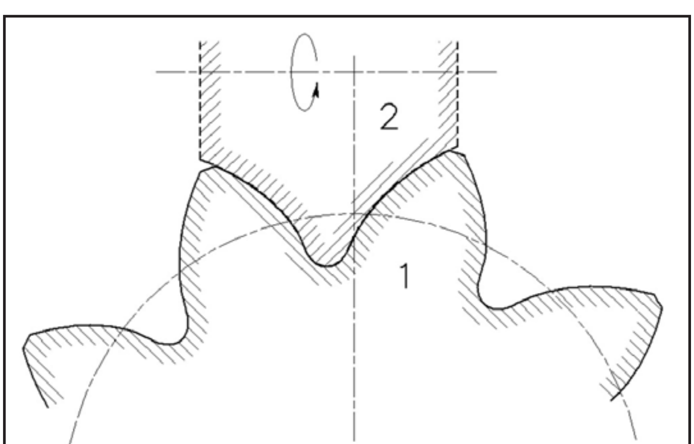

Figure 1 Gear form machining: 1) gear profile; 2) tool profile.

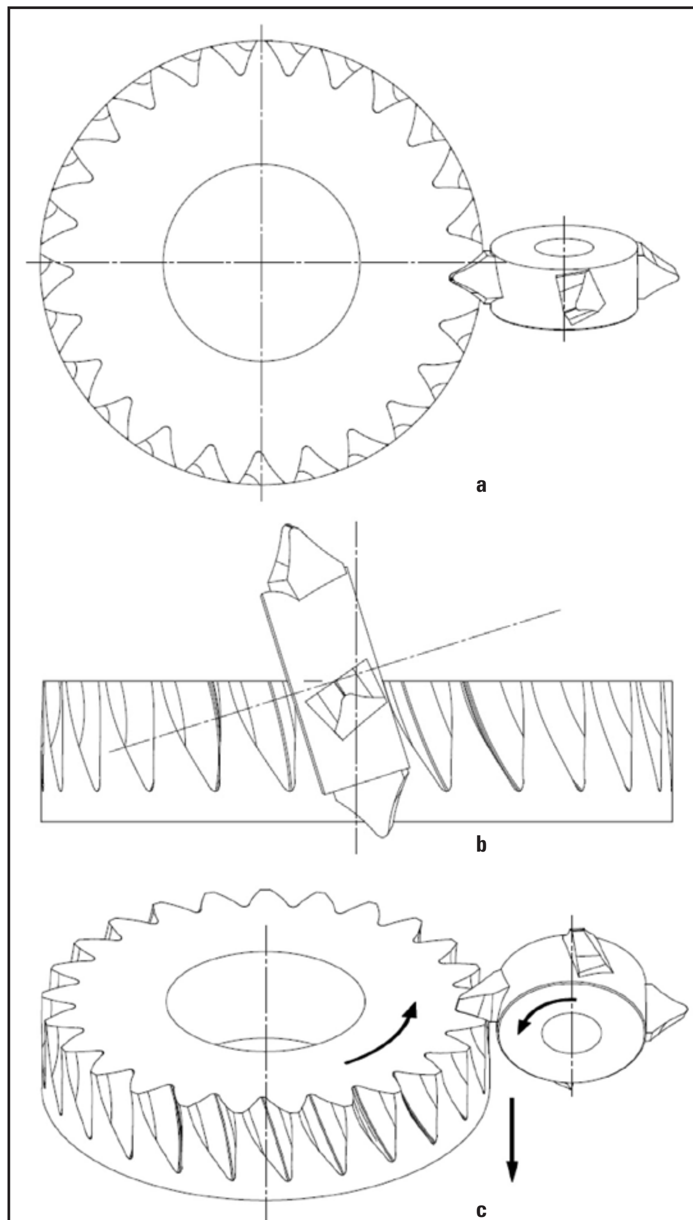

Figure 2 Gear fly cutting schematics: a) top view; b) right view; c) isometric view.

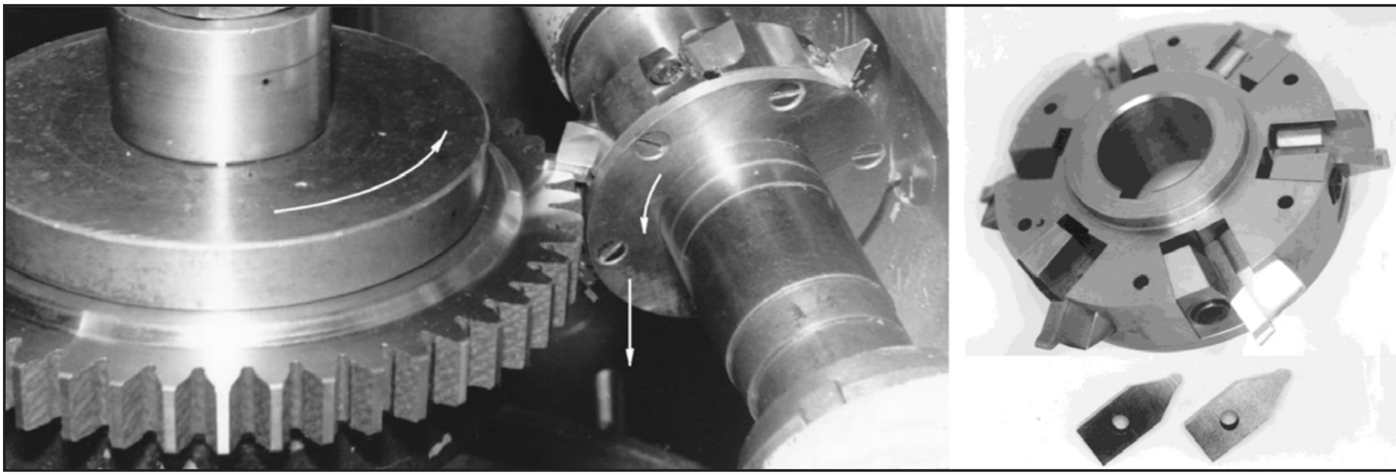

Figure 3 Gear fly cutting: a) hobbing machine set-up; b) adjustable fly cutter with inserts.

Gear Machining

Form machining. In the form gear cutting or grinding process (Fig. 1), a tool profile is the same as a space profile between gear teeth; this process is applicable for spur and helical gears. A form machining tool is unique for every gear tooth profile and its cost is practically the same for standard or custom-directly designed gears. *Note*: *accuracy of form-cutting-tool-positioning relative to the gear blank is critically important*.

In gear form machining, usually one tooth is machined after another. When machining of one tooth is completed, the indexing device (rotary table) positions a gear blank for the next tooth cutting. But there is one type of form machining process, i.e. — gear fly cutting (Ref. 2) — that has a tool (fly cutter) in mesh with the gear blank (Figs. 2–3). It uses conventional gear hobbing machines that have a cutter and gear blank in constant synchronized rotation. However, unlike the gear rack generating process, the space between teeth is shaped by a whole cutter tooth profile — exactly as in conventional form machining with the disk cutter (Fig. 1).

The gear fly cutter also looks similar to the conventional gear disk cutter, but all cutter edges are turned at the start angle ϕ that is defined as:

$$\phi = arcsin\frac{m_n n_t}{d_t} \quad (1)$$

where:

m_n is the normal module of the gear
n_t is the number of the fly cutter teeth
d_t is the fly cutter pitch diameter

A gear fly cutter also can be considered as the multi start gear hob that has just one tooth in each start. The cutter set up angle ϕ relative to the gear plane is defined the same way as for gear hobbing:

$$\varphi = \beta \pm \phi \quad (2)$$

where:

β gear helix angle, sign "+" if the gear helix and cutter start angle have similar directions (right or left); and sign "–" if the gear helix and cutter start angle have opposite directions.

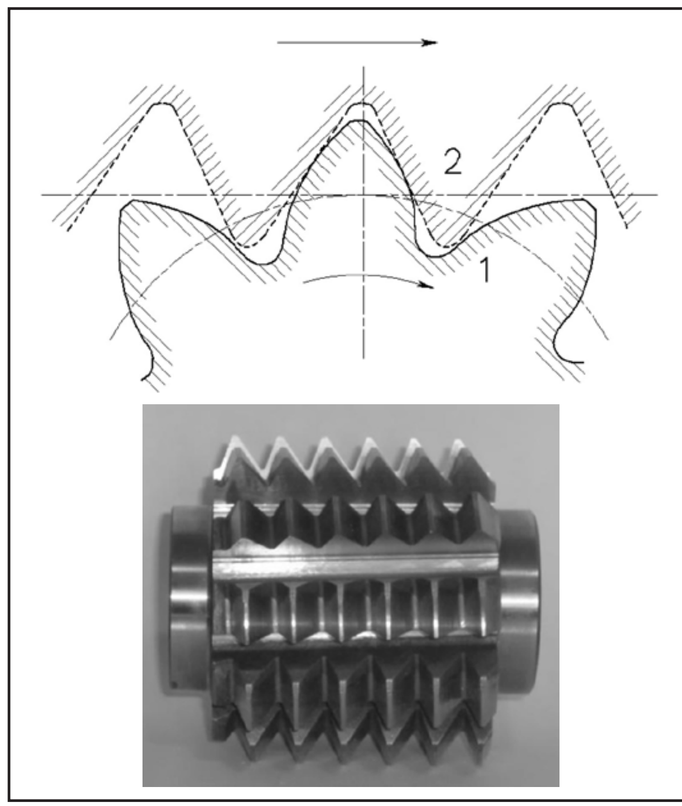

Figure 4 a. rack generating: 1) gear profile; 2) hob or rack cutter profile; b. asymmetric gear hob cutter.

The adjustable gear fly cutter is shown in Figure 3b; it makes possible the machining of gears with different numbers of teeth and modules by using replaceable cutting and angle inserts.

Generating machining. Schematics of the rack generating gear cutting or grinding process are shown in Figure 4. In this process a gear blank and tool are engaged in a mesh, and all gear teeth are machined practically simultaneously. In traditional gear design the tooling (a hob or rack cutter) profile is determined early on in the gear design procedure. In combination with its position relative to the gear center (addendum modification or *X*-shift), the tooling rack profile defines the gear tooth and whole gear profiles.

Direct Gear Design applies a different approach. The optimized gear tooth and whole gear profiles are described without use of any redefined tooling rack parameters. Next, the reverse-generating technique is applied to find the tooling rack profile, using the known gear profile. This technique assumes that in the rack/gear mesh, every point of the gear tooth profile has its mating point on the rack tooth profile. Figure 5 illustrates how the tooling rack profile point A_t position is defined from the gear tooth profile point A_g position. In order to find the generating rack profile point A_t corresponding to the gear tooth profile point *Ag*, the line A_gB_g perpendicular to the tooth profile in the point A_g is constructed. The point B_g lays in an intersection of the line A_gB_g with the gear pitch circle. The gear tooth profile and line A_gB_g are rotated on the angle X_g, relative to the gear center until the point B_g reaches its pitch point position B_g', where the gear pitch circle 3 is in tangent with the rack pitch line 4. Then the point A_g is in the position A_g' where the gear tooth profile 1' is tangent to the rack profile 2'. The line A_g'B_g' is moved parallel to the rack pitch line 4 on distance B_g'B_t that is equal to the length of the arc B_gB_g'. This movement puts the point A_g' in position A_t at the rack profile that is corresponds to the point A_g at the gear tooth profile. This approach allows for the defining of any generating rack profile point that is related to a certain gear tooth profile point.

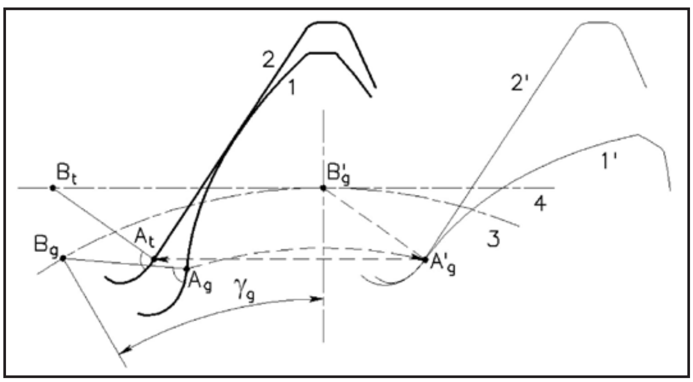

Figure 5 **Generating rack profile definition: 1 and 1' – gear profile positions; 2 and 2' – rack cutter profile positions; 3 – gear pitch circle in mesh with rack; 4 – rack pitch line in mesh with gear.**

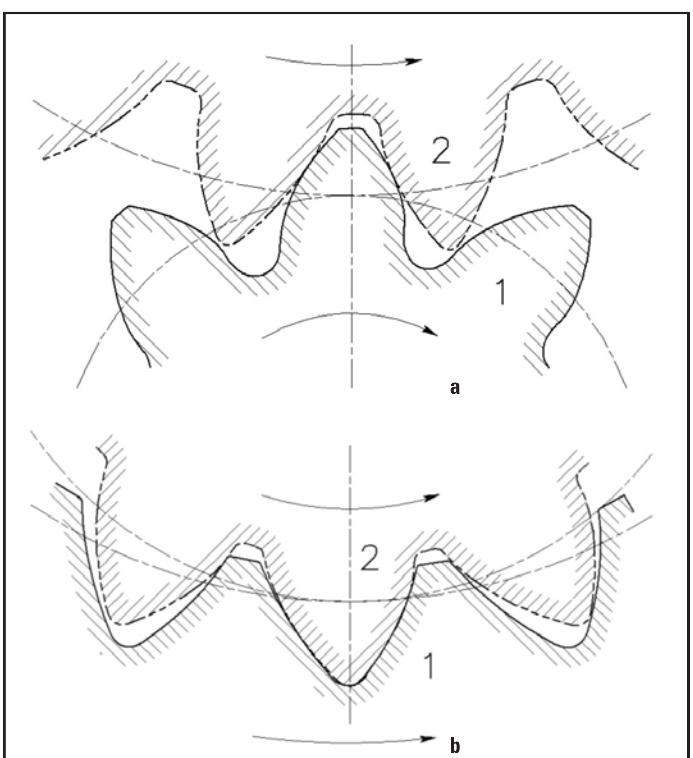

Figure 6 **Generating of external (a) and internal (b) gears: 1) gear profile; 2) shaper cutter profile.**

In those cases where a gear is made by shaping cutting, traditional gear design suggests that the shaper cutter parameters and profile are known prior to gear design. In combination with its position relative to the gear center (addendum modification or *X*-shift), the shaper cutter profile defines the gear tooth and whole gear profiles (Fig. 6).

In Direct Gear Design, the shaper cutter profile is also defined after the gear profile is already known. This gear profile is used for the shaper cutter profile reverse-generating, using the similar technique as for the rack-type tooling profile definition. It assumes that in the shaper cutter/gear mesh, every point of the gear tooth profile has its mating point on the rack tooth profile.

Figure 7 demonstrates how the shaper cutter profile point A_t position is defined from the gear tooth profile point A_g position. In order to find the shaper cutter profile point A_t corresponding to the gear tooth profile point A_g, the line A_gB_g perpendicular to the tooth profile is constructed. The point B_g lays in an intersection of the line A_gB_g with the gear pitch circle. The gear tooth profile and line A_gB_g are rotated on the angle γ_g relative to the gear center up until point B_g reaches its pitch point position B_g, where the gear pitch circle 3 is tangent to the shaper cutter pitch circle 4.

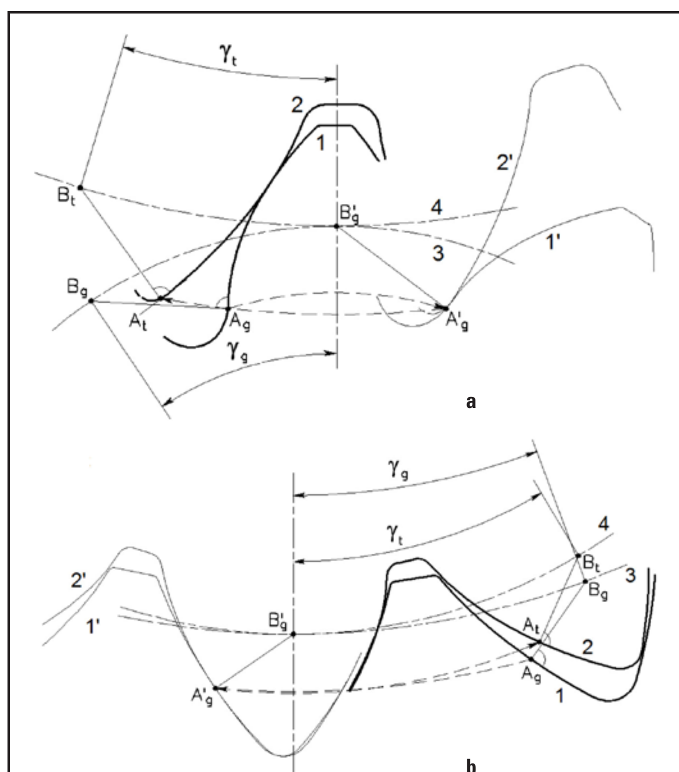

Figure 7 **Generating gear shaper cutter profile definition for external (a) and internal (b) gears: 1 and 1' – gear profile positions; 2 and 2' – shaper cutter profile positions; 3 – gear pitch circle in mesh with shaper cutter; 4 – shaper cutter pitch circle in mesh with gear.**

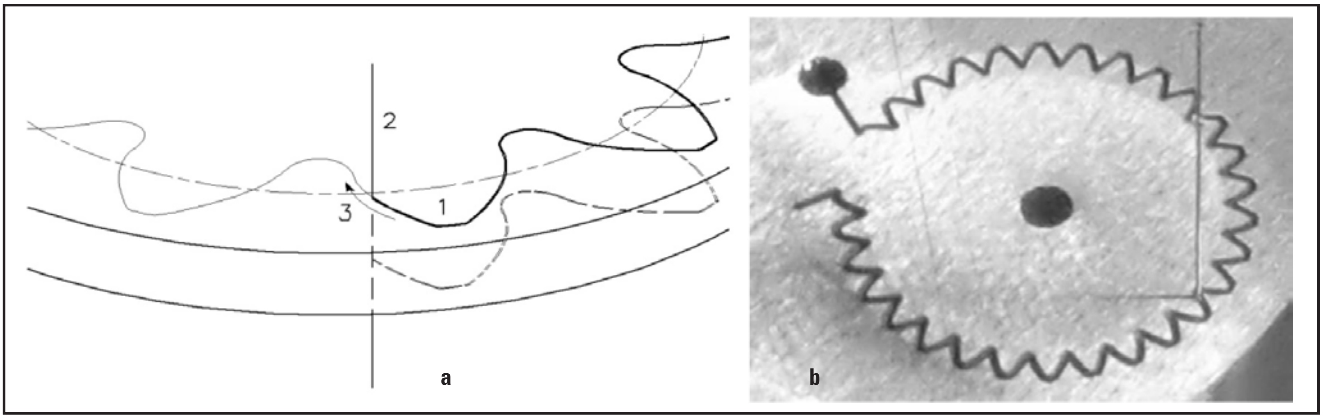

Figure 8 **a. schematic of contour gear machining: 1) gear profile; 2) cutting tool; 3) cutting direction; b. wire EDM gear cutting.**

The angle γ_g is:

$$\gamma_g = \frac{B_g B_g'}{d_{pt}} \quad (3)$$

where:
$B_g B_g'$ is the length of arc $B_g B_g'$
d_{pg} is the gear pitch diameter in the mesh with the shaper cutter

Then the point A_g is in the position A_g' where the gear tooth profile 1' is tangent to the shaper cutter profile 2'. The line $A_g'B_g'$ is rotated back relative to the shaper cutter center on angle γ_t that is:

$$\gamma_t = \gamma_g \frac{d_{pg}}{d_{pt}} \quad (4)$$

where:
d_{pg} is the gear pitch diameter in the mesh with the shaper cutter.

This movement puts the point A_g' in position A_t at the shaper cutter profile that corresponds to point A_g at the gear tooth profile. This approach allows definition of any shaper cutter profile point corresponding to a certain gear tooth profile point.

The gear pitch diameter in mesh with generating tooling (hob, rack or shaper cutters) is not necessarily equal to the operating pitch diameter with the mating gear. Accordingly, the pressure angle in mesh with the generating tooling can differ from the operating pressure angle. The pressure angle in mesh with the generating tooling selection is important. An extreme pressure angle (close to zero) results in a tooling profile that cannot sustain the required gear profile, due, for example, to the pointed tooling tooth tip or its overly small radius. It also adversely affects cutting condition, gear tooth profile surface finish, and tooling life.

One of the benefits of the generating gear process is the ability of using one tool (hob, rack or shaper cutter) for machining gears with different numbers of teeth. This allows reduction of tooling inventory and cost of low- and medium-volume gear production where tooling-share-per-one-gear is relatively high. In general, traditionally designed mating gears are machined with the same generating gear cutter; however, in mass gear production, gear cutting (or grinding) machines are typically set up to machine one gear and they use a dedicated set of tools — including the gear cutters.

Directly designed gears require a custom-dedicated generating tool for every gear with a different number of teeth. This increases tooling inventory and gear cost when production volume is low. Although, even in this case, application of directly designed gears can be beneficial if their improved performance justifies a production cost increase — like, for example, in aerospace and racing transmissions. In mass gear production, a share of custom-dedicated-machining-tool-per-gear is low and, as a result, the cost of directly designed gears becomes practically equal to traditional gears. This makes them applicable and sensible for automotive, agriculture, and other industries. Reverse-generating of the tooling profile from the gear profile is applicable for involute as well as for non-involute gears.

Contour machining. Contour machining (Fig. 8) is not a highly productive gear fabrication method; but, unlike form or generating machining, it does not require special tooling. This makes it very useful for gear prototyping and the quick fabrication of a relatively small quantity of gears.

The contour gear machining processes include CNC milling, wire-cut EDM, laser cutting, water jet cutting, etc. In many cases, in order to achieve higher accuracy and surface finish, the contour machining process may require several passes, with the final pass removing just a small amount of material. While most of these processes are used only for spur gears, the CNC ball cutter milling can be used for helical gears as well. The contour cutting path (Fig. 9) is defined with off-set S from the nominal (average material condition) gear profile. This off-set contains one-half of the cut width W_c and some additional off-set that depends on the machining process. The additional off-set

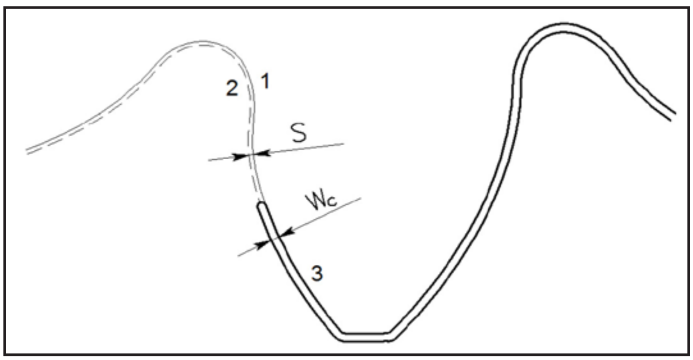

Figure 9 **Contour cutting path: 1) nominal (average material condition) gear profile; 2) tool path; machined gear profile; W_c – cut width; *S* – tool path off-set.**

may include a stock for final machining, over-cut or over-burn (for wire EDM and laser machining), and/or a defective layer that should be removed by a tooth surface treatment operation; e.g. — polishing.

Gear Forming

Forming gear fabrication processes. Plastic and metal injection molding; powder metal processing; net forging; stamping; die casting; extrusion; gear and worm rolling; etc. are very cost-efficient for mass-produced gear drives. Most of these forming gear fabrication processes have a similar tooling component that actually defines a gear shape and its accuracy, i.e. — a tooling (mold or die) cavity. Any gear forming process cavity is dedicated to a particular gear profile, which makes Direct Gear Design very acceptable for gear forming technology, as the production cost of the custom-optimized gears is practically the same as that of the similar-sized, standardized gears.

The cavity has a profile similar to the gear — but adjusted for shrinkage and warpage (Fig. 10) that greatly affects both gear size and shape accuracy. This makes the accurate prediction of shrinkage and warpage critical for all gear forming technologies — but *particularly* for the plastic injection molding process. Plastic gears often have intricate body shape, including ribs or spokes to maintain limited, maximum material thickness to exclude voids, and/or for weight and cost reduction. They also are often incorporated as one piece with other mechanism components such as, for example, shafts, cams, etc. These design specifics, in combination with a huge variety of available gear polymers and enhancing additives (for increased strength, thermo resistance, lubricity, etc.) make prediction of gear shrinkage and warpage an extremely difficult process. In many cases, gear molders rely on a sometimes costly trial-and-error method — with varying degree of success. Typically, this "educated guess" method works better for gears with relatively simple body shapes (like, for example, the flat uniform disks with small central holes) that are made out of generic unfilled polymers.

A totally different approach to molding distortion compensation is proposed in the literature (Ref. 3), referred to as the Genetic Molding Solution. Similar to how DNA contains genetic information about the entire living organism, the shape of the molded part reflects the originally designed profile, polymer material properties, tooling design, and molding process parameters. The Genetic Molding Solution method is based on mathematical prediction that defines a transformational function describing relations between the initially molded sample gear profile and its actual, initial cavity profile. Once this function is defined, the target gear profile replaces the first molded sample profile as the transformational function variable to calculate the final cavity profile. The transformational function is based on a system of trigonometric and polynomial functions.

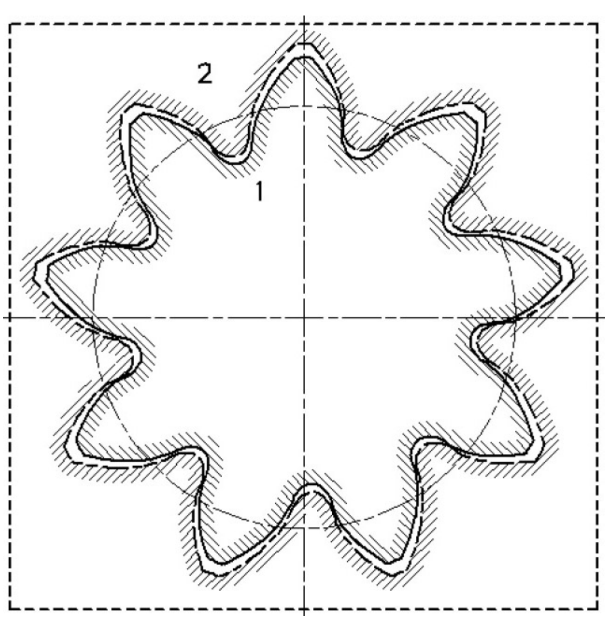

Figure 10 Gear molding; 1) gear profile; 2) mold or die cavity profile.

The initial cavity profile coordinates are:

$$M_1 = K_{sh} \times D \tag{5}$$

where:

D target gear profile data set, presented as X,Y coordinate points of the 2D CAD model typically constructed for average material conditions

K_{sh} polymer linear mold shrinkage coefficient provided by the material supplier. These initial cavity profile coordinates M_1 can be also presented as:

$$M_1 = f(P) \tag{6}$$

where:

P initial sample gear profile data set, presented as X,Y coordinate points provided by the CMM inspection of actual molded gear

f transformation function describing relations between the initial cavity and initial sample gear profiles

Then the final cavity profile coordinates are:

$$M_2 = f(D) \tag{7}$$

Unlike previously mentioned approaches, the Genetic Molding Solution method is based on the "black box" concept and uses only gear and cavity inspection results and math that define transformation function between them. It does not require knowledge of any specific data related to polymer material, tooling, and molding process parameters.

Practical application of this method entails eight steps:

(1) ***Target gear profile definition (data file #1).*** The X,Y coordinate points extracted from the gear CAD model present a desired nominal gear profile at average material condition. A number of these coordinate points are typically several-hundred-per-one-gear-tooth.

(2) ***Initial cavity profile definition***. Initial cavity profile is the scaled up target gear CAD profile using the polymer linear mold shrinkage coefficient K_{sh} from its specification.

(3) ***Fabrication and inspection of initial mold cavity (data file #2).*** CMM inspection produces the X, Y coordinate points (several-hundred-per-one-tooth-space) accurately describing the initial cavity.

(4) Molding process optimization. Gears are molded using the initial cavity, without concern about the gear shape. A goal here is to achieve a stable and repeatable molding process with the part dimensional variation significantly lower than the required accuracy tolerances. Any material flaws — voids, for example — are unacceptable. Once this goal is reached, the molding process must be "locked in" and certified; no changes to the process are now allowed. Using the optimized process, several dozen gears are molded.

*(5) **Representative gear specimen selection.*** All molded gears are roll tested and inspection data is analyzed. The single-most representative preliminary gear specimen is selected. This specimen should have average statistical tooth-to-tooth and total composite errors (TTE and TCE).

*(6) **Gear specimen inspection (data file #3).*** CMM inspection produces the X, Y coordinate points (several-hundred-per-one-gear-tooth) accurately describing the initial cavity. Inspection data of the initial cavity and the gear specimen must have the same axes orientation to provide the each gear tooth and its cavity space accordance.

*(7) **Final cavity profile definition and fabrication***. The Genetic Molding Solution software uses the gear specimen and initial cavity data (files #2 and #3) to generate a transformation function *f*. The target gear data (file #1) is then used as the variable of this transformation function to define the final cavity profile, or output data set. The same axes orientation of all three data file is absolutely critical. Any angular rotation or mirroring of the data points totally compromises the mold cavity adjustment results. The final cavity manufactured and then undergoes a CMM check-inspection.

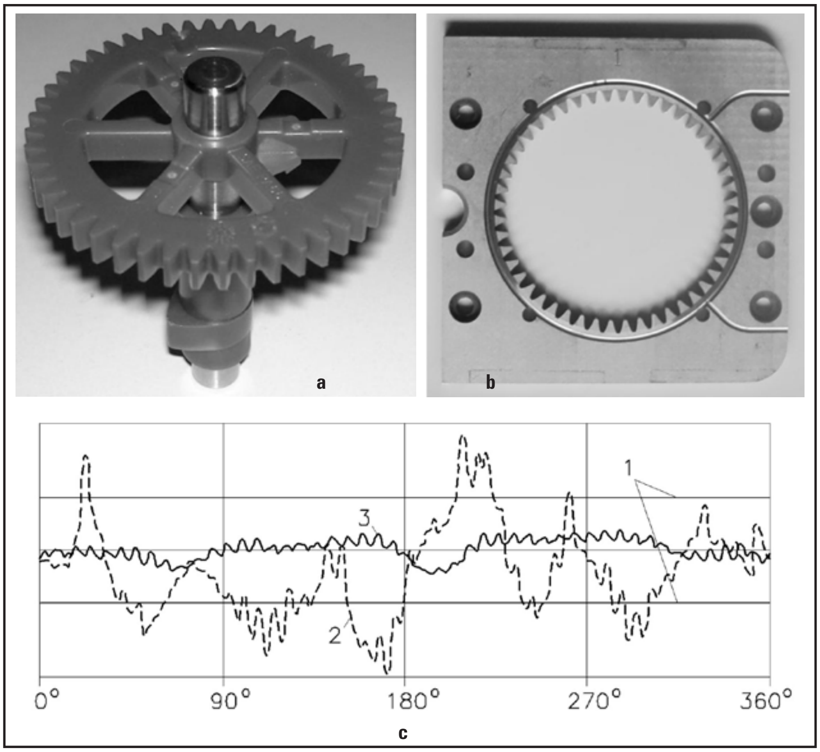

Figure 11 **Genetic Molding Solution application: a) camshaft gear; b) gear mold cavity; c) roll rest chart overlay; 1) total composite tolerance limits; 2) initial specimen chart: 3) final gear chart.**

*(8) **Final gear profile.*** And last, gears are molded using the final mold cavity. The CMM data of the molded gears should be identical to the specified gear profile, within the molding process accuracy variation.

For successful application of the Genetic Molding Solution method, the initial and final gear molding must be done with the same-batch polymer, on the same molding press, using the same tool. The current version of the software uses the 2D data sets and works well for spur plastic gears with relatively low face width. For helical and wide spur gears, this method should be used for several (typically 2 – 3) gear sections.

An example of this application method for the camshaft gear is shown in the Figure 11a. This gear is not particularly molding friendly; it has a metal, over-molded shaft, two cams, six spokes, and three injecting gates located in the middle of these spokes. Mold development for this gear using traditional methods requires considerable time and guesswork, and several mold cavity iterations. The Genetic Molding Solution method develops the desired cavity in short order by *direct calculation* — with only *one* extra (initial) cavity.

Figure 11c shows a comparison of roll test graphs of the initial, most representative gear specimen with the final gear sample. The initial gear roll test measurements (TTE and TCE) greatly exceed the required accuracy level, but the final gear roll test results fit well inside the TTE and TCE tolerance limits.

The Genetic Molding Solution method significantly accelerates the injection plastic mold cavity development by eliminating the "guesswork" component of the final cavity prediction and providing its profile definition by use of direct calculation. It also can be considered for other gear forming processes that use mold or die cavities, such as power metallurgy, die casting, net forging, and more.

Summary

- Main methods of the directly designed gear fabrication are described
- Fly gear cutting process is illustrated
- Reverse-generating method for definition of the custom hob and shaper cutter profiles is presented
- Genetic Molding Solution technique for compensation of differential warpage and shrinkage for plastic injection molding tooling is explained

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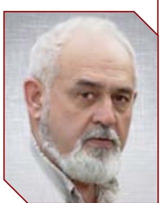
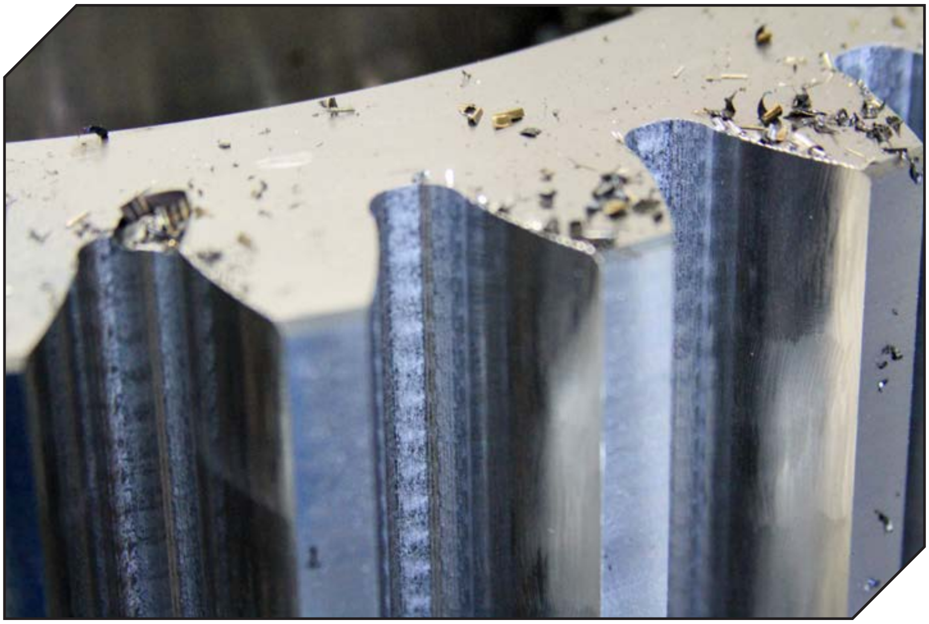
Dr. Alexander L. Kapelevich is the owner of the consulting firm AKGears, LLC, developer of modern Direct Gear Design methodology and software. He has over 30 years of experience in custom gear drive development. Kapelevich is the author of the 2013 book — *Direct Gear Design* — and has presented/published dozens of technical articles at gear conferences and symposiums worldwide. *(ak@akgears.com)*.

Given his 40-plus years of experience, **Dr. Yuriy Shekhtman** is an industry expert expert in mathematical modeling and stress analysis. For example: he has created a number of FEA- and other numerical methods-based computer programs. A software developer for AKGears, Shekhtman has in addition authored many technical publications *(y.shekhtman@gmail.com)*.



Making it in Mobile

Alabama manufacturer puts InvoMilling to the test



"If it's broken, bring it on in." That's the advice offered by Roy Parker, president and owner of Jones Welding Company Inc. Since 1911 the Mobile, AL machine shop has enjoyed a reputation for taking care of whatever parts need fixing. It's no wonder. With 11 Mazak CNC lathes and machining centers — several with 5-axis or multitasking capability — along with a full complement of gear hobbers and shapers, and a handful of skilled machinists to run them, Jones Welding (JWC) can deal with most anything that comes through its doors.

JWC sits not far from the Port of Mobile, the only deep-water port in the state. David Deering, power transmission specialist at Jones, explained how the company benefits by its close proximity to the water. "We service much of the shipping industry in the area. There's a lot of service and repair work, and quite often we have to analyze and reverse engineer one-of-a-kind parts."

Aside from replacing the broken components found in cargo ships and container handling equipment, JWC also does custom work for the steel and chemical industries. "We're quite versatile," Deering said. "We started in the pulp and paper industry and evolved from there. Today we service whatever industry we can sell a product to."

Despite its extensive CNC capability, however, Deering pointed out that JWC isn't a production job shop, specializing instead on quick-turnaround, low-volume work. "An order for 50 pieces is a large quantity for us."

With small production runs, changeover is a big factor in any company's profitability. To meet the need for reduced setup time, JWC invested in quick-change chucks and workholding, and outfitted its machines with Coromant Capto toolholders, a modular tooling concept from Sandvik Coromant Corp., Fair Lawn, NJ. The Capto system, Deering explains, allows JWC's machinists to change cutting tools in seconds, making this job shop very effective at producing parts in small batches.

Many of those parts are gears. JWC's equipment allows the company to cut gears between ½" to 88" in diameter. The problem, said Deering, is tooling up for all those different gears. "Each gear profile requires a specific hob. At a few hundred bucks a pop, it can really add up."

This means JWC invests in hobs that will quite possibly never be used again, a cost that is difficult to pass on to the customer. Adding insult to injury, many of JWC's jobs are emergencies — when a ship can't leave port because of a broken transmission gear, millions of dollars in automobiles, fuel oil or commercial merchandise become stranded. If the hob needed to cut that gear isn't sitting in JWC's tool crib, it frequently becomes necessary to overnight one in, further increasing costs and downtime.

Exploring New Waters

JWC's president is a big believer in continuous improvement. "We're always trying to push the envelope," said Parker. "That means increasing efficiency and production wherever possible." Because of this, the company started milling gears on its 5-axis vertical machining center, using carbide end mills to interpolate the tooth form. "We'd rough out the slot, then come back with a ball end mill and profile the face. But the only way you can get decent part quality and surface finish is by using very small stepovers, similar to 3D machining a mold cavity. It's very time intensive."

Despite the long cycle time, this was still the best option for some jobs, short of ordering an expensive hob that might be used once. Parker knew there had to be a better way. As it turns out, he was right. "We first saw the InvoMilling process at IMTS, and again at Gear Expo in Detroit. We recognized it as a way to drastically reduce our tooling inventory and cut down on the time spent waiting for hobs." Unfortunately, InvoMilling was only available on DMG/Mori equipment at that time, so adopting the modular tooling system would mean a move to new machine tools and controls.

So when Parker received the invitation to Mazak's 2013 Discover open house, he and his team boarded an airplane and headed to Kentucky. They were impressed by what they saw there. Mazak and Sandvik Coromant had recently reached a licensing agreement on InvoMilling, and before Parker left the show, he'd purchased the InvoMilling system and a shiny new Mazak Integrex i-630V Multi-tasking CNC to go with it.

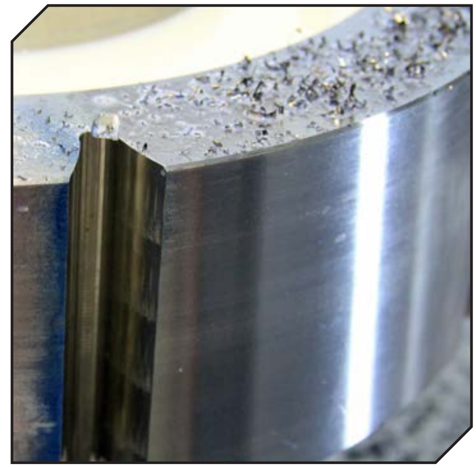
"Over the past few years, we'd gotten much better at gear making with our CNCs. We decided it made sense to jump in all the way." What convinced him most is InvoMill's ability to cut the complete range of helical and spur gears — module 1 to module 12 — with just 3 cutter bodies. In addition, a cutter with carbide inserts would run at spindle speeds 3–4 times faster than the HSS hobs they'd been using, and take heavier cuts besides. "We knew the combination of InvoMilling together with the Integrex would give us a higher quality gear with a shorter cycle time."

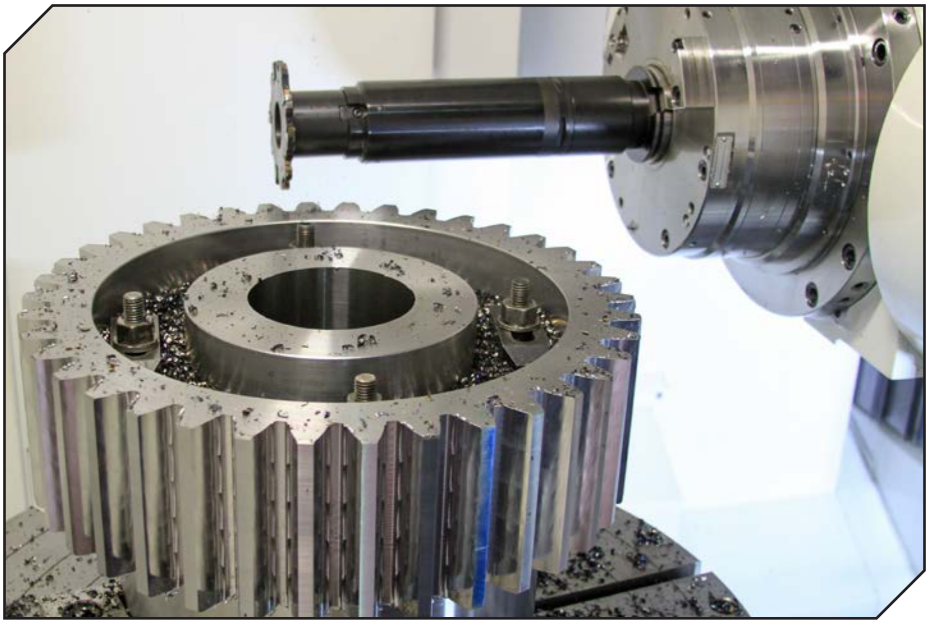
Putting InvoMill to the Test

The new Integrex arrived shortly after Parker and his team's return to Mobile and they got to work. Supporting them was Mark Briel, application engineer at Sandvik. He helped JWC with the initial setup and programming of its first job for the Integrex — the replacement of a 1045 steel spur gear off of one of the port's overhead crane systems. With a finished size of 18.9" diameter × 5.5" wide, there was plenty of metal to remove from the gear blank, giving machines and cutters alike a thorough test.

Briel recommended Sandvik's PVD-coated 1030-grade carbide, an insert well suited for gear milling applications. "Because it was such a large module size, we used one of our 331 slotting cutters to rough out the gear form. We took one pass straight down the middle, and another pass for each of the flanks. Once the majority of the material was removed, it only took one InvoMilling pass to generate the completed involute gear form. All they had to do after that was sandblast, nitride treat and ship to the customer."

Not every gear is this simple, Briel explained. Some customers will use InvoMilling to rough prior to heat treat and grinding, but it could also be used





for hard milling heat treated material. “The processing is largely determined by the amount of material removed, how the gear is going to be used, and what AGMA grade is required.”

Parker explains that this first gear was a beta test of the Invomilling process, and that JWC has used conventional HSS hobs to cut this particular gear a number of times in the past. This gave them a good baseline for comparison. That said, he was unable to share the actual before and after cycle times, except to say it produced “a better gear in less time.” Deering agreed. “The InvoMill’s radial cutting action allows you to plunge, mill and slot at the same time. There’s none of the back and forth profiling needed with an end mill. And we can use a greater portion of the cutter, reducing tooling costs. Compared to an end mill, it gives us a phenomenal increase in production rates.”

In all fairness to conventional hobs, Parker admitted they have their place, and many of JWC’s gears are still cut on manual machines. Quite often, this means set it and forget it—the machinist can walk away for a few hours while the hob does its work. The problem, Parker said, is that jobs at JWC have short shelf lives. “Customers come in and tell us their equipment has broken down. They need a new gear, maybe several of them, right now. Most of the time we can accommodate them, even if it means running the job overnight. But we can’t possibly keep every gear hob on hand, and they don’t have time to wait for us to order one.”

With InvoMilling, three cutter bodies and a few packs of inserts cover the lion’s share of gear profiles, without worrying about when the FedEx man will show at the door, or how many teeth that HSS gear hob will last. “There are only so many production hours in the day,” said Parker. “Our goal is to use efficient tooling and machines to produce parts more quickly, allowing us to get that much more through the door in a given time.”

Parker said JWC has invested in the future. Like many shops, production and customer service is their top priority. “Whether it’s for the steel mills or the shipping industry, we’re trying to stay ahead of everybody else. By becoming more efficient, we’re money ahead, and have time to move on to the next emergency. InvoMilling helps us do that. It’s an impressive tool, and an impressive process.”

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OSG

DONATES NEW TOOLING TO CHICAGO-AREA COLLEGES

OSG recently announced that it is donating over $85,000 in new tooling to the College of DuPage in Glen Ellyn, IL, Joliet Junior College and the College of Lake County in Grayslake, IL to support their manufacturing technology programs.

As part of this effort, Mike Grzybowski, OSG regional manager, delivered over $30,000 worth of tooling to the Manufacturing and Machining department of the Business and Technology Division of the College of DuPage. Included with the tooling donation was other OSG training aids including wall and pocket decimal charts, catalogs and safety glasses.

"By giving these cutting tools to the colleges, OSG is providing students with the opportunity to be trained with industry-proven, high quality tooling, and OSG also enables the schools to save valuable funds that are not always available," said Grzybowski.

Grzybowski met with Jim Filipek, the associate professor and program coordinator at the College of DuPage, who will be teaching students with the tooling from OSG.

"This action by OSG allows us to train the work force of tomorrow with the tooling of today." said Filipek. "The manufacturing programs are vital to train a skilled workforce for the future, and OSG is committed to helping shape future manufacturers."

Modern Heat Treat

ADDS ITS SEVENTH AFC-HOLCROFT BATCH FURNACE

Modern Heat Treat, a commercial heat treating operation located in Richland Hills, TX, is prepared to take delivery of a new AFC-Holcroft Universal Batch Quench (UBQ) furnace, size 36-72-44. The UBQ furnace is scheduled to ship during the fourth quarter of 2014.

This addition brings the number of AFC-Holcroft UBQ furnaces bought by Modern Heat Treat to seven. Modern Heat Treat has systematically added one furnace per year for the past four years. The addition of this seventh AFC-Holcroft UBQ furnace further boosts the its production capability by another 6,000 pounds gross load capacity, and will be a duplicate of existing AFC-Holcroft furnaces already running production.

Modern Heat Treat selected the UBQ design to gain maximum flexibility in controlling their production. As production increased, Modern Heat Treat has benefited from the modular, flexible UBQ design to add new equipment to their facility incrementally. Individual furnaces can be idled, then restarted as needed for maintenance service, changes in process or production.

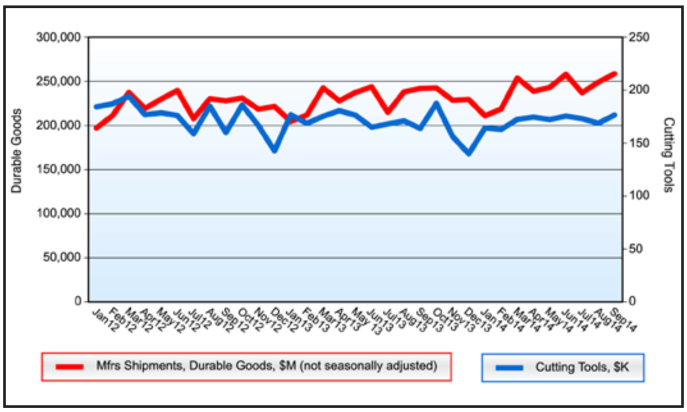
"The modular design of the UBQ allowed Modern Heat Treat to select the options that meet their specific needs. AFC-Holcroft is proud to be a part of the continued impressive growth of Modern Heat Treat," said Tracy Dougherty, sales manager of AFC-Holcroft.

Cutting Tool Market Report

REVEALS CUTTING TOOL CONSUMPTION UP 4.6 PERCENT

The cutting tool consumption in the United States for September totaled $176.5 million, according to the U.S. Cutting Tool Institute (USCTI) and the Association for Manufacturing Technology (AMT). This total, as reported by companies participating in the Cutting Tool Market Report (CTMR) collaboration, was up 4.6 percent from August's total and up 7.7 percent from September 2013.

These numbers are based on the totals reported by the companies participating in the CTMR program. The totals represent about 80 percent of the U.S. market for cutting tools.



"The 4.6 percent increase for September's cutting tool shipments was not a surprise as the market's expectations were for a strong finish in 2014," said Brad Lawton, chairman of AMT's Cutting Tool Product Group. "There is every indication that the momentum from the fall of 2014 is a harbinger of continued growth in industrial production and cutting tool sales for 2015."

The CTMR is jointly compiled by AMT and USCTI, two trade associations representing the development, production and distribution of cutting tool technology and products. It provides a monthly statement on U.S. manufacturers' consumption of the primary consumable in the manufacturing process – the cutting tool.

Arrow Gear

BECOMES DISTRIBUTOR FOR SAMP GEARS

Arrow Gear has signed an exclusive agreement with SAMP of Bologna, Italy to market and sell their gear products in North America. Arrow Gear, based in Downers Grove, IL manufactures open gearing for the Aerospace, Mining, Oil & Gas, Medical and other miscellaneous industries. SAMP manufactures gearing for the Robotics, Light Rail, Industrial Machinery, Textile and Pumps and Compressor industries.

Both companies supply spiral bevel gearing as well as spur and helical gearing for the various industries. SAMP's ability to manufacture spiral bevel, spur, helical and internal gearing in annual quantities between 500-10,000 pieces complements the existing business of Arrow Gear. Additionally, Arrow Gear will promote SAMP's line of small, custom made gearboxes. The agreement includes the countries of the United States, U.S. Territories, Canada & Mexico.

John Oller

NAMED ENGINEERING MANAGER BY RJ LINK

Rj Link International, Inc. announced that **John Oller** has been named engineering manager. Oller will be responsible for engineering, quality and business development support in the development of new markets.

Oller has over 25 years of product engineering, quality and manufacturing experience including a master's degree in both mechanical engineering and business. Most recently, Oller was a senior engineer in new product development at B/E Aerospace Ecosystems in Rockford, IL. Prior to that assignment, he was the director of manufacturing engineering and quality at Rockford Products, Inc.

Oller is a member of the Academy Support Team for Roosevelt High School and an active member of the Rockford Chamber of Commerce Manufacturing Council.

Rj Link International, Inc., headquartered in Rockford, IL, is a precision manufacturer of gears and gearboxes including speed increasers, speed reducers, transfer cases and custom designs for major industrial original equipment manufacturers world-wide.

Santasalo

RECEIVES ON-TIME AWARD FROM VALMET

In October, gear manufacturing company Santasalo received the award for "Most On-Time Delivery" at the Valmet Supplier Day in Helsinki, Finland.

The Valmet Supplier Day welcomed over 100 attendees from 64 companies worldwide. The aim of the event was to underline the partnerships with suppliers and to provide a more transparent view of the business. The day itself saw senior executives of the Valmet business present information on its current business, the future ahead and the key factors that Valmet expects from their suppliers.

The criteria for the "Most On-Time Delivery" award included a positive trend in on-time delivery with excellent communication, cooperation on all continents and a willingness to develop operations such as product transfer to China manufacturing.

"We at Santasalo have worked hard to achieve this award," said Pasi Jokela, senior vice president of Santasalo Finland & Global Capital Sales. "Our dedicated workforce was the biggest contributor to this success with a good understanding of our customer's needs. We continue to work closely with Valmet and ensure ongoing improvements to meet the customer's requirements."

OSG

SET TO OPEN NEW WAREHOUSE FACILITY IN GEORGIA

OSG Tap & Die, Inc. is expanding its presence in the Southeast by opening a new regional service center at 5324 Georgia Highway 85 in Forest Park, GA. The facility opened on Dec. 1.

The 21,198-square-foot facility will stock a complete line of cutting tools, with over 25,000 SKUs for OSG taps, end mills, drills, indexables, as well as other products including thread gages and holders. OSG expects to create at least 10 new warehouse and customer service positions with this expansion.

With the opening of this facility, OSG customer support is now available nationwide from the Eastern time zone through the Pacific, where OSG already operates a facility in Placentia, CA. The Atlanta facility also creates a second fully functional warehouse operation to service customers in the event of an operations outage at the main headquarters operation in the Chicago-area.

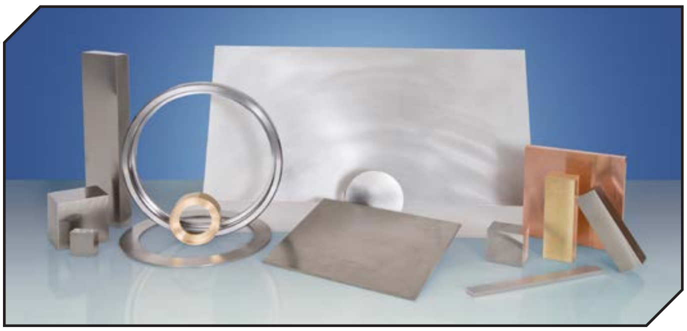
"We are very excited to expand our operations into the Atlanta area," said OSG president Mike Grantham. "This new facility will help improve our order fulfillment times to customers in the Southeast and give them another reason to look to OSG for their cutting tool requirements."

TCI

GAINS DUAL CERTIFICATIONS

TCI Precision Metals, a family-owned manufacturer founded in 1956 and a supplier of precision machine-ready blanks and contract machining services, announced on Nov. 11 that it has received ISO 9001:2008 + AS9100C Certification from SAI Global Certification Services.

The dual certification covers all of the ISO 9001:2008 quality management system requirements and specifies additional requirements under AS9100C for a quality management system for the aerospace industry.



"This dual certification reflects our commitment to constant improvement and quality processes that meet or exceed internationally recognized quality benchmarks," said Ben Belzer, president of TCI Precision Metals.

Keith Reim

JOINS SOLAR ATMOSPHERES AS CORPORATE MARKETING MANAGER

Solar Atmospheres, a contract vacuum heat treatment company with three locations, announced the recent hiring of **Keith Reim** as corporate marketing manager.

Reim, a graduate of Ursinus College with a master's degree in business administration, was formerly the marketing manager of an industrial automation company and has over 19 years of experience in business-to-business marketing. Reim is experienced in all aspects of marketing including marketing communications, business planning and marketing analysis.

In his new role at Solar Atmospheres, Reim will focus on providing strategic direction for all of Solar's marketing activities, such as corporate branding and communications, advertising, website development, trade shows, public relations and social media.

Gleason Hosts WZL Gear Conference USA

Randy Stott, Managing Editor

The 5th WZL Gear Conference USA took place October 22-23 at the Gleason Works facility in Rochester, NY. More than 130 gear technologists participated in the event, which included two days of technical presentations, guided technology demonstrations in the Gleason factory and various networking events.

The conference is a smaller version of the WZL Gear Conference, where members of the WZL Gear Research Circle have gathered annually to discuss the latest research in gear design, manufacturing and testing for more than 50 years.

Day one of the conference began with welcoming remarks by WZL's Prof. Dr.-Ing. Fritz Klocke and Gleason's VP Dr. Hermann J. Stadtfeld, CEO John J. Perrotti and VP Brian M. Perry. Each day of the event included guided tours of the Gleason factory, where Gleason experts explained various technologies and processes used in gear manufacturing. Attendees were divided into small groups, and each group visited nine stations each day, including stops in Gleason's R&D lab, gear inspection lab and machine tool assembly area. At each stop, visitors were encouraged to interact with the experts and ask questions related to the technology being demonstrated.

Prof. Dr.-Ing. Fritz Klocke, Director of the Chair of Manufacturing Technology at WZL-RWTH Aachen University, delivers the opening remarks at the 5th WZL Gear Conference USA.

Most of the participants of the WZL Gear Conference USA gathered in the Gleason auditorium on day two for this group photo.

After the factory tours, Gleason hosted a networking lunch, where visitors could interact with each other, with Gleason staff and with members of the WZL, who demonstrated the research circle's software capabilities during the lunch periods.

The afternoons were devoted to the presentation of technical papers and the exchange of knowledge. Visitors gathered in Gleason's auditorium to hear presentations on a wide variety of gear-related topics, including:

- Gear Research Activities at WZL, RWTH Aachen University, by Dr.-Ing. Markus Brumm
- Non-Involute Gearing, its Function and Manufacturing Compared to Established Systems, by Dr. Hermann J. Stadtfeld and Jasmin Saewe of Gleason
- Gear Design and Operating Performance, by Prof. Dr.-Ing. Fritz Klocke
- Virtualization and Cross-Linking in Production, by Prof. Dr.-Ing. Christian Brecher
- Pulsating Helical Gears and Calculation of the Tooth Root Load Carrying Capacity, by Dipl.-Ing. Markus Rüngeler
- Load Distribution, Root Stress and Efficiency Analysis of Face-Hobbed and Face-Milled Hypoid Gears, by Dr. Ahmet Kahramann and Dr. David Talbot of Ohio State University
- Robust Bevel Gear Design via Variational Calculus, by Dipl.-Ing. Peter Knecht
- Tooth Contact Analysis of Asymmetric Planet Gear Stages, by Dipl.-Ing. Daniel Piel
- Dynamic Transmission Error Measurement in Gear Applications, by Dr.-Ing. Markus Brumm

Gleason's Anthony Norselli describes some of the history and development of manufacturing tools for straight bevel and face gears, from traditional Coniflex cutting with interlocking cutters to Coniflex Plus and Coniface cutting on modern Phoenix machines.

- Trends in Bevel Gear Development, by Dr.-Ing. Markus Brumm
- Gleason 4.0, by Dr. Hermann J. Stadtfeld
- Smart Factories – Challenges and Potentials, by Prof. Dr.-Ing. Fritz Klocke
- Gear Finish Hobbing – Potentials of Several Cutting Materials, by Dipl.-Ing. Deniz Sari
- Process Analysis of Gear Honing of Transport Transmission Gears, by Dipl.-Ing. Marco Kampka
- Development of a Cutting Force Model for Generating Gear Grinding, by Dipl.-Ing. Florian Hübner
- Improvements in Manufacturing Related Surface Strength Increase and Rolling Contact Fatigue Simulation, by Dipl.-Wirt.-Ing. Christoph Löpenhaus

December 1-4 – DMC 2014 Grand Hyatt San Antonio and Henry B. Gonzalez Convention Center, San Antonio, TX. The DMC is the nation's largest annual forum for enhancing and leveraging the efforts of scientists, engineers, managers, technology leaders and policy makers across the defense manufacturing industrial base. This event brings together leaders from government, industry and academia to exchange perspectives and information about critical Department of Defense (DOD) industrial base policies, sector analyses and manufacturing technology programs for the production and sustainment of affordable defense systems. This is the premier national forum for presenting and discussing initiatives aimed at addressing enhanced defense and related national manufacturing capabilities and requirements. Since its inception in 1969 as the Manufacturing Technology Advisory Group (MTAG) Conference, DMC has provided the defense community with a forum for presenting the latest innovative manufacturing technology developments. Average attendance is well over 1,000, divided between government and industry participants, with a small complement from academia. DMC 2014 continues a long-standing tradition of presenting the requisite policy, strategic investment planning, program management, risk mitigation and workforce education and training efforts necessary for efficient technology adoption and resilient, force shaping impact in a period of shrinking defense budgets. For more information, visit *http://dmcmeeting.com*.

December 3-4 – Wenzel/Renishaw Open House Phoenix, AZ. Join Renishaw and Wenzel in a co-sponsored open house event. This event will feature topics such as Renishaw's process control, Wenzel's developments in CMM technology, high-speed comparative gauging with Renishaw's Equator and Renishaw's additive manufacturing system. Register to get free tickets and see how Renishaw metrology technologies and Wenzel machines work together to impact the Aerospace industry. Throughout the open house there will also be machine demos featuring Renishaw's latest technology like Revo, Equator and PH20. For more information, visit *www.renishaw.eventbrite.com*.

December 5-7 – Design for Manufacturability and Assembly (DFM/A) Workshop Pasadena, CA. This two-day workshop includes many examples to illustrate DFM/A principles and exercises to develop practical DFM/A skills analyzing a design for manufacturability. It also introduces a DFM/A assessment methodology that can be subsequently used within an organization to analyze products. Attendees will learn how to identify good and bad design for manufacturability, recognize how to reduce product costs before they are locked in, identify ways to simplify product architecture, and much more. On the second day of the event, participants will spend a significant amount of time analyzing a sample product in a hands-on exercise to reinforce one's understanding of DFM/A principles as they apply to products and to introduce and use manual evaluation methodology. Registration is $1,325 for SME members and $1,525 for non-members. For more information, visit *www.toolingu.com*.

December 8-11 – CTI Symposium Berlin. The 13th International CTI Symposium is the place to get updated on latest technical developments and applications on automotive transmissions for conventional and alternative drives. Exchange experiences and discuss technologies and strategies with automotive experts from USA, Asia and Europe. For more information, visit *www.transmission-symposium.com*.

December 11-13 – PRI Trade Show 2014 Indiana Convention Center, Indianapolis, IN. Billed as "the three biggest business days in motorsports," the 27th Annual Performance Racing Industry Trade Show will feature 1,100 companies that will display the latest advances in racing products and race engineering. Engine parts, suspension components, data acquisition, safety gear, new metal alloys and coatings, machining equipment and race electronics are all part of the world's largest racing trade show. Arriving from over 70 countries and all 50 states, buyers can scour the displays to source the new technology that will be winning races next year. Attendees are pre-qualified. Admission is complimentary, but all attendees must prove they own, manage or are employed by a racing business. For more information, visit *www.performanceracing.com*.

January 5-9 – SciTech 2015 Kissimmee, FL. SciTech 2015 will draw more than 3,000 participants from 40 countries and feature more than 2,500 technical papers, including the best papers from students around the world. Bringing together 11 individual technical events at a single location, this forum is the place to engage with colleagues within each discipline and to interact with experts in those fields. Discuss the science, technologies, policies and regulations that are shaping the future of aerospace. Walk away with innovative solutions that will create new opportunities and overcome challenges. For more information, visit *www.aiaa-scitech.org*.

January 22-28 – IMTEX 2015 Bangalore International Exhibition Centre, Bangalore, India. An initiative of the Indian Machine Tool Manufacturers Association, IMTEX is a flagship event for the Indian Metal Cutting Industry. It is South and South-East Asia's apex exhibition showcasing the very latest trends, as well as technological refinements from India and other global players. The event attracts visitors from a wide spectrum of manufacturing and ancillary industries, starting with key decision and policy makers as well as industry captains who are keen to source latest technologies and manufacturing solutions for their production lines. IMTEX has become a one-stop forum where customers can experience live display of the products, enabling them in their decision making process to enhance their manufacturing capabilities. IMTEX 2015 will spearhead a wide range of opportunities for everyone connected to metal-cutting, machine tool users, manufacturing experts, technocrats, researchers, policy-makers, academia and even budding engineers and technology graduates. For more information, visit *www.imtex.in/imtex2015*.

February 24-26 – Houstex 2015 George R. Brown Convention Center, Houston, TX. Everything about Houstex 2015 is big, from the venue to the location to the opportunity. Exhibitors at Houstex 2015 can solidify their place in one of the nation's leading manufacturing regions, expand into new markets and industries, connect with decision-makers from diverse companies, demonstrate their products in a meaningful way, and network with the biggest thinkers and doers in Southern Manufacturing. Houstex 2015 is an immersive experience, featuring hundreds of exhibitors highlighting the latest manufacturing technologies and new interactive opportunities. Attendees will enjoy scores of new product demonstrations, hear experts share insights on industry trends and make connections that can take their company to the next level. For more information, visit *www.houstexonline.com*.

CORRECTION

In the September/October issue, page 18, we featured an article with the headline "SMT Releases MASTA Suite 6." Although SMT announced the planned release of their MASTA 6 software, the actual release has not yet occurred. We apologize for the confusion and ask readers to visit the company's website at *www.smartmt.com* for the latest information.

Like to Have Your Own Airplane?

Here's How to Do It.

Were Thomas Jefferson around today, he'd be all over the Double-A engine's development and everything it represents.

And what *is* the Double-A engine; what does its successful design and execution represent, you ask?

Well, *maybe* substantial progress towards the democratization of general aviation in our lifetime. If, that is, would-be "con-trailblazers" like Michael Arndt, an enterprising industrial engineer with a vision, can attract enough deep-pocketed investors into a brave new world of flight.

Arndt and some students at Virginia Commonwealth University (VCU) are involved in a work-in-progress, i.e.—The Double-A: The safe and affordable 200 horsepower aircraft engine. The project's goal: To build and ground test (No licensed pilots in the group!) the Double-A engine and make its construction plans and parts list freely available under the GNU open-source license so anyone can build it.

(Exciting as this prospect sounds—and indeed it is—the Dickensian "everything for everybody" concept is not a new one in personal transportation. Think Henry Ford and his Model T automobile: designed, manufactured and price-pointed (in 1914 an assembly line worker could buy a Model T with four month's pay) to make them affordable to more working stiffs than ever imagined up to that time. Nevertheless, that is ancient history. And besides—Ford was no Tom Jefferson. Then again, some historians would say Jefferson was no Jefferson. But we digress.)

High time to let Arndt take the controls from here—in his own words—perhaps informing us of some new history of his own in the making:

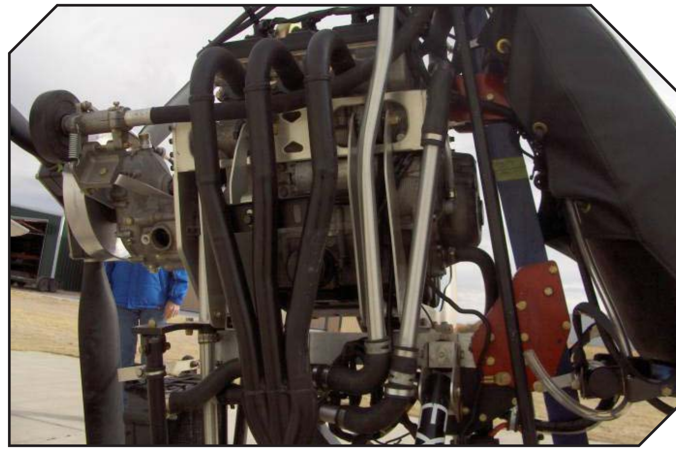
"General aviation (GA) and light planes are a great way to travel and are a lot of fun. But they can be very expensive. An experimental class aircraft body can be had for $15,000, an instrument panel for $2,000. But a new engine will set you back $40,000.

"(Yet even today) the standard engine for a typical two- to four-seater is an air-cooled, four-cylinder design very similar to a 1960 VW Beetle. It's fueled by a carburetor and fired with magnetos—like your lawn mower. Yet the price for this engine is what keeps many people from flying. So we are building this advanced technology prototype to give pilots and student pilots a way out and up.

"The Double-A is a twin-engine, twin-propeller, centerline thrust engine package that fits the place usually occupied by a single aircraft engine. It uses two 130 horsepower, liquid-cooled, fuel-injected engines—one-per-prop— to provide 200 horsepower at 77 percent power for takeoff and 150 horsepower at 58 percent power for cruise. In the event of an engine failure, pilots still have 130 horsepower at their disposal.

"The engines used in the Double-A have already seen aircraft use, and are valued for their reliability and robust design in the snowmobile community, where an engine failure in the bush can easily prove fatal.

"Each engine weighs about 110 pounds dry, and a typical single-engine installation comes in around 150 pounds. We have a target weight under 350 pounds for the Double-A in running condition, compared to the 300 pound *dry* weight (non-running) of a 200 horsepower IO-360C.



A 130 HP fuel-injected engine—similar to the engine 120 HP version pictured here—is considered ideal for one- and two-seater general aviation aircraft (Photo: Wikipedia).

"The first designers to pioneer this configuration (*http://www.infortel.com/cozy*) packaged two 100 horsepower Suzuki Swift engines weighing slightly over 400 pounds; their design is still flying today. Sixteen years of improvements in engine design allow us to shoot for a lower weight than was ever possible before.

"The Double-A package has one other important reliability feature, i.e.—it does not use an aftermarket engine control unit (ECU). A modern engine takes enormous effort—with millions of engineering man-hours to design—and too many aircraft conversions start with cutting off ±25 percent of that design—the original ECU. Most automobile engines leave no choice, as the original ECU will not run without the car. But snowmobile engines do not have this problem and will run just fine—in or out of a sled.

"(Beyond the benefits listed above, the Double-A runs on the same automobile and small-engine gasoline you buy at the pump—not pricey aviation gas. Detailed gallons per hour versus percentage horsepower measurements will be published after the test program.)

"Also, as a used snowmobile engine costs around $4,000—instead of *$40,000*—the cost of replacement parts and repairs is greatly reduced. The closed-deck snowmobile engine used in the Double-A is quite robust; it boasts the very latest fuel-injection technology and liquid cooling. Experimental and professional, certified aviation mechanics will find the Double-A much simpler, and an absolute treat to work on, because it's tighter tolerances, modern gaskets and liquid-cooled body are much more accessible, forgiving, and ergonomically approachable than certified aviation engines.

"So, as the plans will be released for anyone to use, it's possible that a bright spark with more money and a suitable plane (but no engine) might take our work rather quickly and put it into the sky. If anyone is interested in potentially being the first to fly with the Double-A, we encourage them all to contact us (*https://doubleaengine.wordpress.com*)."

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