November/December 2011

GEAR TECHNOLOGY

www.geartechnology.com
The Journal of Gear Manufacturing

Feature Articles

- State of the Gear Industry
- Where are the Jobs?
- Workholding Winner

Technical Articles

- Load-Sharing Model for Polymer Gears
- Flank Breakage on Gears for Energy Systems
- Gear Transmission Density Maximization

Plus

- Addendum: Geared Turbofan Engine

THE GEAR INDUSTRY'S INFORMATION SOURCE

Tool room management solutions

CNC Tool and Cutter Grinder

In-house tool maintenance

Sharpen hobs and shaper cutters

The Star PTG 1 is an affordable solution for sharpening:

+ straight and spiral gash hob designs up to 8” OD x 10” OAL
+ disk, shank and helical type shaper cutters
+ and a wide range of round tools

Grind shaving cutters and master gears

The Samputensili GS 400 tool grinder comes with integrated checking and has an 11th axis. Grind larger tooth widths while enhancing the quality of the finish.

Total tool life management

Control your tool costs and keep your tools running efficiently with individualized support services from Star SU.
From new tools to design work to re- sharpening and recoating, we have the equipment and resources to help you manage your tool room.

GEAR TECHNOLOGY

November/December 2011

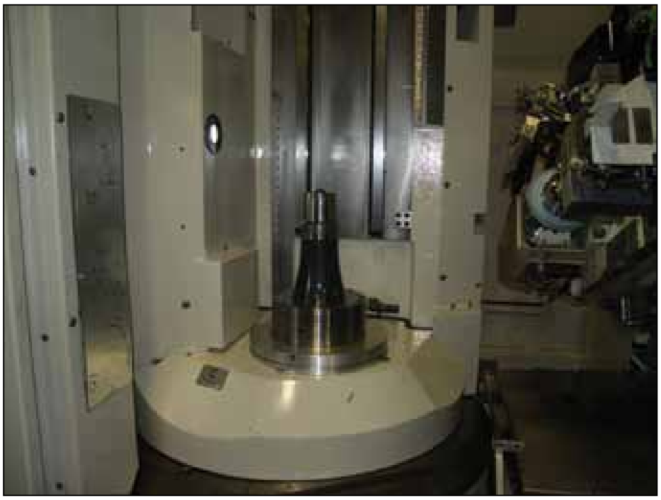
CONTENTS

FEATURES

54 **Best of Times, Worst of Times**
A recovering gear industry no panacea for U.S. manufacturing jobs or economy.

61 **State of the Gear Industry**
Where it's been. Where it's at. Where it's going.

70 **Minimum Set-up Time, Maximum Machining Capability**
Hainbuch designs workholding solutions for United Gear.

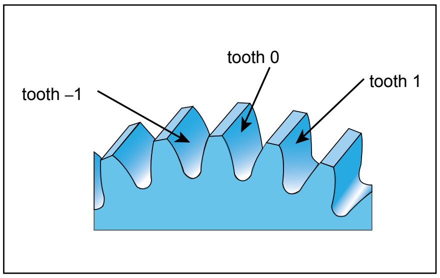


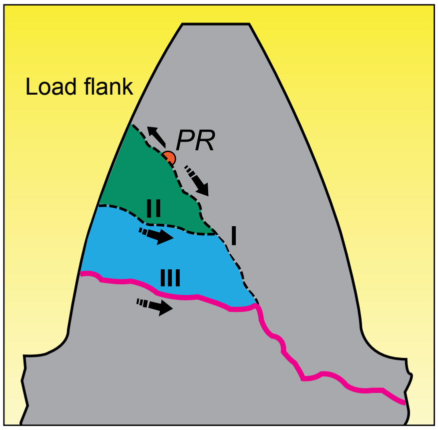
TECHNICAL ARTICLES

28 **Load-Sharing Model for Polymer Cylindrical Gears**
An original method for computing loaded mechanical behavior of polymer gears, including use of new test bench for measuring transmission error and thermal behavior.

36 **Flank Breakage on Gears for Energy Systems**
New calculation model provides accurate benchmark for investigating turbine spur gears with flank breakage.

46 **Gear Transmission Density Maximization**
Optimization of gearbox kinematic arrangement and gear tooth geometry to achieve high-density gear transmission.

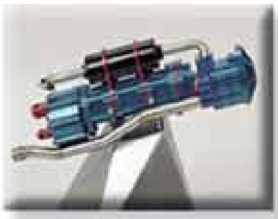




Vol. 28, No. 8 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, July and December by Randall Publications LLC, 1840 Jarvis Avenue, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). Randall Publications makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1840 Jarvis Avenue, Elk Grove Village, IL, 60007.


Brass gear and stainless worm shaft for analytical diffractometer positioning…highest diametral pitch (164) made to date by our engineers


Articulating gear for the electric terminal device on the Utah Arm…patient can tie his shoes

Star gear for racecar fuel pump…every car in the Indy 500 field has our product onboard


Internal spline gear for a levelwind fishing reel…casts twice as far


Gears for the drive wheels and actuators on Mars Rover…no room for failure or a service call

Who Says You Can't Be All Things To All People?

Forest City Gear helps customers in an extremely diverse group of industrial, medical, aerospace, sporting goods, research lab and high-performance racing markets, plus many others. Some might foolishly suggest this makes us "a jack of all trades, master of none," as that old adage goes.

Boy, are they wrong.

Exactly the opposite is true. Forest City Gear is the longtime market leader in special gear solutions, precisely because we've seen and solved problems in virtually any application you can name that requires the highest geometrical integrity, superior repeatable performance, accuracy that's often off-the-charts for other gear companies and a secure, reliable line of supply. O yes, and all at an affordable price that helps keep customers competitive and viable in their markets.

Who says you can't be all things to all people? Well, we suppose the size of our machining centers is a limit, if you can call what you see here limited?

Call Forest City Gear and hear about all we can be…on your next gear challenge! Go to **www.forestcitygear.com** today.

FOREST CITY GEAR

"For high-precision gears, we certainly can!"

Fred Young, CEO

11715 Main Street, Roscoe, IL 61073 815-623-2168

GEAR TECHNOLOGY
November/December 2011

CONTENTS

DEPARTMENTS

9 **Publisher's Page**
All Smiles in Cincinnati

10 **Voices**
Vacuum oil quenching and a proposed life calculation for micropitting

15 **Product News**
Liebherr's LDF 350 turning-milling machine and other new offerings

73 **Industry News**
Shop talk, comings and goings…

82 **Calendar**
Conferences, training venues…

84 **Events**
Sneak preview of IPTEX 2012.

85 **Advertiser Index**
Contact information for all advertisers in this issue

86 **Classifieds**
Our products and services marketplace

88 **Addendum**
Pratt & Whitney GTF Engine

ONLINE

GEARTECHNOLOGY.com
www.geartechnology.com

- **E-MAIL NEWSLETTER**
Sign up for our NEW monthly e-mail newsletter with exclusive gear-related articles and content at *www.geartechnology.com/newsletter*

PTE powertransmissionengineering *www.powertransmission.com* NEW

twitter facebook LinkedIn

- ***Power Transmission Engineering***
Read the October 2011 issue online. Sign up for a free subscription.
- **NEWS**
The latest products, industry news and calendar items.
- **BUYERS GUIDE**
Search for power transmission products and services and communicate with the industry's leading suppliers

GEAR TECHNOLOGY

VOL. 28, NO. 8

Randall Publications LLC
1840 Jarvis Avenue
Elk Grove Village, IL 60007

Phone: (847) 437-6604
Fax: (847) 437-6618

EDITORIAL

Publisher & Editor-in-Chief	Michael Goldstein *publisher@geartechnology.com*
Managing Editor	William R. Stott *wrs@geartechnology.com*
Senior Editor	Jack McGuinn *jmcguinn@geartechnology.com*
Associate Editor	Matthew Jaster *mjaster@geartechnology.com*
Editorial Consultant	Paul R. Goldstein
Technical Editors	William (Bill) Bradley Robert Errichello Octave Labath, P.E. Joseph Mihelick Charles D. Schultz, P.E. Robert E. Smith Dan Thurman

ART

Art Director	Kathleen O'Hara *kathyohara@geartechnology.com*

ADVERTISING

Advertising Sales Manager	Dave Friedman *dave@geartechnology.com*
Materials Coordinator	Dorothy Fiandaca *dee@randallpublications.com*

CIRCULATION

Circulation Manager	Carol Tratar *subscribe@geartechnology.com*

RANDALL STAFF

President	Michael Goldstein
Accounting	Luann Harrold

Cover Illustration by Kathleen O'Hara

BPA WORLDWIDE

KAPP

Customers Say It Best

RILEY GEAR CORPORATION

For over 65 years Riley Gear, registered to ISO/TS 16949:2009, ISO9001:2008 and A9100C, has manufactured precision gears and custom power transmission designs. We produce spur and helical gears from .25 to 48 inches in pitch diameter to AGMA class 15 specifications. Our two manufacturing facilities located outside of Buffalo, New York and St. Augustine, Florida occupy over 100,000 sq. ft.

We purchased our first NILES gear grinder in 1998; the ZP1200 machine was pivotal in our acquiring the high speed double helical pinion and accessory gear box business for the Navy, and our last, a KAPP KX300 (our 5th) in 2011 to support increased demand for a new automotive high production hybrid transmission line.

The KAPP Group's diverse product line, engineering expertise and dedication to detail and service has been a driving force in Riley's ability to triple our sales over the last 10 years. — Riley Gear

KAPP NILES

Geared to make things move.

KAPP Technologies
2870 Wilderness Place Boulder, CO 80301
Phone: (303) 447-1130 Fax: (303) 447-1131
www.kapp-usa.com info@kapp-usa.com
www.kapp-niles.com

The Truth be Told

E Could Stand For:
Excellence.
Extraordinary.
Extreme, etc...
and one would be forgiven for thinking so, because these descriptions certainly represent the Mitsubishi machines which contain this letter in their model name. However, the simple truth is that the letter E denotes that these machines are the latest iterations of the models which carry it. The SE gear shapers, GE gear hobbers, FE gear shavers and ZE gear grinders epitomize the development of the process technology they have been designed for and so aptly carry out. Research and Development is not just a glib phrase at Mitsubishi; it is a philosophy that the company stands by to stay ahead of its competition and to ensure continuing profitability and the profitability of its customers. Yes, E could stand for many things but with continuous striving for perfection and intense R & D, the E simply means it is as good as it gets. Period.

To personally experience the world-class performance of the Mitsubishi E Series of machines visit **mitsubishigearcenter.com** or contact sales **248-669-6136**.

MITSUBISHI
HEAVY INDUSTRIES AMERICA, INC.

Machine Tool Division • Gear Technology Center
46992 Liberty Drive • Wixom, MI 48393
mitsubishigearcenter.com

Gear Expo 2011—Tempered Enthusiasm

I came back from Gear Expo in a pretty good mood, and judging by the smiles on the faces of exhibitors I saw, I'm not alone. In fact, the mood at Gear Expo 2011 was the best I've seen in recent memory.

Every exhibitor we talked to seemed to believe the show was a success—not necessarily because of the show itself—but because of the economic conditions currently affecting manufacturing in general and the gear business in particular.

Although it would be a stretch to say the show was crowded, the exhibitors and visitors all appeared to be busy. Most of the exhibitors had a steady stream of customers visiting their booths. This made connecting with the senior managers and executives at those companies a bit of a challenge. In some cases, I had to stop by a half dozen times or more just to have a chance to meet with them. And those exhibitors weren't just entertaining guests; they were conducting business. Machine tools were being sold off the show floor, and I heard about many other projects that I'm sure will come to fruition in the near future.

Based on what we observed at the show, there are a number of trends that bear watching. For one, there seems to be a shortage of gear manufacturing capacity, especially for very high quality gears. Second, there continue to be extremely long lead times for new equipment and even cutting tools. The demand for gear machine tools is rising, not just in the United States, but around the world.

Much of what we observed anecdotally at Gear Expo is borne out statistically by our annual "State of the Gear Industry" survey, which we conducted in November. More than 300 gear industry professionals responded to the survey. The full results can be found in this issue, beginning on page 61.

But I can summarize the survey highlights for you here.

One of the biggest changes this year was that 60% of respondents now work at locations where employment increased. Last year, only 43% indicated their employment had increased. Similarly, 67% work at locations where production volumes increased in 2011 (compared to 62% last year). More importantly, 74% expect production volumes to increase again in 2012. Finally, 72% saw sales volume increase in 2011 (compared with only 58% last year), and 70% expect sales volume to increase again next year.

The gear industry is clearly very busy, and in fact appears to be growing—despite the fact that there are still significant issues facing gear manufacturers. According to the survey, the top three industry concerns are the economy, material costs, and finding skilled labor. These are the same top three challenges—and in the same order—as were voiced in last year's survey.

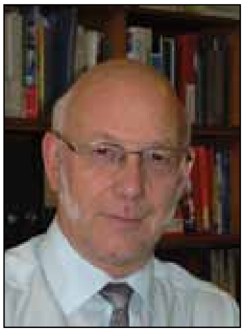
Manufacturing's skilled labor issue has been well publicized, including here in this column. But in this issue we took an in-depth look at the problem and found that even in our own industry, opinions on the subject vary widely (*please see our jobs article beginning on page 54*). One thing is clear, though. The skilled labor shortage is a definite problem for gear manufacturers.

Since returning from the show, I've spoken with several gear manufacturers who are extremely busy. But I was surprised to learn that despite being so busy, some of them are either losing money or barely eking out a profit, so pricing still seems to be an issue. Although they have been cutting gears at a record pace, they're struggling with cash flow. Their order books are full, and they're producing a lot of gears. Material costs are high, and they've had to add equipment and employees to fill their orders, all of which eats into their profits and cash.

Don't get me wrong—I believe the gear industry is still poised for another good year. There are too many signs pointing in that direction to think otherwise. But just because business is good doesn't mean we can afford to lose our focus.

Michael Goldstein,
Publisher & Editor-in-Chief

P.S. At Gear Expo, we received tremendous interest in *Gear Technology India*, our new publication, which is poised to launch in 2012. There's still time to get involved with this new magazine: as a subscriber, as an advertiser or as a contributor. Just visit *www.geartechnologyindia.com* for more information.

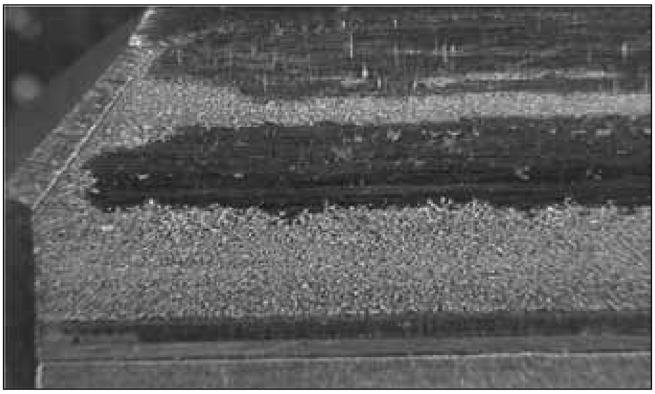


A Proposed Life Calculation for Micropitting

Dave Barnett, Gear Design Consultant

If you make hardened gears and have not seen any micropitting, then you haven't looked closely enough. Micropitting is one of the modes of failure that has more recently become of concern to gear designers and manufacturers. Micropitting in itself is not necessarily a problem, but it can lead to noise and sometimes other more serious forms of failure. Predicting when this will occur is the challenge facing designers.

The new ISO/TR 15144-1 2010 has gone some way to address the problem by proposing a procedure for rating a gear's ability to resist micropitting based on specified oil and operating conditions. However, it is not possible to determine a life for micropitting damage that can be tolerated. One method for determining the "permissible specific lubricant film thickness" is the FVA-FZG-micropitting test, which has the advantage that it is used by the oil industry as a rating procedure for oils with its additives package to resist micropitting. In this test the C type gear, which is a spur gear with a true involute profile, (i.e., no tip or root relief), is run for five different loads until 0.0075 mm flank erosion is reached. This load stage is designated the FZG load stage for the oil. Load stage five is a poor rating and 10 is considered a good oil. The downside of this test is that if the oil has a rating of load stage five, the gears have only been run for 16 hours, and if it is load stage 10, then 75 hours. The fact that the test stops at 0.0075 mm—unless you run the endurance test—does not mean that micropitting stops. It can still continue, and after another 75 hours could have doubled. For example, if you run the standard FZG test gear with an oil that has a designated FZG load stage 10 at a continuous load of 70 Nm—i.e., load stage 5—then after approximately 200 hours of testing there is a high possibility that you could reach the limit of 0.0075 mm, which is designated as a failure. The ideal method would be to use results from an actual test of similar design, but this takes time, and it is not always possible to know the exact duty cycle.



Example of micropitting damage I.

In 2006 a paper "An Analytical Approach to the Prediction of Micropitting on Case Carburized Gears" (D. Barnett, J.P. Elderkin, W. Bennett) presented at the AGMA Fall Technical Meeting, established a procedure to calculate the predicted micropitting erosion based on the macro and micro geometry of a gear set. The calculation procedure was based on testing conducted by the British Gear Association (*www.bga.org.uk*) and the other gears analyzed. At the time no account was made for the additives, but since then the procedure has been improved and an oil retardation factor based on the oils' ability to reduce micropitting was added. Verification is still ongoing, but results to-date show good correlation. Within the procedure, the standard FZG test gear is run with the oil from load stage five until the load stage for the oil is reached with the oil retardation factor set to one. To establish the actual retardation factor for the oil, the limit of 0.0075 mm is divided by the predicted erosion. The ideal procedure would be for the oil retardation factor for the oil to be established by dividing the predicted erosion from the test by the actual erosion, as many oils currently in use are load stage 10 +. This retardation factor will give a better understanding of the oil's potential to retard micropitting. In a newly proposed procedure, the gear set to be analyzed is run through a series of iterations, each one consisting of 1.5 x 10^6 cycles. At the end, the modification to the tooth profile is predicted and then used to establish the load conditions for the next iteration. The number of iterations required for the analysis depends on the running time; a duty cycle consisting of time and load could be constructed for a more realistic result. On completion of the duty cycle, it will be possible to look at the erosion's effect on noise and vibration, contact stress and pitting life and bending stress.

Dontyne Systems software already incorporates the ISO calculation Method A and Method B as part of the *Load Analysis Model* (for LTCA) and *Gear Design Pro* (for gear pair design and rating) modules respectively. The software is being extended to include this procedure as an additional function to enable the user to determine if the micropitting will arrest or continue and whether changing either the micro or macro geometry will reduce micropitting. The software was discussed and demonstrated at Booth 326 of the Gear Expo in Cincinnati. For more information, contact Dontyne Systems directly at *www.dontynesystems.com*.

Additional contributions to this article were provided by David Palmer and Mike Fish at Dontyne Systems Limited.

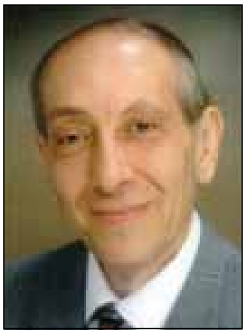
Example of micropitting damage II.

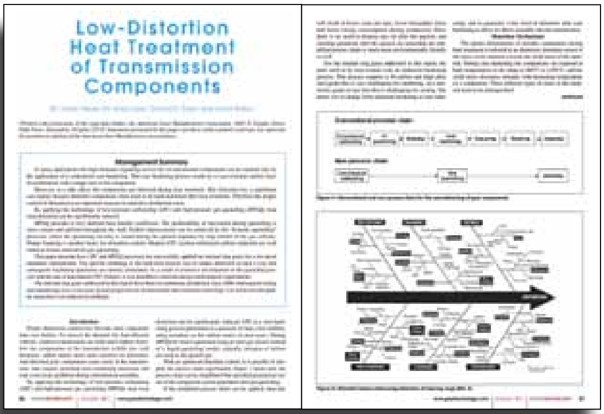
Example of micropitting damage III.

Vacuum Oil Quenching

Dan Herring

(Dan Herring is owner of The Herring Group, Inc.
located in Elmhurst, Illinois; *dherring@heat-treat-doctor.com*)





Low-Distortion Heat Treatment of Transmission Components

The October 2011 issue of Gear Technology *featured the article "Low-Distortion Heat Treatment of Transmission Components," which covered the combination of low-pressure carburizing and high pressure gas quenching in an automotive environment. Here, heat treating expert Dan Herring explains why oil quenching is an appropriate choice for many applications.*

Oil quenching is a viable alternative to high pressure gas quenching in many instances, especially for gears and other components whose cross-sectional thickness, geometry or hardenability, i.e., DI or Jominy values (*Ed.'s note: DI—ideal diameter—value; from the French phrase "diamètre idéal"*; *Jominy refers to a hardenability test for steel to determine the depth of hardening obtainable by a specified heat treatment*) indicate they are marginal candidates for gas quenching. Many components use oil quenching to achieve consistent and repeatable mechanical and metallurgical properties, as well as predictable distortion patterns. The reason oil quenching is so popular is due to its stability over a broad range of operating conditions. Oil quenching facilitates the hardening of steel by controlling heat transfer during quenching and it enhances wetting of steel during quenching to minimize the formation of undesirable thermal and transformational gradients which may lead to increased distortion and cracking. For many, the choice of oil is the result of an evaluation of a number of factors, including:

- Economics/cost (initial investment, maintenance, upkeep, life)
- Performance (cooling rate/quench severity)
- Minimization of distortion (quench system)
- Variability (controllable cooling rates)
- Environmental concerns (recycling, waste disposal, etc.)

Oil quench vacuum systems offer not only the ability to control the normal set of quench variables but, in addition, one can vary and control the pressure over the oil. This technique can extend the range of part cross-sections and materials that can be processed. In addition, the use of vacuum oil quenching has been found to reduce distortion in a wide variety of components such as gears, shafts and ball bearings. Altering pressure over the quench oil allows for a change in the boiling point of the quenchant. The position of the boiling point, i.e., "characteristic temperature," determines where and for how long the various stages of oil cooling take place. The lower pressure allows for longer "vapor blanket" stages and a somewhat long "vapor transfer" stage due to the reduced boiling point of the oil.

Distortion minimization methods have been used in combination with changes to flow characteristics (for example, some manufacturers pull oil down through the workload as opposed to pushing it upward) and oil compositions specially blended for use in vacuum having low vapor pressure oils so that they are easily de-gassed.

The design of an integral vacuum oil quench system requires considerations beyond those of atmosphere oil quenching. For example, the boiling point and vapor pressure of the base oil—as well as the accelerant additives characteristics—must be taken into consideration, along with the quench oil temperature, agitation, cleanliness, pH and viscosity. Also, the vapor pressure of the quench oil must be compatible with the selected operating vacuum level.

Finally, vacuum systems do not permit the build-up of water in the quench tanks. In a vacuum furnace system, where vacuum is used to process the work or purge the quench environment, moisture will be removed as the system is evacuated and the oil circulated. The circulated oil brings any moisture to the surface where it is vaporized and removed from the oil by the pumping system.

Reference:

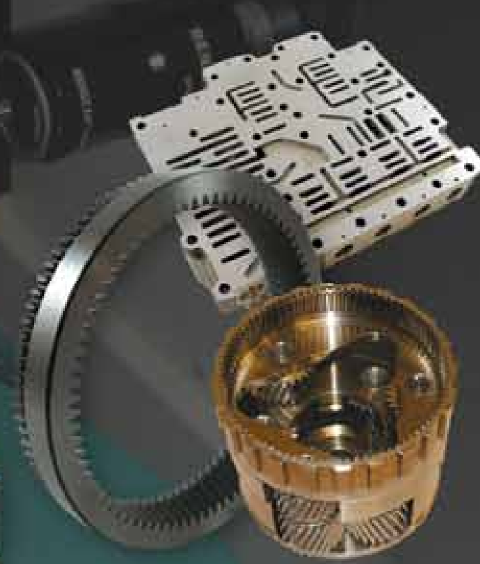
1. Herring, D. H. *Oil Quenching Technology,* On-Line Exclusive, Industrial Heating, 2011.

HIGH PRECISION

DELTA GEAR
Formerly TIFCO Gage & Gear

DELTA INSPECTION

DELTA RESEARCH



Aerospace Precision

As an AS 9100 & ISO 9001 Registered Company, Delta Gear provides aircraft quality gears and machined components at automotive prices. Since 1964, Delta Gear (formerly Tifco Gage & Gear) has been producing precision parallel-axis gears. It is our continued passion to expand our capabilities in high precision gears, machined components, assemblies and inspection – giving you the highest quality, convenience and on-time delivery.

Inspection & Testing

Our newest addition to the Delta Family of Companies is Delta Inspection. Inspired on the understanding that the industry needs expert abilities for contract gear inspection services, Delta Inspection has been introduced to meet your gear inspection and testing needs. Our abilities range from gear inspection up to 39 inches (1 meter) to prismatic inspection of machined components, roundness, laser guided concentricity analysis, surface testing, material testing, Nadcap certified magnetic particle inspection, nital etch and much more.

Automotive Quality & Speed

Delta Research is a world class provider of CNC 3-Axis, 4-Axis and 5-Axis precision machining, jig grinding, cylindrical grinding, precision gears and complete assemblies for automotive, aerospace and industrial applications. From complete automotive prototype transmissions or components, to defense, to aerospace machining and assembly, you will be impressed by our capabilities and commitment to quality.

AGMA

Delta Family Of Companies

1-734-261-6400 | 1-734-525-8400 Fax | ISO 9001 & AS 9100 Registered

www.delta-gear.com www.deltainspection.co www.deltaresearch.com


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

Liebherr's LDF 350

OFFERS COMPLETE MACHINING IN NEW DIMENSION

Liebherr's LDF 350 combines turning, drilling and hobbing in a single clamping arrangement.

The objective, according to Dr.-Ing. Hansjörg Geiser, head of development and design for gear machines at Liebherr, was to develop and design a combined turning and hobbing machine in which turning, drilling and hobbing work could be carried out in the same clamping arrangement as the hobbing of the gearings and the subsequent chamfering and deburring processes. The result of this new development, Liebherr's response to current trends and demands of the market, is the LDF 350. "This offers the latest technical options for the machining of cylindrical gear gearings, not only of wheels but also of shafts," Geiser says.

These kinds of innovative machine concepts are in demand because of: increasing workpiece complexity and the wish for increasingly smaller batch sizes; reduced cycle times; and the need for intermediate layers in production to be as small as possible. The LDF 350 enables the combination of different machining processes, ranging up to complete machining in a single clamping arrangement.

"One special challenge we faced was the controllability of both processes (turning and hobbing) for workpieces up to a maximum diameter of 350 mm, a total length of up to 500 mm and a maximum module of 5 mm," Geiser says."The most important component of the LDF is therefore the workpiece table, which fulfills two main requirements."

These requirements include the high rotation speeds of the turning process and the high rigidity of the gear hobbing.

Aligned in the center of the rotation machine and permanently connected with the machine bed, the table ensures high production turning and gear hobbing. The gripper for loading the machine and the pressure deburring unit are also aligned on the turret lathe (revolver) to the left of the workpiece table, in addition to the necessary tools for the turning and drilling processes. The gripper takes up the blank directly from the storage belt and sets it down on the rapid clamping system of the workpiece table.

To the right of the workpiece table is the hobbing head. This absorbs the high forces of the hobbing process. In order to absorb the forces of the gearing process, Liebherr optimized the entire machine by means of FEM and designed the guides of the radial infeed and of the stroke and its drives to be extremely solid. This type of construction guarantees maximum stability during the machining process, so that even the highest of cutting speeds are possible in dry machining.

The combined machining enables new dimensions for the workpieces—geared parts up to module 5 mm with diameters of 25 to 350 mm. This makes the utilization of the LDF 350 of particular interest, even in the range of larger geared parts.

For tool changes, the hob head swivels the tool axis into a vertical position so that the machine operator can insert the hob mandrel in an ergonomically efficient manner. The counterbearing is automatically tensioned and clamped. After the gear hobbing, the revolver presses the pressure deburring wheel into the gearing and thus eliminates the burrs and/or applies a chamfer to the workpiece. Residual burrs on the face sides can be eliminated by repeated stripping.

In comparison with a conventional production line with three individual processing machines for turning/drilling, hobbing and deburring, the so-called combination cell also reduces, in addition to the logistics outlays for loading and unloading, the non-productive times

continued

between the machining processes. "This results in a shortening of the throughput times and intermediate storage of the workpieces is dispensed with," explains Dr. Geiser. "Product changes also proceed more economically and more rapidly, as only one machine needs to be retooled for this purpose. The LDF 350 can be operated completely automatically and in conjunction with one or more turning cells."

The machine enables the complete processing of a wide spectrum of gear shafts and gears in only one clamping arrangement. In comparison with the other processes, this ensures a greater amount of flexibility and an optimized throughput. Time-consuming retooling from one workpiece type to the next with several individual machines is dispensed with. Given optimum conditions, the processing times of the LDF 350 can match those of the single specialized machines. This was one of the most important objectives for the development of the LDF 350.

As a result of the utilization of the LDF 350, the number of required machines, setup procedures and the overall throughput times for the complete machining of gears is drastically reduced, which means that both the investment expenditures and the workpiece costs are considerably lowered for the user. Advantages include no reclamping, no non-productive times and no intermediate buffering.

Complete machining also opens up new qualitative possibilities: It enables, for example, turning over the bearing seats once more after gear hobbing. This makes it possible to minimize deviations prior to hardening and any warpage which might occur to be held out in an accordingly precise manner.

"Being a specialist for gearing processes, we implemented this innovation together with the lathe manufacturing company of Scherer from Mömbris, a professional partner who has mastered the initial turning process," Dr. Geiser summarizes.

The result of this joint development work, the Liebherr LDF 350, is expected to be available the end of 2011.

For more information:

Dr.-Ing. Hansjörg Geiser
Head of Development & Design
Gearing Machines
Liebherr-Verzahntechnik GmbH
hansjoerg.geiser@liebherr.com
www.liebherr.com

Sicmat

RELEASES RASO 200 DYNAMIC SHAVING MACHINE

The Raso 200 Dynamic has been developed to offer all the characteristics of a gear shaving machine with a competitive price. With a footprint of just 4.4 square meters, it's also the most compact machine of the Sicmat Raso range. The Dynamic is the first shaving machine in the Raso family to utilize Siemens CNC Sinumerik 828D.

"The concept of the Dynamic was to introduce a machine that had the same performance and quality aspects of the Raso line at a reduced cost to the customer," says Carlo Amandola, sales director at Sicmat.

Global gear manufacturers are looking for machines that produce high quality parts at reduced prices, and the Raso 200 Dynamic fits these specifications. Amandola believes selling a gear shaving machine without additional frills is the advantage the Dynamic has in the gear market. "The Raso 200 Dynamic debuted at EMO Hannover in September with great results," Amandola says. "By updating the mechanical aspects and working with Siemens on the CNC controls, we've managed to produce a machine that is energy efficient, simple and inexpensive to maintain and also offers a competitive price."

The Raso 200 Dynamic offers all shaving cycles: parallel, diagonal, underpass, plunge and mixed cycles, user-friendly software and graphic interface, a self-contained coolant system and an optional automatic loader. High quality German components include the Siemens package (CNC, brushless servomotors and electric cabinet), Rittal active refrigeration and a Rexroth hydraulic system.

Technical specifications for the Dynamic include: number of axes

continued

5 +1 spindle with absolute encoder, min/max module 0.8–5 mm, min/max distance between shaving cutter and workpiece 120–202 mm, min/max diameter of shaving cutter 178–245 mm, shaving cutter bore diameter 63.5 (100) mm, min/max shaving cutter width 19–50.8 mm, maximum face to be shaved (diagonal cycle) 100 mm, installed power (including pump and cooling filter) 20 KVA and a net weight (including electrical cabinet) of 4,200 kg.

For more information:
Star SU LLC
5200 Prairie Stone Parkway
Hoffman Estates, IL 60192
Phone: (847) 649-1450
Fax: (847) 649-0112
www.star-su.com/dynamic

Mitutoyo CMM

DOUBLES THE MEASURING RANGE

The new Crysta-Apex S Coordinate Measuring Machine (CMM) from Mitutoyo America Corporation brings new levels of performance and economy to the 1.7 µm class of CNC CMMs. With a maximum error of MPEE = (1.7+3L/1000) µm, the new Mitutoyo Crysta-Apex S more than doubles the effective measuring range at a given measurement tolerance as compared to typical CMMs in its class. Additionally, the Crysta-Apex S drive features high-speed (max 519 mm/s) and high acceleration (max 2,309 mm/s^2). These advances result in higher throughput for greater productivity and lower total owning and operating costs.

The Crysta-Apex S uses the new UC-400 controller to manage digital servo system control loops for position, speed and current. This makes it easy to implement various types of control algorithms. Additionally, the digital servo system has a wide dynamic range and is highly resistant to drift over time. Extreme rigidity helps the Crysta-Apex S maintain accuracy. The Y-axis guide rail is integrated into one side of the granite surface plate. Precision air bearings located on the bottom, front, rear and upper surfaces of the X-axis slider minimize vibration and ensure stability even during high-speed, high-acceleration operation. Accuracy is further enhanced by an advanced temperature compensation system. The system consists of a thermometer unit that measures the temperatures from thermal sensors located on the scale units of the CMM main unit and from a set of workpiece thermal sensors. The temperature data is transferred to the UC-400 machine controller for thermal compensation. For proper workpiece compensation, the thermal expansion coefficient of the workpiece material is entered by the user; since the material of scale units of the CMM is constant, this expansion coefficient is permanently stored in the temperature unit. The Crysta-Apex S supports a wide range of probes that offer increased capabilities including the MPP-310Q scanning probe that collects cloud point data at speeds of up to 120 mm/s. Other probes suited for screw depth measurement, ultra-small diameter measurement and non-contact measurement are also supported.

Available software options enable the Crysta-Apex S to tackle a wide variety of measurement applications. Software packages include *Geopak*, a high-functionality general-purpose measurement program which is at the heart of *Mitutoyo Controlled Open System for Modular Operation Support* (*MCOSMOS*) software. *MCOSMOS* supports virtually every CAD format while providing routines for in-line measurement, data feedback, and process management. Additional software supported includes: *CAT1000S* for freeform surface evaluation; *CAT1000P*, an offline teaching program; *Scanpak*, for contour measurement; and a range of programs supporting laser and vision probes. Crysta-Apex S provides USB communications for connectivity. Additionally, Crysta-Apex S supports *MeasurLink STATMeasure Plus*, Mitutoyo's proprietary statistical-processing and process-control program. *MeasurLink STATMeasure Plus* per-

continued

forms statistical analysis and provides real-time display of measurement results for SPC applications. The program can also be linked to a higher-level network environment for enterprise-wide functionality.

For more information:
Mitutoyo America Corporation
965 Corporate Blvd
Aurora, IL 60502
Phone: (630) 820-9666
Fax: (630) 820-2614
www.mitutoyo.com

Sandvik

OFFERS COROMANT CAPTO AND COROMILL 176

For all types of heavy machining operations in large components, Coromant Capto size C10 improves performance by allowing higher feeds and greater depths of cut. A flange diameter of 100 mm means a coupling suitable for heavy loads, providing extreme stability in milling and turning applications. Designed to increase removal capacity at higher torques, the C10 gives the entire tool set up higher bending strength. The C10 includes a wide range of holders and adapters from shrink fit, SL adaptors and ER-chucks to tap adaptors. The stable tool holding system makes it possible to use only one system for the entire workshop, regardless of machine type: turning center, machining center, multi-task machine; manual or fully automatic. The tool system permits standardization, reduces inventory costs, and simplifies physical and administrative handling of tools. The unique polygon shaped Coromant Capto coupling, introduced in 1990, has proven its excellence over the years and is now an ISO standard (26623).

In addition, Sandvik Coromant recently introduced a new full profile hob for gear milling, Coromill 176.

This indexable carbide insert hob can reduce cutting time by 50 percent and double tool life compared to traditional high speed steel cutters. For roughing, semi-finishing and finishing, the hobbing tool solution covers gear profile sizes in the range module 4–6. With standard carbide inserts for gear profiles according to DIN3972-2 it is custom-made for specific profiles with, for example, addendum modification and protuberance. The hob is easy-to-use with the iLock interface ensuring precision and stability. Coromill 176 is registered as Quality class B in accordance with DIN3968.

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

Seco

RELEASES NEXT GENERATION MINIMASTER

Seco introduced its original Minimaster line of end mills with replaceable carbide inserts nearly 25 years ago. Today, the company is presenting its new Minimaster Plus, with advanced features for tackling the most demanding of milling applications in steel, stainless steel, cast iron, aluminum and other difficult-to-machine materials. The most notable new feature on the Minimaster Plus is the high-precision interface between the replaceable carbide insert and the steel shank. The insert has an internal thread and external taper, while the shank has an internal taper with a threaded center pin for added reliability and stability as well as minimized run-out. Additionally, a new axial

continued

stop on the shank increases repeatability and productivity by allowing end users to replace an insert without having to remove the tool from machine spindles. The new insert then repositions axially within 25 microns. Intended for general machining in the aerospace, power generation, die and mold, automotive and medical industries, the Minimaster Plus replaceable tip milling system makes tool-length re-measurement obsolete. The milling system offers a large selection of inserts and shanks for a multitude of

tough milling applications. Twenty-four versions of the shank are available, along with square shoulder and ball nose inserts that have through-tool coolant on all two and three flute designs for excellent cooling and efficient chip removal. Inserts come in two grades for machining all types of materials and E- and M-geometries for a smooth cutting design. Insert diameters range from 0.375" to 0.625" and corner radii are available from 0.0157" to 0.122" to match a variety of design requirements.

For more information:
Seco Tools
2805 Bellingham Drive
Troy, MI 48083
Phone: (248) 528-5200
secotools.us@secotools.com
www.secotools.com

Adcole Tester

MEASURES CAM-SHAFTS WITH GEARS

An upgraded camshaft measuring machine that is designed with a wide diameter offset follower to accommodate larger diameter cams with built-in gears is being introduced by Adcole Corporation of Marlborough,

Massachusetts. The Adcole Model 911 Camshaft Gage is suitable for measuring camshafts up to 90" long and has an offset follower with 6.1" travel to accommodate larger diameters with built-in gears. Featuring an air-actuated open-close of the tailstock, with a video monitor to assure the center hole is lined up and engaged, this camshaft measuring machine has a ball bearing spindle with run-out under 0.2 µm and a footswitch-operated tailstock restraint.

Automatically measuring 360 degrees around the part, including all cam lobes, reference journals, timing features, and keyways, the Adcole Model 911 Camshaft Gage is capable of the submicron detection of material buildup or other form irregularities. This cam tester has become the world standard for milling and grinding machine tool users to make certain there is product conformance among suppliers and OEMs, claims the firm.

For more information:
Adcole Corporation
669 Forest Street
Marlborough, MA 01752
Phone: (508) 485-9100
breece@adcole.com
www.adcole.com

LMC Face Drivers

IMPROVE TURNING PRODUCTIVITY

Gear hobbing is easier and more productive with Neidlein's FDNC face driver from LMC Workholding. With Neidlein's FDNC Face Drivers, hobbing can be done in one operation, eliminating the use of a chuck. These face drivers also deliver high-tolerance concentricity/runout specifications

continued

of .00003" to .00007". Also, the center pin and drive disk system can be adjusted to achieve zero runout.

Using a Neidlein FDNC Face Driver allows the entire workpiece to be exposed for machining and turned in one operation, which eliminates a step in the production process and reduces cycle time. Also efficiency and accuracy are improved since hobs stay on one machine and tolerance stack-ups are eliminated. What's more, the single-axis reference point established by the face driver's center point allows for a higher concentricity.

Neidlein gear hob face drivers are available in flange mount and two shank styles: Morse-taper and straight shank. Specials are available that are produced to customer specifications and needs.

FDNC Face Drivers also offer a quick-change drive disk for faster job changeovers, optional coolant flush, and spring-loaded or fixed-center pin. Drive disks are available in clockwise, counterclockwise and bi-directional drive disks.

Neidlein makes a complete line of face drivers that use quick-change center points and drive pins for increased productivity and cost efficiency. An online video at its website is available to see face drivers in action.

LMC Workholding engineers and manufactures high quality chucks and standard and special workholding equipment, including international style power chucks and cylinders, wheel chucks, high volume machining power chucks, Neidlein face drivers and centers, Atling hydraulic steady rests, Richter manual steady rests, Stiefelmayer specialty clamping tools, Chandox brand chucks and cylinders and T de G large chucks.

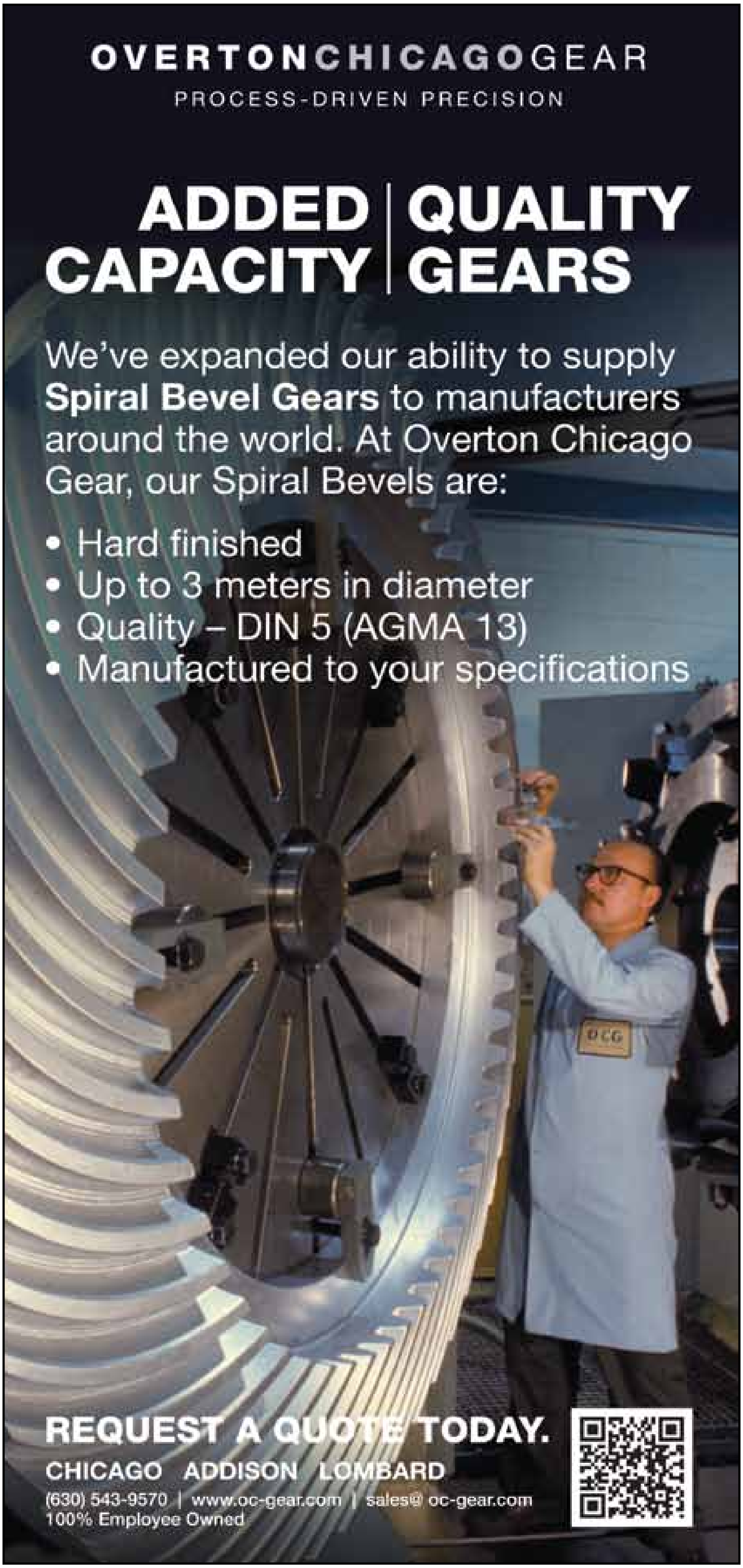
For more information:
LMC Workholding
1200 West Linden Avenue
Logansport, IN 46947
Phone: (574) 735-0225
www.lmcworkholding.com

Royal Filtermist Series

CONTINUES DESIGN IMPROVEMENTS

While many companies are aware of traditional problems associated with oil mist (health and accident risks, cleaning and maintenance costs, etc.), few are aware that failure to adequately address mist and smoke issues often result in reduced productivity and increased machine downtime. In addition, production is often reduced as a result of employees dialing back on feeds and speeds in order to minimize production. An often overlooked maintenance problem is the effect of oil mist on electrical contacts and electronic circuits. For the past 30 years, the Royal Filtermist has been collecting oil mist and smoke generated by all types of metalworking machinery. There are currently more than 125,000 Filtermist units operating in more than 40 countries worldwide. It has undergone continuous design improvements through the years—the latest version, the Filtermist FX Series, is the product of extensive computer-aided modeling and laboratory testing. The Royal Filtermist is avialble in four sizes ranging from 275–1200 cfm, and its flexible design enables it to be mounted in a variety of ways. Maintenance and operating costs are minimal. All Royal Filtermist units are sold with a 45-day risk-free performance guarantee.

For more information:
Royal Products
200 Oser Avenue
Hauppauge, NY 11788
Phone: (631) 273-1010
www.royalprod.com



Rex-Cut

OFFERS ABRASIVE DISC LINE

A full line of cotton fiber quick change abrasive discs for blending and finishing stainless steel, aluminum, and exotic alloys are available from Rex-Cut Products, Inc. of Fall River, Massachusetts. Rex-Cut Cotton Fiber Quick Change Discs incorporate multiple layers of reinforced non-woven cotton which are impregnated with abrasive grains and then pressed, bonded together, and fitted with 3M Roloc and Sockatt style fasteners. Constantly exposing fresh abrasives as they work, these quick change discs grind and finish in one-step with smooth operation. Flexible for use on flat and contoured surfaces, yet rigid enough to reach into corners, Rex-Cut Cotton Fiber Quick Change Discs last up to 25 times longer than unitized discs, claims the firm. Impregnated with either aluminum oxide or silicon carbide abrasive grains, they come in 1", 1-1/2", 2", and 3" sizes in a variety of grits with flexible and medium bonds. Rex-Cut Cotton Fiber Quick Change Discs are priced according to size and quantity. Free samples are available upon request. Kits are also offered.

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

Load-Sharing Model for Polymer Cylindrical Gears

E. Letzelter, J.P. de Vaujany and M. Guingand

(*First presented at the VDI International Conference on Gears, October 2010, Technical University of Munich*)

Management Summary

This paper presents an original method to compute the loaded mechanical behavior of polymer gears. Polymer gears can be used without lubricant, have quieter mesh, are more resistant to corrosion, and are lighter in weight. Therefore their application fields are continually increasing. Nevertheless, the mechanical behavior of polymer materials is very complex because it depends on time, history of displacement and temperature. In addition, for several polymers, humidity is another factor to be taken into account. The particular case of polyamide 6.6 is studied in this paper.

The model to compute the viscoelastic displacement of the polymer materials is presented first. Numerous rheological models exist, but in this study the generalized Kelvin model has been chosen (*Ed.'s Note: Baron (Sir William Thomson) Kelvin (1824–1907), influential Scottish engineer, mathematician and physicist.*)

This model accounts for a wide relaxation time spectrum and—with the time temperature superposition principle—it is linked to temperature and humidity. In addition, a spectrometer experiment is conducted to characterize the mechanical properties at different temperature and humidity.

In a second part of this paper, the viscoelastic model is integrated in a quasi-static load-sharing computation developed by LaMCoS (Laboratory of Contact Mechanics and Structures, University of Lyon, Lyon, France). In calculus, the displacement is obtained with the displacement compatibility relation in a large meshing over the entire surface of the tooth. This relation integrates the viscoelastic displacement and the geometrical influence coefficients. These coefficients permit integration of the bulk and contact deformations. The method shown in this paper provides results such as the loaded transmission error; instantaneous meshing stiffness and pressure; load-sharing and the root tooth stresses at different temperature; and humidity and rotation speed.

Also, a test bench has been developed to measure the transmission error and the thermal behavior. This bench is presented in this paper.

Introduction

LaMCoS has developed numerical models to predict two essential areas—load-sharing and transmission error; they are needed in order to carry out dynamic studies. But these models have been developed for different gear geometries—made with elastic materials—as cylindrical gears (Ref. 1), face gears (Ref. 2), spiral bevel gears (Ref. 3), worm gears (Ref. 4) and pinion rack (Ref. 5). To determine the load-sharing, LaMCoS provides a solution for the displacement compatibility equation. The influence coefficients method is used to separate the contact and volume effects; this method has the advantage of being much less time consuming.

As mentioned, polymer gears present many advantages over steel gears: no lubricant; quieter mesh; and less weight. Generally, the polymer material chosen to produce molded or cut gears is a semi-crystalline polymer; i.e., polyamide (Ref. 6). The mechanical behavior of this polymer is viscoelastic and thus depends on the time, speed and history of displacement and temperature (Ref. 7). In addition, in the case of polyamide, the mechanical behavior depends also on humidity levels (Ref. 8).

Recently, Hiltcher et al. (Ref. 4) have developed a quasi-static load-sharing model of a metal worm gear with a polymer wheel. With this method, they assume that the displacement of the steel worm is negligible compared to that of the polymer wheel. But in this paper the method presented is adapted for polyamide 6.6 gears; therefore, the displacement of the polymer gear is addressed. In addition, the characterization of the mechanical properties is updated. This study is limited to the linear domain of the material and the assumption is made that the tooth is relaxed for each rotation.

Also, the original test bench developed by LaMCoS can measure the transmission error and thermal behavior of polyamide 6.6 gears. The transmission error simulated with the load-sharing model will be compared to the measured one; the thermal measurement is made with an infrared camera, which provides the evolution and repartition of the meshing temperature.

Mechanical Behavior of Polyamide 6.6

The mechanical behavior of polyamide is viscoelastic, meaning that it depends on loading duration or, in other words, on the history of displacement and temperature. Humidity is another factor to be taken into account in the specific case of polyamide 6.6.

The linear viscoelastic properties of polymers, i.e., the material temporal compliance $J(t)$, can be deduced from creep tests and simulated by a rheological model that introduces retardation times τ and the amplitude of the deformation. In the case of a unique retardation time, the temporal compliance can be expressed with the relation (Ref. 9):

$$J(t) = J_r \left(1 - \exp\left(\frac{-t}{\tau}\right)\right) \text{ with } \tau = \eta J_r \qquad (1)$$

J_r is the relaxed compliance and η is the viscosity.

Another technique to deduce viscoelastic properties is the spectrometer test. A DMA (dynamic mechanical analysis) was performed in torsion mode; the complex compliance $J^*(i\omega, T)$ or the complex elastic modulus $G^*(i\omega, T)$ can be deduced from the spectrometer test (Ref. 9):

$$J^*(i\omega, T) = \frac{1}{G^*(i\omega, T)} = J'(\omega, T) - iJ''(\omega, T) \qquad (2)$$

J' is the elastic compliance and J'' is the viscous one.

In order to simulate the viscoelastic behavior, the relationship in Equation 1 has a unique retardation time and is insufficient to account for the viscoelasticity of polyamide 6.6. Thus, a rheological model such as the generalized Kelvin model is proposed in order to account for a wide relaxation time spectrum (Ref. 9); this rheological model is presented in Figure 1.

In order to compute the load-sharing, knowledge of the temporal displacement of polyamide 6.6 material is necessary. Thus, the total strain of the generalized Kelvin model is computed in Equation 4. This requires use of an incremental scheme based on differential equations and the relationship can be written in each block of the model:

$$\sigma(t) = \frac{1}{\Delta J_i}\varepsilon^i(t) + \frac{\tau_i}{\Delta J_i}\dot{\varepsilon}^i(t) \qquad (3)$$

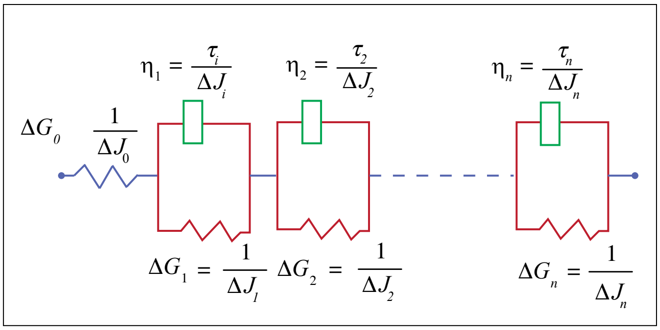


Figure 1—Generalized Kelvin model.

where:

τ_i is the retardation time;

i is the index of the block in the generalized Kelvin model;

and n is the number of blocks in the model:

$$\varepsilon(t) = \sigma(t)\sum_{i=0}^{n}\Delta J_i\left(\frac{\Delta t}{\Delta t + \tau_i}\right) + \sum_{i=0}^{n}\varepsilon^i(t-dt)\left(\frac{\tau_i}{\Delta t + \tau_i}\right) \qquad (4)$$

With this relationship, the viscoelastic displacement $u(t)$ is then deduced:

$$u(t) = l.\sigma(t)\sum_{i=0}^{n}\Delta J_i\left(\frac{dt}{dt + \tau_i}\right) + l.\sum_{i=0}^{n}u^i(t-dt)\left(\frac{\tau_i}{dt + \tau_i}\right) \qquad (5)$$

l is the length of the polyamide 6.6 specimen (small displacement assumption).

The relationship in Equation 5 is used to solve the load-sharing problem, but first it is necessary to determine the viscoelastic properties ΔJ_i and τ_i. Initial DMA tests reveal the evolution of the complex elastic compliance with the master curve; in a second test, a phenomenological model provides the numerical values of viscoelastic properties.

Experimental Characterization of Mechanical Properties

DMA tests were carried out with a spectrometer developed in the MATEIS laboratory (at the University of Lyon). This dynamic test enables determination of the evolution of the complex, elastic modulus or the complex elastic compliance function with the time or temperature. The tests were carried out in both dry and humid environments at 50% relative humidity.

Results and Viscoelasticity Modeling

For polymer material, the time/temperature superposition principle can be applied. With this principle—and the spectrometer tests—it is possible to build at a given reference temperature the storage-compliance curve $J'(i\omega,, T_{ref})$ or the loss-compliance curve $J''(i\omega, T_{ref})$ over a very wide frequency range. This "master curve" is obtained from the shift of experimental DMA curves obtained at different temperatures.

In order to determine the distribution of the retardation

continued

time τ_i, the numerical master curves $J'(i\omega\ T_{ref})$ are necessary. It is determined by using a phenomenological model as a numerical fit of the master curve. To do so, the bi-parabolic model developed by Decroix et al. is used (Ref. 10):

$$J^*\left(i\omega,T_{ref}\right)=\frac{1+\delta\ \left(i\omega\tau'\right)^{-\chi}+\left(i\omega\tau'\right)^{-\chi'}}{\frac{1}{J_u}-\frac{1}{J_r}}+\frac{1}{J_r} \quad (6)$$

To obtain the time spectrum, discretization by pulsation of the numerical master curve $J_i'(i\omega,\ T_{ref})$ is needed. In this study, to account for the large relaxation time spectrum of the polyamide 6.6, it is necessary to use 19 elements of Kelvin-Voigt (*German physicist Woldemar Voigt*) in the Kelvin-generalized model. The distribution of retardation time $\tau_i\ (T_{ref})$ is deduced from pulsation ω_i at the maximum of $J_i''(i\omega,\ T_{ref})$, i.e.—in the middle of the frequency segment. The retardation time is deduced with the relation:

$$\tau_i=\frac{1}{\omega_i} \quad (7)$$

Figure 2 shows the experimental data and those issued from the generalized Kelvin model in a dry environment and 50% relative humidity.

Load-Sharing Model

The method developed by LaMCoS to model the instantaneous load-sharing is based on a unique process used for all types of gears made with steel or steel/polymer materials. This procedure has been used to model the load-sharing for cylindrical gears (Ref. 1); face gears (Ref. 2); spiral bevel gears (Ref. 3); worm gears (Ref. 4); and pinion racks (Ref. 5). This method is divided in three parts:

1. Simulation of manufacturing to obtain the tooth profile of the gear
2. Unloaded kinematics simulation to determine the potential contact zones
3. Computation of load-sharing between all teeth in contact

The relationship (Eq. 5) adapted for semi-crystalline materials has been integrated in the third step. This method yields results for transmission error, load-sharing and instantaneous pressure.

With a steel gear, the meshing used to solve the load-sharing is limited to the contact zone; indeed, this meshing occurs around the contact line. But contrary to steel gears, with polymer gears it is necessary to know the history of the gear and pinion displacements. Consequently, the meshing developed for the polymer gears is different from that of steel gears; it is larger—in tangent with the contact plane—and covers the entire tooth surface. Thus for a kinematics position it is possible to save the displacement of the entire profile of the pinion and gear in computing the following kinematics position.

In order to show some numerical examples for a spur gear made in polyamide 6.6 material, a standard geometry was used in this study. Figure 3 shows the tooth numbering used in the load-sharing model and Table 1 presents the gear data.

Equation of compatibility of displacement. Determination of tooth load-sharing is, above all, a multi-contact problem. The load-sharing problem is addressed by solving the equations of displacement compatibility (8–9) for every point *k* and driving torque (Eq. 10).

Inside the contact zone:

$$p\left(M_k\right)\geq 0 \text{ and } e\left(M_k\right)=\delta\left(M_k\right)+u\left(M_k\right)-\alpha=0 \quad (8)$$

Outside the contact zone:

$$p\left(M_k\right)=0 \text{ and } e\left(M_k\right)=\delta\left(M_k\right)+u\left(M_k\right)-\alpha\geq 0 \quad (9)$$

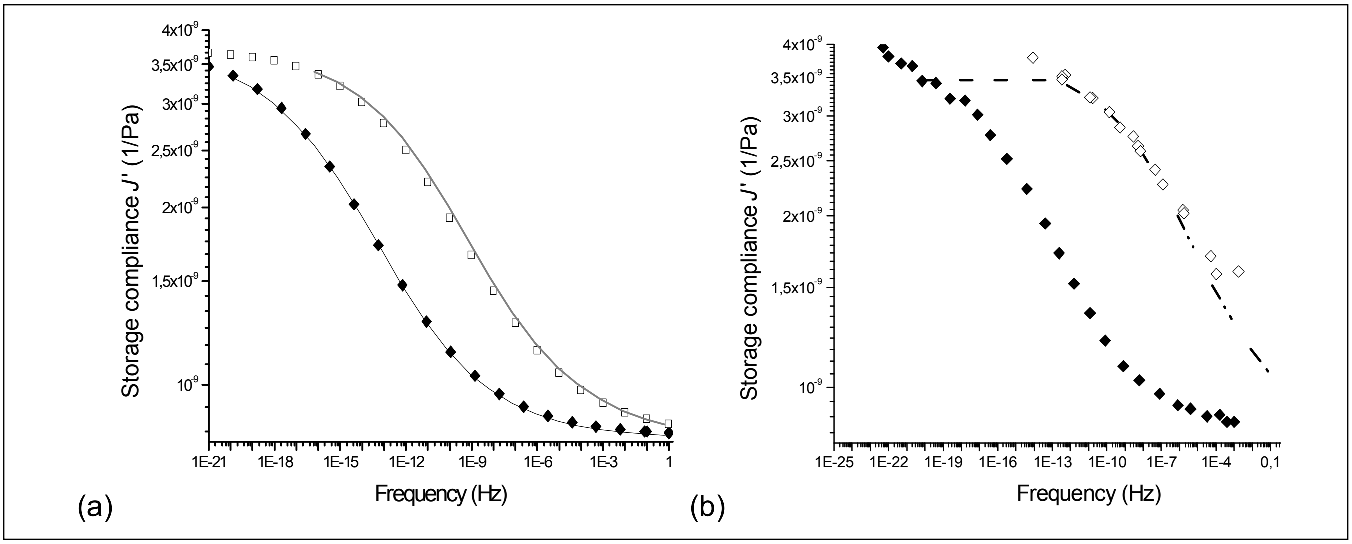


Figure 2—Master curves of storage compliance and fitting with model: a: (♦) dry test at T_{ref} = 0°C; (□) dry test at T_{ref} = 30°C; (–) dry model at T_{ref} = 0°C; (–) dry model at T = 30°C. b: (♦) dry test at T_{ref} = 0°C; (□) humid test (50% RH) at T_{ref} = 0°C; (--) humid model (50% RH) at T_{ref} = 0°C.

$$C_{motor} = \sum_{k=1}^{K} \left(p_k s_k \overrightarrow{n_k} \wedge \overrightarrow{M_k} \right) \tag{10}$$

K = number of nodes of the meshing
$P(M_k)$ = contact pressure at point M_k
$e(M_k)$ = gap between the profiles of the gear and pinion at point M_k—after the loading
$\delta(M_k)$ = gap between the profiles of the gear and pinion at point M_k—before the loading
$u(M_k)$ = displacement at point M_k
α = global body adjustment

The influence coefficient. In order to solve the load-sharing problem, it is necessary to compute the displacement u_k depending on pressure p_k. It is possible to indentify the relationship (Eq. 11) between displacement and pressure with use of the influence coefficients C_{kj}. There are two types of influence coefficients—the bulk-influence coefficients C^v_{kj} computed by finite element method, and the contact-influence coefficients C^s_{kj} computed by Boussinesq theory (*Ed.'s note: Joseph Valentin Boussinesq, nineteenth century French mathematician and physicist who made significant contributions to the theory of hydrodynamics, vibration, light and heat*).

$$u_k = \sum_{j=1}^{K} \text{ with } C_{kj} = C^v_{kj} + C^S_{kj} \tag{11}$$

However, the relationship in Equation 11 is adapted for steel gears; in the case of polymer gears, the geometrical-influence coefficient is used. They are defined by:

$$C_{kj} = J_{mat} C^*_{kj} \tag{12}$$

Viscoelastic displacement on meshing. In order to determine the nodes' displacement in the meshing, the displacement $u_k(t)$ is determined by the link between the relationships in Equations 5, 11 and 12.

$$u_k(t) = \sum_{i=1}^{n} u^i_k(t) \text{ with } u^i_k(t) = \sum_{j=1}^{K} C^*_{kj} p_j(t) \Delta J_l \left(\frac{dt}{dt+\tau_i} \right) + u^i_k(t-dt) \left(\frac{\tau_i}{\tau_i+dt} \right) \tag{13}$$

This system of equations, which includes the relationships in Equations 8–10, is used to calculate the load-sharing. This is done by using a fixed-point algorithm; it is also necessary to create a history of the displacements. To obtain this history, the displacement and the load-sharing are calculated for two teeth situated just before the tooth comes into contact.

Numerical results. Numerical examples for polyamide 6.6 spur gears are presented here; the gear data of the studied gears are presented in Table 1. Figure 4a shows the simulated load-sharing and Figure 4b shows the transmission error simulated for polymer gears at 25°C, 50% relative humidity, 300 rpm and 10 Nm. Figure 3 presents the tooth-numbering used for the simulated load-sharing.

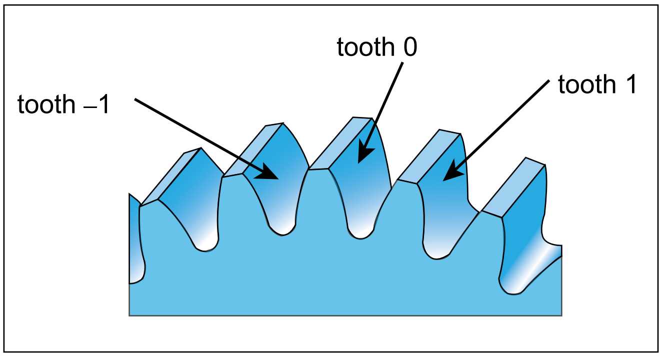


Figure 3—Tooth numbering.

Table 1—Gear Data

	Pinion	Gear
Module (mm)	3	3
Pressure angle (°)	20	20
Tooth width (mm)	20	20
Number of teeth	32	41

Figure 4a shows that the simulated load-sharing has a correct shape. With concurrent geometry simulation, Tooth –1 is unloaded and Tooth 1 is loaded gradually; Tooth 0—the central tooth—remains constant. Finally, for this gear geometry with material having a low elastic modulus and an important strain, there are always two teeth in contact.

The simulated transmission error shows that, at this temperature and in this relative humidity, the material behaves like a rubber material. The retardation time is brief—compared with the time scale of the rotation—and the apparent compliance is therefore high, leading to excessively high transmission error.

Experimental Measurements

Testing device. The unique characteristics of the LaMCoS bench are the instantaneous measure of the thermal behavior by an infrared camera, and transmission error. The gear data presented in Table 1 are used for this bench; Figure 5 shows the scheme of the test bench.

Transmission error measurements. The angular positions of pinion and gear are captured with optical encoders clamped directly on the rotating shaft, which is very useful for measuring transmission error because the encoders are now close to the gears. The principle of this measurement (Ref. 11) is based on counting pulses delivered by a timer at very high frequency (80 MHz) between two rising edges of the signal delivered by the optical encoders. This time-counting method must be carried out simultaneously on the two signals with the same reference; i.e., the same timer and counter. The time evolution of the pinion and gear angular positions is then defined with a sampling rate provided by the number of pulses on each encoder.

continued

The angular sampling method performs the calculation at the rising edge on the pinion signal and gear signal. The transmission error can be given as an angular displacement on either the pinion or gear shaft. With this method the relationship of the transmission error ε(*t*) as an angular displacement on the gear shaft is used:

$$\varepsilon(t) = \theta_2(t) - \frac{Z_1}{Z_2}\theta_1(t) \qquad (14)$$

The test temperature is 25°C and relative humidity 50%. Figure 6 presents the comparison between transmission error measured and simulated at 25°C, 50% relative humidity, 300 rpm and 10 Nm. The simulation includes the assembling parameters as measured before the test; this transmission error is presented during the meshing of one tooth of the gear (8.57°).

This comparison is a good fit between the experimental

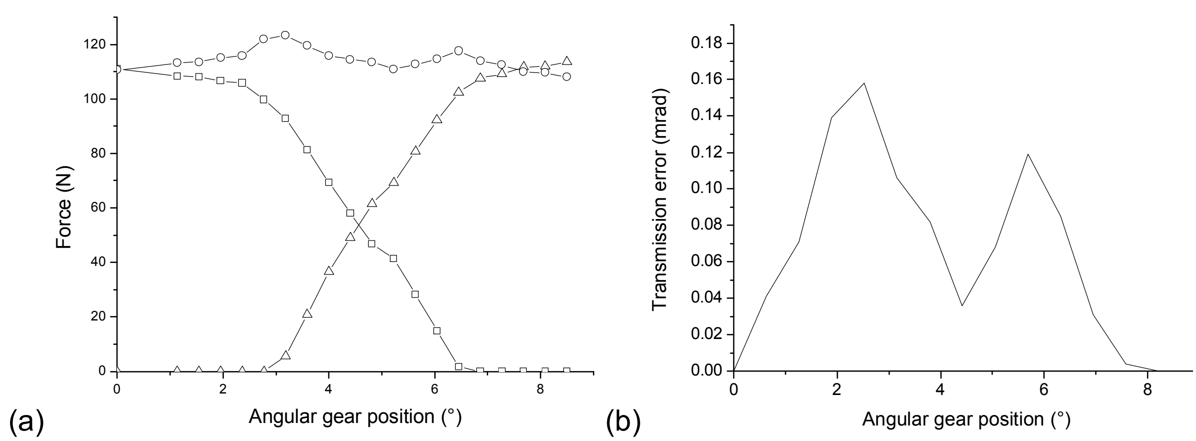


Figure 4—a: Load-sharing model at 25°C, 50% relative humidity, 300 rpm and 10 Nm; (□) Tooth -1; (o) Tooth 0; (Δ) Tooth 1. b: Transmission error at 25°C, 50% relative humidity, 300 rpm and 10 Nm.

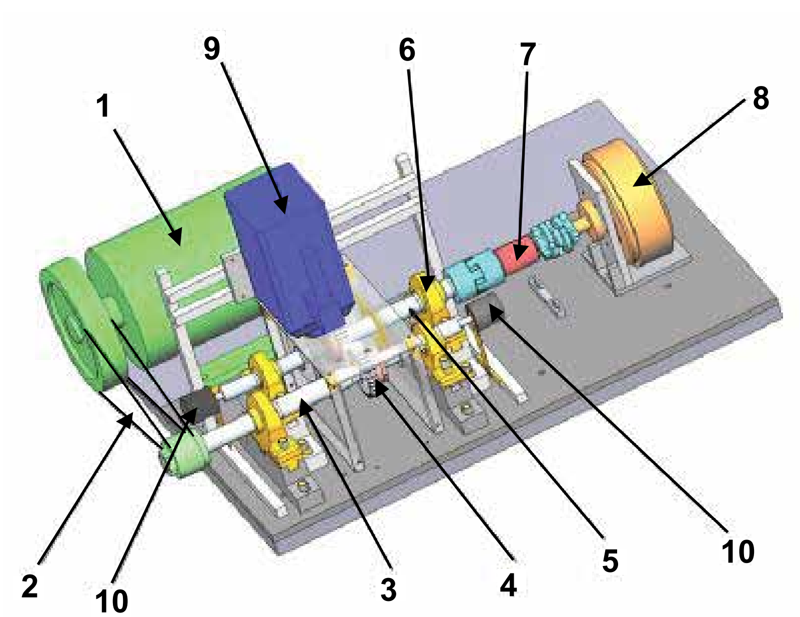


Figure 5—Test bench scheme, showing motor (1), belt (2), rotation axis of pinion (3), gears (4), rotation axis of gear (5), bearings (6), torquemeter (7), break (8), infrared camera (9) and optical encoders (10).

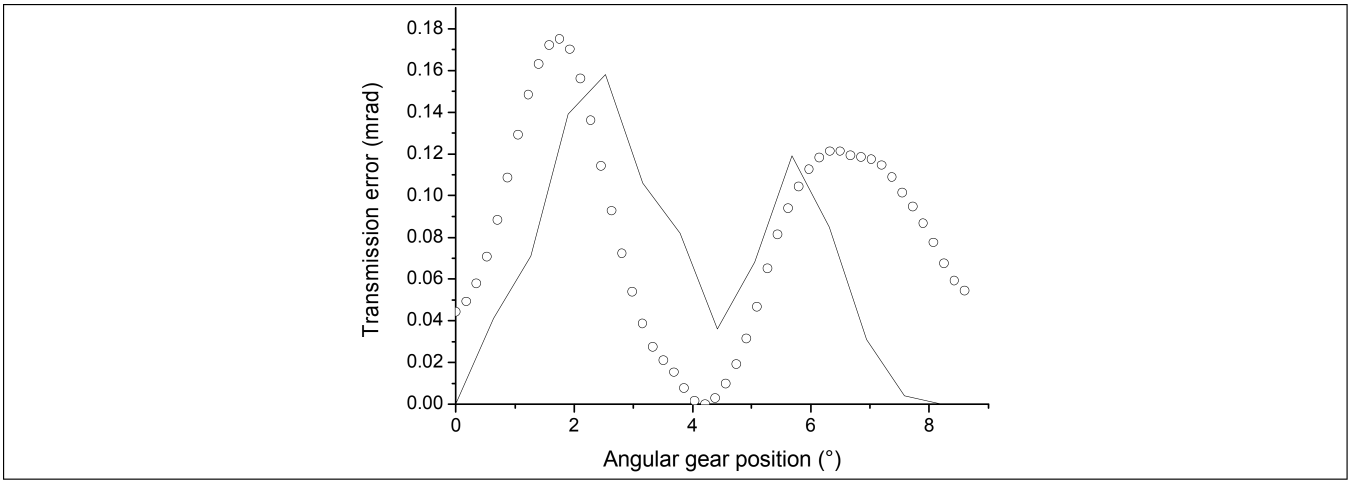


Figure 6—Comparison of measured and simulated transmission error at 25°C, 50% relative humidity, 300 rpm and 10 Nm; (o) = transmission error measured; (–) = simulated transmission error.

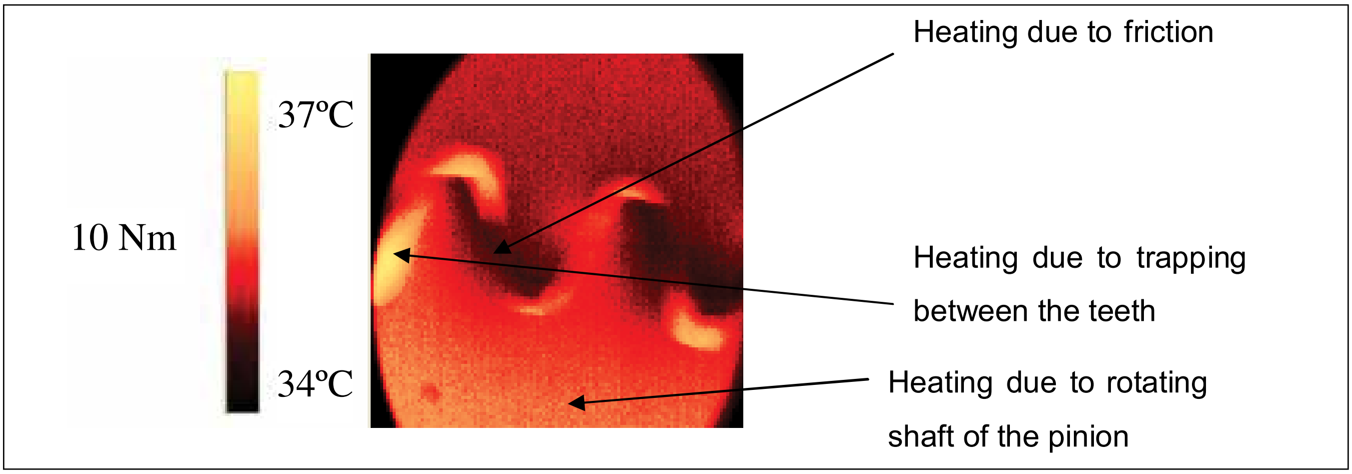


Figure 7—Measurements by infrared camera at 300 rpm and 10 Nm.

and numerical curves. Also, this figure shows that the simulated transmission error has the same shape and amplitude as that of the experimental transmission error.

Thermal measurements. In order to measure the thermal behavior of a polyamide 6.6 gear, an infrared camera was used. Figure 5 shows that the infrared camera (Eq. 9) is mounted on a support close to the gears. The optical encoder (Eq. 10) can trigger the camera at every turn of the pinion; however, the camera was set to record only when the same pair of teeth was in contact.

Thermal measurements are made on the profile of the teeth; but in order to do this, a polished mirror inclined at 45° was used, due to the vertical positioning of the camera; the polished mirror was aluminum-treated to facilitate the transfer of infrared thermal radiation. This solution enabled reflection of the image near the meshing to the camera—thus making it possible to measure the temperature of the gear. Figure 7 shows the results of the stabilized thermal measurements at 300 rpm and 10 Nm. These tests were made for 10 hours at a temperature of 25°C and 50% relative humidity.

The results show the different sources of heat generation with the friction between the teeth, the bearings with the shaft, and the trapping of air between the teeth. The temperature difference between the beginning and end of the test is 12.8°C. For the moment, the quasi-static load-sharing model does not take into account the heating during operation. However, Figure 2 shows that polymer gears are very sensitive to this temperature. The thermal results show that the quasi-static load-sharing model can be improved with the integration of a thermal model; i.e., one that accounts for the heating in the bulk and the contact during operation.

Conclusion

This study presents a fast and efficient method for studying the mechanical behavior of polyamide 6.6 spur gears. The viscoelastic properties are modeled with the generalized Kelvin model, which addresses the speed, temperature and humidity. With the viscoelastic displacement and the method of influence coefficients calculated on the entire surface of the tooth, it is therefore possible to overcome the load-sharing problem.

Also, this study showed an original, experimental test bench developed by LaMCoS. These experiments made possible the measurement of transmission error and thermal behavior of polyamide 6.6 gears. The measure of the transmission error shows a correct correlation between simulation and measurement. In addition, the simulation includes the

continued

precise tooth profile and parameters—assembling, temperature and speed. With thermal measurement it is possible to record the evolution and repartition of the meshing temperature function and determine the sources of heat generation. The next steps of the study will focus on the improvement of the quasi-static model via the thermal model.

References

1. Guingand, M., J.P. De Vaujany and Y. Icard. "Fast 3-D Quasi-Static Analysis of Helical Gears Using the Finite Prism Method," *Journal of Mechanical Design*, ASME, 6 (126) 2004, 1082–8.
2. Guingand, M., J.P. De Vaujany and Y. Icard. "Analysis and Optimization of the Loaded Meshing of Face Gears," *Journal of Mechanical Design*, ASME, 1 (127), 2005, 135–43.
3. Vaujany, J.P., M. Guingand, D. Remond and Y. Icard. "Numerical and Experimental Study of the Loaded Transmission Error of a Spiral Bevel Gear," *Journal of Mechanical Design*, SME, 2 (129), 2007, 129–35.
4. Hiltcher, Y., M. Guingand and J.P. De Vaujany. "Load-Sharing of a Worm Gear with a Plastic Wheel," *Journal of Mechanical Design*, ASME, 1 (129), 2007, 23–30.
5. De Vaujany, J.P. and M. Guingand. "Geometry, Kinematics and Load-Sharing of Pinion Rack Gear with Variable Ratio," *JSME International Conference on Motion and Power Transmissions*, Japan, May 13–15, 2009.
6. Haudin, J.M. "Structure and Morphology of Semi-Crystalline Polymers: Introduction to Mechanics of Polymers;" Ecole des Mines de Nancy, C. G'Sell and J.M. Haudin, 1995.
7.Lemaitre, J. and J.L. Chaboche. *The Mechanics of Solid Materials*, 2nd Ed. (French), 2004.
8.Scaffaro, R, N. Tzankova Dintcheva and F.P. La Mantia. "New Equipment to Measure the Combined Effects of Humidity, Temperature, Mechanical Stress and UV Exposure on the Creep Behavior of Polymers," *Polymer Testing*, Volume 27, Issue 1, February, 2008, pp. 49–54.
9. Ferry, J.D. *Viscoelastic Properties of Polymers*, 3rd Ed., John Wiley, 1980.
10. Decroix, J.Y., A. Piloz, A. Douillard, J.F. May and G. Valet. "Mathematical Model for Viscoelastic Behavior of Polyolefin: Application to Polyolefin Blends and Hexane-1-Propene Co-Polymers," *European Polymer Journal*, No. 11, 1975, 625–30.
11. Rémond, D. "Practical Performances of High-Speed Measurement of Gear Transmission Error or Torsional Vibration with Optical Encoders," *Journal of Measurement Science and Technology*, Volume 9, No. 3, 1990, pp. 347–53.

Jean-Pierre de Vaujany *is an associate professor (1997 to present) at the National Institute of Applied Sciences, INSA of Lyon/LaMCoS Laboratory, where he teaches mechanical design and CADD. De Vaujany also serves as director of the university's International Section Amerinsa (founded in 2000, coursework preparing graduate students for the international requirements that are essential in the engineering profession today).*

Michele Guingand *is a senior associate professor (1991 to present) at the National Institute of Applied Sciences, INSA of Lyon/LaMCoS Laboratory, where she teaches courses in gear design, CADD and product lifecycle management.*

Dr. Eric Letzelter *received his masters degree at the University of Strasbourg in 2007, specializing in mechanical and materials engineering. From 2007–2010 Letzelter taught mechanical engineering development at INSA Lyon before receiving his Ph.D. in 2011 at the Contact and Structural Mechanics Laboratory, LaMCoS of the INSA Lyon; his thesis: "The Mechanical Behavior Model of Polymer Cylindrical Gears." Letzelter is currently an engineer in the automotive industry.*

Flank Breakage on Gears for Energy Systems

Erwin Bauer and Arne Böhl

(First presented at the VDI International Conference on Gears, October 2010, Technical University of Munich)

Management Summary

Gear flank breakage can be observed on edge zone-hardened gears. It occurs, for example, on bevel gears for water turbines, on spur gears for wind energy converters and on single- and double-helical gears for other industrial applications.

The nature of flank breakage is described in this paper. An ultrasonic inspection technique has been shown to be suitable for carrying out an inspection within the volume of case-hardened teeth. The nature of various ultrasonic indications could be identified by means of metallographic and fractographic investigations. Various phenomena such as white etching areas, nonmetallic inclusions and large cracks are involved. Recurring inspections have shown that indications associated with increases in reflectivity and in the lengthwise extent, or in individual indications growing together, have appeared. This confirms a cyclic crack growth under vacuum.

Over time, it can be noticed that the cylindrical form of gears has lost as much as several tenths of a millimeter. Measurements of retained austenite have shown that the content decreases in areas with visible high temperature and loading.

Within the framework of an earlier research project—Flank Breakage with Spur Gears—a calculation model was developed that shows good correlation with the investigated gears that have suffered flank breakage.

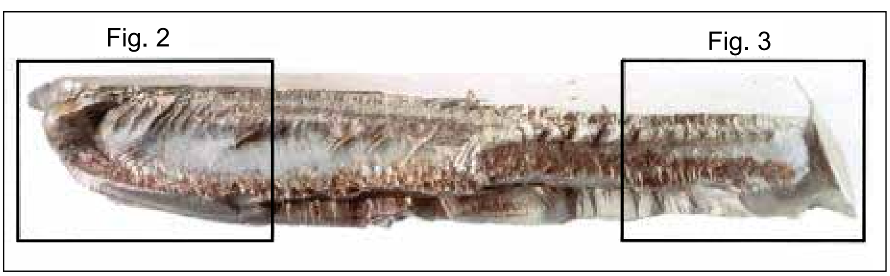


Figure 1—Fragment of a pinion tooth.

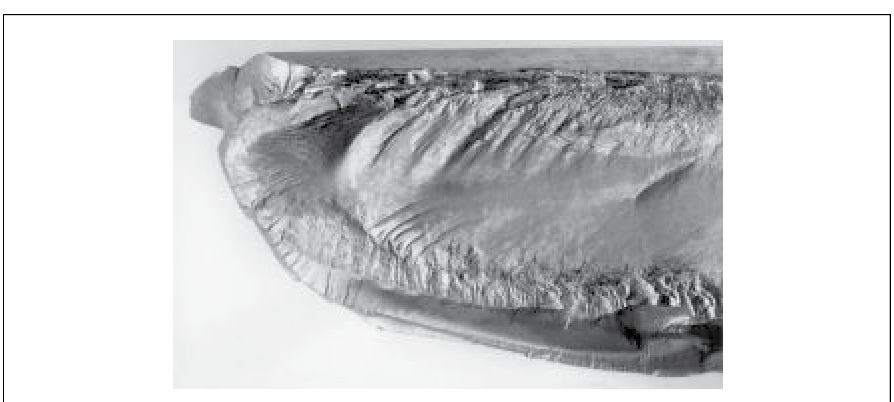


Figure 2—Section of Figure 1–left.

Introduction

In contrast to the known classical tooth damages shown in Reference 1—where the damage starts at the surface—in this presentation the flank breakage—i.e., the primary crack starter—is found in the volume of the tooth; it propagates as a fatigue crack in vacuum towards the surface of the load flank—as well as into the core of the material. The problem of flank breakage in high-performance gears was presented in 1997 (Ref. 2). What follows here are new findings.

The Nature of Flank Breakage

Flank breakage can occur at the pinion and gear wheel. Figure 1 shows a broken piece of a tooth from a case-hardened pinion (double-helical) that was found after several thousand operating hours at the bottom of the casing. The contact pattern indicates that high local loads are present on both tooth halves in the rear of the gap. The broken piece is situated at the turbine-side tooth half over about 30% of the tooth width.

In the middle of the fragment, the fracture surface is distinguished by a planed, finely structured surface. Towards the load flank and the lower boundary (Fig. 1), this surface is surrounded by a border comprised of fretting and fractured surface parts arranged in a terrace shape. At both ends of the fragment (Figs. 2–3), arrest lines can be detected with a local direction of crack propagation—to the left in Figure 2; to the right in Figure 3. Therefore, it can be concluded that the fatigue crack starts in an area between Figures 2 and 3 and propagates along the tooth width in both directions.

The area with the primary crack starter is shown in Figure 4; the crack initiates from the marked region. The investigations of the primary crack starter with the SEM (scanning electron microscope) provide, in general, no suitable information because the fracture surface is—as a secondary effect—strongly deformed. Therefore it is necessary to prepare a microsection through the crack starter.

The primary crack starter (*PR*) can be characterized as a local separation; around the local separation (approx. 20 µm) the structure is plastically deformed (Fig. 5). Starting from the local separation, one can see radial cracks. This implies that the local separation was filled with a globular, nonmetallic inclusion that has disappeared in the course of the metallurgical preparation.

In Figure 6 a model is shown to explain the crack path. The crack starter is located in the region of the pitch diameter and can be found underneath the case-hardening depth (about 1.5 × CHD) where the stress is significantly lower than within the CHD (Fig. 7).

In general, the local separation is filled with a nonmetallic inclusion from the oxide type. It is known that at the boundary of the inclusion, tangential and radial stresses are induced (Fig. 8). The microcracks (Fig. 5) are

continued

Figure 3—Section of Figure 1–right.

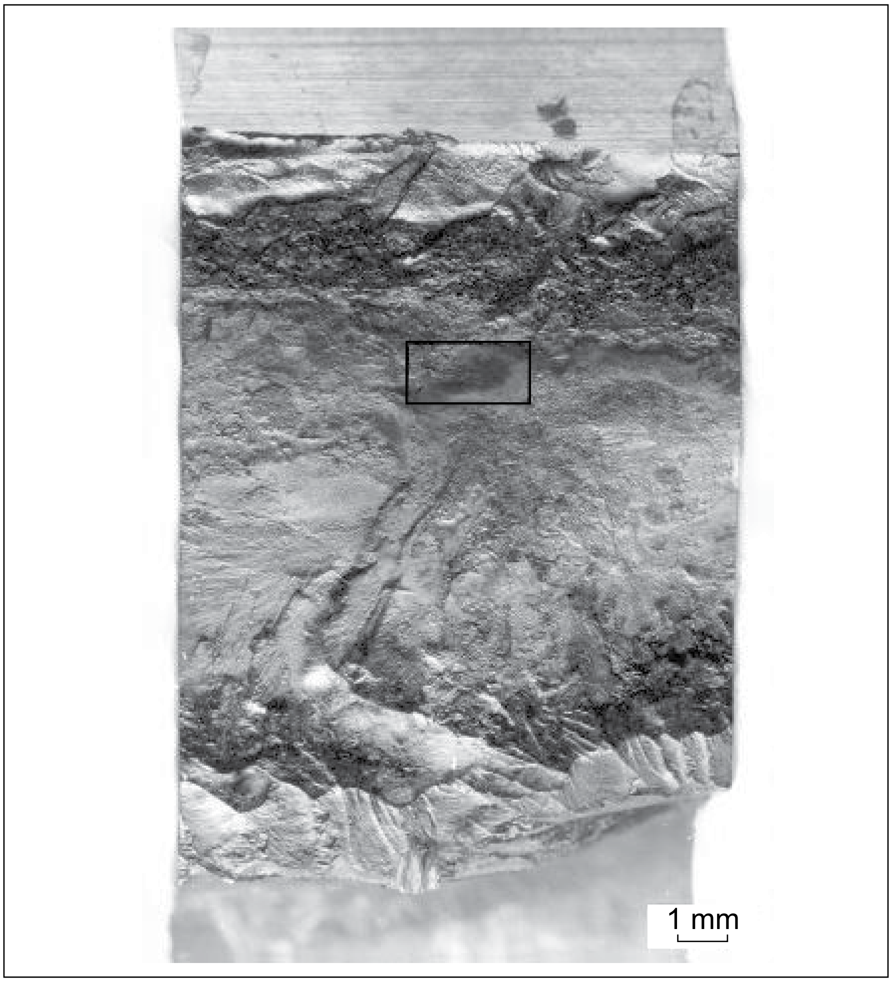


Figure 4—Position of the crack starter *PR*.

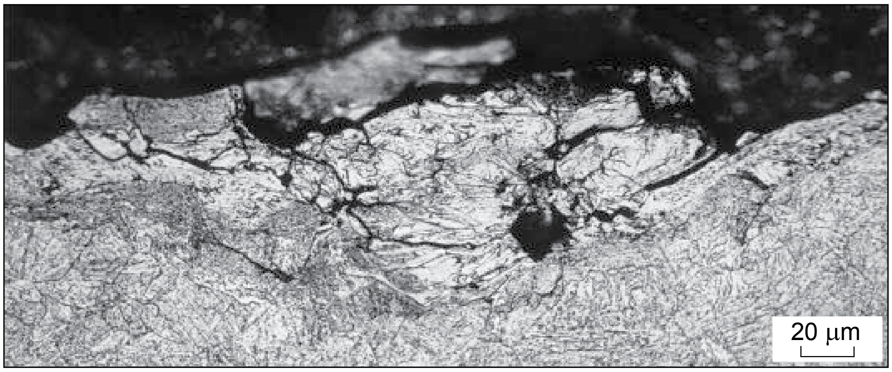


Figure 5—Local separation with radial cracks (Fig. 4).

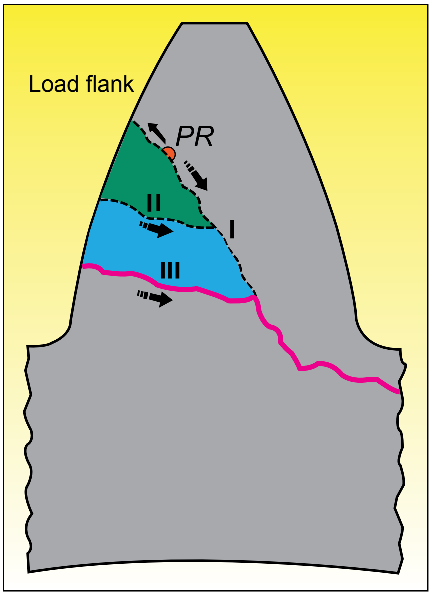


Figure 6—Path of crack.

positioned perpendicular to the direction of the tangential stress. It cannot be excluded that the microcracks are generated during or shortly after the last heat treatment process. Only those microcracks in line with the direction of the main shear stress can propagate towards the load flank and the core (Fig. 6).

With the calculation of load capacity according to DIN 3990/ISO 6336 (e.g., surface durability), it is not possible to estimate the exposure of flank breakage. (In Ref. 2) it is therefore suggested to:

- Develop an inspection method for detecting internal faults within the volume of the teeth
- Develop a calculation model capable of predicting whether an actual gearbox can fail due to flank breakage

Ultrasonic Inspection Technique

The object of ultrasonic inspection is to detect internal discontinuities at the earliest possible date and to check alterations of inner faults during further operation by repeated inspection. All demonstrated results included in this paper were obtained from gearboxes with a module of 10 mm. For better comparison between the inspection findings determined on different gearboxes, a registration limit of 6 dB above the reflectivity from a 1mm circular disk reflector was generally specified. Further details related to inspection technique, adjustment, size assessment and determining the lengthwise extent are described in Reference 3.

To justify the inspection technique, it was necessary to conduct laboratory investigations on single indications (inner faults). Initial tests were done on a tooth segment of a pinion after it had been removed. The number of indications found in this segment was astonishing; some of the findings are shown in Table 1.

The indications are located at depths of between 1.1 mm and 3 mm below the load flank. The maximum indication length is 35 mm in the case of tooth No. 3. The maximum reflectivity is also present here at a level of 11 dB above that from a 1-mm disk shape reflector; the indication was not completely continuous and showed small interruptions.

A metallographic specimen was taken through the area with indications of tooth No. 3 (Fig. 9). Several indications are present within the case-hardening zone (CHD ~ 1.8 mm) and below; they are lying parallel to the surface in the area of the pitch diameter.

In Figure 10 it is shown that the indications consist of White Etching Areas (WEAs).

After further preparation, one of the WEAs was broken up in the laboratory (Fig. 11).

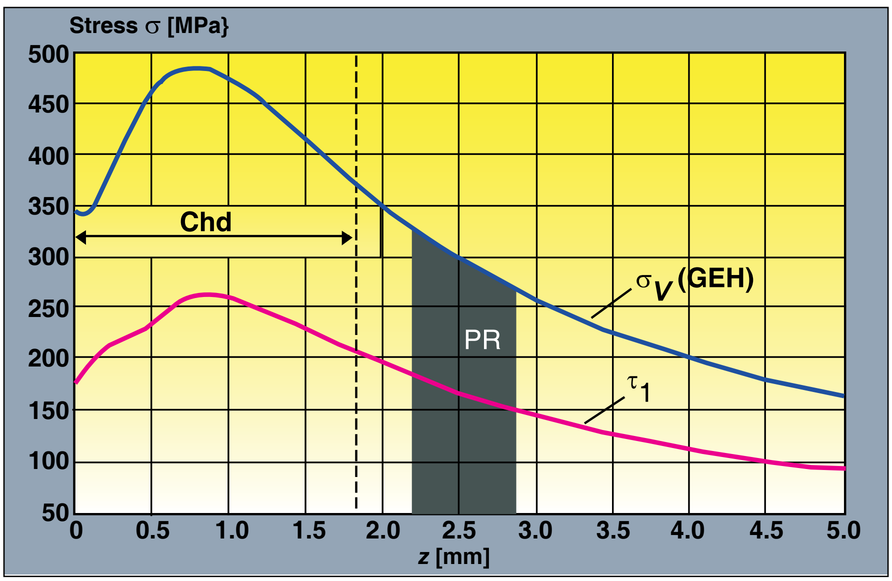


Figure 7—Distribution of equivalent stress and main shear stress over the depth.

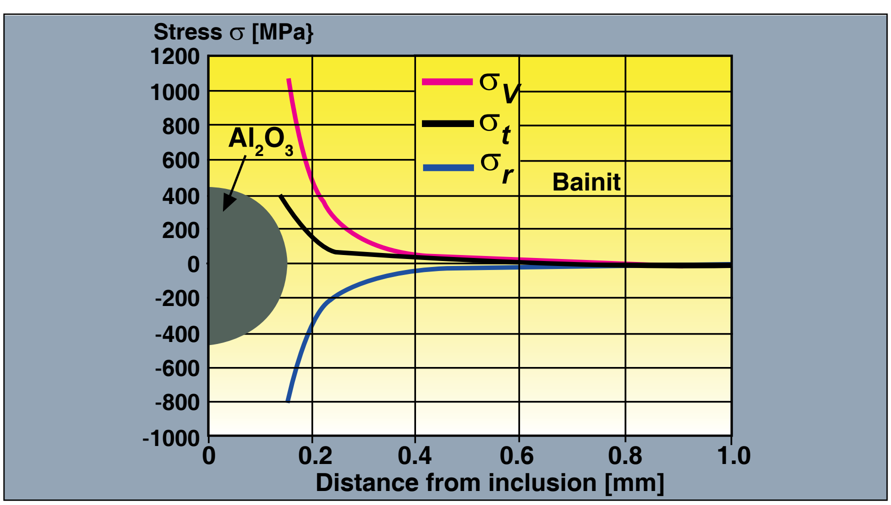


Figure 8—Internal cooling stress at the boundary of a non-metallic inclusion (Al_2O_3).

The structure of the WEA shows the effect of an intense plastic deformation caused by hydrostatic pressure with superimposed shear load (Fig. 12). This structure is quite different from the dimple fracture (D, Fig. 12) produced in the laboratory. The boundary surface between WEAs and surrounding microstructure is sharply lined so that WEAs can be easily detected by ultrasonic inspection.

During a UT (ultrasonic testing) inspection on a gearbox after 44,000 operating hours, indications providing evidence of a large internal discontinuity were found on one tooth of the wheel. An indication with a length of 243 mm is present in tooth No. 4. When scanned from the rear flank, it reflects up to an axial extent of 243 mm from the central recess (gap) and, when scanned from the load flank, between 5 and 212 mm. A maximum reflectivity of more than 20 dB above that from the 1mm disk shape reflector is located at the axial position (153 mm). At one position of the indication, a metallographic specimen was taken (Fig. 13). Within the tooth, a crack with a length of 6 mm is visible in the normal section; the progress corresponds to the known pattern in that it is located with an inclination of approximately 45° to the load flank.

After numerous UT inspections on more than 30 investigated gearboxes, the following changes can be observed:

- Appearance of new indications
- Increase in the lengthwise extent of individual indications
- Individual indications are growing together
- Increase in the reflectivity

Development of a Calculation Model

The previously cited research project (Ref. 4) was started in 2000 at the TU München and was supported by the Bavarian Research Foundation, concluding in 2003.

The fundamental idea for the calculation model is the comparison between the local-occurring equivalent stress and the local strength over the depth—thus determining the risk of flank breakage of an actual gearbox. The Hertzian contact stress, along with shear stress caused by the tangential force and residual stress, are basic data to determine the stress condition. The influence of a nonmetallic inclusion on the local stress is also considered. The strength profile is mainly based on the hardness profile. The investigations show that the main shear stress is responsible for the crack propagation. The calculation of the local stress is based on the equivalent stress according to the shear stress intensity hypothesis (SIH). The ratio between the local equivalent shear stress τ_f and the local

continued

Table 1—Indications at several positions along the tooth width

Tooth No.	Length of indication [mm]	Sound Path [mm]	Position axial [mm]	Position radial [mm]	Reflectivity
1	10	1.7	150-160	13	+2 dB
2	15	1.7 - 3.0	215-230	11-15	+10 dB
3	35	1.1 - 2.5	85-120	8-18	+11 dB (max. at 105 mm)

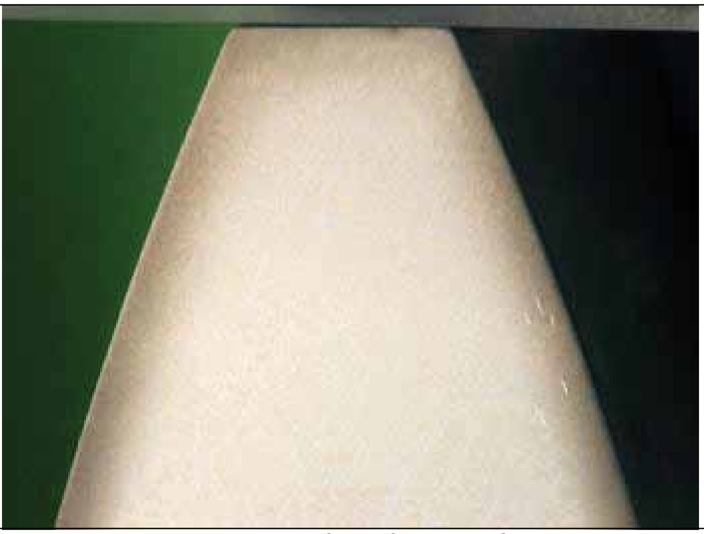


Figure 9—Indications beneath the surface of the load flank.

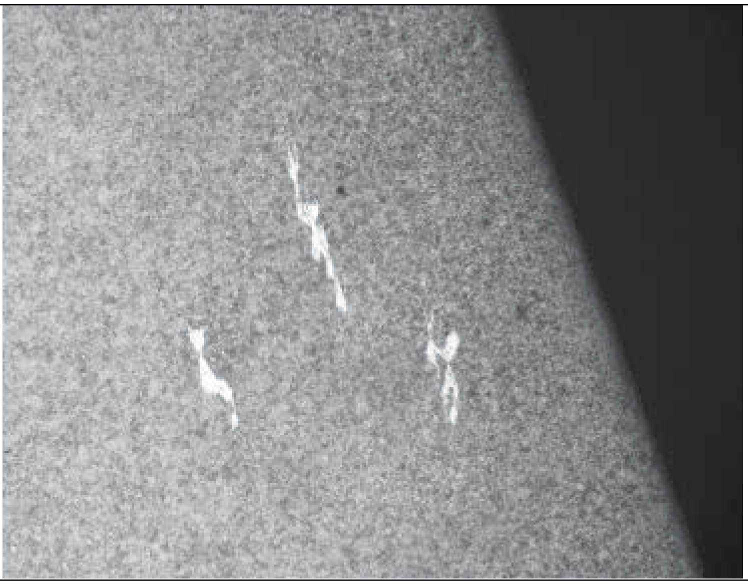


Figure 10—White etching areas (WEAs).

material resistance is defined as the local strain and yields information about the risk concerning flank breakage. According to the experience of FZG, it has to be stated that above a strain value of 0.8, the risk concerning flank breakage increases.

Within the research project some gearboxes that failed because of flank breakage were recalculated with the abovementioned calculation model. From the damaged parts, the actual hardness profile is known. In all cases the maximum of the calculated risk is in a great depth below the flank surface—well underneath the case-hardening depth; the local strain is clearly higher than 0.8.

The calculation model shows good correlation with the investigated pinion and wheels that have suffered flank breakage; it is therefore now possible to:

- Estimate the risk in the stage of construction
- Recalculate the risk of gearboxes in operation
- Use it for failure analysis

An example is provided in Figure 14.

One important point of interest could not be solved within the framework of the research project—i.e., the estimation of the remaining lifetime of teeth with inner cracks of a certain length, as detected by the UT inspection.

The first cracks have a length of only a few micrometers (microcracks). For these microcracks the definite correlation between the stress intensity factor ΔK and the crack growth da/dN does not exist as with "long" cracks. The basis for the prediction of the behavior of microcracks is the knowledge of the fatigue crack growth curve for long cracks.

From the investigations it is known that the inner crack propagates along the mean shear stress under vacuum. Due to an absence of atmospheric oxygen, the absorption of oxygen at the crack tip is prevented. Therefore the crack growth under vacuum is about three to four times slower than under atmospheric conditions. To bridge the gap, it would be helpful to carry out crack propagation tests under vacuum and under Mode II conditions (sliding).

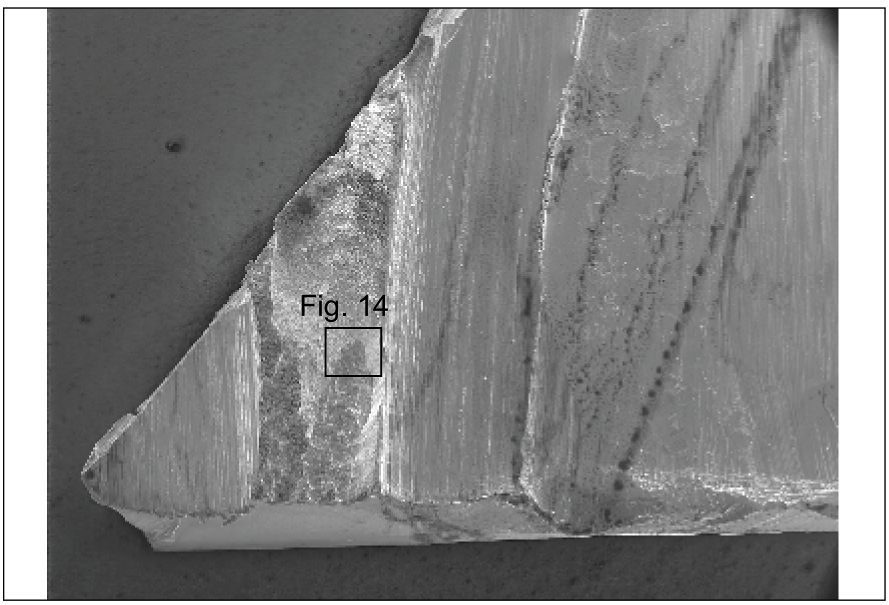


Figure 11—WEA broken up in the laboratory.

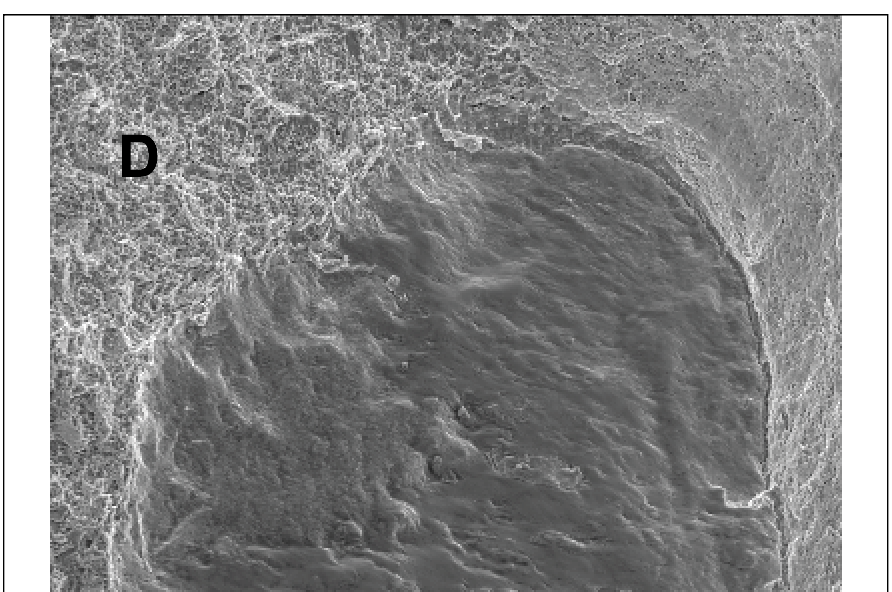


Figure 12—Intense plastic deformation within WEA.

Form Stability of Pinion and Gear

By means of numerous gearbox inspections done by AZT Risk & Technology GmbH, it is noted that the teeth show unevenly distributed discolorations and deposits over the tooth width. The deposits consist mainly of sulfur and phosphor that have been formed by higher temperatures. The measurement of the cylindrical form of pinion and gear shows deviations of several tenths of a millimeter, which in general increase with extended use; these deviations are greater at the gear as compared to the pinion. As a consequence, the contact pattern is changing, resulting in high local loads. Typically, most indications in the volume of the teeth occur in the areas of the UT-inspection. The cause for the missing form stability can be attributed to a microstructural change of retained austenite.

The distribution of the measured content of retained austenite of a pinion is shown in Figure 15. At one tooth a flank breakage was detected at a certain distance from the NDE side. In this range with brown-colored teeth, an accumulation of indications was found by UT inspection. It is significant that in this area the content of retained austenite decreases from 16% to 8%.

Summary

Investigations at AZT Risk & Technology GmbH have shown that below the flank surface, underneath the case-hardening zone, a fatigue crack is starting; it propagates in the normal section in both directions towards the surface of the load flank, rear flank, and into both directions along the tooth width. The primary fracture surface is inclined at approximately 45° to 50° to the load flank (direction of the main shear stress). This failure type is called flank breakage.

In the majority of cases the crack starter is formed from a small, nonmetallic inclusion of the oxide type, with a diameter of approximately 10 to 20 μm. From this type of inclusion, it is known that during hardening, internal cooling stresses are induced. The radial stress has a negative and the tangential stress a positive algebraic sign. Occasionally, the nonmetallic inclusion disappears during metallurgical preparation so that only a local separation can be seen in the microsection. Around the local separation, the structure is plastically deformed, and radial cracks are spreading out from the local separation over a length of about 20–40 μm; these microcracks lay perpendicular to the positive tangential stress. The local separation and the radial cracks are too small to be detected by ultrasonic inspection. In our opinion these microcracks are generated during or shortly after the last heat treatment process (case-hardening). The investigations also show that only cracks in line with the direction of the main shear stress are able to propagate; the crack propagation occurs under vacuum. Due to the absence of atmospheric oxygen, sliding is reversible so that the crack growth is about three to four times slower than under atmospheric conditions. At this time, we don't yet know the behavior of microcracks and the fatigue crack growth curve for long

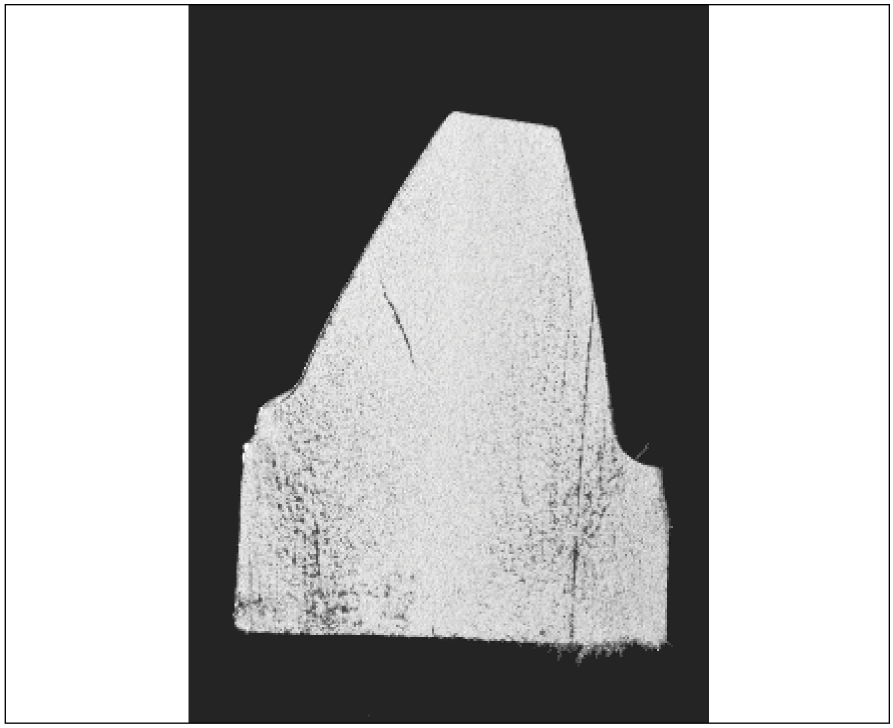


Figure 13—Crack within the volume of the tooth.

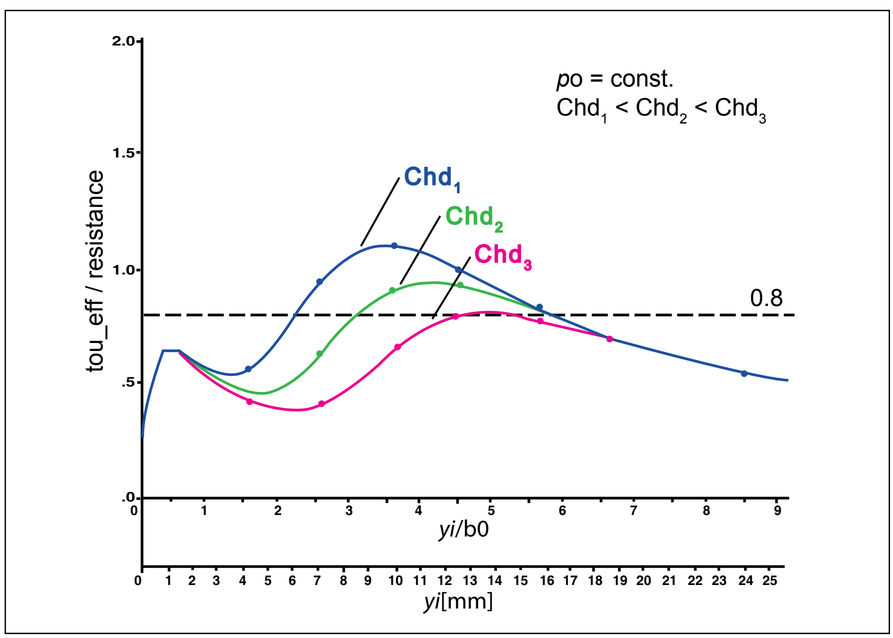


Figure 14—Depth gradient of strain by constant load *p0* (MPa) and variable case-hardening depth (mm).

cracks under vacuum and for Mode II–III conditions. Therefore no statement about the remaining lifetime of a tooth with an inner crack can be made.

In addition, with the calculation of load capacity according to DIN 3990/ ISO 6336, it is not possible to estimate whether flank breakage occurs because these calculations describe the situation at and near the surface—but not in such a depth where the primary crack starter is located. During the AZT Expert Days (a biannual meeting in Germany hosted by AZT Risk & Technology GmbH to promote the exchange of ideas among experts in manufacturing and science, among other disciplines), it was suggested to develop an inspection method for detecting indications within the volume of the teeth and to develop a cal-

continued

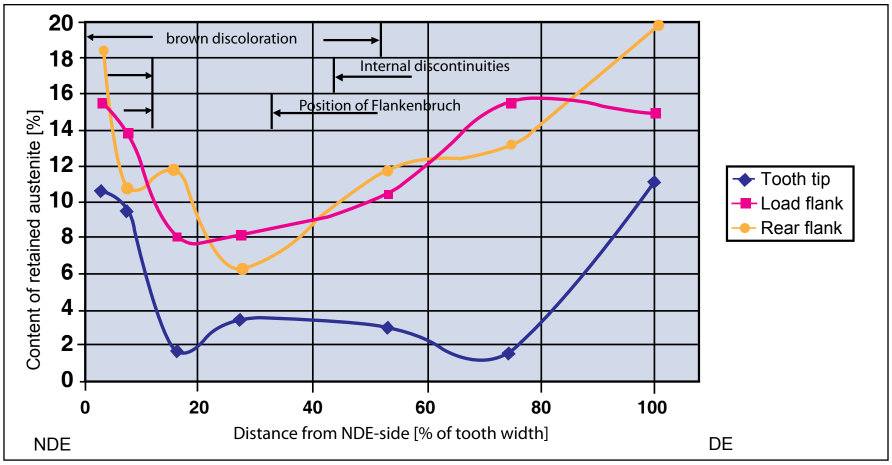


Figure 15—Distribution of retained austenite over tooth width/discoloration, internal discontinuities, position of flank breakage.

culation model to predict the risk of flank breakage. This work was done within the framework of the research project Flank Breakage with Spur Gears, which was supported by the Bavarian Research Foundation; it was managed by the Research Center for Gear Wheels and Gear Construction. An ultrasonic inspection technique has been shown to be suitable for detecting discontinuities within the volume of the teeth. The nature of various ultrasonic indications could be identified by means of fractographic and metallographic investigations. Various phenomena such as white etching areas, nonmetallic inclusions and large cracks are involved. Repeated inspections reveal that in changes of indications associated with an increase in reflectivity, an increase in the lengthwise extent has appeared; this confirms a cyclic crack growth under vacuum. The calculation model developed by FZG gives a second maximum of the strain in such a depth, where the primary crack starter is located. It shows good correlation with investigated pinions and wheels that have suffered flank breakage. It is therefore now possible to estimate the risk of flank breakage in the stage of construction and recalculate the risk of gearboxes in operation.

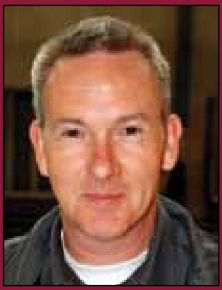
In some gearboxes the pinion and gearwheel have lost their cylindrical form; deviations of several tenths of a millimeter can be measured at the outside diameter. This irreversible deformation is mainly noticed in gearboxes with a high temperature level and where the teeth show unevenly distributed discolorations and debris. As a consequence, the contact pattern is changing and leads to areas with the highest local loads; i.e., where the flank breakage basically occurs. It cannot be ruled out that the irreversible deformation is caused by a microstructural change of the retained austenite (RA). Flank breakage was detected on a pinion of about 20% of the tooth width. In the same region the teeth are brown-colored and an accumulation of indications was found by UT inspection. In the same range the content of retained austenite has dropped from 16% to 8%.

References

1. DIN 3979: Gear Tooth Damage, July 1979.
2. Bauer, E. “Flank Breakage in High-Speed Transmissions,” Alliance Report, 1998.
3. Metzner, B., E. Bauer, K. Graf, A. Böhl and D. Lang. “Ultrasonic Testing of Teeth of Gas Turbine Transmissions,” VGB Power Tech, 2003.
4. Research Project Final Report: Flank Breakage with Spur Gears, Bayerische Forschungsstiftung, Garching, 2003.

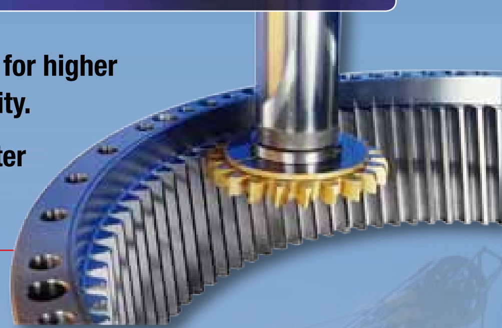
Erwin Bauer *received his mechanical engineering degree in 1983 at TU-München. Upon graduation he began his career as a research engineer at Knorr-Bremse AG, München, moving in 1986 to the Allianz Group’s Center for Technology GmbH (AZT), Ismaning b. München, specializing in failure analysis and technical advice for machinery components—especially relating to gearboxes, bearings, shafts, etc. From 2008–2010 he worked as an executive senior engineer at Allianz Global Corporate & Speciality AG AZT Risk & Technology GmbH, München, addressing the same areas as at AZT. He is owner since 2011 of AEB Kompetenzcenter. Bauer has authored more than 30 technical papers within his area of expertise.*

Arne Böhl *apprenticed as a mechanic, mechanical technician (junior engineer) and welding technologist, acquiring hands-on experience in metallography and quality assurance. He joined the Allianz Group’s Center for Technology in 1994 where—via ultrasonic testing—he currently is responsible for the development, planning and performance of non-destructive testing for gear teeth.*



PRODUCE LARGE CYLIND

SHAPE WITH MORE SPEED, FLEXIBILITY



- ✓ Hydraulic shaping head for higher productivity and flexibility.
- ✓ Delivering optimum cutter spindle backoff.

IMPROVE BY

OPTI GRIND™

- ✓ Increase productivity by up to 40% with OPTI-GRIND™.
- ✓ Ideal for pinions.

titan® 1200H

LARGE GEAR HOBBING BREAKTHROUGH!

- ✓ Optimized chip disposal, optimized accessibility.
- ✓ Superb machine damping, stiffness and rigidity.
- ✓ New operator interface, software and Siemens 840D Solution Line control combine for fast, easy operation.
- ✓ Extremely energy efficient.

Services	Service Parts	Training	Application Development	Equipment Upgrades	Remote Services
250 service professionals, 50 countries, 24/7	Rapid deployment from 8 global stock locations	Industry's largest array of programs	To optimize all your processes	Lowering total cost of ownership	For rapid response, anytime, anywhere

For worldwide sales locations and additional information, visit:

Gear Transmission Density Maximization

Alexander L. Kapelevich and Viacheslav M. Ananiev

(*Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2011 August 29–31, 2011, Washington, DC, USA DETC2011–47021.*)

Management Summary

Maximization of gear transmission density is important in that it delivers increased output torque within given dimensional constraints. This is critical, for instance, in racing gearboxes or in reducing size and weight of aerospace gear drives. It can also yield reduced costs for automotive and consumer product gear trains, for example. There are several ways to increase gear drive load capacity, including advanced design, materials and technologies.

This paper presents an approach that provides optimization of both gearbox kinematic arrangement and gear tooth geometry to achieve a high-density gear transmission. It introduces dimensionless gearbox volume functions that can be minimized by the internal gear ratio optimization. Different gearbox arrangements are analyzed to define a minimum of the volume functions. Application of asymmetric gear tooth profiles for power density maximization is also considered.

Introduction: Volume Functions

The gearbox weight minimization software (Ref. 1) defines internal gear distribution for different gear drive arrangements. However, it does not take into account the gear volume utilization, i.e., the ratio of the actual gear volume to the pitch cylinder volume. It also is not applicable to multi-branch epicyclic gear drive arrangements (Fig. 6). Load capacity or transmission density is defined by a gear tooth's working flank surface durability, which is limited by allowable contact stress level. For a pair of mating gears, this can be described by the gear transmission density coefficient K_o (Ref. 2) that is equal to:

$$K_o = \frac{2 \times T_1}{d_{w1}^2 \text{ x } b_w} \times \frac{u \pm 1}{u} \quad (1)$$

where:

T_1	Driving pinion torque
d_{w1}	Pinion operating pitch diameter
b_w	Effective gear face width in mesh
$u = n_2/n_1$	Gear pair ratio
n_1	Driving pinion–number of teeth
n_2	Driven gear–number of teeth
"+"	External gear mesh
"–"	Internal gear mesh

Depending on the application, the gear pair transmission density coefficient K_o statistically varies about 0.5–4.0 MPa for commercial drives and about 4.0–12.0 MPa for aerospace, racing and automotive drives. The gear pair volume definition is illustrated in the Figure 1.

Weight of the pinion can be presented as:

$$w_1 = \rho \text{ x } V_1 \text{ x } K_{v1} \quad (2)$$

where:

ρ	Material density
K_{v1}	Volume utilization coefficient for the pinion
V_1	Operating pitch cylinder volume that is equal to:

$$V_1 = \frac{\pi}{4} \text{ x } d_{w1}^2 \text{ x } b_w \quad (3)$$

which, considering Equation 1, also can be presented as:

$$V_1 = \frac{\pi}{2} \times \frac{T_1}{K_o} \times \frac{u \pm 1}{u} \quad (4)$$

The operating pitch cylinder volume of the mating gear is

$$V_2 = \frac{\pi}{4} \times d_{w2}^2 \times b_w = u^2 \times V_1 \quad (5)$$

where:

d_{w2} Gear operating pitch diameter

Total weight of two mating gears is:

$$w = w_1 + w_2 = \rho \times (V_1 \times K_{v1} + V_2 \times K_{v2}) \quad (6)$$

where:

Kv_1 Volume utilization coefficient of the pinion

Kv_2 Volume utilization coefficient of the mating gear

Then applying Equation 5:

$$w = \rho \times V_1 \times (K_{v1} + u^2 \times K_{v2}) \quad (7)$$

or applying Equation 4:

$$w = \rho \times \frac{\pi}{2} \times \frac{T_1}{K_o} \times F_v \quad (8)$$

where:

F_v Dimensionless volume function

For the cylindrical pair of gears the volume function is:

$$F_v = F_{v1} + F_{v2} = \frac{u \pm 1}{u} \times (K_{v1} + u^2 \times K_{v2}) \quad (9)$$

where:

$$F_{v1} = \frac{u \pm 1}{u} \times K_{v1} \quad (10)$$

is the pinion volume function;

$$F_{v2} = (u \pm 1) \times u \times K_{v2} \quad (11)$$

is the mating gear volume function.

The epicyclic gear stage volume definition is illustrated in Figure 2. In this case the subscript indexes 1–3 ($_{1,\ 2,\ 3}$) are related to the sun gear, planet gear and ring gear accordingly.

The operating pitch cylinder volume of the sun gear is defined by Equation 4 with a "+" sign because the sun gear is in the external mesh with the planet gear. The planet gear operating pitch cylinder volume is defined by Equation 5. The operating pitch cylinder volume of the ring gear is:

$$V_3 = \frac{\pi}{4} \times d_{w3}^2 \times b_{wi} = p^2 \times V_1 \times K_{bw} \quad (12)$$

where:

d_{w3} Ring gear operating pitch diameter

$K_{bw} = b_{wi} / b_{we}$ Effective gear face width ratio in the epicyclic gear stage

b_{we} Effective gear face width in the sun/planet gear mesh

b_{wi} Effective gear face width in the planet/ring gear mesh

$p = |n_3 / n_1|$ Ring/sun gear ratio in the epicyclic stage

n_3 Ring gear number of teeth

Assuming the same density material for all gears, the total weight of gears in the epicyclic gear stage is:

$$w = w_1 + n_p \times w_2 + w_3 = \rho \times (V_1 \times K_{v1} + n_p \times V_2 \times K_{v2} + V_3 \times K_{v3}) \quad (13)$$

where:

K_{v3} Volume utilization coefficient of the sun gear;

n_p Number of planet gears.

Applying Equations 5 and 12, the total weight is:

$$w = \rho \times V_1 \times (K_{v1} + u^2 \times n_p \times K_{v2} + p^2 \times K_{v3} \times K_{bw}) \quad (14)$$

Then considering Equation 4, the epicyclic gear stage volume function is:

continued

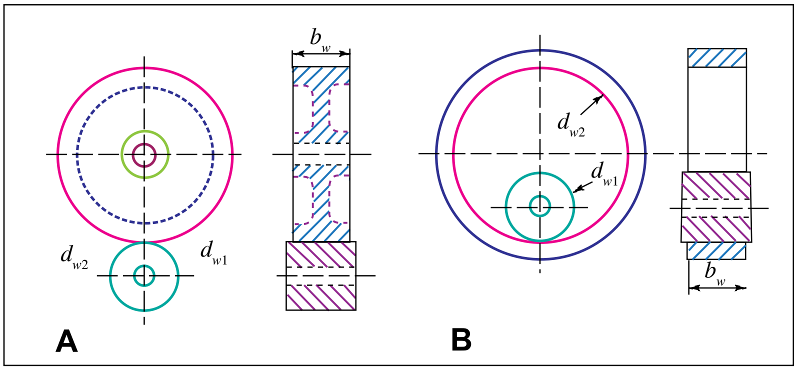


Figure 1—Gear pair volume definition: A = external gearing; B = internal gearing.

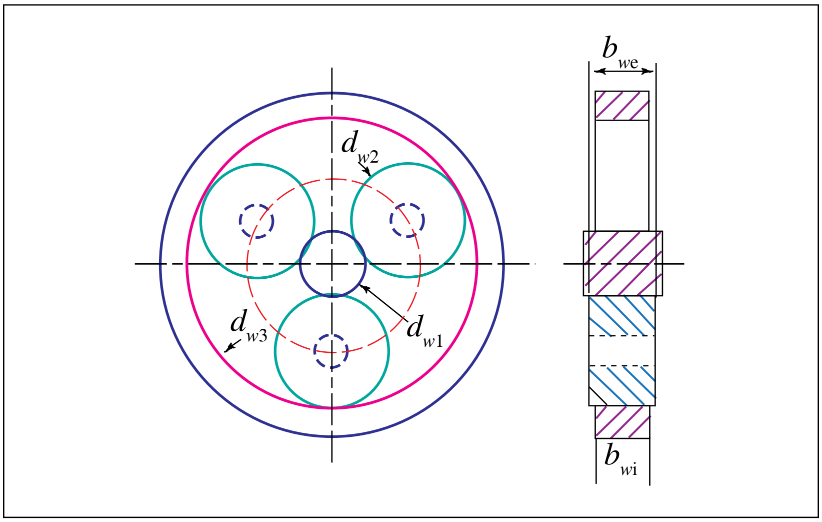


Figure 2—Epicyclic gear stage volume definition.

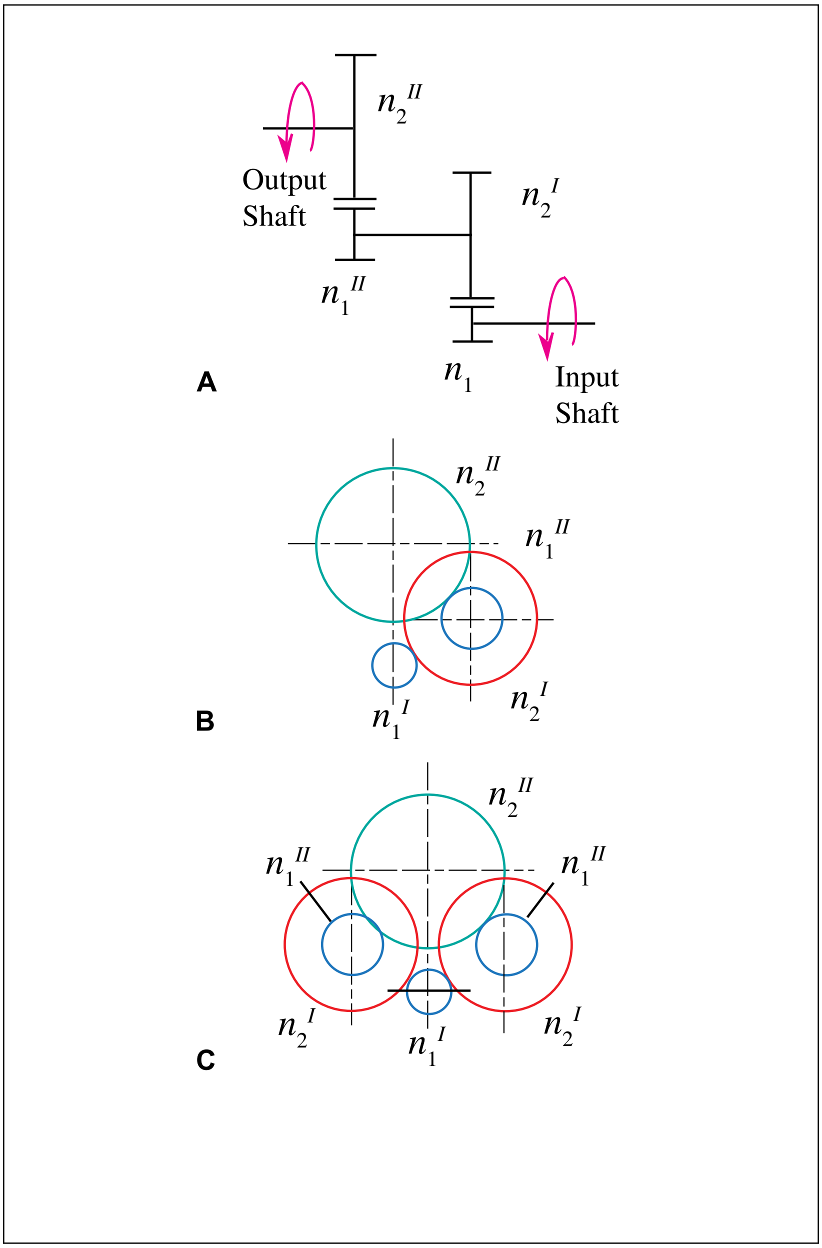


Figure 3—A = two-stage external gear train; B = one-transmission-branch arrangement; C = two-transmission-branch arrangement.

$$F_{ve} = F_{ve1} + n_p \times F_{ve2} + F_{ve3} = \frac{u+1}{u \times n_p} \times (K_{v1} + u^2 \times n_p \times K_{v2} + p^2 \times K_{v3} \times K_{bw}) \quad (15)$$

where:

$$F_{ve1} = \frac{u+1}{u \times n_p} \times K_{v1} \quad (16)$$

is the sun gear volume function;

$$F_{ve2} = \frac{u+1}{n_p} \times u \times K_{v2} \quad (17)$$

is the planet gear volume function,

$$F_{ve3} = \frac{u+1}{u \times n_p} \times p^2 \times K_{v3} \times K_{bw} \quad (18)$$

is the planet gear volume function.

The more planet gears in the epicyclic gear stage, the lower its volume function and more compact the gearbox. However, the selected number of planet gears must exclude the interference between them.

The volume utilization coefficients K_v depend on the gear body shape (solid body or with central and lightening holes, rim, web, spokes, etc.) and, for driving pinions (sun gears), varies approximately in a range of 0.8–1.0; for driven (or planet) gears, 0.3–0.7; and for internal (or ring) gears, 0.05–0.1.

Unlike the convex-convex sun/planet gear contact, the planet/ring gear mesh has the convex-concave gear contact. This allows reduction of the effective gear facewidth in the planet/ring gear mesh in order to achieve a level similar to the contact stress. This typically makes the effective gear face width ratio $K_b < 1.0$; or, typically, 0.7–0.9.

When the input torque and gear ratio are given, and the gear transmission density coefficient K_o is selected according to the application, volume functions allow for estimating both size and weight of the gearbox at a very preliminary stage of design for different options of gear arrangement.

Volume Functions for Different Gear Arrangements

The volume functions are defined for four two-stage gear arrangements.

1. ***External gear arrangement*** **(Fig. 3)**

The gearbox with this simple gear arrangement has a minimal number of gears and bearings; it is less expensive in production and potentially more reliable. Its total gear ratio is:

$$u_t = u^I \times u^{II} \quad (19)$$

where indexes "*I*" and "*II*" are for the first and second stage, accordingly.

The volume function for this arrangement is:

$$F_v = \frac{u^I + 1}{n_b} \times \left(\frac{K^I_{v1}}{u^I} + n_b \times u^I \times K^I_{v2}\right) + \frac{u^I(u^{II} + 1)}{n_b} \times \left(\frac{n_b \times K^{II}_{v1}}{u^{II}} + u^{II} \times K^{II}_{v2}\right) \quad (20)$$

where:

K_{v3}	Volume utilization coefficient of the sun gear
n_b	Number of transmission branches

2. *Epicyclic "star" arrangement* (Fig. 4)

This gear arrangement provides a more compact and lighter gearbox in comparison with the external gear arrangement (Fig. 3), because the number of the transmission branches (planet gears) is typically three or more. The planet gears in this arrangement are not rotated around the sun gear, which makes their lubrication less complicated. The total gear ratio is:

$$u_t = p^I \times p^{II} \quad (21)$$

The volume function for this arrangement is:

$$F_v = F^I_{ve} + p^I \times F^{II}_{ve} \quad (22)$$

3. *Epicyclic planetary arrangement* (Fig. 5)

This epicyclic planetary gear arrangement is a more compact and lighter gearbox than the "star" example (Fig. 4), because the planet gears are installed on the carrier and involved in the planetary motion around the sun gear. The total gear ratio is:

$$F_v = F^I_{ve} + (1 + p^I) \times F^{II}_{ve} \quad (23)$$

The volume function for this arrangement is

$$u_t = (1 + p^I) \times (1 + p^{II}) \quad (24)$$

4. *Epicyclic differential arrangement* (Fig. 6)

The first stage is differential. The second stage has the "star" arrangement with the stationary carrier. Part of the transmitted power goes from the first-stage carrier directly to the output shaft. The remaining transmitted power goes from the first-stage ring gear to the second-stage sun gear and then through the planets to the second-stage ring gear—also connected to the output shaft.

This allows a reduction of the size and weight of the second-most loaded stage and makes the gearbox more compact and lighter than with the planetary arrangement (Fig. 5). The total gear ratio is:

$$u_t = 1 + p^I + p^I \times p^{II} \quad (25)$$

The volume function for this arrangement is:

continued

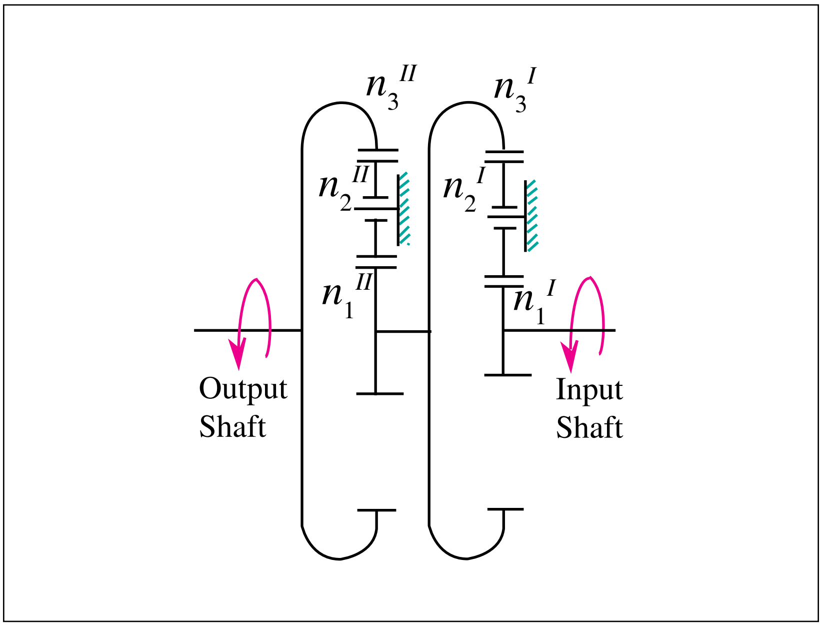


Figure 4—Two-stage epicyclic "star" gear train.

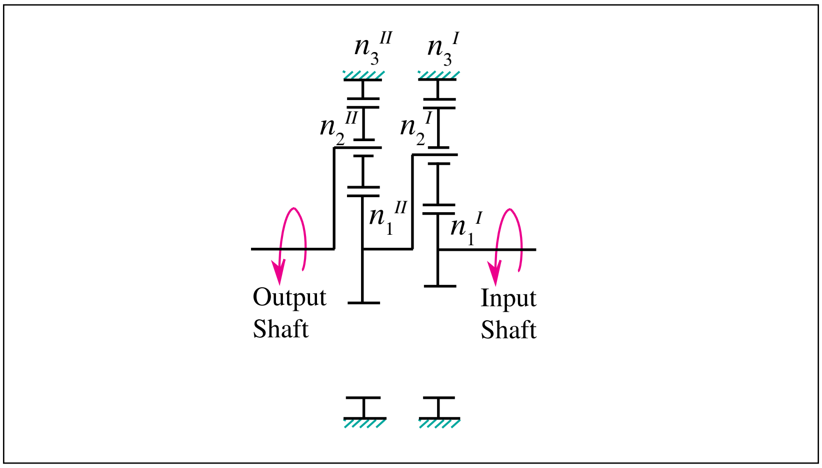


Figure 5—Two-stage epicyclic planetary gear train.

$$F_v = F_{ve}^I + \frac{p^I}{1+p^I} \times F_{ve}^{II} \quad (26)$$

Internal Gear Ratio Optimization

Internal gear ratio distribution for multi-stage gearboxes can be optimized to achieve the minimum of the volume function. For two-stage gearboxes the minimum of the volume function $F_v = f(u^I, u^{II})$ is achieved when the first derivatives $d(F_v)/d(u^I)$ or $d(F_v)/d(u^{II})$ equal zero.

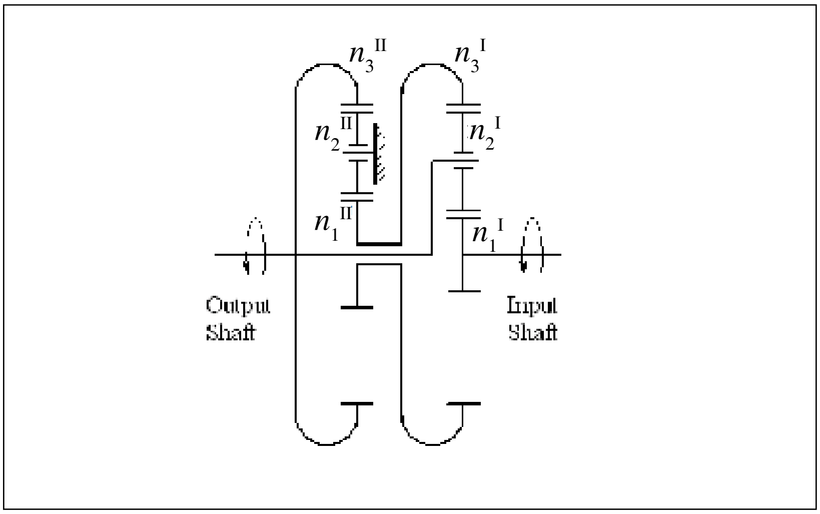


Figure 6—Two-stage epicyclic differential gear train.

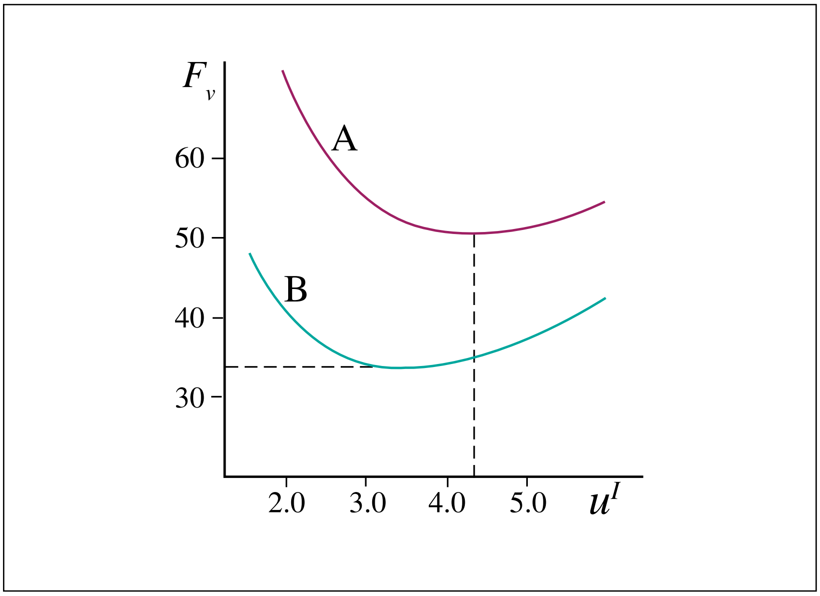


Figure 7—Two-stage external gear train volume function charts; A = with one-transmission branch (Fig. 3-B); B = with two transmission branches (Fig. 3-C).

Figure 7 presents a chart of the volume function versus the first-stage gear ratio for the two-stage external gear arrangement with one and two transmission branches with the total gear ratio of u = 15:1. The volume utilization coefficients are assumed for the pinions (driving gears)—K_{v1} = 0.8 and for the driven mating gears—K_{v2} = 0.5.

Figure 7 makes clear that the minimum of the volume function for the two-transmission-branch arrangement is significantly lower than that for the one-transmission-branch arrangement because of load shearing; results of the volume function minimization and the optimal stage gear ratios are presented in Table 1.

Figure 8 shows the volume function versus the first-stage gear ratio charts for the two-stage epicyclic gear arrangements (Figs. 4–6) with the total gear ratio of u = 15:1; both stages have three planets. The volume utilization coefficients are assumed for the sun gears to be—K_{v1} = 0.8; planet gears—K_{v2} = 0.5; and ring gears—K_{v3} = 0.1. The effective gear face widthratio in the epicyclic gear stage is assumed as K_b = 0.75.

Figure 8 demonstrates that a minimum of the volume function for the epicyclic arrangement with the differential first stage has advantages in comparison with the "star" and planetary arrangements. This is because part of the power is transmitted from the first-stage carrier directly to the output shaft and the second stage is less loaded. The results of the volume function minimization and the optimal stage gear ratios are presented in Table 2.

After definition of the minimal total volume function and the stage gear ratios, the individual gear volume functions can be defined using Equations 10–11 and 16–18. The pitch cylinder volume of the individual gear, considering Equation 4, is then:

Table 1—Results of the volume function minimization and the optimal stage gear ratios

Total gear ratio	15:1	
Number of transmission branches	1 (Fig. 3-B)	2 (Fig. 3-C)
Minimum total volume function	50.469	33.697
1st stage volume function	12.476	8.303
2nd stage volume function	37.993	25.394
1st stage gear ratio	4.320:1	3.465:1
2nd stage gear ratio	3.472:1	4.329:1

$$V = \frac{\pi}{2} \times \frac{T_1}{K_0} \times F_v \quad (27)$$

From here:

$$d_w^2 \times b_w = \frac{4}{\pi} \times V = \frac{2 \times T_1}{K_v \times K_0} \times F_v \quad (28)$$

or:

$$d_w = \sqrt[3]{\frac{2 \times T_1 \times F_v}{K_v \times K_0 \times \psi}} \quad (29)$$

where:

K_v	Volume utilization coefficient
$\psi = b_w/d_w$	Aspect ratio that varies in a range of 0.05–1.2 or higher (Ref. 2)

This allows definition of all the gear diameters and size of all gears in assembly. However, the total volume and weight of the gearbox is not in direct proportion to its volume function. The share of the gear volume and weight is usually higher for simple arrangements like the external gear train. In a more complicated epicyclic gear arrangement, this share could be much lower because of a higher number and volume of other gearbox parts and components, such as carriers, bearings, shafts, lubrication system parts, etc. Statistical data of the gear volume share for the selected type of gear arrangement allow one to define the approximate size of the gearbox. In many cases, the gearbox is built in the overall mechanism assembly, and minimization of its size and weight should be considered to achieve optimum operating characteristics of the whole product, including, for example, cost, lifetime, noise and vibration.

The approach utilizing the volume functions allows estimation of the volume and weight of the gearbox for any multi-stage arrangement in a very early stage of product development. The next phase of gearbox design includes the gear and other component parameter calculation, and stress analysis produces a more accurate definition of the volume and weight of the gearbox.

Gear Tooth Geometry for Higher Transmission Density

In most high-load-capacity gear transmissions, the tooth load on one flank is significantly higher and is applied for longer periods of time than for the opposite one; this creates the possibility of using gears with asymmetric teeth (Ref. 3).

The design intent of asymmetric gear teeth is to improve performance of the primary drive profiles at the expense of performance of the opposite coast profiles. The coast profiles are unloaded or lightly loaded during a relatively short work period. Asymmetric tooth pro-

continued

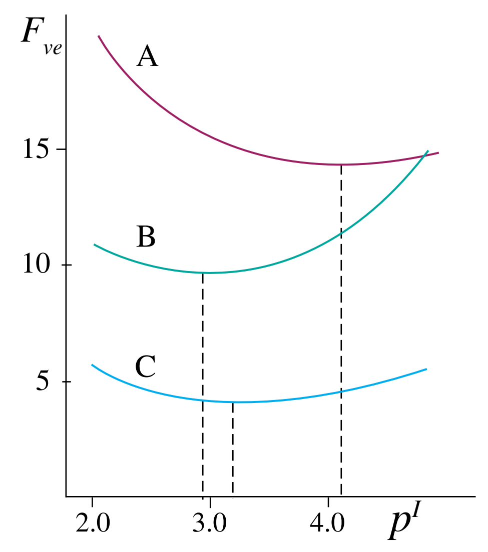


Figure 8—Two-stage epicyclic gear train volume function charts; A = "star" arrangement (Fig. 4); B = planetary (Fig. 5); C = with first differential stage (Fig. 6).

Table 2—Results of the volume function minimization and the optimal stage gear ratios			
Total gear ratio	**15:1**		
Gear arrangement (Fig. 8)	A	B	C
Min. total volume function	14.32	9.66	4.09
1st stage volume function	3.22	2.03	2.24
2nd stage volume function	11.09	7.63	1.85
1st stage planet/sun gear ratio	1.55:1	0.97:1	1.09:1
2nd stage planet/sun gear ratio	1.33:1	0.91:1	1.20:1
1st stage ring/sun gear ratio	4.11:1	2.93:1	3.19:1
2nd stage ring/sun gear ratio	3.65:1	2.82:1	3.40:1

files also make it possible to simultaneously increase the contact ratio and operating pressure angle beyond conventional gears' limits. The main advantage of asymmetric gears is reduction of gear dimensions while maintaining the allowable contact stress level, resulting in higher transmission density coefficient K_o. Asymmetric gear testing at the rotorcraft division of the Boeing Company demonstrated superior scoring performance when compared to conventional (baseline) symmetric gears. The mean value for a limited data set showed an improvement of approximately 25% (Ref. 4).

The combination of the volume function approach and gears with asymmetric teeth achieved extremely high power density in the turboprop engine gearbox (Ref. 5).

Summary

- The dimensionless volume functions were introduced and correlated to gear transmission density.
- The gear train volume functions are described and defined for the gear pair and epicyclic gear stage.
- Different two-stage gear train arrangement volume functions were analyzed to find their minimum and optimal stage gear ratio distribution.
- Application of gears with asymmetric teeth provides enhanced gear drive transmission density.

References

1. Gearbox weight minimization software: *UTS 580* system.
2. Vulgakov, E.B. et al. *Aviation Gearboxes Handbook*, published by Machine Building, Moscow, 1981.
3. Kapelevich, A.L. "Geometry and Design of Involute Spur Gears with Asymmetric Teeth," *Mechanism and Machine Theory*, 2000, Issue 35, pp. 117–130.
4. Brown, F.W., S.R. Davidson, D.B. Hanes, D.J. Weires and A.L. Kapelevich. "Analysis and Testing of Gears with Asymmetric Involute Tooth Form and Optimized Fillet Form for Potential Application in Helicopter Main Drives," ***Gear Technology***, June/July 2011, 46–55.
5. Novikov, A.S., A.G. Paikin, V.L. Dorofeyev, V.M. Ananiev and A.L. Kapelevich. "Application of Gears with Asymmetric Teeth in Turboprop Engine Gearbox," ***Gear Technology,*** January/February 2008, 60–65.

Alexander L. Kapelevich *is a gear design consultant at AKGears, LLC, Shoreview, Minnesota. He holds a Ph.D. in mechanical engineering, Moscow State Technical University and a MS in mechanical engineering from Moscow Aviation Institute. He is a developer of the trademarked Direct Gear Design methodology, which has been implemented in many custom gear drives for a variety of applications. 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.*

Viacheslav M. Ananiev *is a lead scientific researcher of the Central Institute of Aviation Motors (CIAM), Moscow, Russia. With Ph.D. and MS degrees in mechanical engineering from Moscow State Technical University, Ananiev is a prominent and longtime gear expert in the Russian aerospace industry—particularly in mechanical drive systems—and author of many technical publications.*

Best of Times, Worst of Times

An American renaissance in manufacturing is needed—and long overdue

Jack McGuinn, Senior Editor

A successful Gear Expo is behind us. By most accounts it was a grand year for the gear industry. Profits are up, beefy back-orders common, capital investment on the rise.

All this despite the fact that for more than a generation, American manufacturing jobs have disappeared—"from 19.5 million in 1979 to 11.7 million today—even as the overall U.S. population has risen by nearly 40 percent," according to a recent *USA Today* editorial. To be clear, however, let's stipulate that many of those eight million or so lost jobs—those of the mind-numbing assembly line or modern sweat shop variety, for example—are not particularly missed.

Rather, what's missing are more well-paying, family-nurturing, high-skills manufacturing opportunities for American workers of all ages.

But here's the other problem—one that manufacturing hiring personnel are all too keenly aware of: a decided lack of qualified workers to fill those positions. Call it a catch-22 or chicken-and-egg dilemma: i.e., no jobs in the offing due to no workers, or no workers due to no available jobs?

How does that compute? What is wrong with this picture? In its May 19th issue, *Time* columnist Fareed Zakaria adds it up this way:

"(The) disconnect between economic recovery and employment growth is new. Since World War II, recoveries from recessions have followed a fairly stable path. After the crunch, the economy bounced back vigorously, often growing at a rate of around six percent, and employment started picking up steam. We are banking on that pattern recurring. Except that it isn't."

But don't look here for any magic-bullet solutions; it took 30 years to bring us to this precarious situation. It will require culture change, and how long that will take is anybody's guess—or hope—especially since the country in general seems to regard the problem as the crazy uncle in the attic that no one wants to talk about. But know this: time is not on our side.

The September 13 issue of *Crain's Chicago Business* has Caterpillar CEO Doug Oberhelman lamenting, "We cannot find qualified hourly production people (or), for that matter, many technical, engineering service technicians (or) even welders. And it is hurting our manufacturing base in the United States. The education system in the United States basically has failed (students), and we have to retrain every person we hire."

John Morehead, vice president, business development at Dunkermotoren USA Inc., responds to Zakaria and Oberhelman.

"While it's true our education system may have failed in terms of delivering high school graduates with necessary math skills needed in today's more automated manufacturing, very likely the biggest problem is that students over the past decade or more have perceived manufacturing careers to be about as desirable and promising as becoming a television repair man. More importantly, high school guidance counselors see (this) and risk their reputations suggesting that 'Joe' or 'Sally' may find a promising career in manufacturing."

Here with a different take is Kyle Seymour, Xtek president, CEO and AGMA board of directors member. His is a company that has done its own heavy lifting regarding training.

"At Xtek, we do not have this problem and do not share this view. We have invested considerably in productivity-enhancing equipment that allows us to bring in relatively untrained people and make them productive in a reasonably short period of time. We are hiring many people into the shop with varied backgrounds—from burger flippers to skilled machinists—and we have been very successful in training them as machine operators. Employment is not rebounding because hiring by the industrial sector has been offset by unprecedented reductions elsewhere (in the economy."

Here's another perspective, offered by Schafer Gear Works president Bipin Doshi.

"Over the years, social acceptance and respect for manufacturing jobs have decreased versus other service jobs. Manufacturers need an image-building effort that educates the new workforce of a new and challenging work environment and earning opportunities."

Jim Vosmik, president of Drake Manufacturing Services and in fact a degreed economist who happened to choose a life in the gear industry, offers his informed—and unvarnished— perspective.

"The people we do find that are qualified are typically mid–40s or older, leaving us with an increasingly aged workforce. The government monopoly of public education is graduating functionally and technologically illiterate people.

"In a business we are faced with two types of investment choices—labor (human capital) or technology (hard capital). Technology has become relatively less expensive than labor under the recent political climate—not in simple dollars/hour terms—but in terms of flexibility and cost certainty. All of the uncertainty surrounding the future costs of hiring people ('Obamacare,' potential unionization/labor rights changes, tax rates, etc.) make calculating the future costs of labor difficult. At least the costs of investments in technology are knowable."

And of course we had to ask Joe Arvin, Arrow Gear president and co-author of *A Nation on Borrowed Time*, (Amazon paperback $14.95) to weigh in. As those familiar with Arvin are aware, his interest in this subject is beyond passionate.

"The main reason for employment not picking up is because we are no longer an exporting country, but an importing country. The major international corporations are placing jobs off-shore and say they have to do this in order to remain competitive in the world marketplace and they have a responsibility to their stockholders. The shame here is that their off-shore plants typically have the newest automated equipment and are utilizing lean manufacturing practices, while their U.S. plants do not. There must be no tax breaks for new equipment purchased for off-shore plants (including Canada and Mexico) and no government funds or tax write-offs for R&D expenses where the R&D activity is also done off-shore."

Some good news is that in fact there exist—although in most cases below the radar—a number of grass-roots organizations, associations and, yes, unions, working to change the tide. One of them is the Alliance for American Manufacturing (*american-manufacturing.org*). Scott Paul, its founding executive director, offers this:

"The (reason for the 'disconnect') is simple: our trade deficit. We over-consume and under-produce. The past two recessions—2001–2002 and the most recent one—have both exhibited this disconnect. In past recessions we did not run enormous trade deficits, and when consumption picked back up it meant that people were buying American-made goods. That simply is not the case today.

"The skills gap is real," Paul continues, "but pointing fingers will do no good. Manufacturers—especially those the size of Caterpillar—must be willing to invest more and develop partnerships with high schools and community colleges to help fill the gap. Taxpayers must be willing to invest in education to improve outcomes and opportunities. But let's also be realistic—as long as the real money to be made is in finance, and not the productive sector of the economy, that is where the talent will head."

Joining the discussion is Emily Stover DeRocco, president of the DC-based Manufacturing Institute (MI) (*manufacturinginstitute.org*).

"Our recent skills gap report (available on the MI website) shows that 83 percent of manufacturers report a moderate or serious shortage of skilled production talent; and 74 percent of manufacturers say that this lack of talent is affecting their ability to expand operations. I strongly agree that the education system in the United States has failed in terms of providing adequate educational pathways—particularly in high schools—that focus on applied or project-based learning so necessary to producing the technical workforce manufacturers and many other business sectors need."

Next up, Dan Swinney—a founder and executive director of the Chicago Manufacturing Renaissance Council (*chicagomanufacturing.org)* and another individual looking for saffron among those grass roots.

"This reality—the complete break in the linkage between modern manufacturing and our education system—has been developing over the last 30 years. We did a full report on this reality ten years ago. Then it was a crisis; now it is a state of emergency. We need fundamental reform of our entire education system (K-20), returning integrity to the linkage of education with work, production and innovation. Our (Chicago public school)—Austin Polytechnical Academy (*www.austinpolytech.org*)—is an example of what can be done through a private/public partnership to begin to address this crisis."

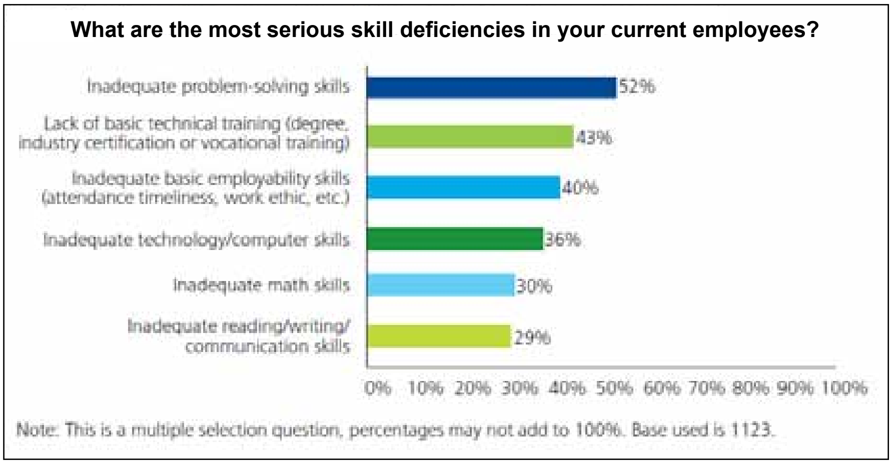
Yet another conundrum is the fact that it is this country's traditionally robust productivity levels that help exacerbate the employment landscape. More is being done with fewer workers—a direct result of American innovation and ongoing advances in robotics and other automation technologies. Of course, those automation capabilities are a must for just about any manufacturing entity hoping to survive and thrive. What to do?

Doshi offers, "While the statistics may be true, the logic may not be. Why would any company hire more than what is absolutely required to produce safely and economically, and to meet all customer requirements? Reduction in jobs is driven by market competitiveness and not a desire to reduce jobs! With all the productivity improvement, Schafer Gear has 25 percent more employees today than last year and a 50 percent increase in sales."

For Vosmik, the situation might be summed up as "no pain, no gain."

"Employment is a cost. Without productivity growth there can be no

continued



(Courtesy Manufacturing Institute)

real increase in wages. On-shoring is occurring because managers are starting to realize that there is a reason that wages are high here—because productivity is high here. *Productive* workers make an economy competitive—not *a lot* of workers. Yes, it is tough for the individuals that are dislocated and have to get another job, but without productivity gains there can be no real wage increases."

"Productivity gains can only be realized by doing proportionately more in output with the same number of people, or doing the same or less output with proportionately fewer people," Seymour believes. "In a downturn, a company focuses on the latter, and in an upturn they focus on the former."

Says Swinney, "Too many larger companies have chosen business models based principally on cutting costs, rather than continuing to invest in the full education and training of their workforce at all levels. We need continued increases in productivity accompanied by aggressive strategies to expand our market share in the global markets associated with advanced manufacturing."

"There is some truth to the argument that productivity in manufacturing has had an impact on employment levels needed to sustain output gains," Paul concedes, "but there is an important caveat: productivity in manufacturing is most likely overestimated because of higher import content in goods, as economists like Michael Mandel and Susan Houseman have argued. The more important point for me is this: why have productivity and wage increases—which rose in lockstep from the end of World War II until the mid-1980s—diverged for the past 25 years?

When things go pear-shaped, it is human nature to seek out someone or somebody to blame. Are technology and globalization the main "culprits" regarding the reduction of gear manufacturing jobs in the U.S.?

"The future growth of gear manufacturing jobs will be closely tied to innovation—either in gear production or gear designs themselves," Morehead says. "The industry must also recognize the strong growth of the distributed drive phenomenon, where the decreased costs of electronics make it easier and cheaper to deploy individual actuators at point-of-use rather than relying on more complicated mechanical gear drives of the past."

"I do not think that globalization or technologies are 'culprits,'" Doshi says. "We have enjoyed lower inflation as a result of appropriate sourcing and application of productivity improvement efforts. Unemployment may be the result of skill levels, inability to start new ventures, risk taking in manufacturing areas, etc., versus quick return in playing in the financial markets and such other reasons."

According to Vosmik, neither productivity nor technology is the "culprit" in this drama. Indeed, they are perhaps what have kept U.S. manufacturing afloat to date.

"Yes, technology is one of the 'culprits' that has freed up all of those workers that used to work in agriculture, steel, carriage making, blacksmithing and other industries at subsistence levels to work in today's industries and have two or three flat-screen televisions per home, two cars, kids in college, larger houses, cell phones, Game Boys, computers in their homes. CNC hobbers, gear grinders and turning centers are the 'culprits'—as well as the reason—we still have a gear industry."

Seymour believes that "Another factor is simply the shift by equipment manufacturers to offshore production, thereby reducing domestic gear demand."

"Globalization is not inherently a bad thing," says Paul, "but having the deck stacked against you certainly is. How do private (gear companies) compete against another country's government (as with U.S.–China trade)? Why doesn't our government stand up and fight unfair trade practices like piracy, intellectual property theft, subsidies, raw material export restrictions and currency manipulation? I'd argue the biggest 'culprit' is our government—Democrats and Republicans alike—and its failure to stand up for manufacturing jobs."

The group was then asked to respond to the following:

"While U.S. manufacturing output is nearly 2.5 times greater than it was in 1972, jobs have declined by more than 30 percent in that span, according to a study by Boston Consulting. But with wage rates in China growing at 15 to 20 percent a year and transportation costs climbing, the advantage is swinging back stateside, where worker productivity makes U.S. factories more efficient." (*Source: Robert Channick,* Chicago Tribune*, June 2011*)

Could this be "the light at the end of the tunnel?"

"Yes and no," Paul responds. "Re-shoring of work back to the United States is still the exception, not the rule. But I think other factors, such as a re-evaluation of supply chains in the aftermath of the earthquake in Japan, a weaker dollar and a surging preference for 'Made in America' have all made American manufacturing much more attractive."

"Or is that 'light' Vietnam, Cambodia or Myanmar?" Vosmik asks. "There will always be foolish accounting managers chasing labor arbitrage as a last-ditch effort to preserve an economically uncompetitive product/business model. But, ultimately, capital—if unhampered by artificial barriers to movement—will find the highest returns, and that means that products will be made by the most efficient companies with the lowest cost, regardless of the nominal price of an hour of a person's time."

"The gap between the West and China is certainly narrowing," says Morehead, "and in the process putting sharper focus on the less-tangible elements that were lost in the pursuit of lowest-cost labor."

Schafer's Bipin believes that "The U.S. will be competitive by 2015 with India and China in several areas. But I am afraid that if we do not have the workforce and capital availability, we may not be able to take the full advantage of the opportunity."

Xtek's Seymour is also looking for smoother sailing ahead.

"At Xtek, we believe that the tide is indeed turning in favor of 'on-shoring' of work back to the U.S. over the next decade. The outflow of manufacturing to China in the past ten years was artificially stimulated by the currency management regime of the Chinese

continued

government—a phenomenon that sustained the U.S. trade deficit well beyond what normal market economics would have allowed. That situation is no longer sustainable."

Stover DeRocco agrees that "The productivity of U.S. workers is an attraction, but we've also reached a point where the real costs of doing business in China are now apparent. As the wage disparity begins to close, those other costs take on greater importance."

Our cultural differences aside, the Zakaria column relates that the Germans "focus on technical education, technical institutes and polytechnics, as well as apprenticeship programs. They specialize in high-end, complex manufactured products that can command a premium price. Call it the BMW model."

Would the U.S. commit to something of that scale? The responses were uniformly and uniquely—American.

"America is not Germany, nor should we become Germany," says Paul. "But we can learn a lot from the German experience. First, we need an integrated approach to education, skills certification, training and formal apprenticeships along the lines of Germany. Second, we need closer coordination between business, labor and government to promote policies that boost domestic manufacturing. Third, we need a government willing to make manufacturing the centerpiece of the American economy, rather than finance."

"Quite simply," Morehead states, "it's a change of mindset that every job has a skill requirement, and in order to meet that requirement training is necessary. In the U.S., companies must abolish the notion of hiring people off the street, having them stand beside 'old Fred' for a week, watching what he does, and then entering the 'skilled' workforce. You get what you give, and a highly skilled workforce that is compensated appropriately as professionals will out-produce at a higher quality level than the haphazard, 'git-r-done' alternative."

"I believe that government encouragement, focusing where we can be good at, incentives, image building, social acceptance and a degree of risk taking may help build the manufacturing base," says Doshi. "We are innovative and industrious people, and still have a strong manufacturing base that can be built upon. Markets are here, why not build here?"

For Vosmik, going Euro would result, he believes, in "higher taxes, a planned economy, throwing out our Constitution (and) more training programs than the 20–30 we already have that are not working."

Seymour reasons that "The U.S. economy is far too large to 'specialize', as the Germans have. Our strengths are speed of innovation, abundance of risk capital and key input resources—and the promise of rich rewards to the winners."

Stover DeRocco agrees. "The German model has been successful, but it is based on a German culture that values highly disciplined and structured systems. Rather than trying to replicate that model in the U.S., we need to create an American model that takes advantage of our cultural strengths of creativity, risk-taking and independence."

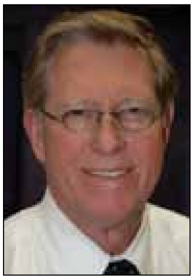
Our lone exception—in part—on this issue is Swinney, perhaps allowing that on occasion the best idea is someone else's. Sometimes there is an alternative to "the Chicago way"—at least regarding education.

"In Chicago and in the National Manufacturing Renaissance Campaign we have borrowed heavily from the German and Danish models in education linked to manufacturing in our efforts in secondary and post-secondary education. Austin Polytech is a case in point, as is the NAM (National Association of Manufacturers)-endorsed Manufacturing Skills Certification System that was embraced recently by President Obama."

And then there's immigration—a topic that elicits raw emotions at times, despite the fact that many of this country's greatest inventors, engineers and scientists were immigrants—or their children. It is an American Dream story that continues today in Silicon Valley and elsewhere in the nation. Again citing Zakaria: "Perhaps the single biggest boon for small companies would be to let in more skilled immigrants. We train the world's best and brightest at our universities (often at taxpayer expense) and then, just when they will begin to file patents, make inventions, start companies and create jobs, we throw them out. Our loss is China and India's gain."

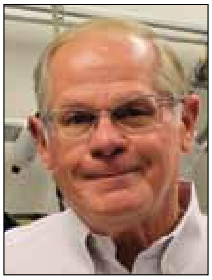
Dunkermotor's Morehead offers that "A good model to follow would be Israel's integration of post-Soviet-state immigrants in the 1990s, recognizing that a group of which 60 percent possessed tertiary education qualifications and 12 percent doctorate or engineering degrees would be an enviable stimulus to innovation and economic development."

Speaking from a quintessentially American experience, Doshi recalls that "Maybe it happened a long time ago, but I am one of those people that

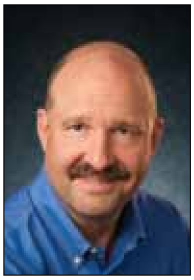


Joe Arvin
President
Arrow Gear

Bipin Doshi
President
Schafer Gear Works



John Morehead
Vice President
Dunkermotoren USA Inc.



Kyle Seymour
President, CEO
Xtek

the U.S. did not throw out! I immigrated to the U.S. in 1960, got educated and stayed. I do agree that, paranoia aside, we need to selectively recruit, welcome and retain the kind of people that built this country in the first place."

Xtek's Seymour believes—strongly, it would appear—that "The national paranoia about immigration is a true tragedy for our country for the reasons mentioned. Our nation was built on immigrants and should continue to embrace them. People who passionately seek to better themselves and their lives are the engines of growth and innovation."

The MI's Stover DeRocco points out that "Unfortunately, the issue of whether to encourage the immigration of skilled foreigners to the U.S. has been lost in the debate about how to address the illegal immigration from Mexico. Foreign talent—either students graduating from our universities or professionals seeking to come to the U.S.—brings the skills, ambition and ideas that create new jobs here in the U.S."

Zakaria's column also points out that "There are millions of Americans in industries like automobile parts in which lost jobs are unlikely to ever come back, certainly not at the pay they once commanded. That means people—many in their 40s or 50s—need to find new jobs. Can we create retraining programs for an entire generation of workers? Nothing we have done so far matches the scale of the problem (as did) the GI Bill, which put returning veterans through college after World War II and prepared a generation of Americans for good jobs."

"We absolutely need education reform linked to a determination to rebuild our modern manufacturing sector with the same scale, energy and determination that we witnessed during and after WW II," says Swinney responds.

"Incentives are good," says Doshi, "but we need to build a desire in people to rebuild the national base. Seems like empty words, but we need to build the national pride back!"

"The best retraining initiative should be formulated by the private sector," Morehead says, "by working closely with educational institutions and the government and with the understanding that the private sector would be required to be an active participant in terms of creating apprenticeship opportunities and formal (not the typical on-the-job) training."

Drake's Vosmik indicates that fewer—not more—skills training programs and other initiatives are what we need. But ones that work.

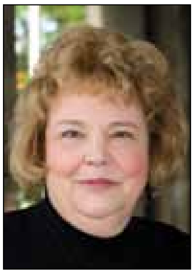
"We have a multitude of retraining programs that do not work, based on countless research studies. Go back to the earlier question about the poorly trained and inept young workers—(they are) the product of government training programs called 'public schools'."

"The GI bill was very successful in its time," Seymour agrees, "but that success has actually led to part of the current problem. The predominant belief in America has become that every child needs to get a college education to be successful, and public policy drives funding for that. As a result, college education prices have soared for all, and yet there are many people who have worthless college degrees or who should never have gone to college in the first place. This phenomenon has starved trade schools and other skill-based training institutions of talent that could be readily marketable in our evolving economy. The solution needs to include a shift of public policy that acknowledges the role and importance of technical skills training that is a viable and respectable alternative to a college education. Manufacturers can and should play a role in this, but at local levels where the training will actually be done."

Sharing that skepticism over a public role, Stover De Rocco says that "The likelihood of creating a vast new government program in today's fiscal environment is remote and would be foolhardy. "(We need) to focus on education and training pathways that result in industry-based credentials that would provide millions of Americans with the opportunity to gain in-demand skills."

Weighing in for older, dislocated workers, Paul says that "The training infrastructure for mid-career and older workers is completely inadequate. Manufacturers not only should get involved with these efforts—they must get involved."

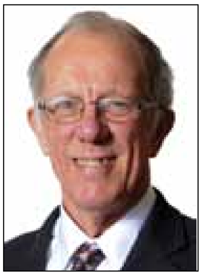
Getting the last word, Swinney believes that "The role of advanced manufacturing in American society is the most important public policy debate of this decade. It is in the deep interests of the public to have a dynamic manufacturing sector as the foundation for our society. Manufacturers, government, labor, community and educators need to forge a true and dynamic partnership—with new responsibilities for all—to ensure that the U.S. experiences a manufacturing renaissance."



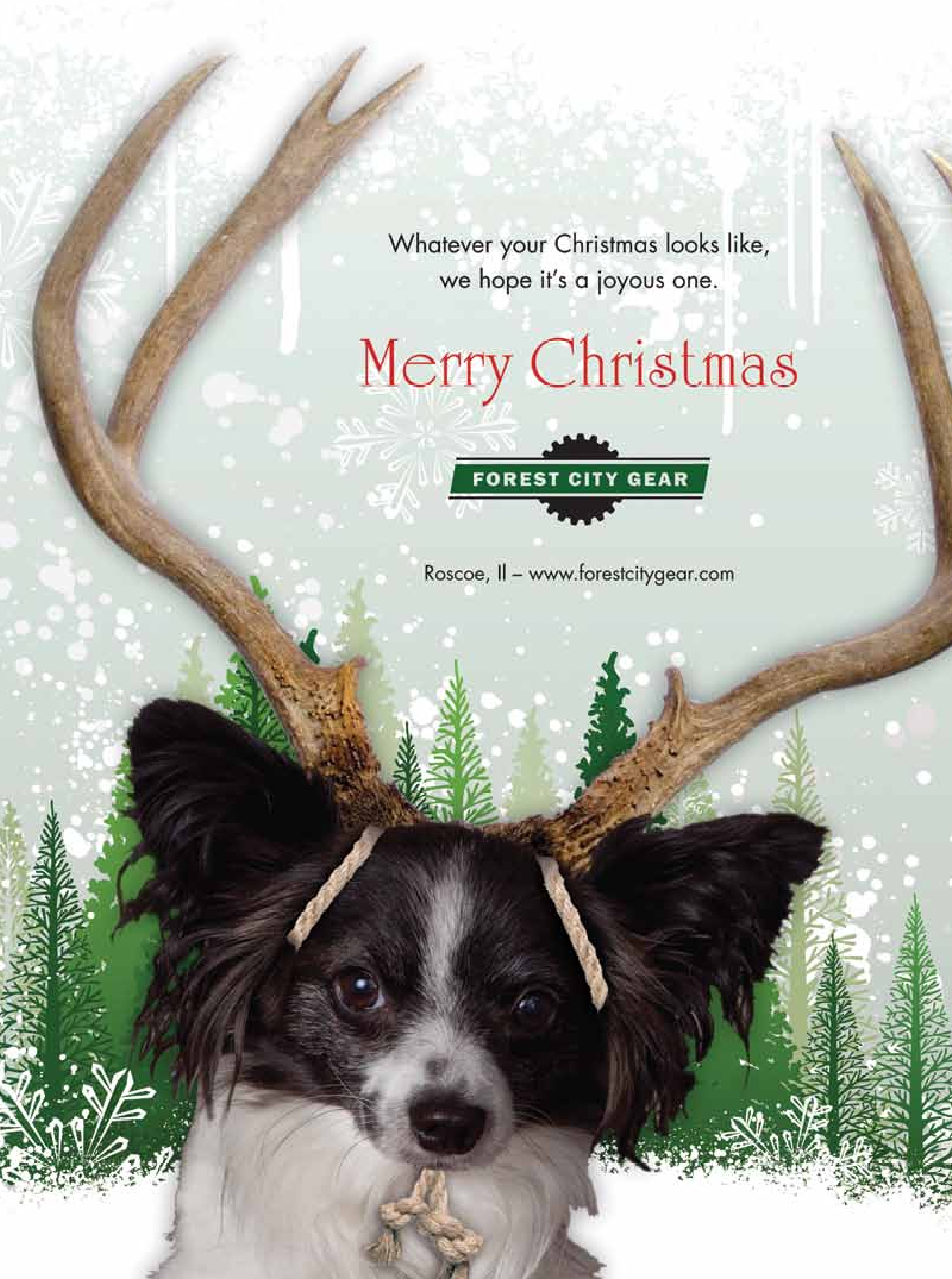
Emily Stover DeRocco
President
Manufacturing Institute

Scott Paul
Executive Director
Alliance for American Manufacturing

Jim Vosmik
President
Drake Mfg. Services

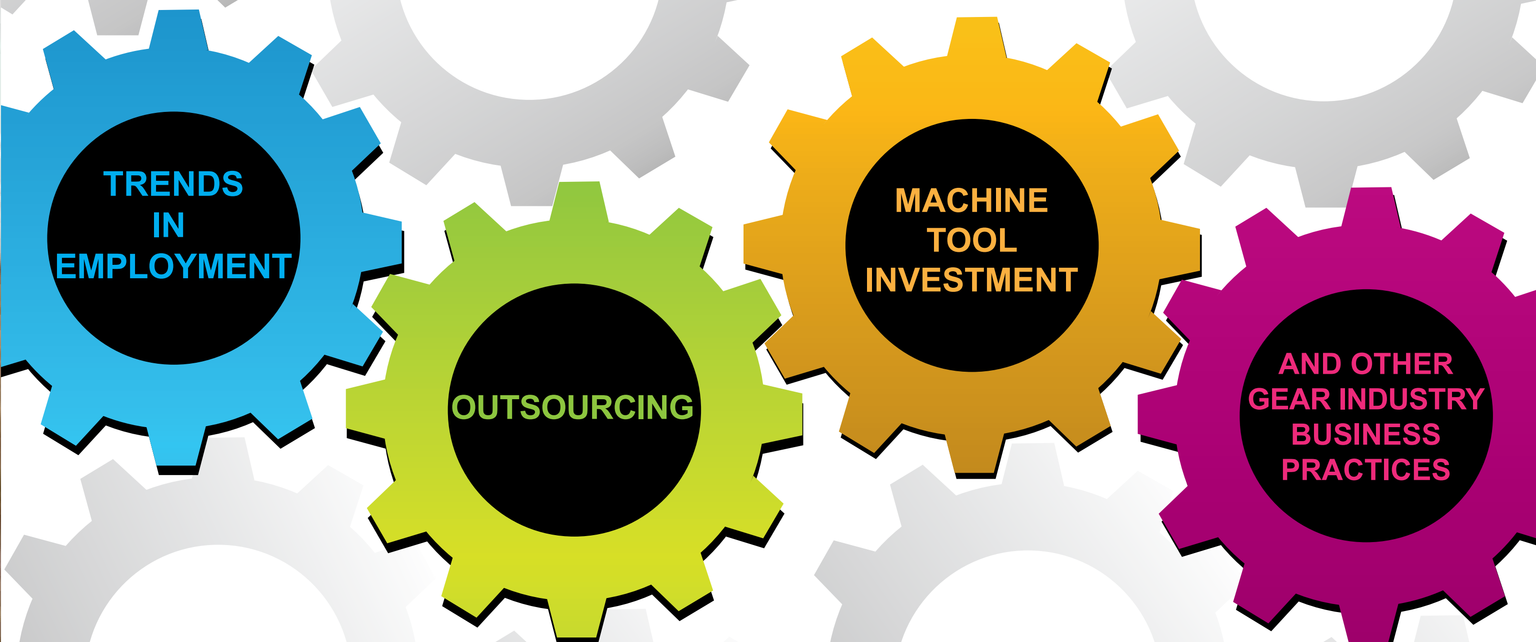


Dan Swinney
Executive Director
Chicago Manufacturing Renaissance Council


Whatever your Christmas looks like,
we hope it's a joyous one.
Merry Christmas
FOREST CITY GEAR
Roscoe, Il – www.forestcitygear.com

2011 STATE OF THE GEAR INDUSTRY

READER SURVEY RESULTS



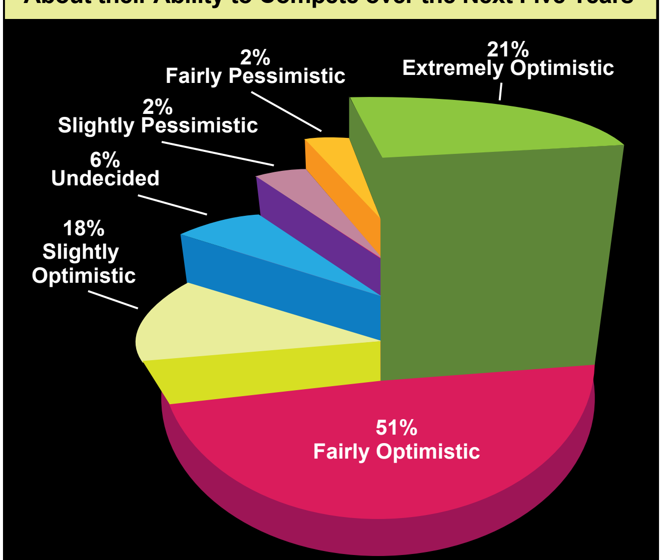
In November, Gear Technology conducted an anonymous survey of gear manufacturers. Invitations were sent by e-mail to thousands of individuals around the world. More than 300 individuals responded to the online survey, answering questions about their manufacturing operations and current challenges facing their businesses.

The respondents considered here all work at locations where gears, splines, sprockets, worms and similar products are manufactured. They work for gear manufacturing job shops (44 percent), and captive shops at OEMs (56 percent).

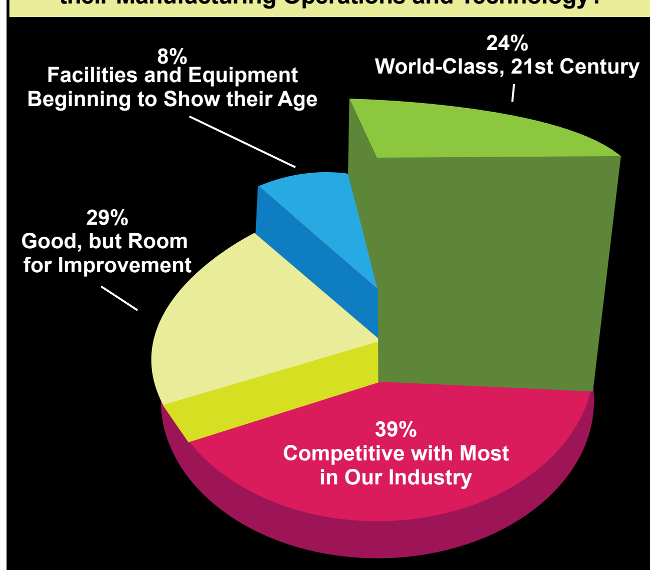
The survey covers gear manufacturing around the world, with 60 percent of respondents working in the United States, and 40 percent outside the United States.

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

88% of Gear Industry Respondents are Optimistic About their Ability to Compete over the Next Five Years



How Do Respondents Describe their Manufacturing Operations and Technology?



What Factors Are Presenting Significant Challenges To Your Business?

"Low price and poor qualities produced from Mainland China; Difficult to enter the wind turbine supply chains, as they are controlled by a few players."
—Design engineer at an Asian gear reducer manufacturer

"Barriers to foreign entry."
—Sales manager at a U.S. gear manufacturing job shop

"Brand recognition."
—Design engineer at U.S. manufacturer of control actuators

"Chemical costs."
—Worker at a U.S. public water utility

"Companies are starting to back-charge for the cost of their blanks when they are scrapped during our operations. Their blanks can be very complex and very expensive. The cost of scrapping a single part can exceed the value of our work."
—Manufacturing engineer at a U.S. gear manufacturing job shop

"Currency change."
—Quality engineer at an Asian manufacturer of automobile transmissions

"Delivery time from vendors (machine shops)."
—Design engineer at a U.S. design/engineering consultancy

"Energy cost."
—Purchasing manager at a South American gear manufacturing job shop

"Energy efficiency, lead times, vendors not cooperating."
—Corporate executive at an Asian manufacturer of plastic gears

"Environmental and government controls."
—Purchasing manager at a U.S. manufacturer of pumps for gas and oilfield

"Finding qualified motor and gear manufacturers for aerospace applications."
—Design engineering manager at a U.S. manufacturer of aerospace actuators

"Finding reliable high quality suppliers."
—Design engineer at a U.S. aerospace OEM

"Gears with high accuracy."
—Quality engineer at an Asian gear manufacturer

"Government change; More socialistic oriented."
—Corporate executive at a European gear manufacturing job shop

"Government regulations."
—Manufacturing engineer at a U.S. auto manufacturer

"Increasing cost of quality audits from suppliers despite years of successful audits and multiple 3rd party certifications."
—Corporate executive at a U.S. company providing services to gear manufacturers

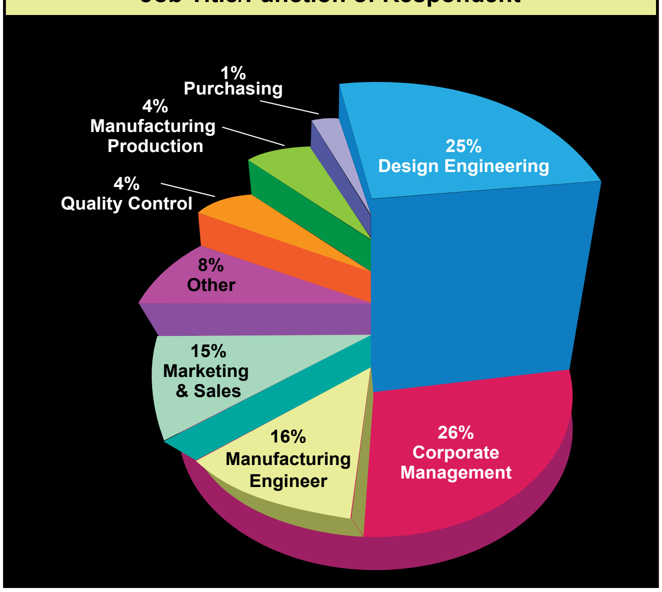
"Low cost, Chinese products."
—Design engineering manager at an Asian manufacturer of industrial air compressors

"Our company is known as a world leader, but competition is always a factor."
—Quality manager at a U.S. manufacturer of printing equipment

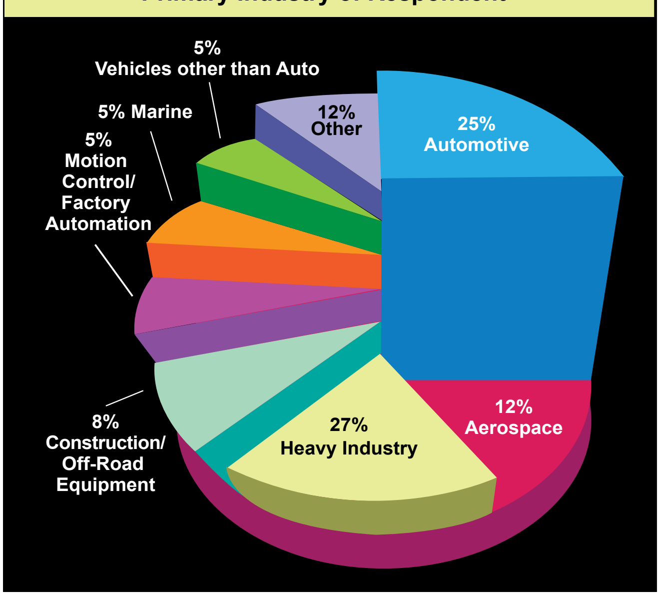
"Outsourcing to China versus quality; Global selling and related service and pricing."
—Corporate executive at a U.S. manufacturer of winches

"Re-shoring efforts and cost to import is rising."
—Sales manager at U.S. gear manufacturing job shop

Job Title/Function of Respondent



Primary Industry of Respondent



What Factors Are Presenting Significant Challenges To Your Business?

"Steel delivery; Cutting tool delivery."
—Corporate executive at a U.S. gear manufacturing job shop

"Technological changes in manual transmissions (dual clutch, CVT); the R&D activities are too costly."
—Design engineer at a Mexican manufacturer of manual transmissions

"The lack of knowledge of gears in mid- to upper-level management."
—Manufacturing engineer at a U.S. manufacturer of power transmission products

"The shortage of skilled workers."
—Manufacturing engineer at an Asian gearbox manufacturer

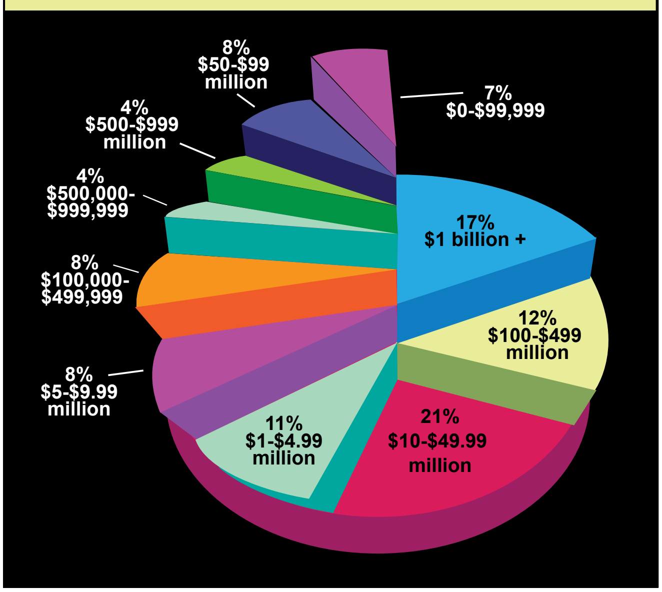
"The unknown about where the business taxes are going."
—Corporate executive at a U.S. aerospace components manufacturer

"Unfocused corporate initiatives."
—Manufacturing engineering manager at a U.S. manufacturer of motors and gearheads

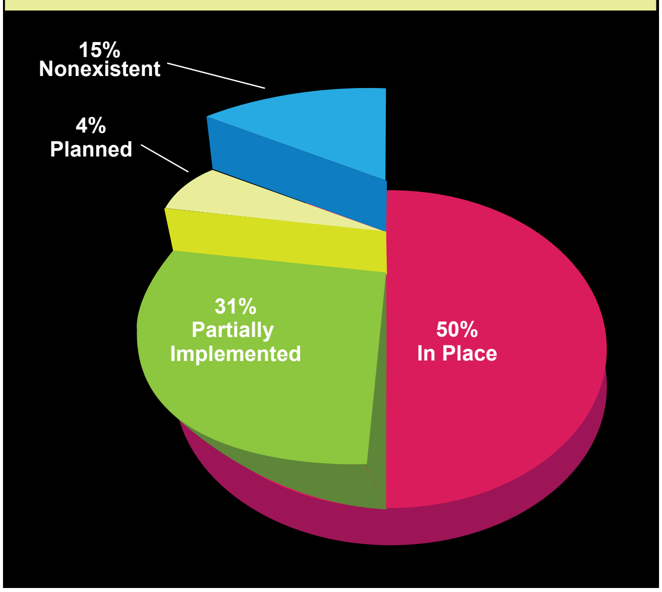
"Washington's ever tightening grip on manufacturing regulations that stifle growth; Useless green and carbon taxing legislation; No energy policies; Less government is what America needs to regain and become the great manufacturing country that it once was."
—Corporate executive at a U.S. manufacturer of coating equipment

continued

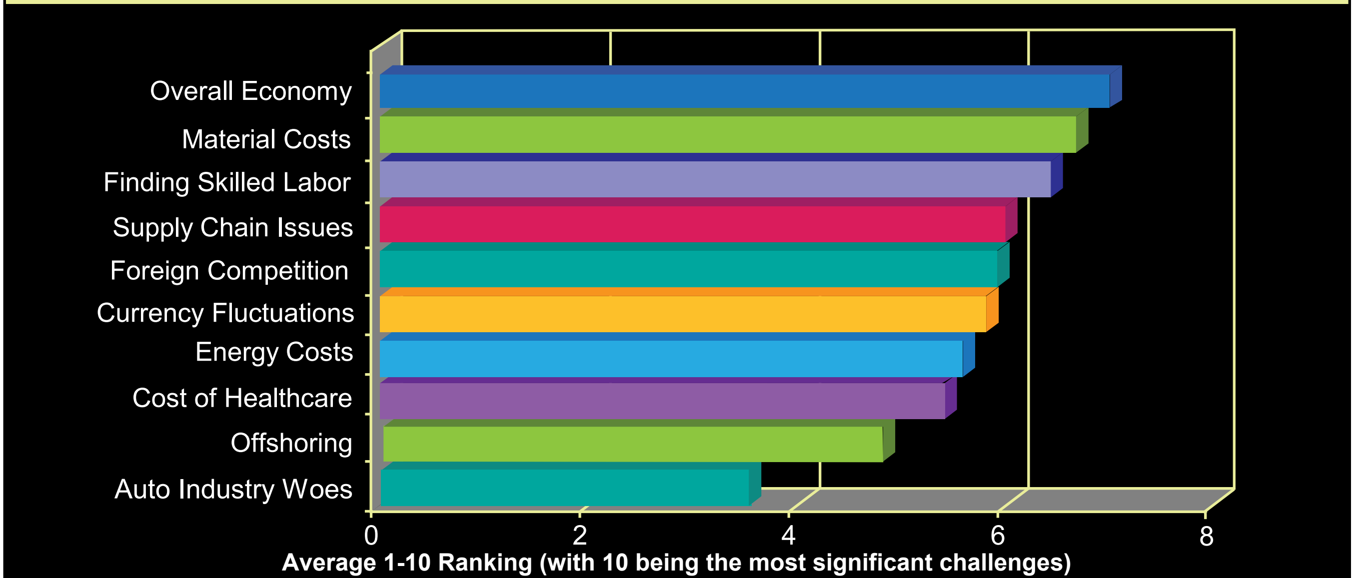
Annual Sales Volume of Company



Lean Manufacturing Implementation



What are the Most Significant Challenges Facing Gear Industry Companies?



What Are Your Company's Greatest Manufacturing/Engineering Challenges for 2012?

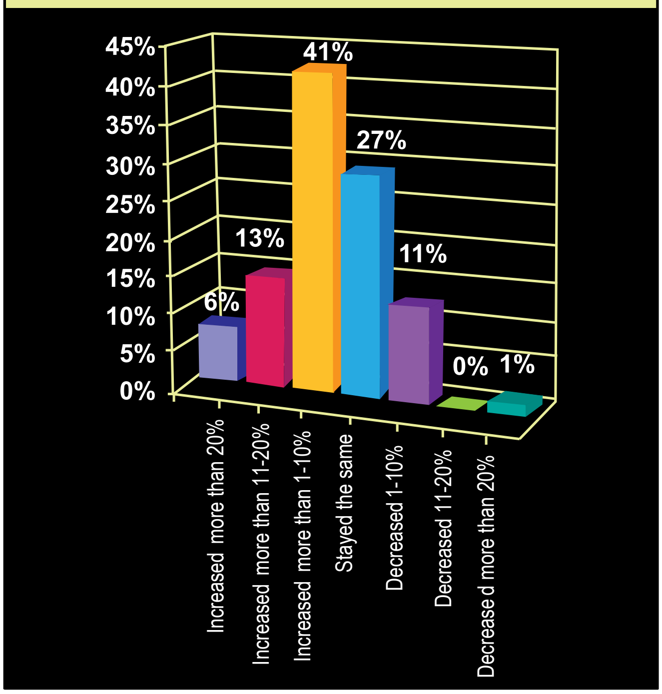
" Shortage of new engineers compared to the orders incoming; Time efficiency for developing new products."
—Design engineering manager at an Asian manufacturer of gear reducers

"Ability to rapidly scale up or down as dictated by projects."
—Corporate executive at a U.S. provider of services to gear manufacturers

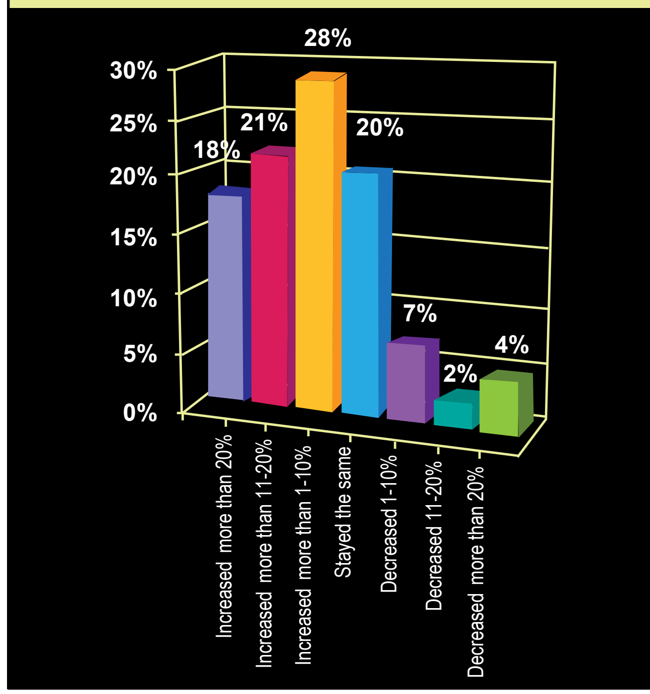
"Accommodating rising demand for our products and services."
—Corporate executive at a U.S. manufacturer of plastic gears

"Advances in electronic technology."
—Design engineer at a U.S. manufacturer of controls and actuators

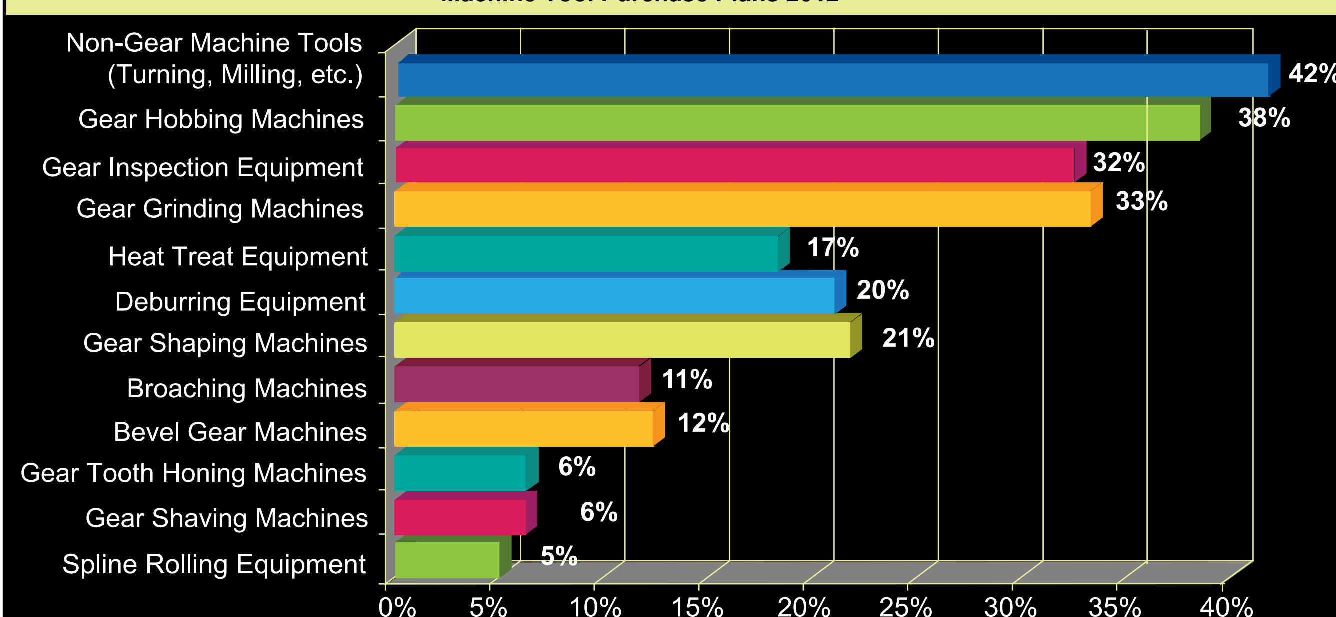
60% of Gear Industry Respondents Work at Locations where Employment Increased in 2011



67% of Respondents Saw Production Volumes Increased in 2011



Machine Tool Purchase Plans 2012



Of those planning to purchase capital equipment, the percentage planning to purchase in each category

What Are Your Company's Greatest Manufacturing/Engineering Challenges for 2012?

"Better quality."
—Purchasing manager at a South American gear manufacturing job shop

"Building production, finding high quality suppliers."
—Purchasing manager at a Canadian manufacturer of gearboxes

"Company's lean production."
—Corporate executive at a European manufacturer of speed reducers

"Competent suppliers."
—Design engineer at a U.S. manufacturer of diesel engine fuel systems

"Consistency in end results."
—Manufacturing engineer at a U.S. manufacturer of reconditioned assemblies

"Continuing to lower costs."
—Manufacturing engineer at a U.S. automobile transmission manufacturer

"Continuous learning and implementation of Gleason's system."
—Corporate executive at a European gear manufacturing job shop

"Cost and on-time delivery."
—Design engineer at a U.S. manufacturer of aerospace actuators

"Cost of manufacturing."
—Quality engineer at an Asian gear manufacturing job shop

"Cost reduction."
—Manufacturing engineer at a U.S. manufacturer of automotive components

"Developing new products to compete."
—Design engineer at a U.S. manufacturer of mining equipment

"Energy efficiency management."
—Worker at a U.S. public water utility

"Fighting raw material cost increases and increases in productivity to offset competition and wage increases."
—Manufacturing engineering manager at an Asian automotive gear manufacturer

"Finding new business in competitive plastics market."
—Corporate executive at an Asian manufacturer of plastic gears

continued

What Are Your Company's Greatest Manufacturing/Engineering Challenges for 2012?

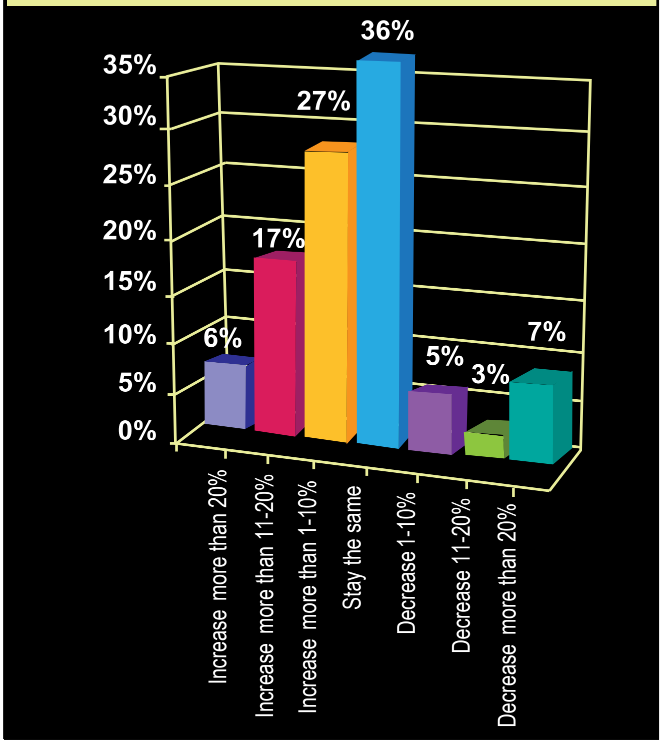
"Finding skilled CNC CAM programmers."
—Corporate executive at a U.S. gear manufacturing job shop

"Gear cutting."
—Corporate executive at a European manufacturer of winches and gearboxes

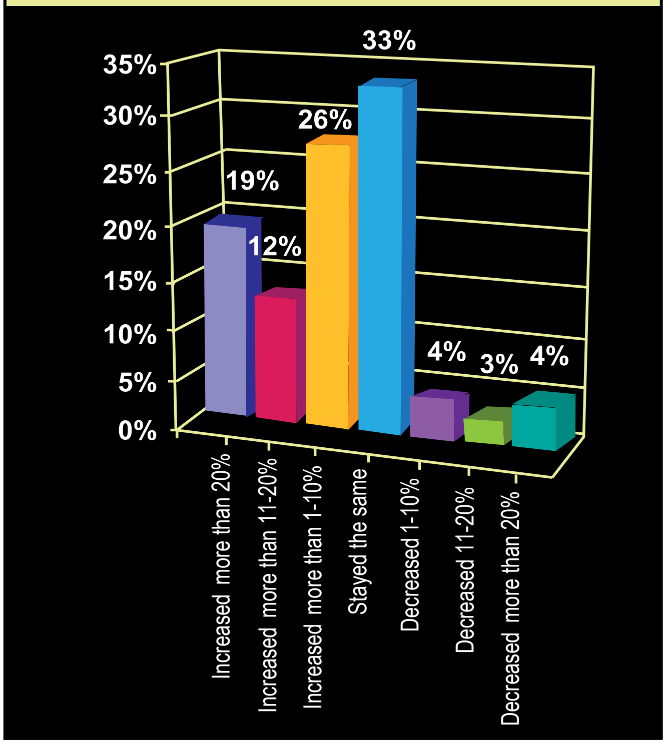
"Getting enough space and capacity fast enough."
—Corporate executive at a European gear manufacturing job shop

"Hiring skilled technicians and engineers."
—Corporate executive at a U.S. manufacturer of packaging machinery

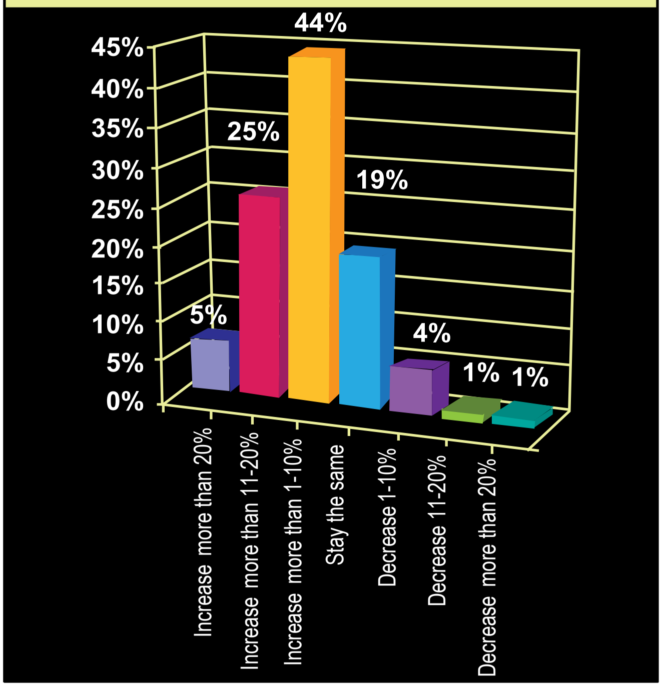
50% Expect Capital Spending at their Locations to Increase in 2012



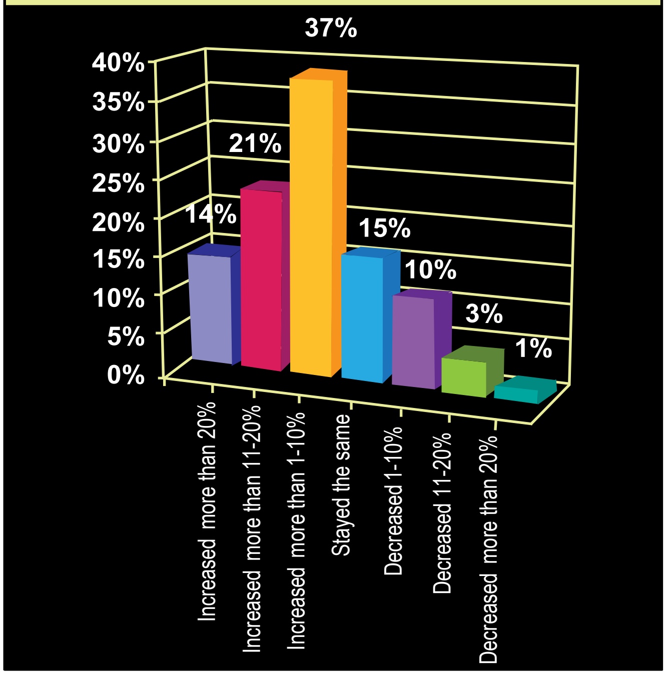
57% Work at Locations where Capital Spending Increased in 2011



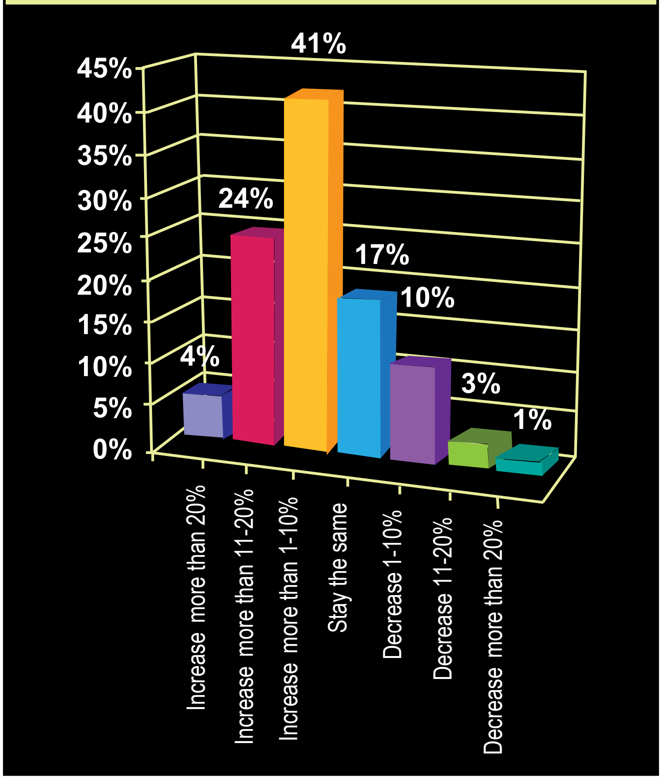
74% Expect Production Volume to Increase in 2012



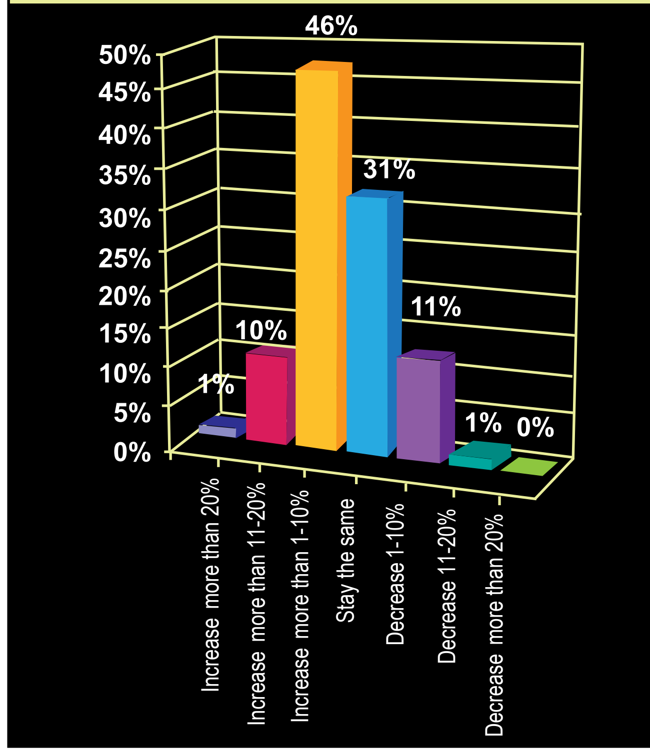
72% Saw Sales Volume Increase in 2011



69% Expect Sales Volume to Increase in 2012



Most Gear Industry Respondents Expect Little Change In Employment in 2012



continued

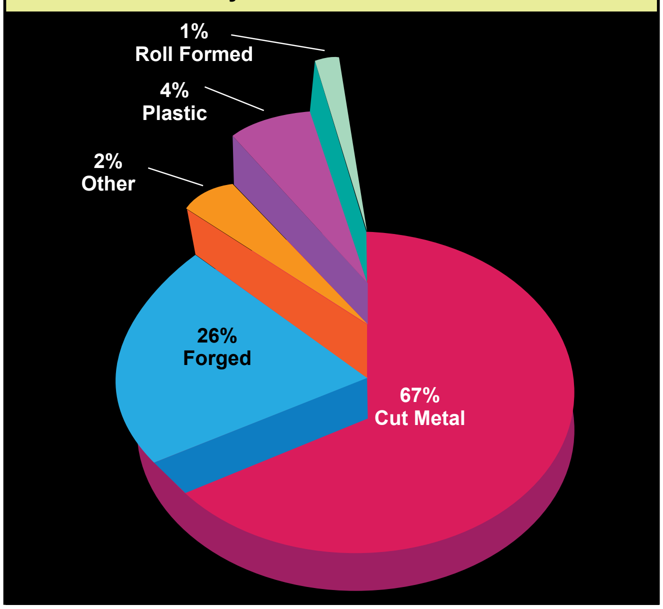
What Are Your Company's Greatest Manufacturing/Engineering Challenges for 2012?

"Increase capacity."
—Purchasing manager at a U.S. manufacturer of pumps for gas and oilfield

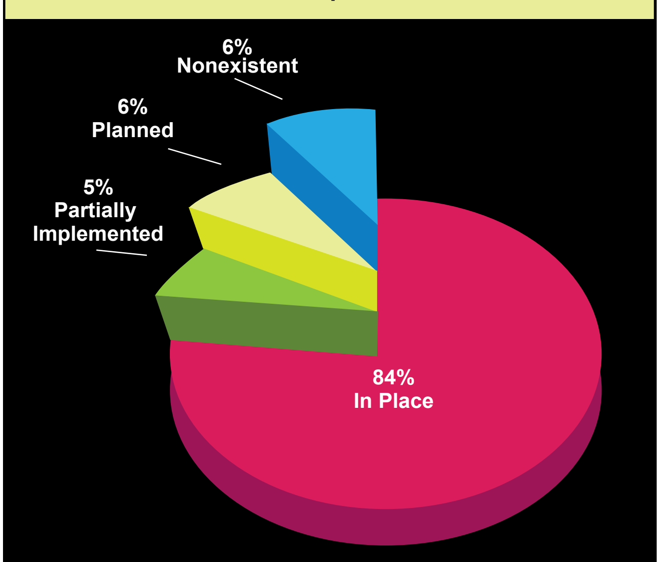
"Keep abreast of the new equipment so as to make up for the loss of skilled labor."
—Corporate executive at a U.S. manufacturer of aerospace components

"Keeping up with new requirements and designing to meet these changes."
—Quality engineer at a U.S. manufacturer of printing equipment

Primary Method of Manufacture



ISO 9000 Implementation



"Lean and six sigma implementation; New technology; Continuous improvement."
—Corporate executive at a U.S. manufacturer of winches

"Manufacture components for a new customer."
—Design engineer at a Mexican manufacturer of manual transmissions

"Manufacture of oil-free compressors, gear noise issues, high vibration levels."
—Design engineer at an Asian manufacturer of industrial air compressors

"Meeting schedules."
—Design engineer at a U.S. aerospace OEM

"Meeting the customer's lead times and price points."
—Sales manager at a U.S. manufacturer of plastic gears

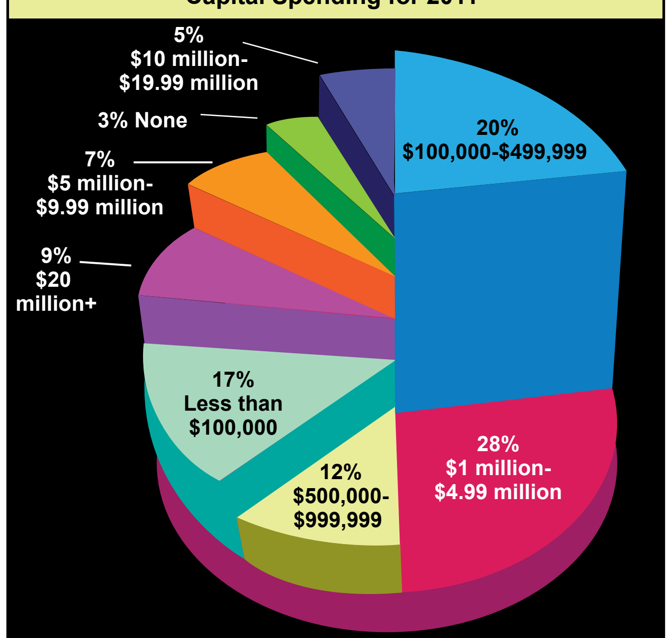
"More parts at less cost with zero defects' Long-term agreements with cost control for ten years; Who can predict any costs for a ten-year contract?"
—Manufacturing engineering manager at a U.S. gear manufacturing job shop

"Process improvement. Cost reduction."
—Corporate executive at a U.S. gear manufacturing job shop

"Reducing cost, meeting delivery."
—Manufacturing engineer at U.S. manufacturer of agricultural equipment

"Rising energy and labor costs."
—Manufacturing engineer at a Mexican manufacturer of industrial gearboxes

Capital Spending for 2011



What Are Your Company's Greatest Manufacturing/Engineering Challenges for 2012?

"Serial production; micro assembly."
—Corporate executive at a European manufacturer of actuators

"Skilled engineering persons that understand plastic gear functions, inspections and manufacturing methods."
—Quality engineer at a U.S. manufacturer of electromechanical actuators

"Staffing experienced engineering."
—Sales manager at a U.S. gear manufacturing job shop

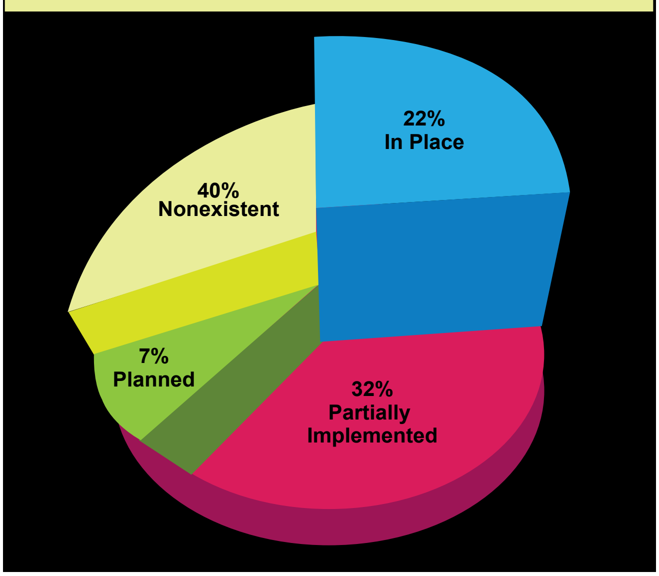
"Supply chain of castings."
—Manufacturing engineer at U.S. manufacturer of hydraulic gear pumps

"Supply of input material constantly and consistently."
—Design engineer at an Asian manufacturer of commercial vehicle gearboxes

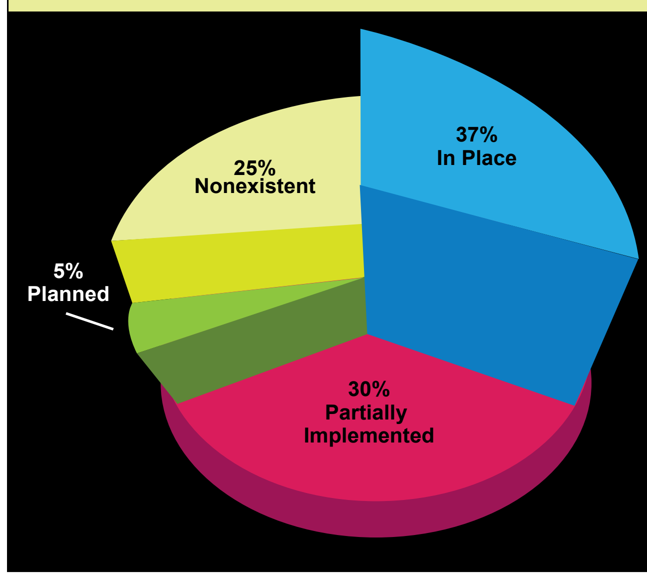
"The age of our machinery and the enormous expense of new equipment."
—Corporate executive at a U.S. gearbox repair facility

"The shortage of skilled workers."
—Manufacturing engineer at an Asian manufacturer of gearboxes

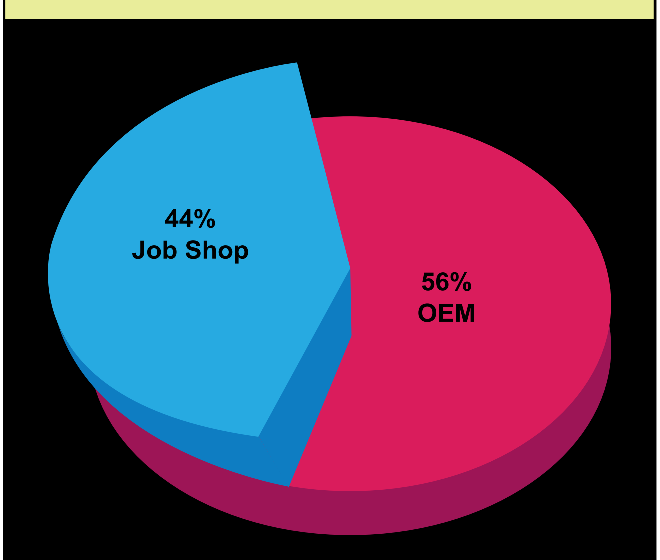
Six Sigma Implementation



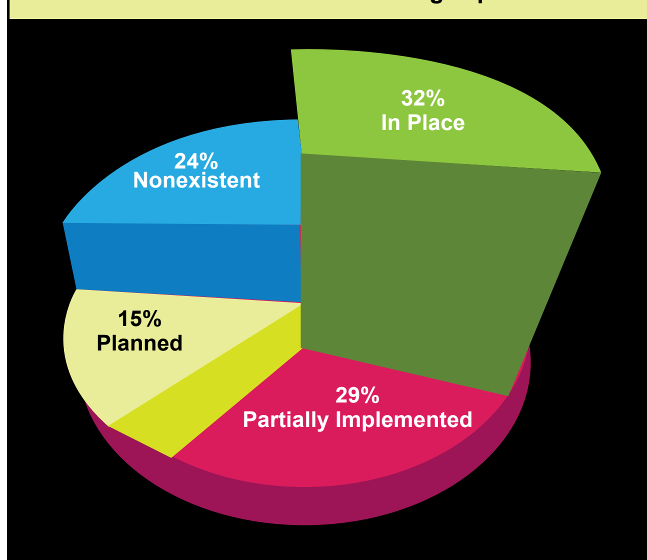
Statistical Process Control (SPC) Implementation



Type of Operation



Green or Sustainable Manufacturing Implementation



Minimum Setup Time, Maximum Machining Capability

Hainbuch Offers Workholding Solutions for United Gear

Matthew Jaster, Associate Editor

One of the goals of having Kapp's KX-500 on United Gear's shop floor was to utilize the form generation capabilities for increased throughput on the machine. Kapp representatives explained that the original workholding United Gear was using for single tooth profile grinding was not going to be rigid enough and they may experience part chatter or vibrations. Since Kapp Technologies had a positive experience in the past with Hainbuch's workholding solutions, they suggested Hainbuch to United Gear.

The workholding solution currently in place at United Gear is a series of Hainbuch T213 style mandrels (courtesy of Hainbuch).

"United Gear had a very large family of parts that they wanted to run through the machine with significant differences in part geometry," says Matthew Block, regional sales engineer at Hainbuch. "Having this high mix coupled with mid to low lot sizes meant that there may be a need to set up the machine multiple times per shift, and it was important to have something that would minimize the idle time on the machine. Hainbuch fit the bill in all these areas."

There are only three mandrel bodies that cover the whole family of parts, and within those three mandrels, changing from one part to the next is as easy as changing the bushing and part endstop. When the time comes to change out the mandrel body, this can be done in as little as 8–10 minutes. "Obviously, since this is a finish grinding operation, the accuracy needed to be top-notch," Block says. "Based on previous part examples from Hainbuch, and the recommendations from Kapp, United Gear was convinced that the accuracies that could be achieved would be second to none."

The workholding in place currently is a series of Hainbuch T213 style mandrels. These units are self-contained and hydraulically actuated. The T213 style was chosen for the ability to have a better cutting profile (tool clearance) while still maintaining a highly rigid clamping solution. “All of the Hainbuch mandrels utilize a vulcanized rubber between hardened steel segments which allow for true parallel clamping and higher accuracies than most other devices,” Block says. “The vulcanization also protects against ‘accidental actuations’—if the operator accidentally actuates the unit without a part on it, there is no failure in the clamping unit. With the old style of clamping, if an operator actuated without a part, he or she would most likely need to replace the spring steel ID collet.”

Another benefit to the T213 style mandrel is that the draw-bolt and clamping element are connected together in a manner that helps prevent grinding swarf from building up in the workholding. This reduces the need for operator intervention to clean the workholding.

While this is the first experience for United Gear with Hainbuch’s solutions, the company is currently looking into several other areas where these workholding tools will be beneficial.

The T213 style was chosen for the ability to have a better cutting profile (tool clearance).

“Setup time from one part to the next was between 30–45 minutes because the fixtures needed to be dialed in after each diameter change. With the Hainbuch solution, changing from one diameter to the next can be as little as two minutes to change the clamping bushing or if the whole man-

continued

drel body needs to change, about 8–10 minutes. Most of the time, just bolting the Hainbuch mandrels on the table, they are concentric within less than 0.0001"," Block adds.

In addition to the setup time reductions, United Gear saved four minutes per part by not needing the tailstock supports to run the parts. The Hainbuch workholding has a pull-down effect to properly seat the part in the Z-direction while increasing clamping rigidity. Because of this pull-down effect, many times, tailstock supports are not required at all.

"As United Gear moves from single profile grinding wheels to form generation wheels, they are seeing further cycle time reductions of 20 percent or better and this just was not possible using the old style workholding because of the lack of rigidity. Every time a particular job comes around, the operators push the machine and workholding a little further to see if they can better the last cycle times they ran on that part," Block says.

The increased accuracy directly translated into a reduced scrap rate and an increase in process stability. With the old fixtures, United Gear would struggle at times to hold 0.001–0.002" on some parts. With the new Hainbuch units, they hold less than 0.0005" all the time.

"One of the intangible benefits from this is that the machine operators no longer hold any animosity for the quality/measurement department. We all know that a happier employee is a more productive employee; it is just difficult to accurately quantify productivity based on personnel mood," Block says.

The benefits of this collaboration have been recognized by everyone from the operators all the way to upper management. United Gear was pleased with the support and project consultation as well as the start-up assistance. Onsite setup and operator training allowed for questions to be addressed immediately. As mentioned earlier, this collaboration will result in future projects between the companies.

"In the past, having quick change often meant that there was a loss in accuracy or rigidity or some other feature. There was always some type of give and take, something needed to be sacrificed and companies would always need to play this kind of balancing game to figure out what works best for them," Block says. "Hainbuch is eliminating that old mentality. With the quick change features that are built into the product, there is no compromise in quality, rigidity, accuracy or functionality. This is a product that really does have it all in one package."

For more information:

Hainbuch America Corp.
10541 N. Commerce St.
Mequon, WI 53092
Phone: (414) 358-9550
www.hainbuch.com

United Gear and Assembly, Inc.
1700 Livingstone Road
Hudson, WI 54016
Phone: (715) 386-5867
www.ugaco.com

Klingelnberg

OPENS BLADE GRINDING CENTER IN MEXICO

In August 2011, Klingelnberg's Mexico site was moved to a new facility in Querétaro City. This investment is part of the company's long-term strategy for this important market. At the new facility, Klingelnberg will soon inaugurate its new blade grinding center with a grand opening event. The new blade grinding center will be part of the company's response to meet the increasing demands for this service. In the new plant at the existing Querétaro location, Klingelnberg will offer first-hand sales support, spare parts as well as professional customized service engineering and application engineering.

"We are now able to support our customers even better and more professionally, regarding both our machines and application engineering," emphasizes CEO Jan Klingelnberg. In terms of grinding, the customers will benefit from Klingelnberg's state-of-the-art automated blade grinding cell B 27, the cutter head setting and checking device CS 200 as well as the stick blade measuring device BC 10 at this new facility. With all the equipment in a closed-loop environment, the company will deliver optimal results in blade grinding service to ensure the quality of the spiral bevel gear production. For more information, visit *www.klingelnberg.com*.

Klas Forsström

NAMED GLOBAL PRESIDENT OF SANDVIK COROMANT

Klas Forsström

On September 1, 2011 Klas Forsström took over the position of global president of Sandvik Coromant, a supplier of cutting tools, tooling solutions, services and know-how to the metalworking industry. Forsström has been with the Sandvik Group for about 17 years, mostly at Sandvik Coromant. His work has included leading positions in R&D, product development, marketing, business development and sales. Most recently he held the position of president of Sandvik Hard Materials.

"It is really exciting and inspiring to be back with Sandvik Coromant. I am truly impressed by what the company has achieved in recent years. As the market leader we are perceptive and forward thinking," says Forsström. His first task as president is to manage and further develop the ambitious strategy that Sandvik Coromant has set. This includes an even stronger customer focus through local presence and global knowledge sharing. "R&D is part of the very fabric that is Sandvik Coromant. We are always focused on product innovation, premium application knowledge and speed to market. Our ambition and motivation for the future is strong. I believe we will be successful in the further development of customer oriented solutions," Forsström explains.

Forsström holds a master of science in material physics and an MBA from Uppsala University, Sweden. He is married and has four children. He enjoys family life, reading, fishing and carpentry.

ZF

OPENS U.S. PLANT FOR WIND TURBINE GEARBOXES

ZF Friedrichshafen AG has opened a plant for the production of wind turbine gearboxes in Gainesville near Atlanta, Georgia. As of 2012, the company will supply gearboxes of the two-megawatt performance class for Vestas from the new location. "After a phase of economic decline, wind power is reviving," says ZF CEO Hans-Georg Härter. "With our new plant for wind turbine gearboxes in Gainesville, we are right in time." Within the last years, the Friedrichshafen Group collected sufficient experience in the service area for large volume gearboxes. Gainesville is the first ZF production location worldwide. After production ramp-up, the plant will offer a production capacity of 1,000 gearboxes per year and 250 jobs. In an expansion stage, production can be increased to 1,500 gearboxes per year.

"As a leading automotive supplier, we can rely on product and process know-how that was developed over decades. Therefore, we distinguish ourselves from our competitors," says Dr. Michael Paul, member of the board of management for the Industrial Technology Division that also includes the Wind Power Technology Business Unit. The new plant in Gainesville will cover the North American market, where Vestas has large production capacities. The aim is to establish ZF as worldwide leading manufacturer in this sector. With the intended acquisition of Hansen, the Belgian wind turbine gearbox manufacturer, the ZF Group wants to tap the important wind power markets in Asia and Europe.

The whole plant with a production area of about 24,000 square meters is focused on a sustainable and resource-saving production. Saving energy and the protection of the environment are at the center of attention. Also, the product itself, the Atlas 1 wind turbine gearbox developed by ZF in the two-megawatt performance class, is designed in accordance with energetic criteria. Special longevity and serviceability are part of the major product characteristics. For more information, visit *www.zf.com*.

Manufacturing Survey

DESCRIBES STATE OF SKILLED WORKERS GAP

American manufacturing companies cannot fill as many as 600,000 skilled positions—even as unemployment numbers hover at historic levels—according to a new survey from Deloitte and The Manufacturing Institute. The survey, "Boiling Point? The Skills Gap in U.S. Manufacturing," polled a nationally representative sample of 1,123 executives at manufacturing companies recently and revealed that five percent of current manufacturing jobs are unfilled due to a lack of qualified candidates. "The survey shows that 67 percent of manufacturers have a moderate to severe shortage of available, qualified workers," said Craig Giffi, vice chairman and consumer and industrial products industry leader, Deloitte LLP. "Moreover, 56 percent anticipate the shortage

continued

to increase in the next three to five years."

"These unfilled jobs are mainly in the skilled production category—positions such as machinists, operators, craft workers, distributors and technicians," said Emily DeRocco, president, The Manufacturing Institute. "Unfortunately, these jobs require the most training and are traditionally among the hardest manufacturing jobs to find existing talent to fill."

Giffi points out that the inability to find workers is taking its toll on manufacturers' competitive readiness. Case in point: 64 percent of respondents report that workforce shortages or skills deficiencies in production roles are having a significant impact on their ability to expand operations or improve productivity. "Ironically, even as unemployment numbers remain bleak, a talent shortage threatens the future effectiveness of the American manufacturing industry," says Giffi. He points out that when respondents were asked to look ahead three to five years, they indicated that access to a highly skilled, flexible workforce is the single most important factor in their effectiveness—above factors such as new product innovation and increased market share by a margin of 20 percentage points.

According to DeRocco, companies need to partner with educational institutions to make developing workforce skills a top strategic priority. "Our education system must also do a better job aligning education and training to the needs of employers and job-seekers. To support this effort, The Manufacturing Institute is deploying the Manufacturing Skills Certification System endorsed by the National Association of Manufacturers (NAM)—a system designed to build educational pathways to in-demand manufacturing jobs."

The survey findings may seem remarkable since the country is facing an unemployment rate above nine percent, but DeRocco says it can all be linked back to a trend that started before the 2008 economic slowdown. "Over the past five years, most manufacturers have redesigned and streamlined their production lines while implementing more process automation. In short, just as the industry is changing, the skills of the workers are changing as well."

"Manufacturers obviously want to fill these roles by tapping the currently available workforce," says DeRocco. "However, they report that the No. 1 skills deficiency among their current employees is in the area of problem solving, making it difficult for current employees to adapt to changing needs. Adding to the problem, respondents report that the education system is not producing workers with the basic skills they need."

Further, she points out that the manufacturing industry's aging workforce is only going to exacerbate the situation.

Respondents say the same old approaches are not enough to close the skills gap. Specifically, manufacturers should pursue more creative approaches to recruitment and talent management to make sure they have the necessary skilled personnel to win in the future. For example, they indicate that while workforce planning is important on its own, it is not enough to deliver what manufacturers need. They suggest that fresh approaches in areas such as employer branding can generate big results when pursued in tandem with more traditional approaches. "Many manufacturers are using the same approaches to talent development as they were a decade ago," says Tom Morrison, principal, Deloitte Consulting LLP and national service line leader for total rewards. "New performance tools and formal processes like industry certifications should be playing a larger role in any manufacturer's talent management plan.

"The results of this survey may appear dire," adds Morrison, "but in reality each of these challenges is surmountable. The United States has among the largest, strongest manufacturing industries in the world and has demonstrated its ability to innovate and adapt time and time again."

A copy of the full report is available at: *http://www.themanufacturinginstitute.org/~/media/A07730B2A798437D98501E798C2E13AA/2011_Skills_Gap_Report.pdf.*

Getrag

COMPLETES SALE OF AXLE BUSINESS

Getrag recently announced that it has completed the previously-publicized sale of its axle business to GKN plc, the U.K.-based global engineering company. At the same time, the co-shareholders Dana Holding Corporation and Volvo Car Corporation have closed the sale of their respective shares in the corresponding companies. This deal transfers the legal entities Getrag All Wheel Drive AB, Sweden and Getrag Corporation, USA to the new owner. With the completion of this transaction, Getrag will fully concentrate on its core transmission business.

GKI

CELEBRATES 40TH ANNIVERSARY

GKI Incorporated, a Crystal Lake, Illinois manufacturing company, is celebrating its 40th anniversary. The company specializes in metal cutting products and services used in various industries throughout North America. It currently serves Fortune 500 manufacturing companies including Caterpillar, Boeing, Ford, Chrysler, Nissan, General Electric and others. GKI was recognized as one of the fastest growing companies in America by Inc. Magazine in 2007 and 2008. The company currently employs 50 people in its facility in Crystal Lake, and has sales offices in Philadelphia, Pennsylvania, and Nashville, Tennessee. The company was founded by Gerhard Klutke, who immigrated to the United States from Germany in 1964 and started GKI in the garage of his home in 1971. Today, GKI is run by his sons, Olaf Klutke, president, and Eric Klutke, vice president. For more information, visit *www.gkitool.com*.

September Manufacturing Technology

ORDERS INCREASE

September U.S. manufacturing technology orders totaled $606.56 million according to the American Machine Tool Distributors' Association (AMTDA) and the Association for Manufacturing Technology (AMT). This total, as reported by companies participating in the United States Manufacturing Technology Orders (USMTO) program, was up 22.9 percent from August and up 51.9 percent when compared with the

total of $399.32 million reported for September 2010. With a year-to-date total of $4,074.00 million, 2011 is up 91.9 percent compared with 2010. These numbers and all data in this report are based on the totals of actual data reported by companies participating in the USMTO program. "September numbers were the second highest monthly dollar total in the last 15 years!" said Peter Borden, AMTDA president. "American manufacturers are still rushing to beat the end-of-year bonus depreciation deadline." The USMTO report, jointly compiled by the two trade associations representing the production and distribution of manufacturing technology, provides regional and national U.S. orders data of domestic and imported machine tools and related equipment. Analysis of manufacturing technology orders provides a reliable leading economic indicator as manufacturing industries invest in capital metalworking equipment to increase capacity and improve productivity. For the full report, visit *www.amtonline.org*.

Metalforming Companies

PREDICT SLIGHT DIP IN BUSINESS CONDITIONS

continued

NEWS

According to the October 2011 Precision Metalforming Association (PMA) Business Conditions Report, metalforming companies predict a slight dip in business conditions during the next three months. Conducted monthly, the report is an economic indicator for manufacturing, sampling 127 metalforming companies in the United States and Canada.

The October report shows that 20 percent of participants expect economic activity to improve during the next three months (down from 24 percent in September), 56 percent predict that activity will remain unchanged (compared to 54 percent last month) and 24 percent report that activity will decline (up from 22 percent in September).

Metalforming companies also expect a decline in incoming orders during the next three months, with 29 percent predicting a decrease in orders, 45 percent anticipating no change and only 26 percent predicting an increase in orders. However, average daily shipping levels continued to trend upward in October. Thirty-eight percent of participants report that shipping levels are above levels of three months ago (up from 33 percent in September), 44 percent report that shipping levels are the same as three months ago, and 18 percent report a decrease in shipping levels. The percentage of metalforming companies with a portion of their workforce on short time or layoff dropped to eight percent in October, down from 12 percent in September. This number is at its lowest level since October 2007, when companies also reported eight percent of their workforce on short time or layoff.

"PMA's manufacturing member companies are less optimistic this month about business conditions for Q-4 than they were in September," observed William E. Gaskin, PMA president. "Economic uncertainty caused by the lack of leadership in Washington, D.C., ongoing concern about the strength of the European banking system and the failure of the private sector to create sufficient jobs to reduce unemployment levels below nine percent are largely responsible for the cautious outlook. For the first eight months of 2011, average industry shipments increased by 10 percent compared to the same period in 2010, demonstrating underlying strength in the metalforming sector."

For more information, visit *www.pma.org*.

ONLINE

Visit
www.geartechnology.com
for the latest Industry News

Januray 19–24—Tooltech. Bangalore International Exhibition Center, Bangalore, India. This exhibition on cutting tools, tooling systems and machine tool accessories focuses on technology, design, quality and production. Exhibitor profile includes: abrasive tools and products, accessories, dies and moulds, electrical and electronic equipment for machine tools, feeding system, finishing and cutting tools, forming tools, hand held tools, hydraulic pneumatic system and components, instrumentation and process control equipment, lubrication/cooling and refrigeration system, material testing, quality assurance testing equipment, production control and networks, measurement and quality control, CAD/CAM, robots, manipulators and automation, safety equipment, services, slitter coilers, decoilers and straighteners, forming simulation software, tooling systems and devices, waste disposal and environment, work and tool holders, work piece and tools handling etc. For more information, contact Knox Johnstone at (703) 827-5224.

March 7–8—Lean Transformation Summit. Jacksonville, Florida. The Lean Enterprise Institute (LEI) summit raises consciousness, generates enthusiasm and explores new frontiers in lean thinking. Attendees will learn from leading lean practitioners and colleagues who have faced the same challenges. They'll also enjoy the industry's best networking to build (or continue to build) their own network of lean thinkers. Summits are two-day events designed for mid- to upper-level managers, with a focus on sustaining the lean journey, and insights into innovative ways to enhance your lean journey. LEI present a series of summits and conferences globally throughout the year to teach actual applications, not just concepts, in plain language with the case studies, worksheets, formulas, and methodologies needed for implementing lean into your business. For more information, visit *www.lean.org*.

March 8–11—The MFG Meeting (Manufacturing For Growth). Hyatt Regency Grand Cypress, Orlando, Florida. The MFG Meeting brings together a broad spectrum of manufacturing business owners and top industry executives for a four-day forum on how manufacturers can work together to restore manufacturing to its rightful place as an engine that drives the U.S. economy. Jointly produced by four major industry trade groups, the Association for Manufacturing Technology (AMT), American Machine Tool Distributors Association (AMTDA), National Tooling and Manufacturing Association (NTMA) and the Precision Metalforming Association (PMA), this event tackles the issues that affect the entire realm of manufacturing and provides a forum for a conversation that can't be found at any event presented from a single sector's perspective. Visit *www.themfgmeeting.com* for registration details and to watch highlights from the 2011 event.

March 13–15—Composites Manufacturing 2012. The Composites Manufacturing conference and exhibition provides knowledge on composite applications, processes and best practices. This three-day program features a combination of education, networking, exhibits, exclusive tours, industry keynotes and in-depth manufacturing insight. Manufacturing engineers and management from the aerospace, medical, wind energy, transportation, recreational, consumer products and green manufacturing will come together to discover new ways to stay relevant and competitive. This dynamic event continues to evolve, grow and improve to provide an array of different learning and networking opportunities. Developed by a team of SME professionals who work hand-in-hand with an industry advisory board, this team has its finger on the pulse of composites manufacturing and understands what attendees need to succeed. For more information, visit *www.sme.org*.

March 27–29—Westec 2012. Los Angeles Convention Center, Los Angeles. Westec returns in 2012 redefined with a renewed commitment to local manufacturing. The manufacturing event includes keynote presentations from industry leaders in aerospace/defense, renewable energy and the manufacturing economy. The show also consists of technical sessions on topics that include small parts machining, high-speed alloy machining, milling, drilling, cutting advanced carbon fiber, carbon laminates and advances in additive manufacturing. Attendees view emerging technologies and emerging equipment applications and many other topics with an emphasis on using technology to innovate. Westec offers a place to network, form relationships and build partnerships, putting an emphasis new developments, integration, lean methods, and how to manufacture with composites, titanium, or other advanced materials. For more information, visit *www.westeconline.com.*

IPTEX 2012

OFFERS A UNIQUE PLATFORM FOR POWER TRANSMISSION TECHNOLOGY

India is rapidly turning into a global manufacturing hub, thanks to the country's manufacturing and engineering capabilities, vast pool of skilled expertise and its size. These qualities offer it a strategic advantage for the manufacturing segment. A large number of international companies in varied segments have already set up a manufacturing base in India and others are following suit. It only makes sense to bring this industry segment together under one roof to discuss the current trends and technology prevalent to the marketplace. IPTEX 2012 is scheduled from February 9–11, 2012 at the Bombay Exhibition Center in Mumbai, India.

IPTEX 2012 has attracted companies such as Bonfiglioli, Gleason, KTR Coupling, Bevel Gears (India) and Gears & Gear Drives. "IPTEX 2012 will give us good reference in India which is one of the top ten countries in the industrial production. Bombay is the economical capital of India and we are expecting to meet many important international visitors and potential customers," says Andrea Genuini, country manager, India, industrial solutions business unit at Bonfiglioli.

The American Gear Manufacturers Association (AGMA) and some of its members have extended their active support for IPTEX 2012, following participation in the 2010 show. "With some help from the gear manufacturers in India, Virgo Communications was able to organize a show that attracted a diverse group of gear/power transmission manufacturers as well as equipment suppliers as exhibitors," says Joe Franklin, AGMA president. "They were equally successful in generating a good audience for the show and even though the economy was just recovering in 2010, IPTEX was rated a success by all involved. I know from the published list of exhibitors and from a number I have spoken to who are planning to sign-up that next February's event will eclipse 2010."

The exhibition itself is expected to be much larger than the previous one in terms of participation, space utilization and visitor traffic. At IPTEX 2010, held from May 20–22 2010 at the Bombay Exhibition Center, participants from seven countries displayed products such as gears and gearboxes, gear machines and tools, linear transmission and drive systems, metrology products, software, bearings, transmission belts and other mechanical transmission products.

"The exhibition of 2010 has been considered a success in terms of qualified and specialized visitors who attended it. It was a great opportunity to reinforce our brand in the power transmission manufacturer's world and we were there with one of the more appreciated booths and qualified teams," Genuini says.

IPTEX 2010 had a turnout of more than 3,000 quality visitors from countries such as Brazil, Bangladesh, China, Ethiopia, Germany, Italy, Japan, Malaysia, The Netherlands, New Zealand, South Korea, Switzerland, Taiwan, United Arab Emirates, United Kingdom, United States and India.

"It is well known that India is one of the fast growing countries in the world and this exhibition is considered one of the more specialized for our industrial sector," Genuini says. "To attend this fair will give the opportunity to meet important people working in the power transmission field, to meet global customers of several industrial sectors, to know the new products developed by our competitors and to understand their market approach."

Adds Franklin, "On behalf of AGMA, I am looking forward to taking our delegation of members to the show and then to see many of our members in India. Outside of North America, AGMA has more members in India than any other country. The delegation will consist of about 25 individuals traveling for about 10 days immediately after the IPTEX show."

For more information, visit *www.virgo-comm.com*.

ADVERTISERS INDEX

Use this index to contact advertisers

ADVERTISER	PAGE	PHONE	E-MAIL	INTERNET
AGMA	74	(703) 684-0211	franklin@agma.org	www.agma.org
Ajax Rolled Ring	6	(800) 727-6333		www.ajaxring.com
American Wera	81	(734) 973-7800		www.american-wera.com
Arrow Gear Co.	14	(630) 969-7640		www.arrowgear.com
B&R Machine & Gear Corp.	IBC	(731) 456-2636, (800) 238-0651	inquiry@brgear.com	www.brgear.com
Bevel Gears India Pvt. Ltd.	75	+ (91) 80-2841-0312	jamalgrp@vsnl.com	www.bevelgearsindia.com
Bourn & Koch Machine Tool Co.	77	(847) 649-1450	sales@star-su.com	www.star-su.com
The Broach Masters/Universal Gear Co.	17	(530) 885-1939	info@broachmasters.com	www.broachmasters.com
Cincinnati Gearing Systems	67	(513) 527-8600	gearsales@cst-c.com	www.cincinnatigearingsystems.com
Circle Gear & Machine Co.	86	(708) 652-1000		www.circlegear.com
Clifford-Jacobs Forging Co.	23	(217) 352-5172	sales@clifford-jacobs.com	www.clifford-jacobs.com
Comtorgage Corp.	20	(401) 765-0900	kgradolf@comtorgage.com	www.comtorgage.com
Delta Gear	13	(734) 261-6400	sales@delrecorp.com	www.delrecorp.com
Drake Manufacturing	16	(330) 847-7291	info@drakemfg.com	www.drakemfg.com
DTR Corp.	25	+ (82) 32-814-1540, (847) 375-8892	alex@dragon.co.kr	www.dragon.co.kr
Excel Gear	86	(815) 623-3414	chinn@excelgear.com	www.excelgear.com
Fässler	18	(414) 769-0072		www.faessler-usa.com
Forest City Gear	3, 60	(815) 623-2168	fyoung@forestcitygear.com	www.forestcitygear.com
Gear Consulting Group	87	(269) 623-4993	gearconsulting@aol.com	www.gearconsultinggroup.com
Gear Motions Inc.	86	(315) 488-0100	ron.wright@gearmotions.com	www.gearmotions.com
The Gear Works—Seattle, Inc.	86	(206) 762-3333	sales@thegearworks.com	www.thegearworks.com
Gleason Corp.	44-45, 87	(585) 473-1000	dmelton@gleason.com	www.gleason.com
Gear Machinery Exchange	86	(847) 437-6605	michael@goldsteingearmachinery.com	www.goldsteingearachinery.com
Goldstein Gear Machinery	87	(847) 437-6605	michael@goldsteingearmachinery.com	www.goldsteingearmachinery.com
Hainbuch America Corp.	11	(414) 358-9550	sales@hainbuchamerica.com	www.hainbuch.com
Hans-Jürgen Geiger Maschinen-Vertrieb	71	+ (49) 7123-18040	geiger@geiger-germany.com	www.geiger-germany.com
Höfler	OBC	(734) 416-9300	info@hofler.com	www.hofler.com
Index Technologies	87	(440) 331-0038		www.gallenco.com
Ipsen International	43	(800) 727-7625		www.ipsenusa.com
IPTEX 2012	83	+ (91) 80-2556-7028	info@virgo-comm.com	www.virgo-comm.com
Joy Mining Machinery	57		dmalacho@joy.com	www.joy.com
Kapp Technologies	7	(303) 447-1130	info@kapp-usa.com	www.kapp-usa.com
KISSsoft	4	(815) 363-8823	info@kisssoft.com	www.kisssoft.com
Klingelnberg	5		info.lgt@liebherr.com	www.sigma-pool.com
Luren Precision Co.	72	(847) 598-3555	Gerald_kuo@luren.com.tw	www.luren.com.tw
Magnum Induction	75	(586) 716-4700	sales@magnuminduction.com	www.magnuminduction.com
McInnes Rolled Rings	57	(800) 569-1420	sales@mcrings.com	www.mcinnesrolledrings.com
Metal Finishing News	80	(212) 633-3100	metalfinishing@elsevier.com	www.metalfinishing.com
Midwest Gear & Tool Inc.	78	(586) 779-1300	midwestgear@sbcglobal.net	
Mitsubishi	8	(248) 669-0614		www.mitsubishigearcenter.com
Niagara Gear	4	(800) 447-2392	info@niagaragear.com	www.niagaragear.com
Normac Inc.	22	(828) 209-9000	info@normac.com	www.normac.com
Overton Chicago Gear	26, 86	(630) 543-9570	sales@oc-gear.com	www.oc-gear.com
Precision Gage Co. Inc.	74	(630) 655-3073	sales@precisiongageco.com	www.precisiongageco.com
Presrite Corp.	21	(216) 441-5990		www.presrite.com
Quality Transmission Components	77	(516) 437-6700	QTCSupport@qtcgears.com	www.qtcgears.com
Riverside Spline & Gear	19	(810) 765-8302	deniset@splineandgear.com	www.splineandgear.com
S&W Gear Machines GmbH	24	+ (49) 371-309-9345	zeidler@sw-gearmachines.de	www.sw-gearmachines.de
Sandvik Coromant	35	(800) 726-3845		www.coromant.sandvik.com/us
Schafer Gear Works Inc.	27	(574) 234-4116		www.schafergear.com
Schnyder S.A.	76	(630) 595-7333	hanikcorp@aol.com	www.hanikcorp.com
The Shot Peener	79	(800) 832-5653, (574) 256-5001		www.shotpeener.com
Sicmat	65	(847) 649-1450	sales@star-su.com	www.star-su.com
Sigma Pool	5	(734) 429-7225	info.lgt@liebherr.com	www.sigma-pool.com
Star SU LLC	IFC–1, 65, 77, 87	(847) 649-1450	sales@star-su.com	www.star-su.com
Stock Drive Products/Sterling Instrument	76	(516) 328-3300	SDP-SIsupport@sdp-si.com	www.sdp-si.com/e-store
Tokyo Technical Instruments USA	56	(201) 634-1700		www.tti-geartec.jp
Wenzel America Ltd.	53	(248) 295-4300		www.wenzelamerica.com

Next

Gear Technology

January/February 2012

Focus

Big Gears and

Topic

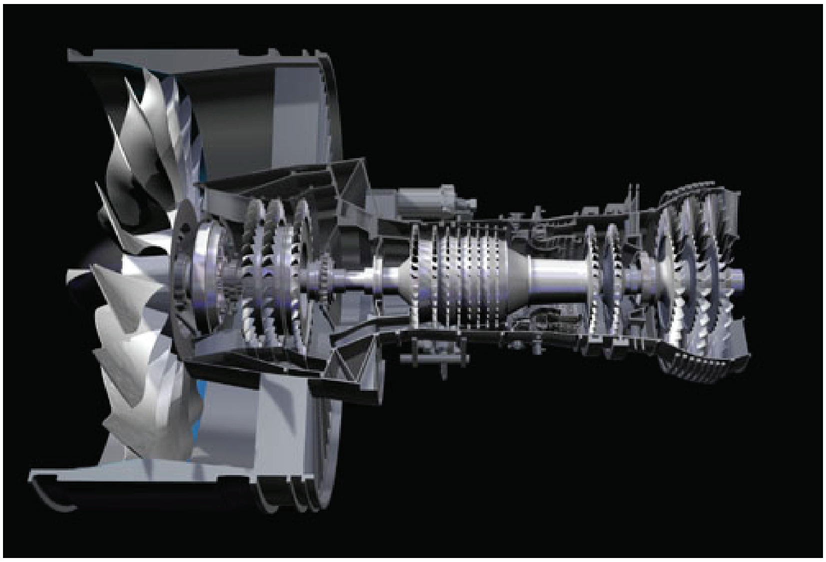
Global Gear Industry

SERVICE

It's No American Dream: Pratt & Whitney GTF Engine Now a Reality...

and chosen in Time's November issue one of "The 50 Best Inventions of the Year"

In the August 2008 issue of *Gear Technology*, we ran a story ("Gearbox Speed Reducer Helps Fan Technology for 'Greener" Jet Fuel Efficiency') on the then ongoing, extremely challenging and protracted development of Pratt & Whitney's geared turbofan (GTF) jet engine. If successful, the engine would provide a 20 percent reduction in carbon emissions and fuel burn and up to 50 percent in general noise reduction. The targeted market and application for the engine was the narrow-body commercial airline industry—until now a dormant market for P&W—which had long demanded a total plane package that would achieve reduced maintenance, lower emissions, better fuel burn, greater reliability and operating costs—all for a better price.



The long-awaited Pratt & Whitney GTF (PurePower PW1000G) jet engine is now a reality, with customer orders now in production (courtesy Pratt & Whitney).

And doesn't that sound familiar?

Today—despite this daunting challenge—Pratt & Whitney is working to fill orders from France's Airbus for 600 GTFs for three of its customers, including Lufthansa. Also known as the PurePower PW1000G, Pratt's successful development of the engine also led to an agreement announced in October that Pratt & Whitney and Rolls-Royce will jettison their former mutual joint venture company—International Aero Engines (IAE)—and begin anew with the mission of the design and development of engines for new mid-size aircraft in the 120–230 seat size.

And with its recent success, Pratt says that while the focus is on the narrow-body commercial market, the United Technologies-owned company is believed to be negotiating with Airbus and Boeing over exploring the potential to upsize the GTF to an A380-size.

Pratt & Whitney's PurePower Geared Turbofan engine has been selected as exclusive power for the Bombardier CSeries aircraft and Mitsubishi Regional Jet. It will also power the Airbus A320neo aircraft, as well as the Irkut MC-21 narrow-body aircraft. Pratt & Whitney has received orders, including options, for more than 2,000 PurePower Geared Turbofan engines from 26 airline and lessor customers. The PurePower engine is not an option on the Boeing 787 Dreamliner program, as previously reported in this publication.

Pratt had to be all-in regarding its confidence in the success and future of its GTF technology—a gamble not to be taken lightly, as failure may have done irreparable harm to the company. Rivals like GE and others were sharking about with designs and prototypes of their own for an engine with the desired industry-tasked capabilities.

For those who can't recall how the GTF works, here's a piece lifted from the 2008 *Gear Technology* article explaining—with help from Robert Saia, Pratt & Whitney vice president, next-generation products—what makes it leading edge:

(*What's unique) is the addition of a reduction gear box—or transmission system—comprised of a star gear system with five stationary gears. As Saia explains, the gear box decouples the fan from the turbine so that each component can turn at its optimum speed while also allowing for a lighter, more efficient turbine to turn at a higher speed in driving a much larger, slower-turning fan. The marrying of a faster-turning turbine with a slower-turning fan results in newfound fuel efficiency at a much-reduced noise level. In fact, the addition of the gearbox provides a low-pressure turbine speed of three times that of the fan.*

Saia says, "Consider that with a typical, direct-drive turbofan engine the limitation is that its turbine is most efficient, i.e.—creating the most power for the least fuel consumption—when it is rotating at optimum speed. And, as mentioned, this type of engine's turbine and fan are unalterably linked, presenting an unavoidable compromise in speed.

"The GTF engine breaks this paradigm. This game-changing engine architecture introduces a reduction gear system allowing both the fan and turbine to operate at their optimum speed. By turning a large fan—increasing the bypass ratio of the engine—fuel efficiency is improved by more than 12 percent. This is directly related to a 12 percent improvement in CO_2 emissions. The slower-moving fan produces much less noise—50 percent less than today's engines. We've also introduced an advanced combustor to reduce (nitrogen oxide) emissions by 55 percent."

So there you have it—of late an all-too-rare American design and manufacturing success story—imagined, executed and manufactured right here in the U.S. of A.

(Sources for this article include "Engine Technology" by Karen Walker, ATW *magazine, Nov. 1, 2011; "How to Build a Job Machine" by Bill Saporito,* TIME, *May 9, 2011; and "Revolutionary New Boeing Dreamliner Takes Off Wednesday" by Charisse Jones,* USA TODAY, *Oct. 21, 2011.)*

Shipped today: *HF 900* Gear Hobber
For SANDVIK COROMANT USA

HÖFLER

From today we turn over a new leaf in the cooperation between **HÖFLER** and **SANDVIK COROMANT**.

In order to have the opportunity to better assist and train our North American customers in the use of machine and tools, a **HÖFLER** gear hobbing machine type ***HF 900*** has been delivered to the **SANDVIK COROMANT** Productivity Center in Schaumburg, Illinois. There the state-of-the-art machine was equipped with high-performance tools and is now available for training of mutual customers. From now on training participants can familiarize under expert advice with tools and processes and assure themselves of the advantages and efficiency of the partnership between **HÖFLER** and **SANDVIK COROMANT**.

HÖFLER once again – for the Performance, Accuracy, Productivity and Flexibility that your company expects and deserves!

HÖFLER gear grinders – from 10 to 8000 mm [0.4" to 315"]
HÖFLER gashers/hobbers – from 10 to 8000 mm [0.4" to 315"]

HÖFLER Maschinenbau GmbH
Industriestraße 19
D-76275 Ettlingen, Germany
www.hofler.com
p. +49 / 7243 599 - 0
f. +49 / 7243 599 - 165
e. info@hofler.com

HÖFLER America Corp.
26 Sky Manor Road
Pittstown, NJ 08867, USA
p. +1 / 908 442 4361
f. +1 / 908 996 6977
e. usa.sales@hofler.com

HÖFLER USA Agent: Great Lakes Gear Technologies
9421 Haggerty Road
Plymouth, MI 48170, USA
www.greatlakesgeartech.com
p. +1 / 734 416 9300
f. +1 / 734 416 7088

Subject to change. www.et300.de