January/February 2007

GEAR TECHNOLOGY

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The Journal of Gear Manufacturing

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- Labor Pains in the Gear Industry
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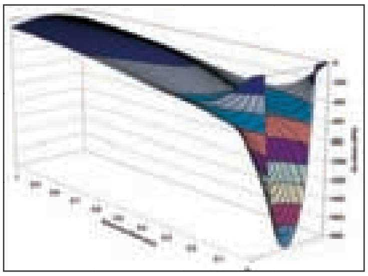
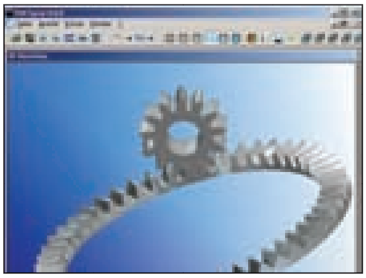
The empty seats in this gear manufacturer's training room bear mute testimony to the fact that the potential for a next-generation pool of skilled workers is very much in doubt. For more on how things came to this sorry state—and what's being done about it at companies in the gear industry—see stories on pages 28, 32 and 34.

TECHNICAL ARTICLES





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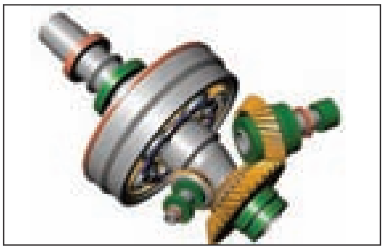

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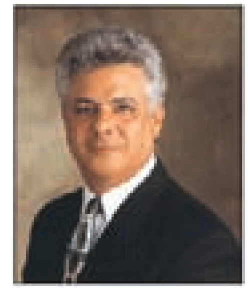


What Do You Think?

Last issue, we promised you a redesigned *Gear Technology*—bigger, better and delivered more often than before. Well, here it is, the first of the eight completely redesigned issues we'll be sending you in 2007.

Aside from the cosmetic changes—the new logo, typefaces, redesigned table of contents, and so forth—we had specific goals in mind. One of them was to expand on the educational focus that has made us *the* industry's publication since 1984.

We've always published the highest quality technical articles, and we'll continue to do so. But we also want to provide you with insight into the business, management and non-technical aspects of gear manufacturing. That's why we've expanded our feature coverage and added a new department: *Voices*.

Voices helps us tap into the gear industry's knowledge base, experience and insight. In *Voices*, you can read the opinions of your peers and even contribute opinions yourself. Your letters to the editor will appear in *Voices*, as will guest editorials and a new column called *Q&A*.

So when I say, "What do you think?" I'm not just asking for your opinions about our redesign. In fact, I'm more interested in your participation. For example, after you read this issue's articles about finding skilled labor, tell us if you have a different opinion or if your company has implemented different solutions. *Voices* is your forum to share your thoughts and insights with the gear industry community. It's your chance to interact with and learn from your peers.

Another goal of the redesign was to provide more integration between our printed magazine and websites. For example, the *Voices* department will have an online component at *www.geartechnology.com* where every month, we'll post questions for our *Q&A* column and an online poll or survey. You can go online anytime to see the results and read the opinions of others in the gear industry. Of course, every issue, we'll print some of the most interesting results in *Voices* as well.

The integration between print and online doesn't stop with the *Voices* department, either. Throughout the magazine, we'll give you additional information and resources online whenever appropriate.

Also, those of you who have given us permission to send you e-mails will soon begin receiving the *geartechnology.com* newsletter, which will provide you with updates about the latest content and features online.

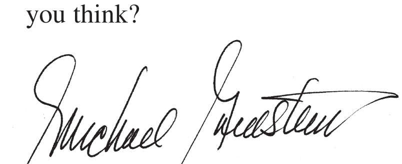
Underneath all these new features, we are still dedicated to bringing you the very best gear-related technical articles available from experts around the world. We're not changing anything there. After all, the technical articles are the reason many of you read—and save—this magazine.

We hope you'll notice that this issue, at 80 pages, is a little bit heftier than has become typical for us. Part of this results from bringing you more high-quality articles, but part of it is also because increasing numbers of our advertisers are recognizing the importance of *Gear Technology*'s role in your success. They understand that you want practical, useful information, not advertorials.

We're going to bring you *Gear Technology*—bigger, better and more often—throughout 2007. But in order to maintain this effort, we want and need your help. Our advertisers count on us to deliver the magazine to people who are interested in gears. That's why we need you to continually update your information and renew your subscriptions by filling out the form attached to the cover or bound in each issue. So if you haven't done it in awhile, or if you're not sure, go online and renew today (*www.geartechnology.com/subscribe.htm*). Be sure to check "yes" to give us permission to send you e-mails.

When I asked "What do you think?" I had one other thing in mind. Perhaps most importantly, I want to know how we can help make you more successful with our information and products. Tell us what you want and need to meet your challenges more effectively. Tell us how we can better help you.

We are excited and enthusiastic about the changes we've made, and we hope you are, too. No matter what, though, what we'd like most of all is your participation in making *Gear Technology* as useful and practical to the industry as it can possibly be. We need your feedback, we need your input, we need your experience and expertise. So tell me, what do you think?



Michael Goldstein,
Publisher & Editor-in-Chief

P.S. We'd like to extend a special welcome to all of our Chinese friends who are reading this issue of the magazine, which was mailed to more than 1,000 individuals in China who work at gear manufacturing locations. We hope you enjoy *Gear Technology*. We'll be mailing a similar bonus distribution to India in May.

3 DIFFERENT MACHINES DIFFERENT DESIGNS

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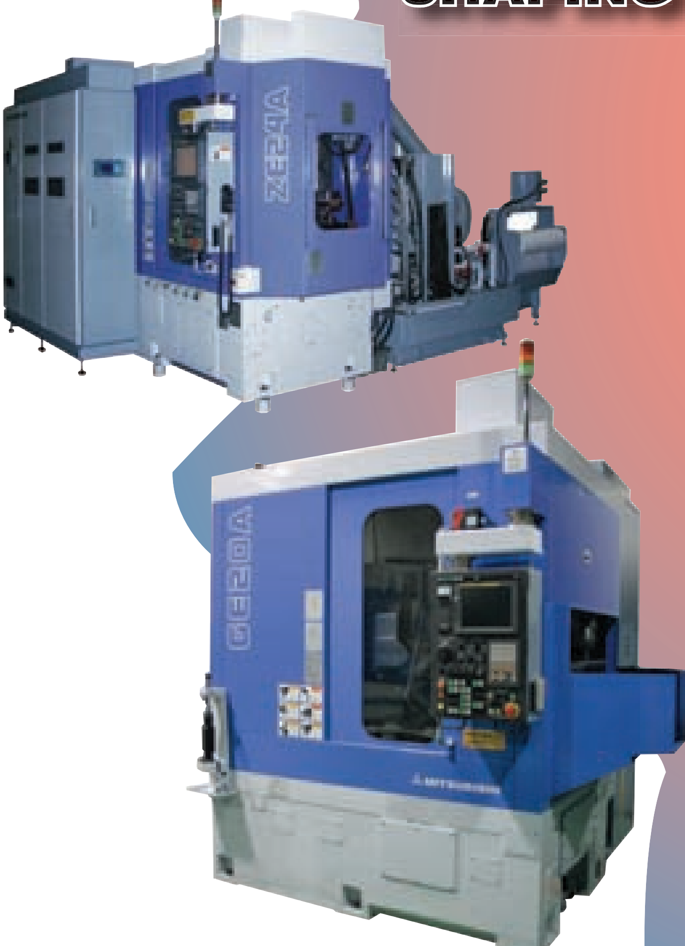

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Help Wanted: Gear Company Seeks Perfect Machinist

Joseph Arvin, President, Arrow Gear Company

Sales are up and it's time to hire some additional gear manufacturing personnel. Let's see—what qualities are we looking for in the ideal candidates?

First of all, the ideal candidates should be very knowledgeable in every aspect of gear geometry and have a well-rounded understanding of all the involved metalworking disciplines. They should be able to read operation drawings and blueprints. And, in addition to good communication skills, they will need to have a solid command of shop math.

That's not all! They must be able to utilize a full range of gaging equipment and be experienced in setting up a wide variety of the machine tools on our shop floor. Of course, they'll need to have machine tool programming experience. And once they get the job running, they must be able to monitor their quality through the use of SPC methods. Finally, let's not forget their demonstrated ability to consistently maintain our targeted production rates. Yes, that's the person we're looking for!

Unfortunately, I wouldn't really expect a person who meets these qualifications to come to our personnel office looking for a job.

Finding skilled people is a genuine challenge facing the gear manufacturing industry. Based on the degree of advanced technology, rigid quality standards and global competition, we in the industry have a desperate need for finding new personnel that possess advanced skills and qualifications. But as we've learned at my company, these people are simply not available.

Why is this? Working in today's gear manufacturing environment certainly pays well and involves some very impressive technology. Perhaps the reason can best be illustrated by a high school career night that my company attended a couple of years ago.

Out of hundreds of students at the event, only two showed up to our presentation on career opportunities in manufacturing. Notably, just down the hall, there was standing room only in the presentation on computer-related careers.

I would bet that if tomorrow we ran a job ad for a highly experienced IT person, capable of advanced database programming, administrating all aspects of our network, e-mail system and website, we'd be flooded with resumes.

So, it would appear that in preparation for a career, young people are definitely not looking at the manufacturing industry as a desirable option.

Several years ago, while on a technical tour of Singapore, I visited a manufacturing training institute that was quite impressive. The government-funded facility was training young people in all aspects of machining, including programming. Upon completion of the program, these young people entered the job market with all the skills of the perfect machinist that I described earlier. I remember at the time thinking, "How on earth are we going to compete with that?"

As someone who is looking for qualified recruits, it would be a dream come true if this type of comprehensive program existed in the United States. I would certainly be on hand at the program's graduation ceremony recruiting graduates to come and work for my company.

Now, this is not to say that there are not high-quality vocational programs here in the United States. In fact, the American Gear Manufacturers Association (AGMA) sponsors a number of gear manufacturing training initiatives that are providing positive results. One of these efforts is located here in Chicago at Daley College—a program that we have used in the past. Also, the AGMA-affiliated Gear Consulting Group runs an on-site gear school operated by Geoff Ashcroft and Ron Greene. In addition to these programs, a number of machine tool companies, educational institutes and other organizations in our industry offer seminars and classes to provide a valuable training supplement to our collective workforce. However, the comprehensive gear-related training that would develop a Top "A" machinist is simply not available.

Logically, one would ask, "Why isn't there a program in the U.S. like the one in Singapore?" The answer is MONEY! AGMA simply does not have the resources to provide comprehensive training on the scale that our industry requires. In Singapore, the training was funded by the government, while here the AGMA's efforts are supported by volunteers and the financial contributions of its membership. In view of the fierce competition in today's global gear market, and narrow profit margins, obtaining sufficient funding from AGMA's membership is simply not feasible.

If I were to suggest to the AGMA a course of action for meeting the comprehensive training needs of the gear industry, it would be to make every attempt to lobby the

continued

government for the type of training program I witnessed in Singapore. Government spending on the skills of this necessary workforce would be a very wise investment in our country and have far-reaching returns. In addition to the economic benefit of skilled workers, strengthening of a domestic defense-critical industry, like gearing, reduces U.S. dependence on foreign suppliers. Not to mention that this would help slow the continued deterioration of our manufacturing industrial base, while strengthening our defense preparedness.

So where does this leave us? The answer lies within our individual companies. Based on current conditions, if we are going to have highly skilled manufacturing people, we must provide that training and develop these people on the job.

At Arrow Gear, where I have worked for over 30 years, we have always realized the necessity for highly trained personnel. One of our strategies to meet this need was the production of an extensive video-based training program. In the early ’80s, just as industrial video production equipment was becoming available, our CEO, James J. Cervinka, saw the value of using video as a tool for internal training. Our video training library has now been in use for more than 20 years and includes programs covering a wide range of subjects—from safety and gearing concepts to machine setup and operation. And while this program has been instrumental in retaining our collective expertise and providing orientation, there still remains a need for traditional classroom training, coupled strongly with hands-on experiential learning.

A number of years ago, Arrow implemented a training program of this type. First we selected 24 recruits from 70–80 candidates. These trainees went through a fairly comprehensive curriculum of subjects including general machining, gearing concepts, blueprint reading and shop math. The results of this on-site training initiative were disheartening, yet very interesting.

Four students left the program before completing the training—citing that they really didn’t feel that manufacturing was what they wanted to be doing. Another four did not pass—leaving sixteen who graduated. However, within 90 days of graduation, eight of the trainees left the company—some to other companies and some to pursue college educations.

In retrospect, our decision to provide the training was not at fault, but rather the selection criteria for the trainees. We wanted to find the A+ students, so we used conventional I.Q. testing to screen the applicants. However, based on our experience, I.Q. testing and grades alone were not necessarily a good indicator of who could develop into a qualified machinist. Additional variables such as mechanical aptitude and special interests of the individual should have been taken into account. For example, an interest in auto mechanics or woodworking would have been a good indication of the recruit's potential as a machinist.

More recently, we worked with Northern Illinois University, who conducted training for nearly all of our production personnel. It was interesting that pre-evaluation determined that 50% of those employees assessed were in need of various types of skill improvement. As a result, training was conducted on English (as a second language), blueprint reading and shop math.

As far as its impact on productivity, there has been a 15% increase in shop output. Obviously, this improvement is tied to the combination of many other factors, but I'm confident that training had a significant impact on this increase.

We feel that the training was very successful and has led to further plans for this type of formal training program.

"Currently at Arrow, our Human Resources Manager—Mary Ann Cervinka—is developing another training program in which trainees will split their work day between the classroom and the shop floor. In addition, the trainees will be cycled through numerous departments in the shop. It is anticipated that this broad exposure will provide insight into which machining discipline the trainees are best suited for."

In today's gear manufacturing environment, the responsibility to provide training rests squarely on the shoulders of the employer. But this is not to say that financial assistance is not available. For companies looking to provide training to their workers, a number of state programs through local universities are in place. State government has heard our pleas for assistance over the years, and they are fully in agreement that ongoing training is essential to the success of the manufacturing sector and our local economy.

In conclusion, until perfectly experienced cadidates start showing up at your door, gear industry managers will have to ensure that training is available, and it must be a top priority. Training is an essential component to remain competitive in the global market that exists today. And that's not going to be changing anytime in the near future.

ONLINE

How is your company finding and training skilled employees?
Log on to *www.geartechnology.com* to post your answers and see what others think.

smart questions & real insights

Challenges and Opportunities in the Gear Industry

One of the regular features of the **Voices** department will be our Q & A column. Here, we'll ask smart questions and get the opinions of smart people in the gear industry. In the future, we'd like to feature the opinions of as many people as possible in this space. But since this is the first issue for this feature, we asked **Fred Young**, president of **Forest City Gear Co.**, to help us by answering some of the gear industry's burning questions.

Q: ***What should gear manufacturers do about the skilled labor shortage?***

A: Finding really talented help continues to be a problem. We (Forest City Gear Co.) have teamed with a local junior college, Rock Valley College, to work with some of their programs and students. We still find that training and mentoring our own is the best method. Sending our trainees to every gear school we can has helped with the fundamentals, plus we have been using the AGMA Certification training as much as possible. The employees appreciate the certificate they receive upon completion of the course work and test. FCG has been using more aptitude screening and psychological profiling and has utilized local temporary agencies to test drive our worker candidates. FCG continues to send promising setup folks to Europe, where our gear equipment is birthed, to gain expertise from the manufacturers with good success.

Q: ***Is OEM outsourcing good or bad for the gear industry?***

A: Outsourcing by OEMs who are currently manufacturing their gears in-house will probably continue to expand, since many people are unwilling to expend funds to update often woefully outdated equipment. Plus, as their seasoned veterans retire, it is harder to find and train new talent. We have heard from a number of people who tried to go to China or other spots that they've not always met with success, receiving inferior quality gears and late deliveries. We feel this will continue to provide opportunities for those willing to buy newer, more productive gear equipment.

As an aside, I recently toured Gear Motions and was delighted to view the super-productive gear cell for grinding, using robotics for moderately high-production jobs. More of that sort of acquisition could go a long way toward retaining business in the U.S.

FCG seems to be picking up lots of new customers who are coming out of the woodwork. Apparently, we get a lot of favorable recommendations from our peers and customers. It seems good service and attention to quality, as always, continues to work. We feel our membership in the AGMA has been a tremendous benefit by keeping us abreast of the most current standards, in tune with the latest developments of our competitors, up to date on training and sharp on internal business practices. Being one of three companies featured in the 2006 IMTS advertising campaign probably did not hurt either.

Q: ***Business is booming. Why should we worry about a changing gear industry?***

A: Those who do not keep a watchful eye on potential future developments awaken one day to find they are sitting on a hollow shell that has not been modernized, and is no longer competitive in what is becoming an increasingly more global market. Rest assured there are lots of companies out there who are fighting to be top dogs. At the same time we must encourage our legislators to help keep favorable tax climates, access to training for our aspiring engineers, and investment tax credit for replacement of older equipment. We can help ourselves by participating with organizations like AGMA to keep updating standards which are familiar to us and not skewed to foreign interests. Many of us pay lip service to these things which are not directly affecting the bottom line, but cumulative neglect catches up with everyone in the end. Inspired management with a long-term outlook on the order of ten years will pay continuing dividends for those who lay out a strategy to be competitive well into the future.

I am optimistic that this generation has the guts and tools to succeed, and am unwilling to relinquish the hope we can continue to be a manufacturing power well into the future.

—Fred Young, President,
Forest City Gear Co.

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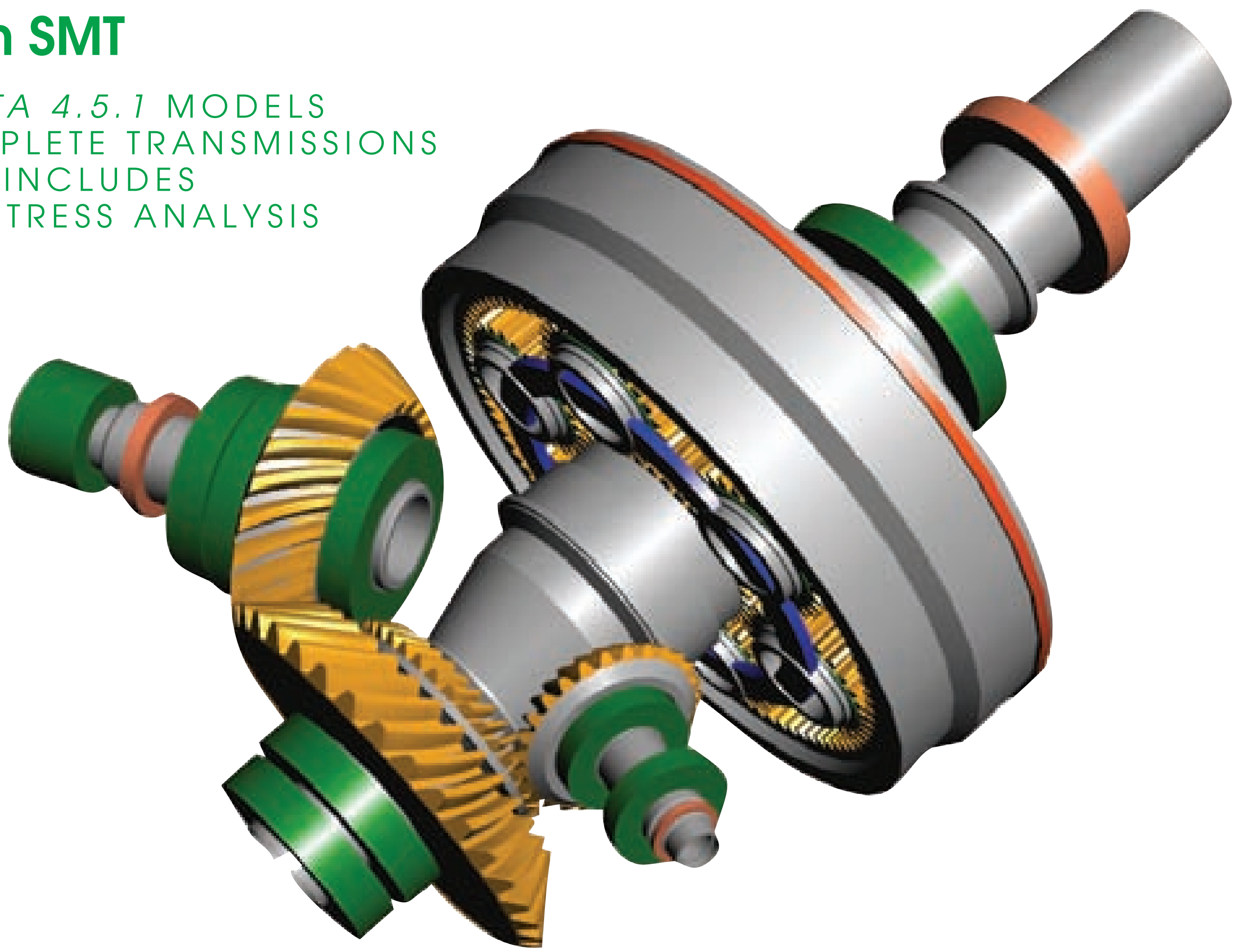
Design Unit Evaluating New Software from SMT

MASTA 4.5.1 MODELS COMPLETE TRANSMISSIONS AND INCLUDES 3-D STRESS ANALYSIS



Smart Manufacturing Technology (SMT) has announced the launch of *MASTA 4.5.1*. The software, which enables users to conduct fully integrated system analysis of mechanical transmissions, is undergoing intensive evaluation by the Design Unit at Newcastle University, U.K.

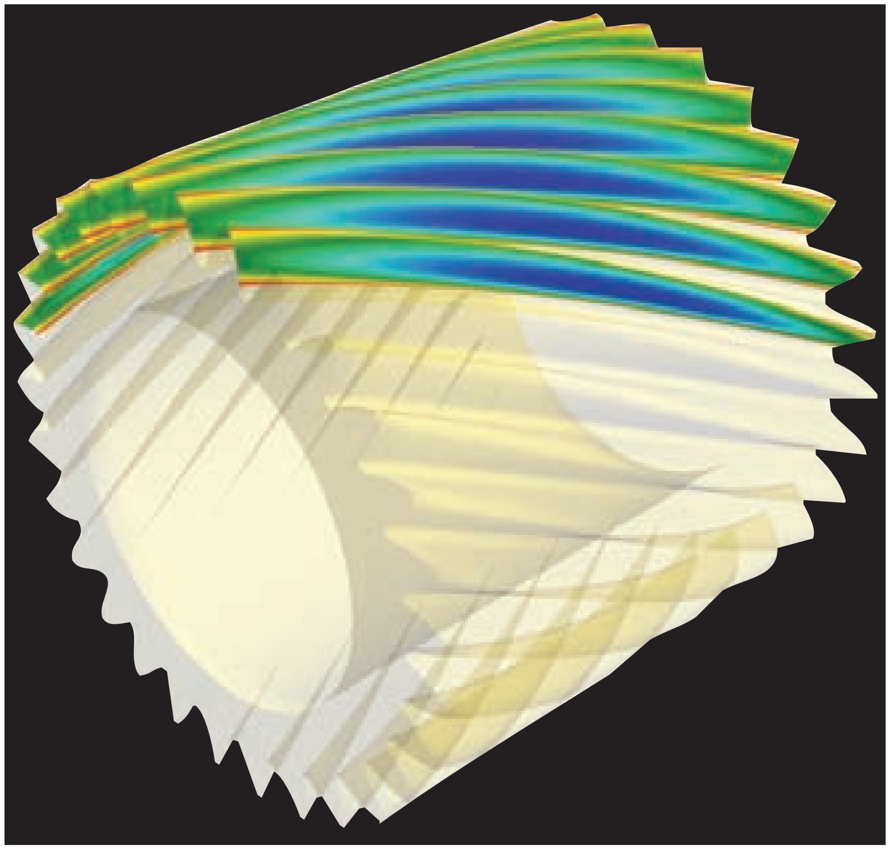
The Design Unit is widely recognized as an authority in gear design and manufacturing technology. The Design Unit has produced the *DU-Gates* program, which includes a 3-D analysis of a gear pair, enabling accurate prediction of root stresses and transmission error.

"The new *MASTA* software provides a 3-D gear stress analysis module whilst taking into account system deformations, and should therefore bring us closer to predicting the operating conditions on gears," says Dr. Brian Shaw, director of Newcastle University Design Unit. "The *MASTA* software appears very powerful, and we are enjoying working with SMT to validate the gear stressing routines."

MASTA can be used to model the full transmission system including bearings, shafts, gears and housings. "This integrated approach has made the software extremely popular," says Dr. Steve Brown, SMT's sales manager.

The release of this latest version of *MASTA* software now means that engineers can design mechanical transmissions while taking account of the gear manufacturing processes to be used. They can now also conduct full 3-D, finite element-based analysis of the gear teeth. According to SMT, these features will significantly reduce the design and manufacturing development times and cost.

The gear manufacturing simulation modules allow manufacturing engineers to predict the requirements for gear manufacturing processes such as



hobbing, shaving, shaping and grinding. "Much of the time during gearbox development is spent solving gear manufacturing issues," says SMT director Dr. Changxiu Zhou. "Our software now allows most of these problems to be solved before metal is cut, saving our customers large amounts of time and money. This technology has been driven by demands from our customers to reduce the process development phase so they can get their products into the marketplace faster and more economically."

The Design Unit's evaluation of the *MASTA* 3-D gear analysis module goes beyond the commonly used gear standards such as ISO 6336 and AGMA 2001 to give a full 3-D stress analysis. "Accurate prediction of root and contact stresses for gears with high helix angles and contacts ratios is becoming evermore necessary," explains Shaw.

Advanced contact modeling of rolling element bearings ensures that the calculated bearing deformations and contact stresses are accurate. This leads to a more reliable prediction of gear mesh misalignment, which is essential in determining in-service gear contact conditions.

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ONLINE

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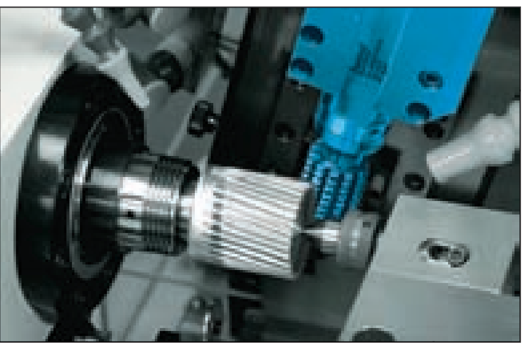
Monnier + Zahner's Versatile MZ 130

PROVIDES SAME-SETUP GEAR HOBBING AND WORM MILLING



The MZ130 hobbing and worm milling CNC machine from Monnier + Zahner was designed with versatility and ease of use in mind. First rolled out at EMO 2005, and in 2006 at IMTS, the seven-axis machine's multiple capabilities include gear hobbing and worm milling for external spur, helical, face and straight bevel gears, as well as for worms, worm wheels, splines and threads. The MZ130 also features automatic, two-hob gear tooth deburring. The machine offers CNC-controlled conversion from gear hobbing to worm milling.

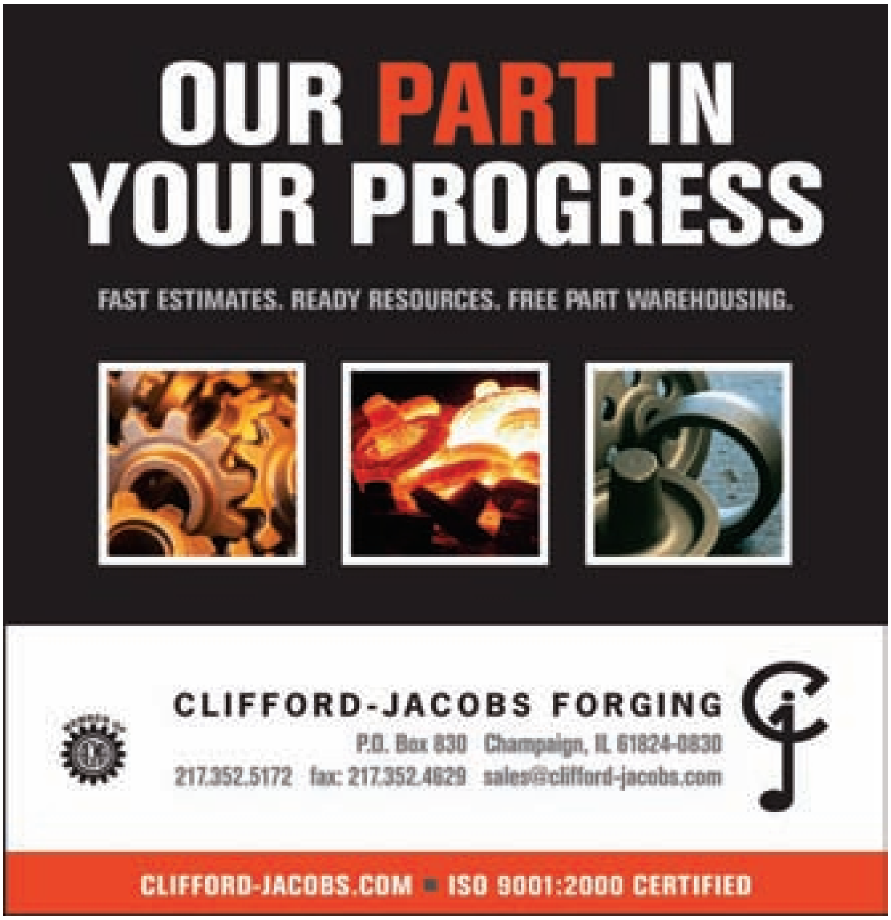
"The software has conversational programming that allows for fast switching from gear-hobbing mode to worm milling mode," says Troy Kutz, service engineer with Koepfer America, the U.S. distributor for Monnier + Zahner. "The Model MZ130 takes it one step further through its specialized tooling that allows you to hob and worm mill in the same setup."

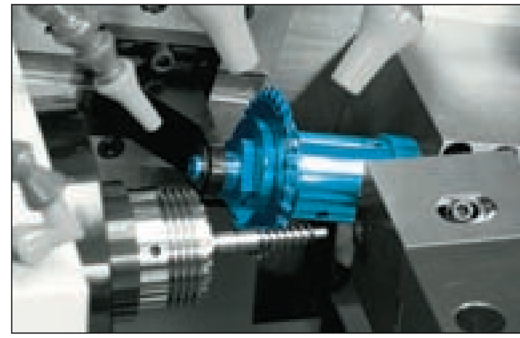
Other machine capabilities and features include: hob head with CNC-controlled shifting; CNC-controlled, multiple-cut cycles; multiple-cut feed rates, selectable via CNC; CNC-controlled dwell for worm wheels, blind splines, etc.; CNC-controlled electronic differential for hobbing of helical gears; machine-mounted hydraulic unit for workpiece clamping cylinder, etc.; and automatic lubrication system with shot tube for machine ways and re-circulation for the hob head and work spindle.

The MZ 130 accommodates large and small batches and includes a universal loader with workpiece magazine.

Available options include an eight-axis CNC synchronized tailstock, flexible automation system and automatic skiving.

Koepfer says the applications/markets best-suited for the MZ130





include power tools, aerospace, fractional horsepower gear boxes and gear motors, as well automotive and contract manufacturing shops.

Maximum workpiece length for the MZ 130 is 250 mm (automatic loading) and 330 mm (manual loading); gear teeth length is 230 mm. The milling cutter diameter for hobbing is 16–40 mm, and 53–100 mm for worm milling.

CNC-controlled milling cycles include: straight, helical and crowned gearing; radial, radial-axial, climb and conventional milling, roughing and finishing; worm wheels, straight toothed bevel wheels, worms, front-end toothing; and tailstock (W-axis) following the milling cutter synchronously (Z-axis).

For more information:

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Fax: (847) 931-4192
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Mahr Federal

UNVEILS LARGER AND MORE FLEXIBLE MEASUREMENT SYSTEM

The new MarForm MMQ 400 Formtester from Mahr Federal is a ground-up redesign which is more robust, less sensitive to environmental influences, faster, more flexible and more accurate than earlier versions of the company's measurement systems. In addition, the MMQ 400 offers features, including solid construction with a generously dimensioned, reinforced steel base. All mechanical components have been optimized in CAD with finite element methods, and all motors and electronic components have been thermally isolated. Wherever possible, homogeneous materials were used in construction to minimize the effects of thermal expansion.

The MMQ 400 is also larger and more flexible than its predecessor and can measure parts up to 60 kg (132 lbs.) in weight. The Z-axis has also been redesigned, making it more stable and improving both accuracy and repeatability of measurements. Despite its size increase, the overall footprint of the unit is smaller than comparable instruments, as the controller and other electronics have been completely integrated into the design.

The MMQ 400 eliminates the need for an air supply by using a high-precision mechanical bearing for the rotary table. According to the company's press release, the mechanical bearing used in the MMQ 400 is up to 70 times stiffer than most bearings, making the system less susceptible to external forces, such as vibration.

Two versions of the MMQ 400 Formtester are available, one with a 350 mm Z-axis and 180 mm X-axis, and the other with a 500 mm Z-axis and 280 mm X-axis. All measuring axes are fully motorized, and they can be equipped with a selection of available probes, including the T7W 360° motorized by-directional probe, and the manual T20W probe, which further enhances measuring flexibility.

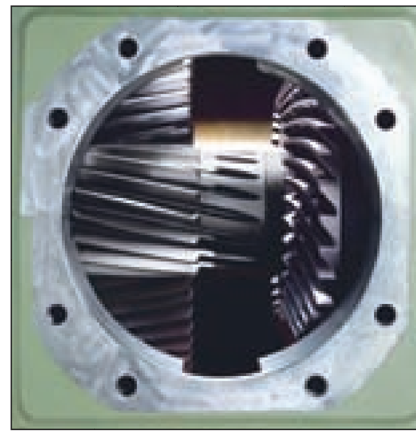
Fully controlled by Mahr *MarWin* software, the MMQ 400 can evaluate all standard form parameters, including roundness, sector roundness, run-out, sector run-out, concentricity and coaxiality, total run-out, cylindricity, straightness, section-by-section straightness, parallelism, perpendicularity, angularity, flatness, conicity, and taper. The system

has been especially designed to measure a wide variety of workpieces, including injection components, ABS components, valves, pistons and piston rods, crankshafts and camshafts, brake disks, gear shafts, ball-bearings, and more.

For more information:
Mahr Federal Inc.
1144 Eddy St.
Providence, RI 02905
Phone: (401) 884-4090
Internet: *www.mahrfederal.com*

New Industrial Gear Oil

ENHANCES GEARBOX DURABILITY



The new Mobilgear 600 XP Series of premium industrial gear oils was introduced by ExxonMobil.

According to the company's press release, the gear oil is formulated to minimize wear and enhance the performance of all critical gearbox components, including gears, bearings and seals. ExxonMobil says the gear oils surpass the industry's most demanding specifications, such as Flender BA Table 7300 A, DIN 5157 Part 3 and AGMA 9005 E02.

Mobilgear helps control micro-pitting and other forms of gear wear. Its balanced formulation improves bearing and corrosion protection while remaining compatible with many commonly used gearbox sealing materials. The oil is also designed to reduce the formation of oil degradation byproducts that require frequent oil changes.

For more information:
ExxonMobil Corporate Headquarters
5959 Las Colinas Boulevard
Irving, TX 75039-2298
Phone: (972) 444-1000
Internet: *www.exxonmobil.com*

Updated Software

INTRODUCED BY KISSSOFT AND GEARTECH

KISSsoft AG and GEARTECH Software introduced a new and updated version of *GEARCALC*, a gear design program originally released in 1986.

GEARCALC requires minimal input data and prompts the user to enter the application, load, material, and heat treatment data for a gearset.

GEARCALC designs maximum-capacity gearsets that have minimum volume and weight. Profile shift coefficients can be selected to maximize pitting and wear resistance, and scuffing resistance or bending strength.

AGMA 2001, which replaces *AGMA218*, rates gears exactly as intended by the American Gear Manufacturers Association Standards "ANSI/AGMA 2001-D04 and ANSI/AGMA 2101-D04, "AMERICAN NATIONAL STANDARD, Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth."

AGMA 2001 performs the following analyses:

• Life Rating—Given the transmitted power and speed, the pitting life and bending fatigue lives are calculated for a single load and speed, or for an entire spectrum of loads and speeds with the resultant lives determined from Miner's Rule.

• Power Rating—Given the pinion speed and required design life, the allowable transmitted power based on gear tooth pitting and bending fatigue is calculated for both the pinion and gear. The allowable power rating of the gearset is the minimum of the four power capacities.

AGMA 925, which replaces *SCORING+*, rates gears exactly as intended by the American Gear Manufacturers Association Information Sheet *AGMA 925-A03*, "AGMA Information Sheet, Effect of Lubrication on Gear Surface Distress."

AGMA 925 performs a complete analysis of the tribology of spur and helical gears. It calculates the EHL film thickness using the Dowson and Toyoda equation and the flash temperature using Blok's critical temperature theory.

AGMA 925 features include:

• Calculation of EHL-specific film thickness and probability of wear.

• Calculation of total contact temperature and probability of scuffing.

• Calculation of rolling, sliding, and entraining velocities, and specific sliding (slide/roll) ratios.

• Calculation of Hertzian contact stress.

• Screen and hard-copy plots of specific sliding, Hertzian stress, film thickness, specific film thickness, and contact temperature.

• Programs *GEARCALC*, *AGMA 2001*, and *AGMA 925* work together in a seamless integrated system that has been optimized using state-of-the-art technology to simplify gear design and analysis.

The software is available as a stand-alone package, or integrated into the CAD programs *Inventor*, *Solid Edge*, *SolidWorks* and *Pro/E*.

For more information:

KISSsoft USA LLC
3719 N. Spring Grove Rd.
Johnsburg, IL 60050
Phone: (815) 363-8823
Internet: *www.kisssoft.com*

Midwest Motion's New Control

FEATURES BUILT-IN REVERSING SWITCH AND SPEED ADJUST POTENTIOMETER

Midwest Motion Products Co. released the MMP20A-24V-RSP motor speed control module. The modular design includes a solid-state PWM switch device that provides bi-directional, open loop, DC motor speed control.

According to the company's press release, the control delivers 20 amps continuous current at 24 VDC with a 20–36V range. Measuring 4.5" x 3.1" x 1", the control can achieve the current required to power most brushed DC motors by delivering 240 watts of continuous output power. The latest design enhancement ensures up to 40 A of peak (momentary) current for a peak output power capacity of 480 watts.

The design is enabled to meet the IP-65 standard rating for resistance to harsh environments. The outer casing is brushed aluminum, and two 1/4" diameter thru-holes are provided for easy mounting to any flat (heat sinking) surface. Sets of four "quick connect" terminals are provided for connecting to power.

The control is designed for operation in applications including pumps, gearmotors, automotive and transportation industries, conveyors, food processing and others.

For more information:
Midwest Motion Products
10761 Ahern Ave. S.E.
Watertown, MN 55388
Phone: (952) 955-2626
E-mail: *sales@midwestmotion.com*
Internet: *www.midwestmotion.com*

Adcole's New Gage

FEATURES SPINDLE REFINEMENTS

A new, high accuracy version of the Model 1200 Gage for measuring crankshafts and camshafts is introduced by Adcole Corp.

The Adcole Model 1200 crankshaft-camshaft gage features proprietary refinements to the spindle, including significant components and subsystems to achieve accuracies for roundness of better than a quarter micron (0.25µm) for measuring pin journals. This exceeds the 10% rule of the new 2.5 micron roundness tolerance now being introduced by engine manufacturers, according to the company's press release.

Capable of measuring pin journal roundness, cylindricity, straightness, parallelism, diameter, taper, radial runout, concentricity, and other critical parameters, the Adcole Model 1200 crankshaft-camshaft gage incorporates a laser interferometer measurement system and is built on a base of structural steel. Applications include machine tool performance verification, manufacturing process control, and final parts inspection.

For more information:

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Marlborough, MA 01752
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E-mail: *breece@adcole.com*
Website: *www.adcole.com*

New Makino

GRINDS, DRILLS, BORES AND MILLS

Makino introduced the G5 Grinder horizontal machining center, capable of grinding, drilling, boring and milling all on the same machine.

"The biggest advantage of a machine like the G5 is the ability to eliminate non value-added time in the manufacturing process," says Tim Jones, product manager of horizontal machining centers at Makino. "Because you can go from milling to grinding in one machine, you're not only saving on capital equipment but you're also able to keep the part in the machine, eliminating all the out-of-cut time that does nothing but add to your costs and lead time."

According to the company's press release, the G5 is a full five-axis machine, with a B-axis of 0.5/1.5 sec (90/180), a C-axis at 100 rpm and a 60-tool automatic tool changer that will hold up to a 8.7" (220 mm) diameter grinding wheel.

A two-axis coolant nozzle allows the G5 to accommodate variations in wheel diameter and changes in cutting direction while maintaining specific cutting conditions. It also allows for intermittent rotary dressing, an NC-controlled, hydraulically powered feature that redresses the wheel to reestablish profile geometry on the cutting wheel.

The G5 features one-piece X-, Y- and Z-covers, proven 1-Series tool changing systems, and a 10-micron cyclonic secondary filtration.

Features that assist with thermal stability include an integral spindle with the cooling jacket linked to the bed temperature for part consistency, a coolant chiller to maintain high-precision machining, core-cooled ball screws in all axes, and the use of high-volume, high-pressure coolant.

For more information:
Makino North America
7680 Innovation Way
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Website: *www.makino.com*

ONLINE

Product News is updated daily online. For the latest product information, go to *www.geartechnology.com*

LABOR PAINS IN THE AMERICAN GEAR INDUSTRY—ANY RELIEF IN SIGHT?

LACK OF SKILLED WORKERS MIRRORS U.S. MANUFACTURING'S DECLINE

Jack McGuinn, Senior Editor

Where to begin? First, know this: no serious discussion of the continued scarcity of skilled, up-and-coming engineers and machinists in the gear industry makes sense without acknowledging the bigger picture. That would be the ongoing loss of manufacturing industries and jobs in general that has literally changed the very fabric of the country. And if we are looking where to assign blame, there is no lack of bogeymen at which to point the collective finger. The usual suspects include recalcitrant labor unions; greedy management; NAFTA and CAFTA; a tilted playing field abroad of low wages and unfair environmental and labor regulations; and an under-performing public education system that does little to encourage young minds that a life in manufacturing is a life well worth living. One more thing to keep in mind: There is as yet no definitive, national consensus on how best to reverse these trends.

As for the gear industry, it must acknowledge and accept its symbiotic relationship with The Big Picture—that its own travails are simply another symptom of a much greater paralysis—or an infusion of much-needed new blood will never happen.

Schafer Gear's Jim Shinall (left) providing Brent Cronk some on-the-job training on gear nomenclature.

And yet, gear makers—from job shops to captive shops to OEMs—can take heart in the fact that there are people of influence in the gear industry and other sectors all across this country who have long-recognized the disease and its symptoms, and who are passionately committed to doing something about it. Whether it be grassroots organizations, industry associations, government-sponsored foundations or enlightened educational entities, all are dedicated to being agents of change regarding the No. 1 challenge: Restoring the image of manufacturing in the eyes of young people—and educators—as a respectable, financially rewarding means to make a living and a life. For the many who are involved in the fight, that perception change begins with the schools and our country's understanding of the influential role they play in preparing our students to compete in today's global economy. In a sense, it's the semantics of when a "job" becomes a "career."

When does a job become a career? "There has been an enormous change in society's perception of education, particularly at the middle class and blue collar levels, says Geoffrey Ashcroft, director of the Richland, MI-based Gear Consulting Group. "Today, a college education is considered a must for anyone having aspirations of a career, rather than a job. This is strongly encouraged by academia at the high school level, where the prevailing attitude is that, without a college education, there is no respectable opportunity for advancement. Blue collar opportunities are rarely discussed, and 'shop' classes are regarded as being for the least-bright of the student body—those who are not destined for a 'good' college.

"I honestly believe that a large percentage of high school faculty are not aware of what rewarding opportunities there may be in manufacturing, and that the opportunities for advancement in those environments may be considerably better than in other careers. It's industry's job to educate our educators in this respect."

Schafer's David Brooke (left) instructs Shane Carpenter at a CNC hobber on the finer points of gear cutting.

Ashcroft, whose company conducts most of AGMA's on-site training programs, believes the gear industry is having some success in recruiting skilled workers, but inherent problems persist.

"There is not, and never will be, a mandatory system of education and certification of machinists and related trades," he says. "The fact that the gear industry utilizes unique machining processes reduces the supply base of qualified people."

But those "unique machining processes" are just one reason for the labor shortage. Concurrent with the lack of young workers, an increasingly graying workforce is also at play. According to AGMA industry figures, in 1997, nearly 25% of the gear industry workforce was between 18 and 29 years old. That share dropped to just over 10%; and the organization's most recent figures reveal that 55% of workers are beyond age 44.

Joe T. Franklin, Jr., president of the American Gear Manufacturers Association (AGMA), in Alexandria, VA, shudders to think what the next report will bring.

"The data from 2005 and 1997 paints a striking picture. Our employees are getting older, and fewer younger employees are being hired to replace them," he says.

Which comes of course as no surprise to him. And as president of AGMA, his concerns are both long- and short-term. The problem he hears most about right now concerns a shortage of workers of *any* age, which he attributes in part to manufacturing's relatively good health, and, like Ashcroft, to the concern younger employees have about the ability of manufacturing to provide them with a longer career.

"Today, most manufacturing industries are booming, and the pressure to find people grew, as the ramp-up from the bottom of the 2000 recession was very quick," he states. "Greater demand for manufactured products emphasizes the drop in available workers."

Training requires management commitment. In addressing that shortfall, Franklin firmly believes AGMA is doing some good things in that regard. He notes there is no shortage of programs, grants and other funding available for training in the gear industry. And it's those companies that consistently avail themselves of those resources that, not surprisingly, are most successful.

"The impact of the (workforce) shortage, and what companies are doing to address it, varies greatly," says Franklin. "Some of our (AGMA) members are very well-positioned with their local high schools, community and technical colleges, and some universities. These companies are successful and do not appear to have much of a systemic problem. But identifying and hiring good people is an ongoing process for them, not something they do sporadically."

Beyond that, Franklin believes it's all about commitment. "Again, like those companies that work with the community colleges and technical schools, it takes a commitment from the company to be successful."

continued

Actions often speak louder than words, and Franklin takes great pride in AGMA's dedication to real-time, on-site training for gear companies (AGMA membership not required). And the results demonstrate that the need—and desire—are out there.

"We have added the option for individual companies to have an (AGMA) instructor come to their plant for 2–3 days to provide individualized instruction. Most recently, we extended these courses by adding three online components—Fundamentals of Gearing; Inspection; and Hobbing. We have had over 2,000 individuals register to use these courses over the last three years. Interestingly, over 40% of the registrants have over two years of engineering." (*Editor's note: Please see article on pg. 32 for more on AGMA's education and training programs.*)

But along with AGMA's efforts, more is needed. According to Stan Blenke, executive vice president for South Bend, IN-based Schafer Gear Works, Inc., and 2006 AGMA chairman, on-the-job training remains a staple for gear makers.

"Today, most gear companies have no choice but to train on the job. AGMA is offering several avenues to assist companies to train their workforce." In addition, Blenke points out, the association sponsors a gear training school at Daley Community College in Chicago, including the recent addition of advanced-level courses online, as well as stand-alone seminars. But he believes companies—as well as the communities in which they operate—can and should demand more. And be willing to pay for it.

"I believe that every company should invest at least 3% of their annual payroll in employee training," he says. "All of us need to get involved with Workforce Investment Boards, government-sponsored training programs, and local

Geoff Ashcroft conducting an AGMA gear class at Mitchell Community College, Statesville, North Carolina. Attendees at the session were from a variety of gear manufacturers, including some from as far away as Australia.

educational institutions such as community colleges that offer training in manufacturing skills.

"We must create an atmosphere that nurtures the aspirations of today's workers. Constantly look for opportunities to empower employees at all levels, and to create the corporate culture for a high-performance, exciting place to work."

Get 'em when they're young—and impressionable. "I believe (interest in gear making) starts at an earlier age," Blenke says. "Whether students plan to go to college or work, they equally need a more rigorous K-12 education, both in academics and in career technical preparation. Much of the support depends in part on the output of the K-12 system." As for manufacturing's tarnished image, "Negative images remain, and some people still consider manufacturing jobs to be low-paying and dirty," he says. "The challenge before all of us is how to broadly communicate information about modern manufacturing, and the satisfying careers it has to offer.

"All of us can do more. We must continue to strive to develop a corporate culture that nurtures the aspirations of today's workers. The best qualified workers are looking for more than a paycheck. They are looking for independence, involvement in decision making, and transferable skills and experiences that will make them valuable to the market, as well as to their current employers."

Daniel W. Carleton is the manager of the Global Gear Program for Detroit-based American Axle & Manufacturing, Inc. He has another take on the situation—somewhat along the lines of "this not your father's gear industry."

"The gear industry has an image problem. College kids, and recent grads, including my own son and daughter, aren't interested," he believes. "We have to sex it up a bit—stress the cool stuff, like the Army did with those ads some years ago. It isn't good to represent ourselves as a bunch of oil-stained, grizzled old farts who talk about the good old days. We need to stress the power aspects of the job. Car and motorcycle racing, the LCAC (Landing Craft, Air Cushion weapons system), sexy stuff that grabs someone's attention."

Boiled down, what Carleton refers to is a need that is recognized by any number of associations, institutes, councils and other entities that have taken up the cause of promoting manufacturing's traditional contributions to our society's quality of life. What is it? Marketing and awareness campaigns. And the more, the better. Getting the word out, as the saying goes, regarding cutting-edge, "clean" manufacturing technologies and processes, and the role they play in positioning high-tech, high-value-added manufacturing as a destination for young people with a desire to perform meaningful work and to be fairly compensated for it.

A need to get our priorities in order. Carleton's views are doubtless shared by many. And, wittingly or not, they refer in some respects to the point made at the outset—the United States must first get its groove back if anything is to change. It is a need to get back to making things again, and making them here. Cam Drecoll, president of Brad Foote

Gear Works in Cicero, IL, minces no words in support of that concept. And he has no illusions over who shares a good deal of the blame on how we got to this point.

"There is a general lack of pride in the U.S. for jobs that produce real products. It is somehow looked down upon if an individual works with their hands," he says. "I think it begins with the expectation that every child is expected to go to college. That viewpoint is expanded in our schools, with little thought to the outcome for those students that will not achieve that goal. It is shocking that, in large cities with a high percentage of students that do not go on to college, there is little thought of their future," he states. "The education system has little interest, and even less knowledge, of the needs of the manufacturing community." And yet, he adds, "A machinist makes more use of trigonometry in a day than most college students do in their entire career."

As evidenced by his comments, Drecoll believes the school system, as well as government, have something of a learning curve of their own to deal with, particularly as it concerns the legitimacy of manufacturing's role in a productive society; a role that continues to be well-respected in Europe, where the priorities are different.

"(The dynamic) is much different in Europe," he says. "A job as a skilled machinist is seen as an honorable career. They take pride in their workmanship and develop their skills. The burden should fall on (our) government to support the manufacturing base in general. This of course has not been a priority for some years, with the illusion that our country can be a service economy. Unless we change our course, the future of our country can be seen easily enough by the decline of Great Britain. The large challenge lies with educating our representatives in the government. This is a steep battle because they are a product of our education system—the same system that does not respect the need to make real products."

Geoff Ashcroft also looks with envy at Germany's regard for manufacturing skills.

"In Germany, the apprenticeship part of an engineer's resume is considered as important as the academic part, and an engineering degree from a part-time institute can only be undertaken in conjunction with an apprenticeship or internship," he says. "A graduate engineer with a related apprenticeship/internship is considered every bit as valuable as a bachelor engineer with a pure college degree, maybe more so. German companies employing skilled workers are expected to maintain a quota of apprentices in their company; there is a financial penalty for not doing so."

So where does that leave things, specific to the gear industry's image and attendant labor challenge? How in fact do we ingrain in our young people—and the teachers and politicians—that skilled positions in today's high-tech, high-reward industries are well within the reach of those who cannot afford college, or who simply decide that college is not for them? For the answers, look to the network of community- and regional-based educational outreach programs and other initiatives that are springing up all around the country. If manufacturing is to again flourish in America, that is where the seeds are and will continue to be planted.

But what of today's lack of skilled workers? From where will relief come for that dilemma? Drecoll and the others quoted here feel that it will have to be more of the same—on-the-job training. But, hopefully, more of it and more effectively. There may even be a silver lining to be found—i.e., a competitive edge for those companies who, as AGMA's Franklin mentioned earlier, excel at it.

"There is little choice but to conduct on-the-job training," agrees Drecoll. "There is not another source for (existing) workers. This leaves training as another competitive tool. The companies that can effectively train new (and remedially train existing) workers will be the ones that survive and prosper."

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Internet: *www.gearconsultinggroup.com*

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www.geartechnology.com/events.htm

On-site or Online, AGMA

TEACHES GEAR BASICS AND BEYOND

Jack McGuinn, Senior Editor

Instructors and students take time for a group photo at AGMA's Gear School at Chicago's Daley Community College.

Despite the many things being done to promote manufacturing nationwide, there still remains an acute need for gear-specific training, remedial or otherwise. Now in its 90th year, the American Gear Manufacturers Association (AGMA), in conjunction with its AGMA Foundation and Education Council, provides that training via a number of multi-level, computer-based and hands-on teaching modules, and in a variety of settings and locations. All courses are intended to produce a better educated and trained workforce, and to improve a company's bottom line.

In-plant instruction is readily available, and can be designed to suit large and small companies; coursework can be customized to address employees' particular learning needs. Participants must have a minimum of six months' experience and be familiar with basic shop safety procedures and rules. Classes are kept to a maximum of 20 students. The curriculum is tailored to benefit just about anyone involved in gearing, including new hires, sales representatives, engineers, technicians, management and quality personnel. The programs are available to members and non-members alike. Here is a brief overview of the course offerings, all of which are made possible by a grant from the foundation.

The learning begins with the online Fundamentals of Gearing ($25), designed to provide students with a solid foundation for advanced learning. Successful participants of this pre-requisite course earn a certificate of achievement and the opportunity to enroll in upper-level offerings.

Next up is Gear Inspection ($150), which teaches the demands of quality assurance as it applies to gearing—why, when, and how. Students and employees learn online several inspection methods, as well as how and when they are applied. A third online course—Hobbing ($150)—has just been added, and leads the student through the basic principles of hobbing. Fees are the same for AGMA members and non-members alike.

Beyond the online program, AGMA's In-Plant Basic Course provides classroom and plant-site hands-on training and education. The classes are taught at Daley Community College in Chicago, but AGMA also conducts them on-site.

Savvy industry professionals present courses in Gearing and Nomenclature; Principles of Inspection; Gear Manufacturing Methods; and Hobbing and Shaping.

Lastly, it should be added that AGMA's Education Council welcomes suggestions in the ongoing development of its curriculum, as well as qualified volunteers to teach it. There are many other gear learning resources out there, too many in fact to list here. Following is the contact information for the AGMA education programs, as well the URL for an article on other schools offering a variety of gear manufacturing classes:

For more information:

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Geoff Ashcroft
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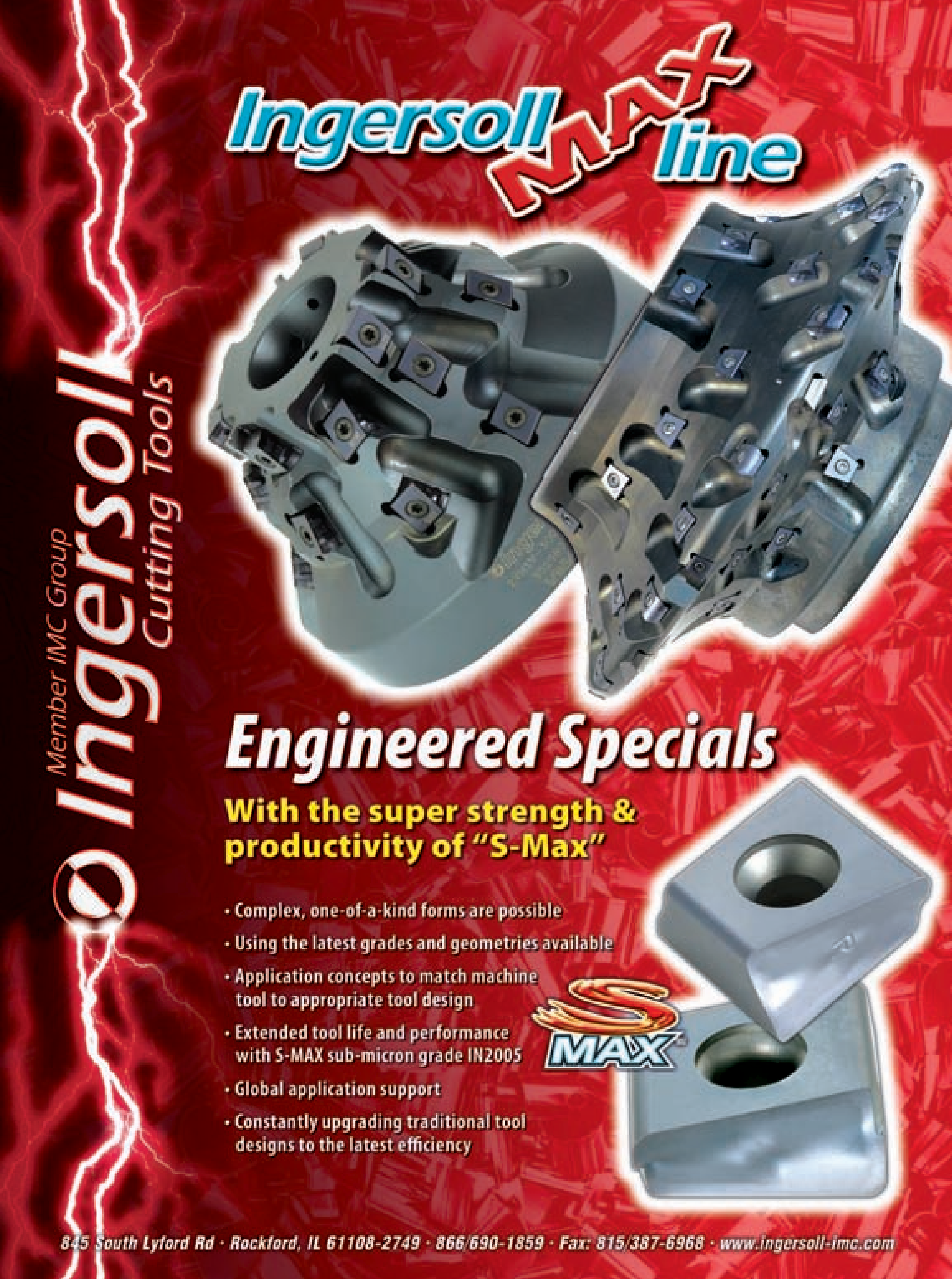
Fax: (269) 623-2055
E-mail: *gearconsulting@aol.com*
Internet: *www.gearconsultinggroup.com*

ONLINE

To learn about other gear education resources, see our online-only article on gear schools at *www.geartechnology.com/schools.htm*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S MAX
845 South Lyford Rd · Rockford, IL 61108-2749 · 866/690-1859 · Fax: 815/387-6968 · www.ingersoll-imc.com

Where Manufacturing and Education Mesh

BUT ASSOCIATIONS AND GRASSROOTS ORGANIZATIONS LACK PUBLIC AWARENESS

Jack McGuinn, Senior Editor

Pick up a newspaper or magazine, tune in the nightly news, or just talk to a neighbor, and what you often hear is that, when it comes to manufacturing, we can't—or won't—make it here anymore. Already for too many Americans, that is an unquestioned reality. The good news is that an array of manufacturing associations, partnered with grassroots outreach programs and other like-minded councils and organizations nationwide, are refusing to accept that reality. Fact is, many of these groups have been fighting the good fight for more than 20 years. The problem—one that continues to exist—is that much of their efforts go unnoticed by the general public.

Following are just two examples of ongoing, collective efforts that should instill hope in Americans and manufacturers alike that much is being done to recruit, educate and train our young people to compete and excel in today's—and tomorrow's—global economy, and in a life in manufacturing as skilled workers, managers, even owners. Their work is dedicated in part to returning the United States to its once-held position of worldwide dominance in the art of not just selling and marketing things, but in making them as well.

> *"None of my peers or my own company have the caliber of workforce we need today. We just don't have the talent in manufacturing that we need to compete globally. (The CMRC is) trying to create an environment that supports complex, high-end, value-added manufacturing."*
>
> *—John Winzeler, Winzeler Gear*

Here is a snapshot of two organizations doing yeoman's work with their efforts to recruit, educate and train tomorrow's manufacturing workforce—the Chicago Manufacturing Renaissance Council (CMRC) and Project Lead the Way (PLTW).

Leading the race to the top. The CMRC, founded in 2005, is a consortium of Chicago-based groups including the Illinois Manufacturing Association, the Tooling Manufacturing Association (local chapter), Winzeler Gear, the Chicago Federation of Labor, the Mayor's Office of Workforce Development, the Chicago Public Schools and Chicago City Colleges. Their mission: piloting the Chicago region's need to attract global high-performance, high-value added manufacturing.

In support of that mission, they work to: educate the public regarding the image and societal appreciation of modern, high-tech manufacturing; reform the public education and workforce development systems; enhance government programs for manufacturers and their workers; develop and coordinate policies in support of these initiatives, both statewide and nationally; and seek to attract "A-list" companies to the Chicago area. The CMRC is in fact an initiative of its larger counterpart—the Center for Labor and Community Research (CLCR), founded in 1982 to respond to the great decline of U.S. manufacturing that began with that decade. But it's all part of what the CMRC envisions as "leading the race to the top."

Which brings us to what the CMRC hopes will someday serve as a crown jewel among its many activities, and as an incubator for a rust-belted community's commercial redevelopment as well as for future undertakings. The Austin Polytechnical Academy, located in the economically depressed Chicago neighborhood of Austin, is scheduled

CMRC executive director Daniel Swinney (left) and Winzeler Gear's John Winzeler.

to open its doors in 2007. The school will be a part of the Chicago Public Schools system's Renaissance 2010 initiative, instituted to replace under-performing schools throughout Chicago.

Some might reasonably wonder why, given the many hurdles manufacturing already faces domestically regarding the global economy, would the CMRC set up shop in an area like Austin. A central reason is that the Austin community in may ways can be looked at as a microcosm of the sorry state of manufacturing in America. Austin used to be home to manufacturers of all shapes and sizes, accounting for 20,000 industrial jobs. In a scenario all too familiar across the country that began in the early 1980s, most of those companies closed or relocated, taking their well-paying manufacturing jobs with them. Neighboring Chicago—"the city that works"—lost 3,000 factories in that decade alone.

Around that same time, in nearby Cicero, IL, more than 50% of the working population found themselves out of work. One of them was Daniel Swinney, a machinist for 13 years, but out of work all the same. Determined to do more than stew about it, Swinney involved himself in a number of community-based, pro-worker and pro-manufacturing endeavors, leading first to the creation of the Center for Labor & Community Research, and in 2005 to forming CMRC, where he serves as executive director and is making, as one former city planner once put it, "no small plans."

As usual, education is key. "It's the whole thing of leading the race to the top," Swinney says. "We do see (the academy) as a way to transform society." He adds that with the Austin community's high school drop out rate of 50%, "Kids turn to crime not because they are criminally minded, but because they really do have limited options, and we need to address that directly. So we see the school as part of a solution that ripples through the community in a way that's profound and different."

Transforming society is a tall order, but make no mistake—Swinney does not see himself tilting at windmills. Rather, he believes that CMRC's goals for Austin are both realistic and attainable, but a buy-in on the part of the education community will be crucial. Swinney cites a 2001 CLCR study commissioned to evaluate what remained of the Chicago area's manufacturing base, that identified a deficient education system as a major problem relative to manufacturing's depleted workforce. The report, funded by the U.S. Department of Labor, was an alarm bell for the CLCR that led to the formation of the CMRC in 2005 and, ultimately, Austin Polytechnical.

"The study was conducted with the Chicago Federation of Labor, and it said that there was a huge problem in education, that it was a non-system which serves neither companies nor the broad population because of its poor functioning. And we proposed a series of reforms, including the need for small schools and academies for manufacturing."

Those reforms can come none too soon for Winzeler Gear's John Winzeler, whose concerns for the future as an owner of a gear company are widely shared by others in the

continued

Bart Aslin, SME Education Foundation director, collaborates with Project Lead The Way to introduce junior high students to engineering and manufacturing.

industry.

"We're not just doing this because of the schools," he says. "It's something that has been sorely lacking. None of my peers or my own company have the caliber of workforce we need today. We just don't have the talent in manufacturing that we need to compete globally. We (CMRC) are trying to create an environment that supports complex high-end, high-value added manufacturing."

Both men believe schools like Austin Polytechnical can serve as incubators where students from all backgrounds can receive an education and the hands-on experience that will help them develop career goals beyond simply learning a trade.

"The career paths we're encouraging are more than just the traditional vocational school," says Swinney. "We're encouraging kids to understand the skills needed to go into management, as well as into ownership. Because in small companies there's a huge problem of succession ownership, where an owner doesn't have an heir to go into the company and everybody loses. Kids who go to Austin Polytechnical will have an exposure, in terms of their career, to be thinking of not only the most highly skilled technical positions, but also in management and ownership. Which means it is real community development, where they can play an active role in the next generation of manufacturing in Chicago."

And one of the resources the CMRC relies on to help make that happen is the national pre-engineering curriculum developed by our other spotlighted organization for change—Project Lead The Way. The courses have earned high praise from organizations like the Tooling Manufacturing Association and other sectors, and are intended to provide high school students with an early understanding and appreciation of high-tech manufacturing and the opportunities it affords them.

"It's a universal curriculum that is lab-based, a new approach to industrial arts classes that requires students to work in a problem solving lab environment on a variety of subjects," says Winzeler. "The beauty of this program is that students who may not be destined for college can go into this program as well. And because they work side by side with pre-engineering students, it brings them along to a much higher level of learning and understanding."

Put another way, Swinney looks at Austin Polytechnical as not just a springboard to a better life for its underprivileged students, but also as an important contributor to manufacturing's vital role in a global economy. And now, the kids will have something else they've lacked—choices.

"Each kid that graduates will have a high school diploma; they'll be college-ready if that's the course they want to go," says Swinney. "Because we believe modern manufacturing needs to introduce kids at an early age to a career in manufacturing. And we hope that some kids will take a job after high school, some will seek a higher place in their career path by going to a community or four-year college. The whole idea is that we want them to come back to manufacturing at some level after they complete their education that's consistent with their aspirations. Because leading a race to the top requires that we start recruiting the best and the brightest kids from all society to come into manufacturing."

Local outreach goes national. Much like the CLCR, PLTW was started in the 1980s, which marked the beginning of manufacturing's long descent of lost industries, jobs, and the skilled workers to fill them. Today, according to its website, "PLTW is a national program forming partnerships among public schools, higher education institutions and the private sector to increase the quantity and quality of engineers and engineering technologists graduating from our education system." PLTW's pre-engineering curriculum is now taught in 45 states and the District of Columbia.

The program was begun by Richard Blais, at that time chairman of the technology department for an upstate New York school district. Already aware that his students' preparation for advanced math and science was lacking, Blais had initially formed an advisory board culled from industry local leaders in order to solicit their suggestions on how best to improve his district's technical-based course offerings. After early success in attracting students to the upgraded coursework, the advisory board received a substantial gift from one of its own members. Richard Liebich, a local businessman and now PLTW's CEO, made funds available from his family's Charitable Leadership Foundation. That seed money eventually led to the expanded reach PLTW commands today, with a presence in 1,700 schools nationwide.

As an example, Niel Tebbano, PLTW vice president for operations, cites a partnership with several other like-minded groups that is helping South Carolina in its aggressive efforts to recruit and train its labor pool to meet the challenge of high-tech manufacturing's worker needs.

continued

"There is a need to attract and retain skilled technologists and engineers across the country," he says. "The defense industry is especially at risk with its future workforce needs. The South is not immune to this need, but the challenge there I believe is to grow its own workforce, as attracting from a diminishing pool will be a challenge. South Carolina is a great example of a state proactively seeking to improve its education programming to do just that."

Asked why the public secondary schools have gotten away from schooling students in the industrial arts, Tebbano says compartmentalized thinking—some might call it tunnel vision—results in limited vision and communication.

"Traditional high school courses are taught in silos," he explains. "There is a silo for math, one for science, etc.; there is very little communication between them. And they are taught by well-intentioned instructors who have never had much work experience outside of teaching, and their understanding of manufacturing and engineering is limited as a result. That's why courses taught in context, that are rigorous and relevant where the students can apply the math and science in meaningful problem solving, like PLTW, produce significant results."

The Society of Manufacturing Engineers (SME) partners frequently with PLTW in its endeavors. Bart Aslin, the society's education foundation director, seconds Tebbano's observations.

"There is now a greater need to attract and train skilled workers to the South as well as nationwide," he says. "Since many school districts moved away from career technical training, qualified machinists, welders, gear designers, etc., are harder to find."

To help meet that need, the SME's educational arm is working with PLTW to combine teaching with week-long day camps to recruit young people for tomorrow's world of manufacturing. It's just another example in support of those in the gear industry who stress that the benefits of manufacturing need to be presented to students at an early age.

Partnering to achieve common goals. "In 2006, the SME Education Foundation partnered with PLTW to establish STEPS (Science, Technology and Engineering Preview Summer) academies for 6th and 7th grade students," Aslin says. "The purpose of these one-week camp experiences is to introduce young people into the wonders of math, science, technology and engineering. Each camp will have manufacturing modules as part of the curriculum. Students who attend the camp are encouraged to continue their 'steps' through the pipeline by entering the PLTW Gateway to Technology program at their local school. Mentoring will be provided so that students will continue this pathway into high school and beyond. (The foundation) will provide scholarships to students who enter technology careers."

Despite the very real and justified concern that exists in the nation today over manufacturing's future role in a shrinking world with an ever-growing global economy, there are many "small-world" success stories unfolding across the country from which we can learn and be encouraged; too many, happily, to spotlight here. Hearts and minds of young people—and educators—are being influenced in a number of ways that is prompting them to give serious consideration to a career in manufacturing.

"We have a number of people we need to sell on this project—students, the community and parents," says John Winzeler. "And there's going to be a broad-based communication project to not only promote (Austin Polytechnical), but to promote the fact that there are meaningful and good-paying jobs in manufacturing, and that (manufacturing) isn't a dinosaur. That's a big paradigm shift."

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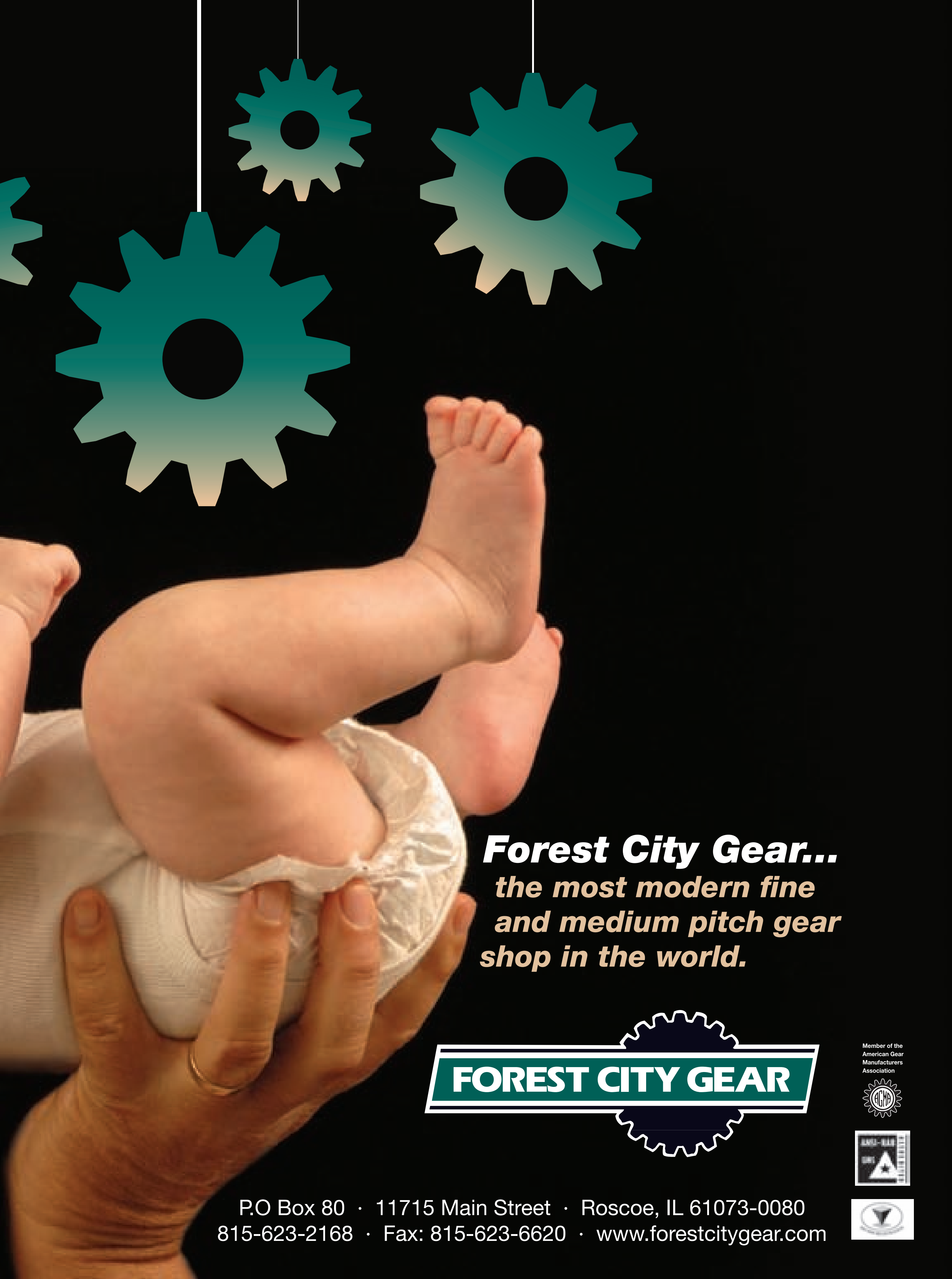
Fred Young holding his grandson Joseph Arnold Mikel.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EFFECTS ON ROLLING CONTACT FATIGUE PERFORMANCE

Dr.-Ing. Gottfried Hoffmann and William Jandeska, PhD.

Management Summary

Reducing weight, increasing fuel efficiency, and reducing costs are the most important forces driving the dessire to increase power density of highly loaded transmissions for automobiles, helicopters and other applications. The major failure modes of gears are surface damage due to rolling contact fatigue (RCF), and tooth root bending fatigue.

Despite many years of testing of coupons and gears, the mechanism of surface damage by RCF is still not fully understood. Systematic studies of the material/process parameters on RCF strength are costly and time consuming. That is most often a barrier difficult to overcome.

This article summarizes results of research programs on RCF strength of wrought steels commonly used for gear applications and PM steels, including surface-densified PM preforms. Using eddy current technology in connection with a special RCF test rig allows—for the first time—an *in situ* study of crack initiation and growth before the actual pitting occurs. This technology will not only lead to a better understanding of failure mechanisms and material behavior, but can also be used to perform systematic tests with a drastically reduced number of test specimens, as well as significantly reduced test time and cost. Hopefully, the application of this procedure will eventually result in material/process RCF-strength relationships that optimize and/or maximize the load carrying capacity of gears and increase transmission efficiency.

Introduction

This is Part I of a two-part article. Part II will be published in the March/April 2007 issue of Gear Techology and presents the results of test programs on the RCF strength of PM steels and discusses the effects on individual material/process parameters on RCF strength.

The desire to improve gear loading capacity is driven by the automotive industry in order to stay competitive in the global market and environment. Therefore, the gear manufacturing industry is encouraged to develop new, cost-effective manufacturing processes that match or improve current gear life without compromising product reliability. However, before advanced materials and/or manufacturing processes are introduced into industrial practice, capabilities and risks must be well-documented in order to:

1. Supply the end-user with reliable property data, comparable to well-known and well-documented traditional materials and/or manufacturing processes.
2. Determine the effects of material and/or process parameters on important design criteria, such as strength under operational conditions, for long-term quality assurance.
3. Support research and development for further improvements or for special applications.

In most cases, these requirements lead to specific product bench testing that provides the confidence and performance data, but often does not translate well to vastly different applications.

This paper summarizes the results of research and development programs on RCF strength of materials for automotive transmission gears. The actual gear contact is very complex and cannot be simulated exactly in any laboratory test equipment (Ref. 1). Therefore, model testing under specific and well-defined test conditions becomes more important because it allows for separating the effects of contact parameters, and for determining the effects of material/process parameters under those specific conditions.

Compared with actual gear testing, model testing reduces test time and costs drastically, but is still too time consuming to study the effect of material/process parameters systematically. Using the eddy current technology to detect failure of the test specimen in very early stages provides additional information about failure mechanisms and crack growth under RCF conditions. Based upon the results of a systematic research program, a procedure was developed that can be used to reduce the number of test samples and allow studying the relative effect of material/process parameters in a very short period of time (Refs. 2–4). The procedure uses the additional information gained by the eddy current technology and can determine changes in RCF strength due to variations of a single parameter.

After describing the most important failure modes under RCF conditions and summarizing the requirements from the designer's point of view, the paper will introduce the ZF-RCF test rig and the eddy current technology used in connection with the test rig. It will also present test results obtained with wrought steel and PM steels, and will introduce the newly developed procedure for future test programs.

Characterizing RCF Failure

The three-dimensional sub-surface stress field. In order to understand the failure of material under RCF conditions, it is important to understand the complex three-dimensional stress field caused by elastic deformation of the contact zone. The stress field (in terms of maximum contact pressure) is calculated in real arithmetic using a software package (Refs. 5, 6). Figure 1 shows as an example the three dimensional stress field under line contact in the x-direction (σ_{xx} is shown in Fig. 1a) and the shear stress (τ_{xy} is shown in Fig. 1b) calculated in the contact zone of the ZF-RCF test rig using the following parameters:

1. Contact pressure = 1,800 MPa
2. Radius of test specimen = 15 mm
3. Radius of load roll = 35 mm
4. Young's moduli = 206 GPa
5. Poisson's ratio = 0.3
6. Coefficient of friction $f = 0$

The contact force produces a complex three-axial stress field within the material (σ_{yy} and σ_{zz} show similar sub-surface stress distributions as σ_{xx}). Only at the line of contact at which $\tau_{xy} = 0$ are the stress components identical to the principal stresses σ_1, σ_2, σ_3. Otherwise, magnitude and direction of the principal stresses change at every point. It must be emphasized that all components of the stress tensor are negative (compressive), with the exception of the shear stress, τ_{xy}, which is positive before the line of contact and negative thereafter.

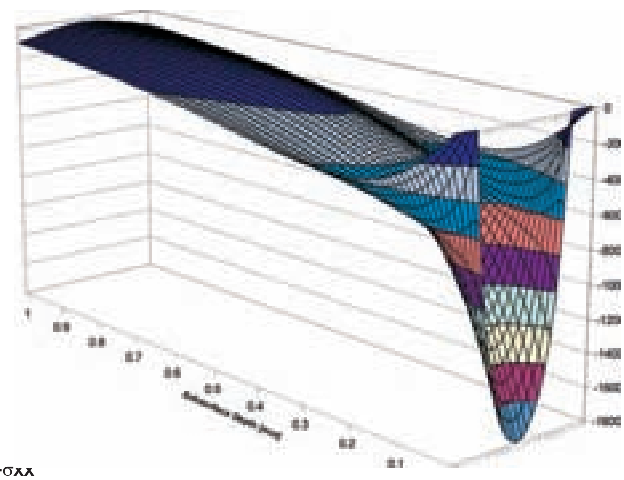

Figure 1a—σ_{xx}

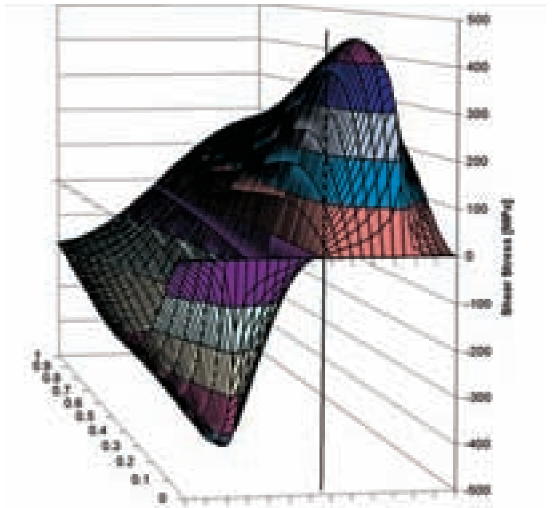

Figure 1b—τ_{xy}

Figure 1—Subsurface stress field due to Hertzian contact pressure.

From the viewpoint of fatigue, there are several ways to convert the multi-axial stress field into appropriate failure criteria:

1. Calculating yield criteria such as von Mises (distortion-energy) or Tresca (maximum shear stress), and using the maximum and minimum stress (= 0 in RCF) to calculate stress amplitude and mean stress (Refs. 6, 7).

2. Finding the maximum and minimum shear stress at every sub-surface point and calculating shear stress amplitude and mean stress (= 0 for f=0 due to symmetric shear stress).

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Gottfried Hoffmann *is president of V-Tech International, a testing service provider and consulting company in general fatigue design and durability studies, located in Milwaukee. In addition, he teaches part-time at several universities in Milwaukee and is a member of MPIF and APMI. Hoffmann was the winner of the 2002 PM World Conference's Outstanding Technical Paper Award.*

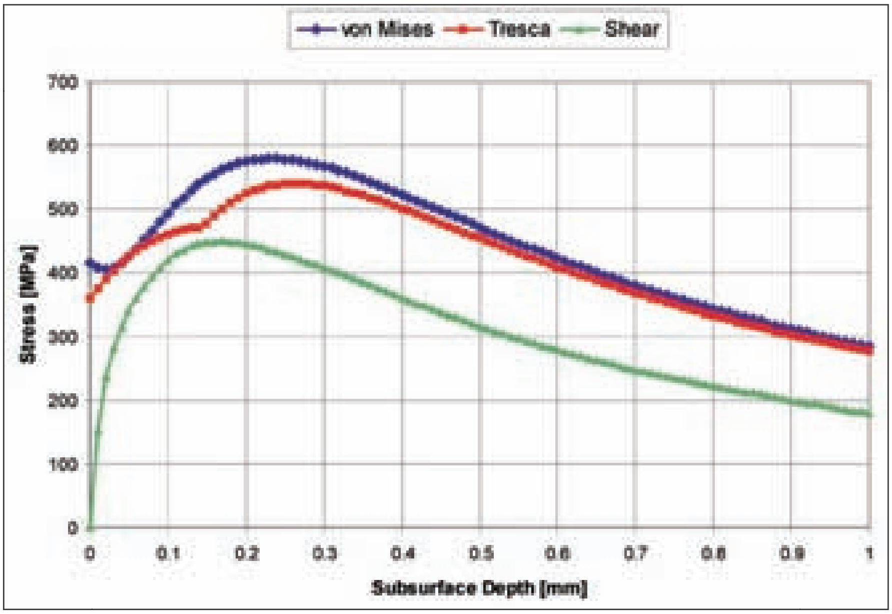


Figure 2—Comparison of Failure Criteria–1,800 MPa f=0.

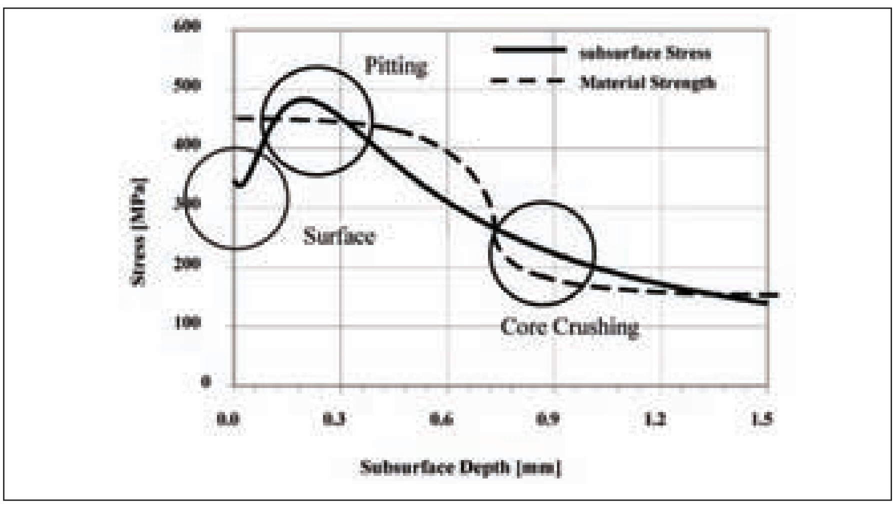


Figure 3—Failure modes in RCF.

Figure 2 shows the comparison of all three criteria as a function of sub-surface depth. All three criteria show a similar sub-surface distribution with a maximum stress between 0.15 and 0.3 mm. Differences occur especially at the surface, at which the shear stress is zero. Von Mises and Tresca stresses are compressive stresses ($R = \infty$); stress amplitude and mean stress would be half of the calculated data. The shear stress represents the amplitude with $\sigma_{mean} = 0$ ($R = -1$).

The sub-surface stress distribution, the position and width of the area of maximum sub-surface stress, and therefore the volume of material exposed to the highest stress, are affected by the type of contact (point, elliptical, and line), the relative curvature of the bodies in contact, the Young's moduli, and the contact pressure. This is different from most conventional fatigue tests, in which the point or volume of maximum stress is almost independent of the load level. This difference can play an important role for RCF strength under variable loading conditions.

Failure Modes Under RCF Loading

Figure 3 illustrates the three most important failure modes for RCF conditions (Refs. 13, 14):

1. Surface-induced cracks. There are two different cracking modes possible:

a) Surface cracks, which usually grow according to the shear component at 30° into the material.

b) Micropitting or gray-stained areas at which many very small surface cracks form. Micropitting most frequently occurs in surface-hardened steels in the regime of mixed lubrication. If lubrication is restored, micropitting may arrest; otherwise micropits may grow and damage the material.

2. Sub-surface cracks are usually formed in the region of the highest von Mises stress. They first grow parallel to the surface and turn toward the surface, forming the pitting.

3. Core crushing or sub-case fatigue (which should not be confused with sub-surface cracking) occurs deep within the material and is usually caused by insufficient heat treatment.

In order to compare the effect of materials and/or process parameters on the RCF strength, it is absolutely essential to identify the failure mode, which in most cases requires intense failure analyses.

Aspects of Material RCF Strength

Analyzing the sub-surface stress field provides design limits for failure under operational loading conditions. If a correlation could be established to other well-known material and fatigue properties, a prediction of lifetime of mating parts in RCF would be possible, and the reliability of gears and transmissions, even under variable loading conditions, could be determined.

The compressive character of the stress state in RCF has been summarized as follows (Ref. 5):

1. The tendency to yield is quite small, hence a substantial pressure may be sustained before the onset of plasticity.

2. Deformation is very ductile, and even normally brittle materials show considerable ductility.

3. If, as is often the case, all three principal stresses are negative, the likelihood of brittle fracture is small, since the only possible growth regime of cracks is shear.

4. Crack growth by fatigue is a complicated process, controlled possibly by shear stress as well as tension and considerably influenced by the presence of residual stresses and

surface treatments.

Despite its helpfulness to interpret failure modes under RCF, it must be emphasized that von Mises and Tresca criteria are yield criteria for materials under tension loading and do not correlate to yielding and fatigue under multi-axial compressive stresses. According to fracture mechanic principles, conventional fatigue data, and crack growth experiments, cracks will not grow under pure compressive stresses (Refs. 5, 8). Therefore, conventional material data, including fatigue data obtained under tension loading, cannot be used to predict the RCF strength of a material.

The fully reversed shear stress component is frequently assumed to be the parameter controlling the RCF strength, which would correspond to the fracture stress intensity factor in Mode II (Ref. 6). Experimentally supported data that would sustain a correlation between RCF strength and fully reversed shear fatigue tests do not exist. Furthermore, due to the fact that the shear stress at the surface is zero (without sliding – $s = 0$) or very small (fully EHD conditions $f<0.1$) it does not explain surface-induced failure modes.

In contradiction to fatigue under tension loading, RCF data show that there is no endurance limit and that failure occurs after very high numbers of load cycles (Refs. 9, 10). It is assumed that the slope of the S-N curve does not change, even at high numbers of load cycles. The effect is important in determining reliability under variable loading conditions and the contribution of small-load amplitudes to crack growth and damage in general.

In order to estimate the effect of material and process parameters on RCF strength, the sub-surface micro-hardness profile is most often used and compared to the sub-surface von Mises stress. The hardness of the material is somehow related to the strength (RCF strength) of the material. This method is successfully applied when case depth is optimized as a function of relative radius of flank curvature in gear design (Refs. 11, 12). For PM, it is a combination of case depth and porosity level at the surface and sub-surface regions. Gears with different equivalent curvatures show similar lifetimes when the case depth is adjusted according to the von Mises sub-surface stress.

Factors Affecting RCF Performance

External factors influence rolling contact fatigue strength by affecting contact conditions, sub-surface stress distribution and failure mode. RCF strength is also affected by material physical properties, micro-structural phases and micro-constituents. Despite many years of RCF and gear testing, the effect of individual factors on the RCF strength of materials is still not fully understood. Necessary tests to study the effect of each parameter individually and systematically are time-consuming and cost-intensive.

Surface Friction and Sliding. Surface shear stress due to relative sliding and friction affects the sub-surface stress distribution. The shear component τ_{xy} becomes asymmetrical with regard to the line of contact. The stress components σ_{xx}, σ_{yy}, σ_{zz} in the line of contact are no longer principal stresses. The amplitude of the shear stress is only affected in the near surface region, but the stress ratio shifts into more negative values (from R=–1 to R =–1.3 at 1,800 MPa, f = 0.1). The maximum von Mises stress (Fig. 4) increases, shifts out of the line of contact, and moves closer towards the surface. The surface stress is also increased and can exceed the magnitude of the sub-surface stress at higher coefficients of friction (f >0.3).

Sliding in gears occurs at every point of the line of contact except at the pitch point. Sliding is positive in the addendum and negative in the dedendum of the tooth profile (Ref. 9). Experience shows that most pitting occurs in the dedendum of teeth at negative sliding (Refs. 13–15). There is only one comprehensive research program that determined the RCF strength of different materials at different sliding ratios (Ref. 16). Results confirm that the RCF strength is reduced by sliding and is leveling off at about –24% (Fig. 5). Due to the fact that the tests were carried out under full EHD lubrication and the coefficient of friction was below f = 0.1, the decrease in RCF strength cannot be explained by the change of the sub-surface stress distribution alone.

Lubrication. The lubrication regime plays an important role in the RCF strength of the material. In mixed lubrication, the coefficient of friction increases significantly, increasing surface stress and surface wear. Therefore, full EHD lubrication is preferred when determining the RCF strength of the material. In full EHD lubrication, elastic relaxation of the contact bodies at the exit of the contact zone compresses the lubricant. This leads to a spike in the contact pressure that may exceed it by up to 30% (Refs. 13, 14).

Surface Topography. The surface

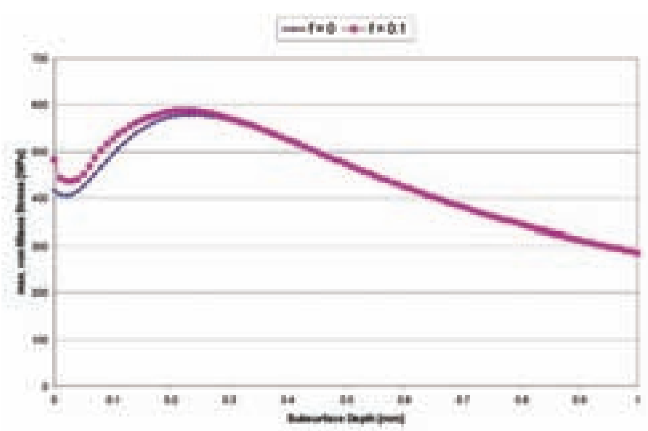


Figure 4—Comparison maximum von Mises stress, with and without friction.

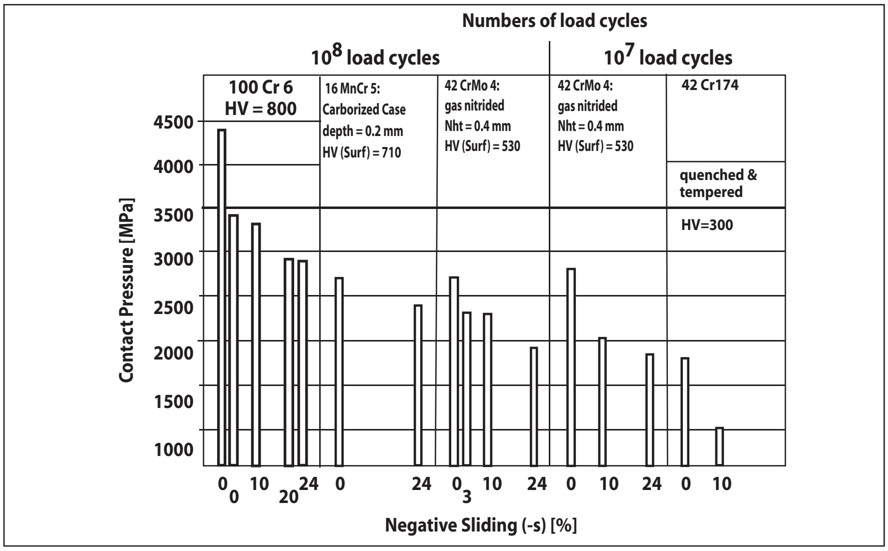


Figure 5—Effect of sliding of RCF strength of gear materials (Ref. 16).

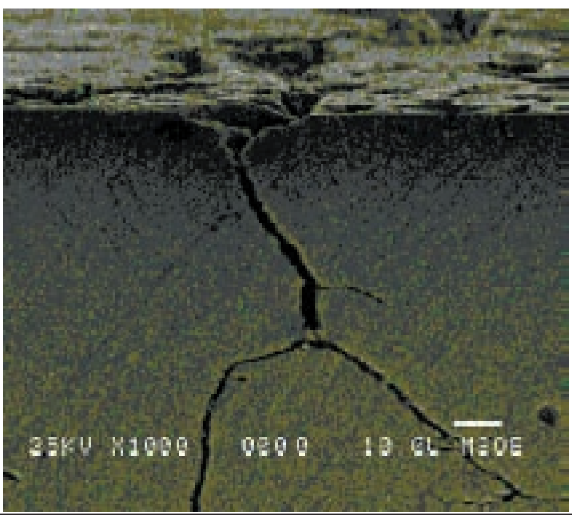


Figure 6a—Surface crack initiated in a dent.

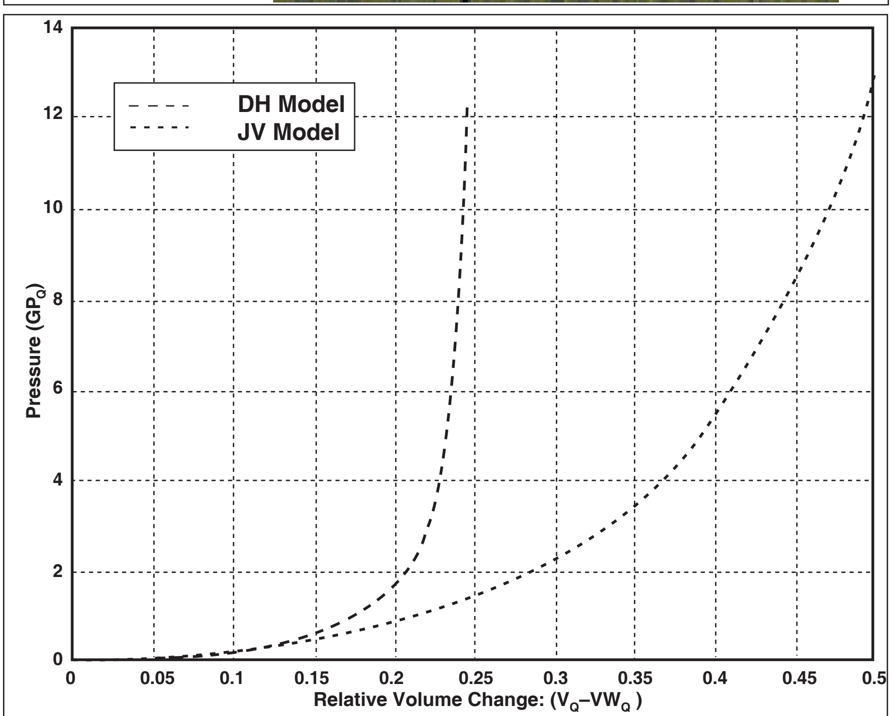


Figure 6b—Lubricant pressure - volume model.

Figure 6—Effects of trapped lubricant in surface dents.

topography affects the RCF strength by an inhomogeneous distribution of the contact pressure over the contact area. There is a higher pressure in high asperities that can lead to localized plastic deformation and crack initiation. Secondly, if lubricant is trapped in surface pockets during over-rolling, i.e., if the dimension of the pocket is small relative to the patch width, the lubricant is compressed by the elastic deformation of the surrounding material, producing a high hydrostatic pressure within the pocket (Fig. 6 a and b) (Ref. 17). Grain boundaries within the pocket are sites for crack initiation. PM materials may additionally be affected when the manufacturing process leaves surface porosity.

Inclusions and soft spots. Inclusions and soft spots within the microstructure can act as sites for crack nucleation. Increased purity of the materials shifts the failure mode more and more toward the surface, and the RCF strength is determined by surface conditions. Soft spots, such as retained austenite and Ni-rich phases in PM steels, may be detrimental to RCF strength. Under compressive forces, retained austenite may transform into martensite, therefore increasing compressive residual stresses and fatigue strength. However, if the grains of retained austenite are completely embedded in martensite, the volume increase caused by the transformation from austenite to martensite may lead to microscopic tension stresses which may support crack opening and growth. The effect of Ni-rich phases on RCF strength of surface-densified PM steel will be discussed later in this article.

Residual Stresses. It is common knowledge that compressive residual surface stresses can enhance the fatigue strength of materials (Refs. 18, 19). Most gears are therefore case-hardened, which produces the proper compressive sub-surface residual stresses. However, the sub-surface residual stress distribution changes due to rolling contact fatigue (Refs. 12, 20). There are still compressive residual stresses in the near surface region, but they are drastically reduced or even turned into tension stresses in the region of maximum sub-surface von Mises stress. These changes in residual stresses could explain the existence of tension stresses necessary for crack opening and crack growth.

Initial Conclusions

Two very important conclusions can be drawn from analysis of failure modes under RCF loading:

1. The RCF strength of a material cannot be predicted. If the microstructure-process-property correlation has not been established, extensive testing is the only way to determine the magnitude of the RCF strength and the factors that affect it.

2. Crack initiation is the most important failure criterion, and it is an essential part for determining and analyzing the failure mode. Most RCF test rigs use catastrophic pitting as failure criterion because pitting results in excess machine vibration and can signal stopping. However, the final pitting characterizes the end-point of the failure, not the initiation of failure. In order to identify the failure mode after the pitting occurs, intensive microstructural analyses are necessary to identify crack origin and crack propagation path.

Gear Designer Requirements

Transmission designers face a big challenge: On one hand, they are forced to reduce weight and increase load carrying capacity of gears and/or power densities of transmissions, and yet find new, cost-effective materials and manufacturing processes to be competitive in the global market. Several sets of data are required to perform reliability calculations and to minimize the risk of a premature failure (Refs. 18, 19):

1. The load-time history must be known, either by calculation or by direct measurement.

2. The S-N curve (50% probability of survival) must be known for the selected material and heat treatment, which is the basis for applying Miner's rule to determine the cumulative damage sum (Refs. 21, 22).

3. The scattering of the fatigue data must be known to calculate the safety factor for a certain probability of failure.

Data are usually available for traditional materials and conventional heat treatments, based upon long years of experience and extensive tests. In order to realize cost savings offered by newly developed materials or processes, the designer requires not only the standard set of material data, but also the statistical variation of the process over a long period of time. Furthermore, relying on more than a single vendor requires comparable technologies and process control methods used by all suppliers in order to exclude additional data scattering due to process variations.

Most companies use statistical methods to keep the manufacturing process in control. However, in order to identify property-relevant process parameters, systematic studies of the effect of those parameters on critical material properties are essential. If those data are not available, extensive tests on prototypes under real-life loading conditions are necessary and required.

There is no doubt that the request for systematic investigations of material/process effects is in the best interest of both partners—the manufacturer and the end-user. The burden shifts to the test engineer to develop test procedures that would provide both partners with the necessary data in a reasonable time frame and acceptable costs. Those model tests pay off over time because they lead to confidence in the capability of new materials and technologies, and provide the database for quality assurance and further improvements.

The RCF Test Bench

The RCF test rig used in this program was developed by ZF Friedrichshafen, Germany, in the early 1960s in order to study RCF at test conditions that simulate live gear contacts. The rig was used in extensive research programs in Germany in connection with the Gear Research Institute of the Technical University in Munich (Refs. 16, 23–25) and was used for the first study of RCF strength of PM steels (Ref. 26). A detailed description of the test rig has been published (Refs. 13, 26, 27).

Figure 7 shows the basic principle of the RCF test rig. The test sample is located in the center of the machine and loaded by three load rolls. The contact force is applied by hydraulic pressure of the lubricant, which furthermore provides the required amount of oil to produce full EHD lubrication in the contact zone. By changing the gear ratio of the gear drive, the relative velocity of the load rolls in regard to the test specimen (the sliding ratio) can

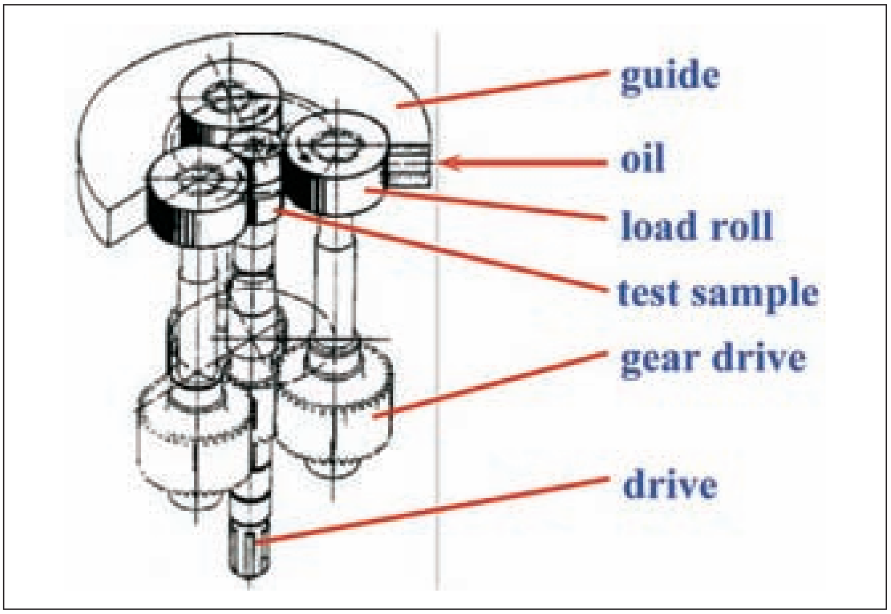
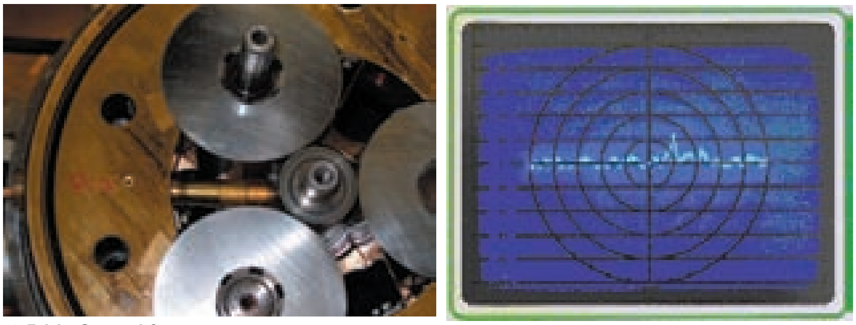


Figure 7—Principle of the RCF test bench.



a) Eddy Current Sensor b) Oscillogram of First Cracks

Figure 8—Eddy current technology used with the RCF test bench (Refs. 3,15).

be easily varied within a wide range.

The test rig offers features that make the unit especially feasible for model testing of materials for gear applications:

1. The design allows cylindrical test surfaces, resulting in line contact, which is normal in gears. If required, crowned test samples can be used, resulting in elliptical contact. The cylindrical surface allows testing of original, native surfaces that are manufactured using the same gear manufacturing process. Due to the fact that the surface topography becomes more and more important, including the actual surface topography is an essential part of model testing. The surface becomes even more important for manufacturing processes, such as PM processes, that produce a unique surface structure.

2. Establishing full EHD lubrication is essential for determining the real material RCF strength, and doing so excludes additional effects such as uncontrollable surface friction and wear.

3. Full EHD lubrication is also a necessary condition to use crack detection technologies. The test rig used in this program is equipped with an eddy current sensor (Fig. 8), which allows the detection of cracks in the very early stage of nucleation (Refs. 3, 15). Therefore, the failure criterion used is the initiation of first cracks.

4. Eddy current technology allows the monitoring of crack growth. However, there is no direct correlation between the actual size of the flaw and the magnitude of the eddy current signal. Therefore, calculation of crack propagation rate uses a modified Paris' equation in which the actual eddy current signal indicates flaw size (Refs. 3, 15).

5. The eddy current technology can be used to determine the threshold for crack growth. By pre-cracking test specimens, stepwise reducing the load, and monitoring the eddy current signal, the contact pressure can be determined at which the crack stops growing (Ref. 3). If such a threshold exists, it could be assumed that it represents the true endurance limit of the material, and that contact pressures below that level do not contribute to the damage sum and can be dismissed in reliability calculations and/or tests under variable loading conditions.

6. The machine is equipped with a variable drive, which allows testing samples at different surface velocities. The standard speed is between 3,000 and 3,600 rpm, which results in 540,000 to 648,000 load cycles per hour.

7. The load is controlled by hydraulic pressure. Changing the level of contact pressure can be done automatically using a servo-hydraulic control valve. This allows tests under variable loading conditions to simulate real operational conditions.

8. As is common with every RCF test rig, the ZF-RCF test bench is equipped with a vibration sensor that shuts off the machine when pitting leads to excessive vibration of the machine. Therefore, tests up to the occurrence of the final, catastrophic failure can be performed.

Table 1 summarizes the standard test conditions used for the test programs included in this paper.

Test Results for Wrought Steels

AISI 5120 and AISI 8620 Carburized. Both wrought steels are very common materials used in today's automotive transmissions, and performance of both materials under operational conditions is well known. Therefore, both materials can serve as benchmark material in RCF investigations. Other materials and/or processes can also be benchmarked.

Figure 9 contains the S-N curves of both materials for final pitting. In the time life region, five test samples per load level were used. A staircase test with 15 specimens has been performed at AISI 5120 and 50 million load cycles. To determine test data scattering, data were plotted in a log-normal diagram and the number of load cycles for probability of survival of 90% and 10% determined graphically. The scattering can be expressed in terms of the probability of survival by

Equation (1): $T_N = 1 : T_{10\%} / T_{90\%}$

with: T_N = Factor for the scattering

Table 1—Standard test conditions.

Test Rig	ZF-RCF Test Bench
Diameter of the test sample	30 mm
Diameter of the load roll	70 mm
Number of load cycles per revolution	3
Speed	3,000 rpm
Number of load cycles per hour	540,000 load cycles/h
Sliding ratio	–24%
Oil	Automatic transmission oil – Dextron III
Temperature	80°C +/–2°C
Oil viscosity at 80°C	8.0 mP*s

of the number of load cycles.

$T_{10\%}$ = Number of load cycles for 10% probability of survival.

$T_{90\%}$ = Number of load cycles for 90% probability of survival.

Using the eddy current technology, the number of load cycles for the occurrence of first cracks has been determined for both the materials at a contact pressure of 2,100 MPa. The results are given in Table 2.

The analyses of the first cracks (Fig. 10) reveal that, in both cases, the failure is surface initiated. The cracks show the typical crack growth at 30° from the surface and branching toward the surface. The cracks propagate until they reach the region of maximum sub-surface stress and turn horizontally, forming the pitting by branching toward the surface. The failure mode indicates that the surface topography plays an important role and that the true RCF strength of both materials may be higher.

The crack propagation rate (Fig. 11a & b) is very comparable to crack propagation in tension. The Paris' exponent, which represents the slope of the log (da/dN) vs. log (ΔK) plot, is within the range of wrought materials under tension. That might be an indicator that even at the compressive stress field, tension stresses may be responsible for crack growth. More research is necessary, however, to generalize those findings.

AISI 1060 and AISI 4150—Induction Hardened. Induction hardening is a second heat treatment to produce favorable surface conditions for RCF applications. Due to the higher carbon content of the material, the core hardness might be higher compared to carburized steel, and the case depth is deeper as well. Both materials were tested at a contact pressure of 2,100 MPa. The number of load cycles for the first crack and the final pitting are shown in Table 3.

As can be seen from Figure 12, AISI 1060 fails by initiating sub-surface cracks at the region of the highest sub-surface stress, while AISI 4150 shows a surface-induced crack that turns horizontally at the region of maximum sub-surface stress. The surface profile (Figure 13) indicates that the surface roughness may play an important role in the failure mode. Figure 14 shows that the crack propagation rate (expressed by the Paris' exponent) of the investigated materials is also within the range of those typically experienced under tension loading.

AISI 1060 was tested for the threshold for crack growth. Pre-cracked specimens (at 1,900 MPa) were tested at lower load levels, the crack propagation was monitored and the number of load cycles before final failure was recorded. Table 4 summarizes the results. Figure 14b shows the crack propagation rates at different load levels.

There are some very important conclusions that can be drawn from the test results:

1.There is a threshold for crack growth. There was no crack growth for more than 10 million load cycles at 1,100 MPa. This threshold level is sur-

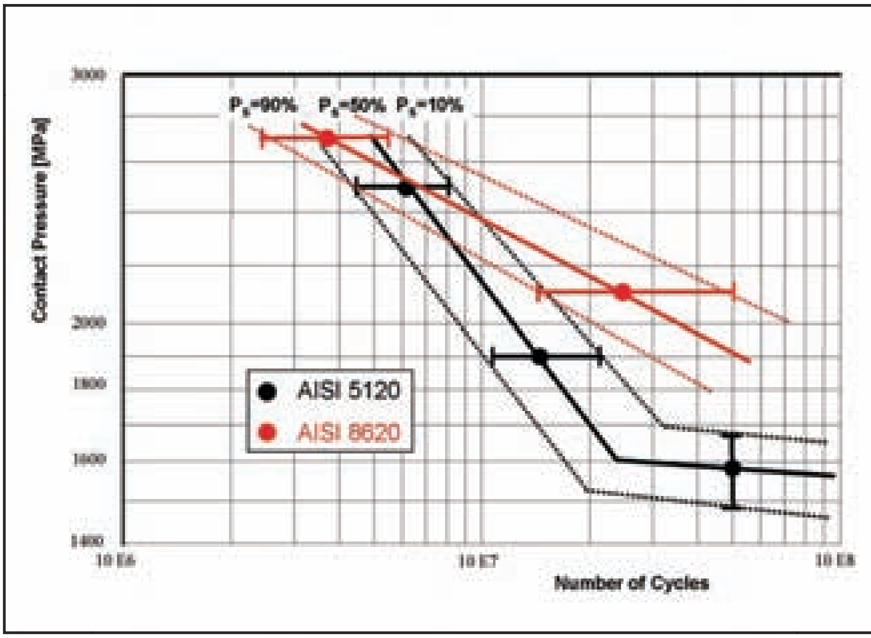


Figure 9—S-N curves of benchmark materials (AISI 5120 and 8620).

Table 2—Number of load cycles until first cracks and for crack growth – 5120 and 8620.				
Material Carburized	First Crack (load cycles)	Final Failure (load cycles)	Crack Growth (load cycles)	Ratio = first/final (%)
AISI 5120	1.21×10^7	1.40×10^7	0.21×10^7	86
AISI 8620	1.55×10^7	2.07×10^7	0.52×10^7	75

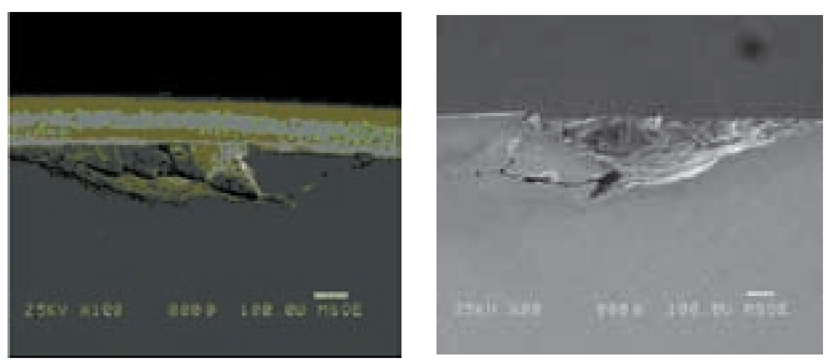


Figure 10a—AISI 5120

Figure 10b—AISI 8620

Figure 10—SEM pictures of first cracks.

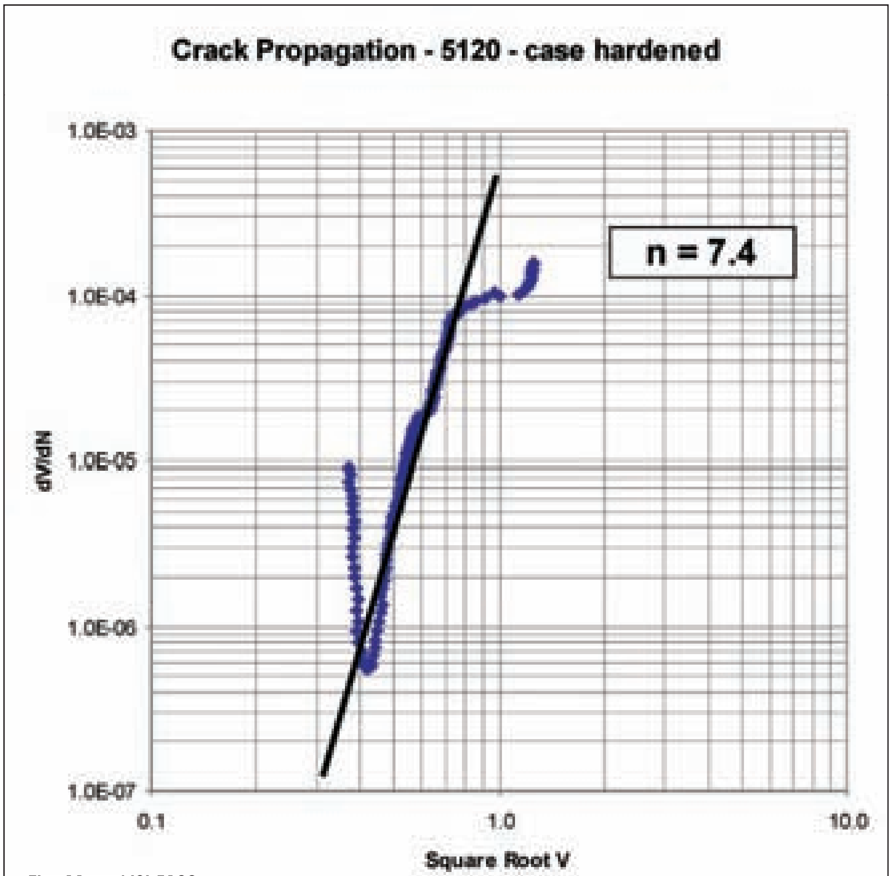


Fig. 11a—AISI 5120

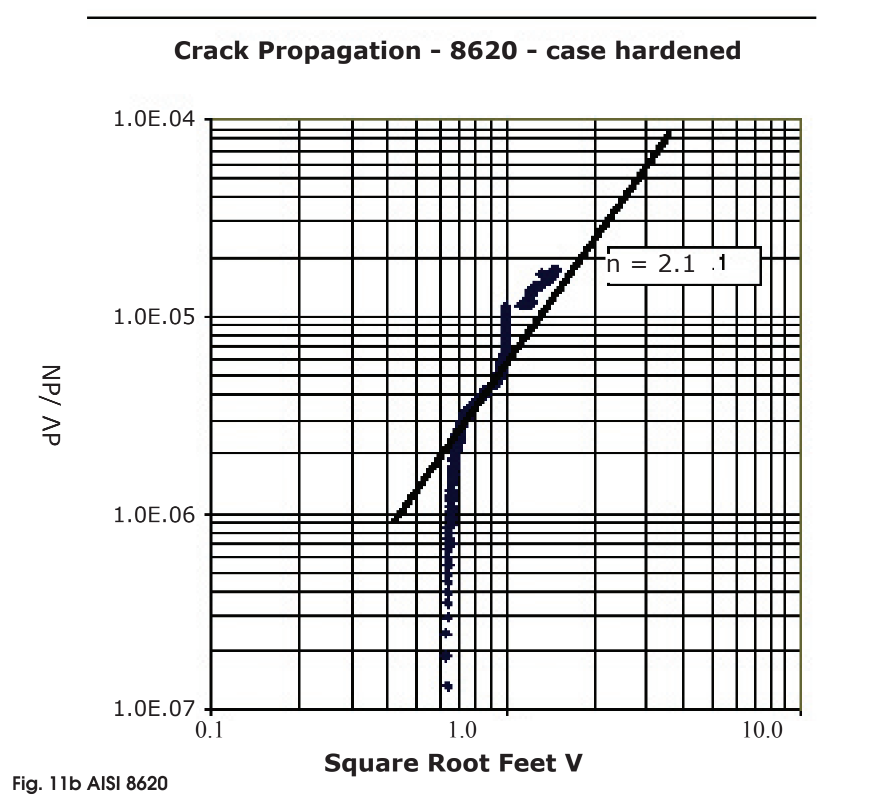


Fig. 11b AISI 8620

Figure 11—Crack propagation rate.

prisingly high.

2. After running the test at 1,100 MPa, the load level was increased stepwise until renewed crack growth could be seen. The load increased by two steps before crack growth occurred. It seems as if load levels at or below the threshold lead to compressive residual stress at the crack tip, which would explain the incubation time for renewed growth.

3.The crack propagation rate at all investigated load levels is very similar and independent of the load itself. This may be another indication that the crack growth is actually governed by tension stresses at the crack tip.

Discussion

The combination of full EHD lubrication and eddy current technology opens a completely new opportunity to study and optimize materials and/or processes for RCF applications. The detection of first cracks allows the analysis of failure modes. Monitoring the eddy current signal over time gives information about the crack propagation and threshold for crack growth. This offers—for the first time—the chance to study the effects of material and process parameters systematically. It is believed that improvement as well as decline of the RCF strength due to variation of those parameters can be determined with only a few test samples, which would drastically accelerate test programs. The savings in test time is especially evident in the determination of the threshold for crack growth. With eddy current monitoring, this can be done in days, instead of weeks with conventional test procedures, which use load levels required for 100 million or more load cycles until failure.

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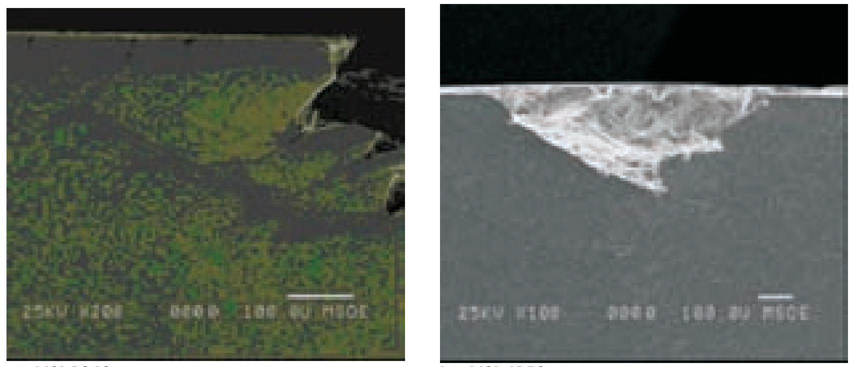
Table 3—Number of load cycles until first cracks and for crack growth.

Material Ind. Hardened	First Crack (load cycles)	Final Failure (load cycles)	Crack Growth (load cycles)	Ratio = first/final (%)
AISI 1060	4.31×10^6	6.17×10^6	1.86×10^6	70
AISI 4150	6.70×10^6	7.50×10^6	0.80×10^6	90



a) AISI 1060 b) AISI 4150

Figure 12—SEM pictures of first cracks.

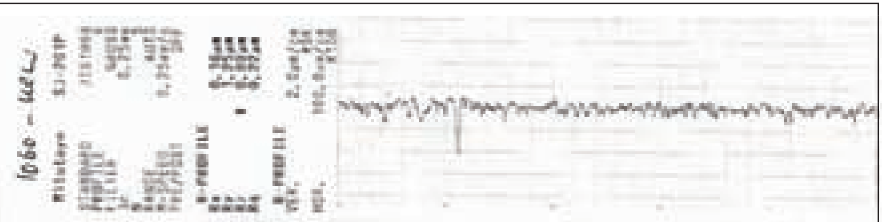


Figure 13a—AISI 1060

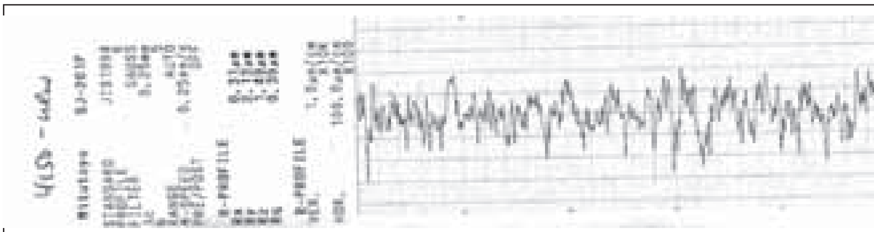


Figure 13b—AISI 4150

Figure 13—Surface Profile Before Test.

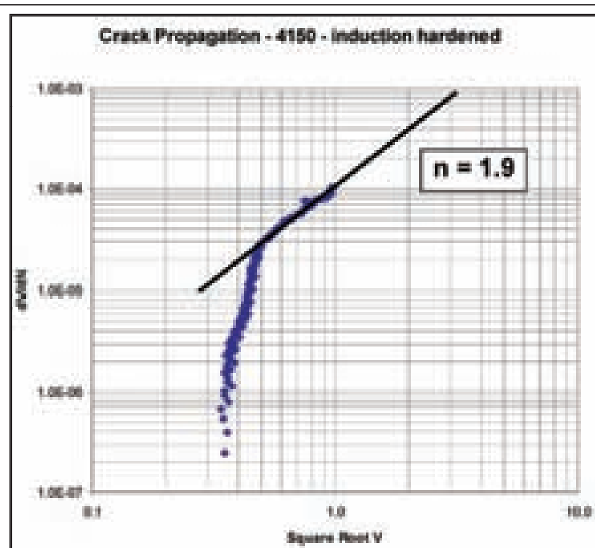


Fig. 14a—Crack propagation rate. AISI 4150 at 2,100 MPa.

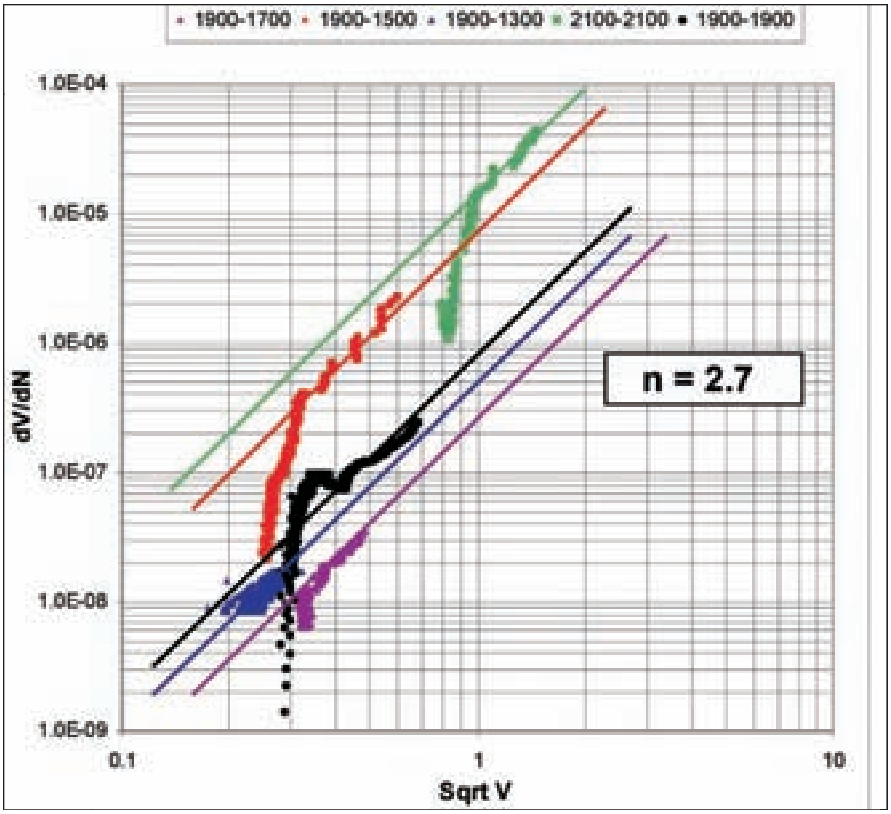


Figure 14b—Crack Propagation Rate. AISI 1060—different load levels.

Table 4—Final failure of pre-cracked specimen at different load levels (AISI 1060).

Specimen	Contact Pressure (MPa)	1. Crack (load cycles)	Contact Pressure (MPa)	Failure (load cycles)
AISI 1060-1	1,900	8.160 * 10^6	1,900 MPa	9.420 * 10^6
AISI 1060-2	1,900	9.336 * 10^6	1,700 MPa	1.335* 10^7
AISI 1060-3	1,900	5.397 * 10^6	1,500 MPa	1.348 * 10^7
AISI 1060-4	1,900	9.600 * 10^6	1,300 MPa	1.716 * 10^7
AISI 1060-5	1,900	7.620 * 10^6	1,100 MPa	no crack growth
			1,300 MPa	no crack growth
			1,500 MPa	7.434 * 10^6

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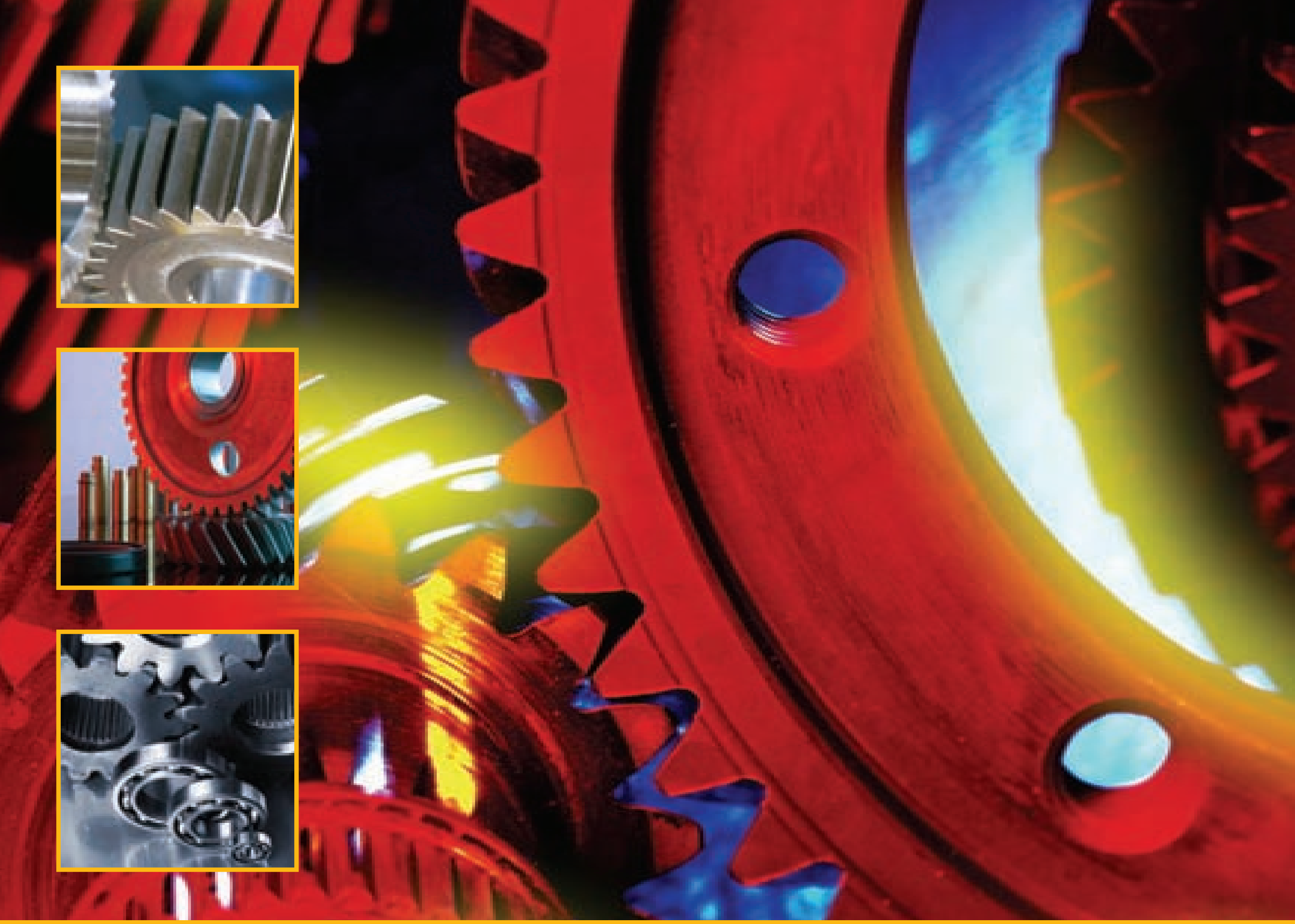

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FACE GEARS: Geometry and Strength

Ulrich Kissling and Stefan Beermann

Management Summary

There are three distinct gear types in angle drives. The most commonly used solutions are bevel and worm drives; a less-often implemented alternative is a face gear drive. This solution—with its specific advantages and disadvantages—is discussed in this document.

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Introduction

Face gears have existed for centuries—the Chinese implemented them on wagons, and the Romans used them in water and windmills. Around the middle of the last century, much attention was given—especially in the United States—to development of the theory and machining of involute face gears. Calculations used in manufacturing proved to be extraordinarily complex. Face gears were at this time installed in relatively lightly loaded gear boxes for transmitting motion. Around 1990, an effort was undertaken in the Netherlands by Crown Gears, which produced face gears under the product name "Cylkro" drive (Ref. 1). Further development was also undertaken in the United States and Japan (Refs. 2, 3).

Face gear projects were also initiated in German academic institutes, with the aim of developing a strength calculation based on experimental data. The further development of manufacturing techniques, most of all in grinding, has allowed for the successful use of face gears in high-performance gear systems.

The main advantage of the face gear over the bevel gear is the axial freedom of the pinion. With face gears, there is no need for the exact axial positioning of the pinion, as is required of a bevel pinion if an ideally distributed contact pattern is desired. This freedom proves especially advantageous in precision technology. In extremely lightly built drives, which give rise to significant deformations in the housing, the contact region is not significantly influenced. For this reason, the helicopter industry has dedicated great effort to implement this type of drive.

The manufacturing of face gears, most of all for large series, proves to be very challenging. The large research and development expense attached to the development of methods for the machining of such gears required a dedicated and costly commitment to engineering and licensing of the product, which of course affects pricing. The relatively high cost was greeted by a subdued market response, but there nevertheless exists a clear interest in the product. Crown Gears has since suspended its development of face gears, and the work has been taken up by ASS AG of Switzerland.

For the manufacturing of face gears not using hobbing or shaping (i.e., by plastic molding, sintering or pressing), the tooth form of the face gear will be defined by direct calculation, and a tool developed for its manufacture.

Calculation of the Geometry and the Tooth Form

A face gear has similarities to a rack in a continual arc (Fig. 1). In contrast to this simplest of all drives, the engineer fights against the restrictions which emerge, due to the bending of the rack form during the sizing of a face gear set. Because the tooth flanks of a straight-toothed face gear must run parallel to a radius—the contacting pinion having flanks parallel to its own axis—it follows from contact theory that the pressure angle must reduce from the outer to inner radius. The following

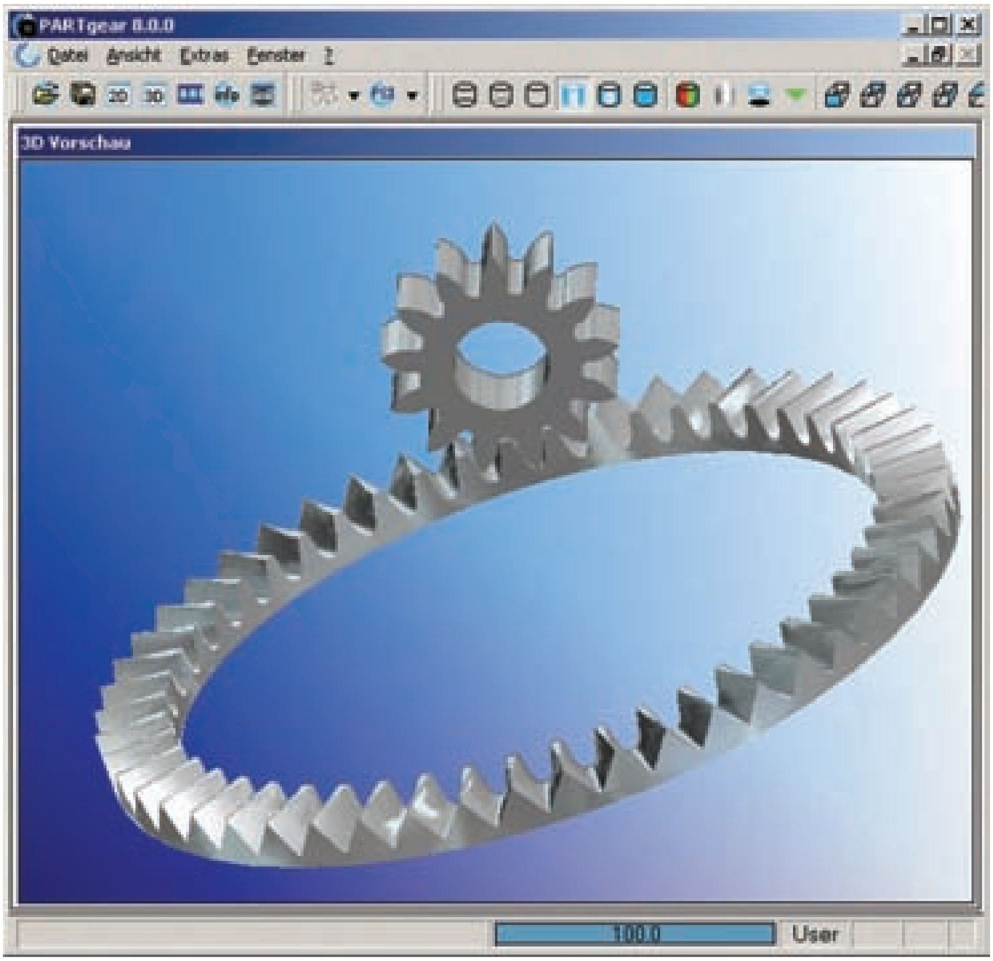

Figure 1—3-D view of a face gear in KISSsoft, produced by the calculation of the mesh process of a face gear with a shaping cutter.

equation (for our purpose considering only straight tooth forms here) applies as the central formula for the determination of the geometry for face gears

$$d_2 = \frac{m_n z_2 \cos\alpha_n}{\cos\alpha_2} \quad (1)$$

where:

z_2 is the number of teeth of the face gear,

α_2 is the pressure angle of the face gear at diameter d_2,

α_n is the pressure angle of the spur-pinion at the reference circle,

m_n is the module of the pinion (Ref. 1).

In the example in Figure 2, the pressure angle changes from about 39° on the outer diameter to around 10° on the inner. This leads to very steep tooth flanks on the internal side, through which the involute becomes very short—and is represented on only a small part of the tooth height—followed by an undercut which further reduces the usable region. On the outer part, the tooth gets a pointed tip. As a result, minimum and maximum diameters are determined, which limit the total possible tooth width of the gear. This represents a distinct difference compared to a bevel gear pair. While bevel gears can transmit a higher torque through a higher tooth width, the face gear pair is limited to the region forming acceptable tooth contact conditions with a spur gear.

By clever choice of width offset b_v (Figure 3), i.e., through a shift of the tooth width center opposite the reference circle, the maximum permissible tooth width can be optimized.

When sizing a face gear, it makes sense, after fixing a minimum and maximum pressure angle, to next determine the inner and outer diameter. By setting the outer and inner diameter as reference diameter, Equation 1 is redefined for the range of module available.

$$m_{min/max} = \frac{d_{2\,min/max} \cos\alpha_{2\,min/max}}{z_2 \cos\alpha_n} \quad (2)$$

Beyond considering the raw numbers, it is helpful to also consider a graphical representation of the teeth. With a little experience, the engineer will determine from a 2- or 3-D graph (for example, Figs. 1 or 2) in which direction the significant parameters should be changed in order to reach an optimum solution.

The overwhelming number of applications use straight-toothed face gears. Helical face gears can, with the appropriate design procedure, offer benefits in strength and noise development.

In contrast, the problem emerges that the flanks are no longer symmetric in that the left flank no longer corresponds to the right. In practice, this implies that a possible undercut on a flank appears earlier on one side than on the other. In Figure 2, for example, a distinct undercut can already be seen on the right

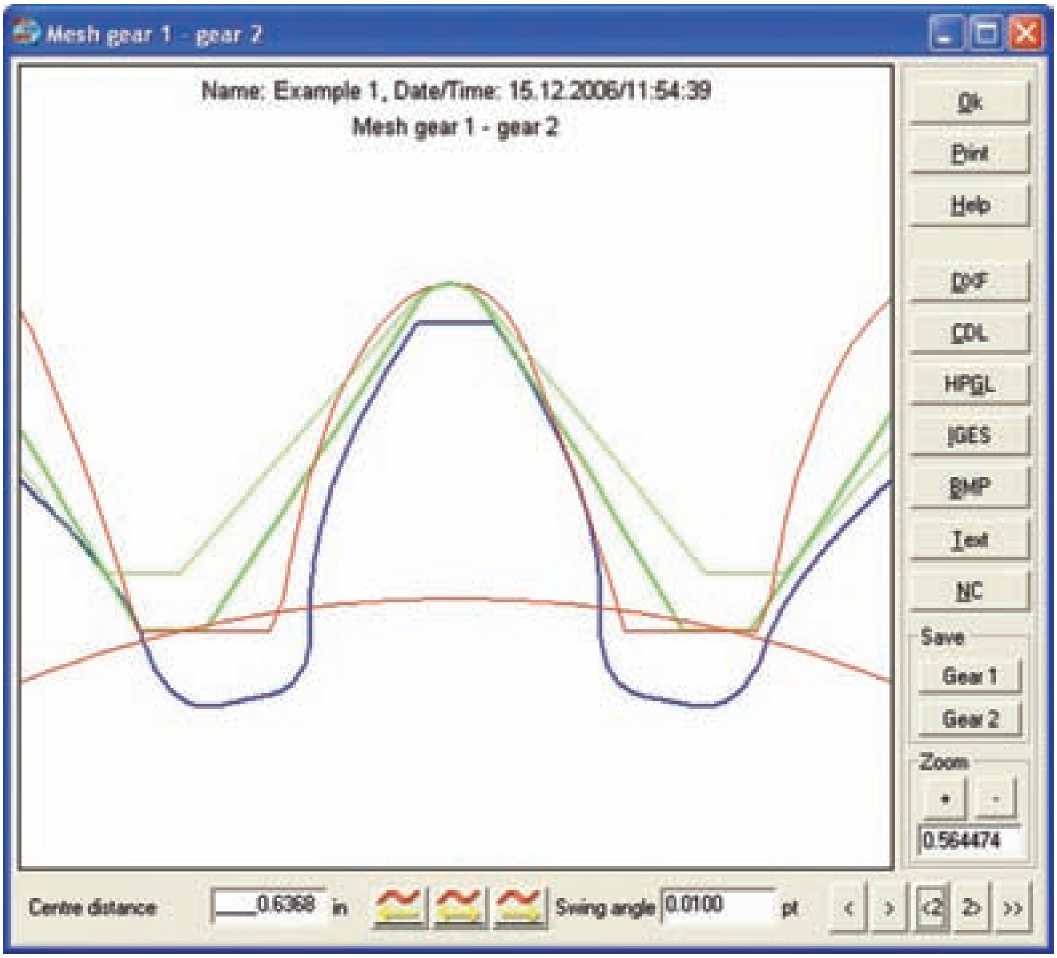

Figure 2—Plot of the pairing of a cylindrical helical with a face gear. Three sections of the face gear are illustrated. Inner: Violet; Middle: Green; Outer: Red.

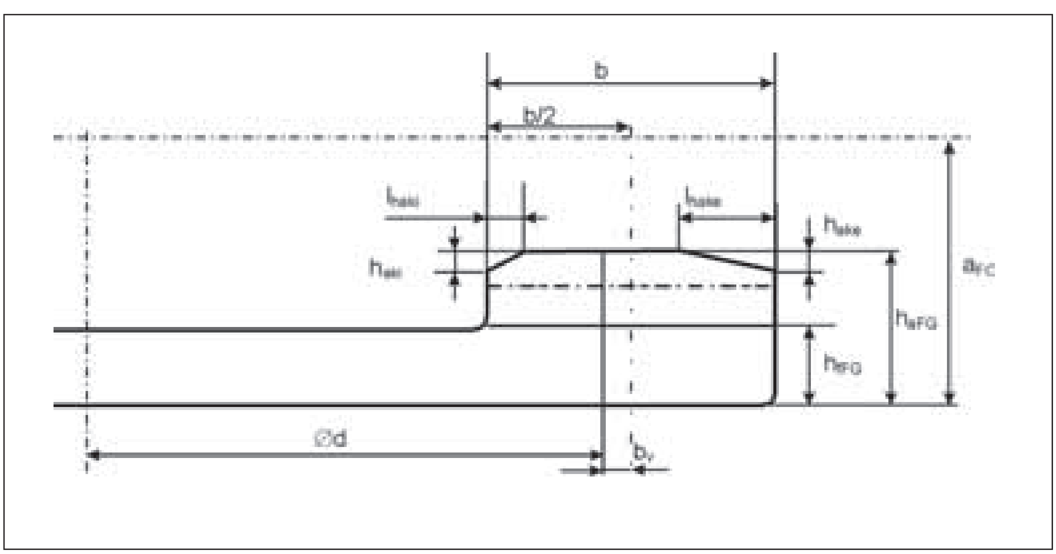

Figure 3—Definition of the tooth offset b_v and the addendum change $h_{ake/i}$ at the inner and outer diameters.

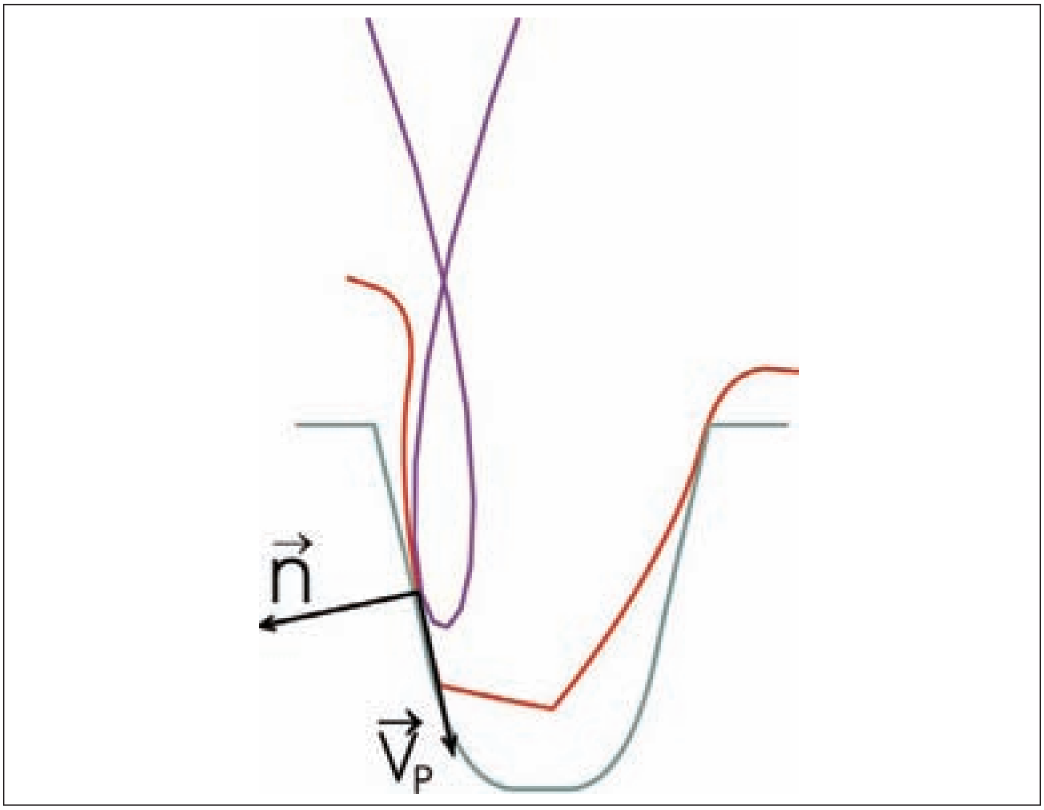

Figure 4—Trajectory (blue) of the surface point of the pinion (red) relative to a face gear surface (green). The position with zero relative speed defines a potential contact point.

gear flank at the inner diameter, while on the left flank there is only a very slight undercut. Likewise, the pressure angle in the example is different, being 31.2° (on the middle section) on the left, and 29.5° on the right flank of the tooth.

These differences on the flank have an influence on the strength so that transmissible power is different, depending on the direction of rotation. If only one direction is to be used, then the flank to be used can be optimized without consideration of the opposite flank.

Experience teaches that theoretical geometry considerations, which describe a flank form in terms of the involute function, lines and arcs, always tend to a limit sooner or later. Tried-and-tested, and much safer, are tooth form calculations which are based upon simulation of the meshing process, or, better yet, on a simulation of the machining process. In these simulations, the trajectory of a point on the active surface is traced (Fig. 4) until the speed normal to the surface of the tool is a zero point (Fig. 4). These positions are potential places of contact on the tooth form surface. The actual points of contact must then be determined, removing any so called "imaginary" points whose relative motion satisfies the contact criteria but whose position is actually outside of the material on the gear surface. Attempting to identify the difference between real and imaginary points presents the greatest difficulty to this approach. Apart from the usual standard algorithms for the classification of points in a plane, empirical approaches must be employed which recognize the known properties of the required tooth form in order to achieve a well-defined tooth form with a degree of certainty.

The calculation of the 3-D tooth form of the face gear can, on the basis of traditional production methods—meshing with a pinion-like shaping cutter—be defined in this way (Fig. 1). The 3-D body can be output in a variety of graphics formats so that, in any arbitrary CAD system, a form can be constructed in order to manufacture face gears using other production methods such as injection molding, sintering or form forging.

The 2-D representation is well-suited for the checking of undercut or pointed teeth in a face gear. In the previous diagram (Fig. 2), the tooth forms at the inner-, mid-, and outer-gear diameters of the face gear are simultaneously drawn. If the gear is rotated in discrete steps, the meshing conditions at each position can be checked throughout the meshing cycle. In the case of extremely pointed teeth or unacceptable contact ratio, the tooth height can be

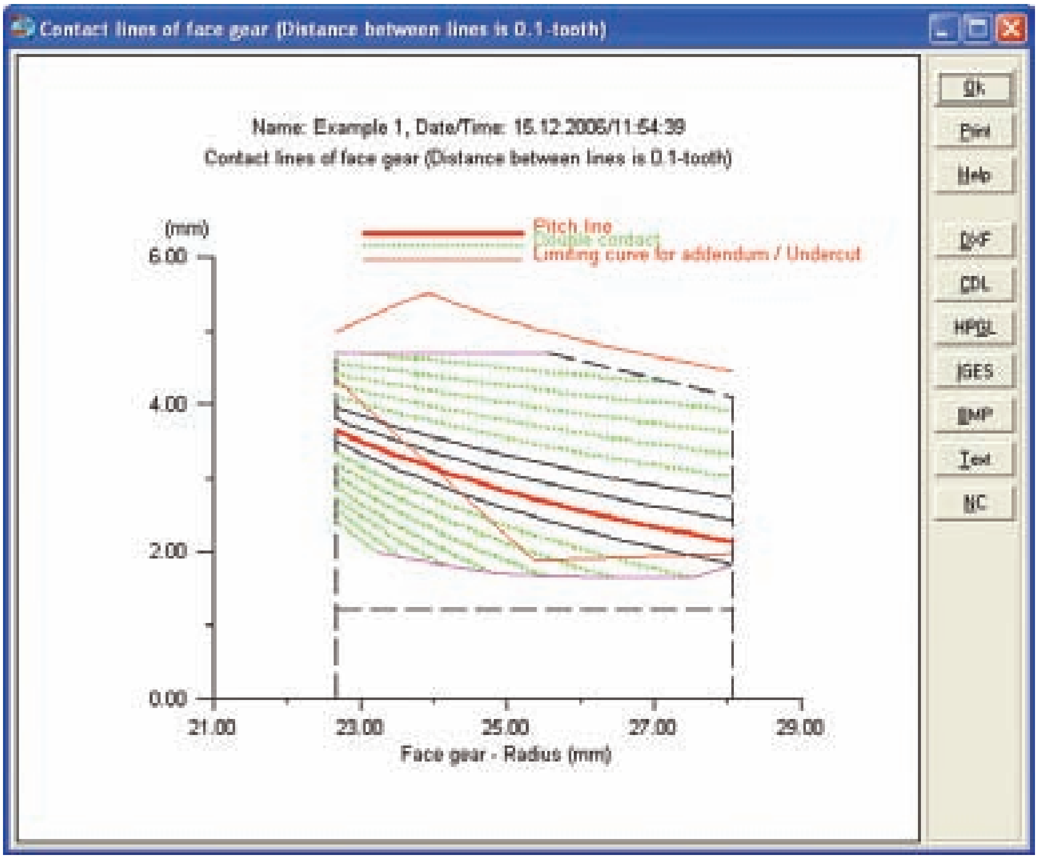

Figure 5—Position of the contact lines on the face gear flanks.

shortened (Fig. 3), analogous to the approach in hypoid gears.

In order to reduce sensitivity from errors in the axis position or axial distance, crowning can be produced on the tooth flanks. This can be applied relatively easily to face gears produced with a pinion-like shaping cutter (or equivalent milling tool) which has one or two teeth more than the intended pinion. A comparison of the tooth forms shows the influence of the higher tooth number of the cutter on the crowning of the tooth form. For a large-width offset, b_v, of the face gear, the crowing can be shifted to one side.

Each transverse section through the spur with the corresponding part of the face gear basically corresponds to a rack and pinion system. Based on the rack theory, it is possible to calculate the pressure angle, contact line and contact ratio in each section (Fig. 5).

Strength Calculation

Following are various approaches for the strength calculation of the face gear:

1) Development of proprietary calculation methods—for example, a finite element method (FEM) calculation combined with a pressure evaluation.

2) Adjustment of the method for the resistance calculation of spur/helical gearing (e.g., ISO 6336).

3) Adjustment of the method for the resistance calculation of bevel gearing (e.g., ISO 10300).

The first possibility is not practical, in that it is possible to spend years conducting a comprehensive series of measurements. The development of ISO6336, for example, has taken decades to prepare, being founded upon multiple theoretical and practical—by means of test rigs—work programs.

The third method is relatively simple, but leads in the end to ISO 6336. The ISO 10300 calculation method converts the bevel geometry in the first step to an equivalent helical gear, and then derives calculation methods directly from ISO 6336.

This leaves only the second approach—the adjustment to a suitable standard for spur/helical gears (e.g., ISO 6336), to which can be added some of the more similar concepts of the ISO 10300. Critical points to consider in doing this are that the contact ratio from inner to outer diameter changes to such an extreme that only a calculation based on contact ratio at the mid-diameter is carried out (analogous to bevel

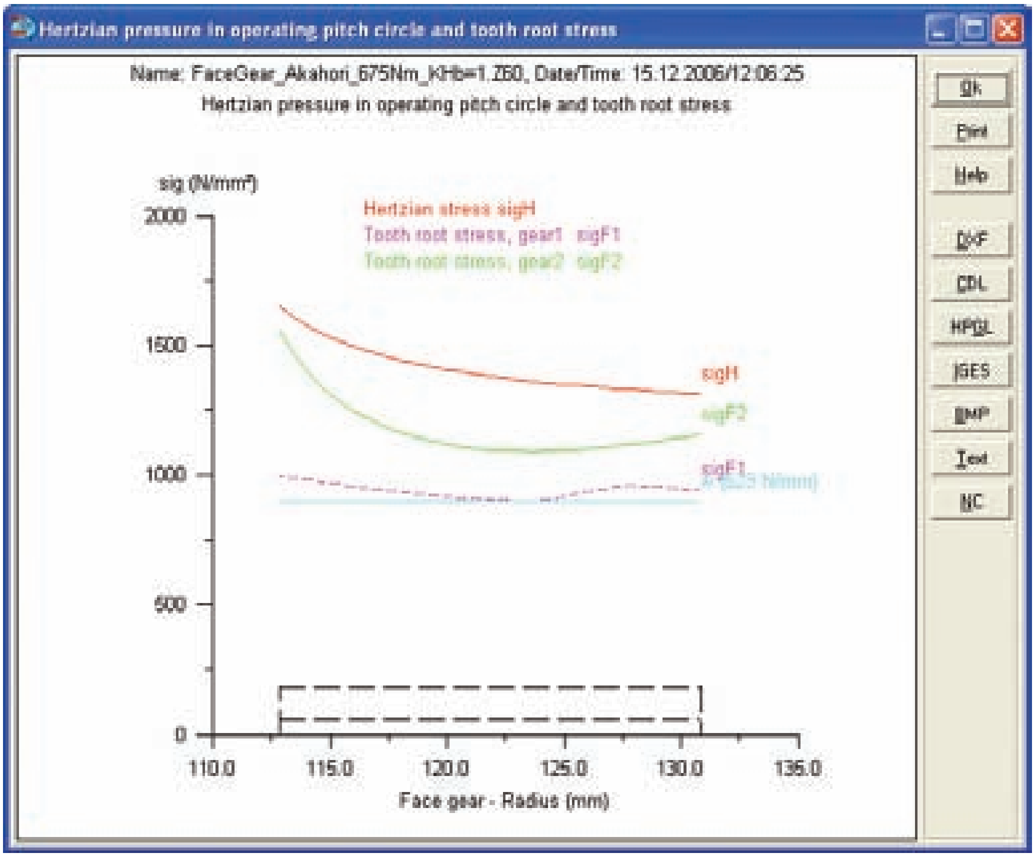

Figure 6—Course of stress curves of a face gear: geometry of the face gear corresponds to the test gear of Akahori (Ref. 2).

gears), or that only the average of the three calculations at the inner, mid and outer diameters is considered. Furthermore, all the important dimensions of the spur/helical gearing being used are in conjunction with the plane of the reference circle. But in a face gear, the reference circle lies in a plane at right angles to the reference circle of the pinion. Certain formulae must therefore be adjusted to cope with the concept of an infinite radius. This problem is identified by the analysis of rack gearing

Calculation to ISO 6336

The Crown Gears method of calculating the strength of face gears is based upon the spur/helical calculation according to ISO 6336 (Ref. 1). Because of the curvature in the path of contact, there is a raised total contact ratio due to the so-called lead overlap ratio. This is somehow comparable to the overlap ratio in helical gearing in which helical-toothed face gears contain an overlap ratio that is given by the helix angle β. A virtual helical angle, β_v, can be derived from the curvature of the contact line, with which the effect can be considered using the helix angle factors Y_β and Z_β. Transverse contact ratio $\varepsilon\alpha$ becomes the value used in the middle of the tooth width. The derivation of the face load coefficient KH_β and transverse coefficient KH_α, according to methods from ISO 6336, cannot be directly implemented for face gears. Again using the Crown Gears calculation, the values are usually set to $KH_\beta = 1.5$ and $KH_\alpha = 1.1$, so that a similar approach to the calculation of bevels (ISO 10300) is chosen.

Calculation to ISO 10300

As previously mentioned, the use of the strength calculation according to ISO 10300 for bevel gears can be an appropriate alternative. Face gears belong to the class of bevel gears, and can be thought of as a limiting case, with cone angle 0° (pinion) and 90° (face gear). The strength calculation for bevel gears is conducted on the basis of an equivalent spur/helical gear, the spur/helical having the same tooth form as the bevel. In the case of the face gear, this gives the virtual tooth number $Z_{1v} = Z_1$ and $Z_{2v} = \infty$ for the pinion and gear, respectively.

A validation with Crown Gears calculations, and the methods of ISO 6336 or ISO 10300, produces a very good match in that deviation at the root and flank safety factors in all cases is under 10%, with most under 5%. However, because the Crown Gears method is restricted concerning the correct length of the

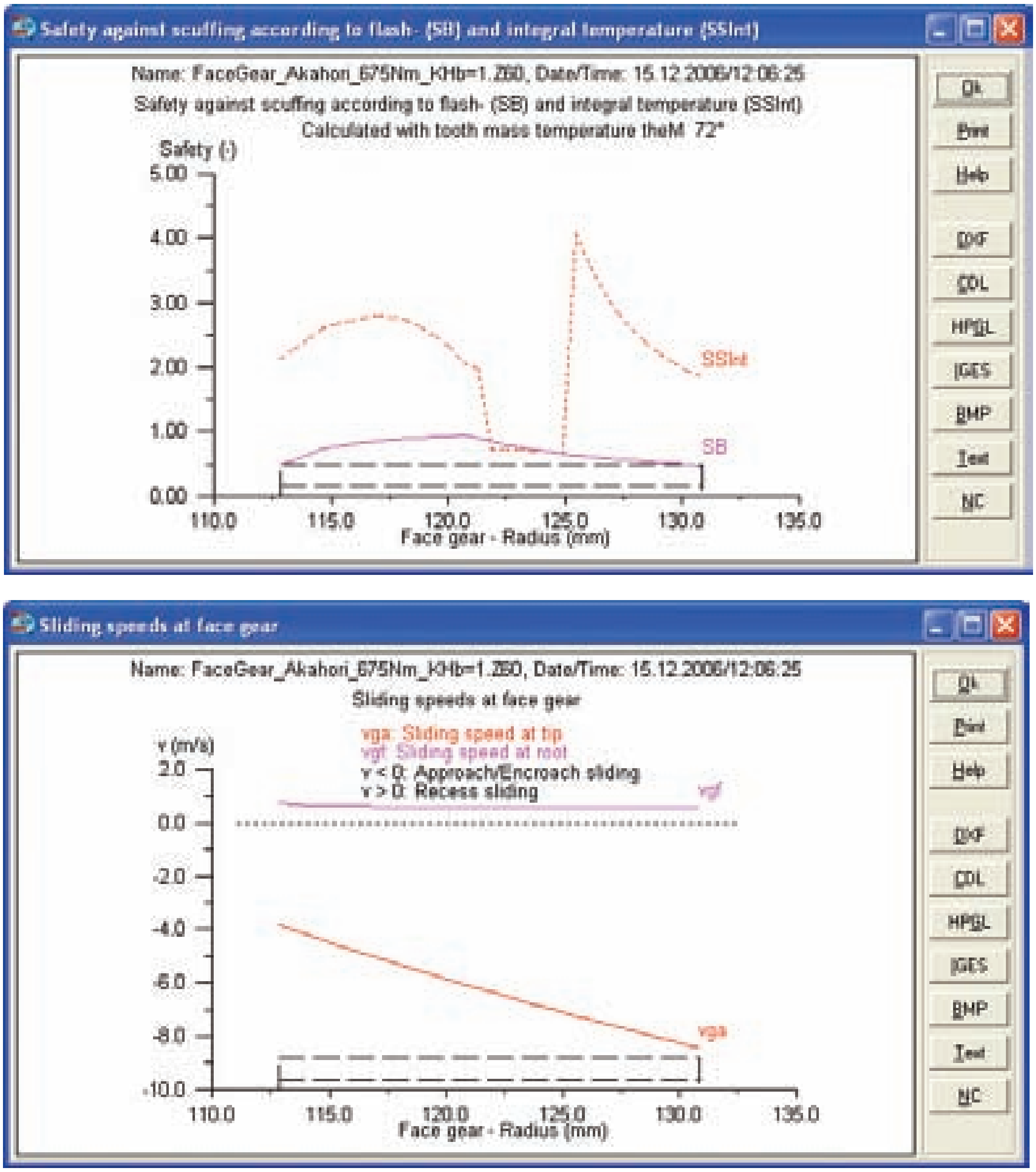

Figure 7 (Top & Bottom)—Scoring pitting safety factor against flash and integral temperature and speed at tip and root. Geometry of the face gear corresponds to the test gear of Akahori (Ref. 2).

Table 1—Calculated safety factors for the face gear (Ref. 2).				
Calculated factor:	Root Pinion	Root Gear	Flank Pinion	Flank Gear
With KH_β = 1.5, KH_α = 1.1:	0.43	0.34	0.77	0.88
With KH_β = 1.0, KH_α = 1.0:	0.70	0.56	0.98	1.13

contact lines, the ISO6336 method is recommended.

Load distribution over the tooth width. The load distribution at the root and on the flank can be calculated very accurately by using an FEM analysis. But this requires a comparably large time investment, while a very quick method for the estimation of the Hertzian pressure and root stress is given by performing the calculation in discrete steps as a rack. In doing so, the course of the pressure at the pitch point and the root stress (calculation procedure according to ISO 6336 for racks) can be defined, assuming a constant linear load, across the tooth flank (Fig. 6).

Akahori carried out investigations of ground case-hardened face gears (m_n=2.75 mm; b=18 mm; b_v=5 mm; Z=28:85) (Ref. 2). The tooth root stress, which has been measured via strain gage, provides a good match with the calculated course of tooth root stress for the face gear (Fig. 6). Also, the photo of the tooth flank after 10^7 load cycles shows a pitting condition, which corresponds well with the region of higher Hertzian pressure on the tooth flank in Figure 6 (Ref. 2).

Theoretical Safety Factors

As with every gear, a validation of the strength is given as safety factors for pitting and root strength. In order to evaluate these factors, it is important to know the minimal required values. This is a general problem associated with machine construction. Minimum safety values can (according to the conditions and requirements) be very different, and should be determined most of all on the basis of experience and proven results from a test rig. In cases where nothing similar is known, the following values can be used as a starting point:

Minimum root safety factor (SF_{min}): 1.4
Minimum flank safety factor (SH_{min}): 1.0

Regarding face gears, well-documented results are readily available. During the measurements of Akahori (Ref. 2), a distinct pitting was observed at a driving torque of 675 Nm after 10^7 load cycles. Cracks or breaks in the root did not appear. A validation according to ISO 10300, when using the factors discussed above (KH_β = 1.5 and KH_α = 1.1), gives factors in Table 1 by calculation. These factors are impressively low. In Akahori's testing, the gear used was a ground face gear of very high precision. The face load co-efficient chosen in this case was set much too high. A validation through ISO 10300 with factor KH_β=1.0 gives a flank safety factor of 1.0, and root safety factor of 0.80. The flank safety factor corresponds roughly to expectation, but the root safety is so low that a break in the root can be expected. Evidently the calculation method is very conservative in this case. Based on the analysis above, where obviously the gear must be hardened, it can be cautiously interpreted that, for industrial applications with face gears made from steel, the root strength is less critical than in spur gears, and presumably the safety factors can in fact be set as follows:

Minimum root safety factor (SF_{min}): 1.0
Minimum flank safety factor (SH_{min}): 1.0

Calculation of the scoring safety factor.

The calculation of the scoring safety factor is difficult because of the very different sliding velocities, and the changing flank pressure across the tooth flank. In the Crown Gears calculations, no check for scoring is conducted (Ref. 1). On the other hand, Akahori reported massive problems with scoring in the higher sliding speed region (Ref. 2). It is therefore necessary to consider adding similar calculations to detect a scoring problem. As previously described in the stress distribution, a reasonable possibility can be the calculation of the scoring safety factor according to German Institute for Standardization (DIN) 3990 in discrete steps. Figure 7 shows the course of the scoring safety, according to criteria of flash and integral temperature across the tooth flank.

In order to arrive at a realistic calculation, all steps should be calculated at the same temperature. In working through the calculations, it can be shown that the factor according to the integral temperature contains many jumps. This occurs if the point E of the contact line is close to the pitch point. The re-calculation of the flank temperature at point E relative to the average flank temperature with the formulae of (DIN) 3990, becomes somewhat imprecise. On this principle, the use of the flash temperature criterion is recommended for face gears.

Summary

The face gear is certainly a challenging component to design, but its use in some applications is significantly more advantageous than an equivalent bevel gear solution. Through the availability of software for sizing face gears and their associated tooling, it is now possible to efficiently overcome special calculation and manufacturing problems associated with tooth forms of this type in arriving at a practical, alternative solution.

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AGMA DELEGATES

MEET CHINESE COUNTERPARTS

The AGMA Pavilion was a hot spot at October's PTC-Asia Show in Shanghai, as evidenced by the intense quoting reported by the exhibitors.

PTC-Asia 2006 took place October 10–13 and was held simultaneously with Metal Working China, Factory Automation Asia, Energy Asia, CeMAT Asia and INTERKAMA Asia. The six shows are combined to attract audiences from the Chinese automotive, aerospace manufacturing, machine tool, agricultural machinery, metallurgical machinery, building equipment and related industries.

Joe Arvin, president of Arrow Gear in Downers Grove, IL, was pleasantly surprised to discover that he was one of the only aerospace gear manufacturers present in the group.

"We really stood out because, out of the twelve companies, Arrow was the only manufacturer of aerospace components. We were extremely pleased with the overall outcome of the show. We had a few hundred visitors stop by our booth and six companies promised RFQs. Within a month, Arrow Gear already received two of the six," he says.

One of the most interesting parts of the experience was the fact that about one-third of the show's engineers were women, says Arvin. The AGMA delegation visited several gear companies near Shanghai, and Arvin was impressed by the overall caliber of the employees. He reported that operators were earning $1.12 per hour and engineers/supervisors make approximately $2.24 an hour.

"The Chinese gear companies feel that they're lagging behind the rest of the world. In truth, they're catching up very fast. We visited one company that had equipment as good as ours, and

Arrow Gear has about $2–3 million in new equipment."

Brian Slone, business unit manager of metrology systems at Process Equipment Co. in Tipp City, OH, noted that the on-site visits to Chinese gear plants were one of the most useful parts of the Shanghai experience. Chinese gear manufacturers, he says, are attracted to the Process Equipment inspection systems' ease-of-use, competitive pricing, technical service and Chinese-language user interface, which allows them to train operators quickly.

"In a market where reverse-engineering is no longer a dirty word, the unknown gear measurement program was also seen as a desirable tool. Above all, though, it was the Chinese language interface that reset the bar in their minds," he says.

AGMA has participated in the show for the past several years, but this is the first year the association sponsored a pavilion for member companies as well as companies manufacturing mechanical power transmission equipment. Delegates included representatives from Arrow Gear, Bevel Gears India, Cleveland Gear, Gear Motions Inc., Process Equipment Co., Schafer Gear Co. and Seitz Corp.

March 6–9—UTS Gear Design & Manufacturing. UTS facility, Rockford, IL. The course aims to provide a fundamental understanding of spur and helical involute gear geometry, teach attendees to apply gear design concepts and develop a working knowledge of UTS software tools. Other topics to be covered include gear fundamentals, gear tooth forms, gear geometry, standard proportions, quality, gear modifications, gear design considerations and the gear design process. Students also have the opportunity to tour Gleason Cutting Tools and Forest City Gear. An optional Basic *TK Solver* course is offered on March 5 to familiarize students with the program for equation solving, manipulation of units and creation of tables and plots in math models. The *TK Solver* Course is $295 and the Gear Design Course is $1,250. For additional information, contact UTS on the Internet at *www.uts.com*.

March 13–15—Expo Manufactura. Cintermex, Monterrey, Mexico. Metalworking and manufacturing event designed for manufacturing personnel. Registration is free and takes place on-site. For more information, contact E.J. Krause & Associates by telephone at (301) 493-5500 or by e-mail at *poblete@ejkrause.com*.

March 15–17—AGMA/ABMA Annual Meeting. Marco Island Marriott Resort, Marco Island, FL. Discussions include Dr. Mike Bradley's Report on the Economy, American Politics: Looking Toward 2008 & Beyond; The Worker of the Future: Why the Profit Future of American Business is Tied to the Quality of America's Future Workforce; and ExtraPreneurship: Reinventing Industrial Work to Compete in a Flat World. $895 for the first registrant from an AGMA/ABMA member company, $795 for additional registrants from an AGMA member company. For more information, contact the AGMA on the internet at *www.agma.org* or by telephone at (703) 684-0211.

March 26–29—WESTEC 2007. Los Angeles Convention Center, Los Angeles, CA. Exhibitors include advanced machine tool, cutting tool and accessories, manufacturing technology, and emerging technology companies. The event is sponsored by the Society of Manufacturing Engineers and showcases automation and assembly solutions for the aerospace, automotive, biotechnology, chemical, computer, cosmetics, defense and electronics industries. Registration is free. For more information, visit the show's website at *www.sme.org/westec*.

Explosion at Falk

KILLS THREE EMPLOYEES, INJURES 46

An explosion at Milwaukee-based Falk Corp. occurred on December 6, killing three employees and injuring an additional 46.

Falk employees Daniel Custer, Curtis Lane and Thomas LeTendre were killed in the explosion.

The blast shook the surrounding area, overturned cars in the parking lot and blew out windows of nearby companies in the industrial park.

Despite the blast damage, the majority of the facility remains structurally sound. Shops 1 and 2 and the foundry were cleared during an initial inspection.

Nearly 500 employees returned to work December 18 and limited production began again. At an evening meeting held December 19 for employees and spouses at the Wisconsin State Fair Park Expo Center, company leaders said they anticipated bringing back all 750 workers and resuming full-scale operations at the Canal Street site by late January.

"With the help of local contractors, the City and, of course, our valued employees, we are taking significant strides toward restoring Falk's facilities," said Dave Doerr, Falk president. "Some equipment is already up and running, and we began assembling and manufacturing component parts on Monday [December 18]. Replacement equipment and supplies have been ordered and, this past weekend, the company shipped its first orders since the accident."

Further updates can be found on the company's website at *www.falkcorp.com*.

Donations can be sent to:

Curtis Land Memorial Fund
Landmark Credit Union
955 Lexington Dr.
Oconomowoc, WI 53066

Thomas LeTendre Children's College Fund
Alex Flynn & Associates SC
1233 N. Prospect Ave.
Milwaukee, WI 53022

Falk Families Survivors' Fund
Rexnord Industries LLC
4701 W. Greenfield Rd.
Milwaukee, WI 53214
Attn: Treasurer

Moventas

RECEIVES ORDER FOR MASS DELIVERIES OF WIND TURBINE GEARS TO ACCIONA

Moventas signed a supply agreement for substantial deliveries of wind turbine gearboxes to Spanish turbine manufacturer ACCIONA Windpower.

Moventas plans to increase its gearbox deliveries for Acciona Windpower's 1.5 megawatt wind turbines. The order more than doubles Moventas' annual delivery volume of main gear units of type PLH-1000 from 2007–2009. Moventas' gearboxes have been part of Acciona's wind turbines since the beginning of their turbine production in 2003.

Moventas designs, manufactures and markets power transmission solutions and services for the process and energy industries.

Acciona Windpower is a subsidiary of Acciona Energia, a renewable energy company. In wind power, the company has put 4,122 turbines into service in 153 wind parks. Through its subsidiary Acciona Windpower, it produces 1.5 megawatt wind turbines using in-house technology in three manufacturing plants.

Philadelphia Gear

OPENS DUBAI SALES OFFICE, APPOINTS MANAGER

Philadelphia Gear Corp. opened a new sales office in Dubai, United Arab Emirates in November. James Aston was appointed Middle East regional sales manager.

According to the company's press release, Aston will be responsible for setting up the Middle East office and handling sales and service related to gear products and services within the oil and gas, petrochemical and power generation industries throughout the region. At the outset, Aston will focus on marketing the Philadelphia Gear, Western, WesTech and Delaval brands, and coordinate with Middle East distributors.

Aston was engineering sales manager for Sabroe Industries in Denmark, covering 19 Middle East countries. Prior to that, he was national sales manager for Kooltech in the U.K.

AMT Reports

MANUFACTURING TECHNOLOGY CONSUMPTION ON BEST PACE SINCE 2000

September U.S. manufacturing technology consumption totaled $407.21 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 USMTC program, was up 31.9% from August, and up 43.1% from the $284.47 million reported for September 2005. With a year-to-date total of $2,815.34 million, 2006 was up 26.2%, compared with 2005.

These numbers and all data in this report are based on the totals of actual data reported by companies participating in the USMTC program.

"Strong sales at September's International Manufacturing Technology Show pushed year-to-date consumption to its largest lead over 2005," says John J. Healy, AMTDA President. "It now looks likely that 2006 will post the best results for U.S. investment in advanced manufacturing equipment since 2000."

The USMTC report, jointly compiled by the two trade associations representing the production and distribution of manufacturing technology, provides regional and national U.S. consumption data of domestic and imported machine tools and related equipment. Analysis of manufacturing technology consumption provides a reliable leading economic indicator, as manufacturing industries invest in capital metalworking equipment to increase capacity and improve productivity.

Eicher Motors

ACQUIRES BMC DEWAS' GEAR UNIT

Eicher Engineering Components, the automotive component division of Eicher Motors Ltd., acquired the

Dewas, India-based transmission gear unit of the British Motor Car Co. Ltd. (BMC)

Siddhartha Lal, managing director and CEO of Eicher Motors, says "Our engineering components business has a portfolio of products ranging from differential and transmission gears to gear boxes."

Eicher Motors Ltd. entered into a business purchase agreement with BMC on Oct. 20, 2006, and formally completed the transaction Nov. 1.

mG miniGears

NAMED ONE OF EUROPE'S FASTEST GROWING COMPANIES

mG miniGears SpA of Padua announced that it has been listed No. 272 among the fastest growing European companies included in the 2006 Europe's 500 Listing, the annual ranking of high-growth, job-creating companies published by Europe's 500-Entrepreneurs for Growth and supported by Microsoft and KPMG.

The 500 dynamic companies have enjoyed sustained growth since 2002, boosting employment at an average annual rate of 16%, and sales at 18%.

Despite the challenging business environment, these companies have created nearly 150,000 jobs across Europe in three years.

mG miniGears has increased employment by 20%, and turnover by 22%, adding 83 new jobs.

The 2006 listing reflected the emergence of winners from many of the new EU member states for the first time, including Estonia, Hungary, Latvia, Lithuania, Poland and

Slovenia. They joined the Czech Republic, which was listed for the first time in 2005. France and Germany received high rankings in Western Europe.

Company CEO Alexander Bossard says, “This growth has been achieved in a difficult market environment. It shows that the team is able and wants to face up to the difficulties and to take the opportunities. Companies like mG miniGears grow fast and manage to sustain their growth, making them excellent role models for Europe’s future.”

mG is one of 29 companies in the manufacturing sector that qualified for Europe’s 500.

“Mid-size businesses are the champions of economic growth in Europe. Today’s mid-market companies are using technology to empower their workforce, recognizing that people are at the core of success—a trend that will see continued growth in Europe for years to come,” says Gabriel Indalecio, Microsoft EMEA senior director of Small and Midsize Solutions and Partners.

Awards were presented to the winning companies in recognition of their performance and contribution to European economic welfare by European Commission vice-president, Günter Verheugen, in charge of Enterprise and Industry, at the Europe’s 500 Awards on Nov. 25, in Vienna.

Philadelphia Gear

NAMED ONE OF PENNSYLVANIA’S BEST PLACES TO WORK

Philadelphia Gear Corp. was honored at an awards ceremony Nov. 28 as one of the state’s best places to work.

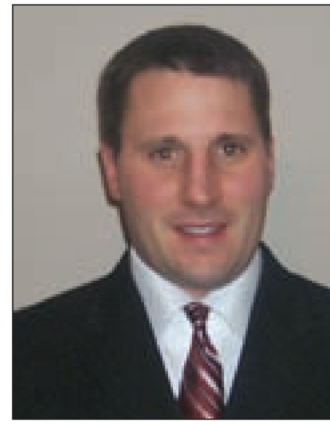
According to the company’s press release, the program recognized 100 companies in total—50 medium-sized companies (25-250 employees) and 50 large companies (251 or more employees). Philadelphia Gear was recognized in the medium-sized category.

“It’s a tribute to the extraordinary people who work here,” says Philadelphia Gear CEO Carl Rapp. “We’ve spent the past five years collectively retooling our offering to the marketplace and trying to get better for our customers. It’s great to see the tangible results of these efforts resonate with so many people. I am very proud of our team’s ability to focus on strategy and deliver results, but even prouder of how our people treat one another. That’s what makes Philly Gear a great place to work.”

The competition focused on an evaluation of workplace policies, practices, philosophy systems and demographics, as well as a survey measuring employee experience.

New Sales Manager

FOR REISHAUER NAMED



Jeff Hocevar

Jeff Hocevar has been appointed national sales manager for Swiss-based Reishauer AG's North American diamond and CBN tool division. Schooled in industrial engineering at the University of Wisconsin and Six Sigma Green Belt-certified, Hocevar worked previously at Greenlee Diamond Tool Co. as a customer service representative before joining their sales engineering/abrasives division. His new duties at Reishauer will include the sales and distribution of all direct- and reverse-plated super abrasive products for gear/thread and non-gear-related applications, grinding wheels, and workholding equipment.

Says Reishauer vice president Dennis Richmond, "Jeff brings a keen technical understanding of the plating process with him, along with his intense organizational skills."

Two Specialty Coating Facilities

JOIN METAL IMPROVEMENT

Metal Improvement Co. acquired two coating facilities from Diversified Coatings Inc. of Ridgeway, PA, that specialize in the application of high-performance coatings for automotive industry components.

The two new facilities are located in Fremont, IN, and Ingersoll, Ontario. The 72,000-square-foot Fremont facility previously operated as Allegheny Coatings – Fremont, and the 44,000-square-foot Ingersoll facility as Diversified Coatings – Canada.

According to the company's press release, both utilize highly automated spray coating lines for high-performance coating for corrosion, oxidation, lubricity and cosmetic applications.

The primary business is the spray application of galvanic high-performance coatings for automotive brake rotors, ball studs and stamping, but the facilities also provide application services to the farm equipment, trailer, military, marine and construction equipment industries.

Roger Pennycook

RECEIVES PTDA LIFETIME ACHIEVEMENT AWARD

Roger A. Pennycook, former president of Boston Gear and former vice president of Textron Fluid & Power Co., was the 17th recipient of the Warren Pike Award for lifetime achievement in the power transmission/motion control industry.

Pennycook, retired after a 20-year career, received the award at the association's annual industry summit.

According to the association's press release, the award is not automatically given every year and is presented only if a qualified individual is identified. Nominees are reviewed by the officers of the PTDA's board of directors and the manufacturer council chair. Once a candidate passes this review, he must be approved by the full board of directors.

Pennycook spent most of his career at Boston Gear, eventually becoming president. He completed his career at Textron Fluid & Power before retiring in 2004. He served on the PTDA Manufacturer Council from 1984 to 1988 and as chair in 1987. He was a board director for two years and served on the steering committee for four.

Gerry Ferris, Boston Gear's vice president of global sales, says "Roger is a very customer-focused individual who knows how to grow and improve relationships. His passion for our partnership with distribution spread throughout our organization."

Tom Lang

RETIRES FROM KAPP

Thomas J. Lang, vice president and general manager of Kapp Technologies, left the company at the end of 2006 to pursue personal interests.

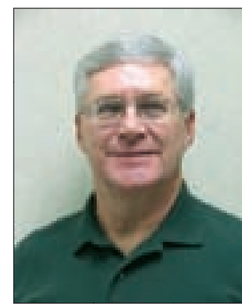
Lang started Kapp Technologies' Boulder, CO facility in 1991. According to Kapp's press release, the company now has 40 employees and conducts business throughout North America under the name Kapp Technologies.

Lang's duties will be assumed by James Buschy and Bill Miller. Buschy, manager of technical services, will assume Lang's position as VP and general manager on Jan. 1. Miller was named vice president of sales for Kapp in September.

In 1978, Lang began working as a production engineer for General Cable Corp. He later moved to the gear industry as a development engineer at Advanced Energy Technology. In 1989, he and a business partner started Aerocom Industries, a gear and special form manufacturing company.

AGMA

PROMOTES CHARLES FISCHER


Charles Fischer

AGMA announced the appointment of Charles S. Fischer to replace recently retired Bill Bradley as VP of the association's technical division, effective March 1.

Fischer joined AGMA in 1994, after 19 years at Philadelphia Gear. As a senior engineer and assistant manager of AGMA's technical division, his responsibilities included liaison activities with many AGMA technical committees, standards editing, educational meetings and assisting with the ISO standards development process.

In making the appointment, AGMA president Joe T. Franklin, Jr. said, "AGMA is fortunate to have an employee like Charlie who is well-versed in both the technical activities of AGMA and in business management issues. In his 20 years with AGMA, Bill Bradley has broken new ground for the association and the industry, especially on the international front. I know Charlie will continue AGMA's long tradition of technical excellence and, because of his knowledge of business issues, will be key to better integration of the technical solutions with the industry's business needs."

AGMA Chairman Stan Blenke praised the decision noting, "Promoting Charlie is well-deserved recognition of his contributions to the industry and the association and, more so, to his vision for both the department and the AGMA as we move forward."

Ed Lawson, chairman of AGMA's technical division executive committee, said, "From working with Charlie on a number of projects, I know him to have a great love for our industry and for AGMA. I know his detailed understanding of the technical needs of the industry and the capabilities of the AGMA will be of great value."

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Beachfront Gear Manufacturing

Lots of us became interested in gears while taking drafting classes in high school. Kirk Rademaker got hooked on orthographic projection as a teenager, but went about pursuing his passion for gears in a unique way.

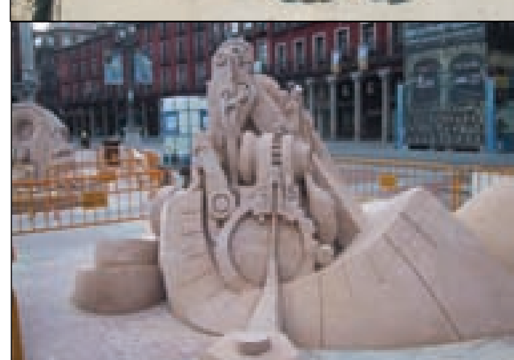
Rademaker became an interactive environmental artist and makes his living creating gears, transmission, nuts and bolts, turbines and various other industrial machinery out of sand. He's based in Santa Cruz, CA, and travels the world participating in corporate team-building events and creating customized sand sculptures for parties. Gears are a favorite of the artist's because of their sharp lines and abstract shapes.

"I just love doing gears because they're a sign of movement. My abstracts always have a lot of movement. I looked at some of the sculptures and decided they looked mechanical and went mechanical," he says.

It takes from three to five days for Rademaker to construct a sculpture. He compares the sand's consistency to working with stale mashed potatoes and, upon completion, sprays the sculpture with glue for adhesion.

Sand gears don't come cheap and Rademaker says he was recently paid $1,000 per sculpture per day, plus airfare and lodging at the Ritz-Carlton San Juan for a gas turbine he created for a conference.

"This isn't a job that I'll ever get rich doing, but I've been able to travel to Europe and all over the world making sand sculptures, and I love the creativity and working with people on the beach," he says.



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