gear TECHNOLOGY®

JAN/FEB 2014

TAKING BIG GEARS' MEASURE

GEAR TECHNOLOGY 30 YEARS 1984–2014

THERE'S NO SKILLS GAP IN KAUKAUNA

Q&A WITH ANTONIO MACCAFERRI

APPRENTICESHIPS: CAN THEY BE RELEVANT AGAIN?

TECHNICAL

ASK THE EXPERT: PLANETARY GEAR DESIGN

OPTIMAL USE OF DOUBLE FLANK TESTING (PART I)

NEW UPGRADES BOOST POWER SKIVING

THE XL GEARS PROJECT: SOURCING NEW "BIG-GEAR" MATERIALS

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THE JOURNAL OF GEAR MANUFACTURING

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GS 400

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JAN/FEB 2014

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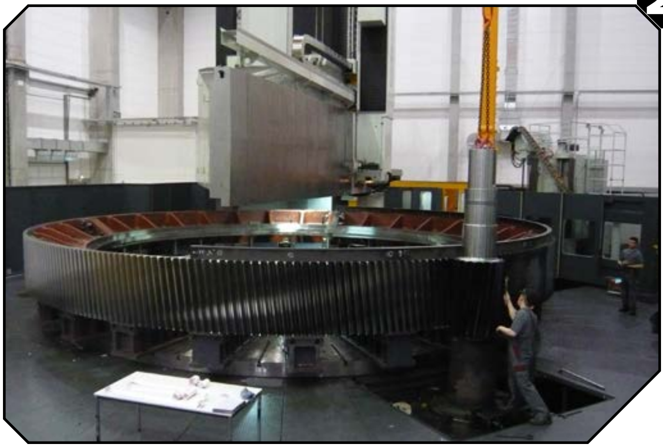

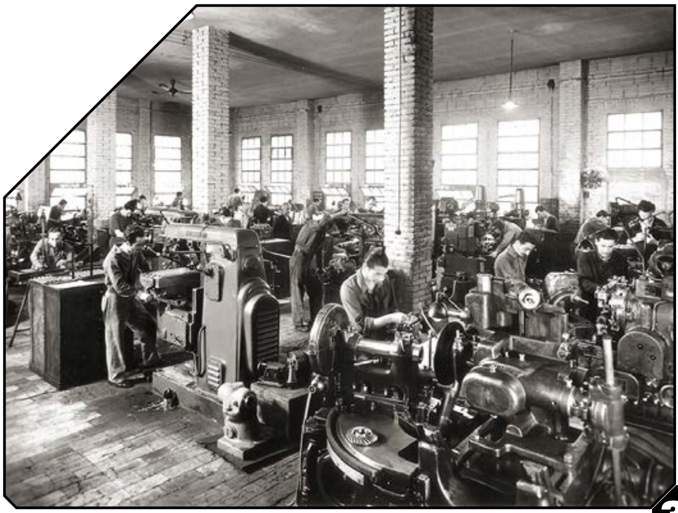

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features

technical

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our machines are making history

Gears for the Curisoity Rover were ground using the KAPP VUS 55P.

August 2006
NASA begins development on Mars Science Laboratory Rover(MSL)-later renamed Curiosity.

December 2008 *(date for illustrative purposes only)*
Critical gears are required for MSL's 6 wheels. An American manufacturer is chosen to produce these. KAPP VUS 55P is chosen to grind them.

November, 2011
Curiosity launches into space from Cape Canaveral Air Force Station, Florida.

August 6, 2012
Curiosity lands successfully on Mars.

September 2012 - July, 2013
Curiosity collects first samples of material ever drilled from rocks on Mars. Analysis shows evidence of conditions favorable for life in Mars' early history.

Gears good enough for NASA.

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KAPP NILES

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gear TECHNOLOGY

Vol. 31, No. 1

departments

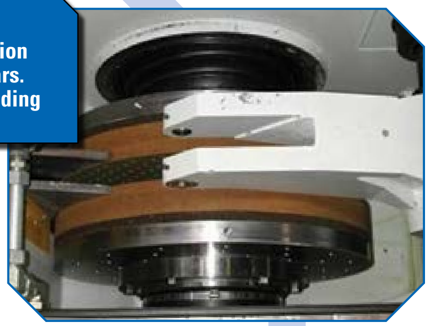
Photo courtesy of Wenzel America Ltd.

THE GEAR INDUSTRY'S INFORMATION SOURCE

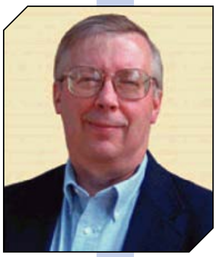
www.geartechnology.com

GT VIDEOS

The *GT* website currently features a video on C&B Machinery's Double Disc Grinding Cell for transmission gears. This cell will handle a total of 17 different gears. For additional information on this and other disc grinding solutions, visit *www.cbmachinery.com.*



Gear Technology Blog



Charles D. Schultz is offering his insights into the gear manufacturing industry and asking readers to share their knowledge as well. Read his most recent post at *www.geartechnology.com/blog*.

GT Events:

The 3rd International Power Transmission Expo (IPTEX) is dedicated to the gear and power transmission industries. India is rapidly turning into a global manufacturing hub, thanks to the country's manufacturing and engineering capabilities, vast pool of skilled expertise and its size. IPTEX 2014 takes place February 27 – March 1 at the Bombay Exhibition Center, Mumbai, India. See both websites (*www.geartechnology.com* and *www.powertransmission.com*) for additional information.

ONLINE EXCLUSIVE:

Big or Small: Inspection is Key to Success

Experts from gear inspection equipment manufacturers explain the special technology and requirements of inspecting large geared components in this online-only article.

www.geartechnology.com/big_gears.htm

LinkedIn

Check out the Gear Technology LinkedIn page for product previews for IPTEX 2014 including Gleason's 300GMS inspection system. The page also includes a recap of the latest Gear Technology articles and information you can use on the gear manufacturing industry.

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BPA WORLDWIDE

FOREST CITY GEAR

Pearls of Wisdom

Publisher & Editor-in-Chief
Michael Goldstein

In 2014 *Gear Technology* will celebrate its "pearl" anniversary—30 years. Although technically the anniversary doesn't happen for a few more issues, we're very proud of everything we've accomplished since 1984. So we're adding our "30 Years of *Gear Technology*" medallion to each issue this year, and we're starting the celebration now. At every milestone we look back on what we've achieved. When our publication turned 10, we looked back and saw how far we'd come. We did the same at 20 years, and now we're reflecting again at 30 years.

When we launched *Gear Technology*, the gear industry had never had a magazine of its own before. Our original premise was to provide a forum for the presentation of the best technical articles on gear-related subjects from around the world. We wanted to give our readers the information they needed to solve specific problems, understand new technologies and be aware of the latest applications in gear design and manufacturing. We believed then, as we do now, that the better informed our readers were about the technology, the more competitive they and their companies would be.

In the past, a very limited number of people had the opportunity to attend technical conferences and see information presented. Our goal was to make that information available not only to the VP of engineering who attended the conference, but also to all the other engineers, both in the office and on the shop floor, who could benefit from it.

That premise has served us well over the years, combined with the support of our readers, advertisers and contributors. So in celebrating our 30 years of publication, we're also reaffirming our mission and renewing our pledge to continue bringing you the best and most accurate information on gears that's available.

And that's not always easy. It takes a lot of extra effort, highly skilled employees and the contributions of experts in the industry who generously donate their time and experience. The gear industry experience on our staff is measured, not in months or years, but in decades. And when you add in the combined experience of our technical editors, with whom we consult each issue for accuracy and relevance, we're talking about centuries of gear industry knowledge.

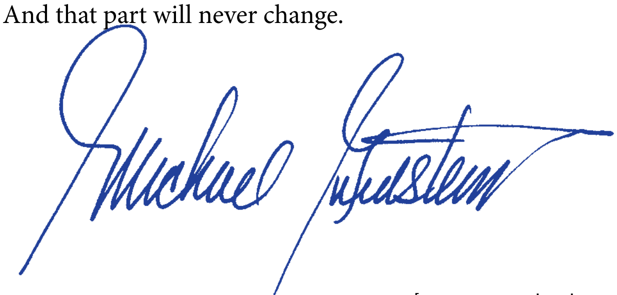
But we're not just a bunch of old guys sitting around kibitzing. In fact, as technology has changed over the years, we've continually embraced it to find new and better ways to bring you the information you need – via our website, our e-mail newsletters, our electronic product alerts, and most recently—thanks to our technical editor Chuck Schultz—our blog (which you can see at *www.geartechnology.com/blog*). Chuck posts interesting articles several times per week, including gear-related tidbits that have already begun to generate a lot of discussion and feedback.

The Internet has proven to be an extremely powerful tool for us, and our website, *www.geartechnology.com* is a great place for reflecting on our 30 years as a publication. I encourage each of you to see for yourself by making use of our extensive online articles archive. Every issue we've ever published can be found at *www.geartechnology.com/issues*. You'll find three decades of information that's been instrumental in the education of engineers. You'll find thousands of articles dating back to 1984—many of which are just as applicable today as when they were first written. We invite you to read them online, download them or send them to friends or colleagues.

The online archive is in large part *Gear Technology*'s legacy. You don't have to register, and you don't have to pay anything extra. From anywhere in the world, you can access any of the articles that have appeared in our pages since 1984. We want you to use those articles, to learn from them and refer to them when needed. It's not just our gift to the industry, but an example of our ongoing partnership with the industry.

Perhaps the thing that I'm most proud of is that we continue to grow, mature and improve as a publication. At each milestone, we've been able to look back and see how far we've come—not just since the beginning, but since the last milestone. Although our core mission remains the same, we're constantly striving to do better than we've done before, to be your best source of industry and technical information available—anywhere, by anyone.

And that part will never change.



NUM

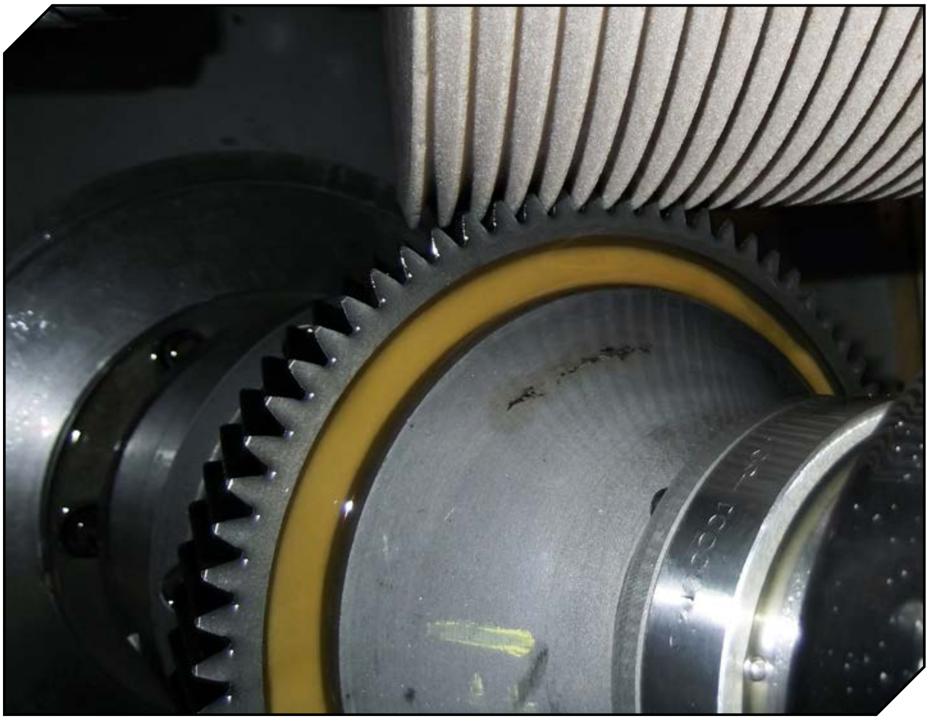
ANNOUNCES CNC SOLUTION FOR GEAR PRODUCTION

NUM has announced a high-performance CNC solution for gear production machines that fully automates threaded wheel grinding. Incorporating unique high-speed gear alignment technology that is believed to be an order of magnitude faster than comparable control schemes, the new CNC system dramatically reduces grinding machine threading-in times to accelerate throughput significantly. The comprehensive new solution is suitable for machine tool manufacturers seeking to improve the performance of their gear production machines, or to help companies expand their gear manufacturing range with threaded wheel grinders.

Based on NUM's new-generation Flexium+ CNC platform, the threaded wheel grinding solution joins the company's *NUMgear* suite of gear production software. Originally developed for gear hobbing applications, the capability of *NUMgear* has been continually extended and now includes solutions for a broad range of gear manufacturing processes, including shaping, grinding and honing, and is used by many of the world's foremost manufacturers of gear production machines.

NUM developed the latest addition to its *NUMgear* portfolio while helping an Asian gear manufacturing machine company to improve the performance of a prototype threaded wheel grinder. To improve grinding speed compared with current levels, NUM decided it needed to develop custom technology software. The principal aims were to reduce the time overhead of learning the teeth positions of the hardened gear prior to grinding, and improve the accuracy of the gear grinding process.

NUM's new product offers a comprehensive CNC solution for gear manufacturing machines. At the heart of the system is a high performance electronic gearbox that allows all master axes – such as the grinding, X, Y and Z axes – and the spindle (C axis) to be fully synchronized. As part of the development work on the new threaded wheel grinder, NUM has added a major new capability to the gearbox, which is now able to predict the acceleration of axes as well as their speed, in order to minimize synchronization time. Together with the Fast Gear Alignment, it forms part of the new *NUMgear* threaded wheel grinding application.



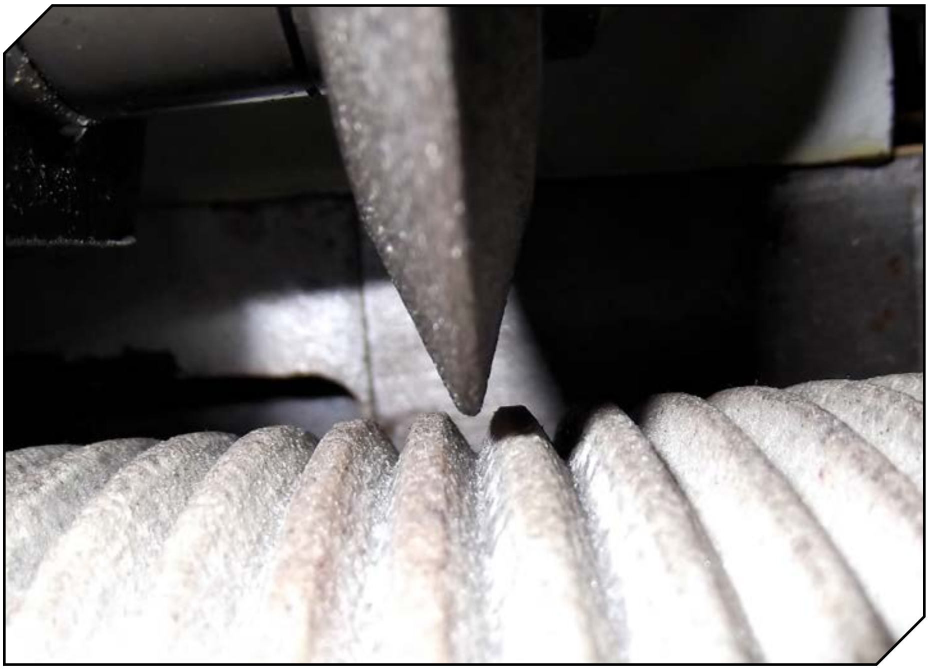
During gear production, "threading-in" – the process of bringing the grinding wheel into contact with the gear blank – involves continuously adjusting the position of the grinding wheel relative to the workpiece. A similar process is employed when bringing the machine's dressing wheel into contact with the grinding wheel. Using acoustic emission sensors to learn the sound signatures of a master gear and then using them to control positioning during production runs is a common technique for automating processes like this. However, the speed and accuracy of NUM's newly-developed Fast Gear Alignment Function eliminates the need for this entirely. As an example, aligning the grinding wheel with a 180 mm diameter gear with 71 helical teeth takes just 0.5 of a second – without any need to acquire acoustic signatures or make manual adjustments.

A second aim of NUM's development required that the gear grinder CNC control should generate gears as accurately as possible. The latest machine from NUM's Asian customer produced gears with a tooth profile quality of DIN class 7. During the development process, NUM found that the diamond plated dressing wheel did not come up to specification. To overcome this problem without incurring major tooling costs, NUM decided to support their customer by helping to modify the technology programs. The positive results of this action far exceeded expectations, and NUM's solution can help a machine to consistently grind gear teeth profiles to within 3.5 microns, comfortably achieving DIN class 3 – an improvement of four class levels.

The latest gear grinding development is an example of one of the major principles underpinning NUM's business philosophy: a willingness to customize its CNC technology for machine makers. NUM supports this with a decentralized

R&D structure which locates engineering staff around the world to allow it to work closely with machine builders. In this case, the new gear grinding solution was jointly developed by NUM's HQ in Switzerland and the company's technology centre in Changzhou, China, which is close to many major gear manufacturing machine builders and is currently undergoing major expansion.

"NUM is committed to helping its customers develop market-leading machines through close partnership," according to Peter von Rüti, CEO of NUM Group. "Our local presence and willingness to work directly with customers to resolve technical issues very quickly provide both parties with a key competitive advantage."



For more information:
NUM Corporation
Phone: (630) 505-7722
sales.us@num.com
www.num.com

Coord3

INTRODUCES BENCHMARK CMM

The new Benchmark CMM from Coord3 offers a high performance budget CMM with the added benefit of a small footprint. The unique "half-gantry" advanced alloy design has its X and Y axes at the same level, providing increased rigidity and offering a metrology platform for high accuracy small and medium part CMM inspection. The open structure Benchmark provides suitable ergonomics for the inspection of high volume production parts or single part inspection in the smaller manufacturing operations. Its compact size is suitable for production CMM or quality room applications and fits through a standard door width. The full air-bearing Benchmark CMM, with accuracy of 2.5 microns and a measuring volume of 500 mm × 400 mm × 440 mm comes standard with a Renishaw touch-probe. Benchmark is available in manual or CNC configurations. Manual units can be upgraded to full CNC in the field at a later date, offering a two-phase investment in CMM technology. The CMM can be used in job shops and can also be used as a programmable production gage. In addition, optional wireless thermal compensation allows the Benchmark to measure accurately in shop conditions. This Benchmark CMM is equipped with *TouchDMIS* software for CMM usability, offering the world's first all *TOUCH CMM* software with full CAD capability. *TouchDMIS* requires just a few hours of training and an incredibility short learning curve.

For more information:
Coord3 Metrology LLC
Phone: (855) 4-COORD3
usa.sales@coord3-cmm.com
www.coord3-cmm.com

Dillon

PROVIDES SOFT BLANK TOP JAWS

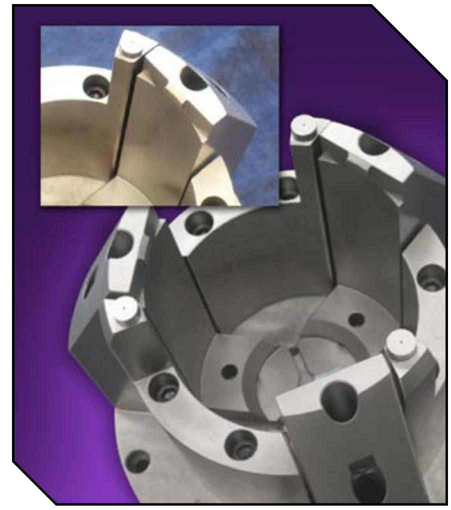
Soft blank top jaws from Dillon Manufacturing, Inc., provide a smooth gripping surface, low T.I.R. (Total Indicator Reading), and have greater holding power due to increased part contact. The smooth jaw surface leaves little or no markings on the finished surfaces. Available in 1018 steel, and 6061 aluminum, as well as 4140, 8620 and A2, brass, Delrin, or stainless steel to suit virtually any CNC or manual chuck project involving turned or bored parts. Dillon soft blank top jaws can be removed and later reused for the same operation, or machined to grip an altogether new part, until the blanks are consumed, making them ideal for machine shops which routinely handle parts with different shapes and geometries. The soft blank top jaws can be custom bored, turned, or shaped. A shoulder can be machine to provide a locating stop for parts to gain close tolerance repeatability for the parts length and depth. They may be left soft or heat treated if the material is steel, depending upon project and quantities machined. Dillon soft blank top jaws are suitable for second operation finishing work such as shafts, gear blanks, wheel hub, and bearings.

For more information:
Dillon Manufacturing, Inc.
Phone: (800) 428-1133
sales4@dillonmfg.com
www.dillonmfg.com

Northfield Precision

AIR CHUCK INCLUDES TOP TOOLING AND AXIAL LOCATOR

Northfield Precision Instrument Corporation introduces their Model 1000 sliding jaw air chuck. This air chuck, with 0.0001" TIR, has a special top tooling and axial locator. This particular air chuck was custom designed for a gaging company that needed to grip a small area of a large casting so they could check OD runout of their part. Special, tall top jaws are diamond-coated for a secure grip on the casting. An axial locator with button pads is used as a resting surface for the part's flange while swallowing the rest of the part. Northfield Precision designs and manufactures air chucks for any lathe, boring machine, grinder or VMC. Models include through-hole, high-speed and quick-change. Chucks are available in



SAE or metric, in sizes from 3" (76 mm) to 18" (457 mm). Accuracies of 0.001" to 0.00001" (0.254 m) are guaranteed. Custom workholding chucks and jaws are available and free engineering assistance is offered.

For more information:
Northfield Precision Instrument Corp.
Phone: (516) 431-1112
info@northfield.com
www.northfield.com

IDC Industries

INSTALLS NILES ZP24 GEAR GRINDER

IDC Industries is installing their new Niles ZP24 gear grinder. This new machine, the largest of its type in Michigan, will allow IDC to better serve their customers in the steel, mining and paper manufacturing industries worldwide. IDC repairs, rebuilds and manufactures new gears and reducers from their new facility in Clinton Township, MI. The new Niles ZP24 grinder is capable of grinding internal and external gears over seven feet in diameter, and includes on-board gear inspection.

This machine can also grind worms sectors and cutting tools. Jamie Pangborn, president of IDC Ind., said, "The Niles ZP24 represents the state-of-the-art in gear grinding. It fits perfectly with our growth plans and our ability to provide solutions to our customers in a wide range of industrial markets." In addition, Pangborn commented, "Clinton Township has been very supportive and helpful in our business development since our move here in 2012. We anticipate continued growth through all of 2014 and beyond."

IDC Industries, Inc. was established in 1968 to provide industrial drive components such as pulleys and gearboxes. It soon evolved to rebuilding gear reducers as a response to customer requirements. Now, IDC engineers and builds new gearboxes, open gears and rebuilds customer units for virtually any large industrial application.

For more information:
IDC Industries, Inc.
Phone: (586) 427-4321
www.idcind.com

Precipart Corp.

EXHIBITS HIGH PRECISION GEARS AT MD&M WEST

Precipart, a global supplier of custom mechanical components, gears and motion control assemblies, exhibited at MD&M West, February 11-13, 2014 in Anaheim, CA, with a wide range of high-precision machined parts, molded and assembled components used in medical devices. Located in booths 3266 and 3268, Precipart featured several examples of its motion control technology along with a variety of mechanical components designed and manufactured with advanced materials according to precise specifications and exact tolerances. Precipart products are used in many different medical technology applications, including: surgical tools and instruments, powered surgical handpieces, orthopedic implants, diagnostic equipment, surgical robotics and drug delivery systems. As an ISO 13485 registered company, Precipart provides turnkey solutions, including concept development, design, prototype, qualification and manufacturing for medical technology and other industries. Precipart product and engineering experts were available at the show to speak with attendees about medical and other applications, as well as the company's approach to continuous improvement, lean manufacturing and design for manufacturability.

For more information:
Precipart Corporation
Phone: (631) 694-3100
www.precipart.com

Hexagon Metrology

ANNOUNCES LEICA B-PROBE

Hexagon Metrology recently announced the Leica B-Probe, an entry-level, wireless probing device which extends the capability of the Leica Absolute Tracker AT402. The handheld Leica B-Probe is designed for the inspection, alignment and assembly of large scale fabrications such as railway coaches, construction and off-highway vehicles or agricultural machinery.

The Leica B-Probe works within a 32.8 ft (10 m) radial distance from the AT402 with an accuracy of +/- .008 in (0.2 mm) over a full measurement range, offering greater capabilities and flexibility over similar systems that have fixed-base stations. The lightweight 6.7 oz. (190 g) B-Probe features IP50 certification and is AAA battery-powered. By using the move station method, the working range of the system can easily be multiplied with almost no loss in probing accuracy. For even larger parts or measurements that require higher accuracies, a standard retroreflector can also be used in combination with the B-Probe to take full advantage of the AT402's accuracy and 525 ft (160 m) radial measuring range.

"The B-Probe fills a niche between reflector-based measurements and our high-performance 6DoF (six degrees of freedom) offering based on the Leica T-Probe and the Absolute Tracker AT901," said Duncan Redgewell, general manager of Hexagon Metrology's Laser Tracker Product Line. "We recognized that many industries manufacturing large-scale assemblies required range, portability and inspection of hidden features, but had only modest accuracy requirements. The B-Probe was designed specifically for these users."

For more information:
Hexagon Metrology
Phone: (855) 443-9638
www.hexagonmetrology.us

Forkardt

RELEASES OMNIGRIP COLLET SYSTEMS

Forkardt OmniGrip Collet Systems are flexible, sealed collet heads that interchange in seconds and are available with spindle mounts for most brands of CNC lathes. However, quick changeover is not the only benefit you'll experience. With an accuracy of .0004" TIR on the A and D styles, and a .0008" TIR on the DL style, the OmniGrip falls in the "special accuracy" collet classification. These systems achieve the same gripping capability as conventional collets while using less draw bar force.

Vulcanized rubber bonds the hardened, chrome-nickel steel collet sections together providing superior elasticity for repeated opening and closing of the collet without deterioration. A manual wrench can be used to compress the collet providing quick changeover in seconds instead of minutes. The collet head has a gripping range of ±.020" (.5 mm) of its nominal size to allow variation in bar stock without having to change the collet. True parallel clamping minimizes stock "push back" that could create inconsistent part lengths. Purchase one spindle mount and interchange collet heads from job to job. Forkardt

OmniGrip collet heads are fully interchangeable with competitor's models.

An emergency collet can be kept on hand for just-in-time machining when the proper size hardened collet is not in your tool drawer. The taper and collet seat of an emergency collet are hardened while the ID and the face of the collet head are soft. A face boring ring will hold the collet in nominal position for boring to size. Emergency collets are reusable. Standard collets, ordered to size, are stocked in round smooth, round serrated, hex smooth, hex serrated, square smooth, emergency and S-master style collets. Square sizes are made to order.

The OmniGrip Collet Systems are available in 42, 65 and 80 mm sizes and are suitable for machines experiencing multiple changeovers daily and where stock variations occur. When using a Forkardt OmniGrip system, it takes less than 10 seconds to change a collet. Setup time is drastically reduced when compared to 191 seconds to change three jaws on a power chuck or 79 seconds that it takes to change a collet in a standard collet chuck. Test results from repeated collet actuation indicate a highly durable, fully sealed gripping solution.

For more information:
Forkardt
Phone: (800) 544-3823
www.forkardt.us

Suhner

MULTI-MASTER FLEX MACHINING UNITS PROVIDE SOLUTIONS

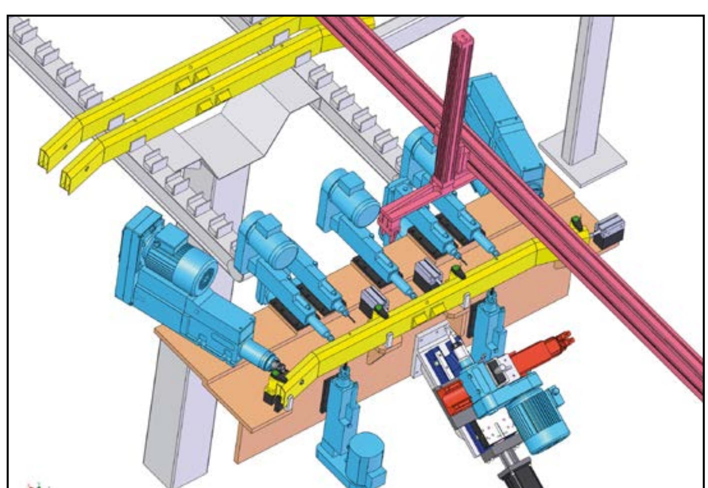
Bulky part machining can often become very difficult to integrate into a manufacturing process, when attempting to perform multiple operations on conventional CNC machines. Limited space or axis travel, one-sided spindle or tool accessibility are common restrictions when trying to design and fit multiple tool requirements onto a rigid machine concept. In addition, cycle time demands and accessibility issues from all sides and angles can make a single tool, 3-axis CNC machine option a losing proposition.

One new solution involves compact and self-contained single tool Multi-Master flex shaft machining units from Suhner. These units are modular in design, which means they can be positioned in any direction around a workpiece. In most cases, all operations can be performed in one cycle, thereby reducing the overall machining cycle time to a minimum. Since all tooling modules work simultaneously, the cycle time is basically determined by the longest single machining operation and not the addition of all the tools working together. There are virtually no limitations to part size and the number of tools that are engaged at the same time, with this arrangement.

Suhner offers a complete spindle program with optional feed systems...pneumatic, hydraulic and CNC...available in a quill feed or slide-and-spindle design. In combination with modern tooling technology, Suhner Multi-Master machining units can achieve a high degree of performance and accuracy, when incorporated into a machine design.

Solid carbide tools permit cutting speeds up to 300 m/min in aluminum, at feed rates of 0.5 mm/rev. These rates result in very short cycle times and extended tool life.

For more information:
Suhner Industrial Products, Corp.
Phone: (706) 235-8045
Automation.usa@suhner.com
www.suhner.com



R&P Metrology

ANNOUNCES CMM CAPABILITIES FOR PORTABLE GEAR PRODUCTION

R&P Metrology GmbH announced new measurement capabilities for the RPG PM 750/1250 Portable Gear Metrology machines. When the system is used with the available docking station, it is capable of a full range of 3-D prismatic metrology. The RPG PM 750/1250 Portable Gear Metrology system now can perform CMM measuring tasks with full CNC control and lab grade accuracy.

According to Hans Rauth, president of R&P Metrology, "The docking station, with the extremely accurate rotary table, extends the use of the PM system beyond the plant floor, to the inspection lab. Not only can it use generative metrology for gear inspection, it can become a precise CMM with the customer's choice of software." All R&P Metrology systems adhere to the I++ (Inspection Plus-Plus) protocol and can utilize any CMM software that is compliant, such as Wenzel and Zeiss. Rauth continued, "When used as a portable system, the PM 750/1250 can measure gears of unlimited size. We offer docking stations with 3,000 mm outside capability for inspection lab use for gear inspection and 3-D CMM metrology."

When the R&P PM 750/1250 system is docked, the built-in active rotary table provides higher accuracy for form and roundness measurements, as well as faster measurement times than CMMs without an integrated rotary table. This gives customers a uniquely flexible machine with both shop floor portable gear inspection and inspection lab CMM capabilities, with high accuracy in both modes – truly the best of both worlds.

R&P Metrology designs and builds metrology equipment, concentrating on medium and large parallel axis gears, bevel gears, tools, shafts, bearing rings and 3-D parts. The range starts at approximately 1.0 meter in size. R&P also offers hybrid systems that uniquely combine gear measurement with conventional CMM metrology.

For more information:
Kapp Technologies
Phone: (303) 447-1130
www.kapp-niles.com

Oelheld U.S.

DEVELOPS HSS GRINDING OIL

SintoGrind HSS was especially developed for profile and flute grinding of steel alloys and in particular for High-Speed-Steel and medical steel. It is based on synthetic Polyalphaolefins free of chlorine or heavy metal compounds. All additives are synthetic and have excellent high pressure (EP) and superb lubrication properties. Most important the product is physiologically absolutely safe. Oil misting and evaporating tendency is very low and it has a suitable viscosity-temperature relationship. Due to its 100 percent synthetic formula, SintoGrind HSS cools, lubricates and cleans better than any mineral oil based grinding oil and has grinding wheels remain clean and unclogged. SintoGrind HSS has an extremely low evaporation and misting rate and sheds air very quickly and does not foam.

For more information:
Oelheld U.S.
Phone: (847) 531-8501
www.oelheld.com

SUPER-SIZED Quality Control

A Guide to Improving Big Gears

Matthew Jaster, Senior Editor

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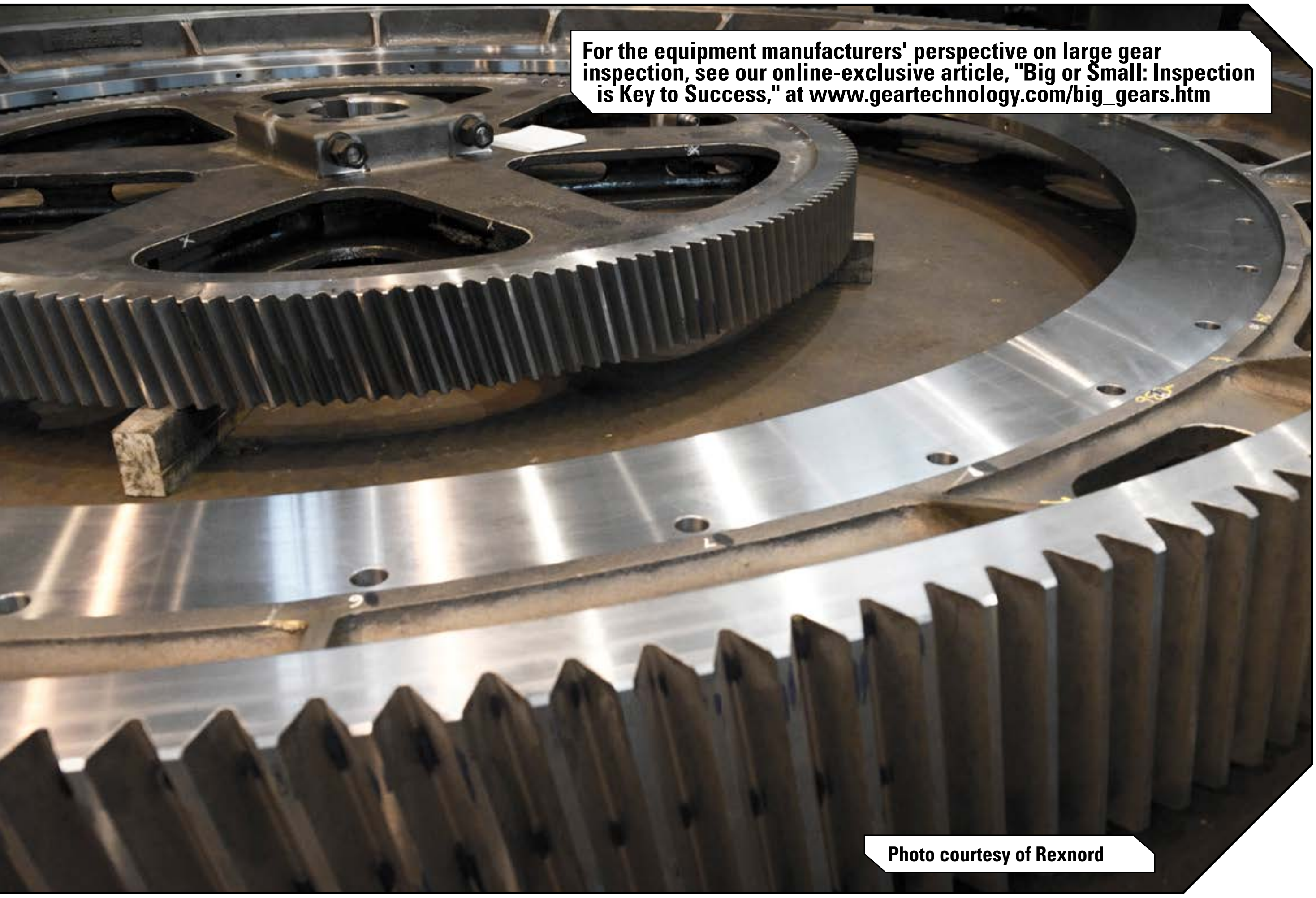
It's not easy being big. Maybe that's not exactly how the phrase goes, but it's applicable, particularly when discussing the quality requirements of large gears. The size alone promises unique engineering challenges. Those involved in producing large gears continually strive to meet higher quality requirements, adapt to new testing methods and seek out ways to top their own manufacturing capabilities. Seems an awful lot needs to go right in order to achieve the quality requirements necessary to survive in the big gear business.

"In-shop inspections are mandatory," says Fabrice Wavelet, product line manager, Ferry Capitain. "No customer can afford to put a gear into service that is not 100 percent sure/sound. A mining company, for example, can do nothing without a functional driving system on its mill, as 100 percent of the ore is going through it. Failure is not acceptable."

"The quality of large gears takes technical expertise, years of experience and proper equipment," says William Quinn, business development lead, mill products at Rexnord. "Improvements in materials, lubrication and gear quality levels have made positive impacts in the life of today's large gears. Modern gear cutting and grinding machines need to be met with equally advanced geometric inspection equipment."

"With higher accuracies of the gearing we can extend the lifetime of the equipment," says Holger Fritz, product manager mill gearing, Hofmann Engineering. "To be able to determine higher qualities, the measuring equipment has to be a minimum of one accuracy level higher than the item that is being inspected. This is a challenge for the future and we're working hard to improve the inspection methods and one day might have a minimum big gear (above eight meters) quality level of AGMA 12."

"While it's always good to improve the quality of large gears, the current requirements are *already* impressive thanks to ASTM A609 and ASTM E709 or E1444," adds Wavelet. "The same requirements for a 3 m gear and for a 10 m gear makes the 10 m gear of a comparatively higher



For the equipment manufacturers' perspective on large gear inspection, see our online-exclusive article, "Big or Small: Inspection is Key to Success," at www.geartechnology.com/big_gears.htm

Photo courtesy of Rexnord

quality, simply because casting such a heavy part (more than 20 tons a segment, finished weight) has nothing to do with casting a 3-ton segment."

Tools of the Trade

What's the best way to inspect these large gears? According to our big gear experts, it's a combination of many different tools.

"Hofmann Engineering is using laser trackers for the dimensional inspection on big mill gears and portable CMM arms to determine the form on the involute and the lead line," Fritz says. "For the pitch we use a special D&P pitch tester. But the ultimate test is still the mesh test of a precision ground mill pinion that is measured on a CMM together with the mill gear. Mill pinions are always measured on a gear CMM machine."

He adds that before they even start machining at Hofmann they use ultrasonic units and magnetic particle units to determine the quality of the material or of the welds.

"Varying challenges exist depending on the inspection required; in-process nondestructive inspections can be done with relative ease in the manufacturing environment. Once the gear is in operation, the same type of nondestructive testing can take a significant amount of time—from a couple hours to multiple days. Usually this involves shut down, removing guarding, and cleaning the area to be inspected of lubricant," Quinn says.

Other operational inspections can be completed continuously or with ease, such as vibration monitoring, lubrication testing, and infrared temperature monitoring," says Quinn. "In-process non-destructive testing is done primarily with magnetic particle inspection and ultrasonic inspection. Complex geometry in large gears can present challenges to ultrasonic inspection, but with skilled technicians and control processes we can overcome these."

For field inspections, infrared thermometers and cameras, and multi-axis vibration monitoring equipment with read out capability make continuous monitoring relatively straightforward. "More in depth field inspections of the gear may involve using a MAAG TMA gear checker to check pitch, magnetic particle inspection with a hand yoke, and standard ultrasonic inspection equipment," Quinn adds.

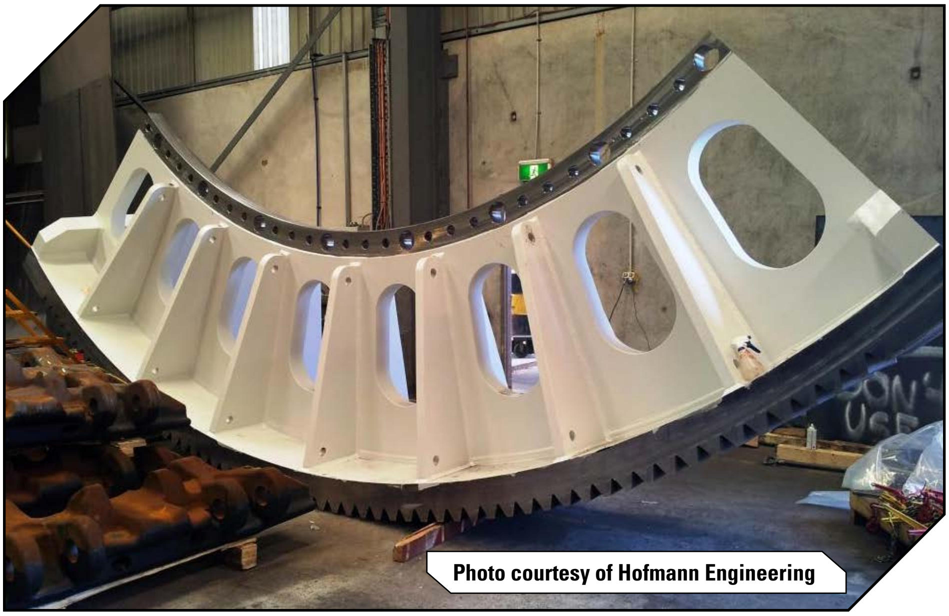


Photo courtesy of Hofmann Engineering

"The development of UT Phased Array and of Eddy Current (classical or Phased Array) is of the highest interest for us. These techniques have been successfully used on site, allowing an interesting time saving compared to the classical methods, but they are not economical on large surfaces and in-process inspections … for the moment," Wavelet says.

"The question regarding the most useful inspection can't really be answered as all the above mentioned inspections are necessary to prove that we manufactured a top quality gear," Fritz adds.

Why are so many different inspection requirements necessary for big gears?

"The size of the items in question," Fritz says. "Temperatures for example have a big impact on the final sizes and a temperature controlled environment is necessary."

Also, large gears today imply large module and consequently, large rim thickness, particularly when talking about foundry. "I suppose it is the same thing with forgings or plate; the main challenge is to maintain the high quality level required into such parts. For a gear module 36 in cast steel (something that was exceptional 10 years ago and usual today), the as-cast gear rim is easily wider than 220 mm, considering both the machining stock and the riser deformations. Avoiding internal indications as small as 5 cm^2 in this outer rim is the highest challenge a foundry is confronted with today," says Wavelet.

Such defects have to be avoided or the foundry undertakes the risk of having the part rejected.

"This is where the experience and the knowledge come into the equation, whether the gear is in steel or in ductile iron. The number of foundries capable of doing small gears (i.e. 3 m) in cast steel or ductile iron is high throughout the world. The number of foundries capable of producing the largest and most powerful gears today can be counted on the fingers of one hand," Wavelet says.

Although size matters, the inspection techniques (ultrasonic or magnetic particle) are identical for small and large gears… as well as the quality requirements.

"These techniques are reliable and repeatable when used by qualified personnel. The type of products being made for narrow markets use in-house inspection people. This is what we do in Ferry Capitain. All our inspection personnel are qualified ISO 9712 / Cofrend level 2 (at least equivalent to ASNT level 2) for UT, MPI, dye penetrant test and radiography, although these two last techniques are not commonly used on gears. Use of classical techniques, rather than the UT Phased Array, for example, is still justified as this saves time in production, while the equipment is economical. We believe at Ferry Capitain that the new techniques, including UT Phased array, are of the most interest, but for expertise, not production control," Wavelet says.

"Magnetic particle inspection is still the industry standard for checking surface discontinuities; it is widely used and acceptance criteria are clearly defined by manufacturers and industry standards," adds Quinn. "Ultrasonic inspection is the accepted method for checking subsurface discontinuities. Continuous temperature monitoring, lubrication testing, and vibration monitoring are still the most beneficial inspections that can be performed in the field. Monitoring these parameters over time and tracking deviations from baseline readings quickly allow a user to identify potential problems."

One wonders how much time these techniques take from a quality control perspective.

"It really depends on the type of inspection being performed. In-process ultrasonic testing of our largest ring gears can take up to 7 hours; magnetic particle inspection of the teeth can run up to 3 hours per segment," Quinn says. "Field inspections consisting of contact checks and root clearance measurements can take from 4 to 8 hours. More involved inspections are usually scheduled during planned shut downs and can last from a couple days to a week plus."

Big Gear Standards

One area that continues to play a vital role in the inspection process is the gear standards. Whether it's AGMA, ISO, DIN or any others, they need to be updated and modified regularly to keep up with demand.

Fritz at Hofmann Engineering believes AGMA standards cover most of the inspections. "It would be good if they would have chapters about mesh test results, surface finishes and general guidelines for dimension tolerance. As a gear designer/manufacturer you know all about these things, but most third-party inspectors want to have some documentation/recommendation of an AGMA standard referring exactly to these points," Fritz says.

"AGMA 6014, and especially the next version, which should be issued sometime next year, addresses all the inspections and quality requirements large gears need to respect. We, at Ferry Capitain, have developed an intensive R&D program on materials and defects with the aim to be able to quantify the influence of surface or internal defects on the service life," Wavelet says. "The number and concentration of indications do not matter to us as one defect is enough to ruin a complete gear and compromise the driving function of it. Then, the size of a unique defect, and its location, are the parameter to be considered. A better understanding of the nature of the defect and its influence on the service behavior is what we are working on today."

Quinn at Rexnord agrees that the standards work but tweaks are in order.

"AGMA 6014 addresses magnetic particle, ultrasonic, as well as geometric inspections required during the processing of large gearing. The annex contains essential operational inspections and recommended frequency for large gears, recommending lube analysis, vibration monitoring, infrared alignment, visual inspection, gear joint tightness, pictures, contact pattern and root clearance. (But) the AGMA standard does not directly address nondestructive field inspection of ring gears," Quinn says.

Pushing the Technology Forward

What's next for inspecting big gears? What can the industry look forward to in the near future? Hofmann, Rexnord and Ferry Capitain all have ideas. The technology and the machines will grow, according to Fritz.

"I know of an eight-meter machine so far but I know that there are plans to build bigger machines. The challenge of big gear measurements will be to measure the much tighter tolerances of AGMA 12 or 13 on 15 m gears," Fritz says.

"The development of computer-assisted are not economically viable for in-shop inspection and for Eddy Current. It is thus probable Eddy Current will take over MPI in the close future, as this technique is easy, fast and reliable. As for

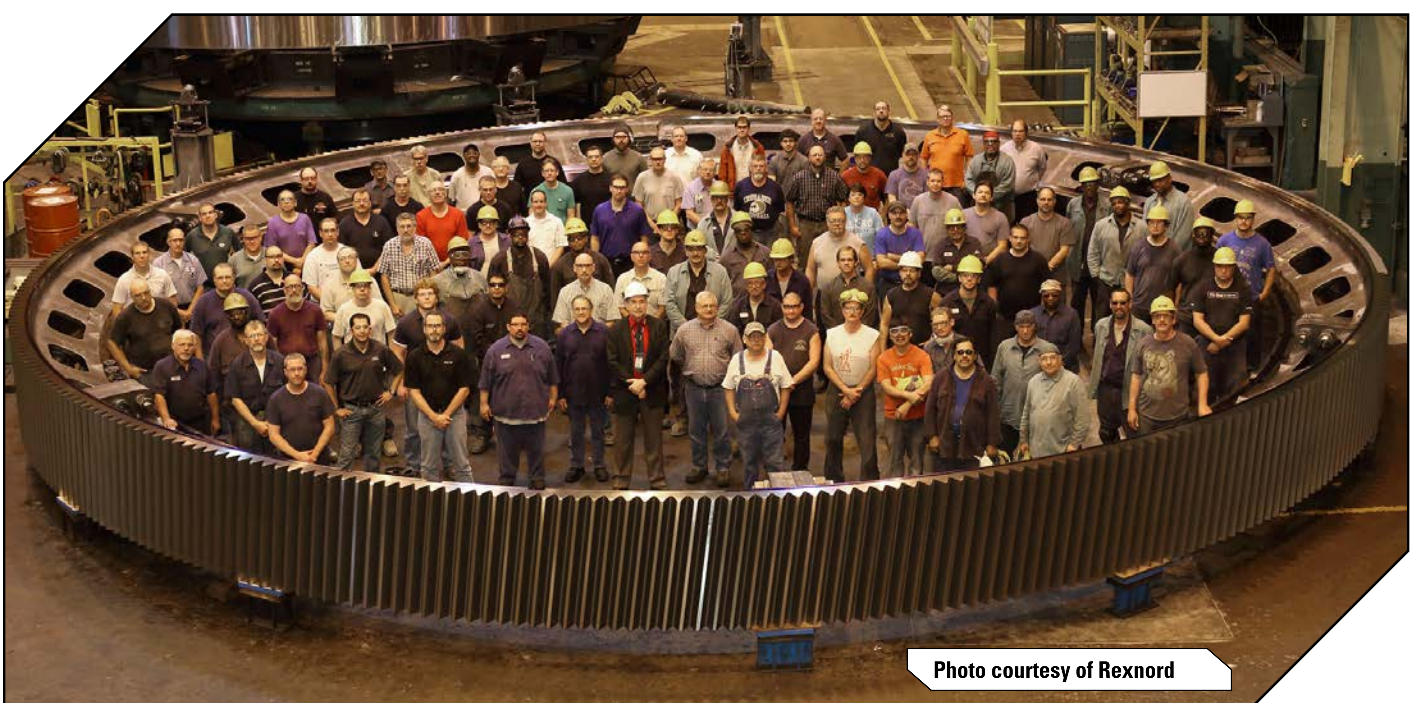


Photo courtesy of Rexnord

UT Phased Array, the only question that inspection equipment manufacturers have to solve is the question of probes: they have to be reliable, economical and adaptable to all kinds of materials, surface finish and size," Wavelet says.

"Improvements in continuous monitoring system analysis will offer faster indication of distress, helping plant personnel to make necessary adjustments and avoid costly downtime. Condition monitoring/analysis systems allow the user to identify a problem in one area before it has an adverse effect on equipment in another. Eddy current inspection is likely to gain ground as a quick and thorough way to check for surface discontinuities in ring gears, allowing the user to log a permanent record (map) for future reference. Phased array will gain wider acceptance as an improved method for inspecting subsurface defects as acceptance criteria are established and validated in the large gearing industry," Quinn says.

The technology is changing when it comes to inspecting large gears. Manufacturers of these components will be the first to tell you there are no shortcuts. Good news for those looking for the highest quality components for a massive application.

Photo courtesy of Ferry Capitain

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Learn to Work, Work to Earn

Apprenticeship programs are back in the USA — sort of

By Jack McGuinn, Senior Editor

Mike Bryan, (center) veteran Bosch Rexroth training specialist, has had a lot to do with the success of the German company's apprenticeship program here in America. Bosch Rexroth's long history and an inherent dedication to training their own, coupled with Bryan's expertise and dedication, are a powerful combination (photo courtesy Bosch Rexroth).

Once upon a time, long before shiny young people began eagerly humiliating themselves on The Donald's cable "reality" dumbfest *The Apprentice,* to actually *be* an apprentice in this country was a noble enough thing. And to learn, train, and work to become a master craftsman — especially, by the 1900s, in the industrial trades — was to earn the respect of ones' peers and "betters."

The apprenticeship formula was a triad representing a mutually beneficial — almost populist — bargain struck between a local area's businesses, indigenous workforce, and local public school entities. This unofficial clause in the country's social contract served its willing participants and the nation well. Proof of this was provided at war's end in 1945, and the United States found itself — by an almost grotesque serendipity (due to a war it did not want) — the one and only economic/military superpower on the planet. Hell — along with maybe Switzerland and a few other countries that managed to avoid the hostilities, ours was the only country left that *had* an economy.

Those of us paying attention in grammar school history class know that apprenticeships harken back at least to medieval times. Here in the U.S. the apprenticeship movement, brought over from Mother England, took hold in the early 1700s, once there was semblance of an economy not entirely agrarian-driven. With the blooming in the mid-1700s in England of the Industrial Revolution, and its booming in America from the early to mid-1800s, apprentice programs flourished in this country's cities and towns — helping to plant, grow and sustain OEM factories and family job shops with the aid of a steady stream of eager and able tradesmen. Until, that is, the 1970s — and the beginning of U.S. manufacturing's ongoing, thus far inexorable, decline.

Like a marriage gone bad, the trusting relationship between those very same businesses, workers and local school boards frayed over the years and finally broke down — each group seemingly losing relevancy, one to the other. Result: cuts in apprenticeship funding and other programs led to a disconnect between young people and any interest they may have once had in pursuing work in high-tech manufacturing.

And so from the 1970s onward apprenticeship programs began falling increasingly into disfavor, although falling down the memory hole might be more precise. It wasn't long before anybody was even talking about apprenticeships. But by that low-point, the business consensus had coalesced that apprenticeship programs were "too expensive," and led to "job flight (we train them, they go elsewhere)." From the educators, with full parental backing, it went something like, "We don't educate kids for manufacturing jobs. What's the point?"

With dwindling funding, technical schools across the country folded their tents and its precious pool of qualified and dedicated instructors was lost, forced off looking for jobs. And as the '70s unrolled, kids with Education degrees were proliferating like drunken rabbits; but not to teach gear crowning or gear design. In fact, a great many of them ended up not teaching anything at all and pursuing altogether different careers.

Back here in 21st century U.S.A., it is truly a *Bizarro World* moment when you think about it: even some 40 years out, as need and demand continue for skilled manufacturing talent, apprenticeship programs — a proven winner throughout history — are largely ignored in this country. Indeed, despite support for apprenticeships from President Obama, who cited the German model in his last State of the Union address, these positions are becoming ever harder to find. Since 2008, the number of apprentices has fallen by nearly *40 percent*, according to a Center for American Progress study.

Oh — almost forgot. Meanwhile, over in Europe: Germany, England, France, etc. — apprenticeships? Flourishing. But not so much the European economy right now, so go figure.

Who said this stuff had to make sense?

But the end of 2013 did bring some welcomed good news with the distribution of a press release announcing, "Bosch Rexroth's Mike Bryan Named Trainer of the Year by the German American Chambers of Commerce (GACC)."

Bryan is a training specialist — and obviously a very good one. He trains

American workers at the German-owned Bosch Rexroth manufacturing facility in Fountain Inn, S.C., and was recently recognized for his invaluable expertise in workforce training and skills development — especially of young people, where it counts most. But it so happens that this year's award was presented in recognition of Bryan's success with Bosch's apprenticeship program (*In fact, it was the impetus for this article*). So we presented some apprenticeship-specific questions to three people who are intimately involved in working to help American manufacturing — and its workers — restore their swagger and reclaim some bragging rights.

We began by asking Bryan why there aren't more apprenticeship programs in the U.S., since the ones that do exist here seem to be successful, regardless of ownership.

"Apprenticeships traditionally haven't played a major role in the educational institutions in the U.S. or in the U.S. business environment. I think the tradition here has always been oriented more toward a short-term internship, followed by entry-level employee 'baptism by fire.' The difference now is that everything is moving much faster, so we need to bring in technically skilled employees who are ready to go."

As for Laura Hopkins, executive director of the Washington state-based Aerospace Joint Apprenticeship Committee (AJAC), it's a three-part answer (italics ours): "*Infrastructure*: the United States' entire education system and funding structure are set up to support students pursuing the four-year college degree; this type of degree has been established as a pathway to success. *A lack of awareness*: no marketing of apprenticeship programs to employers, candidates, parents, teachers, counselors, etc. *The history of manufacturing*: outsourcing manufacturing jobs to other countries."

In researching this article, it appeared that those companies with the most successful apprenticeship initiatives were foreign businesses with U.S. locations, such as the mentioned Bosch Rexroth, but also BMW, Tognum AG (now Rolls-Royce Power Systems AG) Michelin, and Germany's Continental Tire among them.

In acknowledging the many valuable benefits of the Bosch program, one can't help wonder why more — a lot more — American-owned companies aren't doing the same thing.

"Sometimes our international investors can also be tremendous innovators," said Scott Paul, Alliance for American Manufacturing (AAM) president. "After all, they've come willingly into the American system, while many American companies spend a lot of time fighting or complaining about our system. Companies like Siemens and ArcelorMittal, just to name two, have fantastic programs that could be called apprenticeship programs.

"That's not to say there are no good ideas that have originated from the U.S. In my travels I've come across dozens of great examples of companies that have partnered with their union or workforce and local community college to develop strong programs."

We also asked Bryan why he thinks Europe leads the way on apprenticeships.

"The concept of apprenticeship has a very long tradition in Europe," said Bryan, "and especially in the area of technical education. It's a model that's been very successful. However, the apprenticeship idea has gained significant traction in the U.S. on its own.

"Especially when I think about the students I mentor who are involved in the FIRST Robotics program (*An international high school robotics competition organized by For Inspiration and Recognition of Science and Technology*), they leave the program ready for technical challenges. And FIRST has been around since 1989. We use FIRST Robotics as part of our high school youth apprentice program and it serves as a feeder program for our adult apprenticeship as well."

Turning once again to Paul, It has been written that "The central answer to the mismatch between jobs and employment is a 21st-century apprenticeship program." If you agree, how can that happen on a national scale?

"I disagree with the thesis. I'm more of a *Field of Dreams* kind of guy: "If you build it, they will come." The central problem is not enough jobs, rather than not enough pathways. If our economy grows at a strong rate, you'll see more jobs, and along with more job openings, you'll see more innovative apprenticeship and workforce programs materialize to meet the demand. While some like to think it's the other way around, that's simply not the case."

The responses by Bryan and Paul led to wondering whether Hopkins' AJAC recruits—or needs to recruit—apprentices.

"No, AJAC is a non-traditional aerospace and advanced manufacturing apprenticeship program that does not serve as a placement agency for apprentices, but instead is employer-driven. AJAC enrolls the employees of its 140-plus participating companies (training agents). AJAC and its advisory committee, comprised of employers and employees, have developed and implemented AJAC's apprenticeship programs based on employer and industry need for machinist (aircraft-oriented); aircraft mechanic airframe; precision metal fabricator; and tool and die maker." AJAC does attend career fairs and other outreach events to create awareness of apprenticeship programs, explain the benefits and requirements, and to educate attendees on how to start a career in the aerospace and advanced manufacturing trades, which is by contacting one of AJAC's participating companies."

Backing things up a bit, we asked Bryan—a guy who should know—if reaching students at the elementary and middle school age is perhaps the best time to spark their interest in manufacturing—years before the job fairs and career days, etc.

"The earlier, the better," he affirmed. "One of the schools I work with is now implementing FIRST programs in their elementary and middle schools, too—and the kids love it. Clearly, if students become active with technical education early in their lives, they'll have more options later in life—even if they choose a different career path."

And as a follow-up: Are there any prequalification steps required before one joins the Bosch apprenticeship program? (As you'll see, the program is not for slouches—goofs need not apply.)

"Applicants wanting to join our apprentice program are well aware that they are competing with other applicants for a chance to become a Bosch Rexroth apprentice," he said. "They are working on gaining a competitive advantage by preparing for the entry-level position with taking various courses at Greenville Technical College, learning manufacturing processes, and working on their workplace skills.

"The applicants have raised the bar for becoming a candidate for our program. Candidates are those that move to the next level of the selection process and they must be ready to learn and be able attend college at the starting level of our program's academics."

Some have called for a public-private apprenticeship initiative, saying it would increase competitiveness and youth employment, upgrade skills and wages, achieve positive returns for employers and workers, and reduce government spending if companies played a larger role (i.e., spent more) in skills development. We asked Paul if that could ever happen here.

"I think there's a reasonably strong chance that we'll see more robust public-private partnerships to promote career pathways and apprenticeships," he said. "And I think that more executives will concede they have to invest more company cash in these, and not wait for some massive (but imaginary) spending increase from Washington."

Others point to the thoughtless disparity in public funding of the college-only approach as the top reason why apprenticeship programs went away. Government spending on colleges and universities tops $300 *billion* per year, while outlays to apprenticeship programs total less than $40 *million* annually. Is there any way to turn this tide?

"Increased student debt and an emerging reality in our economy will help to turn the tide on this equation," said Paul. "A four-year degree is still incredibly valuable, but there are likely to be many more opportunities for non-college graduates to secure jobs that come with a middle-class label. An aging manufacturing workforce, the U.S. energy boom, and the re-shoring fad all contribute to this. You'll see public policy respond in some way to this, but by no means will it reverse the imbalance in spending for universities compared to training programs."

So the need and demand for highly and middle-skilled manufacturing talent intensifies, but apprenticeship programs remain a largely untapped source for advanced manufacturers facing a skills gap. But not in Washington state. What makes it different? Aerospace—and foresight.

"The demand in Washington (for apprentice programs) is driven by employers in the aerospace and advanced manufacturing supply chains," said Hopkins. "AJAC's apprenticeship program supports over 140 aerospace and advanced manufacturing companies across Washington state.

"Washington aerospace and advanced manufacturing employers realized a considerable portion of their workforce is going to retire and there isn't going to be a large pool of highly skilled candidates to select from due to the lack of high school shop classes and the emphasis on four-year college degrees being the only path to pursue after high school. As a result, former Governor Chris Gregoire took action and identified funding for aerospace and manufacturing apprenticeships." (Wonder what *she's* doing in 2016.)

We conclude with asking Paul to comment on the thinking in some quarters that the solution to the needs of both job seekers and employers is a modern-day apprenticeship program.

"I was recently at a major manufacturing expo in Chicago," Paul said. "Every welding class instructor there told me he had a waiting list for his program. I think the answer is to expand a number of pathways — community colleges, high school technical programs, training programs and apprenticeships — to meet the interest of younger people in manufacturing careers."

A final word about the three organizations involved in this article.

For those of you reading this who happen to be involved in some way in your company's employee training program — and, even better, have the "juice" to implement needed changes — you will find a mother lode of valuable information on apprenticeship programs at both the Bosch Rexroth (*www.boschrexroth.com*) and AJAC (*info@ajactraining.org*) sites. More than just coursework offerings, the information includes instruction and insight for both would-be apprentices and employers. Check it out.

And just a bit more on the Alliance for American Manufacturing (AAM) (*info@aamfg.org*), a non-profit, non-partisan organization formed in 2007 by some of America's leading manufacturers and the United Steelworkers. They exist "to strengthen American manufacturing and create new *private-sector* jobs through smart public policies." For the AAM, a robust and sustaining manufacturing base is as vital to Homeland security as is the latest jet fighter. And it is much easier to build another fighter plane than to build and maintain an economy. The AAM strives daily to build coalitions around the issues that matter most to the country, etc., its manufacturers, and its workers.

(*Sources for this article*: Washington Post, *May, 2013*; *AJAC* (info@ajactraining.org); New York Times, *Nov*., *2013*.)

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The Sales Pitch

Kaukauna Holds Secrets to Skilled Labor Shortage

Matthew Jaster, Senior Editor

The skilled workers are still missing in action. An entire generation of personnel with the manufacturing, engineering and mathematic skills to succeed is retiring. Small communities around the country can't fill these positions fast enough. Manufacturing ghost towns are becoming the norm. It's a story that's been reported thousands of times.

But not this time.

This is a success story. We've been inundated with so much bad news in manufacturing that when we hear some good news it's a wonderful change of pace. Even better is the fact that the people involved have barely scratched the surface when it comes to solving the skilled labor shortage; they have bigger plans and bigger ideas for the future. Listening to these ideas and hearing the enthusiasm and passion for what they've done and what they plan to do, it becomes difficult, almost impossible, to not buy into what they're selling.

A Recipe for Success

100 miles or so north of Milwaukee, Wisconsin sits a town on the Fox River called Kaukauna. You've heard of it. In 1918 Hubert Fassbender formed a distributing company known as South Kaukauna Dairy which eventually became Kaukauna Cheese. Fassbender experimented with several methods of cheese production. The company eventually became the nation's largest manufacturer of cheese balls and cheese logs. But it's not just cheese in Kaukauna, Wisconsin. The town (15,000+) and surrounding area manufactures black boxes for airlines, oil and gas probing equipment and military defense equipment. There are paper mills, wind and solar technologies and plenty of metal fabricating and machining job shops.

"You're looking at an area that specializes in high-tech and high-quality metalwork," says Nels Lawrence, technology education teacher for the Kaukauna Area School District. "If a student has an interest in a career in manufacturing/engineering in and around Kaukauna, they have plenty of options."

Ryan Veldman is a senior at Kaukauna High School. His Youth Apprentice employer has been hiring Lawrence's students for many years in this program. One of his current supervisors is a former student from the class of 2000. Veldman had to apply for the program and has already taken machine tool classes at school (photos courtesy of Nels Lawrence).

There are a few particular statistics that set the town of Kaukauna apart from similar small towns in the Midwest. While the national unemployment rate is hovering around seven percent, the unemployment rate in Kaukauna is at 5.4 percent. The salaries in Kaukauna for full-time workers under 25-years-old are $12,000 over the national average of $38,000. In fact, Lawrence has placed 600+ students in manufacturing positions from the Kaukauna High School Technology and Engineering Program.

"There's probably not a machine shop within 20 miles of my front door that doesn't have a former student of mine," Lawrence says. "I'm enthusiastic every day I come in to teach a class because I see that it's paying off. Our local companies are doing well and our community is thriving."

Get the Message

The skilled worker epidemic is being fought on the local as well as national front. When the SME acquired Tooling U in 2010, it combined two important organizations to promote the health and growth of the manufacturing industry.

"Our online training compliments SME's in-person training and certification programs and the full range of development resources," says Chad Schron, division manager, Tooling U-SME. "We're here to support both the schools and the companies as they try to solve the skilled labor shortage."

Therese Schustrich, government and education group, Tooling U-SME, worked with Lawrence to customize the online curriculum at Kaukauna High.

"The same curriculum works for both industry and education. We offer beginner, intermediate and advanced classes. Each class offering allows the instructor to tailor the workload for each student," Schustrich says. "It's similar to taking different courses in college. Students get a mindset that this is something they might want to pursue down the road as a career."

So what is it about manufacturing and engineering that is interesting for kids at the college, high school and even middle school level?

"It's the demand for highly skilled and highly technical careers that I think kids are starting to pay attention to," Schron says. "The dirty, grimy shop floor perception is still wrong. These jobs include robotics, lasers and advanced CNC equipment. Entry-level positions are high-paying and students are beginning to realize the options available to them. The more awareness we can bring to the industry the more it benefits educators, manufacturers and their communities."

Lawrence, in particular, knows what keeping Kaukauna grads in Kaukauna after graduation means to the community.

"I'm proud to say that some of my recent students that were apprentices during high school are now full-time employees in job shops around town. These are 21-year-olds that are purchasing homes, buying cars and establishing their careers. The school board can relate to this. These are your taxpayers, these are your citizens; this is your community. If the kids in Kaukauna become doctors or lawyers it's wonderful, but they typically leave town the first chance they get."

Lawrence can't stress enough the snowball effect that takes place when industry, education and government work together on these initiatives.

Getting Around Town

Students in and around Kaukauna are starting to see firsthand the tremendous opportunities available in their own backyard. Leave it to someone like Lawrence to produce the sales pitch. It's his own personal history that makes him more than qualified to do the job.

"I returned from deployment in the Gulf War and made a career change from sales engineer for a medical laser company and used my GI benefits to get an MS in technology education," Lawrence says. "I also have certifications in manufacturing, construction and transportation. I served as a Naval Engineering Officer in the Coast Guard, ran a department for a large interstate construction company, managed shipyard operations, and worked in medical manufacturing."

He's been teaching now for 18 years and watching the interest continue to grow in manufacturing and engineering over that time period. "The biggest change is the number of advanced students who want to be engineers learning hands-on skills in our area," Lawrence says. "For them it rounds out their education. We've maintained a steady flow of students who enter Technical College, or apprenticed trades through our Youth Apprentice cooperation with industry."

Companies like G&G Machine, Fox Valley Tool & Die and Team Industries have former Kaukauna students that represent Lawrence's entire teaching career. "Many of my students were placed in apprenticeships when I first started teaching," Lawrence says. "Last year, I was able to have several students hired at a brand new machine tool operation that was founded by former co-op students.

Ryan Veldman's work day varies as they rotate him between the stamping and metals plant and the CNC operation across town to maximize his learning. He plans to continue full time while attending Fox Valley Technical College to earn a two year A.S. degree in machine tool.

Five to ten years out of high school and these guys started their own company."

Since engineering/manufacturing still boasts many more men than women, Lawrence taps three young female engineers (and former students) to come back regularly and talk to the girls about the opportunities available. "One recent graduate is a foundry engineer at Waupaca Foundry and she's responsible for troubleshooting parts for General Motors," he says.

Another former student recently came to speak to Lawrence's class. "He's 24-years-old and he's the head of prototyping at Kimberly/Clark, a company that has more than 52,000 employees. Kids were really excited to hear about what he does on the job. It's always great to get that phone call from a former student that wants to come back and talk to the kids," Lawrence adds.

More to Come

When Lawrence isn't taking his class outdoors to see the inner-workings of a wind turbine, you'll probably find him writing grants. "I went to J-School and I learned how to write well enough to put together a nice grant proposal or two," Lawrence says.

Currently, his students have access to a weld shop for up to 28 students with Mig Tig and Stick welders as well as a computer plasma table. "Our machine shop has mostly older machines: 13 South Bend Lathes, two horizontal mills, two Bridgeports with readout, and an older Mazak with Cam2. We also have a foundry set up to do aluminum castings and an assortment of sheet metal working tools breaks and rollers," Lawrence says. "In the Engineering FAB Lab we have two rapid prototype machines (smaller Makerbot) two small mills, a laser 3-D scanner, an injection molding system and a 3-D router table. This is also supported by a 30 seat lab with *Solidworks* CAD software and a stand-alone Electronics lab."

Additionally, students learning control systems can use the Haas Trainer in the Fab Lab and they can earn one college credit for completing the Programmable Logic Controller class with PLC programming hands on instruction.

"Our high school has kept many machines and equipment that other high schools have scrapped," Lawrence says. "The grants definitely help. My writing is better than the average shop teacher so they keep giving me money."

He's currently on a personal quest for some newer CNC equipment. "We need some help in this area. I'd like to replace some of our older machines and upgrade. We're also working on getting more solar and wind energy equipment in here to promote careers in green technology," Lawrence says.

He will continue to get more advanced equipment into the classroom that the students can truly benefit from as well as promote the apprenticeship opportunities around Kaukauna. These apprenticeship opportunities offer their own distinct set of challenges for both the school and the companies involved.

"Companies need to adjust to teenagers, for sure," Lawrence jokes. "Part of the secret of making this work is that we

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screen things up front. You need to know the strengths and weakness of each student. You can't take an ineffective student out of school and place him or her in a high-tech job and expect it to work out."

"There certainly is a lot of math to know," says Schustrich at Tooling U-SME. "The math requirements are some of the biggest challenges. People are starting to realize that they need to go to the middle school level to discuss options in science, engineering and manufacturing. We need to get to the kids earlier. Time management is another challenge. It's important that each student is comfortable with the workload."

But the benefits of these apprenticeship programs are numerous. "My students who took apprenticeship positions at G&G Machine felt they had a big head start on older workers and were really ready for Tech College," Lawrence says.

With all the machines in school, the apprenticeship programs and the curriculum from Tooling U-SME, you'd think Kaukauna would sit back and enjoy each and every success story.

Not quite.

"There's a blueprint in place for sure, but so much more we can do," Lawrence says. "I always talk to employers and try to get more field trips in place. We also need to work more closely with the Tech Colleges."

"This is the future of manufacturing we're talking about here," Schon says. "The discussions need to continue. How can the schools and the manufacturing communities do better?"

"Perceptions still need to change across the board," says Schustrich. "Facility tours are ideal so students can come and see what actually happens on a shop floor instead of what they think happens."

"I love when engineers/manufacturers come to the school to talk with my students, but it's much more beneficial to spend more than just 45-minutes discussing the work," Lawrence says. "I've had people from industry come in and do things with the students. They might spend three or four class periods building something hands-on."

How about summer externships for teachers?

"The science, math and technology instructors have experience in these fields, but what about the principals, the counselors and the English teachers? Many of them have no idea what's behind the door to manufacturing facilities in their own cities and towns. We need to get teachers to work in a plant over summer break, get an idea of the jobs available and the skill sets needed to succeed in the community. Once they see the modern working conditions they begin to realize that we shouldn't push students in just one direction," Lawrence says.

Reinvigorating manufacturing in the United States is going to take a little thinking outside of the box. Some other examples from Lawrence:

There's a major electronics company in Wisconsin that farms out small jobs to a local high school where the students are putting together circuit boards. There's also a job shop in a high school that is making parts for a local manufacturer. The profits are going back into the school to assist the technology/manufacturing program. "By participating in projects like this, the work becomes real to the kids. They see what is being manufactured in their own communities and they want to be a part of it."

ToolingU-SME is also doing their part.

"Our government and education group formed six years ago to prepare students for positions in manufacturing," adds Schustrich. "Today, there are more than 450 high schools and community colleges taking part in a hybrid learning environment that offers more hands-on training and less administration."

Sometime in the first quarter of 2014, ToolingU-SME will roll out another initiative that will help the cause.

"We're going to create a roadmap that will basically break down the common job classifications within areas like engineering, welding, fabricating and other industrial segments," says Schron. "It will identify exactly what skillsets you need to do those jobs. The potential is extremely exciting and with the combined efforts of ToolingU and SME this will serve as curriculum development in the future."

And Lawrence has one more story from his classroom:

"I have a 16-year-old student that raised more than $7,500 in a week on Kickstarter for a manufacturing project. He has already found a supplier in China willing to make the stuff. He came up with a backpack that charges your cell phone. When I first had him in class two years ago his parents were concerned. They thought he was wasting all this money on these crazy inventions. I told them to wait and see. This kid is your retirement plan."

There's a sales pitch any parent could buy into.

Ryan Veldman (right) wants to learn to program CNC equipment. Here he is using a Haas simulator trainer with instructor Nels Lawrence.

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GEAR SAMPLE: INTERVIEW WITH ANTONIO MACCAFERRI

Q: What are the keys to success for a family-run business now in its third generation, operating on a global scale?

A: SAMP is in fact only a part of the family business, the Maccaferri Industrial Group, which is an international company boasting a rich portfolio of activities ranging across the widest of sectors, from environmental engineering solutions to real estate and construction, from the food industry to tobacco, going through biotechnologies and the field of renewable sources of energy.

One of the main keys to success can be found in the fact that our Group has always relied on a strong team of experienced managers and high-skilled professionals specialized in their own field, whereas family members take care of the strategy and coordination.

Q: How has the gear industry evolved since you took over as President in 1995?

A: Surely the industry has dramatically changed, especially as far as internationalization and diversification on a global scale are concerned. For example, when I started in 1995 nobody could imagine that China would grow in such a spectacular way, to the point that today SAMP has three manufacturing plants in Shanghai, one for each business unit of the company (Samputensili, Sampsistemi and Sampingranaggi).

Another important effect of the globalization was represented by the huge opportunities offered by the North American market. For this reason, in 2002 Samputensili started a strategic partnership with Star Cutter Company through the creation of the joint-venture Star SU LLC, the sole go-to-market organization based in Hoffmann Estates, IL, responsible for the sales and distribution of cutting tools and machine tools technology for the North American market.

Q: What are your goals for SAMP in both the near-term and long-term with regard to being a supplier to the worldwide gear manufacturing community?

A: We have always followed a global, international approach both as a company and as an industrial group. Our main goal has always been the satisfaction of our customers' needs with high professional skills, capacity and quick actions driven by our will to constantly improve.

By doing this, we have always worked hard in order to be close to our customers as a reliable manufacturing company, providing them with the support and service they need in a fast and comprehensive way. This approach had led us through the decades to the creation of a broad network of manufacturing facilities, such as the one in Brazil in 1974, the one in South Korea in 1995, the creation of our American joint-venture Star SU in 2002 and of a Chinese joint-venture between Samputensili and STW in 2005. This has always been our philosophy and we will certainly continue to do so also in the years to come.

Q: What do you see as your major challenges in both the near and long term, both as a company and as a manager?

A: Our major challenges will be represented by the continuously evolving technology, the ever growing competition amongst machine tool manufacturers and gear cutting tool manufacturers, as well as the features and new technologies that are specific to each market in which we are present and to each market that we serve. These are and will continue to be our major challenges both in the near and in the long term.

Q: What regions of the world are showing the most promise for growth for SAMP in gear manufacturing and why?

A: We are closely following the evolution of China, South-East Asia, Brazil and South America in general. Of course, in terms of volume, Europe and the United States remain our most important markets for high-quality gears and gearboxes, supplied by our business unit Sampingranaggi, and we expect these areas to recover very shortly.

Q: What innovations, changes or trends do you see in the coming years that will impact the worldwide gear manufacturing community?

A: The innovations we are experiencing around us are not real revolutions. More than anything else, we are seeing production centralizations, large companies merging together, especially in the automotive sector, and we believe that the average size of corporations in the future will continue to grow.

Q: What are your goals for SAMP over the next five years? Do you have any plans on expanding in the near future, outside your existing operations?

A: We will surely strive to remain among the market leaders and further increase our market penetration in those segments where we still are not a reference brand. At the moment we do not foresee

THE HISTORY OF SAMP

BY ANTONIO MACCAFERRI

The history of SAMP and its brands has always been eventful, and it represents a perfect example of company verticalization. At the end of the 19th century, in Casalecchio di Reno near Bologna, Italy, my grandfather's uncle began to use wire mesh to assemble gabions (boxes filled with rocks, concrete, or sometimes sand and soil) to repair dams destroyed by floods of the river Reno. At the beginning of the 20th century, he purchased a patent for a new type of wire mesh box gabion and started the industrial production of gabions for civil engineering use.

As a consequence, **in 1936** Gaetano Maccaferri, my grandfather, started out with a small workshop for the production of wire machinery. The production included wire drawing machines, looms for weaving metallic meshes and general mechanical parts. He called his company **S.A.M.P.**, which translates from the Italian as "Company for Precision Metalworking." Since it was difficult to find good quality gears at that time, he started manufacturing his own.

During the Second World War, SAMP supplied the Italian air-force with precision gears, but the demanding quality requirements forced the company to produce its own high-precision gear cutting tools. For the same reason, the company was later to start developing its own tool grinding machinery, manufacturing equipment that set the standard at those times.

With a wide range of quality gear cutting tools on board by 1949, SAMP decided to establish **Samputensili**, an ad hoc structure and trademark through which to trade these products. In the years that followed, this new company was to grow into a worldwide supplier of gear cutting tools and, later, also of grinding machines for cylindrical gears, shafts, worms, rotors and screw threads.

The second spin-off of SAMP, **Sampingranaggi**, came into being in 1973, extending the company's gear production program to include bevel gear sets and high-precision gearboxes. Before long, Sampingranaggi was able to sup-

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the opening of new manufacturing plants, but we are working towards the creation of new sales and distribution offices in India and in South-East Asia.

Q: How have your customers' demands changed in recent years? What is SAMP doing to accommodate those demands?

A: Our customers are becoming more and more price-sensitive. In addition, we have experienced an increase in the request for technical support and production optimization, as a consequence of the internal restructuring that many companies have carried out over the past few years.

In order to meet these needs, we have established new sales and technical capacities and have further expanded our network. In our main markets we are locally present with manufacturing plants to supply our customers with fast, reliable and excellent sales and after-sales service.

Q: Tell us about your North American distribution, sales and service oriented representation.

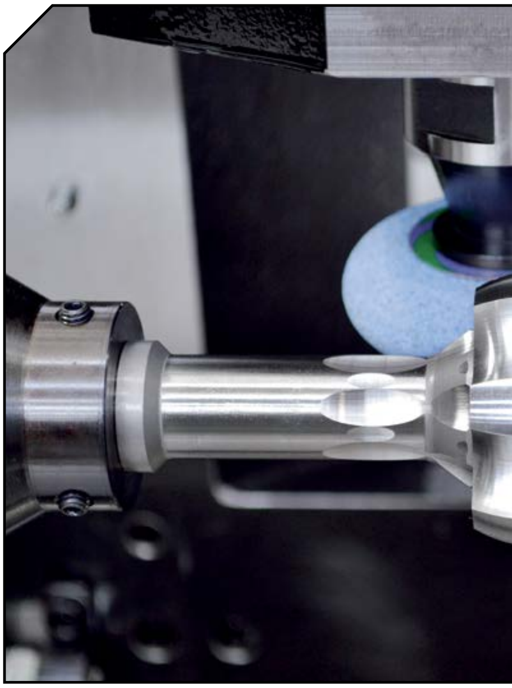
A: SAMP S.p.A. and SU America have a strategic partnership with Star Cutter Company through Star SU LLC (Hoffman Estates, IL) to sell our machine tools, gear cutting tools and tool services under the highly visible Star SU brand in North and South America. Star SU is supported by 30 direct regional sales managers and eight service engineers.

Our partnership with Star started in 2002 and was further extended in 2013 to include not only the sales organization, but also the manufacturing plants in the United States, the service center in Mexico and the Samputensili plant in Brazil.

Q: What do you see as your major challenges as a supplier to the gear industry?

A: We are challenged to supply a broader range of support activities within customer facilities. We are managing this by extending full product support and manufacturing support activities with Star SU on-site engineers. Though challenging, this is a tremendous opportunity to supply these services as an added value proposition at a reasonable cost.

Q: Do you have any concerns regarding recruiting and retaining skilled workers in your workforce?

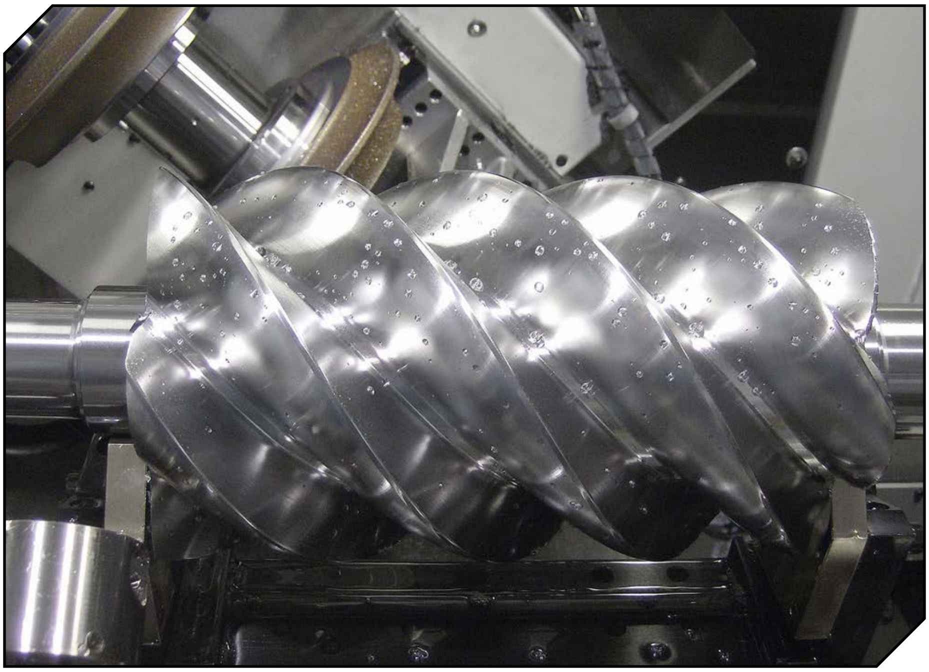


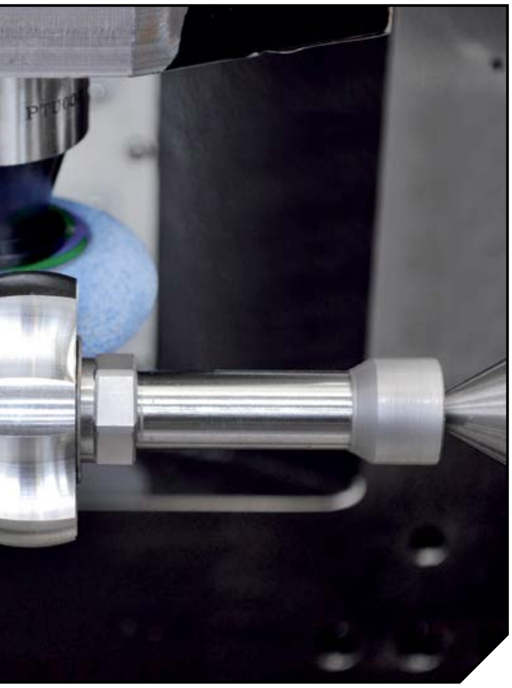
A: In manufacturing, we are faced with the great challenge of making our business attractive to young, skilled engineers and technical people. This involves a great commitment to promote and educate potential employees by our company and private industry, but it must also work in cooperative partnership through universities and high schools. Once we have recruited these young workers we need to have the right training available to them and growth plans in place to keep them.

Q: Are there any other subjects you would like to talk about?

A: SAMP is known to the world market not only for its high-quality and reliable gear manufacturing tools, but also for its wide range of grinding machines. At Samputensili we began producing machine tools some 50 years ago to improve the manufacturing quality of our gear cutting tool range.

In particular, our horizontal grinding machines are amongst the finest machine tools for gear, rotor and screw manufacturing in the world. Our experience stems from our own manufacturing needs in terms of prototyp-





ing and in-house job shopping. Know-how matured in such a way has flowed directly into the end product, and this is what distinguishes our solutions from the rest. Our machines are extremely flexible and allow customers to use both ceramic grinding tools and electroplated CBN grinding wheels. Therefore they represent the ideal solution both for prototyping/small batch production and for high-volume gear manufacturing.

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ply both single components and finished gearboxes.

In 1997 SAMP's wire drawing machinery division took the name of **Sampsistemi** and, thanks to the acquisition of competing companies, it broadened its portfolio to include extrusion equipment for the manufacture of finished cables.

In 2000, with the acquisition of the former Modul company based in Chemnitz (Germany), Samputensili added hobbing technology to its manufacturing program, becoming one of the few players in the world to offer a complete gear manufacturing program, covering both roughing and finishing operations.

In 2002 Samputensili started a strategic partnership with Star Cutter Company through the creation of the joint-venture Star SU LLC, the sole go-to-market organization based in Hoffmann Estates, IL, responsible for the sales and distribution of cutting tools and machine tools technology for the North American market.

In 2006 Samputensili, Sampsistemi and Sampingranaggi merged to form SAMP S.p.A, a new holding company which put together the three macro-sectors of its business:

- Samputensili, global provider of complete solutions (machine tools, tools and services) for the production of gears;
- Sampsistemi, manufacturer of machines and systems for wire and cable production;
- Sampingranaggi, specialized producer of high-quality spur and bevel gears as well as complete gearboxes.

Each of the three business units has its own technical department, sales force and after-sales service, whereas corporate services like human resources, procurement, IT, finance and administration are shared among the three divisions.

In 2009 SAMP moved to a brand new plant in Bentivoglio (Bologna), Italy, which integrates all European manufacturing sites of the three divisions in one modern, state-of-the-art plant.

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Planet Carrier Design

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QUESTION

With all the advantages of building float into a planetary gear system, what advantages are there to using a carrier in the first place, rather than simply having your planets float in the system?

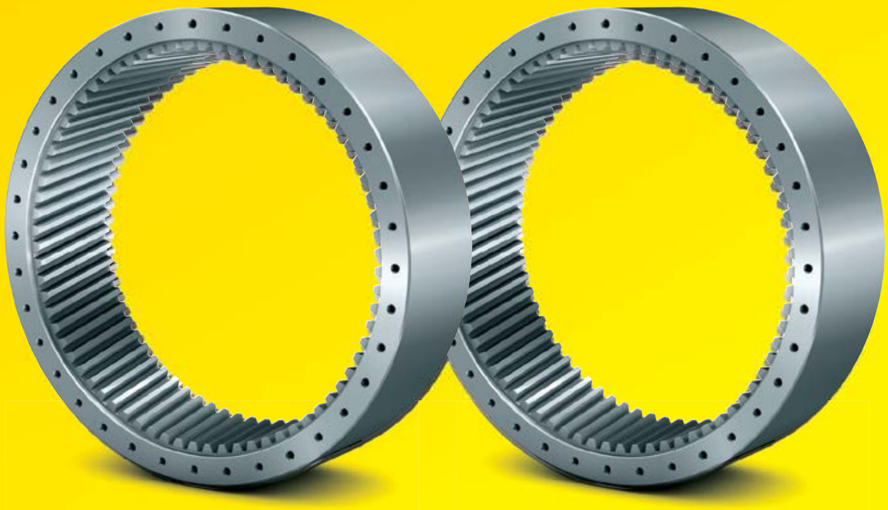
Expert response provided by Chuck Schultz:

Designing planet carriers is one of the challenges awaiting the gearbox engineer. While it is theoretically possible to have load sharing so equalized that a carrier would not be necessary, theory never quite works out in practice due to manufacturing tolerances and gravity. At some point the gear forces of the planets must be transferred to a shaft or the housing; this is the primary function of the planet carrier.

Good carrier designs overcome load-sharing imbalance and allow for accurate assembly without damage to the gears or bearings. The carrier/planet sub-assembly will "self-center" under load, but care must be taken to have sufficient clearance to account for start and stop conditions. Vertically arranged assemblies must have provisions for thrust forces between carriers on multi-stage units. Consideration must also be given to alignment and "tipping" of the stages with respect to each other.

ANSI/AGMA 6123-B06, *Design Manual for Enclosed Epicyclic Gear Drives*, contains the latest thing on this subject from some of the most experienced engineers in the business.

Charles D. Schultz, PE is Chief Engineer for Beyta Gear Service *(gearmanx52@gmail.com)* in Winfield, Illinois, and a Technical Editor for *Gear Technology* and *Power Transmission Engineering* magazines. He is also a longtime AGMA member, having served on or chaired a number of its committees over the years. And now you can follow Chuck's new *Gear Technology* blog three days a week at *geartechnology.com.*



Practical Considerations for the Use of Double-Flank Testing for the Manufacturing Control of Gearing - Part I

Ernie Reiter and Fred Eberle

Part I of this paper describes the theory behind double-flank composite inspection, detailing the apparatus used, the various measurements that can be achieved using it, the calculations involved and their interpretation. Part II, which will appear in the next issue, includes a discussion of the practical application of double-flank composite inspection, especially for large-volume operations. Part II covers statistical techniques that can be used in conjunction with double-flank composite inspection, as well as an in-depth analysis of gage R&R for this technique.

Double-flank composite inspection (DFCI) is a valuable technique that can functionally provide quality control results of test gears quickly and easily during manufacturing. However, the successful use of DFCI requires careful planning from product design, through master gear design and gage control methods in order to achieve the desired result in an application. This document explains the practical considerations in the use of double-flank testing for the manufacturing control of spur, helical and crossed-axis helical gearing.

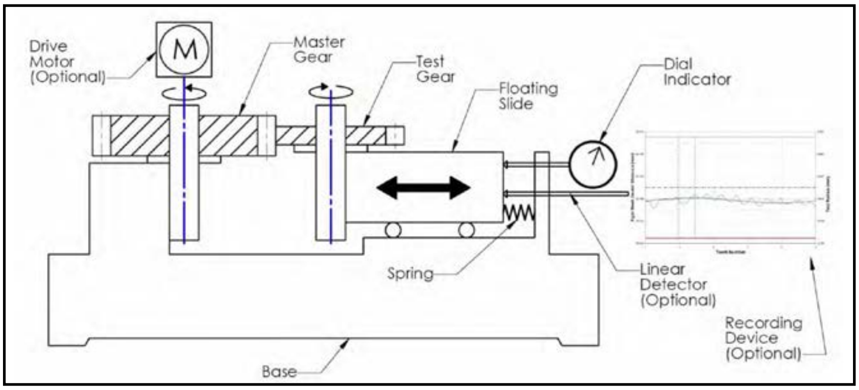


Figure 1 General arrangement of a double-flank composite tester.

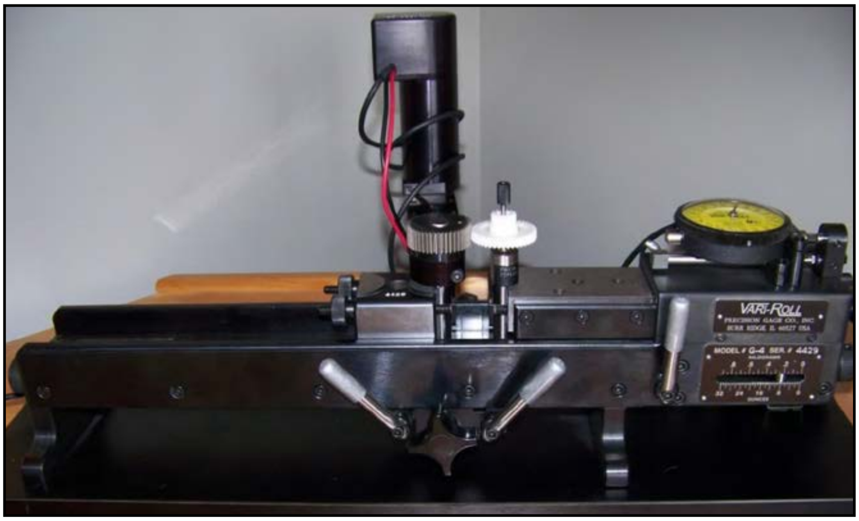


Figure 2 An actual double-flank composite tester in tight mesh (courtesy of Web Gear Services Ltd.).

Description of Double-Flank Composite Inspection

Double-flank testing is a technique that has been used in the gear industry to identify potential manufacturing defects in the design intent of the gear. It is a practical, fast and effective screening tool that can identify when the gear manufacturing process has deviated from an ideal condition that could result in a loss of conjugate action, a change in backlash, or an unwanted noise in a gear mesh.

The test itself involves an apparatus of general layout as shown in Figure 1 and of actual configuration as shown in Figure 2. A master gear of known precision is mounted on a fixed base with only rotational freedom. The test gear is mounted on a floating slide mechanism that allows rotation of the test gear and movement along an axis between the line of centers of the master and test gear. A spring (with a preset force) pushes the floating slide, resulting in zero-backlash, double-flank contact (i.e., on both left and right flanks) on both the test gear and the master gear.

As the master gear is rotated (by hand or by motor), the test gear follows. Involute theory dictates that perfectly formed teeth will prevent any movement of the floating slide between the line-of-centers. However, since no gear can be manufactured in absolutely perfect condition, there will always be some movement of the floating slide as the gears rotate. The magnitude of this movement is measured with either a mechanical indicator or electronic detector that contacts the slide mechanism. If the measuring instrument is calibrated to an actual distance reading between the centers of the gears, then an actual tight mesh center distance result can be obtained.

In order to maintain accuracy in the measurement, intimate double-flank contact must be maintained at all times. Therefore the selection of the pre-set spring force and the speed-of-rotation of the gears should be given careful consideration to limit measurement errors.

The pre-set force may need to be selected specifically for the test gear's design, taking into account the material's ability to resist deformation under load (i.e., plastic gears), where a large pre-set force may distort the gear into conformity. In addition, if there is excessive resistance coming from the mounting of either the master gear on its mandrel, or, more commonly, of the test gear on its mandrel, then a low, pre-set spring force will result in separation of the two gears out of double-flank contact, creating an error in the measured values. The correct pre-set spring force is the minimum force needed to maintain continuous, double-flank contact without distorting the test gear.

The speed of rotation of the gears should be selected by taking into account the natural response of the mechanical and electrical (if so equipped) elements of the tester. It is generally recommended that at least 20 data points per tooth are available in the data set collected to ensure sufficient sensitivity of the results.

The types of measurements that can be made on a double-flank tester are shown in Figure 3 and will be explained in the following sections.

Total composite variation. Measurement of the total composite variation (error) is the difference between the maximum and minimum indicator (or linear detector) readings during one rotation cycle of the test gear (Fig. 3). The total composite variation result includes effects of runout in the gear, plus anomalies in the tooth pitches, profiles and helix. It also reports the total effect in terms of this linear change as variation in tight mesh center distance. It is not possible to accurately establish the magnitude of each individual effect on the total composite variation using the double-flank test alone. Hence, the double-flank test is very good at screening production quality and flagging potential errors, but the results may not identify the specific nature of the problem. Other tests, (such as analytical inspections) would need to be performed in order to more closely identify the exact nature of the defect.

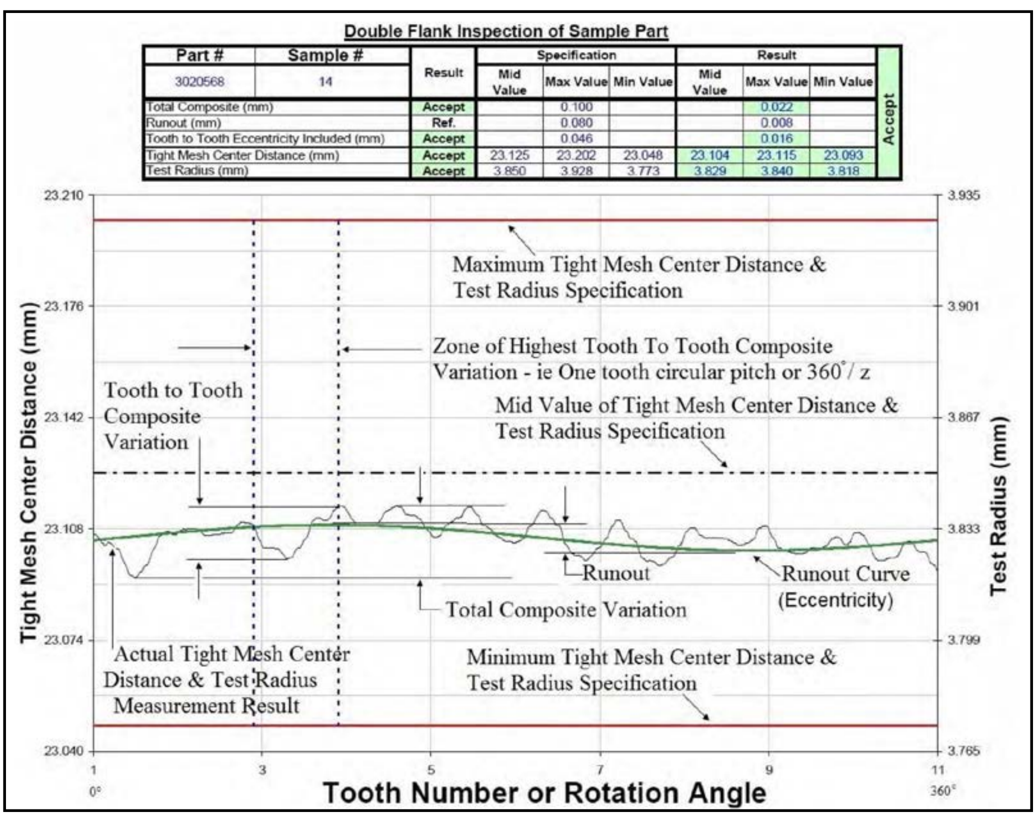
Tooth-to-tooth composite variation. The tooth-to-tooth composite variation (error) is defined as the greatest deviation indicator reading within a single, circular tooth pitch. This result is based on the worst tooth on the entire gear. The gear tested in Figure 3 shows this to be in the zone around tooth 3.

As the number of teeth in a gear becomes smaller, the ratio of the tooth-to-tooth error to total composite error generally increases. In the extreme condition, a single-start worm (i.e., one tooth) will have a tooth-to-tooth composite error equivalent to its total composite error. As the number of teeth increases, the tooth-to-tooth results are considered to be a better indicator of anomalies in the tooth pitch, profile and helix.

Errors in gear pressure angle will result in a repeated pattern of arches similar to that shown between teeth 5 and 7 in Figure 3. Use of tooth-to-tooth test limits also helps to control burrs and nicks in gears that are not always detected by analytical measurement techniques.

Tight mesh center distance. One of the most powerful uses of the double-flank test is to measure and control gears not only for total composite variation, but also for tight mesh center distance. The ability to measure this variation gives the necessary insight to control both tooth size and composite parameters simultaneously. Since AGMA and ISO accuracy standards do not include the effect of tooth size, tight mesh center distance is not discussed in those standards. However, the effectiveness of this tooth size measurement should not be overlooked when evaluating backlash in a gear mesh.

Tight mesh center distance, as shown in Figure 3, can be measured if an additional calibration step is performed during the



Part #	Sample #	Result	Specification			Result			
3020568	14		Mid Value	Max Value	Min Value	Mid Value	Max Value	Min Value	
Total Composite (mm)		Accept		0.100			0.022		Accept
Runout (mm)		Ref.		0.080			0.008		
Tooth to Tooth Eccentricity Included (mm)		Accept		0.046			0.016		
Tight Mesh Center Distance (mm)		Accept	23.125	23.202	23.048	23.104	23.115	23.093	
Test Radius (mm)		Accept	3.850	3.928	3.773	3.829	3.840	3.818	

Figure 3 Double-flank inspection report (courtesy of Web Gear Services Ltd.).

Figure 4 **Calibration for tight mesh center distance (courtesy of Web Gear Services Ltd.).**

gage set-up. If the dial indicator or detector is calibrated to a known center distance reading between the spindles prior to measurement (Fig. 4), then the actual tight mesh center distance will be the difference between the calibrated value and the rolling variation. Maximum and minimum test limits must be established for tight mesh center distance. These limits are shown by the horizontal red lines on the chart in Figure 3. Every portion of the actual tight mesh center distance measurement must be within the minimum and maximum boundaries for a test gear to be acceptable. When properly calculated through the gear design process, adherence to these boundaries will ensure maximum and minimum operational backlash levels in the gear mesh.

The Calculation of Tight Mesh Center Distance Limits for Spur, Helical, Crossed-Axis Helical and Worm Gears

In order to establish the maximum and minimum tight mesh center distance limits for external or internal spur, helical, crossed-axis helical and worm gears, the following gear design data must be available:

m_n Is the normal module of the system, mm
z_w Is the number of teeth on the test gear
Note: For external gears, use a positive value for z_w, and for internal gears, use a negative value.
z_3 Is the number of teeth on the master gear
β_w Is the helix angle of the test gear, degrees or radians
β_3 Is the helix angle of the master gear, degrees or radians
Note: For spur gears, $\beta_w = \beta_3 = 0$, degrees or radians
Note: For right-hand helical gears, worms and worm gears, use a positive value for the helix angle. For left-hand helical gears, worms and worm gears, use a negative value for the helix angle.
α_n Is the normal pressure angle for the mesh, degrees or radians
$s_{nw\,max}$ Is the maximum normal circular tooth thickness of test gear, mm
$s_{nw\,min}$ Is the minimum normal circular tooth thickness of test gear, mm
s_{n3} Is the normal circular tooth thickness of master gear, mm
F_{idTw} Is the total composite tolerance for the test gear, mm

The calculation procedure that follows is sufficiently general to account for gears with non-standard tooth thicknesses and heavily modified profiles.

Step 1. ***Calculation of the standard center distance, a.*** The standard center distance, a, of an external or internal test gear when meshed with an external master gear on a double-flank tester is:

$$a = \frac{z_w}{|z_w|}\,\frac{m_n}{2}\left[\frac{z_w}{\cos\beta_w} + \frac{z_3}{\cos\beta_3}\right] \quad (1)$$

where
a is the standard center distance between the test gear and the master gear, mm.
Note: These equations are sufficiently general to account for external or internal spur, helical, crossed-axis helical and worm gears.

Parallel-axis double-flank tight mesh center distance limits. The following additional steps are needed for the calculation of tight mesh center distance test limits for external and internal parallel-axis spur and helical gear meshes.

Step 2. ***Calculation of the transverse pressure angle,*** α_t. The transverse pressure angle, α_t, for the mesh on the double-flank tester is:

$$\alpha_t = \tan^{-1}\left(\frac{\tan\alpha_n}{\cos\beta_w}\right) \quad (2)$$

where
α_t is the transverse pressure angle for the mesh in degrees or radians
Note: For spur meshes $\alpha_t = \alpha_n$

Step 3. ***Calculation of the maximum tight mesh center distance limit, $a_{d\,max}$.*** The maximum tight mesh center distance, $a_{d\,max}$, of the test gear with the master gear for a spur and parallel-axis helical double-flank mesh is:

$$a_{d\,max} = \frac{a \cos \alpha_t}{\cos\left\{ \mathrm{inv}^{-1}\left[\mathrm{inv}\,\alpha_t - \frac{z_w}{|z_w|}\left(\frac{\pi m_n - s_{n3} - s_{nw\,max}}{2\,a \cos\beta_w} \right) \right] \right\}} + \frac{z_w}{|z_w|}\frac{F_{idTw}}{2} \tag{3}$$

where

$a_{d\,max}$ Is the maximum tight mesh center distance of the test gear with the master gear, mm

inv φ Is the involute function and inv $\varphi = \tan \varphi - \varphi$ with φ expressed, radians

$\mathrm{inv}^{-1}\,x$ Is the inverse involute function where $x = \mathrm{inv}\,\varphi = \tan \varphi - \varphi$.

Therefore, the result of the function $\mathrm{inv}^{-1}\,x = \varphi$, where φ is an angle.

For more information on the calculation of this function, see AGMA 930-A05, Annex E (Ref. 1).

Step 4. ***Calculation of the minimum tight mesh center distance limit, $a_{d\,min}$.*** The minimum tight mesh center distance, $a_{d\,min}$, of the test gear with the master gear for a spur and parallel-axis helical double-flank mesh is:

$$a_{d\,min} = \frac{a \cos \alpha_t}{\cos\left\{ \mathrm{inv}^{-1}\left[\mathrm{inv}\,\alpha_t - \frac{z_w}{|z_w|}\left(\frac{\pi m_n - s_{n3} - s_{nw\,max}}{2\,a \cos\beta_w} \right) \right] \right\}} + \frac{z_w}{|z_w|}\frac{F_{idTw}}{2} \tag{4}$$

where

$a_{d\,min}$ is the minimum tight mesh center distance of the test gear with the master gear, mm.

Note: For internal gears, Equation 3 will actually give a minimum value result and Equation 4 will give the maximum value result.

When specifying tight mesh center distance limits, it is important to also include a definition of the master gear's number of teeth and normal circular tooth thickness upon which the tight mesh center distance limits are based.

Crossed-axis helical and worm gear double-flank tight mesh center distance limits. The calculation for crossed-axis and worm gear double-flank meshes differs from other cylindrical gear meshes because the gears "see" each other in a way that is analogous to two racks in mesh, as opposed to two involute gears in mesh. Crossed-axis helical gears include the case where the driving member is a master worm (Fig. 5) used to measure a helical gear at right angles. The calculations presented here are also sufficiently general to include the scenario where two helical gears mesh at shaft angles other than 90°, as well as a situation (Fig. 6) where a plastic test worm is meshed against a master spur gear. In the case of worm gears, the master gear would actually be a cylindrical worm mounted at a right angle to the worm gear.

Note: The formulas presented here allow for meshing on the double-flank tester at any shaft angle.

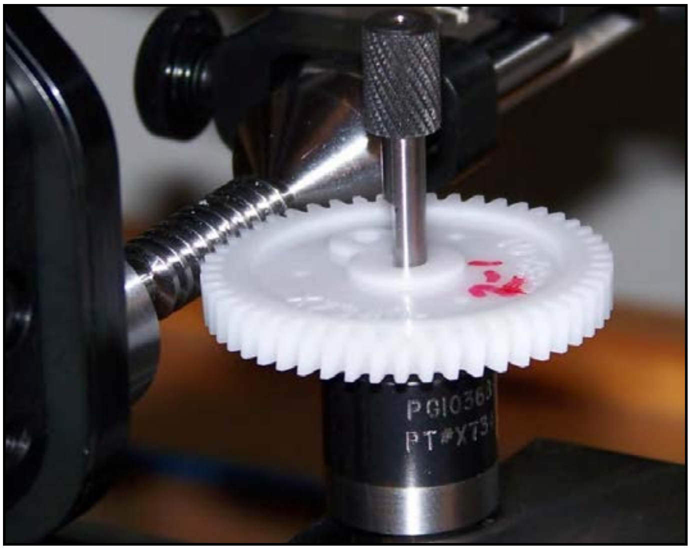


Figure 5 Master worm in double-flank mesh with a plastic helical gear (courtesy of Web Gear Services Ltd.).

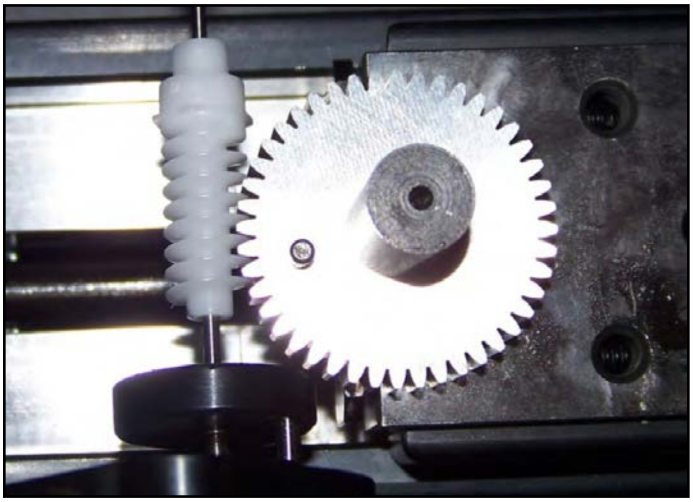


Figure 6 Plastic test worm in double-flank mesh with a master spur gear at an offset shaft angle (courtesy of Web Gear Services Ltd.).

Step 2. ***Calculation of the meshing shaft angle on the double-flank tester, ψ.*** The shaft angle ψ, on the double-flank tester for a given crossed-axis helical gear or worm gear mesh, is calculated as follows:

$$\psi = \beta_w + \beta_3 \tag{5}$$

where

ψ is the meshing shaft angle on the double-flank tester, degrees or radians.

Note: *Careful adherence to the sign of each of the helix angles (i.e., right- and left-hand) is crucial in this calculation.*

Step 3. ***Calculation of the maximum tight mesh center distance limit, $a_{d\,max}$.*** The maximum tight mesh center distance, $a_{d\,max}$, of the test gear with the master gear for a crossed-axis helical or worm gear double-flank mesh is:

$$a_{d\,max} = \frac{(s_{n3} - s_{nw\,max} - \pi\,m_n)}{2 \tan \alpha_n} + a + \frac{F_{idTw}}{2} \tag{6}$$

Step 4. ***Calculation of the minimum tight mesh center distance limit, $a_{d\,min}$.*** The minimum tight mesh center distance, a_d

<table>
<tr><th colspan="4">Table 1 Numerical example of the effect of master gear normal circular tooth thickness and number of teeth on the test radius</th></tr>
<tr><th></th><th>Master gear A</th><th>Test gear</th><th>Master gear B</th></tr>
<tr><td>Module, mm</td><td>1.0</td><td>1.0</td><td>1.0</td></tr>
<tr><td>Number of teeth</td><td>38</td><td>20</td><td>50</td></tr>
<tr><td>Pressure angle, degrees</td><td>20</td><td>20</td><td>20</td></tr>
<tr><td>Total composite tolerance µm</td><td>-</td><td>96</td><td>-</td></tr>
<tr><td>Normal circular tooth thickness, mm</td><td>50% of circular pitch
1.5708 ±0.000 mm</td><td>40% of circular pitch
1.2566 ±0.020 mm</td><td>60% of circular pitch
1.8850 ± 0.000 mm</td></tr>
<tr><td rowspan="2">Test radius limits, mm</td><td colspan="2">9.539 ±0.080</td><td></td></tr>
<tr><td></td><td colspan="2">9.568 ± 0.075</td></tr>
</table>

$_{min}$, of the test gear with the master gear for a spur and parallel axis helical double-flank mesh is:

$$a_{d\,min} = \frac{(s_{n3} - s_{nw\,max} - \pi\, m_n)}{2\tan\alpha_n} + a + \frac{F_{idTw}}{2} \tag{7}$$

Some software programs incorrectly calculate tight mesh center distance for crossed-axis helical gears and worm gears using the parallel axis approach in the previous section, instead of this method. If the sum of the normal circular tooth thicknesses between the master gear and test gear are close to the normal pitch, the calculation procedure detailed in the previous section may present results that are close to the actual values. However, as the sum of these tooth thicknesses deviates from the normal pitch, calculation error becomes increasingly significant. As such, the method shown in this section is always preferred for crossed-axis helical and worm gears.

Test radius. Test radius can be measured on a double-flank tester, as is demonstrated in Figure 3. Test radius is similar to tight mesh center distance in terms of set-up and calibration. However, it differs in that it is calculated as the tight mesh center distance of the mesh, minus the test radius of the master gear, as shown in the following equation:

$$R_{rw} = a_d - \frac{z_w}{|z_w|} R_{r3} \tag{8}$$

where

- R_{rw} Is the instantaneous test radius of the external or internal test gear (i.e., working gear), mm
- a_d Is the instantaneous tight mesh center distance of the mesh on the double-flank tester, mm
- R_{r3} Is the test radius of the master gear, as seen by a rack (see next section for further explanation), mm

Thus the scale between the left-side vertical axis in Figure 3 and right-side vertical axis is shifted by the magnitude of the master gear test radius.

One of the reasons why test radius is specified instead of tight mesh center distance is due to the common misconception that the master gear's number of teeth and its normal circular tooth thickness have no influence on the limits of a test gear's test radius. The assumption is that, regardless of the master used, the test radius limits of a test gear are constant. If this statement were true, it would then obviously be an advantage in circumstances where a manufacturer may have a different master gear than the purchaser. However, in reality, careful analysis of Equations 1–8 shows that there is some difference in the test radius results, depending on the master gear's number of teeth and normal circular tooth thickness. An illustrative example is shown in Table 1, where master gears A and B have different numbers of teeth and normal circular tooth thicknesses, resulting in significantly different test radius limits on the same test gear.

There is therefore no practical advantage in specifying test radius instead of tight mesh center distance. In both cases the master gear's number of teeth and normal circular tooth thicknesses must be defined to make the specification valid. It is common to report either tight mesh center distance or test radius, but not necessarily both. Tight mesh center distance has greater international usage as compared to test radius. Most North American electronic versions of double-flank testers available will report tight mesh center distance and test radius, while European or Asian equipment often does not include test radius results with their equipment.

Test radius of the master gear, R_{r3}. In order to calculate the result in Equation 8, the test radius of the master gear, R_{r3}, must be determined. Unfortunately, there are several methods by which the test radius of a master gear is defined — all having

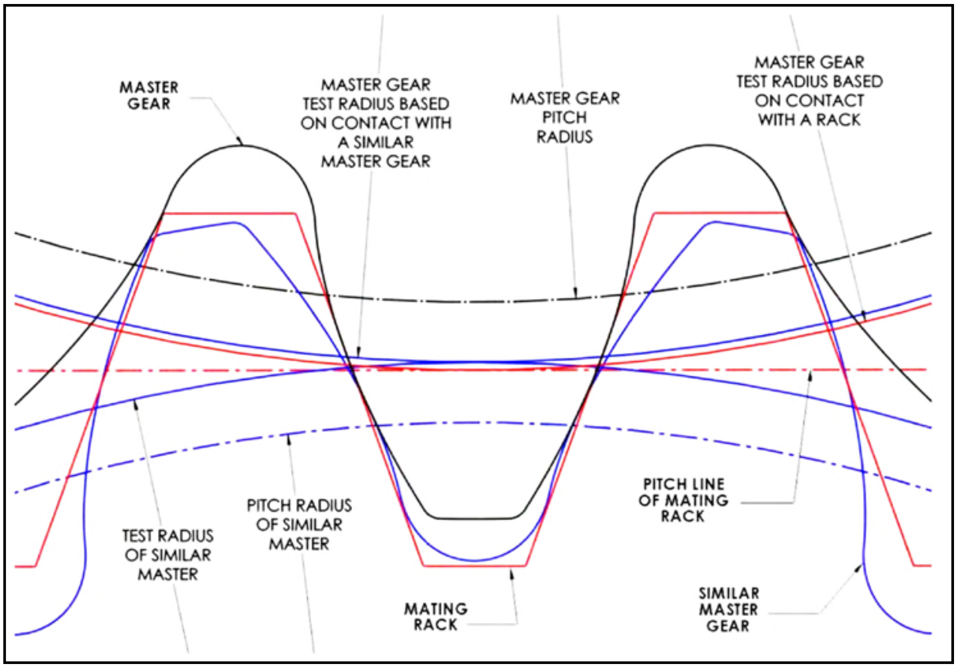


Figure 7 Test radius of a master gear (in black) against a rack (in red) or a similar master (in blue).

potentially different results — thus creating even more confusion in the industry.

The practical issue in the definition is that the test radius may be different, depending on whether the master gear is defined by its action against a rack or itself (Fig. 7), or against another cylindrical gear. Furthermore, if using a definition based on its action against another cylindrical gear, a single master gear may have many different test radius values, depending on the cylindrical gear it mates with. Hence, based on Equation 8, the test radius of a test gear will change, depending on the test radius of the master. Therefore if a master gear has an ambiguous test radius definition, the part gear test radius will also be inherently ambiguous. Specifying tight mesh center distance as opposed to test radius will remove this ambiguity.

However, if test radius must be used, the most common practice to avoid ambiguity is to define the test radius of a master gear by the tight mesh radial distance between the master gear center and the pitch line of a mating rack, whose pitch line is defined as the location where the tooth thickness is equal to its space width. In making such a standardized definition, a master gear will have a single test radius, regardless of the gear it mates with.

The equation for the test radius of a master gear, R_{r3}, as seen by a rack, is as follows:

$$R_{r3} = \frac{m_n z_3}{2\cos\beta_3} + \frac{(s_{n3} - 0.5\pi m_n)}{2\tan\alpha_n} \quad (9)$$

where

R_{r3} is the test radius of the master gear as seen by a rack, mm.

Test radius limits of a test gear. The test radius of a test gear is related to tight mesh center distance by the following equations:

$$R_{rw\,max} = a_{d\,max} - \frac{z_w}{|z_w|} R_{r3} \quad (10)$$

and

$$R_{rw\,min} = a_{d\,min} - \frac{z_w}{|z_w|} R_{r3} \quad (11)$$

where

$R_{rw\,max}$ Is the maximum test radius limit of the test gear, mm

$R_{rw\,min}$ Is the minimum test radius limit of the test gear, mm

Eccentricity (double-flank runout). In electronic (and computer-driven) gages, it is possible to use a Fourier transform calculation to extract the first-order, sinusoidal wave component from the measured double-flank data. The first-order component is shown as the green sinusoidal wave in Figure 3. By using this technique, the magnitude and orientation of the test gear's eccentricity can be established. In the Figure 3 example, the "runout" result (i.e., the peak-to-peak amplitude) is reported as 0.008 mm. This data may be useful in identifying how to improve net-shape gears (such as plastic, powder metal, or die cast gears) where the location of the mounting datum (i.e., bore or journal) to the gear geometry can sometimes be adjusted through tooling changes. The Figure 3 example would therefore report that the gear's datum as mounted on the double-flank tester is eccentric from the gear's teeth (as a single set) by one-half of the runout or, in this case, 0.004 mm.

The term runout is a misnomer when it is derived by this double-flank method. To be more precise, this is a double-flank runout and should not be confused with the runout result one would obtain by actually inserting a pin or ball between the flanks of the teeth and comparing the maximum and minimum result of the individual readings. The two methods may yield slightly different results. When using double-flank runout methods, the test reports should indicate the identifier "double-flank runout" instead of just "runout."

Master Gear Design Considerations

Master gears used in double-flank composite measurements must meet the following criteria in order to mesh properly with a test gear.

- The tip of the master gear must not contact the test gear below the form diameter of the test gear. This applies to initial contact and to any type of secondary contact in the fillet zone due to inadequate clearance.
- The tip of the test gear must not contact the master gear below the form diameter of the master gear. This applies to initial contact and to any type of secondary contact in the fillet zone due to inadequate clearance.
- The minimum contact ratio of the double-flank test must not be less than 1.0 when accounting for maximum tooth thickness, minimum outside diameter, maximum root diameter and maximum tip radius of the test gear. Should the contact ratio drop below 1.0, the meshing action of the gears on test will generate an immediate jump in the double-flank result for every tooth meshing cycle. This happens when the spring of the slide on the composite tester compensates for the loss of mesh force by abruptly pushing the gears together.
- The master gear and the test gear must have the same normal base pitch. In most cases, this is the case when the normal module and normal pressure angle match between the master and the test gear. However, mathematically it is possible to mesh a master gear with a different normal module and normal pressure angle than the test gear if the following equation is satisfied:

$$\pi m_{nw} \cos\alpha_{nw} = \pi m_{n3} \cos\alpha_{n3} \quad (12)$$

where

m_{nw} Is the normal module of the test gear, mm

m_{n3} Is the normal module of the master gear, mm

α_{nw} Is the normal pressure angle of the test gear, degrees or radians

α_{n3} Is the normal pressure angle of the master gear, degrees or radians

This may be useful in some special circumstances, depending on product design.

- For parallel-axis helical gear double-flank arrangements, the master gear must have an equal helix angle to the test gear but of opposite hand.
- For crossed-axis helical gear double-flank arrangements, the shaft angle setting on the double-flank tester must fulfill Equation 5.

In addition, the following recommendations for good practice may also be of use:

- The maximum contact ratio of the double-flank test should be less than 2.0 when taking into account minimum tooth thickness, maximum outside diameter, minimum root diameter, and minimum tip radius of the test gear. High contact ratios on the double-flank tester promote more overlapping of the mesh and may hide errors in the test gear that may other-

- wise exist. Helical gears, due to their face widths, may have an overall contact ratio greater than 2.0 when run against a master gear covering its full face width. In such cases a decision should be made to either accept the possible smoothing out of errors that would result with this high contact ratio, or to possibly reduce the face width of the master gear and measure the helical gear in different contact zones along the test gear's axis while maintaining an overall contact ratio of less than 2.0.
- In the case of crossed-axis helical double-flank meshes where the driver is a worm, a worm can also be considered for the master gear. This may provide an advantage for the test gear in that only the functional zone is measured and other tooth errors that will not even be seen in the actual product mesh will be ignored. In some cases, a narrow-face-width helical gear master may provide a similar result in a parallel-axis arrangement. In applications where a worm master is used, it may be necessary to add lubrication to the double-flank mesh to assist a sliding action in the mesh without causing reading errors.
- The extent of the master gear's reach (i.e., the master gear's outside diameter) into the test gear should be carefully chosen. Although, as stated above, the mesh under test must have a minimum contact ratio of 1.0 and a maximum contact ratio of less than 2.0, there must also be no contact of the master beyond the form diameter of the test gear. This may afford a wide range of choices in between those requirements when establishing the outside diameter of the master gear. The decision on what master design to use may be based on the cost and availability of existing or commercially available master gears, or it may be based on measuring a test gear to at least its start of active profile location in the actual application.
- Every combination of master gear and test gear should be checked at all tolerance levels to make sure the mesh meets the criteria described here. Just because an off-the-shelf master gear is commercially available does not mean it will mesh properly with a specific test gear.
- In order to machine and produce high-quality master gears by grinding, the bore on the master would need to be sufficiently large enough for a stable mandrel to hold the master gear during machining. Ground master gears with bores less than 6 mm should be carefully considered for the effect on master gear precision from a small-diameter machining mandrel.

Product Design Considerations

Tight mesh center distance and test radius have been described as a means of using double-flank composite inspection to control functional tooth thickness. The functional tooth thickness is the tooth thickness as perceived by a mating gear and therefore includes effects of all tooth deviations as previously described. The nominal tooth thickness (sometimes referred to as "design tooth thickness") does not include any tooth deviations other than allowance for thickness variation at the standard pitch diameter without runout.

As a result, the inspection of tight mesh center distance or test radius will provide information on operational backlash expected in a gear mesh if both gears are double-flank tested individually and the actual mounting center distance is known.

When designing gears, one of the goals is to control backlash. Too little backlash may result in power loss, heat build-up, wear and noise. Too much backlash may result in excessive lost motion and potentially abnormal noise upon direction reversal. One of the common errors in gear design is to ignore the effect that total composite variation has on backlash. As an example: in an external gear mesh, when the tight mesh center distance of two gear positions peak simultaneously, the result will be a minimum backlash condition. On the other hand, the same gears with minimum simultaneous tight mesh center distance positions will result in a maximum backlash condition. Housing center distance variation will further contribute to the backlash result.

When designing gears, the total composite tolerances need to be established simultaneously with the tooth thickness selection criteria in order to establish the true design backlash. The selection of total composite tolerances as an afterthought at the end of the design process may result in an inappropriate level of backlash or a potential for gear binding in the assembly.

Calculation of Backlash on External Spur and Helical Gears, Including the Effects of Total Composite Tolerances

When designing external spur and helical gears, the following calculation procedure may be useful in establishing backlash goals when taking total composite tolerances into consideration.

Calculation of the standard pitch diameters. The standard pitch diameter of a pinion or gear is:

$$d_k = \frac{z_k m_n}{\cos\beta} \tag{13}$$

where

k Is a general subscript with value k = 1 for the pinion, and k = 2 for the gear
d_k Is the standard pitch diameter of the pinion or gear, mm
z_k Is the number of teeth on the pinion or gear
m_n Is the normal module of the pinion and gear, mm
β Is the helix angle of the pinion and gear, degrees or radians

Calculation of the transverse pressure angles. The transverse pressure angle, α_t, of the pinion and gear is:

$$\alpha_t = \tan^{-1}\left(\frac{\tan\alpha_n}{\cos\beta}\right) \tag{14}$$

where

α_t Is the transverse pressure angle of the pinion or gear, mm
α_n Is the normal pressure angle, degrees or radians

Calculation of the base circle diameters. The base circle diameter, d_{bk}, of a pinion or gear is:

$$d_{bk} = d_k \cos\alpha_t \tag{15}$$

where

d_{bk} Is the base circle diameter of the pinion or gear, mm

Calculation of functional operating pitch diameters. The functional operating pitch diameters of the pinion and gear differ from the operating pitch diameters typically calculated in other documents in that the effect of the total composite tolerances are included.

The maximum and minimum functional operating pitch diameters are:

$$d_{wk\,max\,functional} = \frac{z_k(2\,a_{max} + F_{idT1} + F_{idT2})}{(z_1 + z_2)} \tag{16}$$

and

$$d_{wk\,min\,functional} = \frac{z_k(2\,a_{min} - F_{idT1} - F_{idT2})}{(z_1 + z_2)} \tag{17}$$

where

$d_{wk\ max\ functional}$ Is the maximum functional operating pitch diameter of the pinion or gear, mm

$d_{wk\ min\ functional}$ Is the minimum functional operating pitch diameter of the pinion or gear, mm

a_{max} Is the maximum mesh center distance, mm

a_{min} Is the minimum mesh center distance, mm

F_{idT1} Is the total composite tolerance of the pinion, mm

F_{idT2} Is the total composite tolerance of the gear, mm

Calculation of functional operating transverse pressure angles. The functional operating transverse pressure angle is calculated at the functional operating pitch diameter positions as follows:

$$\alpha_{wtk\ max\ functional} = \cos^{-1}\left(\frac{d_{bk}}{d_{wk\ max\ functional}}\right) \quad (18)$$

and

$$\alpha_{wtk\ min\ functional} = \cos^{-1}\left(\frac{d_{bk}}{d_{wk\ min\ functional}}\right) \quad (19)$$

where

$\alpha_{wtk\ max\ functional}$ Is the maximum functional operating transverse pressure angle, degrees or radians

$\alpha_{wtk\ min\ functional}$ Is the minimum functional operating transverse pressure angle in degrees or radians

Calculation of maximum and minimum transverse circular tooth thicknesses at the functional operating pitch diameter. The maximum and minimum transverse circular tooth thicknesses at the functional operating pitch diameter can be calculated based on the following equations:

$$s_{wtk\,max\,functional} = d_{wk\,max\,functional}\left(\frac{s_{nk\,min}}{d_k \cos\beta} + \operatorname{inv}\alpha_t - \operatorname{inv}\alpha_{wtk\,max\,functional}\right) \quad (20)$$

and

$$s_{wtk\,min\,functional} = d_{wk\,min\,functional}\left(\frac{s_{nk\,max}}{d_k \cos\beta} + \operatorname{inv}\alpha_t - \operatorname{inv}\alpha_{wtk\,min\,functional}\right) \quad (21)$$

where

$s_{wtk\ max\ functional}$ Is the maximum transverse circular tooth thickness at the maximum functional operating pitch diameter for the pinion or gear, mm

$s_{wtk\ min\ functional}$ Is the minimum transverse circular tooth thickness at the minimum functional operating pitch diameter for the pinion or gear, mm

Calculation of mesh backlash. The maximum and minimum transverse circular backlash at the functional operating pitch diameter is:

$$j_{wt\ max} = \frac{\pi\, d_{w2\,max\,functional}}{z_2} - s_{wt1\ max\ functional} - s_{wt2\ min\ functional} \quad (22)$$

and

$$j_{wt\ min} = \frac{\pi\, d_{w2\,min\,functional}}{z_2} - s_{wt1\ min\ functional} - s_{wt2\ min\ functional} \quad (23)$$

where

$j_{wt\ max}$ Is the maximum transverse circular backlash at the function operating pitch diameter

$j_{wt\ min}$ Is the minimum transverse circular backlash at the function operating pitch diameter

Conclusion, Part I

(*Ed.'s Note: Part II of this paper will appear in the March/April issue of* Gear Technology.)

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Power Skiving of Cylindrical Gears on Different Machine Platforms

Dr. H.J. Stadtfeld

It has long been known that the skiving process for machining internal gears is multiple times faster than shaping, and more flexible than broaching, due to skiving's continuous chip removal capability. However, skiving has always presented a challenge to machines and tools. With the relatively low dynamic stiffness in the gear trains of mechanical machines, as well as the fast wear of uncoated cutters, skiving of cylindrical gears never achieved acceptance in shaping or hobbing — until recently. Indeed, the latest machine tools — with direct drive train and stiff electronic gearboxes, complex tool geometry and the latest coating technology — now present an optimal opportunity for the skiving process, including the soft-skiving of cylindrical gears.

The Power Skiving Machine Setup Definitions

The geometric setup of a skiving cutter relative to an internal ring gear is shown (Fig. 1). The front view of the generating gear system is shown in the upper left graphic. The ring gear is oriented in the main coordinate system with its axis of rotation collinear to the Y_4 axis. The cutter center (origin of R_w) is positioned out of the center of Y_4 in the X_4-Z_4 plane by a radial distance vector Ex. The pitch circles of the cutter and the ring gear contact tangentially at the lowest point of the pitch circle. The top view, which shows the tool inclination angle or shaft angle Σ, is drawn below the front view. In case of a spur gear the stroke motion is directed in line with the Y axis. The relative velocity required as cutting motion is generated with a shaft angle Σ around the X_4 axis of the coordinate system shown in Figure 1. In case of a helical gear, the cutter inclination can be chosen independently from the helix angle. However, a helix angle of 20° or greater offers the possibility to be matched with the shaft angle Σ and to use a simplified spur gear-style shaper cutter for the skiving operation. Also in this case, the stroke motion is oriented in Y direction but an incremental rotation ω_2, which depends on the stroke feed, has to be added to ω_1. The shaft angle Σ can also be defined differently than the helix angle and it will still require the same incremental ω_2, but the tool front face orientation and side relief angles have to be calculated from the difference between helix angle and the shaft angle Σ. The side view to the right (Fig. 1) shows a second possible tool inclination which is called the "tilt angle." This tool tilt angle can be used to increase the effective relief angles between the blades and the slots; it can also be used to eliminate interferences between the back-side of a long spur gear-style shaper cutter with minimum relief angles (*see section* Skiving Tools). Within limits, it is also possible to utilize the tilt angle for pressure angle corrections.

The three-dimensional side view (Fig. 2) shows an internal helical gear with a shaft angle Σ between work and tool. The graphic shows the base angular velocities of the work ω_1 and the formula for its calculation. Figure 2 also includes the incremental angular velocity ω_2 and

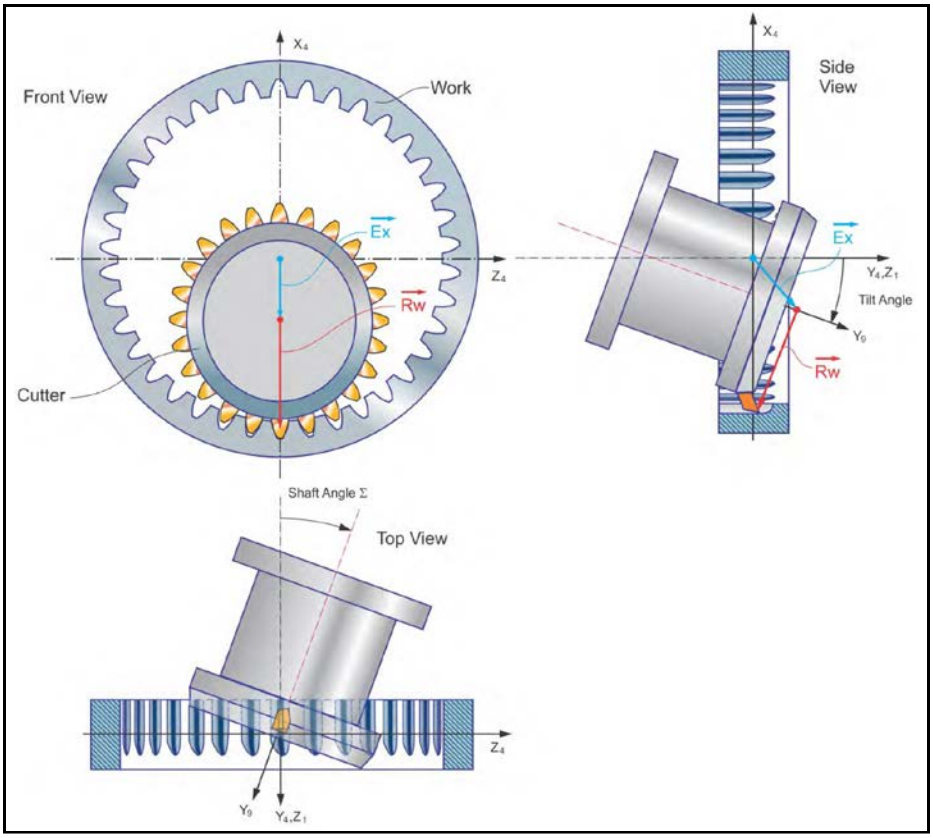

Figure 1 Basic geometry and kinematics of power skiving.

the formula to calculate it from the helix angle and the axial feed motion (stroke motion). The cutting velocity is calculated as the difference vector between the circumferential velocity vectors of work and tool in the cutting zone. Figure 3 shows a top view of the configuration between tool and work with the velocity vectors.

The reference profile of the tool is determined from the reference profile of the work applying the procedure (Fig. 4). The reference profile of the work with pressure angles α_1 and α_2 and point width W_p is drawn as a trapezoidal channel, and it is cut with a plane under the shaft angle Σ (Fig. 4, top, right). The profile is defined by the intersecting lines between the plane and channel, and it represents the reference profile of the tool. This tool reference profile is used in order to generate the involute in the tool cutting front (Fig. 4, bottom right).

The machine setting calculation is shown (Fig. 5, top) on the example of a bevel gear cutting machine. The explanation of the formula symbols are:

- X, Y, Z Machine axis directions (Y is perpendicular to the drawing plane)
- Σ Shaft angle between cutter and work
- *CRT* Cutter reference height
- B Cutter swing angle
- P_Z Pivot distance to spindle front in Z direction if $B = 0°$
- P_X Pivot distance to spindle center line in X direction if $B = 0°$
- Z_1, Z_2 Components in Z direction

Depending on the helix directions in work and cutter, the cutting takes place below or above the work gear center line in order to keep the B axis angle below 90°. Should there be no corrections needed, the crossing point between the cutter axis and the work axis lies in the cutter reference plane. The bottom section of Figure 5 shows the cutting blade definitions as reference.

Chip Formation and Optimization of Chip Load

Although the chip formation process of skiving appears different when compared to traditional gear cutting operations, understanding it is a fundamental task in recognizing weaknesses or strength of the skiving process. Power skiving has been called a combination of "cold forming"

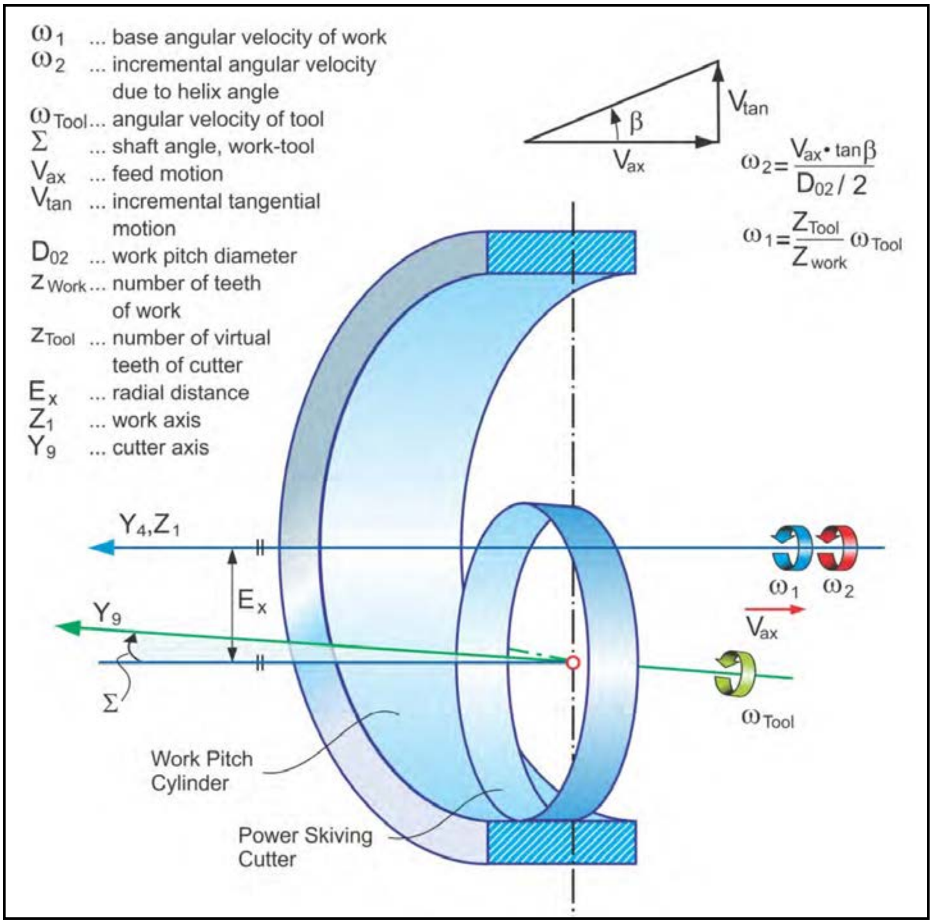

Figure 2 **Pitch cylinders of work and tool.**

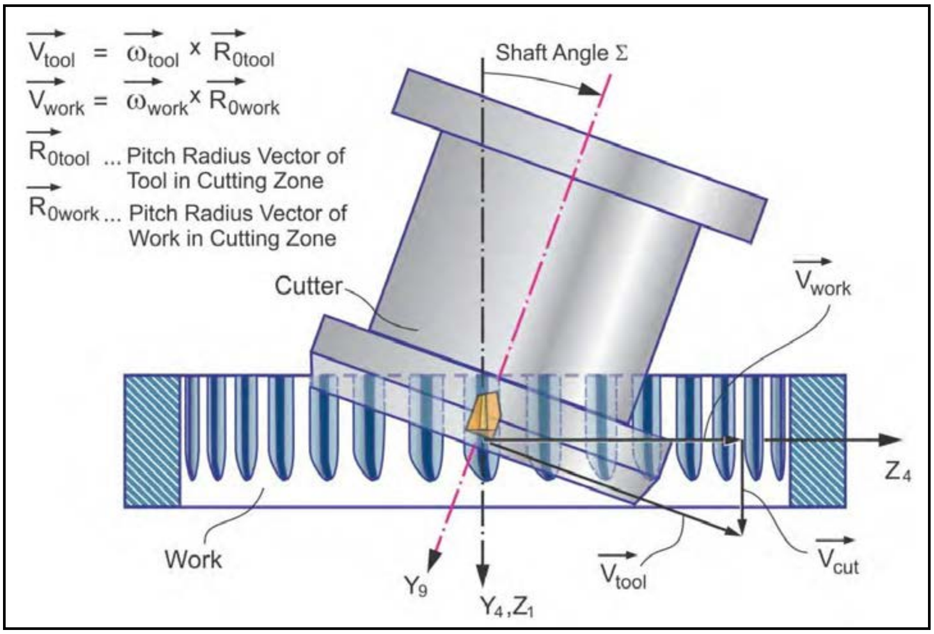

Figure 3 **Calculation of cutting velocity.**

and cutting. But is not every metal removing process such a combination? The task of a successful process is an economical combination of speed, part quality, tool life (tool-cost-per-part), and of course the investment in the machine tool.

The plane in Figure 6 shows a segment of an internal ring gear to be skived, and it is defined along the face width at the point where the last generating occurs. The second cutting tooth from the left has just entered into a part of the slot which is already rolled out from the previous cutting action. The third cutting tooth is advanced towards the observer and just begins a generating cut (see top view of unrolled partial slots). The generating cut continues to cut tooth number six. The lowest scallop in the top view was generated between the second and sixth cutting blade position. Cutting blades seven and eight finish the form cut end section of the slot.

A photograph of the tooth sequence from Figure 6 is shown in Figure 7 as a close-up. As one blade rotates through the cutting mesh, the orange-colored scallop is generated and the green-colored section is form-cut. The entire cutting action of one blade produces one chip, which includes the material removal from generating and form cutting. Beginning with its addendum, the right side of the blade gradually engages with the gear slot during the generating motion. It approaches the tip, and at this point it smoothly peels the chip up to the top of the gear. As the generation works its way from the right flank of the gear to the tip, and from this point up to the flank, every section that had at one point chip removing contact with the work now stays in contact to the end of the cut. Only the generating chip removal (within the scallop) converts quickly into form-cutting.

The form-cutting section might seem like an interesting phenomenon but it can be found in a similar form in all other generating cylindrical or bevel gear cutting methods. It is also common in all generating and form-cutting processes, that the tip region of the blades have the longest exposure to chip removal action within the green form-cutting region.

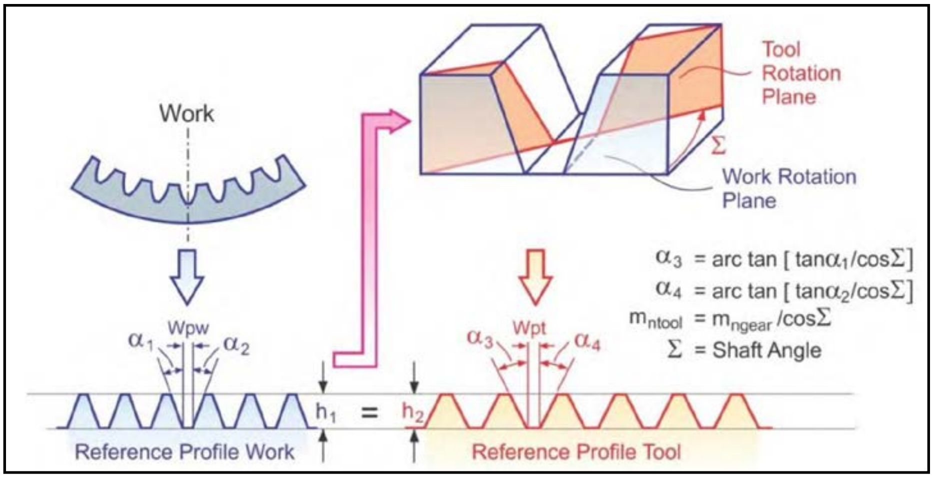

Figure 4 **Procedure for the calculation of the tool reference profile.**

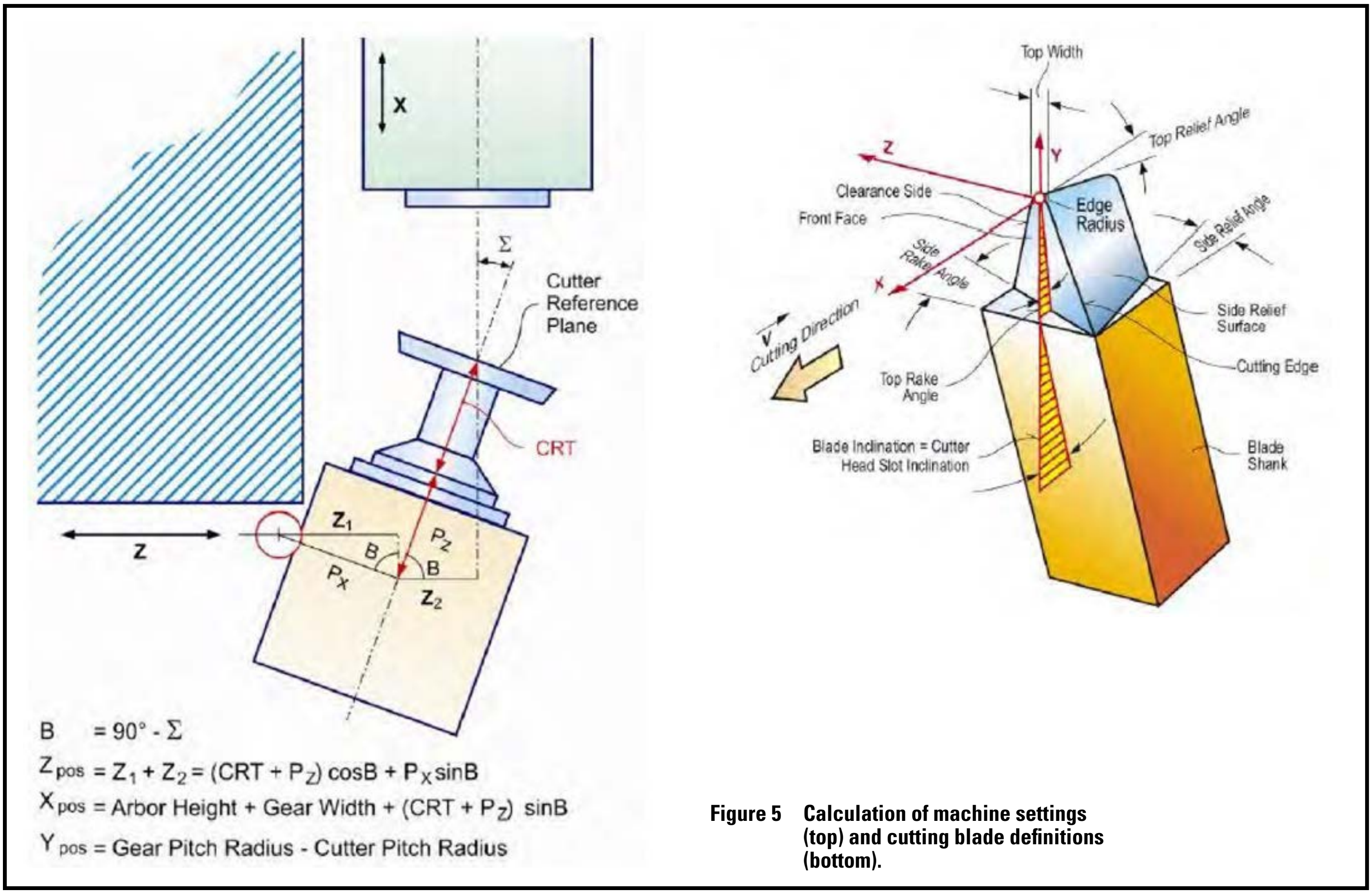

Figure 5 **Calculation of machine settings (top) and cutting blade definitions (bottom).**

Since the front face of power skiving blades is a plane that connects the cutting edges for both flanks, the side rake angle cannot be positive for both cutting edges. An acceptable compromise is a side rake angle of zero degrees. In order to enhance the cutting performance of the blade tip, a significant top rake angle can be introduced. However, peripheral cutter heads with carbide blades and top rake angles above 4° seem to fail with blade chipping in the tip area (Fig. 5).

Power skiving chips with a 5× magnification are shown (Fig. 8, top). The first chip (A) is a side chip from the first roughing pass of a module 4.0 mm gear with a 5 mm in-feed. The second chip (B) is U-shaped, which means, unlike the first chip, the side chips and the bottom chip have not been separated. This chip is from a second roughing pass with 3 mm in-feed. The third chip (C) is from a finishing pass with 1 mm in-feed. The result of an unrolled and uncompressed chip that is just sheared off is a curved channel like that indicated in the drawing at the bottom left of Figure 8. The two side walls, as well as the bottom section of the channel, are rolled up individually and mostly without breaking into separate pieces.

The microscope photo (Fig. 8, bottom right) shows a cross-section through the left wing of one chip with a magnification of 100×. At the beginning of cutting (center of the chip spiral), the chip thickness is small and increases slightly during the rather short generating section (orange scallop, Fig. 7). A proportional increase of the chip thickness occurs from the beginning to the end of the form-cutting section (Fig. 7, green area).

The right sides of the chips are thinner than the left sides, and a crack in the middle of the rolled-up sidewall can be observed. As the bottom left image indicates, the right channel wall has a more complex shape than the left side, and the skiving kinematic provides slightly different cutting conditions on both flanks. This explains differences in chip thickness between the two sides and the additional crack of the right side of the chip.

In order to avoid U-shaped chips, Gleason has developed an in-feed strategy. After each stroke an in-feed amount and a work angle set-over is applied in order to generate L-shaped chips (Fig. 9, left); L-shaped chips reduce the wear on the cutting blades.

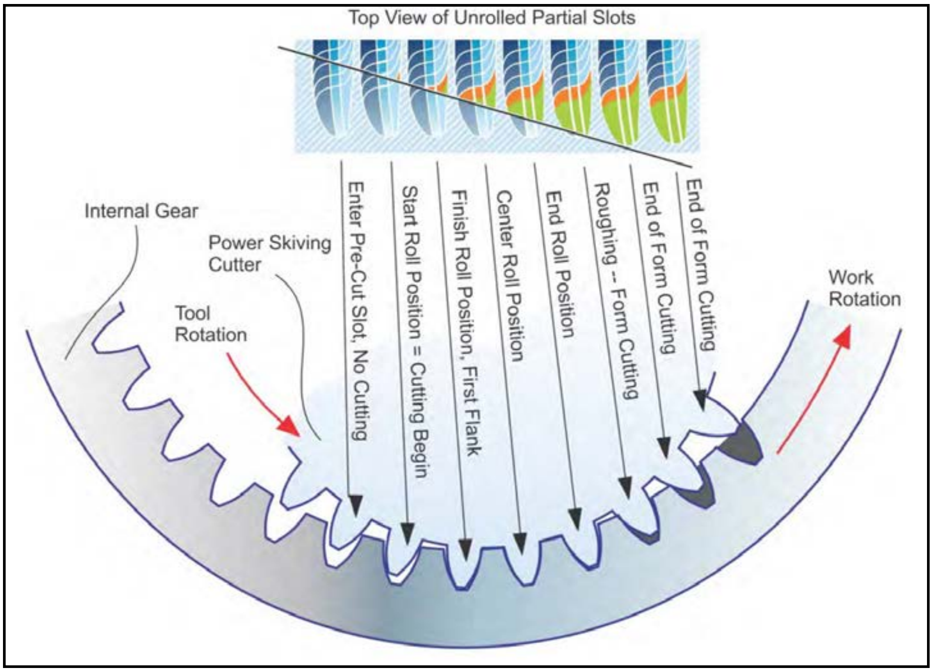

Figure 6 **Cutting sequence from engagement to exit.**

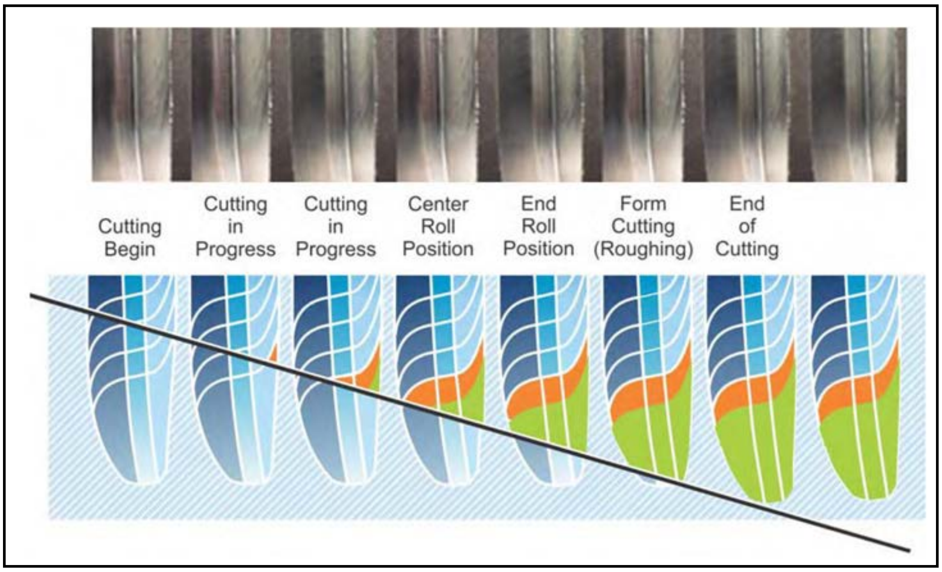

Figure 7 **Top view of unrolled partial real slots (top) and graphics (bottom).**

It is possible to alternate the in-feed work angle set-over direction from part to part in order to achieve even tool wear. Another possibility is to apply a positive side rake (e.g., 2°) to the left side of the blade (Fig. 8) that will enhance the cutting action on this side and generate L-shaped chips. If the resulting feed direction (Fig. 8) is not exactly parallel to the right flank, but about 3° "steeper," then a perfect clean-up of the right flank is guaranteed and the surface finish of the right flank will be equal or slightly better than the finish on the left flank.

HSS Cutters for Power Skiving and Surface Speed Calculation

Traditionally, power skiving is performed with common shaper cutters. However, a variety of different tools used for power skiving is shown; the first cutter (Fig. 10, left) is a shaft type that is slightly tapered without helix angle in the cutting teeth. This cutter can be used for gears with a helix angle. The shaft angle between cutter and work will be set to the helix angle of the work. This also means that the helix angle of the work should be above 10° in order to generate sufficient cutting speed. Due to the straight nature of the cutting teeth, workpieces

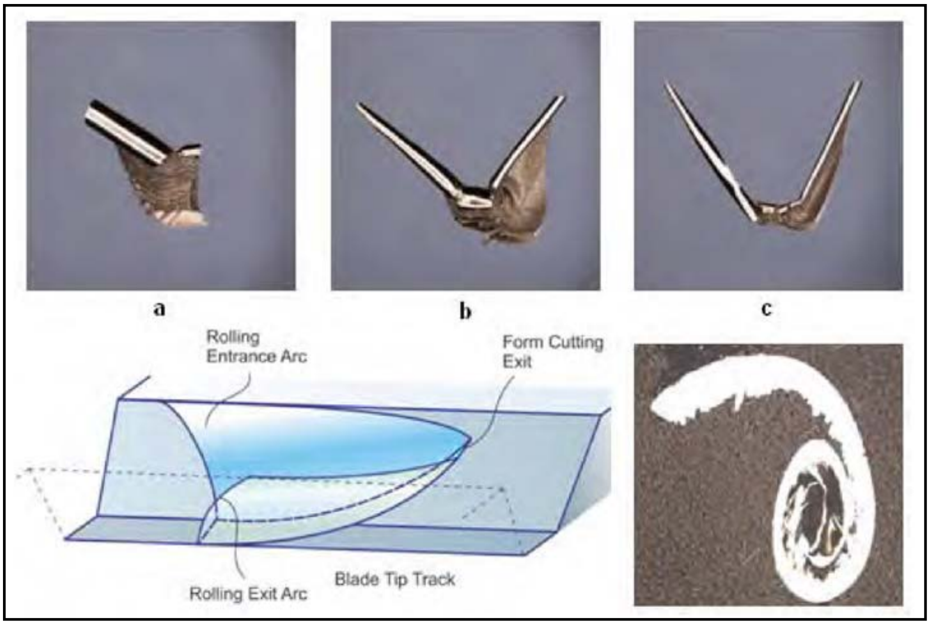

Figure 8 **Analysis of chip formation.**

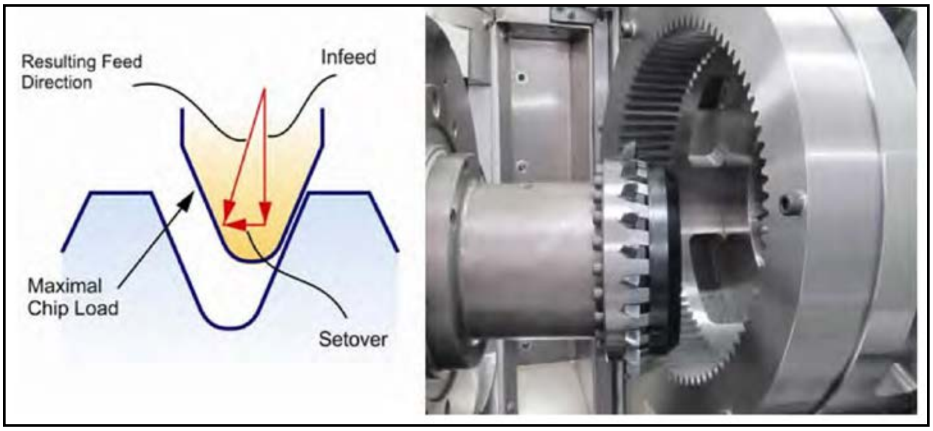

Figure 9 **In-feed strategy for optimized chip formation (Refs. 2, 3).**

Figure 10 **Solid HSS power skiving cutters coated with TiN and AlCroNite.**

with small diameter and large face width might cause interference between the slot and the far end of the cutting blade. The skiving cutter in the center (Fig. 10) is a wafer cutter with only a few re-sharpenings. The cutting teeth are straight, which makes this cutter only suitable for workpieces with a helix angle. The wafer cutter has very short, relieved teeth, which will prevent interference problems in case of helical slots that wind around a small-diameter workpiece.

The skiving cutter on the right (Fig. 10) has serrated blade front faces and teeth that are oriented under a helix angle; the black coatings are AlCroNite and the golden coating is TiN.

If the helix angle of the workpiece is 15° and the tool helix angle is 20°, then the shaft angle between skiving cutter and work has to be set up to 5° (same helix direction). If the helix directions are opposite, then a shaft angle of 35° must be used. An interesting situation presents itself if the gear helix angle of the work is identical to the cutter helix angle (same amount and same hand). In this case the shaft angle between cutter and work is zero, and no skiving motion is generated. The calculation of the cutting surface speed, depending on the helix angle β of the work and the shaft angle Σ, is shown (Fig. 11). The upper graphic represents the unrolled pitch cylinder with teeth and slots indicated (see also Fig. 11, right side graphic) for a spur gear. With $\beta=0$, the formula is simplified to the first special case. The lower graphic shows the formula simplification for the second special case, which occurs if the helix angle β is equal to shaft angle Σ. The cutting velocity formula also considers — next to the circumferential velocity at the work gear pitch diameter — the helix angle β of the work and the shaft angle Σ between work and skiving cutter. The cutting velocity vector is automatically directed in the flank lead direction if the formula (Fig. 11) is applied. Although the formula indicates some interplay between Σ and β, the major parameter for generation of sufficient cutting velocity is the shaft angle Σ between the work and tool axes.

High-Speed Carbide Cutter Head System for Power Skiving

A new type of cutter head — PentacPS — that uses stick blades has been developed especially for power skiving (Fig. 12). The blade material is carbide and the blade profiles are 3-face-ground and all-around-coated. The blade profile resembles an involute that is derived from the tool reference profile (Fig. 4). The blades can either be ground as full profile blades — just like the profiles of the standard skiving cutters shown in Figure 10 — or as alternating left flank/right flank blades that allow it to realize sufficient side rake angles. This alternate blade arrangement offers very good tool life and an exceptionally smooth cutting operation. However, the productivity is slightly lower than using full-profile blades.

Due to the design of the PentacPS cutter head, the blades have spaces between them that are larger than the tooth thickness of the reference profile. PentacPS cutters are selected for a certain module, such that the blades in the cutter head represent every second, third or fourth slot of the reference profile. Regarding low workpiece run-out and high spacing quality, it is required to avoid a common denominator between the theoretical number of skiving cutter teeth and the number of work gear teeth. The same rule applies for solid skiving cutters as well.

In order to establish a new cutter design, a procedure was developed that allows a minimum of cutter head types. For example, external gears with a maximal pitch diameter of 360 mm or internal ring gears with a minimal pitch diameter of 450 mm and above can be skived with a 9-inch peripheral cutter head. The spreadsheet in Figure 13 uses modules from 2 to 7 mm, in 0.5 mm steps, to calculate a pitch diameter and the theoretical number of teeth z_2. The value for z_2 must be rounded up or down in order to receive an integer number. This requires a change in the pitch diameter of the tool. The developed stick blade system allows adjustment of the blade stick out by some small amount to match the required pitch diameter for the number of teeth selected.

However, the 9-inch-size cutter heads only have blade numbers of 15, 17, 19, 21 and 23. In the next columns of the spreadsheet (Fig. 13), all existing inte-

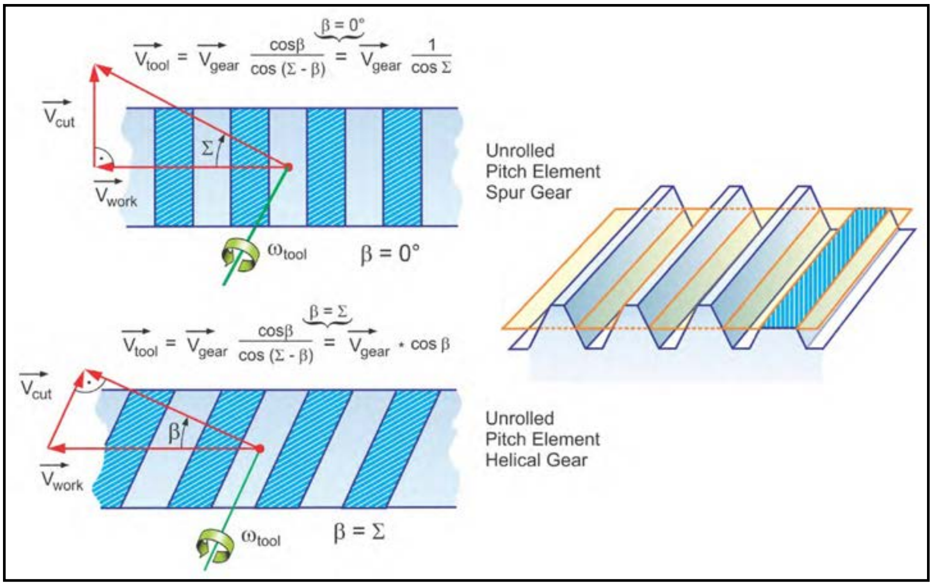

Figure 11 Cutting velocity calculation.

Figure 12 Stick blade cutter PentacPS for power skiving with carbide blades.

Module	D_{02}	Z_2			D_{02}*	D_{02}*(Selected)	Fraction Generating Gear						Fraction Gear		Cutter Slots
		Calculated	Rounded	Selected			Calculated	Divisors				Selected			
2	223.7433	105.1250	106	105	225.6057	223.4773	105	5	0	3	0	5	1	5	21
			105		223.4773		21						21	105	
2.5	222.6791	83.7000	84	84	223.4773	223.4773	84	0	4	3	2	4	1	4	21
			83		220.8169		21						21	84	
3	221.6149	69.4166	70	69	223.4773	220.2848	69	0	0	3	0	3	1	3	23
			69		220.2848		23						23	69	
3.5	220.5508	59.2143	60	57	223.4773	212.3035	57	0	0	3	0	3	1	3	19
			59		219.7527		19						19	57	
4	219.4866	51.5625	52	51	221.3490	217.0923	51	0	0	3	0	3	1	3	17
			51		217.0923		17						17	51	
4.5	218.4224	45.6111	46	46	220.2848	220.2848	46	0	0	0	2	2	1	2	23
			45		215.4960		23						23	46	
5	217.3582	40.8500	41	42	218.1564	223.4773	42	0	0	3	2	2	1	2	21
			40		212.8356		21						21	42	
5.5	216.2940	36.9545	37	38	216.5602	222.4132	38	0	0	0	2	2	1	2	19
			36		210.7072		19						19	38	
6	215.2299	33.7083	34	34	217.0923	217.0923	34	0	0	0	2	2	1	2	17
			33		210.7072		17						17	34	
6.5	214.1657	30.9615	31	30	214.4318	207.5147	30	5	0	3	2	2	1	2	15
			30		207.5147		15						15	30	
7	213.1015	28.6071	29	30	216.0281	223.4773	30	5	0	3	2	2	1	2	15
			28		208.5788		15						15	30	

Figure 13 Calculation scheme for cutter diameter and number of blades.

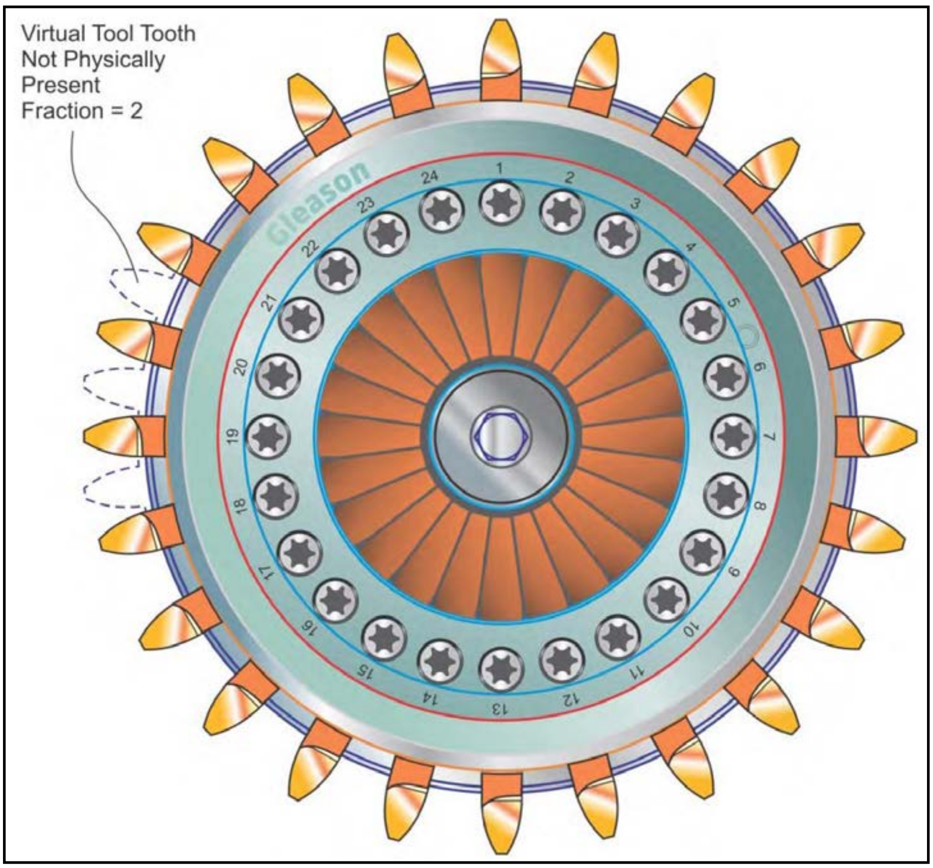

Figure 14 Virtual tool teeth.

ger fractions between two and five are determined. The goal is to find the largest number of slots available in the 9-inch PentacPS line of cutters to assure the maximal productivity. In other words, the PentacPS cutter never represents the theoretical tool tooth number with the number of slots — rather, only a fraction thereof. The theoretical number of tool teeth becomes the virtual tool tooth number of which only a fraction is represented on the cutter head. If a number is selected and typed in the spreadsheet next to the actual fraction of slot and theoretical tooth number, the resulting number of cutter slots is shown in the last column. If this number does not match an existing cutter head, then a second or third number has to be chosen until a matching cutter is found.

Depending on the number of teeth of the work gear, the virtual number of tool teeth may be even, and never is a prime number. This will not be of any disadvantage as long as a hunting-tooth relationship between work and virtual cutter exists. In such cases the hunting-tooth principle exists between work and real cutter. The peripheral stick blade cutter design will physically prevent a fit of the virtual number of blades next to each other. The cutter drawing in Figure 14 represents each other tooth, as indicated with the dashed drawn (virtual) blades between the real blades.

Power Skiving Machines and Software

During the last years dedicated power skiving machines have been introduced, starting from very small gear sizes (below 100 mm) up to 600 mm gear diameter (Fig. 15, left). A technology software was developed that calculates machine settings from part geometry and chosen tool parameters; the software also determines the chip removal volume, depending on the shaft angle between work and tool. The optimal in-feed strategy utilizing an involute roll simulation also features an interference check by comparing the tool path with the simulated slot surfaces (Ref. 4).

For the convenience of both gear engineer and machine setup personnel, the power skiving technology software resides on the control of the power skiving machine. Coincidentally, during development of the power skiving process, it became apparent to Gleason that there was interest in applying this successful process to bevel gear cutting machines as well. Manufacturers who wanted fuller optimization of their Phoenix bevel cutting machines began utilizing the power skiving process for prototyping or manufacturing of small- and medium-batch sizes as a value-added task for this rather versatile machine. In order to address this interest, Gleason applied the power skiving developments that had been conducted until 2012 — and strictly on dedicated machines — to all current Phoenix bevel gear cutting machines (Fig. 15, right); Figure 15 shows a power skiving setup in a Phoenix 600HC.

Along with this significant step, the Gleason power skiving development team was expanded from only cylindrical gear experts to a mix of cylindrical and bevel gear experts. The experience in bevel gear manufacturing using carbide stick blades then led to development of the PentacPS peripheral skiving cutter system, which in turn was applied to the dedicated power skiving machines as well.

As for power skiving, the Gleason bevel gear cutting machines use the same software as used on the PS machines. Summary development, cycle optimization, and corrections are conducted on the machine — not on a remote desktop — as is common in bevel and hypoid gear manufacturing. Figure 16 shows the main screens for gear data, process parameter and workholding entry.

The power skiving technology software can also be used as a standalone package on the gear engineer's desktop. This allows the gear engineer to conduct experiments and pre-optimizations of future gear designs that will be soft-machined by power skiving. The desktop software version is also more suitable for the stick blade geometry calculation. This calculation delivers a blade-grinding summary following the same standards used for bevel gear cutting blades. The blade-grinding machine accepts those summaries like summaries for regular bevel gear cutting blades.

The technology software for power skiving on Phoenix machines allows the input of tooth thickness, depth and helix angle corrections. Tooth thickness and

Figure 15 Different machines with power skiving setup.

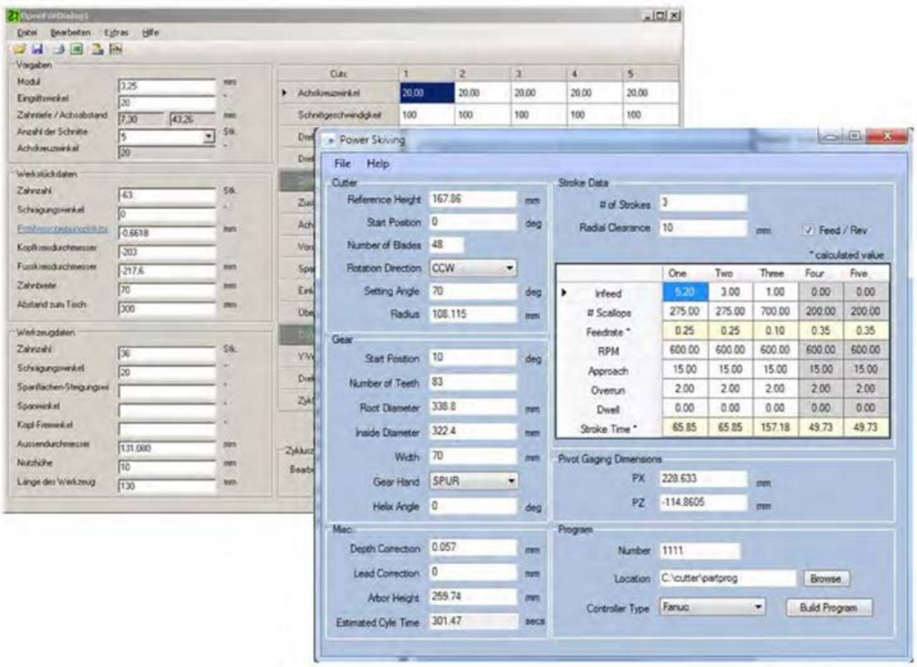

Figure 16 Technology software process input screens (Ref. 4).

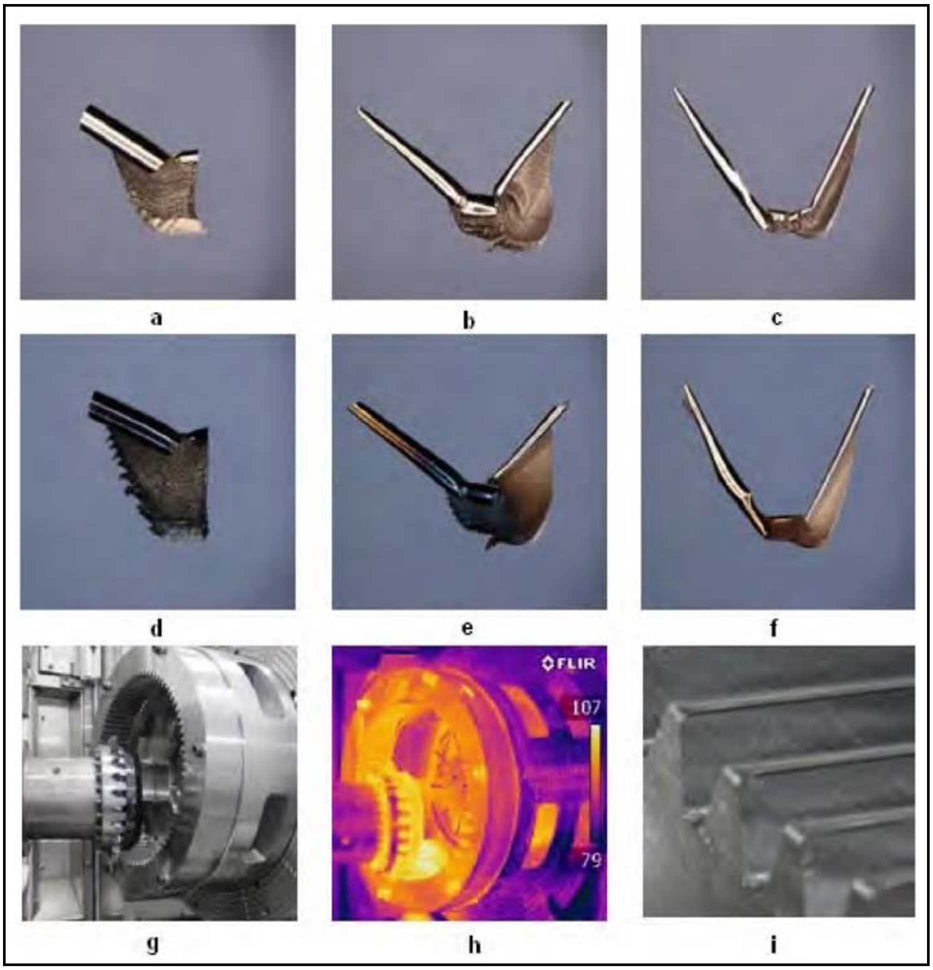

Figure 17 **Chips from wet/dry skiving and process temperature.**

depth are coupled corrections that follow a certain strategy. The correct tooth thickness has the higher priority than the depth. In order to achieve the correct thickness, the slots can be cut deeper within the limit the gear engineer allows. It is not recommended to cut the slots shallow because of implications like roll interferences in the operation of the gearset. If the correct slot width cannot be achieved within the given possibilities, then the blades have to be corrected; or, in case of an undersized slot, a side cutting in a second pass is possible, although it adds unwanted cutting time. If both flanks have similar, small unidirectional pressure angle errors (same sign), then a correction via the cutter tilt angle (Fig. 1) is possible; larger pressure angle errors with inverse signs must be executed by grinding corrected blades.

Wet or Dry Power Skiving?

A solid cutter from G50 (Rex76) material with an AlCroNite coating is suitable for a surface speed of 100 m/min in a wet skiving environment. Carbide stick blades (H10F) with an ALCRONA-Pro coating allow about 300 m/min surface speed. However, regarding tool wear it has to be considered that in skiving very high rpms are required in order to achieve the desired surface speed. This in turn creates a profile sliding which is superimposed to the cutting speed. The profile sliding might have its highest value at the blade tip, which has already a long chip removing engagement path and experiences due to the sliding and additional side relief wear.

Cutting trials in Power Skiving have shown it is possible to reduce the surface speed down to numbers between 150 and 200 m/min (Under-Critical Speed, UCS) and increase the in-feed and feed rate in order to keep the productivity high, and at the same time achieve a significant improvement in tool life.

Chips from wet UCS skiving with Alcrona-Pro coated carbide blades and 172 m/min surface speed are shown in the top row of Figure 17. The first roughing pass used an in-feed setting of 5 mm and a feed rate of 0.045 mm per blade. The chips (Figure 17a) are large and only slightly curved. Each chip represents one flank and part of the slot bottom. The second pass used an in-feed setting of 3 mm and a feed rate of 0.28 mm per blade. This chip consists of the two flank chips connected by the bottom chip (Figure 17b). The finishing pass used an in-feed of 1.00 mm and a feed rate of 0.015 mm per blade, and this chip has the two flank and the bottom chip connected to a U-shaped appearance.

Chips d through f in Figure 17 have been created also with Alcrona-Pro coated carbide blades and 172 m/min surface speed in a three-pass dry cutting process using the same in-feed values and feed rates as applied in the wet cutting (Figure 17 a through c). The dry chips seem to have the same appearance as the chips from wet cutting except for the brown and blue color from the process heat.

The comparison between the wet and dry versions of power skiving with coated carbide blades shows a clear advantage of the dry process. The process heat helps to plastically deform the chip during the shearing action. If the process parameters and tool geometry are chosen to move the process heat into the chips and with the chips away from tool and work piece, then a cool skiving process is the result. Dry power skiving delivers a better surface finish and causes equal or even lesser tool wear than the "wet" process version. However, the chip surface on the side adjacent to the sheared off side is smoother, and the machine power reading showed about 15 percent lower spindle power during dry skiving. The current skiving developments indicate the dry process version will deliver the better tool life, which is expected to be more significant than in bevel gear cutting.

Dry high-speed UCS power skiving with coated carbide blades result in the optimal combination between low tool wear and low skiving times. The additional advantage is, that machines with medium-speed, high-torque spindles (e.g., 1,000 rpm max for machine size 600 mm OD) can be applied without compromising the performance of the machine e.g. for bevel gears which require low rpm and high torque. This argument is important if a manufacturer applies power skiving to bevel gear cutting machines.

The bottom row in Figure 17 shows a dry UCS setup "g," and it shows a thermographic photo taken during the roughing pass at mid-face. The highest temperatures of 107°F (42°C) occur around the cutter and at the work gear sections, which move away from the cut. These temperatures can also be measured on part and cutter after the cycle. It can be concluded that the dry UCS process has an optimal heat transfer into the chips and quickly reaches a rather low and steady-state temperature of cutter and work holding.

A productivity comparison between the traditional processes hobbing and shaping with three variations of the new power skiving process is shown (Fig. 18). The goal of this chart is to compare the preferred embodiment of the different processes. In order to establish the same basis for each process, an external ring gear with the gear data shown in the diagram was used for all processes. The objective was a finishing quality with scallop or generating flat amplitudes at or below 5 μm. The shaping process used an AlCroNite-coated shaper cutter from G50 material with 34 teeth and it was set up as a 3-cut finishing cycle. The identical shaper cutter was used for the wet power skiving where the cutting was done in four passes. For the hobbing process, a one-start hob with 16 gashes, also from AlCroNite-coated G50 material, was utilized in a 2-cut cycle. Dry power skiving with ALCRONA-Pro-coated H10F carbide blades is represented in the diagram as UCS-skiving with 172 m/min and as high-speed skiving with 300 m/min — both set up as a three-pass cycle. The dry power skiving bars are based on a 24-blade and 9" diameter PentacPS cutter head. The chip thickness in the case of UCS-skiving is 10 percent-to-20-percent higher than in the case of high-speed skiving, which reduces the productivity difference between the two process variations, yet gives the UCS-skiving a tool life advantage. Figure 18 indicates that power skiving has between 6-to-12 times the productivity of shaping and between 1.6 and 3.3 times the productivity of hobbing.

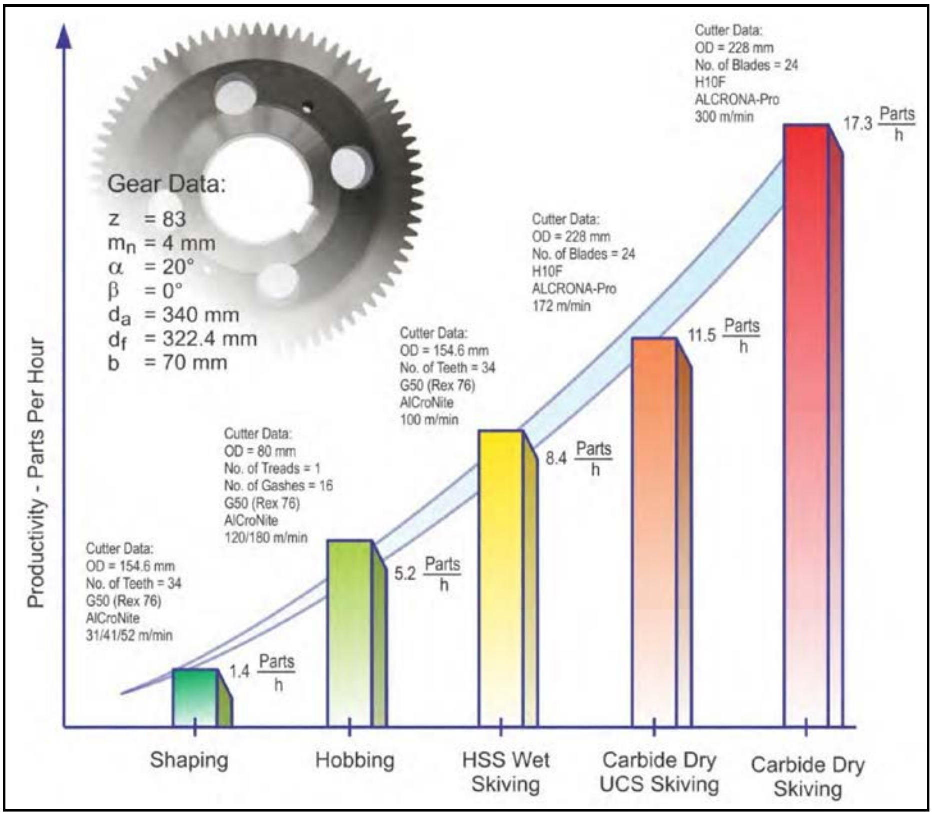

Figure 18 Productivity comparison.

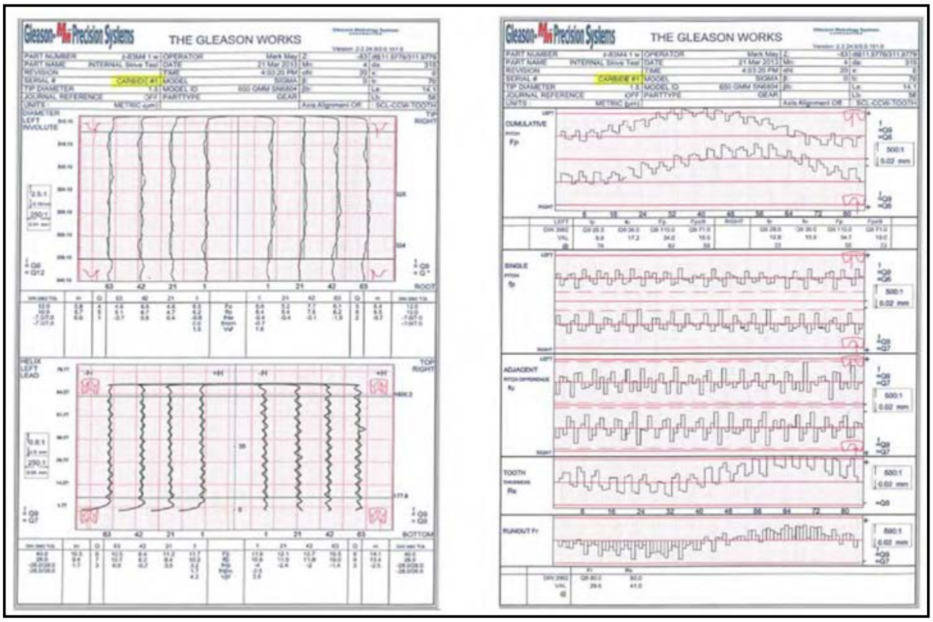

Figure 19 Measurement: profile, lead and spacing.

Measurement Results

This section discusses measurement results from the newly developed UCS power skiving with Pentac PS tools. As mentioned earlier in this paper, corrections of the lead angle can be accomplished with machine motions and corrections of tooth thickness and depth are possible within limits using machine settings. Unlimited tooth thickness and depth corrections, as well as pressure angle corrections, are possible by regrinding the stick blades. The measurement results (Fig. 19) show profile (top) and lead (bottom) measurement in the left-side evaluation sheet. The measurement was taken after a pressure angle correction on the skiving blades. The lead direction showed a perfect result after the first sample cutting. The waviness of the

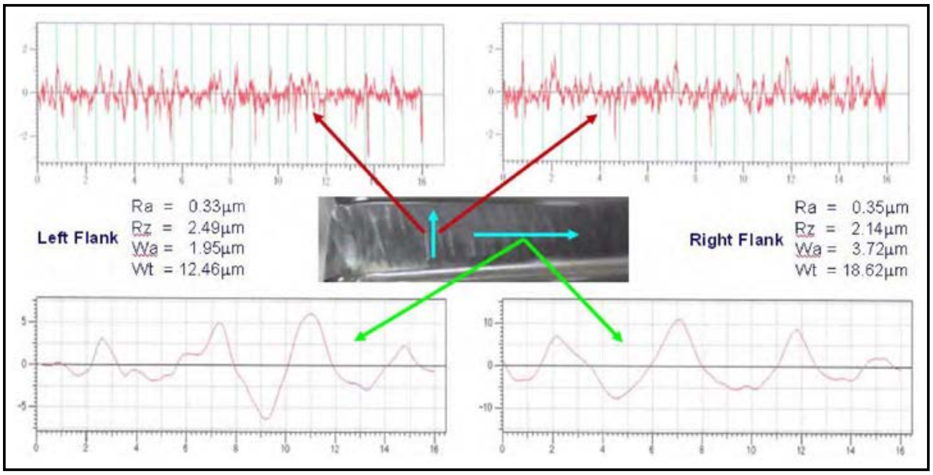

Figure 20 Measurement: surface roughness and waviness.

lead graph is typical for power skiving and reflects the skiving scallops; however, their amplitudes are below 5 μm.

Surface roughness and waviness measurement results from a Zeiss surface tracer are shown (Fig. 20). The profile roughness results in the two graphs on top of Figure 20 delivered excellent values for R_a and R_z. The waviness in lead direction is basically the result of the scallop amplitude of 5 μm (theoretically). Due to the different cutting condition on the two flanks, the waviness on the right flank shows about 1.5 times the magnitude of the waviness of the left flank.

The right hand chart (Fig. 19) show good results regarding f_p and f_u, considered the skiving scallops are phase-shifted from tooth to tooth. Cumulative pitch error F_p and run-out F_r reflect the imperfect temporary workholding (Fig. 17g). Improved gear quality can be achieved by using production workholding or individual run-out truing in case of small manufacturing quantities. Single and adjacent tooth spacing numbers can be improved by a lower feed rate, which will reduce the tooth-to-tooth variation due to the "moving" scallops.

Summary

Complex solid skiving cutters lack some flexibility for lower quantities and for larger parts. Next to the solid cutter disks, Gleason developed a second solution that offers a high-speed dry power skiving based on peripheral cutter designs. The new cutter system consists of three different cutter sizes where each size is available with different blade numbers. Depending on the part size, this combination allows coverage of a range between module two to module seven, with five different cutter bodies; and the stick blades can be ground on every modern blade grinding machine.

The power skiving process with stick blade cutters is performed on 6-axis CNC bevel gear cutting machines. Feed and stroke motion are optimized in connection with the particular stick blade geometry in order to create an optimized chip formation. All parameters for feed and stroke are calculated in advance in order to assure high cutting performance, even tool wear and high tool life.

Lead correction, pressure angle balance and anti-twist correction can be achieved via delta value input directly from the K- and lead-chart into the technology software screen on the skiving machine. Although the perception in the market is that power skiving seems to compete only with shaping, and is particularly suitable only for internal gears, it can also be applied to external gears and is also equal — and perhaps faster — than hobbing.

In the case of a power skiving process performed next to bevel gear cutting on a Phoenix 6-axis machine, the conflict of compromising the machine's ability for bevel gear power cutting with a high-speed spindle, which suits the high-speed dry power skiving, was solved with the development of under-critical-speed (UCS) skiving. Power skiving with UCS only requires 150 to 200 m/min effective surface speed, is highly productive, and has excellent tool life.

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The XL Gears Project: Researching New Materials and Manufacturing Processes for Large Gears, Bending Fatigue and Surface Performance

Carlo Gorla, Edoardo Conrado,
Francesco Rosa and Horacio Albertini

Much of the existing guidelines for making large, high-performance gears for wind turbine gearboxes exhibit a need for improvement. Consider: the large grinding stock used to compensate for heat treatment distortion can significantly reduce manufacturing productivity; and, materials and manufacturing processes are two other promising avenues to improvement. The work presented here investigates quenchable alloy steels that—combined with specifically developed case-hardening and heat treatment processes—exhibits reduced distortion and, in turn, requires a smaller grinding stock.

Introduction

Manufacturing processes and material selection for large gears of wind turbines are topics of great interest, because traditional production methods are proving to be inadequate for a cost effective mass-production of large and high quality gears. In particular, due to large distortions in the heat treatment phase, the final finishing grinding operations require a severe stock removal, which reduces the productivity of the process.

Manufacturers of grinding machines are actively working to improve the productivity of the grinding process, but on the other side, the selection of materials and heat treatments which can reduce the distortions of the quenching phase represents an effective contribution to the final scope of reducing manufacturing time and costs.

The aim of the XL Gears Research Project, which has been supported by Regione Lombardia, is to identify alternative gear manufacturing processes and materials, in order to reduce the heat treatment distortions, with the aim of easing the final grinding operation. Two innovative materials have been identified, the former characterized by a high Jominy hardenability and the latter by a bainitic structure, both suitable for air quenching, thus reducing the heat treatment distortion. Also the environmental impact is significantly reduced, since the cooling oil bath is no more necessary. As a baseline for comparison, a common case hardening gear material (18NiCrMo5) has been selected, in order to evaluate the performances of the new materials.

In the first stage of the research, metallurgical specimens have been manufactured and analyzed in order to define a suitable heat treatment process. The bending performances of the new and of the baseline materials have then been compared by testing specifically designed gear specimens on a mechanical resonance test bench. The surface performances of these materials have been investigated by means of disc-on-disc micropitting tests with a load stage procedure. In this article the results of the STF and disc-on-disc tests on the new materials as well as on the baseline are presented and discussed.

Bending Fatigue Strength

Bending fatigue tests have been performed on a Schenck mechanical resonance pulsator, loading one tooth at a time (single-tooth fatigue test). Three families of materials were tested: 1) 18NiCrMo5 case-hardened, 2) Jomasco and 3) Metasco. The typical staircase approach has been adopted in order to determine the bending fatigue limit of these gear materials. The tests were conducted with a stress ratio R—i.e., the ratio of minimum-to-maximum applied load—equal to 0.1, since in our tests it is not possible to completely unload the tested teeth, and with a load frequency of about 35 Hz. Five million load cycles was adopted as the run-out value, as the kNee of the bending fatigue S/N diagrams for case-hardened materials is typically at three million load cycles (Ref. 1). Two toothed wheels for each material were used during bending fatigue tests.

Table 1 Main data of gear specimen for bending tests

Parameter	Symbol	Unit	Value
Module	m	[mm]	**8**
No. of teeth	z	[/]	**32**
Pressure angle	α	[deg]	**20**
Face width	b	[mm]	**20**
Addendum modification coef.	x	[/]	**0.226**
Basic rack	ISO 53.2 – B		

The main geometric data of the specimens are listed (Table 1). Their geometry has been designed so that their fatigue limit will likely be a lower maximum load (60 kN) than the available testing machine can exert. Regardless, the module has been kept in the range in which the size factor (Y_X according to ISO 6336) is different from one, the typical condition for gears in wind turbine gearboxes. Eight tests can be performed on each wheel, since three teeth are comprised between tooth under test, and

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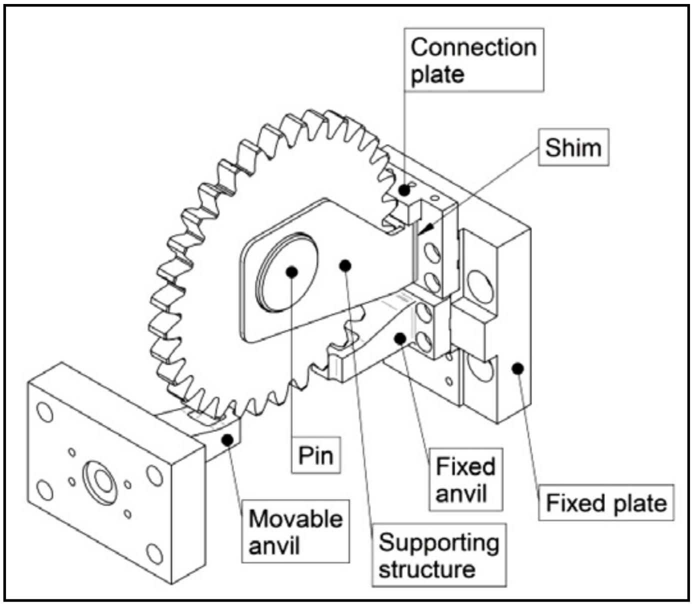

Figure 1 Bending fatigue test apparatus: 3-D schema and part nomenclature.

tooth reacting to the load and teeth adjacent to tested tooth are not used.

The test gears were positioned on the test rig by means of a pin inserted in the hole of the hub and in the supporting structure (Fig. 1). This pin was used only in the setting phase and was subsequently removed. While the vertical position of the axis of the supporting structure holes was fixed and set at a distance equal to the base radius r_b from the axis of the machine, the horizontal position of the gear was adjusted using shims. A symmetric loading condition is obtained (i.e., same root stress on the two teeth) if the pin axis is set at a distance (X) from the fixed anvil equal to half of the span measurement (W_5). In the performed tests, a non-symmetric condition has been used to maximize the obtainable root stress. This configuration was obtained by shifting the gear in a horizontal direction of $\delta_s = 2.89$, in regard to the symmetric loading condition. In this asymmetric condition, one loaded tooth is stressed more than the other one since the load is applied at a higher radial distance from the toothed wheel center that, according to the geometrical quantities shown (Fig. 2), can be calculated as follows:

$$R_L = OC_L = \sqrt[2]{(W_5/2+\delta_S)^2 + r_b^2} \quad (1)$$

Bending stress calculation. In order to compare experimental results with standard limits, the relationship used in method B of ISO 6336-3:2006 — between load and root bending stress — should be adapted to the above-described loading conditions. The general ISO relationship between applied load and root bending stress, simplified here to account for test conditions, is:

$$\sigma_F = \frac{F_t}{b \cdot m} \cdot Y_F \cdot Y_S \quad (2)$$

where

F_t is the tangential force, m the module, b the face width and Y_F and Y_s are geometric factors named according to the standard ISO 6336-1. These geometrical tooth factors have been determined according to the procedures described in Reference 2 and in Reference 3, and their values are listed in Table 2.

Table 2 Factors according to ISO 6336

Symbol	Unit	Value	Description
Y_F	-	1.676	Tooth form factor
Y_S	-	2.012	Stress correction factor
Y_{ST}	-	2	Stress correction factor for test gears
Y_{NT}	-	1	Life factor for tooth stress
$Y_{\delta relT}$	-	1.001	Relative notch sensitivity factor
Y_{RelT}	-	0.957	Relative surface factor
Y_X	-	0.97	Size factor
σ_{F0}/F	[MPa/kN]	19.807	

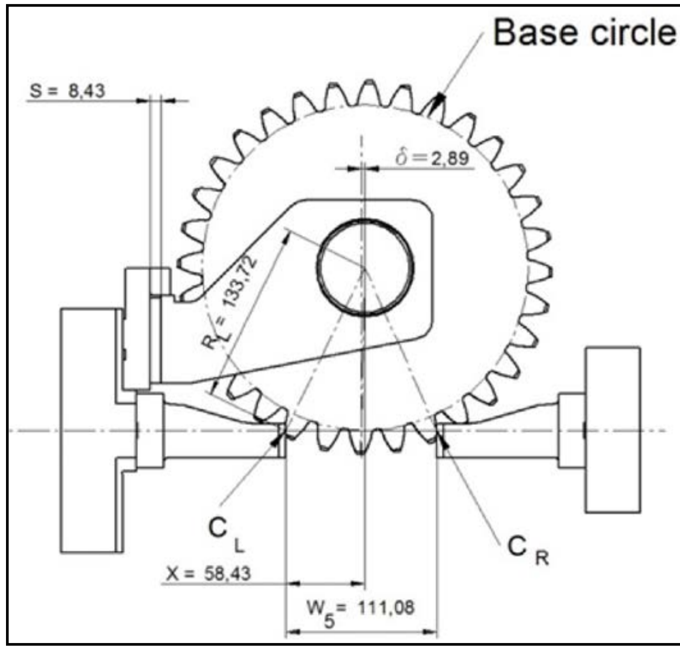

Figure 2 Bending fatigue test apparatus: main dimensions of rig and gear.

Starting from the definition of the tooth root stress limit σ*FG* given in the standard and assuming a safety factor against tooth failure equal to one, the "nominal stress number (bending) from reference test gears" σ_{Flim} can be obtained from test results expressed in terms of maximum applied force as follows:

$$\sigma_{Film} = \left(\frac{F \cdot \cos\alpha}{b \cdot m}\right) \cdot (K_A \cdot K_V \cdot K_{F\alpha} \cdot K_{F\beta}) \cdot \frac{Y_F \cdot Y_S \cdot Y_\beta \cdot Y_B \cdot Y_{DT}}{Y_{ST} \cdot Y_{NT} \cdot Y_{\delta relT} \cdot Y_{RrelT} \cdot Y_X} \quad (3)$$

where

all the symbols are defined according to the standard ISO 6336 and their values for the test gears are listed in Table 2, if they are not equal to 1.

Analysis and synthesis of experimental test results. Figure 3 shows, in terms of staircase sequences, the results of the bending tests on the Jomasco and Metasco specimens, as well as results of the tests conducted on the 18NiCrMo5 case-hardened specimens. The Dixon and Mood approach (Ref. 4) was adopted to analyze these results.

Practically, for each test specimen, experiments have been grouped in load levels (i) in order to determine the number (n_i) of tests in which the less frequent event occurs. These values have been then used to compute the coefficients A and B, and to finally determine the fatigue limit (μ_D) at 50 percent of failure probability and its standard deviation (σ_D) as follows:

$$A = \Sigma_i \, i \, n_i; \quad B = \Sigma_i \, i^2 \, n_i;$$

$$\mu_D = F_0 + d \cdot \left(\frac{A}{N} \pm \frac{1}{2} \right)$$

$$\sigma_D = \begin{cases} 1.62 \cdot d \cdot \left(\frac{N \cdot B - A^2}{N^2} + 0.029 \right) & if \ \frac{N \cdot B - A^2}{N^2} \geq 0.3 \\ 0.53 \cdot d & if \ \frac{N \cdot B - A^2}{N^2} < 0.3 \end{cases}$$

where

$d = 2\,kN$ is the step between two consecutive load levels, F_0 is the lower load used during tests; the positive sign is used if the run-out is the more frequent event; otherwise, the negative sign is used.

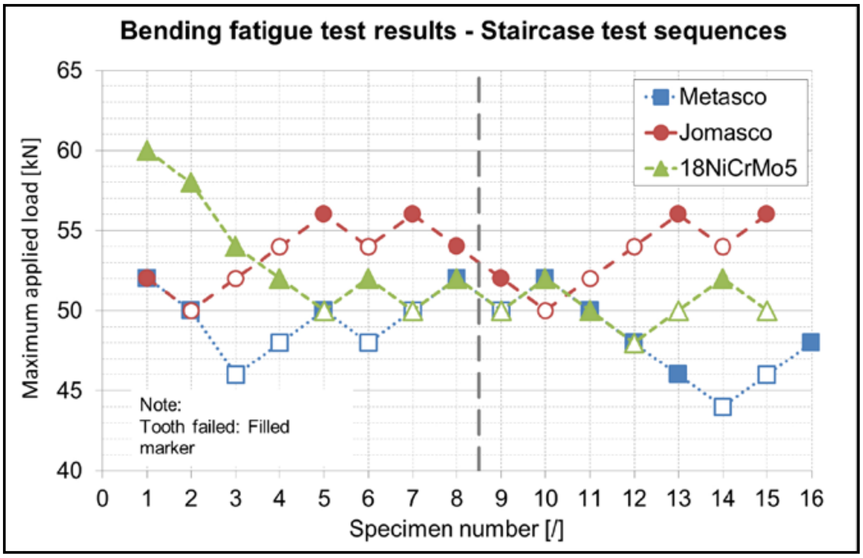

Figure 3 Bending fatigue test results.

Table 3 Results of the bending fatigue tests

Material	μ_D [kN]	σ_D [kN]	$\mu_{(99\%)}^{(a)}$ [kN]	σ_{Film} [MPa]
18NiCrMo5	50.67	1.06	48.20	513.8
Jomasco	53.57	2.60	47.52	506.5
Metasco	48.43	3.53	40.22	428.7

(a) $\mu_{(99\%)} = \mu_D - 2.326355 \cdot \sigma_D$

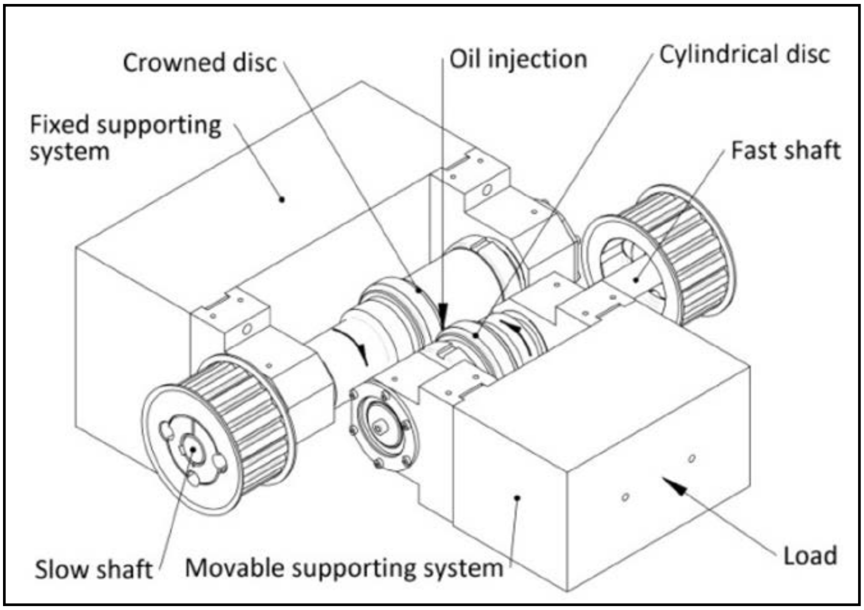

Figure 4 Layout of the twin-disc test rig.

The bending fatigue limits obtained for the three materials under investigation, along with their standard deviations, are listed (Table 3). In the first and third columns of this table the bending fatigue limits for the three gear materials are expressed in terms of applied load for, respectively, a 50 percent and 1 percent failure probability in order to be comparable with the limits given by the standards (Ref. 1).

By replacing F with the above-determined fatigue limits $\mu_{99\ percent}$, the values of the "the nominal stress number (bending)" listed in the right-most column of Table 3 has been obtained. These results are in the typical range of the standardized values of case-hardened wrought steels.

From the bending fatigue aspect, even taking into account the statistical nature of the results, it can be concluded that Jomasco is comparable with the baseline solution, while Metasco results in a slightly lower limit.

Micropitting

The micropitting strength of one of the two innovative materials presented in this study — the Jomasco steel that has demonstrated the best bending fatigue performance, as well as of the base line material, the 18NiCrMo5 steel — were investigated by means of disc-on-disc tests. In this type of test, two test discs are pressed — one against the other — in order to generate contact pressure sufficiently high to induce micropitting. Figure 4 shows the layout of the disc-on-disc test rig. In particular, in this figure it is possible to see the two parallel shafts on which the two discs are mounted. One shaft is connected to a support system fixed to the test rig frame, the other one to a mobile support system actuated by a hydraulic linear actuator controlled by means of a closed-loop control system that integrates a load-cell to measure the exerted force. The two shafts are driven by two independent timing belt transmission systems driven by an adjustable-speed (0-3,000 rpm) electric motor. Thus the two discs rotate in opposite directions, at different speeds, and with a fixed ratio of their tangential velocities in the ideal point of contact. The test bench is also equipped with a controlled lubrication system for the test discs so that they can be spray-lubricated with an adjustable lubricant flow rate using two directional nozzles.

Each pair of test discs was made up of two case-hardened and ground discs with the same external diameter of 65 mm in the transverse cross-section, while, in a meridian cross-section, one had a flat profile and the other a profile circularly crowned with a radius of 65 mm. Figure 5 shows the drawing of a test disc pair. The geometries of the disc's active surfaces result in a so-called point contact condition, and the contact area is an ellipse with the major axis aligned along the direction transversal to the circumferential direction. This geometry was chosen in order to generate sufficiently high contact pressure with the available test apparatus and to be as representative as possible of gear contacts. Concerning the microgeometry of test discs, they were circumferentially ground at the end of their manufacturing process so that a surface laying oriented in the circumferential direction was generated. The mean arithmetic surface roughness parameter, *Ra*, had a mean value over the measurements performed on all the tested discs equal to 0.35 μm in the circumferential direction and equal to 1.10 μm in the axial direction.

Test procedures. The tests were performed with a load stage procedure, increasing stepwise the applied normal load up to 3 kN and, consequently, the maximum Hertzian contact pressure up to about 2 GPa. The load levels were chosen in order to obtain a constant increment of about 230 MPa between one load stage and the next one. Each load stage was run for 1 million load cycles for the fastest disc, i.e. — the cylindrical one, apart from the running-in stage; the first load stage that was run for 0.5 million load cycles at a reduced speed of 1,500 rpm. All the load stages, after the running-in stage, were run at the same operating conditions. The rotational speed of the electric motor and the transmission ratios of the two belt systems were chosen so that the discs operated with a slide-to-roll ratio of 10 percent and a rolling velocity of 6.5 m/s, being the rotational speed of the fast shaft equal to 2,000 rpm. In the tests, the discs were spray-lubricated by means of an ISO VG 100-mineral oil injected at the ingoing side of the contact. This was a typical gear lubricant, commercially available under the trade name Agip Blasia 100, formulated from paraffinic base stocks and additives such as phosphorous compounds, which ensure good low-speed and high-load performance. These test conditions were chosen in order to obtain tribological conditions as close as possible to those generally found in industrial gear applications, but also able to promote micropitting damage on the active disc surfaces.

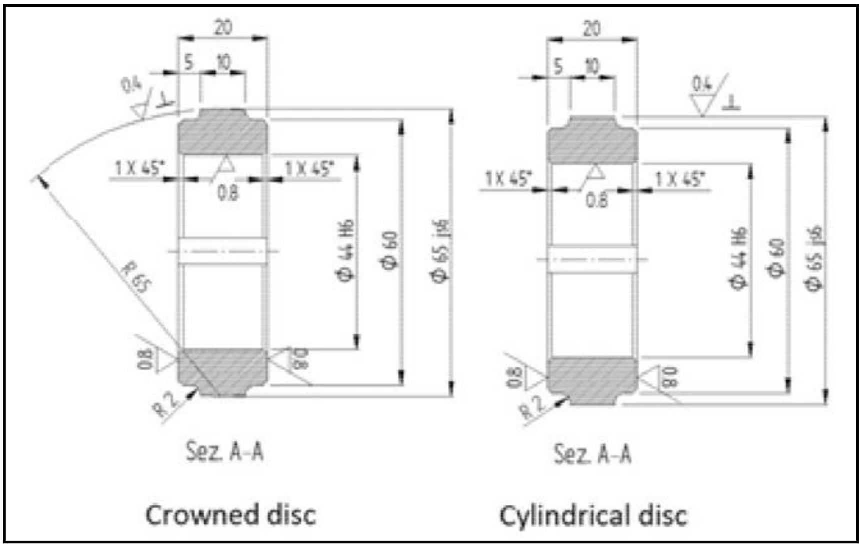

Figure 5 Longitudinal sections of the test discs.

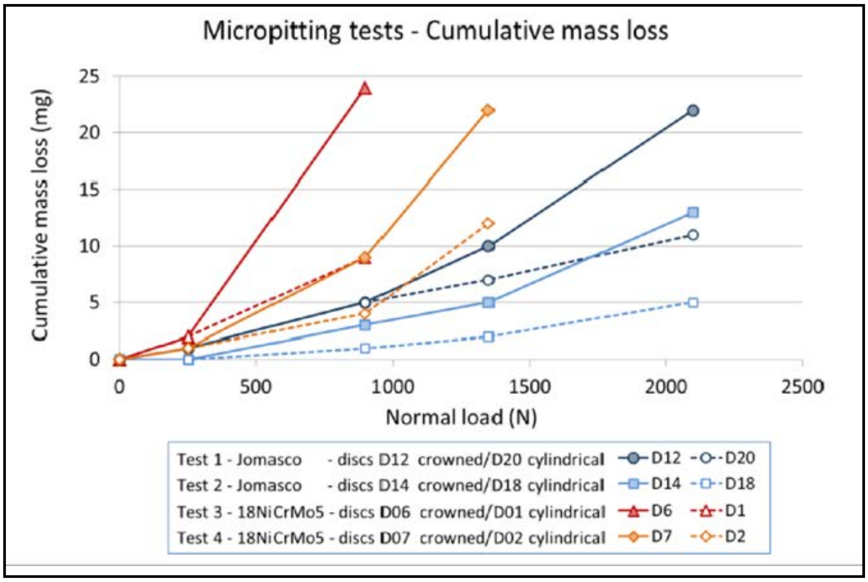

Figure 6 Results of micropitting tests in terms of cumulative mass loss vs. applied load.

During the tests, in order to analyze and quantify the micropitting damage evolution, as well as to document the test results, at the end of each load stage the discs were dismounted, cleaned with white spirits in an ultrasonic bath and, finally, inspected by means of a SEM and weighted with a high precision scale determining the mass loss per each load stage.

In this load stage test, the contact fatigue strength of gear materials is determined under specific operating conditions (rolling and sliding velocities, lubricant and lubrication types, etc.) in the form of a failure load stage. A failure criterion based on the mass loss-per-load stage has been adopted to identify the failure load stage and, thus, to determine a parameter that can be used to discriminate between the micropitting strength of the gear materials analyzed.

Of course in this kind of test, as well as in other type of gear material tests, e.g. pitting tests, the failure criterion must be somehow arbitrary since the damage phenomenon does not result directly in a catastrophic and clearly identifiable failure as, for example, in bending fatigue tests. For this test the limit value of eight mg-per-load-stage was chosen as a failure condition.

Experimental test results. In Figure 6 the results of the micropitting tests are shown in a diagram in which the cumulative mass loss is plotted against the applied normal load. The results obtained for the two materials for both cylindrical and crowned discs are shown in this diagram. Tests on cylindrical discs as well as on crowned ones resulted in a weight loss for both materials due to their surface damage. To the naked eye this looks like typical micropitting damage: i.e. — surface bands with a frosted and light grey appearance. Under an SEM, damage typical of rolling contact fatigue appeared evident. Many micropits (5–10 µm deep and with an extension of about 10 µm) and surface cracks (the first step of micropit formation) were found on the active disc surfaces. Therefore, the damage that occurred during the tests can be surely classified as a rolling contact fatigue damage and, in particular, as micropitting.

In all the performed tests, a weight loss of the crowned discs, operated in a negative sliding condition, was higher than the one observed for the cylindrical discs, operated in positive sliding condition. These results support experiments conducted on gears in which micropitting damage is, generally, more severe on the dedendum flank of gears than on the addendum flank, as observed, for example, in Reference 5. The quantitative evaluation of the micropitting damage by means of mass loss measurements on crowned discs showed that, in the tests performed, the Jomasco steel had a micropitting strength higher than that of the baseline material — 18NiCrMo5 steel. In particular, and taking into account the failure criterion chosen for this test regimen, both the Jomasco disc pairs failed at the fourth load level, while both the 18NiCrMo5 disc pairs failed at the second load level. This experimental finding confirms the suitability of the Jomasco steel as an alternative material to the widely used 18NiCrMo5.

Conclusions

- In this article, the bending strength and surface performances of two innovative gear steels, as well as of a reference steel, have been investigated and quantified by means of laboratory tests on gears and discs.
- These tests have shown the suitability of the Jomasco steel to be used as an alternative material for large gears, thanks, on one side, to its good resistance against bending and surface contact fatigue in comparison with the reference steel and, on the other side, to its high Jominy hardenability that makes it suitable for air quenching and, thus, for reducing heat treatment distortions.

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GE Oil & Gas

SIGNS AGREEMENT TO ACQUIRE ALLEN GEARS

Expanding its presence in the industrial gears sector, GE Oil & Gas recently announced it has signed an agreement to acquire Allen Gearing Solutions (Allen Gears), a privately held designer, manufacturer and service provider of gears for industrial and marine applications. The move comes two years after GE acquired a 35 percent minority interest in the business. Allen Gears employs approximately 160 people and has one manufacturing facility in Pershore, U.K.

Allen Gears produces high-speed, high-power gearing solutions specializing in epicyclic gears, which are desirable in industrial and marine applications that require smaller footprints. The U.K. firm has an installed base of more than 6,000 units worldwide with the vast majority being epicyclic gears. Currently, Allen Gears' primary markets include Europe, the United States, Japan, Brazil, South Africa and South Korea with an emphasis on industrial segments including power generation, oil and gas, hydroelectric, marine and nuclear energy.

Allen Gears will be integrated into the Power Transmission division of GE's Texas-based Lufkin business, a leading supplier of artificial lift and industrial gears technology for the oil and gas industry. GE announced it completed the acquisition of Lufkin Industries on July 1, 2013. Lufkin's three power transmission production facilities and seven service centers manufacture industrial gears and engineered bearings, particularly parallel shaft gears that are designed to produce high and low speeds in turbine applications, predominantly for energy-related industrial applications.

"This acquisition underscores the importance of Allen Gears' industry-leading technology and GE's ongoing commitment to grow all areas of our newly acquired Lufkin business," said Ian Milne, president of GE Oil & Gas' Lufkin division. "Bringing Allen Gears fully into GE will help Allen Gears grow by leveraging GE's global sales and service footprint."

"Allen Gears will add manufacturing and field service capacity, boosting GE's ability to compete for projects with tight production and delivery schedules," said Kevin Johnson, managing director of Allen Gears. "Our advanced technology combined with Lufkin's will also give us the ability to provide a more complete offering to customers."

Mazak Corp.

SHOWCASES OIL AND GAS PRODUCTION INNOVATIONS

Mazak invited oil and gas and other large part manufacturers to its Discover More With Mazak event that took place Jan. 15 and 16 from 10 a.m. to 7 p.m. at the company's Southwest Technology Center in Houston, Texas. Attendees had the opportunity to experience the latest and most innovative metalworking solutions for the growing energy industry as well as learn new machining techniques for boosting productivity and profitability.

The company demonstrated the latest milling, turning, five-axis and multitasking processes on new Mazak machines that included: the heavy-duty Slant Turn Nexus 500 turning center with a 10.8" diameter bore for machining large, long shaft workpieces; Megaturn Nexus 1600M vertical turning center with multi-tasking functionality for efficient large part production; Quick Turn Nexus 450-II MY with a long boring bar and long vertical mill for processing large parts in single setups; and Quick Turn Nexus 550 MY with a 14.7" spindle bore, an upper turret with rotary tool milling as well as Y-axis capability for processing large parts in single setups.

Mazak invites manufacturers to its next Discover More with Mazak event, taking place March 25 – 27 from 9 a.m. to 6 p.m. at the company's Technology Center in Schaumburg, Illinois. The event will focus on ways to boost production efficiency through total manufacturing solutions, highlighting advancements in machine tool technology, automation systems, cutting tools and more. Plus, special presentations on the use of Mazak technology in the racing industry and the growth of U.S. manufacturing. In addition, attendees can participate in technical seminars on how to improve factory utilization using the MTConnect open-source royalty-free manufacturing protocol as well as how Sandvik Coromant cutting tools can enhance gear production on Mazak multitasking machines. For more details, visit *www.mazakcorp.com*.

Gleason

ACQUIRES IMS KOEPFER CUTTING TOOLS GMBH

Gleason Corporation has acquired IMS Koepfer Cutting Tools GmbH of Eisenbach, Germany from IMS Gear GmbH and Koepfer Verzahnungsmaschinen GmbH. IMS Koepfer Cutting Tools is a producer of high-quality gear cutting tools and related products and services. The company, which has approximately 70 employees, will be renamed Gleason Cutting Tools GmbH and continue to operate at its current location in Eisenbach, Germany, with its existing management team. IMS Koepfer Cutting Tools has a small subsidiary in Taicang, China which is included in the acquisition.

Commenting on the acquisition, John J. Perrotti, president and chief executive officer of Gleason Corporation, said, "IMS Koepfer Cutting Tools is recognized as a leader in technology, quality and delivery lead times for gear cutting tools. Their established presence in the European market and strength in the design and manufacture of carbide hobs provides us great opportunities to expand our product reach to both local and global customers in industries including medical, power tools, automotive and gear job shops."

Dieter Lebzelter, managing director of IMS Gear, said, "On behalf of both IMS Gear and Koepfer Verzahnungsmaschinen GmbH we are pleased to have a company such as Gleason with its long tradition in the gear production equipment market become the new owner of this business. The IMS Koepfer management team and employees have done an excellent job in developing the business and we are confident will continue to do so in the future."

LMC Workholding

NAMES VICE PRESIDENT OF DEALER AND OEM SALES

LMC Workholding has named Brian Lane vice president of Dealer and OEM Sales. Lane has over 40 years of experience with Bardons & Oliver, Inc. and Logansport Machine Company (known today as LMC Workholding) in growing sales and developing marketing programs for technical engineered products and manufacturing systems. He has held positions such as general sales manager, vice president general manager and regional sales manager and was most recently vice president sales at Bardons & Oliver, Inc. Jay Duerr, president of LMC Workholding, said, "We are excited to be continually expanding and growing, and are always looking for qualified candidates. We currently have six openings available for designers, manufacturing engineers, quality system administrators and auditors, and sales and channel marketing managers. With Brian joining the team, we expect the need to fill and expand even further in the future."

ALD-Holcroft

ANNOUNCES 2014 VACUUM CARBURIZING SYMPOSIUM

ALD-Holcroft has announced the dates for the 8th Vacuum Carburizing Symposium, to be held in 2014 on May 6th and 7th. This two-day event will be held at the Ford Motor Company Conference and Exposition Center in Dearborn, Michigan. The Symposium will feature two days of information and presentations by industry experts, with audience participation encouraged. The evening of May 6 will be highlighted by a private cocktail and dinner reception at a Ford light truck assembly facility. Guests will have plenty of networking opportunities and the chance to enjoy multimedia experiences along with private tour access to an actual Ford Motor Company assembly line in operation. Presentation topics will be announced in early 2014 and will cover highly specific and technical subjects relevant to the vacuum carburizing process, including recent innovations, best practices and the business of vacuum carburizing. The speakers will be available for question-and-answer, as well as open discussion during several networking opportunities. This event will appeal primarily to business executives, design engineers, manufacturing engineers, drive train engineers, metallurgists, commercial heat treaters, current and prospective users of vacuum technology, and industry leaders in the carburizing community. ALD-Holcroft encourages interested parties to monitor the company's website below as well as industry publications and other media for additional details as they become available. Registration for the event is required. For more information, visit *www.ald-holcroft.com.*

Guyson Corp.

ACQUIRES AUTOMATED BLASTING SYSTEMS

The Guyson Corporation of U.S.A. has announced the acquisition of all assets of Automated Blasting Systems, Inc., of South Windsor, CT. ABS has been a premier supplier of wet blast machines to the aerospace, automotive, cutting tool, electronics, metal working and other industries since 1988. The company was formed as a result of purchasing the "Vaqua" product line from The Spadone Machine Co., which made the slurry-blast equipment for over 40 years.

In making the announcement, Steve Byrnes, president of Guyson Corporation, stated that "We are excited about this significant expansion of our equipment offerings and the added growth potential of wet-blasting technology. Guyson USA and ABS share many of the same customers today. Guyson and ABS share many of the same goals and are dedicated to providing leading edge robotic and automated systems to customers around the world. Guyson is making a commitment to provide uninterrupted service to the customers of ABS with the employment of Richard Gillott, the former vice president and general manager of ABS.

"This acquisition is further evidence of the commitment by Guyson to continue its growth strategy by offering surface preparation and cleaning systems that deliver superior performance and exceptional value to our customers," Steve Byrnes added.

All work-in-process machines, spare parts inventories, ABS laboratory testing equipment, design engineering assets or intellectual property and customer files will be relocated in the coming days from South Windsor, Connecticut, to Guyson Corporation's 80,000 square foot plant in Saratoga Springs, New York.

Rexnord

ACQUIRES PRECISION GEAR

Rexnord has announced that it has acquired Precision Gear Holdings. Precision Gear has two operating subsidiaries, Merit Gear LLC, located in Antigo, WI, and Precision Gear LLC, located in Twinsburg, OH. PGH employs approximately 190 associates and has annual net sales of approximately $45 million. Merit Gear is a build-to-print manufacturer of high-quality gearing and specialized gearboxes primarily for the North American oil and gas market, along with other diversified industrial markets. "Merit's capabilities and offering are highly complementary to our core Falk product line," stated Dean Vlasak, Rexnord vice president, innovation and energy. "This acquisition presents the opportunity to enhance the value and breadth of solutions we can bring to Rexnord and Merit customers. Moreover, Merit strengthens Rexnord's presence in key oil and gas markets and brings strong relationships with leading OEMs and drillers."

Precision Gear is a manufacturer of highly specialized gears primarily serving the aerospace market, along with various other industrial markets. "Precision Gear represents ongoing strategic investment into Rexnord's aerospace product portfolio within its Process and Motion Control platform," said Darryl Mayhorn, president, Rexnord Aerospace. "We are excited with this expansion of our aerospace gear manufacturing capabilities as well as the additional products and services the Precision team brings to better serve our existing customers."

Heller US

APPOINTS NEW CEO

Heller Group has appointed **Keith Vandenkieboom Heller** US president and CEO effective January 1, 2014, upon the retirement of Robert Pelachyk. Vandenkieboom was formerly vice preseident of operations and will retain those responsibilities. In making the announcement, Manfred Maier, Heller Group COO Gebr. Heller Maschinenfabrik GmbH, Nürtingen Germany, said the new appointment will assure a smooth transition and seamless continuation of Heller policies and operations in the NAFTA market, Maier added.

Maier also thanked Pelachyk for his highly effective service to Heller Group over the past seven years during which time the company's U.S. operation booked its highest ever sales. Heller in the U.S. is the largest supplier of manufacturing systems to the heavy-duty diesel engine industry and a major supplier to the U.S. automotive industry.

Other key managers will maintain their roles at Heller. Vandenkieboom will have the full support of Vincent Trampus, vice president sales and proposals and J. Scott Babyak, vice President, engineering and program management.

"In North America alone, Heller has installed more than 1,000 machine tools in the last few years, and we intend to expand, maintain and grow our ability to fully support Heller customers and help them maximize the productivity of Heller solutions over the long term," Maier said. "Keith's appointment will help Heller continue its progress in this very important market."

Vandenkieboom has been with Heller US since 2006 and has been well known to its customers and suppliers first as vice president group procurement and most recently vice president of operations at Heller US.

Felsomat USA

APPOINTS NEW PRESIDENT

Felsomat USA, Inc. recently announced the appointment of **Patrick Seitz** to the position of president. Effective on January 1, 2014, Seitz took over from Richard Gilchrist who started Felsomat USA, Inc. in 2002 and held the position since that date. Gilchrist will remain on a reduced schedule as chairman while providing managerial and consultative support to the management team in order to achieve a smooth transition. Seitz, a native of Switzerland, studied mechanical engineering at the Federal Institute of Technology in Zurich where he obtained his masters degree. His enthusiasm for automobiles resulted in an internship at Audi and the compilation of his thesis at Lamborghini.

After completing his studies in 2007, Seitz joined Reishauer AG in Wallisellen, Switzerland as an application engineer where he managed projects for Skoda, Ford, and Toyota. Transferring to Reishauer Corporation (Elgin USA) in 2008, he served as a product manager of major projects such as Ford and Toyota in addition to providing technical sales support.

In 2012, Reishauer and Felsomat obtained significant orders from ZF in South Carolina. Seitz played a key role in the management of this project where he gained experience in the wide range of Felsomat machines and automation products. During this process Seitz was appointed "president designate" and he officially joined Felsomat in the spring of 2013.

Star SU

APPOINTS PRODUCT MANAGER FOR ROUND TOOLS

Chris Cella has been promoted to product manager for solid carbide round tooling and gundrill products at Star SU LLC. Cella joined Star SU in 2013 to bring additional depth to the application engineering department. Additionally, his extensive background in manufacturing, sales and as a customer, will be an asset to the manufacturing sites, regional sales managers and, ultimately Star SU's customers. Cella, 46, brings two decades of experience in the fields of round tools, gundrills and gundrilling to his new position. In the decade prior to coming to Star SU, he provided tool reconditioning services, continuous improvement programs, and troubleshooting support in the aerospace, automotive, heavy truck, hydraulic, power generation and transportation industries. He holds a bachelor of science degree in mechanical engineering from the University of Illinois at Chicago.

February 24–26—MIM 2014. Hyatt Regency, Long Beach, California. The International Conference on Injection Molding of Metals, Ceramics and Carbides explores new advances, assists in the transfer of technology and investigates new developments for injection molding. The conference is targeted at product designers, engineers, consumers, manufacturers, researchers, educators and students. All conference and tutorial registrants will receive *Injection Molding of Metals and Ceramics* and *MPIF Standard 35, Materials Standards for Metal Injection Molded Parts*. These publications will be distributed at the conference. With continued growth and interest, the metal injection molding industry has realized major technological advances and overcome numerous business challenges and has reported estimated sales of $1.5 billion. All individuals with an interest in this technology are encouraged to attend. For more information, visit *www.mpif.org*.

February 27–March 1—IPTEX 2014. Bombay Exhibition Center, Mumbai, India. The 3rd International Power Transmission Expo is dedicated to the gear and power transmission industries. India is rapidly turning into a global manufacturing hub, thanks to the country's manufacturing and engineering capabilities, vast pool of skilled expertise and its size. These qualities offer it a strategic advantage for the manufacturing segment. A large number of international companies in varied segments have already set up a manufacturing base in India and others are following suit. Exhibitors include those involved in gear processing equipment, cutting tools, gear inspection and testing instruments, chains and belt drives. Key participants include Gleason and Klingelnberg. IPTEX is supported by the AGMA, and its media partner is *Gear Technology India*. GRINDEX, an exposition on grinding and finishing processes, will run concurrently with IPTEX. GRINDEX is designed to meet the emerging demand for precision driven applications as manufacturing needs new technology and solutions. For more information, visit *www.iptexpo.com*.

March 5–8—MFG Meeting 2014. Arizona Biltmore, Phoenix. Collectively representing a cross-section of the industry, the Association for Manufacturing Technology (AMT), the National Tooling and Machining Association (NTMA) and the Precision Metalforming Association (PMA) combine their annual meetings to pursue the common goal of building sustained U.S. economic growth by strengthening the country's manufacturing sector. Together, these associations comprise more than 4,000 small and medium-sized manufacturers from all 50 states that provide products for the aerospace, automotive, construction, energy, medical and many other industries in the United States and abroad. By sharing resources, the Manufacturing for Growth conference will provide an opportunity for more than 500 top manufacturing executives to exchange best practices as the industry seeks to reassert and expand its U.S. economic footprint. For more information, visit *www.mfgmeeting.com*.

March 11–13—Gearbox CSI: Forensic Analysis of Gear and Bearing Failures. Sheraton Suites, Philadelphia Airport, Philadelphia. Determining the cause of a failure in a gearbox is like a "who done it" mystery. What caused the failure? The bearings, a gear, the lubrication or a shaft problem? Where do you start, and how can you tell? This seminar helps gear designers gain a better understanding of various types of gears and bearings. Learn about the limitations and capabilities of rolling element bearings and the gears that they support so you can properly apply the best gear-bearing combination to any gearbox, whether simple or complex. A certificate will be awarded upon completion of the seminar. For more information, visit *www.agma.org*.

March 19—AGMA Webinar Series. Gear quality is of utmost importance to a manufacturer. Presented in the webinar *Common Material Inspection Methods* are several commonly used gear inspection methods to ensure the quality of a gear from the raw material through to the final manufactured form. The speaker is Sarah Tedesco from Ashford Consulting and the webinar will take place from 1:00 pm – 2:30 pm Eastern. Additionally, the AGMA webinar series *Contact Stresses* will be presented by Steven R. Schmid, professor, mechanical engineering, University of Notre Dame. This webinar will present a discussion of the stresses that result in gear tooth contact, including Hertzian contact stress theory, point and line contacts, extension to elliptical contact and application to gears. Discussion of the AGMA contact stress equation and its foundation in theory. It will also take place from 1:00 pm – 2:30 pm Eastern online. Please visit *www.agma.org* for more information.

April 10–12—AGMA-ABMA Annual Meeting. Vinoy Renaissance Resort and Golf Club, St. Petersburg, Florida. Expert presentation topics include "Accountability and Achievement," "Global Megatrends; Major Forces in Manufacturing," "Unconventional Oil and Gas: Game Changer If We Don't Screw it Up," "Economic Outlook" and "How to Turn Republicans and Democrats into Americans." The annual golf tournament returns as well as the First Timer's Reception on Thursday night prior to the Welcome Reception. Friday night features the "Sounds of Soul" and Saturday night features "Hot Havana Nights" with a cigar-making demonstration. The hotel features an 18 hole golf course, private marina, and 12 tennis courts, in addition to newly renovated meeting, gathering and sleeping rooms. It is ideally located near Tampa International Airport, St. Pete Beach and downtown St. Petersburg, home to the Salvador Dali and Chihuly Museums. For more information, visit *www.agma.org*.

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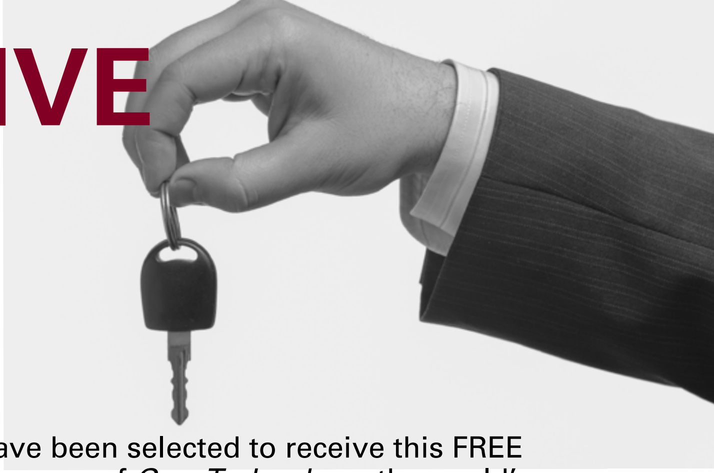

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4 → What is your primary JOB FUNCTION (check ONLY one)

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

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

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

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Gear Engineer by Day, Baritone by Night

When they're not solving the latest mechanical engineering puzzle, the seven members of the group sINGer are busy engineering their voices to create the perfect sound. Yes, you read that correctly. Mechanical engineers *do* have hobbies outside of gears.

The group sINGer (the ING stands for Ingenieur) was founded in a pub in Germany. Members of the group were all participants of the Colegium Musicum Choir of RWTH Aachen University. "We used to go to a pub after rehearsal and we spoke quite often about founding an *a cappella* group," says Jannik Henser, RWTH Aachen University (WZL). "One Thursday evening in 2006 we decided to make things happen. Our goal was to sing songs of the Comedian Harmonists, but we started with some barbershop arrangements."

The members of sINGer: Rüdiger Ruwe (counter tenor), Sebastian Wittgens (counter tenor) Alexander Hoffmann (tenor), Andreas Röhser (baritone), Jannik Henser (baritone) and Ulrich Dehof (bass) and standby Dr. Felix Kruse (baritone) all have a background in engineering. "Three of us are still studying mechanical engineering (diploma/masters degree), two are Ph.D. students and two are working as engineers at the German Aerospace Center," Henser adds.

They have performed concerts with partner groups (Vokalschlag, einKlang, Collegium Musicum), participated in charity events and have sung at the International Chorbiennale Aachen (*chorbiennale.com*). The group performs everything from traditional German and Irish folk songs to some Billy Joel (*The Longest Time*) and even some film music of John Williams.

You'd think there is very little common ground between gear engineering and singing *a cappella* but the group manages to find a nice balance.

"In singing, the psychological aspects play a more important role. The goal of singing is mainly to create a good feeling in the brain of the audience. It is not easy to plan this. Sometimes it happens that one first recognizes on stage that one should sing in a different way," Henser says. "On the other side, engineering can be a good help for the rehearsals. If you have a good understanding of acoustics and an accurate ear, it is possible to 'engineer' a good sound."

For Henser, singing is a nice change of pace from his daily routine.

"After hard and concentrated work as an engineer there is nothing more relaxing than going to a rehearsal. It happens very often that headaches or muscle tensions vanish after two hours of singing," he says.

Of course, you can't take the engineer out of the singer no matter the time or the place. "Sometimes it happens that one of the members brings a model of a special gear to the rehearsal and the rehearsal needs to be paused until everybody has figured out how the gear mechanism works," he adds.

When the group members aren't singing or working they enjoy sports, dancing, aviation, foreign languages and family. The most important goal is to keep the group together, even though some of the members have moved to other cities. They continue to get together and rehearse on a project-based concept. "The biggest challenge for the group is finding enough time in the day for rehearsals and concerts," Henser says.

sINGer is looking forward to putting aside the math and engineering soon and focusing once again on the music.

"We were invited to sing three to four songs in the big Eurogress concert hall in Aachen," Henser says. "We are all looking forward to this event."

For more information on sINGer visit the group's homepage at *www.singer-aachen.de* or check out some video performances at *http://www.youtube.com/watch?v=bCpukrczYAM*, *http://www.youtube.com/watch?v=f3lA7Erf0Xc* and *http://www.youtube.com/watch?v=mzzVq-Op8pEa.*