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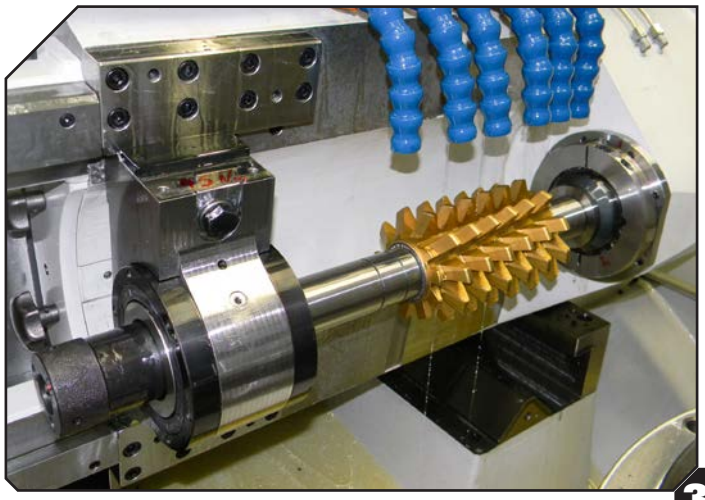

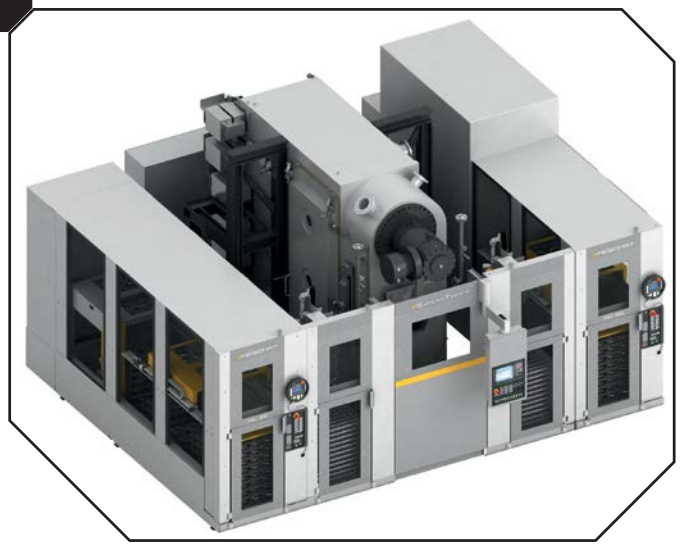

features

technical

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December 2008 *(date for illustrative purposes only)*
An Illinois manufacturer produces critical gears for Mars Rover "Curiosity" on their KAPP VUS 55P.

November 2011
Curiosity launches into space and on the sixth of August, 2012 lands successfully on Mars.

December 2012
Curiosity's mission is extended indefinitely.

December 9, 2013
Evidence reported from the Curiosity shows Gale Crater contained an ancient freshwater lake which could have been a hospitable environment for microbial life.

February 19, 2014
In planning Curiosity's route toward the slopes of Mount Sharp, images piqued interest in the striations on the ground formed by rows of rocks.

See photo at(www.photojournal.jpl.nasa.gov/catalog/PIA17947)

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departments

Photo courtesy of Liebherr Gear Technology Inc.

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Gear hobbing machine LCH 180 two

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- Primary hobbing time is done in parallel to the load/unload, and roll/press deburr-chamfering, between two cuts – on two work-tables

Gear hobbing machine LC 180 Chamfer Cut

- High chamfer quality with one-cut hobbing strategy
- Primary hobbing time is done in parallel to chamfering in a second machining position

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The Group

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GT VIDEOS

The *GT* website currently features a video on the new *Masta-Cage* link, an essential software tool for developing, testing and manufacturing bevel and hypoid gears. Comments from both Smart Manufacturing Technology Ltd. and Gleason Corporation are included. For additional information visit *www.smartmt.com* or *www.gleason.com*.

GT at 30

We're celebrating the 30th Anniversary of Gear Technology in June. Please send your most memorable stories about the gear industry to mjaster@geartechnology.com. Some of these may be included in our feature about the past, present and future of gears.

Twitter: Check out the latest links to Charles D. Schultz's *Gear Technology Blog* as well as product and industry news updates from companies like Overton, LMT, ASM, EMAG, Dontyne Systems and more.

Ask the Expert: Do you have a question about gear design, manufacturing, heat treating, inspection or assembly? Submit your questions to our panel of experts at: *www.geartechnology.com/asktheexpert.php*

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SCAN NOW!

Goodbye, David

Michael and Marsha Goldstein (left) with David and Georgina Iveson (right) at Ascot Racecourse.

I've lost a long-time and dear friend.

Sadly, David Iveson of Westminster Machine Tools Ltd. in the U.K. passed away on April 9 – a day before he was to turn 75.

David and I met in the late 60s, having been introduced by my father, who had met him on earlier business trips. We became instant friends. Sometimes I 'd make half a dozen trips a year to England, as I was a principal in the industrial auctioneering company, Industrial Plants-UK (IPC-UK), and each time we would meet up.

Many of you have known David or have done business with him. Like me, he spent the majority of his career specializing in used gear manufacturing equipment, especially machines built by Gleason.

Born in the North of England, David worked the coal mines as a young boy. In British society, those circumstances should have limited his growth and opportunities. But David—ambitious, smart and hard-working—never allowed his background to limit him economically or socially.

David formed Westminster Machine Tools in about 1965 and he was known worldwide for his knowledge and acumen in the gear field. He was also an expert dealer in all types of non-gear machines. David was well known and trusted by both dealers and customers alike, on several continents. His word was his bond, and his knowledge of the features and values of all types of metalworking equipment was deep. David's opinions and knowledge reflected all facets of business and life and were sought out and respected by his customers, fellow dealers and competitors. While you, our readers, may have known him and done business with him, either buying or selling machinery, David and I, and our families, have been competitors, partners and friends for nearly 45 years.

Perhaps because of his early life of poverty, David pursued with gusto the finer things in life: exotic travel, excellent food, the finest wines and champagnes, the fastest cars, the hottest clubs, etc.

When he was young, David traveled with a very fast crowd, partying with the Rolling Stones and with Margaret Trudeau, who was formerly married to the Canadian Prime Minister. Those were wild times in England, and David was one of the wild ones. I still have vivid memories of driving through central London at absurdly high speeds with David in his Jaguar XJS.

David's first and second marriages didn't work out, but with more maturity and more than a bit of luck, he met Georgina Wynyard, whom he dated for quite some time before settling down.

I spent time with David and Georgina while they were dating and I remember his excitement when each of their daughters was born. I have had the good fortune to be able to watch them grow up to be beautiful and accomplished young women.

We had the opportunity to travel extensively together, as both Westminster Machine Tools and my former company, Cadillac Machinery, were members of the European Association of Machine Tool Merchants (EAMTM). Because I was on their Council for over 21 years, my wife, Marsha, and I attended almost all of the annual meetings with David and Georgina. Together, our families saw the highlights of Europe: Marbella, the Algarve of Portugal, Santa Margherita Ligure in Italy, the Canary Islands, Berlin, The Arts Hotel in Barcelona, The Isle of Jersey, Sorrento, Palma in Mallorca, Castelnuovo del Garda in Italy, Estoril in Portugal and too many others to name. David introduced Marsha and me to the pleasures of Chateau d'Yquem Sauterne, surprisingly sold by the glass at the Hotel Splendido, high on the hill overlooking Portofino, Italy. We held memorable birthday parties for Marsha at the Greek Island of Rhodes and again in Cascias, Portugal. In 2011 we were again together in Budapest. David and I were also both members of the Machinery Dealers National Association (MDNA), which brought us to conferences in Cambridge, Mass., Houston, San Francisco, Washington, D.C., Orlando, Colorado Springs, New York, and too many other venues to name or remember. What glorious memories of places I visited and times I had with David and our families.

The last time both our families were together was Christmas 2012, when we all met in Paris. The seven of us had a fabulous, memorable dinner, where we drank Sauterne and Champagnes. My last visit with David was at his home this past January, where over lunch and dinner, we celebrated our friendship.

David was one of a kind, never to be replicated. He will be sorely missed, not only by myself, but by all who knew him, customer and friend alike.

My father used to tell me that after we're gone, all we leave is our reputation, and David left his as a giant legacy.

David, you did far more than most, and you did it in style.

May you now rest in peace, Mate!

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Is the Manufacturing Comeback Just an Illusion?

A great deal of attention has been paid to the decline of manufacturing in America, and I've been accused of being a "town crier" since the 1980s, when I began to see our nation lose its edge to foreign competition.

My concerns have proven well-founded. Depletion of the wealth-generating engine of manufacturing is the root cause of many of our economic problems, as billions of dollars have left our shores for the purchase of foreign-made products.

Yet for some time now I have heard little but good news about manufacturing. The output of U.S. factories is up. Manufacturing is adding jobs at a faster rate than other industries. "Re-shoring" is gaining momentum. Could it be that happy days are here again? Could it be that wealth generated by a refortified U.S. industrial base will finally be able to address the many domestic problems we now face?

Manufacturing, after all, was the primary factor in America's becoming an economic superpower in the years after World War II. While much of the world's postwar industrial capacity was decimated, the U.S. manufacturing base was never stronger. We became king of the economic world by *exporting* products and importing wealth. But over the past 30 years, we've been *importing* products and exporting wealth.

The good news today is that manufacturing is indeed coming back, and for many reasons: transportation costs, rising wages overseas, lack of contract and property rights laws, etc. The bad news is that these gains are simply too meager to have any significant impact on reversing America's economic decline. Our exporting of wealth continues unfettered.

Bottom line: We must look beyond the growth in U.S. manufacturing jobs as the measure of our industrial success. Instead, look at the actual scorecard that measures the flow of wealth in and out of our economy — the trade deficit of manufactured products.

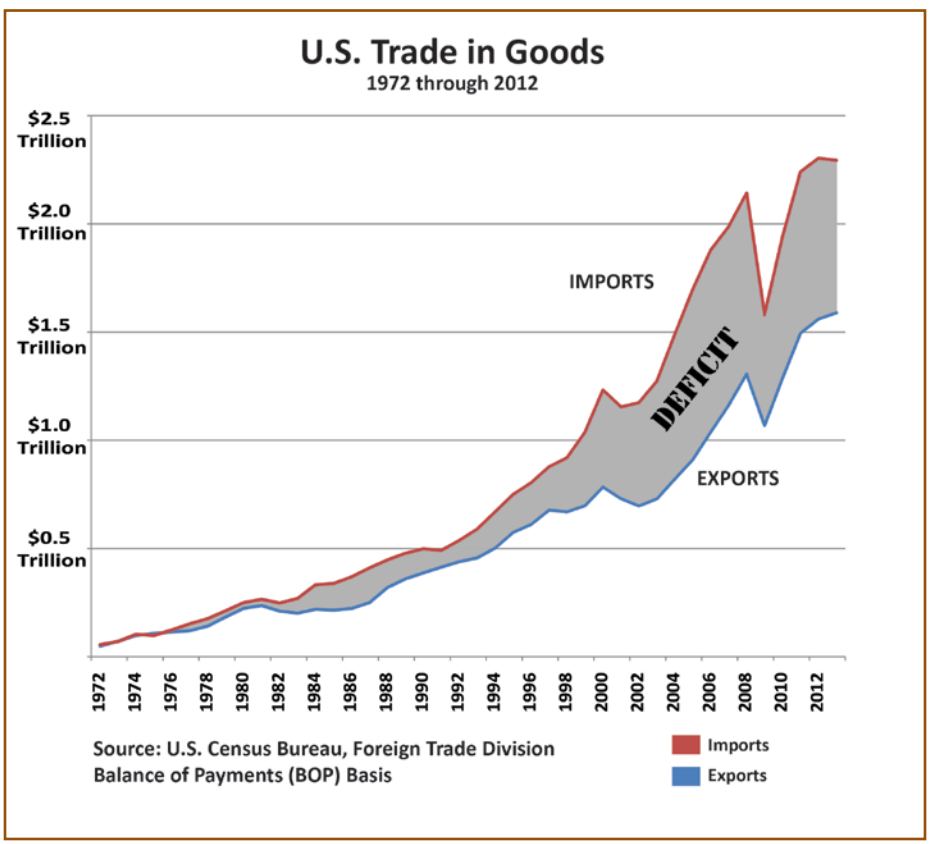
> As a nation we must embrace the high-tech, innovative manufacturing model. And we must develop a workforce capable of the skills needed for that model.

Trade data tracking imports and exports from 1972 to 2012 indeed show an increase in exports, but we also see an increase in imports — almost as if the two are linked. As we bring in more wealth to our economy, we simultaneously send away an ever-increasing amount to purchase imported products, continuing on the losing side of this equation. In this 40-year period, we have sent an almost inconceivable $11.2 trillion out of our economy. Is it any wonder that so many of our social needs are underfunded and millions of Americans are struggling?

So despite the positive news about gains in manufacturing, and the subsequent waving and chest-thumping in the media and by those in Washington, performance at its current level is simply unacceptable. It will not have a beneficial impact on our economy — not for the creation of jobs or the tax revenue required for our social systems, infrastructure and to pay our government employees.

Investing and Training

So what can be done? My experience as president and chief operating officer of Arrow Gear Co. suggests a thing or two. When I'm asked how Arrow has sur-



> We must look beyond the growth in U.S. manufacturing jobs as the measure of our industrial success. Instead, look at the actual scorecard that measures the flow of wealth in and out of our economy — the trade deficit of manufactured products.

vived and thrived in the precision gear industry, I cite a willingness to invest in advanced technology, innovation, leading-edge design and development capabilities, and, most of all, a skilled workforce.

So how can other companies achieve what we've done at Arrow? The answer is as simple as it is complex: As a nation we must embrace the high-tech, innovative manufacturing model. And we must develop a workforce capable of the skills needed for that model.

The federal government also needs to do some things. The U.S. corporate statutory tax rate is 39 percent, while those of our top three largest trading partners (Canada, China and Mexico) range from 15 to 28 percent. Other industrialized nations seem to better understand the economic value of their industrial base and the deleterious impact of corporate taxes. It's a serious inhibitor to U.S. competitiveness in the global market.

There is a reawakening of awareness about the importance of manufacturing. But we need to preserve the momentum, because if we blindly assume that growth will continue, we are most certainly destined for renewed decline. Manufacturing creates well-paying jobs, and those jobs, in turn, provide for the needs of society. If we fail in this, let no one be surprised when we see an increase in social unrest among those forced to live without the basic necessities and opportunities that life in America should provide.

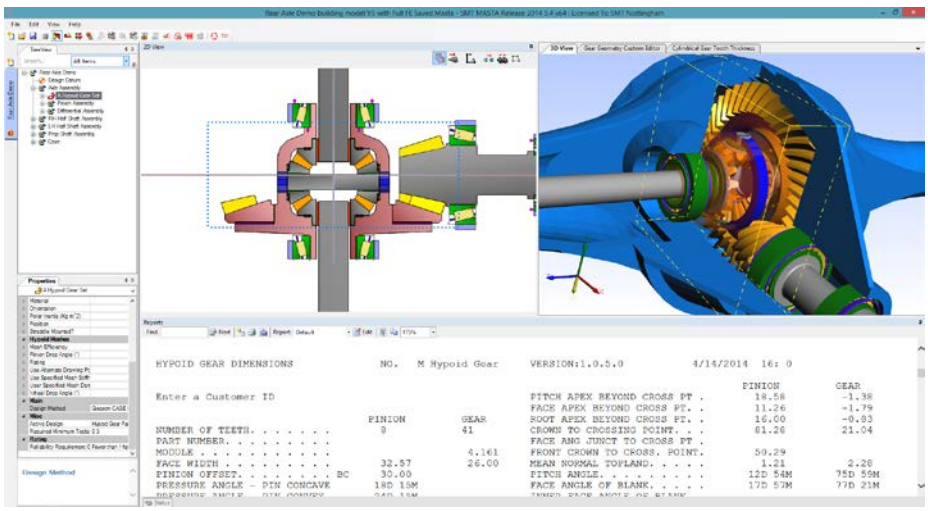
Joseph L. Arvin
President, Arrow Gear Co.

Joseph L. Arvin is president and chief operating officer of Arrow Gear Co. in Downers Grove, IL. He is also a member of the Illinois Institute of Technology's industrial, technology and management advisory board and founder of the nonprofit Citizens for American Manufacturing *(www.camusanow.com).*

Gleason and SMT

LINK MASTA AND CAGE SOFTWARE

Gleason Corporation and Smart Manufacturing Technology Ltd. (SMT) recently announced the release of the first phase of their strategic global partnership. New versions of SMT's premier full-system transmission design and analysis software (*MASTA*) and Gleason's industry-leading software for bevel and hypoid gear design and manufacture (*CAGE*) are now available with a seamless link between the two packages. Together these provide a new design-to-manufacture solution for bevel and hypoid gears with significant performance advantages and cost savings over current processes. For the first time, gear manufacturers can now benefit from an integrated workflow that fully considers the design geometry of bevel and hypoid gear tooth flanks, via the manufacturing machine settings, within the context of the full system.



Full-system durability and NVH analyses can be performed easily at any stage to help solve bevel and hypoid noise problems while gear flank geometry can be quickly optimized by performing system-level loaded tooth contact analysis. This improved virtual analysis and testing helps avoid the costs associated with repeated manufacturing and testing of prototype gears, saving customers both time and money. The new software was formally unveiled to the public at the Gear Solutions Forum at Gleason-Pfauter Maschinenfabrik GmbH, April 1-3, in Ludwigsburg, Germany. John J. Perrotti, president and CEO of Gleason Corporation, says, "Gear designers and producers have typically lived with many different software packages to satisfy their needs from design through production. Our new software offerings developed in collaboration with SMT for bevel and hypoid gears takes an important step towards delivering these solutions in a more integrated way."

David Beedan, operations director of Smart Manufacturing Technology, adds, "The joint vision of our partnership with Gleason was to allow *MASTA* and *CAGE* to work as if one product, best utilizing the strengths of both products. This first collaborative installment does just that; indeed this marks a revolution in bevel and hypoid gear design-to-manufacture and we look forward to working with Gleason to bring further improvements to the design-to-manufacture process for the benefit of engineers worldwide."

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

SMT North America
Phone: (315) 440-4657
www.smartmt.com

R&P Metrology

CUSTOMIZES MEASURING SYSTEM

Responding to specific customer requirements, R&P Metrology GmbH announced a new model in their full line of custom metrology systems, the RPS 1350V. Designed for ball screws and shaft parts, this system boasts capacity for 1,350 mm between centers, and 1,300 mm of vertical measuring travel.

"A customer asked if we could design and build an inspection system for their specific needs. That is what R&P Metrology does, so of course we said yes," said Hans Rauth, president of R&P Metrology. He added, "The customer produces ball screws and gears up to 600 mm in diameter. The RPS 1350V is a generative, four-axis gear inspection machine, and also measures 3-D CMM type features as well as profiles and forms. The X, Y and Z axes use linear motors for ultimate precision. Since the machine rests on an active suspension system, no separate foundation is required. The high precision, air bearing rotary table is mounted on a granite bed and is driven directly by a torque motor."

The RPS 1350V achieves the highest European class for inspection equipment accuracy: VDI/VDE 2612/13 Group I. Using an industry standard CNC control system, the RPS 1350V is I++ compliant,

allowing the use of many CMM inspection packages.

R&P Metrology designs and builds custom and special systems, and produces hybrid systems that uniquely combine gear measurement with 3-D CMM metrology. One example is the world's largest CNC gear checker, the RPG 4000-5500, which measures gears with generative inspection as well as performing CMM measurements. Specializing in medium and large parallel axis gears, bevel gears, tools, shafts, bearing rings and 3-D parts R&P's range of extreme precision custom metrology solutions starts at approximately 1.0 meter in size.

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Heller Machine Tools

DELIVERS FLEXIBLY-CONFIGURED HORIZONTAL MACHINING CENTERS

More machines than ever underscore the aim to respond to the user's operation, not only with options and automation, but increased energy efficiency. The new affordable Heller H 4500 4-axis machining center, a highly capable horizontal machine with Heller-produced HSK A 100 spindle (also available in sk/bt 50 taper) and a 500 × 630 mm pallet and 800 mm strokes in X, Y & Z aims to do just that.

With the H 4500, Heller introduced a machine designed for robust processes while providing an affordable, economical cutting solution for limited space. The machines are also designed for energy efficiency, capable of energy savings of up to 30% compared to conventional machine designs.

"The more universal and varied the machining assignment, the more important becomes adaptive power consumption of peripheral equipment and main units in order to optimize power use at various operating points," said Vincent Trampus, Heller vice president of sales. Air, coolant, hydraulics, and other energy consumers are flexibly controlled based on demand rather than always on. This strategy is called Heller Blue."

Reliable, productive, the H 4500 delivers high degree of precision, due to the proven machine concept, the inherently rigid design of the machine bed, the double motor Z-axis, the dynamically stiff, short design of the spindle unit, and the water-cooled spindle housing.

"With our new 500 N-m, 52 kW, 12,500 rpm spindle option, the H4500

can provide the low-speed torque it takes for cutting tough materials like iron and steel as well as higher speeds for machining lighter alloys. There is no other machine in its market segment that offers this capability," said Trampus. With its machine design, Heller has also minimized positioning times. Instead of extremely high rapid traverse and acceleration rates, Heller focussed on realistic dynamic rates.

The H 4500 offers a wide range of basic equipment, so each machine can be customized for each user's application. This includes 50/100/150 pocket chain-type magazines for tool lengths of up to 600 mm, tool break monitoring with reference measurement and cleaning of the tool cartridges and holders. Workpiece management is equally flexible. The rotary pallet table has a maximum loading capacity of 1,400 kg.

Chip disposal is efficient. In particular, the H 4500 is designed for free chip fall below the spindle and between the rotary table and pallet changer, with steep chip chutes in the work area and at the loading station and with a 600 mm wide scraping or flat belt design chip conveyor over the complete Z-stroke.

To accommodate the end user, the machines are available with either Siemens Sinumerik 840D or Fanuc 31i-B CNC. Heller's industry exclusive NC controlled out-facing head option is available on the H 4500 for performing turning operations on the machine. A measuring probe for on-machine part checking, and instant tool breakage monitoring are also available. The machines, consistent with efficient cell operation, may be loaded with a robot or other automated loading systems.

For more information:
Heller Machine Tools
Phone: (248) 288-5000
www.heller-us.com

Affolter Technologies

HOBBING MACHINE TAILORED FOR MICRO MOTOR INDUSTRIES

Affolter Technologies SA presents its most recent innovation. "The GEAR AF110 sets a new benchmark in regards to flexibility, high precision and stiffness. It is tailored to the needs of all micro motor industries, such as automotive, aircraft, dental and medical equipment and watchmaking," states Marc-Alain Affolter, managing director of the Swiss family enterprise. The AF110 complements the existing gear product line towards the realization of larger parts with diameters of up to 40 mm and a module of up to 1.0 mm.

In 2010, the Affolter R&D team in Switzerland started to design the AF110. "Compared to the AF100, we doubled the clamping force to 1,000 newton. Torque and stiffness of the spindles were increased, the Y-axis is more robust and there is only one clamping axis moving, optimizing the overall rigidity and minimizing vibrations," explains Affolter. The AF110 is very compact, using the same base and volume as the AF100.

Flexibility a plus: worm milling

The Affolter experts are currently developing the add-on "Unit 90." After a quick changeover, the AF110 will be able to perform worm milling operations. Affolter explains, "We will intro-

Mitutoyo

OFFERS SALES AND SUPPORT FOR RENISHAW PROBE SYSTEM

Mitutoyo America Corporation is pleased to announce sales and support of the Renishaw PH20 probe system with the Crysta-Apex S500/700/900 series Coordinate Measuring Machines by Mitutoyo. The Crysta-Apex CMM line offers durability and high accuracy at an affordable price. It supports a wide range of inspections solutions including laser scanning, optical, and surface roughness inspection. With the addition of the high-speed scanning capabilities of the PH20 the Crysta-Apex CMM becomes the ideal solution for just about any part inspection, in the quality lab or on the shop floor.

duce this optional feature in the second part of 2014. The AF110 will be the most flexible machine for gear cutting and worm milling on the market."

Short cycle times: optimizing productivity

The Affolter engineers aimed to reduce cycle times to make the machine as productive as possible. The AF110 is equipped with the user-friendly, internally developed CNC Leste control, making communication with the micro gear hobbing center easy and quick. The compact design and the improved rigidity are other key features that guarantee short cycle times and highest efficiency. The distributor of Affolter Technologies SA in the United States, Canada and Mexico is Parker Industries Inc., based in Bohemia, New York.

For more information:
Affolter Technologies SA
Phone: +(41) 32 491 70 67
www.affoltergroup.ch

The PH20's unique "head touches" allow measurement points to be taken by moving only the head, rather than the CMM structure. Using only the rapid rotary motion of the head, points can be taken faster, and with improved accuracy and repeatability. Users of the PH20 probe head will immediately have access to the range of proven TP20 probe modules, providing a wide selection of trigger forces, directional sensing options and extensions to meet application requirements. The detachable modules provide crash protection and can be automatically changed using the TCR20 change rack (optional accessory).

The TCR20 is a compact probe module rack for use with PH20 that provides the capability for quick and repeatable tool changing and tip correction based on the MCR20 rack systems. It securely stores modules for rapid automatic changing and protecting mating surfaces from any airborne contaminants within the working envelope of the machine. The TCR20 supports the full range of TP20 modules which are compatible with the PH20 system and features an integrated tip datum artifact in the center of the rack assembly, minimizing the cycle time of the tip correct procedure.

For more information:
Mitutoyo Corporation
Phone: (630) 820-9666
www.mitutoyo.com

Solar Atmospheres

INSTALLS MID-SIZE VACUUM HEAT TREATING AND BRAZING FURNACE

Vacuum heat treat services expert, Solar Atmospheres of Western PA, recently announced the installation of a new high-temperature, high-purity, production-scale, 2-bar vacuum furnace in an environmentally controlled room for heat treating and brazing of small to mid-size loads. This new furnace will allow Solar to service customers with small to mid-size furnace loads more efficiently, economically, and precisely. The "Mentor" furnace, designed for processing medical, tool & die, aerospace, nuclear, and other industrial heat treated or brazed parts was installed and commissioned in the Hermitage, PA plant one hour north of Pittsburgh. Because the furnace is enclosed in an environmentally controlled room, Solar's customers are more assured that the dangers of humidity and resulting discoloration of some metal parts will be eliminated or severely reduced.

Michael Johnson, sales manager at Hermitage, said, "This new furnace will give us the ability to process a variety of loads we were not competitively able to quote using our larger furnaces. The Mentor is a great furnace and we're excited about the heat treating and brazing opportunities that this little workhorse is opening up to us."

The furnace, designed and built by sister company, Solar Manufacturing, is installed in an environmental cleanroom where humidity and temperature remain stable compared to typical heat treat facility conditions. The controlled environmental will allow Solar to more

Walter USA

INTRODUCES ROUND INSERT

Walter has introduced Tiger·tec Silver HU6, a round insert with a new geometry, specifically developed for medium and heavy-duty roughing of solid railroad wheels and other forged parts. Large chip build-up is a common problem, particularly when turning the inner profile of a railroad wheel, with the chips often failing to break as desired. Productivity and tool life both suffer as a result. Tiger·tec Silver HU6 was developed to address these chip control problems, and field tests at wheel manufacturers have shown that this new Walter insert provides up to 40 percent longer tool life.

The key innovation is the insert's geometry, featuring specially formed chip dimples for ideal chip formation, facilitating chip breaking in the required area. This new round

quickly and efficiently process parts providing quick turnaround to customers.

The furnace has an effective workload area of 12" wide by 12" high by 18" deep, is capable of holding a load of up to 250 pounds, and is rated at a normal operating temperature of 2,500°F/1,370°C. The hot zone is constructed of high-efficiency graphite felt and boards and allows for rapid heat-up and cool-down cycles. In order to achieve desired metallurgical properties for some metals, the furnace is equipped with a 2-bar quenching capability.

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insert benefits from Walter's proven Tiger·tec Silver coating which enhances cutting speed, reliability and tool life. The inserts are available in four different grades: three for steel and one for cast iron machining. Insert diameter selection ranges from 10 to 32 mm. This combination of coating and geometry, with its specially designed chip breaker and strong cutting edge for process reliability in heavy and interrupted cuts, boosts the productivity of heavy-duty roughing operations, such as railway vehicle manufacturing, generator and turbine manufacturing, and forged components in general. In addition, Walter Capto turning toolholders can be used with the HU6. This interface enables quick tool changes and easily handles the transfer of large forces.

For more information:
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EMAG

INTRODUCES SMALL GRINDING CENTER

Demand for components such as gearwheels, planetary gears, chain gears or flanged components for cars typically runs in quantities of millions. Thus, short cycle times in production have become mandatory. The internal contour of a gearwheel, for example, must be ground in the shortest possible time and the machine's workholding unit has to be loaded with a new workpiece equally as efficiently. This represents a critical moment in many production environments, as idle time is often a decisive factor in establishing the economic viability of an entire production process.

Efficiency through two grinding wheels

An important feature of the VLC 100 G is the possibility of utilizing two grinding spindles used to perform different grinding operations, to handle both rough and fine-grinding work, for example. "For the removal of large amounts, two wheels offer a shorter cycle time than one, with the first wheel designed to do the rough-grinding and the second one in charge of finish-grinding work," explains Dr. Guido Hegener, managing director of EMAG Salach Maschinenfabrik GmbH. The first wheel performs the "rough" job of removing excess material from the raw-part at high feed rates (the CBN wheel is specially designed to absorb the necessary forces), while the second wheel, with different specifications, takes over the finishing work to guarantee a perfect surface finish on even the most challenging geometries. Through this intelligent tooling combination, EMAG design engineers have succeeded in drastically reducing the grinding time of even very complex components.

The automatic loading advantage

High output levels with short cycle times is exactly what the VLC 100 G Vertical Grinding Center from EMAG was developed for. For chucked components with a maximum diameter of 100 mm, the VLC 100 G utilizes its built-in pick-up system to load itself. While one workpiece is being machined the operator, or the automation system, re-loads the raw-parts onto the conveyor belt. This reduces idle times and increases output rates. The vertical machining concept, the signature EMAG design, ensures that grinding sludge falls to the bottom of the machine unhindered and away from the machining process, where it is then transported out of the machine.

Integrated quality control

Measuring can also be integrated into the machine, making quality control an integral part of the whole process. The measuring probe is located between the machining area and the pick-up station, where it is protected from contamination.

A convincing machine concept

The combination of fast loading and efficient grinding processes leads to a very compelling machining concept. The VLC 100 G works very well with the dynamic developments in automotive production. Now, with the rapid increase in required quantities, demand for new machine concepts that can be seamlessly integrated into existing production grows. Two features of the VLC 100 G enable it to be effortlessly integrated into established production lines.

"Programming the workpieces with our new EMAG Navigator software is simple and intuitive, saving valuable setup time. For many production environments this is an advantage that should not be underrated," states Dr. Hegener. Furthermore, the exceptionally small footprint of the VLC 100 G should make the work of every production planner easier. The stand-alone machine only takes up 4.5 square meters/48 square feet, making sure that growth of a production facility will not be limited by floor space requirements.

For more information:
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EMCO and UltraTech

COLLABORATE ON MODULAR AUTOMATION PACKAGE

Machine shops of all sizes continue to seek ways to automate what they do to improve consistency, save time, and reduce cost per piece produced. In response to that need, EMCO Maier has partnered with UltraTech Machinery, Cuyahoga Falls, Ohio, a designer and builder of high production equipment, to offer a modular robotic automation cell that provides cost-effective, flexible part load/unload for its turning machines.

The new package was demonstrated recently with an EMCO Maier HT45 SMY universal production turning machine, a versatile, multi-task production turning/milling center designed for a wide range of applica-

tions on bar stock to 45 mm diameter. The Hyperturn 45 includes high-performance main and counter spindles, two tool systems with a total of up to 24 driven tools, and a stable Y axis with a 70 mm travel in the upper slide system and a Z2 axis in the lower slide system.

Says Philipp Hauser, EMCO Maier USA president, "The integration partnership with UltraTech will be a positive for us and our customers. About 10 months ago we saw more and more sales activity and RFQs for turnkeys and automation. One of our strategies was to find a local U.S. partner, especially for robot integration. Having Motch & Eichele as one of our bigger dealers, and a partner company of UltraTech, it was clear we should work with UltraTech to develop a solution."

According to Bob Hagarty PE, CEO of Motch & Eichele, "The challenge was to put a flexible handling solution around a compact turning machine that was also scalable to a use with a larger machine. We developed a universal base with left

and right hand versions configurable to the machine model. It is a production-proven solution with millions of open/close cycles.

"We call it the EMCO Factory Automation Solution, designed to be easily used in small shops as well as larger plants. The overall package is non-threatening to machine operators. Often, the most challenging portion of an automation solution is part infeed and outfeed. The multi-drawer part cabinet offers a simple, reliable, flexible method to provide a useable buffer of oriented parts to the robot. The user is responsible for very little, including only part specific gripper fingers and trays for the drawers, robot path point teaching and minor program modifications as needed for tray unload/load and machine unload/load."

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Moving Parts

Machine Tools Boost Speed and Throughput with Automation Technology

Matthew Jaster, Senior Editor

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In order to streamline gear manufacturing equipment in 2014, many shop floors are utilizing some form of automation (gantry, robotics or pallet-based systems). These automation concepts, prevalent to the automotive industry, have become advantageous in off-highway, alternative energy, commercial gearbox production and more. The end game is separating personnel from machine operation time and making these manufacturing cells both cost effective and extremely fast.

"Internal and external automation facilitates higher productivity as well as streamlined management of equipment," says Alois Mundt, managing director at Liebherr-Verzahntechnik GmbH. "Reducing long set-up times, minimizing costs and extending performance is a must for most machines in gear manufacturing today."

"When perfectly matched, automation and a gear-cutting machine mesh like gears, achieving productivity and precision benefits for the end user," says Alan R. Finegan, director, marketing at Gleason Corporation. "Productivity improvements come through reduced chip to chip time and the possibility of autonomous operation, enhanced process consistency and repeatability, and improved material handling, reducing operator fatigue and injury. Also, automation allows for more than just part handling, where other operations such as part washing, inspection, part marking can be integrated."

"Companies can achieve quality that is better and much more consistent by increasing the level of automation in the production process. This is only possible if the initial quality of the components that are being machined is defined and constant," says Hartmuth Müller, CTO, Klingelnberg Group. "Variations in the initial quality mean that the operator has to continually adjust the process parameters, which ultimately leads to greater quality variance and therefore loss of consistency. It is not the human factor that causes fluctuations in the production process, but rather the lack of consistency in the upstream processes."

A key aspect of automation is shortening the setup time, according to Bill Miller, vice president, Kapp Technologies. "Most calculations are automated. Onboard quality inspection, including corrections, is automated. Tool change in many Kapp machines is semi-automated. Combined, these innovations save, on average, over 50 percent of batch processing time. Modern machines, tools and processes increase productivity anywhere from two to four times, over machines which are 10 to 20 years old. So, manual workpiece mounting and truing time becomes a large proportion of the total cycle. Palletized systems are designed for semi-automatic workpiece change. Mass production applications also prioritize setup and/or changeover time. Equally important is the economy of the automatic part loading solution."

The RLS is a cost-effective, entry-level solution for users with very small batch sizes (batch size 1 and above) or small batch manufacturers (courtesy of Liebherr).

Get the Balance Right

Challenges abound for factory automation, from cost concerns to floor space to the speed of the entire automation process. "Customer philosophies differ with respect to production goals and priorities. Optimizing for safety, speed, flexibility and cost efficiency often require very different solutions," Finegan says. "Even within a given philosophy, covering the full spectrum of customer parts with respect to size, weight and configuration is a challenge, as is the integration with the machine tools and automation of other manufacturers, and with established systems in the plant."

"The biggest challenge is to combine automation and flexibility characteristics that appear to be conflicting at first glance," adds Müller. "It is ultimately a balancing act between these two requirements, and the fundamental question is the degree of automation that should be chosen."

Müller believes past experience has shown that flexibility is lost at high levels of automation. "A fully automated gear machining tool lacks the flexibility to deal with batch sizes that are becoming increasingly smaller, and a machine without automation lacks consistency in terms of machining time and component quality," Müller says.

Kapp's Miller says that many automation concepts are available and customers may prefer a certain supplier. "The result is a vast number of available options, which is not efficient for the machine builder to implement."

"Automation is a cost-driven system," Mundt explains, "The money customers want to spend on certain solutions might not work. So you have to create a cost-effective product, and that can be a big challenge. The other challenge is to speed it up like hell. These automation solutions need to be fast. It shouldn't take longer than 10 percent of the machining time."

"First-time buyers of automation often succumb to 'sticker shock' as they perceive the automation to be a non-process and thereby a non-value added cost. Existing users tend to look more for continuous improvement, faster speed and minimal footprint," says Patrick Seitz, president at Felsomat USA. "We collaborate closely with our customers and calculate the overall benefits in terms of machine uptime, efficiency, reduced manpower, potentially reduced number of machine tools, reduced utilities, and reduced floor space."

Covering the full spectrum of customer parts with respect to size, weight and configuration is a challenge, as is the integration with the machine tools and automation of other manufacturers, and with established systems in the plant (courtesy of Gleason).

Automation in Gear Manufacturing

So what options are available to gear manufacturers considering automated work cells? Gantry and pallet robotics systems are available and many machine tool companies combine elements of each. We asked our experts to break down the advantages and disadvantages of these various automation concepts.

Gantry

According to Seitz at Felsomat, gantries, in conjunction with Felsomat patented vertical buffer systems, offer the fastest and most efficient solutions in the smallest footprint.

"Gantry-based systems are sometimes considered the lower end of automation due to their relative inflexibility. However they may be optimized to one part or family of parts and are thus very fast,"

Finegan says. "Operating in a narrow and well-defined range and paths, safety and security issues are generally reduced."

Gantry systems are much less flexible than robots, since the different options for depositing components are extremely limited, according to Müller. "Components are usually loaded from above and thus can essentially only be stacked in two ways (adjacent to or on top of one another). The major advantage of gantry loading is simple operation and programming. Almost any machine tool operator is capable of operating and loading a gantry."

"Gantry systems offer a closed envelope approach to allow for quick loading without the floor space or mess of a robot. However they tend to be more costly and certainly less flexible," says D. Kirk Stewart, Jr., director of sales at EMAG LLC.

Robotics

"The major advantage of robotics is without doubt the significant flexibility that it provides. Because any loading method can be used, these systems provide maximum freedom for determining how individual components are deposited and brought into the system. Everything that is needed and desired in this respect is possible, including stacked components, components placed in baskets, or components deposited onto conveyors. However, this technology requires in-depth knowledge on the part of the operator, who must know how to program a robot," Müller says.

"Robotics offers the benefits of replacing an operator in front of a machine with some of the physical articulation required to accomplish this demand," says Stewart at EMAG. "However, the tradeoff is significant floor space utilization, a fenced in area which does not allow easy access to the machine for an operator for tool change or setup, and in many cases a less than clean working environment with residual chip and coolant debris on the floor."

"Robots tend to be more flexible, versatile and re-deployable, and such systems are generally easier to replicate in cells at multiple customer locations. Representative of the higher end of automation, they are able to adapt to several or many part sizes and configurations, and they may facilitate the integration of multiple cells," Finegan says. "However, robotics tend to consume more floor space and demand robust safety and security measures surrounding the entire operating envelop."

Basket or Pallet Systems

"Particularly for gear technology involving small batch sizes, the biggest benefit in terms of automation is obtained with basket or pallet systems. It does not matter whether the parts are supplied via a gantry, a robot or a machine in a basket or pallet system. The advantage of pallets and baskets is that they provide an easy, flexible way of transporting parts inside the plant," Müller says.

"A palletizing system is quite popular," adds Mundt. "You can transport parts that have been machined wherever you want to. A palletizing cell can be connected to the material flow inside the shop so you can complete a combination of tasks such as honing, deburring, grinding, etc. It's one of the most successful forms of automation in manufacturing. "

"Pallet systems also require a large amount of floor space and often create physical barriers in the plant," adds Seitz.

Combining Technologies

"Most automation systems combine a robot with a conveyor with a basket stacker, etc.," adds Miller at Kapp. "The machine is designed with standard optional features to adapt to most types of available automation. This allows customers to take responsibility as the integrator."

Liebherr takes advantage of the external and internal automation concepts to create a system that is dedicated to the specific needs of the customer. "Most of our machines have multiple automation solutions," Mundt says. "You start with the part carrier, followed by the conveyor belt and the ring loader before gear cutting on a hobbing machine, for example. The overall efficiency of a machine manually loaded is 60 percent if people are in front of it all the time; this goes up to 80 percent with automation."

"The movements of a machine-integrated part transportation system can be designed to be synchronized with the machining axes of the machine tool at CNC level, and are therefore significantly faster than a conventional automation interface," adds Müller at Klingelnberg. "Another advantage lies in the flexibility of automation. Any gantry or robot system can be used, and any degree of automation can be selected."

"At Felsomat, we do not have one automation solution that fits all applications. We have a wide variety of standard modular building blocks which are easily configured to achieve the highest efficiency possible on each operation which

Consistently high machine utilization results in a greater number of components per hour and also reduces the energy consumption of the machine tool (courtesy of Klingelnberg).

is calculated to achieve the lowest overall investment for the customer," Seitz says.

The Current Market

While a single article cannot provide all the automation products and technologies available in the gear market today, here are some highlights:

Liebherr's Rotary Loading System (RLS) offers cost-effective entry into high-efficiency production with one or two machines – delivering utilization of more than 90 percent.

Using the RLS to extend a machine's running time makes investing in an additional machine completely unnecessary in certain cases. "This solution is clearly more effective than marginal increases in productivity that could result, for example, from optimizing CNC programs or the tools of machines that are manually fed or partly automated. One or two machining centers can be docked to the system. For batch size 1 and above, the RLS unleashes considerable efficiency potential," Mundt says.

In the case of EMAG solutions, the automation is inherently built into the machine. The inverted vertical spindle is loading and unloading the workpiece by itself, thus not requiring an operator or robot to load into the spindle. "This allows for EMAG to provide a standalone automated cell with very predictable productivity," Stewart says. "The new Modular Standard and Modular Customized solutions EMAG offers on the VL and VLC platforms, respectively, offer machines tied together with various automation configurations to meet the customer's requirements. These modular systems can be set up to interface with downstream and upstream systems, for Chaku-Chaku loading, for buffered loop conveyors, or for common highway solutions."

Flexible and intelligent automation solutions allows for a new generation of machining capabilities (courtesy of EMAG).

"Our Genesis line of machines have fast part loading systems with options to chamfer and deburr in parallel, and our Phoenix 280CX Bevel Gear Cutting Machine provides fast loading from the cutting spindle to an auxiliary chamfer & deburring spindle that runs in parallel to the cutting cycle," Finegan at Gleason says. "Agilus is a combined process machine that combines gear hobbing with turning, chamfering & deburring, and drilling. Our Titan series of large cylindrical gear grinders offer

The Kapp KX100 offers practical efficiency gains of 10 to 20 percent (courtesy of Kapp).

Power Grind, which combines the benefits of threaded wheel grinding productivity with the precision of profile grinding. We also offer the BPG Stick Blade Grinder with a standard includes blade load/unload system capable of running in an unmanned mode."

Klingelnberg is working on making automation more intelligent. "An automated machine tool depends on coordination between the workpiece, the workpiece fixture and the workpiece program. In this respect, an automated machine tool is not fault-tolerant. The first process involves gripping a new component using the automated system. Another important point is to standardize the interface between the machine tool and the automation system. Every manufacturer has its own original interface, which has to be adapted or at least coordinated for every automation manufacturer. An international standard would help to reduce the effort involved and make the customer more competitive in terms of costs and flexibility," Müller says.

"A fully automatic solution using our basketized FlexStackingCell is the most appropriate solution in highly developed and high labor cost regions such as North America and Europe," says Matt Skelton, sales manager at Felsomat USA. "Customers operating in these regions are also demanding highly flexible systems that can be quickly changed from one part to another without tools within 5-10 minutes. Also required is the ability to re-tool and re-deploy automation assets to meet rapidly changing product lifecycles. In developing countries with low labor costs, our customers demand a manual/automation hybrid solution with lower investment criteria."

"The Kapp KX100 breaks new ground by applying a proven design to gear grinding where the work spindle also performs the loading function, as well as aligning and spinning. Cost and space are conserved," Miller says. "Practical efficiency gains of 10 to 20 percent are easily possible with this machine."

Intelligent Machining

The future of automation technology revolves around making the machines smarter. Initially, these concepts might make operators nervous (and replaceable) but the truth is that an intelligent machining platform can only be as effective as the operators utilizing the technology. Smart machining will become more beneficial when they are running 24/7 or during lunch or coffee breaks. These automation systems aim to make the entire production process much more efficient.

"Our vision is to have seamless transparency throughout the production process: Each step of the process is stored in a database, meaning that all product-related information is clearly documented in chronological order. This allows the entire production process to be tracked down to the last detail for each component. The advantage: Users can identify correlations, for example, and draw conclusions as to steps in the production process that require readjustment," Müller says.

Felsomat is striving to influence the design of machine tools to reduce the level of automation required. "To that end Felsomat has developed twin spindle turning and hobbing machines with integrated automation where the idle spindle is loaded automatically while the second spindle is in production. This reduces idle time, or "chip to chip" time to the absolute minimum and on large automotive gear manufacturing programs there is the potential to significantly reduce the level of machine tools and automation investment. Felsomat is also leading developments in the field of heat treatment of gears within the gear manufacturing process thereby further reducing separate independent automation processes," Skelton says.

"Well trained machine operators are still difficult to find in manufacturing," Mundt adds. "We've set up intelligent program structures at Liebherr to do most of the work. Instead of the operators telling the automation what to do, the automation will tell the operators what to do. The ERP system (enterprise resource planning) will point out the production needs and the machine will answer the call. This (along with adaptive controls) is already taking place within the gear industry."

And how do some of these machine tool manufacturers feel about the potential downside to some of these new technologies? An automated system, for example, might make it possible for a customer to purchase two machines instead of four, saving energy and valuable floor space in the process.

"As a manufacturer of machines, I'm not happy about the situation," says Mundt, laughing. "But we are fighting for the benefits of our customers."

(*Additional information for this article was provided by William McGlasson, Michael Walker, Craig Ronald and Matthias Philippin at Gleason Corporation*)

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Coming Home, But to What?

Many Vets Have the Skills, but No Place to Apply Them

Jack McGuinn, Senior Editor

"Thank you for your service." We've all heard that one before — and have maybe spoken the words ourselves. Typically, however, we hear it during election season at political debates or town hall meetings. That's when the candidates deign to take questions from the audience, and —uh-oh— one of the questioners happens to be in the military — perhaps just back from Iraq (oh yes, we're still there) or Afghanistan. The soldier is interested in knowing what his (her) thankful congressman or senator plans to do about the inadequate job training, education, and treatment programs that are at minimum a cold slap in the face to returning veterans — some as yet too young to buy themselves a beer. The pol's face tightens noticeably, but he or she always has a well-rehearsed non-answer down cold.

But think about it: beginning with Bush *père*'s Iraq invasion in 1991, the country has been in a dystopian-like state of war (Somalia, Bosnia, Iraq II, Afghanistan), with more than a generation of young (and not-so-young) Americans being killed or maimed in the process — and all of this on a voluntary basis.

And yet — except for those who were there — can anyone name one memorable battle from the last 30 years? Today's soldiers have no claim on epic battles to rival those such as Belleau Wood to leave their mark on history (the grateful French re-named the forest "Wood of the Marine Brigade"); no D-Day; no Tuskegee Airmen; no Mt. Suribachi; no Pork Chop Hill, V-E Day, V-J Day; no "Greatest Generation" or *Band of Brothers*. And certainly no ticker-tape parades.

All of which raises the question: are returning or recently discharged veterans at least receiving the training and education opportunities they deserve in return for their service? Let's see.

To do that, we interviewed individuals who are intimately involved with veteran training and employment issues, but from differing perspectives, including: Michael J. Aroney, principal consultant, consulting & training, for Allied Reliability Group (ARG), a manufacturing consulting service with particular emphasis on training, employment consultancy, veteran transitioning and hiring practices from an employer need and perspective; Douglas Pierce, chief learning officer, DMG Mori Seiki Academy; Tom Peters, director of business operations, Symbol Training Institute; and Joe Barto III, founder and president (and former U.S. Army Major), TMG (Training Modernization Group), Inc.

Given these individuals' experience in military affairs, at some level or another, and their recognition in the veterans community, they more than most are wired in to what is happening around the country. And they, sooner than most, became aware that government services for veteran training and hiring were lacking — but not so much in areas where you might think. Yes, we definitely need more qualified training venues and instructors. And for sure more hands-on, practical training is needed.

But what many say is now needed most of all is focus — and much better coordination between business (HR, hiring agents); trainers (technical colleges, private entities, community colleges); and the military (Veterans Administration) in publicizing and describing good jobs that are available *right now*. Because as things stand today, the unvarnished truth is that every month many good-paying jobs with a future go unfilled. These breaks in the jobs supply chain and the continued need for more training opportunities led people involved in veteran affairs to conclude that more had to be done — on both sides of the equation.

On the training side, Peters states that "Veterans are trained on and have utilized advanced technology in the military, and we at Symbol (with two locations in the Chicago suburbs) are also training on advanced technology within the manufacturing field. Thus it is a logical progression to continue the training for veterans with the transition from military technology into manufacturing technology. Our training also helps the veterans who are coming back home get into a routine to ease the adjustment from military service to civilian life.

Speaking to the fuzzy focus side of the equation, Aroney's epiphany came five or six years ago when he attended the kick-off of the Wounded Warriors Association (*www.woundedwarriorproject.org*), sponsored by the Naval Sea Systems Command.

"I noticed then — and since then — that all the emphasis was on job creation by the civilian sector and educating them on the value and desirability of the veteran. This included educating the prospective employers on military occupational specialties and how they translate into desirable civilian technical and leadership skills. At that time, North American manufacturing was entering the leading edge of a craft skills crisis for technicians who could fix manufacturing equipment and keep it running. We had jobs, but needed to make the military services aware of them, and that their maintainers could move into these roles easily and quickly — *without* a college degree.

"I found the military leadership was being told that their transitioning enlisted service members needed college degrees to find jobs in the civilian sector. *Not true!* One can become a successful reliability engineering professional without a degree by putting to use all their military technical maintenance training and experience. That, along with the work ethic they bring and the ability to solve complex problems in a high-stress environment, makes the service member a sought after candidate."

"Our involvement in this effort was not born out of frustration with government programs," says DMG's Pierce, "but from a growing need for qualified workers — both internally and from our customers. We have a number of successful veterans as employees and had a good experience with a few veterans who applied for our initial apprentice program."

Barto says "Ninety-five percent of the government programs have to do with teaching vets how to find a job and providing resources when someone does not have a job. AME Values Vets (amevaluesveterans.com) is working on the demand side of the equation — teaching *employers* how to re-capitalize their business by hiring and retaining vets.

So what we have developing here is a triad of sorts, with each part working in support of each other, the ultimate goal being a career-based job for every vet who wants one. We have government online programs, especially the VA, tutoring vets on job searching; we have other groups tutoring busi-

"Military training certainly helps prepare veterans after they are done with the service. Veterans can walk into civilian life knowing that they are already trained on modern equipment, have a strong foundation of discipline, and are mechanically inclined."

Tom Peters, Symbol Training Institute

nesses (HR, hiring agents, etc.,) on how to recruit veterans, what to look for on their resume, how to project their military skills and training onto the job requirements.

All of which sounds like good, common sense. Unfortunately, something else that makes sense is a negative — i.e., trying to get these three groups on the same page is like herding cats. Some are of the opinion they all seem to mean well, but they also seem to have their own agendas; not in any sinister way — merely in insisting on having their own way of doing things. But for Aroney, that's missing a bigger point.

"I'm not seeing lack of collaboration as an issue," Aroney says. "It's more a lack of *awareness*. Of the 12 companies in several different manufacturing industry verticals that I support, all are aware of the federal and state programs available to help transition veterans, and they have programs in place that utilize the programs and funding. The employers we work with get it; the missing element is creating awareness on the military side to make the veterans aware of who is hiring and how their skills translate to the civilian sector. We are now starting to see some movement in that area by coordinating with the military service's respective Transition Assistance Programs (TAPs), sitting on panels at military-sponsored job fairs, and advertising in military journals like *Navy Times* and *Air Force Times*.

Symbol's Peters, while not addressing the awareness issue, does believe better coordination is needed.

"I would have to agree with that. Within the past two years, the talk of veterans returning and the revival in manufacturing appears to be on everyone's radar. Many organizations are trying to help veterans, and not all of them have the training or expertise that Symbol has. We were a manufacturing company since 1985, and we know precisely what the manufacturing community expects from our students. Our training delivers what the industry demands."

With that said, Peters is confident that a good student-veteran graduating from Symbol can reasonably expect good things to happen.

"The starting wage for CNC machinists is in the range of $12-$18 per hour," Peters says. "Due to the skilled labor pandemic that is affecting the manufacturing workforce, the manufacturers are

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paying more due to the lack of supply and, as such, we have seen some of our graduates command a yearly salary with overtime and benefits that can be in the range of $40,000-$60,000 the first year after graduating from Symbol. These are truly livable wages."

Count Pierce in as another one looking for better communication among veterans groups.

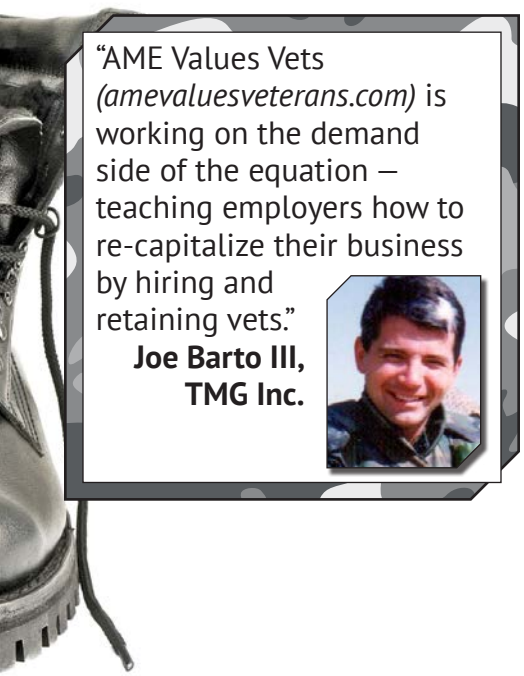
"Yes, we do agree (on the lack of collaboration). Oftentimes the veterans are not aware of the programs, nor are there links to the actual companies that can provide job opportunities."

If this all seems rather complicated, that's because it is. In trying to dumb it down a bit, we posed the question to our participants this way: Why is hiring vets today seemingly more complicated than it was after WW II or Korea?

"I think there is not the same coordinated approach and national awareness as there was during those two conflicts," Aroney offers. "We dumped a lot of military into the private sector in a short time frame. Today, we're cycling them out and only took notice when unemployment numbers showed a disparity between vets and their civilian counterparts. Subsequently, we began spooling up awareness through various nonprofit organizations to reach a tipping point — which I think we are nearing." He might have added that vets coming home after Europe, the Pacific and Korea weren't returning to a Brave New World-type of industrial workplace with constantly evolving, sophisticated technologies that required new skillsets and remedial training as needed.

Adding credibility to veterans' claims for a fairer shot at the American Dream, General David Petraeus, former commanding general of Multi-National Forces in Iraq, has said that "After World War II, exemplary programs and support for veterans created the American middle class and helped the 'greatest generation' to become great. We owe this generation nothing less."

"Perhaps, the World War II generation had a greater sense of responsibility and work ethic, which has been fading over the past few generations," Peters observes. "Here at Symbol we are proud of our country and we are aware that the veterans are an important part of our society, and should be treated as such. Symbol's preparation of veterans for civil life is what we are proudly achieving. We



"AME Values Vets *(amevaluesveterans.com)* is working on the demand side of the equation — teaching employers how to re-capitalize their business by hiring and retaining vets."

Joe Barto III, TMG Inc.

are honored to be producing 'Made in the USA CNC Machinists.'"

ARG's Aroney — not to put words in his mouth — perhaps thinks the analogy doesn't quite hold up in the 21st century.

"In the 12 manufacturing companies I work with in seven different industry verticals, we find a very old work force from the generation described by Gen. Petraeus, and a very young, entry-level workforce — and not much in between. Technical colleges and apprentice programs are making a comeback after a lull of 20 years to fill a technician gap that will become critical in the next five to six years from the pending 'silver tsunami' — the retirement of a majority of the Baby Boomer workforce. All the more reason to emphasize process standards and automation and preventive maintenance technology."

And an equally good reason to wonder if training that veterans received in the service can translate to a promising career path in civilian life. Most say it is so.

"Military training certainly helps prepare veterans after they are done with the service," says Peters. "Veterans can walk into civilian life knowing that they are already trained on modern equipment, have a strong foundation of discipline, and are mechanically inclined. The trades are a wonderful way for them to apply these skills that they have honed serving in the military."

"Absolutely," Pierce seconds. "The military trains veterans for careers beyond soldiering. In addition to the obvious training and experience they have received — leadership, work ethic, teamwork, perseverance, integrity, etc. They also in many cases have other hands-on experiences which translate well to manufacturing — mechanical, electrical, technology skills, etc.

"One initiative which we know is supported by Congresswoman (Tammy) Duckworth, U.S. Rep. (D-IL) is to give veterans credit for some of the skills they acquired and demonstrated in the military upon their discharge. One simple example is a CDL driver's license."

TMG's Barto points to the number of learned soft skills veterans have acquired that position them ahead of their civilian peers.

"For 90% of entry level production jobs — regardless of industry — the basic military three-year experience creates the skills and abilities to make veterans best-qualified over their non-military peers. Basic training teaches how to follow instructions; how to ask questions; how to perform complex problem solving; how to work safely; plus the life experiences of moving away from home; being promoted; being deployed. Compare that experience to their peers and the best-qualified test is more than matched."

Before proceeding, the following point must be firmly established, as it figures predominantly in the remainder of the story. It is one of those things that is so simple and yet hides in plain sight. It seems that good-paying manufacturing jobs with a future go begging every day in this country. Indeed, polls indicate that employers say they are ready, willing and capitalized to hire veterans.

So where's the problem?

"Vets don't know the jobs are available," says Aroney.

And there you have one of the best kept secrets since Orson Welles's *War of the Worlds*.

Incredibly, in this age of technically wondrous military communication, Aroney says "There's no central clearing house to provide that information (job opening) to them and let them know how they fit the bill. They will typically take the first job that comes along, not necessarily the best job for which they are qualified."

But some "help" from the military does exist, Aroney points out — if with a degree of circumspection — and a piece of information some will find disturbing.

"The military has Transition Assistance Programs (TAPs), but I find there is wide variation in the level of service and support they provide. There are also rules in place that prohibit potential employers from interfacing directly with these government agencies to hire transitioning military."

Which leads Aroney to wonder if these rules were instituted with a whiff of mendacity attached to them.

"I'm not certain, but I speculate (they are in place) to keep potential employers from luring away candidates who otherwise might re-enlist; just a thought.

"Plus, (the military is) just not aware of the specific jobs that are available from specific employers in specific industries," he continues. "(Vets) are only prepared to transition in general terms, by job category such as sales, finance, maintenance, operations, etc. Before budget cuts, most transitioning military sought employment with government contractors; those jobs are drying up."

TAPs also work with vets in teaching them how to dress for an interview and how to write a resume in "civilianese." Yet, Aroney says, "There is still a challenge in understanding what specific jobs there are available and how to tailor the vet's training and experience into language on a resume that will be understood by a specific civilian HR specialist and hiring manager. We've also done fairly well educating the HR specialists and hiring managers on what they get and how to translate the vet's language."

As for Barto, he need point no further than his own Vet STRONG program (*www.vetstrong.us*). "We have been extremely successful in getting employers, after they are educated, to pledge to hire and retain vets."

Peters relies on word-of-mouth, knowing that Symbol is "well known in the greater Chicagoland manufacturing community. A lot of our students are working in (local) manufacturing companies. Symbol has a very tight working relationship with the manufacturing community, and the companies are waiting for our graduates to enter their workforce. At the end of the day, the manufacturers want qualified candidates (vets or no vets). However, hiring a veteran would be beneficial — especially if the company manufactures a lot of defense or military type components."

These welcome success stories aside, what is still needed is "the squeaky wheel" to disseminate veterans-only job openings — yes, a password-protected national jobs board reserved strictly for veterans — because they've earned it. We have *Monster*; we have *Careerbuilder*; why not a *Kickstarter*-seeded, national *jobs* board for veterans?

As we close, we compared Aroney's statement about the Army's reluctance in sharing work skills-related information

about soon-to-be-discharged soldiers with prospective employers, and manufacturers' disinclination to open the purse strings for quality technical training, the rationale being a fear of losing newly trained employees to competitors offering higher pay. The irony could not go unremarked.

"The excuse used by manufacturers not to train for fear of losing those who received training is, in my opinion, the response of a reactive environment," says Aroney. "If those who are trained are in an environment that provides a mechanism where their work is rewarding and needs for affiliation are met, then there is no fear of employees leaving. The data shows that a satisfied employee will require at least a 20-30% increase in pay to leave a job where they are appreciated.

"A company that is afraid to spend money on training for fear the employee will leave has much bigger problems to solve."

And one last thing — if you are in the position to help a vet and you would really like to do so, here's a thought from former U.S. Secretary of Labor Hilda Solis: "If you own a business, the best way to thank a veteran is to hire one."

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Heroes, Every One

Alan Knight *served for five years during Operation Desert Storm as a mechanic and QA inspector for M1 Abrams tanks and Bradley fighting vehicles. He has appeared with ARG's Mike Aroney at various veteran-oriented events, as well as others. Despite his mechanic abilities, upon his discharge Knight scuffled to find work, eventually settling for work as a truck mechanic at $6.50 an hour. We caught up with Alan and asked him a few questions.*

Gear Technology (GT): Why do you think the military has been so slow to develop a pipeline between soon-to-be-discharged soldiers and potential employers in need of skilled workers? With so many personnel on hand, you'd think they could spare people to do that.

Alan Knight (AK): In my opinion, the main reason is that it is the military's job to train, and retain, skilled soldiers/marines/seamen/airmen to perform the military's mission at the highest levels. They have spent tens, or even hundreds of thousands of dollars for training and caring for each service member to maintain operational readiness, so they are less interested in preparing someone to leave. I would offer that it isn't any different than the civilian world in that respect. I know of no company that I have chosen to leave that offered me any assistance in pursuing my next job opportunity.

GT: Does the army conduct an equivalent to the civilian "exit interview" with outgoing soldiers?

AK: I had "exit" counseling that consisted of resume help from a civilian person that, looking back, had zero HR experience and likely had no outside employer experience for years as a government civilian worker.

GT: One common thread running through all the stories over recent years about the skills gap, the greying workforce, and the training and hiring of veterans is the disconnect between the trainers, the trainees, and the employers — as if they are all working in their own vacuum chambers. I see where you tout working with Hiring America's Heroes (HAH) (*hireamericasheroes.org*), but is that enough? What more can be done to fix this?

AK: Working with HAH is a start. There are many other organizations that work with veterans and corporations as well. I think the key is getting these organizations involved at the base level as part of the transition process would be very beneficial to the service member, but getting the word out to the HR directors in the business community is perhaps even more important.

GT: How are things working for you these days?

AK: I would say very well. I have left my reliability consulting position at Allied Reliability Group and have taken a position at Mueller Company in Albertville, AL as the reliability engineer. I have already been in contact with our HR director about these veterans organizations as a way to fill the employee needs that we have right now and for the future.

J. McGuinn

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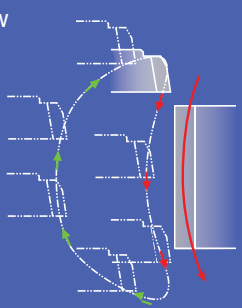
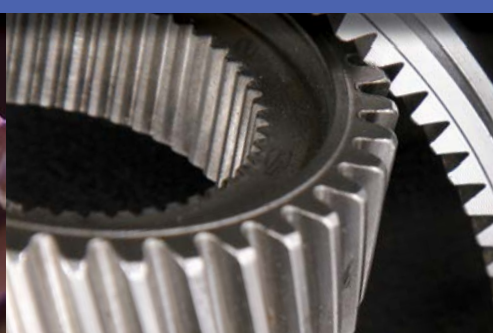


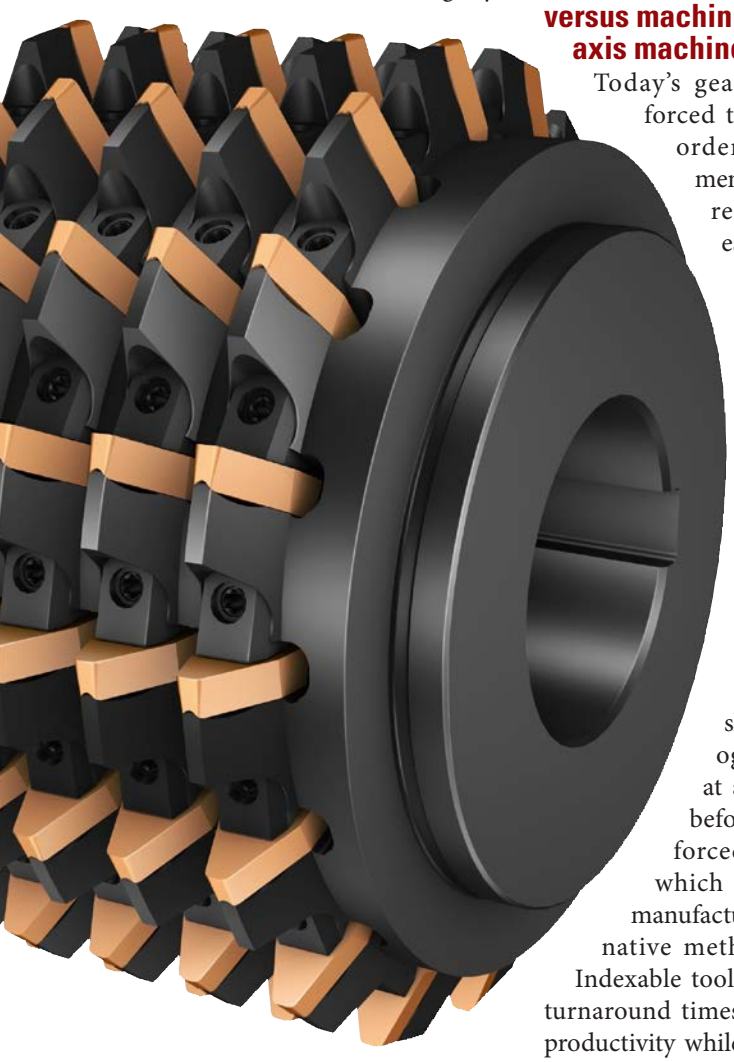


The Technology Shift

HSS vs. Indexable in Gear Hobbing

Mats Wennmo, senior technical manager, gear milling solutions, Sandvik Coromant
Miikka Holopainen, sales and application specialist, gear milling solutions, Sandvik Coromant

Decades ago, technology shifted from HSS to indexable inserts in turning and milling. This movement wasn't immediately realized in gear hobbing because coated PM-HSS hobs and complex gear profiles remained highly effective and productive methods. Only fairly recently have gear manufacturers started to take a serious look at indexable technology to cut gear teeth. A shift away from conventional gear machining to machining centers/five-axis machines is one of the major factors in this shift. Furthermore, advances in both productivity and quality in indexable gear tooling also play a central role in this development. Finally, new materials in gear production are making indexable tooling attractive to many gear manufacturers.



Conventional machine tools versus machining centers/five-axis machines

Today's gear manufacturers are forced to be more flexible in order to satisfy requirements for shorter runs and relatively small batches of gear profiles with greater variety in specifications from run to run. We all know that HSS machining is still the most common process for gear hobbing, but for aerospace, automotive, construction and heavy machinery industries alike, the pace of change is accelerating. Product lifespans are getting shorter as new technologies are implemented at a faster clip than ever before. Part runs are then forced to become shorter, which in turn requires gear manufacturers to consider alternative methods of gear cutting. Indexable tooling can provide faster turnaround times, providing improved productivity while retaining quality and better consistency.

The technology shift from HSS to indexable tooling and from conventional machining to machining centers/five-axis machining can be advantageous not only for small-volume gear producers, but also for medium- to high-volume gear producers. Tooling technology is moving away from special tooling and toward standard tooling, which means an operator of the future will be able to get all the necessary tooling in one to two days. Large-volume gear shops are attacking the new landscape with indexable tooling flexibility, augmenting and replacing the traditional HSS lineup of tools.

Industry trends toward smaller batches and more variety are similar for larger- and smaller-volume gear production facilities alike. But for dedicated shops, total gear volume is high regardless of batch size. The shift from a single, specialized tool for every job, to increasingly standardized tooling systems capable of addressing a variety of gear machining, is a major change for the gear industry as a whole.

InvoMilling, for example, uses standard tools. This technology allows operators to machine the tooth gap and gear on a multitask/five-axis machine as customer needs change. One indexable tool with inserts can be used for a range of modules, which means that no dedicated tools need to be ordered.

Previously, specialized tooling had to be ordered 10 weeks before any production could start. The flanks, which provide the contact length between two mating gears, can be machined in any way the gear transmission designer chooses. The same can be said about the root of the gear, which provides the transmission's strength.

Productivity and quality in indexable gear tooling

In most cases, an indexable hobbing tool like the CoroMill 176 from Sandvik Coromant not only replaces HSS hobs, but also can be used as a roughing hob next to an existing solid HSS hob on the same arbor, when quality demands cannot be reached only by the indexable hob. The road to increased productivity is all about freeing up time on a shop's existing hobbing machines, and mini-

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mizing downtime. This is the main driver for gear manufacturers to begin incorporating indexable hobs in their shops.

Indexable hobbing systems like these can more than double tool life and reduce cutting time by more than 50 percent, depending on the situation, compared with traditional HSS hobs. But a multitude of factors need to be taken into account. For instance, for all of their potential in increasing productivity, current models of indexable hobs cannot outperform the ultra-precise tolerances that *new* HSS hobs are able to hold. After a traditional hob's first regrinding, however, most quality parameters that influence the quality of the gear wheel are in the same tolerance range for both the HSS and indexable hob. Indexable hobs don't require regrinding or recoating; instead, the inserts can be swapped out as necessary. What's more, the minuscule cutting deviations that can occur on a gear wheel as a result of changing from a worn insert to a new insert in an indexable hob are normally much less pronounced compared to the deviations that can occur between a worn HSS hob and its first regrinding.

Cost per part is a major consideration. Operators can produce more parts in the same machine, and postpone investment in new machine tools. Another factor is speed of delivery, as adding new inserts to an indexable hob is a lot less time-consuming than ordering and waiting for a specialty HSS hob or sending the hob away for regrinding, coating etc. And keeping extra hobs on hand to keep production going during regrinding is adding expensive inventory to an operator's tool selection.

However, indexable hobs serve a specific window of gear sizes, ranging from module 3 to 10. Typical components are large gear wheels for heavy vehicles, aerospace gears and industrial transmissions. For even larger gear operations, hobs like the CoroMill 177 cover module ranges 10 to 26. Insert grade, coating and geometry also must be considered with indexable hobbing solutions, as they factor directly into the tool quality.

Increased machine capacity and uptime aren't the only advantages of some indexable tools. With the CoroMill 176 hob specifically, operators are also able to capitalize on modular capabilities.

With this versatility, an operator is able to speed up tool changes, reduce downtime and increase quality – independent of the existing hobbing machine brand in the shop. (See Figures 1-2)

Tool setup time can be reduced thanks to the modular nature of a hob with a Coromant Capto toolholder and spindle interface. Setup time can drop to five minutes for a job that once took 30 minutes. The high accuracy of the Coromant Capto couplings automatically minimizes runout in the tool assembly. When using a modular solution, the operator no longer requires an arbor, spacer or hydraulic nut, reducing the number of connections to create a more rigid, faster-to-set-up tool assembly. This directly translates to improved gear wheel quality and process reliability. The improved stiffness of the CoroMill 176 modular

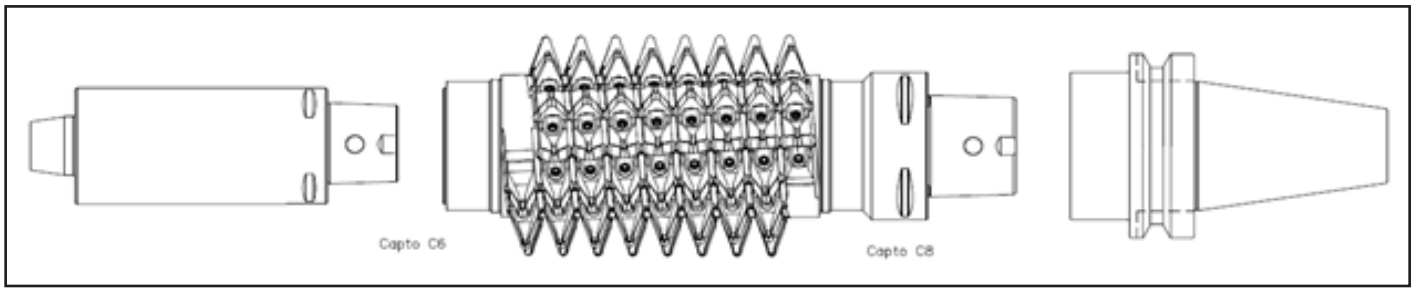

Figure 1 CM 176 Modular hob is equipped with Coromant Capto couplings. Only three parts are needed for tool assembly; Adapter to support side, CM 176 hob and adapter to spindle side.

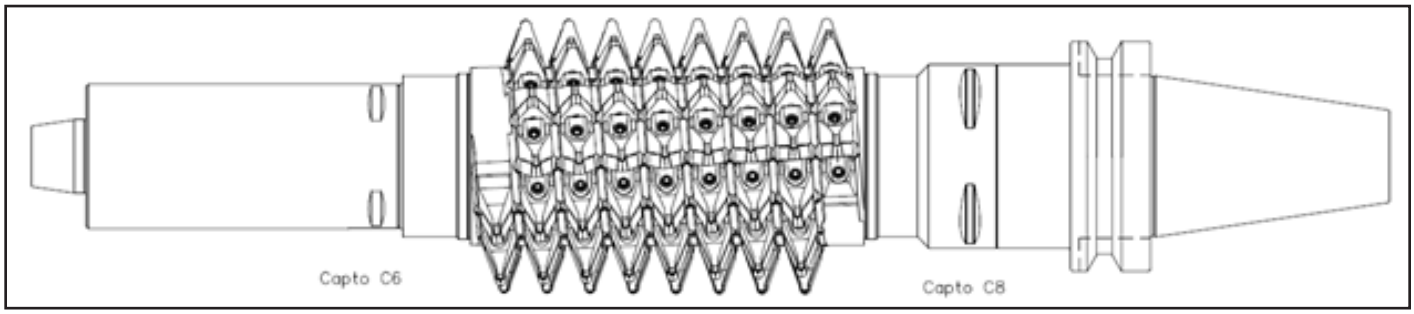

Figure 2 Stiffness and runout accuracy in the assembled tool are very good.

hob design makes the tool much more solid; neither bore nor arbor is required. Increased stiffness also reduces vibration, leading to better gear quality. It is a real problem-solver in cases where smaller-diameter hobs are needed.

Older machines still get the job done

Even with all of the movement towards gears on multitask machines, indexable hobbing tools offer plenty of benefits to traditional, dedicated hobbing machine operations. It's a common misconception today that productivity gains from the latest tooling technologies can only be realized with the latest in machine tools and equipment. In reality, operators can greatly benefit from the latest tooling even if you choose not to invest in new machine tools at the moment.

Older machines can indeed be limited in spindle speed and table feed compared to a state-of-the-art machine tool. But tests show that productivity improvements between 50 and 300 percent are still regularly achieved, even on older machines. Modular flexibility improves productivity via improved tool setup time and a higher-quality gear wheel, regardless of the spindle speed or table feed.

Partnerships breed innovation

Partnerships between tool makers like Sandvik Coromant and machine builders like DMG Mori and Klingelnberg/Höfler push gear tooling technology forward. New machine capabilities stretch the barriers of what tools are able to do, so tool manufacturers need to constantly evolve to keep pace. And to a certain extent, tooling technology pushes machine tool technology, as well. In a frequently changing landscape, constant collaboration helps tool maker and machine tool manufacturer evolve together, building in efficiencies and streamlining in ways that wouldn't be possible without cooperation. The feedback loop between machine tool builder partners is crucial to Sandvik Coromant's service to the end user, making it key from a quality perspective to get these tools into various machines and get feedback on the machine tool side.

In addition to using the tools themselves, both Höfler and DMG Mori use a Coromant Capto interface in the machine spindle. Coromant Capto, together with the modular technology, improves quality and setup time considerably. And because these partners use Coromant Capto, introducing the CoroMill 176 indexable hobbing system is simple – just another example of how co-evolution of tooling companies with machine tool manufacturers results in simplified experience for the end user.

The machine tool manufactures that Sandvik Coromant partners with are also skilled in software development for their machines. Since the machine, clamping and tool each has an effect on the quality of the gear wheel, it is really important that they all be designed to work in unison.

The InvoMilling technique is a recent example of this type of collaboration. Sandvik Coromant developed the software, but has been working closely with machine tool builders to implement it correctly, optimize it for a machine or group of machines, and ultimately benefit the end users' experience.

Gear material and design development

Corporate social responsibility and sustainability are setting new standards for the future of gear machining. Increased pressure in combustion engines improves combustion and reduces emissions. Power density on existing transmissions is increasing. This translates into new gear materials and new steels – clean steels.

With indexable tooling, it's easy to dry-machine gear profiles. Keeping coolant and oil out of the chips allows operators to eliminate any additional or exter-

nal process that might be required to sanitize chips or remove oil.

This not only provides clean chips with a higher scrap price and less work for operators, it saves time and money. Coolant oil is expensive, and removing the oil mist in production makes life in the shop cleaner, healthier and more comfortable. Plus, limiting the use of these types of oils is a positive for the global environment.

Also, current gear development leans toward increased contact lengths on the flanks of the gear tooth. This means asymmetrical gears are more and more common. Because of the basic rack profile, these gears are more difficult to produce with conventional HSS gear tools and conventional gear machines.

What's next

More indexable tooling will be introduced to the market in coming years. One area of interest includes bevel gears, which are mainly made with conventional machining today. Power skiving indexable tooling, together with monoblock finishing tools, also offers a lot of potential over conventional machining. Through one setup, an operator can do all necessary machining. So by eliminating runout and center deviations that result from multiple setups, average gear component quality can be maximized. On top of that, an operator can considerably reduce the cycle time, in most cases by more than 50 percent.

As we look to the future, many different factors and trends are working in unison to bring indexable tooling to the forefront in gear manufacturing. New machine tool technology and capability, better performing inserts and insert geometries, environmental and sustainability requirements on what OEMs are producing, special requirements of new, hard materials used in gears, and the increasing pressure to turn around high precision gears more quickly and for less – each has had a hand in the ongoing technology shift.

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Machine Marks on Gear Flanks: Their Cause and Prevention

QUESTION

What causes shaving cutter marks on gear flanks and can they be prevented?

Email your question — along with your name, job title and company name (if you wish to remain anonymous, no problem) to: *jmcguinn@geartechnology.com*; or submit your question by visiting *geartechnology.com*.

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Expert answer provided by Jim Caldwell, Star SU LLC

Ideally, the shaved gear tooth surface should be smooth with very light, uniform feed marks and have a soft, non-glossy appearance. It may not always be possible to attain the ideal condition due primarily to factors such as the gear tooth dimensions (module, face width, number of teeth), the method of shaving (conventional or plunge), having a suitable cutter design, or the machine condition and cycle parameters. The good news is that undesirable shaving marks can be prevented — or at least minimized. There are several common types of shaving marks, each stemming from different causes. Below we will define (describe) them and identify potential remedies.

Glossy stripes near one face. With conventional shaving it is common to see a series of stripes on the side of the gear where the shaving cycle stops. These stripes will be glossy in appearance and their width will coincide precisely with the width of the serrations on the cutter. These stripes or pressure marks are the result of tool pressure remaining at the end of the cycle. Often these pressure stripes are merely cosmetic and no action is necessary. However, if too much tool pressure remains at the end of the cycle, you will be able to see and feel undesirable ridges accompanying these pressure stripes.

Preventive measures:

- Add an extra pass to the machine cycle.
- If the machine allows, try using a negative infeed on the last pass in order to reduce pressure.
- Shave with a slight diagonal angle (10° or 12°).
- Consider reducing the amount of shaving stock.
- Consider going to another method of shaving, such as underpass or plunge.

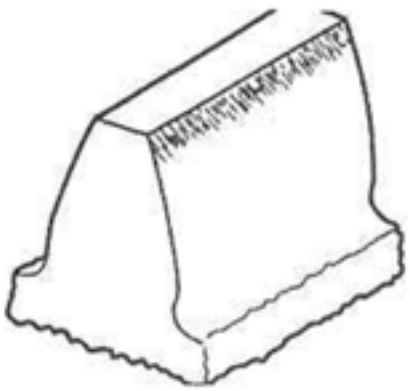

Figure 1 Example of tip gouging.

Consistent, heavy feed marks. The gear has somewhat consistent, heavy feed marks across the entire face width — from top to bottom — marks that sometimes are even visible in a lead trace. If it is a new application, it could be a problem with the machine cycle. The cutting time may be insufficient to remove the stock, or the feed direction may be wrong. It could also mean that the tool being used is not compatible with the part; check the manual or with the vendor.

If it's a plunge shaving application, it could be that the tool has become dull, which will cause the waviness you are seeing across the face of the part.

Tearing or gouging near the tooth tip. A very rough tearing or gouging occurs across the entire face width, but only in the upper portion of the tooth (Fig. 1). The dedendum of the tooth will have a completely normal, shaved appearance. This condition tends to occur in conventionally shaved pump gears or in other applications having a low number of teeth, high pressure angle, or larger modules. It occurs when the involute sliding velocity is too high relative to the helical sliding with the cutter. The following actions have proven effective to ameliorate this condition:

- Slow down the rotation speed of the cutter to a minimum.
- Make sure the coolant is not degraded; change as needed.
- Certain cutter profile modifications have proven helpful; check with your vendor.
- Consider having the cutter redesigned. It may be possible to change the helix angle and serration dimensions of the cutter design to rid yourself of this condition.

Random marks or irregular scratches. If the marks do not occur in a consistent fashion across the face width or around the circumference of the gear, here are a few of the more likely causes:

- Damage to some of the cutter teeth.
- Gears being shaved without having been properly deburred, resulting in heavy burrs from hobbing or shaping breaking off during shaving and getting lodged in the mesh or between the cutter lands, causing heavy random marks on the part.
- Too many shaving chips circulating in the coolant, causing a scratchy finish; chip separator not working properly or dirty machines are the likely causes.
- Insufficient coolant flow or misdirected coolant nozzle, allowing chips to collect on the part, rather than being carried off by the coolant flow.

Jim Caldwell is the Gear Cutting Tool Product Manager for Star SU LLC.

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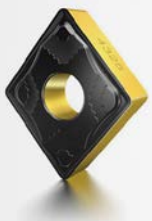

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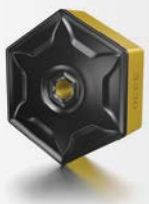

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Load Distribution Analysis of Spline Joints

J. Hong, D. Talbot, A. Kahraman

A finite elements-based contact model is developed to predict load distribution along the spline joint interfaces; effects of spline misalignment are investigated along with intentional lead crowning of the contacting surfaces. The effects of manufacturing tooth indexing error on spline load distributions are demonstrated by using the proposed model.

Introduction

Splines are used commonly in power transmission systems for coupling two rotating components such as a shaft and its gear. They provide higher load carrying capacity over keyed shafts, and hence, represent better durability performance. In addition, they can tolerate a certain amount of angular misalignment and relative sliding between their internal and external components. The most common failure modes observed in spline joints include surface wear, fretting corrosion fatigue, and tooth breakage (Refs. 1, 2). In spite of such experimental studies, little is known about spline failure mechanisms since accurate load distribution prediction models are not available, especially for the cases where the loading is three-dimensional as in the case of helical or cross-axis gear splines (Refs. 3–10). These models can predict load distribution of splines, but they are limited to simple loading conditions. Other complicating effects such as spline surface modifications and spline tooth manufacturing errors such as indexing or spacing errors are also not considered in these models.)

This paper aims at developing a finite elements (FE)-based computational model of gear-shaft splines. The objectives of this paper are as follows:

- Develop a computational model of a gear-shaft spline interface under combined torsion, radial forces and tilting moments.
- Establish nominal load distribution conditions under pure torsion, spur gear loading (torsion and radial force) and helical gear (torsion, radial force and tilting moment) loading conditions.
- Quantify the change to baseline load distributions caused by misalignments, spline tooth (lead and profile) modifications and spline helix angle.
- Investigate the influence of indexing errors on baseline spline load distributions.

Computational Model

A commercial FE-based contact mechanics model *Helical-3D* (Advanced Numerical Solutions, Inc.) designed specifically for loaded contact analysis of helical gears is modified here to analyze spline joints. The core contact solver of this software (*CALYX*) is based on a formulation by Vijayakar (Ref. 11), which combines the finite element method and surface integral method to represent the contact bodies, and calculates the load distribution and rigid body displacements by using the linear programming method. Details of the application of *Helical-3D* to analysis can be found in Reference 12. A brief description will be provided here for completeness purposes.

The first phase of contact analysis is to determine the contact zone. *CALYX* estimates the contact zone by using Hertz's model after locating a set of primary contact points on the contacting surfaces and determining relative principal curvatures and directions. For this, two contacting surfaces, Σ_1 and Σ_2, are defined in terms of their curvilinear parameters s and t as $\mathbf{r}_1(s_1,t_1)$ and $\mathbf{r}_2(s_2,t_2)$. The primary contact points are determined and located when $\mathbf{r}_1$ and $\mathbf{r}_2$ become the closest to each other (Ref. 11). For this, the surface $\mathbf{r}_1(s_1,t_1)$ is discretized into a grid of points $\mathbf{r}_{1ij}(s_{1i},t_{1j})$. For each of these grid points, a primary contact point $\mathbf{r}_{2ij}(s_{2i},t_{2j})$ is determined such that $||\mathbf{r}_1(s_1,t_1) - \mathbf{r}_2(s_2,t_2)||$ is minimum. The principal curvatures and principal directions of two surfaces at the common contact point **p** are determined in terms of the coefficients of the first and second fundamental form of the surfaces. The second phase is to compute the compliance matrix and set up the contact equation to be solved by a modified simplex method. Hertzian theory is used to predict the size of the contact zone and consequently a grid of points in the contact zone is laid out on both surfaces. Then a surface integral method near the contact zone and a finite element method away from the contact zone are combined to predict cross compliance terms between the set of grid points.

The displacement $u(\mathbf{r}_{ij};\ \mathbf{r})$ at a field point **r** caused by a unit normal force at surface grid point $\mathbf{r}_{ij}$ is given as (Ref. 11):

$$u(r_{ij};r) = (u^{(si)}(r_{ij};r) - u^{(si)}(r_{ij};q)) + u^{(fe)}(r_{ij}r;q) \quad (1)$$

Here **q** is some location inside the body on a matching surface, sufficiently far beneath the tooth surface. The first two terms in this equation denote the relative deflection of **r** with respect to **q**, which is evaluated using the surface integral formulae. The third term denotes the displacement of **q**, which is computed using finite element method. The point **q** is chosen such that elastic half-space assumption will be valid and the finite element prediction will not be significantly affected by local stresses on the surface. The surface integral and finite element solutions are combined along this matching surface interface, as

This work is the sole property of the Gear and Power Transmission Research Laboratory Department of Mechanical and Aerospace Engineering, The Ohio State University, 201 W. 19th Avenue, Columbus, OH 43210, USA

described in detail (Ref. 11). The combination of surface integral formulae and finite element method described above provides an accurate and numerically efficient way of obtaining the compliance matrix for the contacting bodies.

Finite Element Model of an Example Spline and Analysis Results

Figure 1 shows the contact model for an example clearance-fit spline joint that is designed according to ANSI Standard B92.1-1996; Table 1 lists its main parameters. The system model consists of a shaft, an external spline and an internal spline. Over the potential contact area, the model shown in Figure 1 uses a contact grid with M number of elements in the face width direction and N number of elements along the profile direction. Within each contact element there are two contact grids in both face width and profile direction. Width of the contact cells is defined such that $2N$ grids in the profile direction can capture all the contact on the tooth. With this, a spline joint with Z teeth would have a total of $Z \times 2M \times 2N$ grid cells defining the contacts along the drive flanks of the teeth. The model allows intentional deviations from the involute spline tooth surfaces such as profile and lead modifications as in spur and helical gears to prevent any undesirable edge contact conditions. In addition, a similar contact grid with the same resolution can be defined along the other Z coast tooth surfaces to capture any back side contacts.

This example spline interface is loaded in two different ways. In the first case, a moment (torsion) T is applied to the end of the shaft (Figure 2a), while the cylindrical disk having the internal spline is constrained along its perimeter to represent a purely torsional loading of the spline with no radial force and tilting moment. The second loading case (Figure 2b) represents a spline supporting a gear where T, applied torque, is balanced by (a) the mesh force $F_n = 2T/(d_p \cos\alpha_n)$ where α_n and d_p are the normal pressure angle and pitch circle diameter of the gear, respectively, F_n that is acting on the normal plane of the gear along the line of action has a tangent component $F_t = 2T/d_p$, a radial component $F_r = F_t \tan\alpha_n / \cos\beta$ and an axial component $F_a = F_t \tan\beta$, where α_n, β and d_p are the normal pressure angle, helix angle and pitch circle diameter of the gear, respectively. This results in a torsion T about the rotational axis z of the shaft, radial forces $F_x = F_t$, $F_y = -F_r$, and tilting moment $M_x = T \tan\beta$ about the x axis in Figure 2b. In this case, the moment M_x was applied in addition to F_x and F_y to the gear tooth and T applied to the input end of the shaft.

Influence of loading conditions. In case of pure torsion loading (Figure 2), identical load distributions on each spline tooth are predicted with the load varying in an exponential manner in the face width direction. Figure 3a shows various views of the shaft spline to demonstrate the loads carried by individual contact grid cells on each tooth. As this type of a representation of the tooth load distributions is not practical, the contact surface of each tooth of the shaft spline was mapped to a rectangular window (Figure 3b) with the load distribution of the tooth surface displayed on this window. Using this method, load distributions on all of the teeth can be viewed simultaneously and conveniently (Figure 4) for this torsional loading case. Figure 4 shows the load distributions on the spline teeth under pure torsion at torque levels of $T = 2{,}000$ and $4{,}000$ Nm. For instance, at $T = 4{,}000$ Nm, maximum contact stress is predicted to be about 123 MPa that occurs at the edge on the input side where the torque is applied to the shaft. Contact stresses reduce significantly with the axial distance from this edge. Non-uniform load distributions become clearer with increased T while the location of maximum stress remains at the input-side edge. It is noted that as the torque increases, the contact area extends towards the edge of the spline teeth along the profile direction and the contact stress increases simultaneously — with the load distribution pattern remaining the same.

Table 1 Example spline design used in this study

	External spline	Internal spline
Number of teeth	25	
Spline Module [mm]	3.175	
Pressure angle	30°	
Base diameter [mm]	68.732	
Major diameter [mm]	82.550	85.725
Form diameter [mm]	76.022	82.728
Minor diameter [mm]	73.025	76.200
Circular space width [mm]	-	5.055
Circular tooth thickness [mm]	4.981	-
Inner rim diameter [mm]	58	95
Outer rim diameter [mm]	64	150
Inner shaft diameter [mm]	45	-
Outer shaft diameter [mm]	58	-
Profile crown [µm]	5	0.0

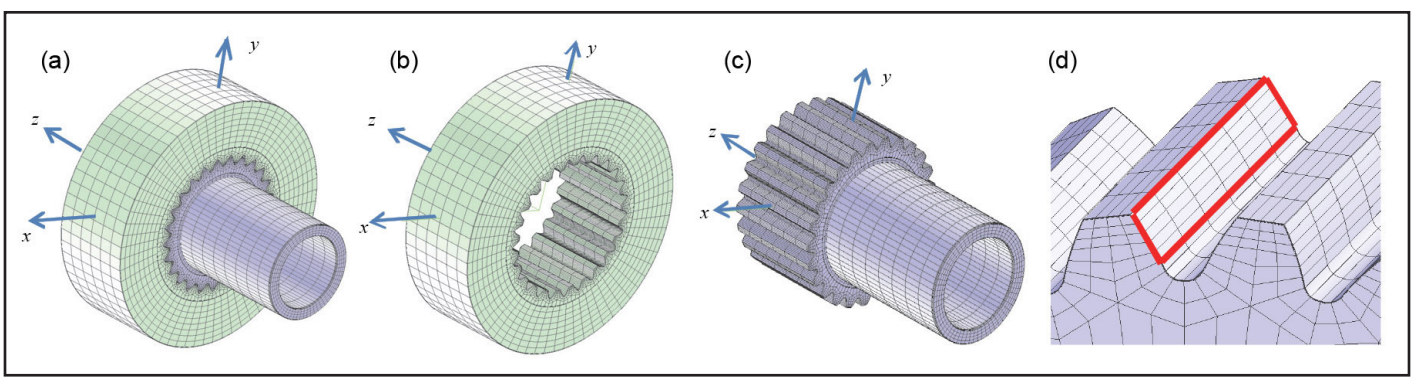

Figure 1 Spline finite element model; (a) spline interface, (b) internal spline, (c) external spline and shaft, (d) potential contact area and contact elements.

Next, consider a helical gear loading case. Relevant helical gear tooth parameters are the normal pressure angle of $\alpha_n = 20°$, and the pitch circle diameter of $d_p = 160$ mm. Helix angle β of the gear is varied from 0° (spur gear loading) to 20° at a torque value of 4,000 Nm to predict the load distributions shown (Figure 5). For the spur gear loading (Figure 5a), load sharing along the face width direction is still biased towards the side where torque is applied. Load distributions are no longer identical for all the spline teeth since the loading is no longer axisymmetric. With tooth #1 centered below (and closest to) the gear mesh, teeth 1-8 and 21-25 are shown to experience larger loads while teeth #9-20 bear less load. For instance, the resultant maximum contact stresses at $T = 4{,}000$ Nm are 129, 108, 101 and 167 MPa for teeth #5, #10, #15 and #24, respectively, as a direct consequence of this unequal loading. In comparison to Figure 5a, helical gear loading maintains the same qualitative load sharing characteristics of spline teeth. Figures 5b and 5c show that teeth #1-8 and #21-25 carry larger load, while teeth #9-20 are loaded less. This can be explained by the fact that the spline interface transmitted the same radial load in spur gear loading and helical gear loading conditions. However, a remarkable difference is observed that axial load distribution on teeth #19-25 and #1-2 is biased to the opposite side to which torque is applied. This is due to the additional tilting moment M_x transmitted over the spline interface, which causes the load on some teeth to be biased to the other side to balance it. It is observed that as β increases, the load on each tooth gets more concentrated on the side where the load is biased. For instance, loads on teeth #3-10 are concentrated to the side where the torque is applied, while loads on teeth #20-25 are concentrated to the opposite side. The maximum contact stresses are 182 and 334 MPa for $\beta = 10°$ and 20°, respectively, with the corresponding tilting moments of $M_x = 705$ and 1,456 Nm. The load concentration increases significantly because of the larger resultant tilting moment on the spline when the β increases.

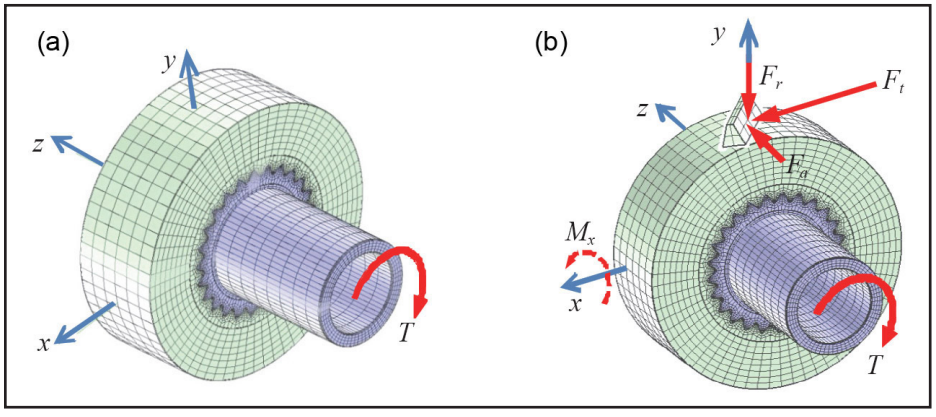

Figure 2 A spline model with different loading conditions; (a) pure torsion loading and (b) gear loading.

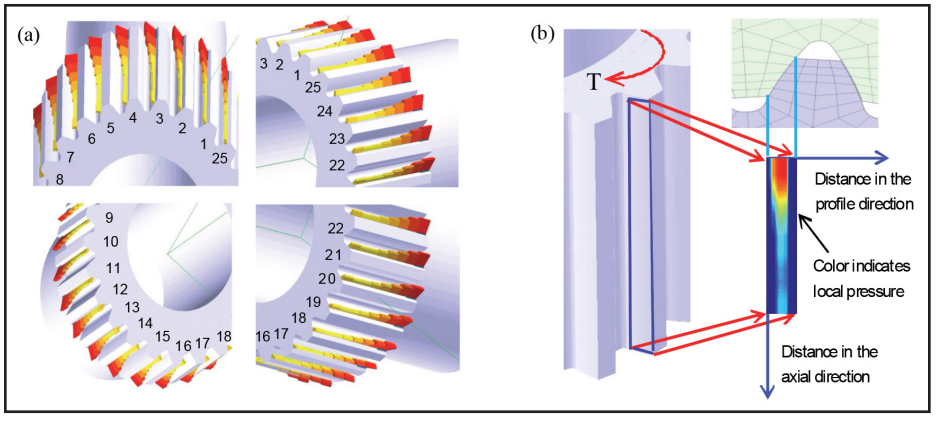

Figure 3 (a) Load distribution of a spline under pure torsion loading, and (b) mapping of the load distribution on a tooth to a rectangular window.

Effect of Design Variations

Misalignments and lead crown modifications. Misalignment of spline couplings has been recognized as harmful to splines because it causes significant load concentration on spline teeth, and accelerates wear and fretting fatigue of splines (Refs. 2, 13). Significant load concentration observed in both misaligned splines (Figure 6a, a misalignment of $\varphi = 0.12°$) and splines experiencing helical gear loading (Figure 5b-c) can be potentially remedied by applying a lead crown modification along the face width direction. Figure 6 shows load distributions of a spline having a misalignment of $\varphi = 0.12°$ along with different lead crown modifi-

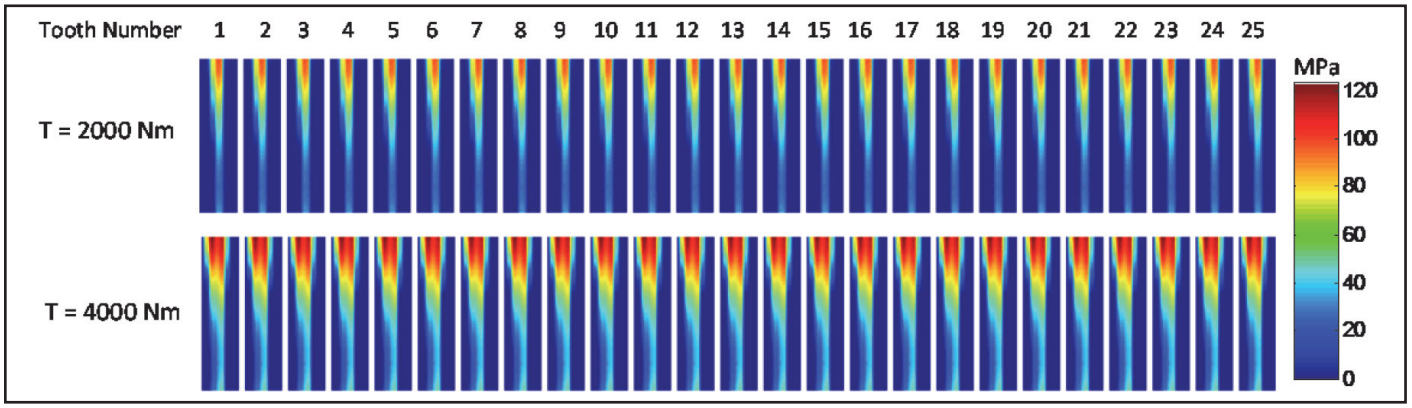

Figure 4 Load distributions of the example spline under pure torsion loading at different torque levels.

cation magnitudes of $\delta = 0$ and 40 μm at $T = 4{,}000$ Nm under pure torsion loading. It is observed that the crown modification moves the load from the edge to the center of the spline, in the process reducing the maximum contact stresses significantly. Figure 7 shows load distributions on the splines with different lead crown modification magnitudes of $\delta = 0$ and 40 μm for helical gear loading with $\beta = 20°$ at $T = 4{,}000$ Nm. Unlike in the misaligned spline case, lead crown modification under a helical gear loading condition neither reduces load concentration, nor moves the tooth load from the edge to the center. This occurs because the moment acting on the spline remains a constant for a given torque in helical gear loading despite the lead crown modification. The biased load concentration exists no matter how much lead crown modification is adopted.

***Helical splines*:** Figure 8 shows the load distributions of helical splines having different spline helix angles of $\gamma = -10°$, 0° and 10° under helical gear loading condition with a helical gear ($\beta = 20°$) at $T = 4{,}000$ Nm . A negative spline helix angle represents a left-handed helix and a positive helix angle represents a right-handed helix. It is observed that a right-hand spline helix helps reduce load concentration, and a left-hand spline helix condenses the load concentration. For instance, the maximum contact stresses are 334 MPa for a spur spline ($\gamma = 0°$) under helical gear loading with a right-hand helical gear. The maximum contact stress increases dramatically to 754 MPa for left-hand spline helix angles of $\gamma = -10°$. On the other hand, the maximum contact stresses drop significantly to 211 MPa for right-handed splines with helix angles $\gamma = 10°$. The maximum contact stress is reduced by more than 35% and more teeth are observed to carry load (Figure 8c). The dominant factor is that the spline helix introduces an axial load that can either increase the tilting moment or counterbalance the tilting moment, depending on its direction. For a spline loaded by a right-handed gear, a right-hand spline helix would induce an axial load to counterbalance the tilting moment thus reducing the load concentration. On the other hand, a left-hand spline helix would induce an axial load, which would increase the tilting

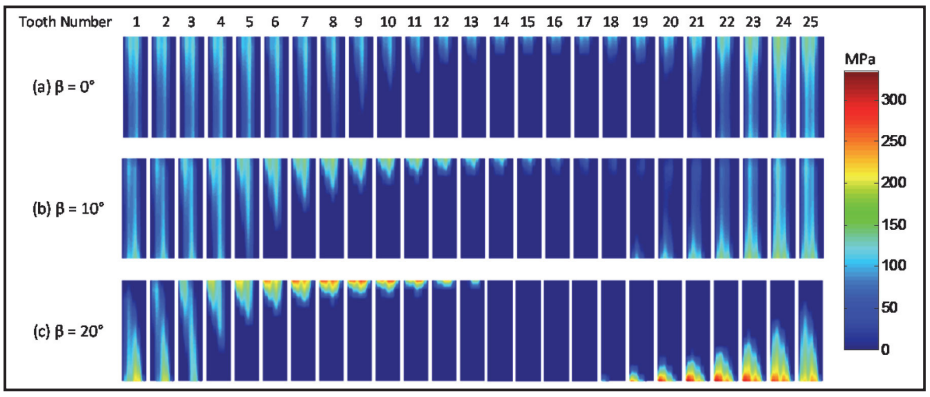

Figure 5 Load distributions of a spline under helical gear loading with different helix angles, β, at T = 4,000 Nm.

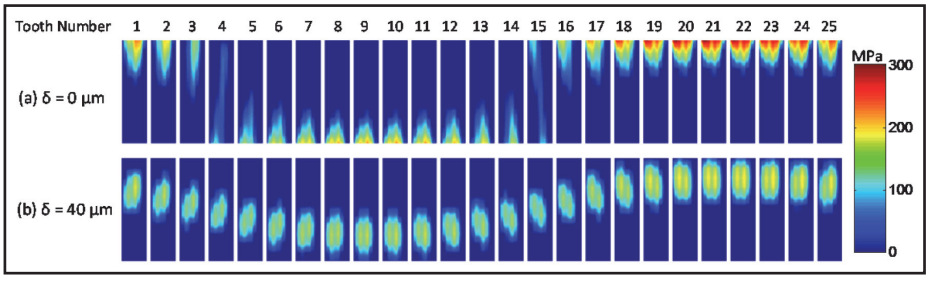

Figure 6 Load distributions of a misaligned spline having different lead crown modification magnitudes, δ, at T = 4,000 Nm and φ = 0.12°.

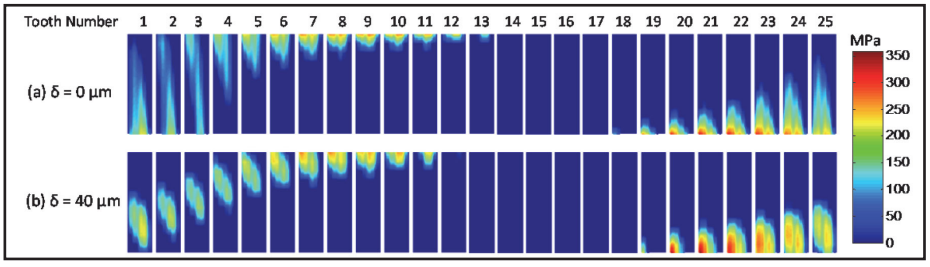

Figure 7 Load distributions of a spline under helical gear loading having different lead crown modification magnitudes, δ, at T = 4,000 Nm, and β = 20°.

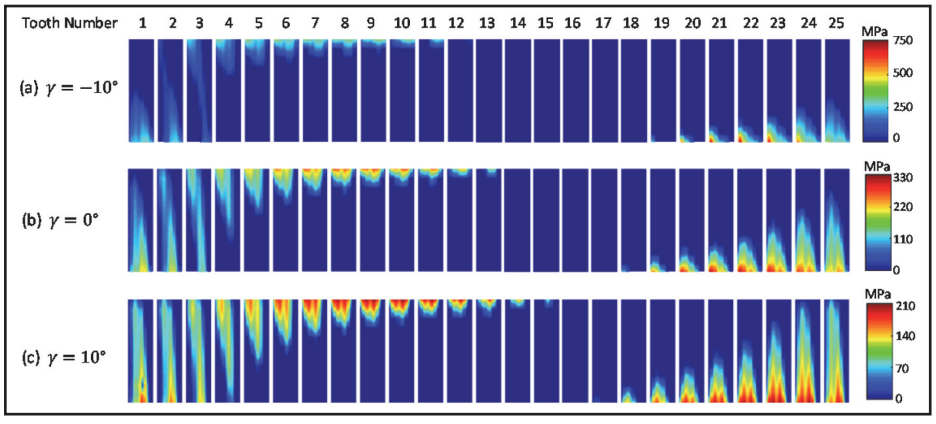

Figure 8 Load distributions of helical splines having different spline helix angles, γ, under helical gear loading with a gear helix angle, β = 20°, at *T* = 4,000 Nm.

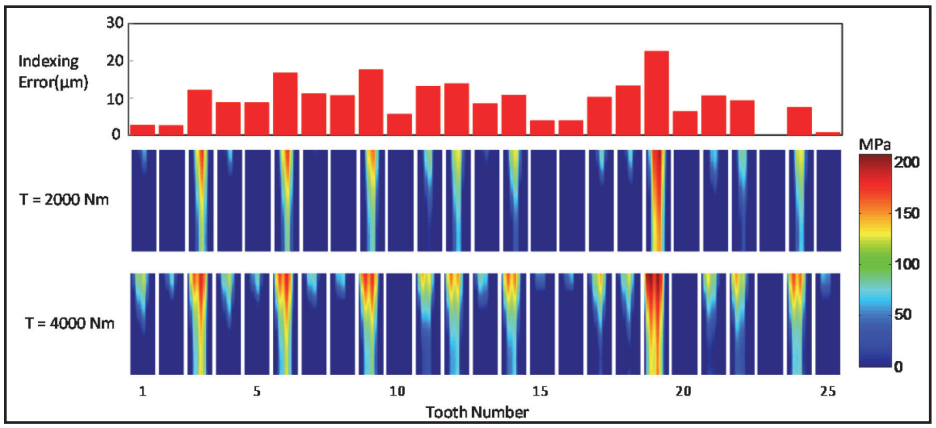

Figure 9 Load distributions of a spline having random tooth indexing errors at different torque levels.

moment thus resulting in larger load concentration on the spline teeth. The result implies that in helical gear loading conditions, selecting a helical spline with the same helix direction as that of the helical gear could reduce the load concentration, and improve load distribution.

Effect of Spline Tooth Indexing Errors

Investigations of spline load distributions discussed above all assumed perfect tooth geometry, ignoring the effect of tooth indexing errors. However, it occurs frequently that some spline teeth exhibit heavier damage than others, which might be caused by spline tooth indexing errors (Refs. 12-14). In order to demonstrate the effect of indexing errors on spline load distributions, a spline joint with a random tooth indexing error distribution is considered next. Figure 9 shows a random tooth indexing error sequence considered together with the corresponding spline load distribution at $T = 2{,}000$ and 4,000 Nm under pure torsion condition. Load concentrations are observed on spline teeth having larger indexing error, such as spline tooth #6, #9, #12 and #19. Teeth with larger indexing error have smaller clearance, and they will engage first. Teeth with smaller indexing error have larger clearance and they will gradually come into contact when the torque increases to a certain level. Figure 9 emphasizes that the load concentration resulting from spline tooth indexing error is significant and must be accounted for in the design of a spline at a certain quality level.

Summary and Conclusions

A finite element-based computational model of a gear spline-shaft interface under combined torsional load, radial load and tilting moment was proposed. Load distributions of the baseline system of the spline coupling under pure torsion, spur gear loading and helical gear loading were characterized. Pure torsion loading results showed identical load distributions on all spline teeth, with each tooth exhibiting exponentially decreasing load in axial direction while helical gear loading led to cyclic load concentration oscillating across the face width of the spline teeth. The effectiveness of lead crown in improving load distributions of misaligned splines was demonstrated. Selecting a helical spline with the same helix direction as that of the helical gear loading the spline was shown to reduce the load concentration and improve load distribution of splines undergoing helical gear loading. Finally, effects of indexing errors of spline teeth were investigated for the pure torsion loading case to show significant unequal load sharing at spline teeth due to indexing errors.

Acknowledgement. *The authors thank Dr. Sandeep Vijayakar of Advanced Numerical Solutions, Inc. for making* Helical-3D *available.*

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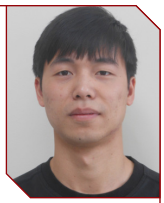

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Application and Improvement of Face Load Factor Determination Based on AGMA 927

Accurate and Fast Algorithm for Load Distribution Calculation, for Gear Pair and Planetary Systems, Including Duty Cycle Analysis

Dr. Ulrich Kissling

The face load factor $K_{H\beta}$ is one of the most important items for a gear strength calculation. Current standards propose formulae for $K_{H\beta}$, but they are not always appropriate. AGMA 927 proposes a simpler and quicker algorithm that doesn't require a contact analysis calculation. This paper explains how this algorithm can be applied for gear rating procedures.

Introduction

The face load factor $K_{H\beta}$, which in rating equations represents the load distribution over the common face width in meshing gears, is one of the most important items for a gear strength calculation. In the international standard for cylindrical gear rating, ISO 6336-1 (Ref. 1), using method C, some formulas are proposed to get a value for this factor. But as the formulas are simplified, the result is often not very realistic. Also AGMA 2001 (or AGMA 2101) (Ref. 2) proposes a formula for $K_{H\beta}$, different from ISO 6336, but again not always appropriate. Therefore a note in AGMA stipulates, that "It may be desirable to use an analytical approach to determine the load distribution factor."

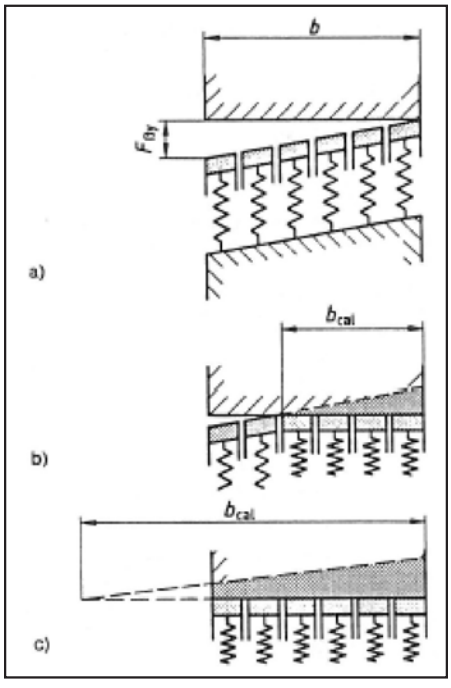

Figure 1 Display of the gap and the corresponding load distribution following ISO 6336-1 (Ref. 1).

In the last edition of ISO 6336 (2006), a new annex E was added: "Analytical determination of load distribution." This annex is entirely based on AGMA 927-A01 (Ref. 3). It is a well-documented procedure to get a direct and precise number for the face load factor.

Today an increasing number of gear designers are using tooth contact analysis (TCA) methods (Ref. 4) to get precise information about the load distribution on the full gear flank. Contact analysis is very time consuming and does not permit to get a value for $K_{H\beta}$, as defined by the ISO or AGMA standard. A contact analysis result combines different factors of ISO 6336 as $K_{H\beta}$, $K_{H\alpha}$, Z_ε, Z_β, Z_B, Z_D and buttressing effects, etc.; thus to extract $K_{H\beta}$ from a TCA is not possible.

The use of the algorithm, as proposed by AGMA 927, is a good solution to get proper values for $K_{H\beta}$; it is simpler and therefore much quicker than a contact analysis calculation. This paper explains how this algorithm can be applied for classic gear pair rating procedure, for ratings with complex duty cycles and even for planetary systems with interdependent meshings between sun, all planets and ring.

How it Began: A Problem during the Drilling of the World's Longest Tunnel in the Swiss Alps

Since 1999 the world's longest tunnel (57 km or 36 miles) has been under construction in the Swiss Alps. In 2002 a problem was found in one of the tunnel boring machines during an inspection. The main drive of the machine consists of a large ring gear, driven by 8-12 pinions. The outer ring of some of the bearings on the pinion shaft rotated in the housing and therefore the bearing seat was worn. Underground in the tunnel the boring machines were repaired as well as possible; a final check showed that the coaxiality had a deviation up to 0.2 mm (0.008 in). We were requested to propose the best possible flank line modification to compensate the coaxiality error. For logistical reasons all the pinions had to be replaced; all pinions should get the same modification. Therefore our job was to propose a modification that would best compensate for possible coaxiality error between −0.2 and +0.2 mm, and to prove that with these pinions, the remaining 1,500 operation hours until the tunnel break-through could be performed without failure.

This engineering problem contained some new, interesting aspects. In the shaft calculation of *KISSsoft* (Ref. 5) we had for a long time a feature to calculate the gap between the face of the gear and a stiff wall. This was a helpful feature to find easily the optimum flank line modification. But the given problem needed some improvement of the software, because for the lifetime calculation according ISO 6336 the determination of the face load factor $K_{H\beta}$ was needed; and therefore the load distribution over the

face width had to be calculated considering the stiffness of the mating gear.

Determination of load distribution over face width. The cause for the uneven load distribution over the face width is flank line deviations in the contact plane of two gears. Deviations are caused mainly by elastic deformations of the shaft, stiffness and clearance of bearings and housing, manufacturing tolerances and thermal deformations.

The determination of the load distribution is – as documented in the gear theory – performed in two steps. At first the gap in the tooth contact is calculated. Then, using the tooth mesh stiffness $c_{\gamma\beta}$ (Ref. 1), the line load distribution is determined. This approach is well documented in ISO 6336-1. The standard simplifies the real situation through assumption of a linear load distribution (Figure 1).

Determination of the gap in the tooth contact. In the MAAG book (Ref. 6) the deduction of the gap through superposition of bending and torsion deformation is explained (Figure 2). As additional simplification it is assumed that the mating gear is infinitely stiff. Without flank line modification, as in the example shown (Figure 2), the load would be bigger on the torque input side. If a modification (Figure 2) is applied on the pinion flank line, then a uniform load distribution would result. This is true if the meshing gear is effectively very stiff — or if also on the mating gear a flank line modification is applied. In the formulas for $K_{H\beta}$ of ISO 6336-1 (Chapter 7) it is assumed that the pinion shaft is much more slender than the gear shaft — thus the deformation of the gear shaft is much

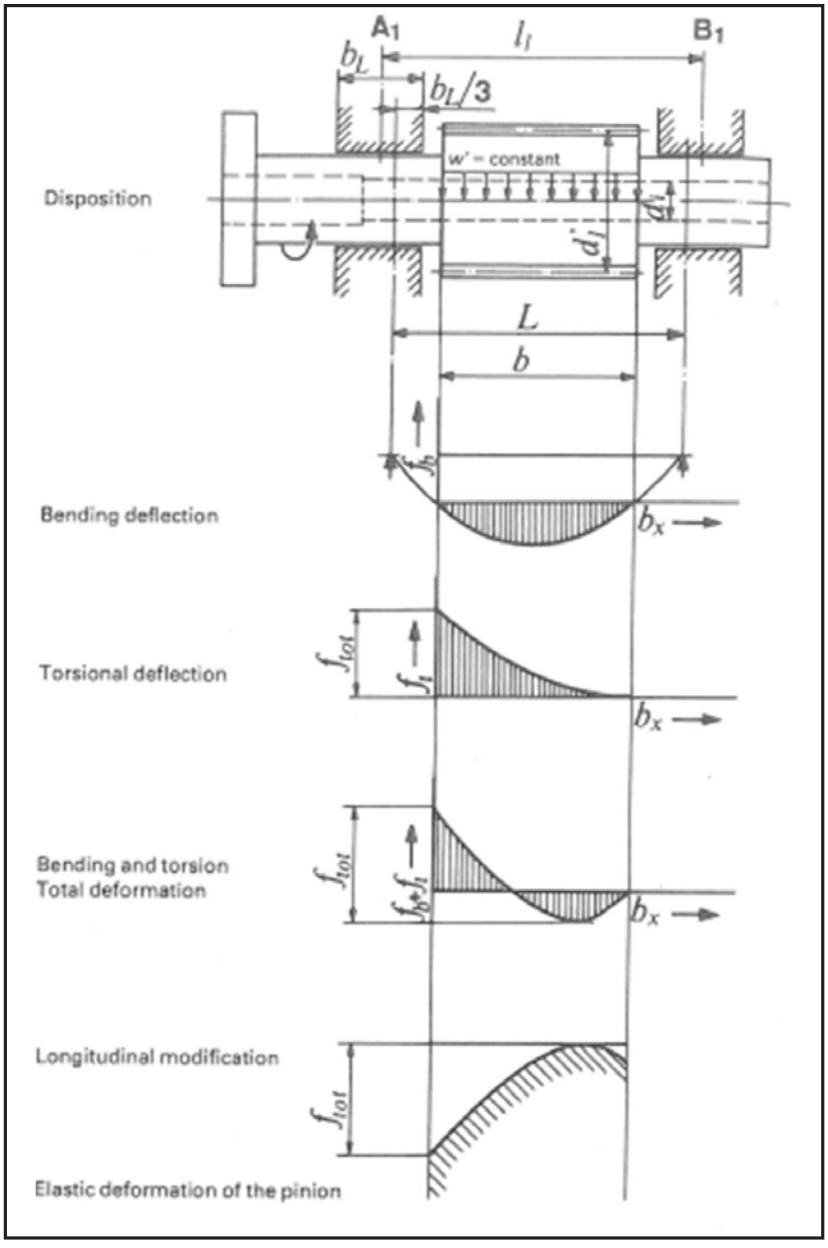

Figure 2 **Display of the determination of gap through the deformation components, and deduction of the corresponding flank line modification (Ref. 6).**

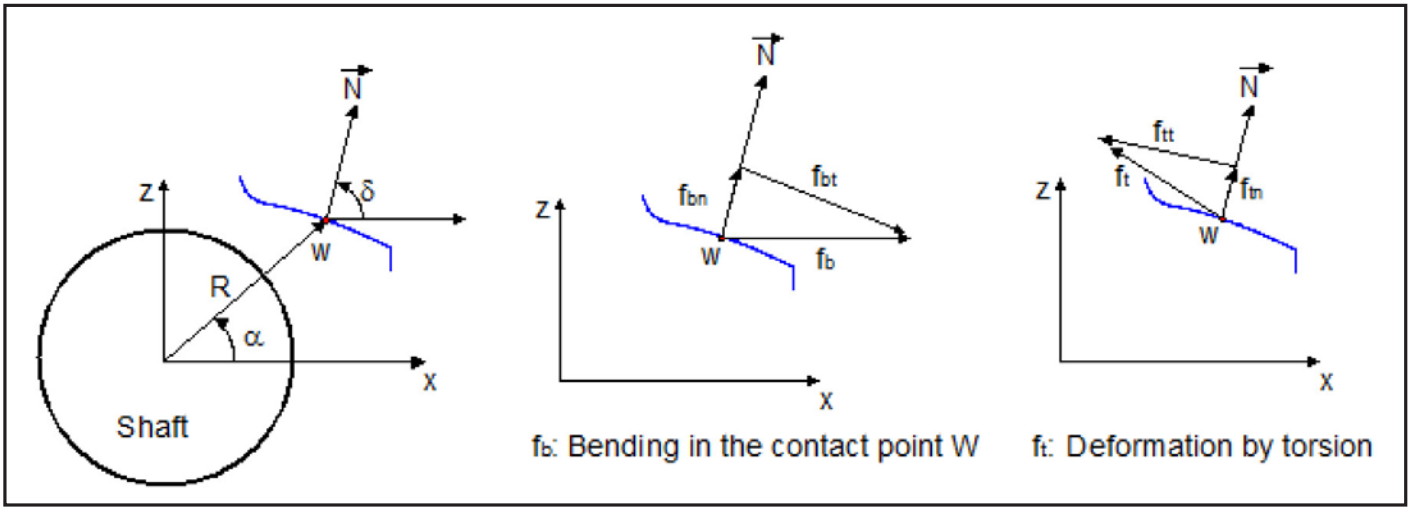

Figure 3 **Determination of the gap in the gear mesh (in a shaft section).**

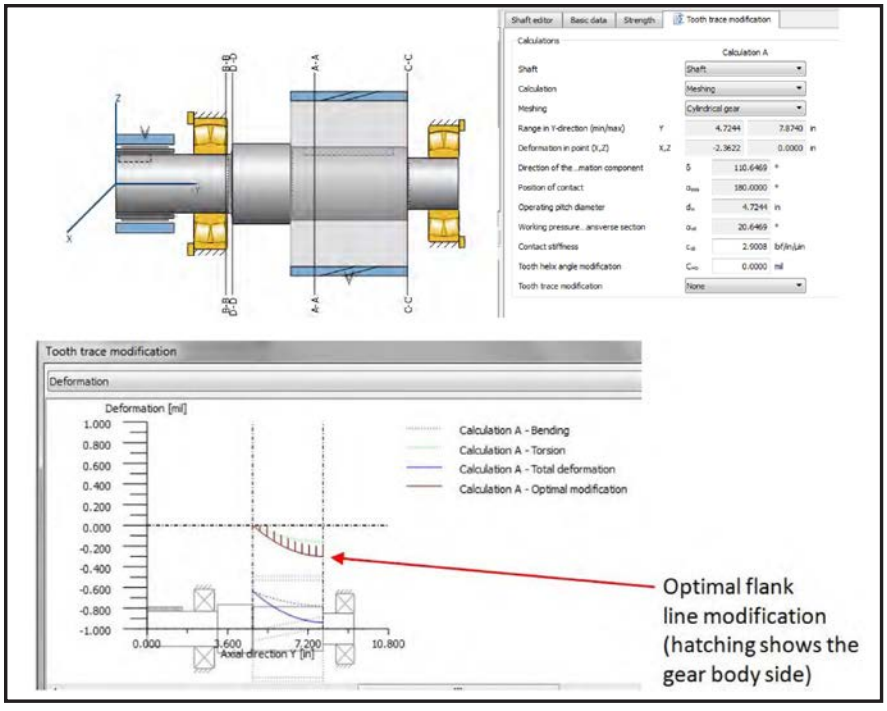

Figure 4 Display of the gap and proposition for an optimum flank line modification in *KISSsoft*.

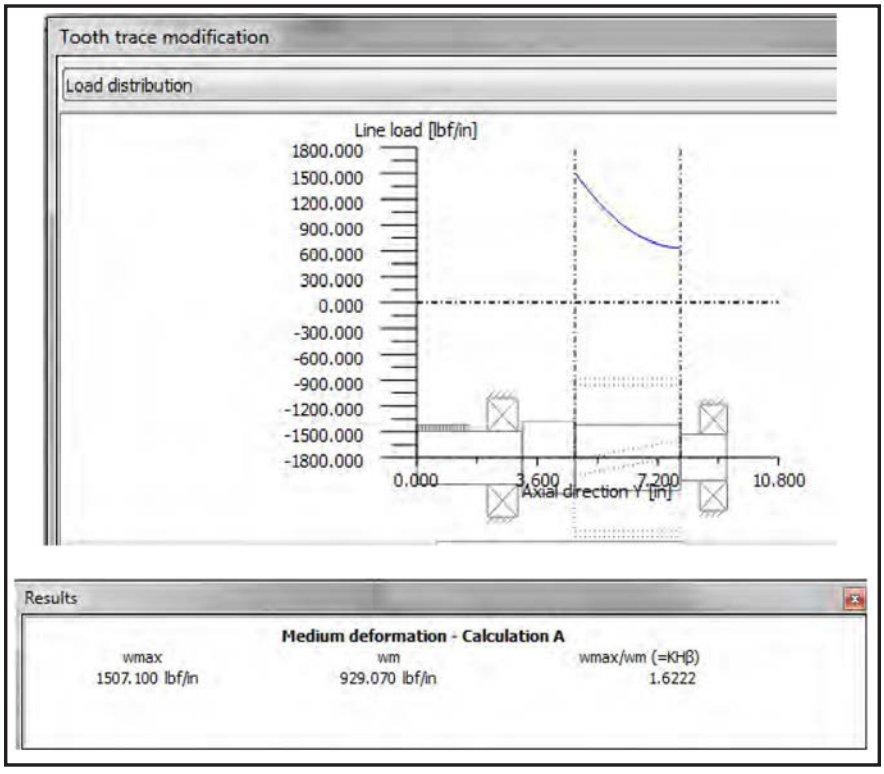

Figure 5 Load distribution and numbers for the maximum and mean line load and $K_{H\beta}$.

less and can be neglected. For gear pairs with a reduction $i > 2$, in many cases this is a realistic assumption.

In Figure 3 the wording "deviations in the contact plane" is explained. The deformation in every section of the shaft must be determined in the operating pitch point (W). A displacement of the point W due to bending or torsion parallel to the tooth flank will change a little bit the sliding velocity between the flanks, but otherwise has no effect at all. To get the necessary data for the determination of the gap, the components of deformation in point W (x, z coordinate) normal to the flank, f_{bn} and f_{bt}, are requested. With this data the gap between the meshing flanks is directly located.

Manufacturing errors, housing deformations and bearing stiffness result normally as linear deviation over the face width. These values can be considered through radial displacement of a bearing vs. another and through considering the bearing stiffness when calculating the shaft deflection. This procedure was implemented in our shaft calculation software (Ref. 5) in 1997. Figure 4 displays the user interface; the software recognizes automatically all the gears on the shaft, and deduces the meshing point W coordinates and the normal N to the flank.

Load distribution in the tooth contact and face load factor $K_{H\beta}$. The determination of the load distribution (in N/mm or lbf/in) according ISO 6336 (Ref. 1) is simple, because the tooth meshing stiffness $c_{\gamma\beta}$ is considered as constant over the face width. The calculation is performed as displayed in Figure 1. The face width is subdivided in some (11 to 100) sections. To start the iteration, an initial distance δ between the teeth is assumed. Then with $c_{\gamma\beta}$ the partial load F_{ti} per section is calculated. The sum of all F_{ti} has to be identical to the transmitted tangential load F_t:

$$F_t = \sum_{i}^{!} F_{ti} \tag{1}$$

The distance δ is therefore (by iteration) changed until Equation 1 is fulfilled. The result is the line load distribution as in Figure 5. The face load factor $K_{H\beta}$ is then the quotient of the maximum line load divided by the mean line load as defined in ISO 6336 (Ref. 1):

$$K_{H\beta} = \frac{w_{max}}{w_m} = \frac{\text{maximum load per unit face width}}{\text{average load per unit face width}} \tag{2}$$

To compensate uneven load distribution (Figure 5), adapted flank line modifications should be used. As shown in the theory (MAAG book, Fig. 1), the optimum flank line

modification is identical to the inverted gap curve (Figure 4).

Optimization of Load Distribution with Adapted Flank Line Modifications

In most cases, the optimum flank line modification can be composed of a helix angle modification plus a crowning (in some cases, an end relief is added). If these two basic modification types are correctly combined, the load distribution can become nearly uniform. We added therefore the input possibility for crowning (C_b) and helix angle modification (f_{Hb}) data in the user interface. When the calculation is executed with modifications, the gap is determined (as before), but compensated with the profile modification. Then the load distribution including profile modification is calculated and displayed. The $K_{H\beta}$ is again defined according to Equation 2.

In the example of Figure 5, a crowning $C_b = 1.8\,\mu m$ (0.07 mil) and a helix angle modification $f_{Hb} = -7.6\,\mu m$ (−0.30 mil) would give a uniform load distribution (Figure 6). With such a modification the face load factor $K_{H\beta}$ is theoretically $K_{H\beta} = 1.0$. However, for a real gear, not only the deformation should be compensated; due to manufacturing errors, the gear will have a flank line error that is in a predefined tolerance band — depending on the tolerance class.

Manufacturing errors are stochastic — they may reduce or increase the gap. Good design practice is to get the maximum load in the center of the face width; thus the only way to compensate for manufacturing errors is to increase the crowning (or to apply additional end relief). The proposition in ISO 6336-1 (Ref. 1), annex B, is to increase the crowning by 0.75…1.0 * $f_{H\beta}$ (helix slope deviation). If this technique is used — and which is recommended — then the face load factor will theoretically be higher than 1.0 — but in the end will provide a better practical design.

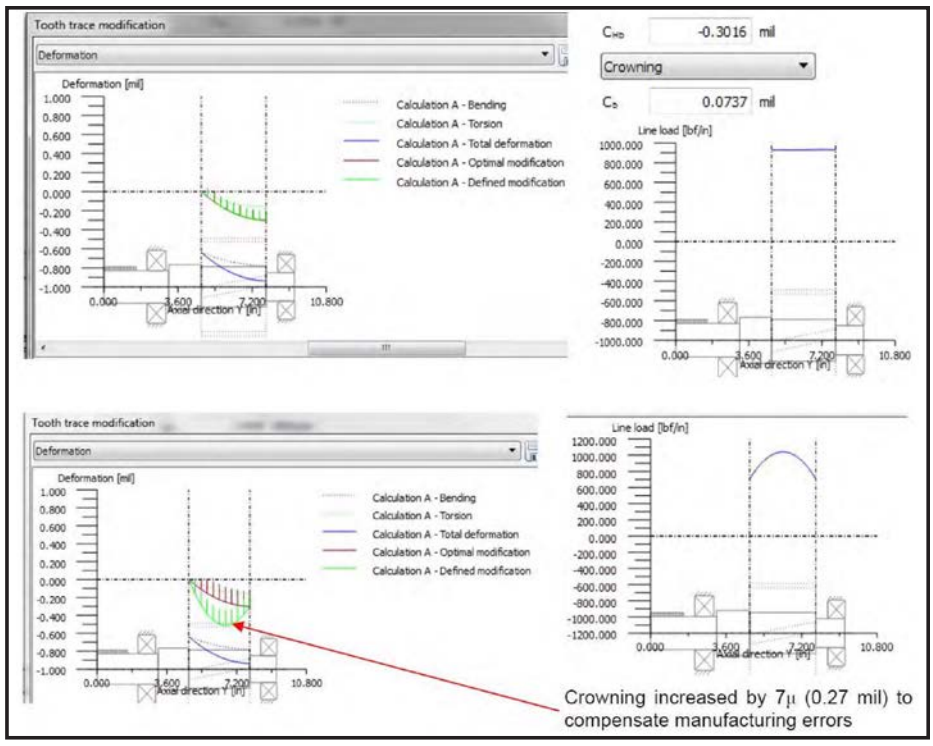

Figure 6 Same shaft as in Figure 5, but with optimum profile modification (top) and with practical modification (bottom) — including additional crowning to compensate manufacturing tolerances.

Flank Line Modification for the Tunnel Boring Machine

The approach to determine the load distribution described in this section is based on a single shaft, and normally applied to the pinion shaft — thus assuming that the meshing gear shaft is infinitely stiff. The approach is therefore comparable but less general then the method described in AGMA 927 (Ref. 3), which considers the deflection of both shafts. Still, for the problem encountered in the tunnel boring machine, where the huge ring gear is much stiffer than the driving pinion gear, this simpler procedure can be quite effective.

To best offset the deviation of up to 0.2 mm (0.008 in) of the pinion shafts, different modification variants (modifications with crowning and/or end relief) were calculated — always assuming the maximum deviation. As a best solution, a long end relief (over 30% of the face width on both sides) with C_b 40 µm (1.57 mils) was found (Ref. 9).

In the worst-case example (Table 1), the pinion with no modification would last only 500 hours. With flank line modification the estimated life is increased by 1,350% — or 6,750 hours. The requested life time to finish the task was 3,000 hours; we therefore could attain the goal. The pinions were produced — as recommended. Meanwhile, the tunnel was successfully finished.

Table 1 Lifetime preview

Modification	Supposed deviation of the shaft	Deviation of the shaft (maximum) mm (in)	$K_{H\beta}$	Life time (hours)
Without modification	Worst case	0.2 (0.008)	2.53	499
Without modification	Reasonable case	0.1 (0.004)	1.05...2.53	1'200
Without modification	No deviation	0.0	1.05	2'800'000
With modification	Worst case	0.2 (0.008)	1.77	6'750
With modification	Reasonable case	0.1 (0.004)	1.28...1.77	14'500
With modification	No deviation	0.0	1.28	113'000

Load Distribution and Face Load Factor Determination Based on AGMA 927

The basic idea in AGMA 927 is exactly the same as described in the previous section, but applied on the gear pair; thus much more general. As this standard was added in the newest edition of ISO 6336-1:2006 (Ref. 1), annex E, this process is now available as an international standard. It is, as will be shown by example in this paper, a very useful calculation method. It is therefore astonishing that, since 2006, no one to our knowledge in Europe or even the U.S. has implemented this algorithm in an available software

tool. We decided in 2008 to implement the complete algorithm in our software.

Compared with the simpler algorithm described in the previous section, ISO 6336/AGMA 927 proposes some very important improvements:

- The gear mesh (pinion and gear shaft are both taken into account) is considered.
- The load distribution over the face width is iterated: The area of the gear teeth is split into ten equal sections. The first calculation run is performed using uniform load distribution to get the shaft deformation. From the initial gap, an uneven load distribution is calculated. This new load distribution is then used to calculate a new shaft deformation. This iteration process is continued until the newly calculated gaps differ from the previous ones by only a small amount. Usually only a few — two or three — iterations are required to get an acceptable error (less than 3.0 µm change in gaps calculated).

The procedure to get $K_{H\beta}$ has to be included in a gear strength calculation, and has to be performed automatically at the beginning of the calculation following ISO 6336. The input of data needed for the software to calculate the gap in the meshing and the load distribution is represented in Figure 7. If the deviation of the axis is calculated by an external program (e.g., in an FEM of the housing), then the deviation can be directly introduced as deviation and inclination errors. The other variant (and exactly in keeping with the spirit and intent of AGMA 927) is to introduce models of both pinion and gear shaft.

Improvement of the algorithm as proposed in AGMA 927 (ISO 6336-1, Annex E). The algorithm as proposed in AGMA 927 has some restrictions, which should be overruled, to increase the precision of the results.

- Shear deformations of the shaft are not included; this is not critical on long shafts, but can be important on short shafts with large diameter. Therefore we included shear deflection in the bending calculation.
- Iteration is continued until less than a 3.0 µm change in gap calculated is obtained. This is a good criteria for big gears, but not for gear sets with module smaller than 2.0 mm (DP smaller than 12.7). We changed the criteria to get more accurate results for any dimension of the shaft. We stop iteration if the gap change is less than 0.1 %.
- When calculating shaft deflections, the area of the gear teeth is broken into 10 equal sections. If short end relief or similar fast changing flank line modifications are applied, then the effect of the modification cannot be simulated with only 10 sections. We increased to 41 sections (and more if requested).
- The tooth stiffness is called "stiffness constant" in N/mm/µ with symbol $c_{\gamma m}$; but there is no reference to this symbol in other parts of ISO 6336. In principal, the stiffness used should be exactly the stiffness $c_{\gamma\beta}$, as defined in ISO 6336-1, Chapter 9. In AGMA 927 an additional indication is given, claiming that $c_{\gamma m}$ is ~11 N/mm/µ for steel gears. Eleven N/mm/µ is very low; the typical stiffness calculated accurately for a wide range of gears is 16-24 N/mm/µ. A low stiffness value (such as 11 N/mm/µ) will result in a low $K_{H\beta}$- value; therefore the assumption of 11 N/mm/µ is NOT on the safe side!

  We decided to provide the choice to the calculation engineer: the stiffness $c_{\gamma\beta}$ as in ISO, or 11 as in AGMA — or any other value calculated with a more precise algorithm.
- For the calculation of the shaft bending, the equivalent outside diameter of the teeth is halfway between tip diameter and root diameter. This is correct for solid shafts. For typical shrink-fitted gears or connections, the equivalent outside diameter is less. ISO 6336 proposes in Chapter 5 for this situation to use a diameter in the middle between hub diameters and bore. We decided to give full choice to the calculation engineer. Depending on the shrink-fitting, the stiffening effect can vary widely; therefore this is a difficult topic to handle.

Application of the algorithm. With these additional improvements, the algo-

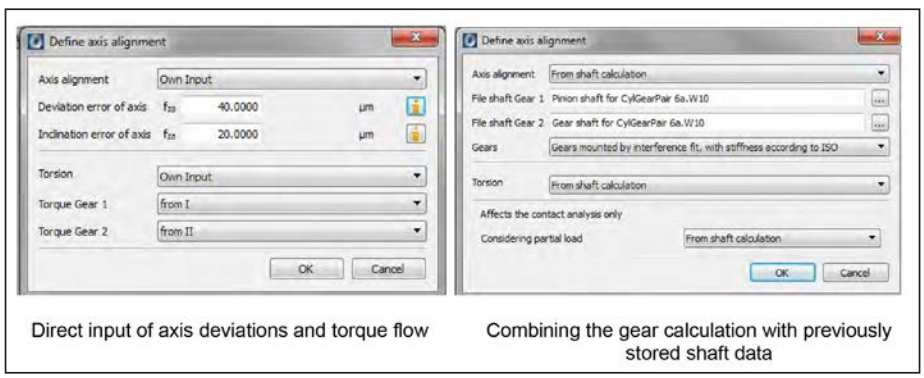

Figure 7 Definition of axis alignment in a gear calculation is possible in two ways.

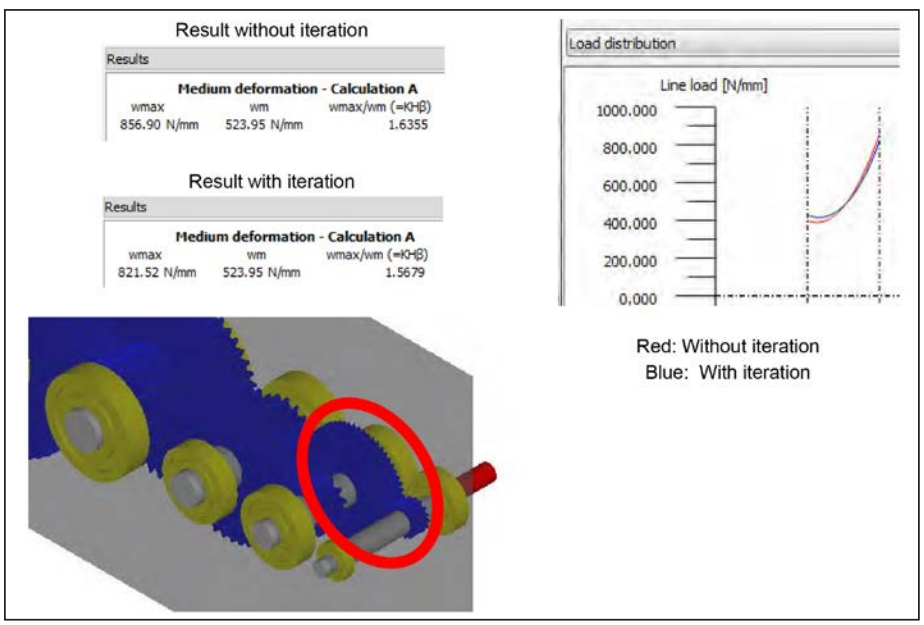

Figure 8 Calculation of $K_{H\beta}$ of a gearbox input stage; with (as proposed by AGMA 927) and without iteration of the gap. Normally through iteration, a more precise and lower $K_{H\beta}$ is obtained (here 11%).

Table 2 Duty cycle with axis misalignment of a ship steering module					
Element (load case) no.	Frequency	Load on a pinion, kNm	Speed, 1/min	Radial mesh misalignment, $f_{\Sigma\delta}$, mm	Tangential mesh misalignment, $f_{\Sigma\beta}$, mm
1	0.980097	33.5	5.5	+-0.143 (5.6 mil)	+-0.183 (7.2 mil)
2	0.019602	67.0	5.5	+-0.121 (4.8 mil)	+-0.411 (16.2 mil)
3	0.000294	111.6	5.5	+-0.084 (3.3 mil)	+-0.686 (27.0 mil)
4	0.000007	111.6	5.5	+-0.078 (3.1 mil)	+-0.754 (29.7 mil)
Total requested lifetime				32'000 hours	

rithm shows a very high performance and, compared with contact analysis and FEM results, is very accurate. As shown in Figure 8, the iteration of the gap is necessary to get more precise results.

If it is possible, as in the modern shaft calculation, to introduce bearings with stiffness calculated according to ISO 16281 (Ref. 7) (based on the inner bearing geometry and operating clearance), the results are still more accurate. But even if all these improvements are included, the method is still relatively simple compared with a contact analysis. Therefore the calculation time is very short. For instance, also for duty cycles with 100 and more elements, if for every element the line load distribution is analyzed, the required calculation time is a few seconds.

Today's trend in gear software is to use system programs able to handle a complete power transmission chain. In these applications (Figure 8) all data needed to perform a load distribution analysis according to AGMA 927 are available (the shafts and connecting gear set), so executing such a calculation does not require any additional input from the user side, thus making the task easier.

Manufacturing tolerances. AGMA 927 and ISO 6336-1, Annex E, advises to take manufacturing tolerances into account (f_{Hb} for the lead variation of the gears ($f_{Hb1}+f_{Hb2}$) and f_{ma} for the axis misalignment). $K_{H\beta}$ has to be calculated five times:

- without tolerance
- $+f_{Hb}$ and $+f_{ma}$
- $+f_{Hb}$ and $-f_{ma}$
- $-f_{Hb}$ and $+f_{ma}$
- $-f_{Hb}$ and $-f_{ma}$

The highest $K_{H\beta}$ value found must be used as a final result. This is a logical approach to have $K_{H\beta}$ reflect the worst-case situation in order that the $K_{H\beta}$ value can be used in a strength calculation. This algorithm can also be used to find optimum flank line modification. Now it is much better not to consider manufacturing tolerances, because the modification to offset the deformation is much easier to find. As explained earlier, after the modifications to compensate the deflection are found, to compensate the manufacturing tolerances, only the crowning need be increased. It is therefore important that both calculation methods are available — with and without manufacturing tolerances.

Layout and Optimization of Flank Line Modifications

Flank line modifications for nominal torque (no duty cycles). A combination of flank line and profile modifications is a must today in gear design. Flank line modifications are intended to effect a uniform load distribution over the face width to improve the lifetime of the gear. A first layout of modifications is typically accomplished based on experience; to verify that the modifications lead to the requested results, contact analysis has to be used. Contact analysis calculation is extremely complex; hence even specialized software programs need up to one minute and more calculation time. In short, any optimization is time consuming.

For a gear pair with a given load, the most expeditious manner to design the optimum flank line is to use the simple method described earlier — separately for pinion and gear (using only the shaft calculation). With that, the optimum flank line modification for each gear is found easily. Clearly, if desired, the totalized modification can then also be applied to only one of the gears. Then the proposition has to be checked, using the AGMA 927 method with the gear mesh. In the vast majority of all cases, this simple approach provides very good results with $K_{H\beta}$ lower than 1.1; hence there is often no need for further optimization steps.

Flank line modifications for applications with duty cycles. For gears subject to duty cycles, the approach for an optimum flank line modification is much more complicated. For which of the duty cycle elements should the modification be optimal? This is in many cases very difficult to know. If the modification is optimum for the element with the highest load (having normally a short operating time), then often the other elements (having higher operating time) get an increase of $K_{H\beta}$ — so far that the overall lifetime of the gear pair may decrease!

As a first step we combined the AGMA 927 method with the calculation of the lifetime with duty cycles, as described in ISO 6336-6 (Ref. 8). For every duty cycle element, the deformation of the shafts with the torque of the element is recalculated and the individual $K_{H\beta}$ is derived. Then the "normal" calculation approach is executed.

In the second step we combined this procedure with an advanced optimization tool, which for a given gear pair can automatically vary different combinations of flank line modifications. The best way to explain the course of action is to describe a recent example.

The steering module drive of a big ship consists of a big ring gear driven by multiple pinions. The load cycle of such a drive is defined in Table 2. It is a special duty cycle, having very high load for a short time and low load for most of the time. A first check of the different load cases, calculated individually, results in $K_{H\beta}$ and safety factors (Table 3).

Table 3 $K_{H\beta}$, SF, SH calculated individually for each load case with given data			
Load case	$K_{H\beta}$ (AGMA 927)	Bending safety factor, SF	Pitting safety factor, SH
1	2.22	2.96	1.38
2	2.23	2.73	1.27
3	2.28	2.78	0.97
4	2.40	2.80	0.94

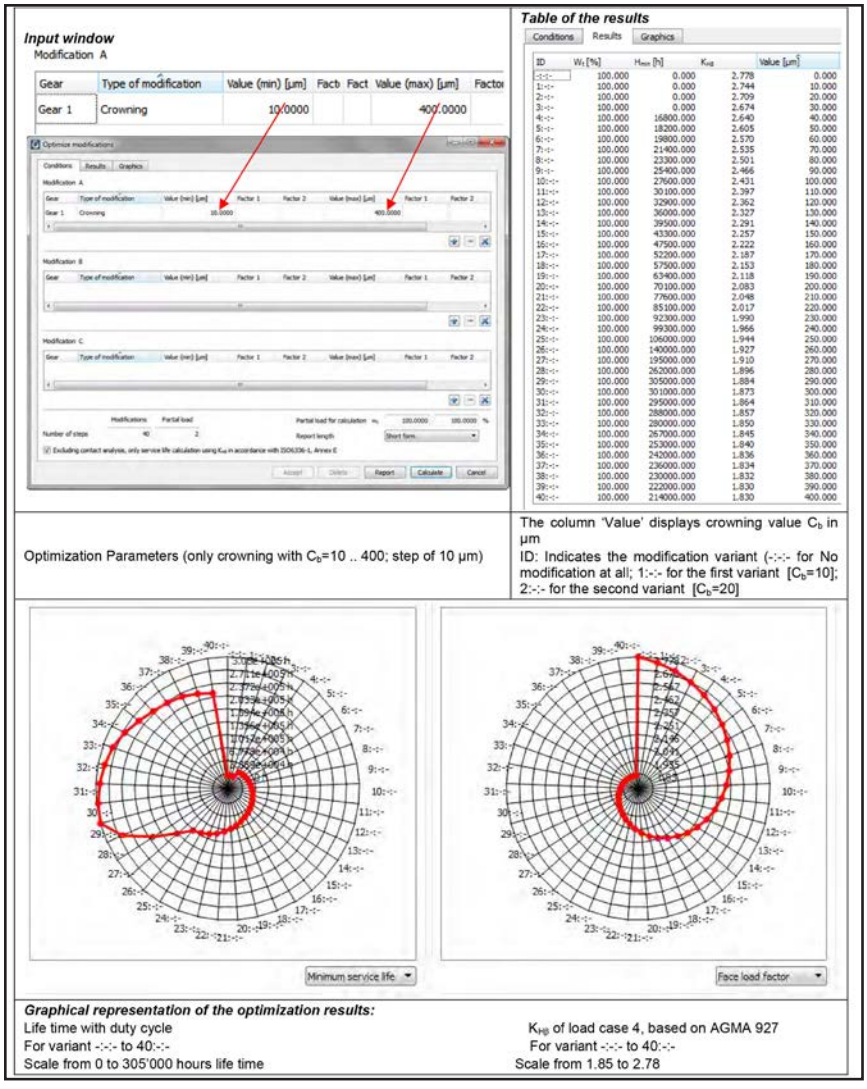

Figure 9 Finding the best crowning for a ship steering drive with extreme duty cycle.

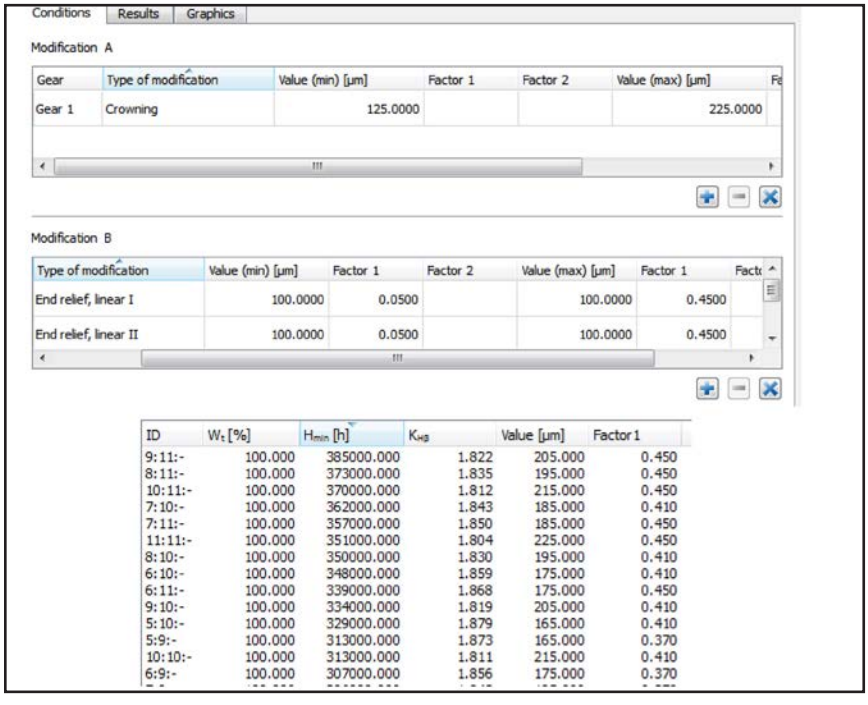

Figure 10 Additional improvement of the load distribution with a combination of varied crowning and end relief with varied length.

Table 4 Damage (%) of the different load cases, when analyzing the overall lifetime using PalmgreNminer rule

Load case	Damage (%)
1	0.00
2	71.93
3	27.19
4	0.88

The most critical load case is No. 4, having highest $K_{H\beta}$ and lowest pitting safety. But when the total lifetime, using Palmgren-Miner rule (ISO 6336-6) (Ref. 8), is calculated and the damage of the different load cases is found, then it is evident that No. 2 is the critical case, limiting the overall lifetime (Table 4). So it is not easy to decide for which load case the flank line modification should be optimized.

Recently in our calculation software a tool called *Modifications Optimizations* was added to help find the best solutions for profile modifications. This tool calculates automatically the resulting lifetime with duty cycle — defining for every load cycle element $K_{H\beta}$ based on AGMA 927. As the misalignments are depending on the manufacturing tolerances, they can be positive or negative (Table 2), thus only symmetric flank line modifications should be used. A first check showed that the end relief with 125 µm (4.9 mil) of the original design is too small. Therefore, as a first attempt, a crowning was used — varying C_b from 10 to 400 µm, in steps of 10 µm (0.4 to 11.8 mil) (Figure 9). The results of the *Modifications Optimizations* are displayed in a radar chart (Figure 10) (Ref. 12), that shows that the highest lifetime can be achieved with a C_b of approximately 290 µm. Estimated lifetime is 305,000 hours. This is, compared to the current design (end relief with 95 µm and 29,000 hours) an increase in lifetime of more than 1,000%.

The result could be further improved with a second run, where a combination of end relief and crowning was checked. The crowning was varied from C_b = 125 to 225 µm, in steps of 10 µm, cross-combined with an end relief of 100 µm with a varied length from 5 – 45% of face width, step of 5. The results table shows a small increase in lifetime (26%), if a combination of crowning C_b = 205 µm with end relief of 100 µm (length 45% of face) is used.

Adaptation of the Method for Epicyclic Gear Combinations (Planetary)

For planetary gear sets, the application of the Annex E algorithm must be adapted to the specific properties of the combination of sun shaft, planet carrier — with pin and planet — and ring. The deformation and tilting of the planet

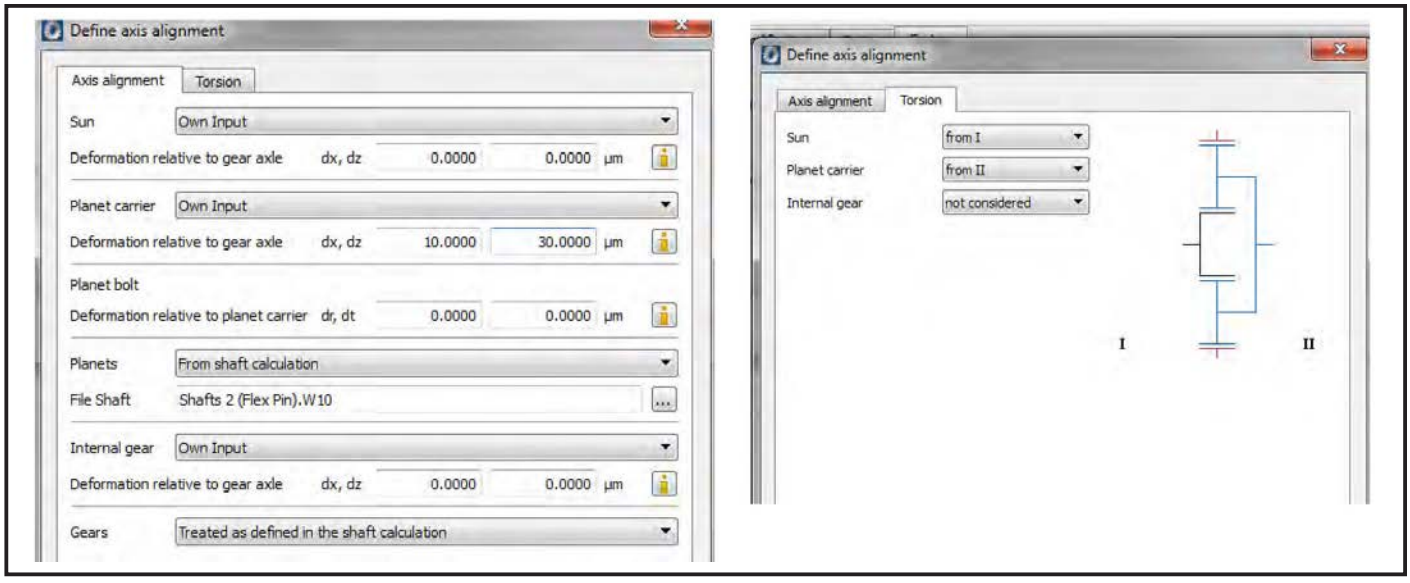

Figure 11 Definition of deformation and tilting of the different elements in the planetary system.

carrier resulting from FEM and bending/torsion of the sun shaft and the pin/bearing/planet-system must be combined (Figure 11).

The algorithm as described in AGMA 927 is defined for one gear mesh. In a planetary stage, the sun is meshing with three or more planets. The load distribution in one of the sun's meshings interacts with the other ones. This also applies to the two meshings on every planet and the meshings of the planets with the ring. For this a specific calculation approach using a concurrent iteration over all meshings is needed, and is documented in Figure 12. Basically a second iteration on system level is required. For normal cases, about five iterations on system level are needed. Hence to get the final solution for a planet stage with three planets, five times the six meshings of the system must be calculated. This takes about 20 seconds, which, if compared to the time needed for an FEM or contact analysis, is very fast.

Hence, as before, it is possible to evaluate different flank line modifications rapidly. As an example, the load distribution of a planetary stage in a wind turbine gearbox is analyzed. In modern wind turbine gearboxes using planetary stages, the so-called "flex pin" design for the planet shafts is well known (Ref. 10) (but not often used). The planets can better adapt with this concept to the tilting of the planet carrier, thus improving the load distribution over the face width. In the example, a conventional design and a flex pin design are compared. For both designs an optimum flank line modification is applied, so that – without carrier tilting – $K_{H\beta}$ is near to unity. Figure 14 shows the difference in the load distribution, when the planet carrier is tilting by 0.02 mm (0.79 mil) in

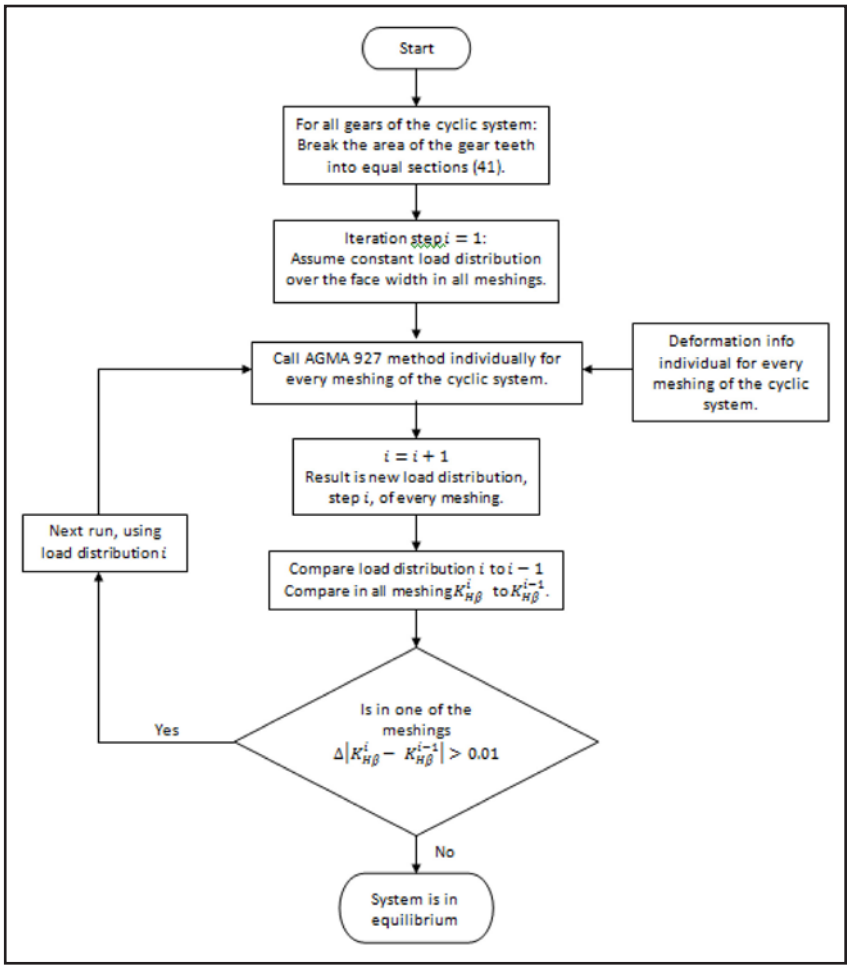

Figure 12 Application of AGMA 927 algorithm to planetary stages.

z-axis (Figure 13). A tilting of the carrier generates in every meshing a different load distribution, therefore also a different $K_{H\beta}$. The conventional design has an increase of $K_{H\beta}$ from 1.04 (without tilting) up to a maximum of 1.83 (in the meshing of the planet at 0° position); the flex pin version has an increase from 1.04 (without tilting) up to 1.60. This proves nicely that the flex pin concept adapts better to carrier tilting than conventional design.

Contact Analysis Comparison

All input data used for the flank line optimization can directly be used for the contact analysis (Ref. 4). The contact analysis displays the load distribution over the full contact between the two gears. Therefore the validity of the proposed modifications over the full contact area can be checked. Contact analysis includes also the effect of profile modifications. The calculation process is more complex, consuming much calculation time, but producing many useful results, as the transmission error for noise optimization or the lubrication film thickness for the micropitting risk determination (Ref. 11).

It is therefore logical that the outcome of the load distribution as calculated according to AGMA 927 is not identical to the contact analysis results; but when the line load in the area of the operating pitch diameter is compared, the results are very close. Simply put, AGMA 927 performs a one-dimensional contact analysis, considering only the situation in the operating pitch point of every section. The result is a 2-D graphic, showing the line load distribution over the face width, which is easier to understand than the 3-D colored contact pattern results (Figure 15). A difference, which has to be remembered when using helical gears or deep tooth profile gears, is that the line load calculated following AGMA 927 tends to higher results, than the load as calculated by contact analysis. The differences depend on the transverse overlap ratio εβ and the contact ratio εα, because AGMA 927 does the calculation supposing $\varepsilon\gamma = \varepsilon\alpha + \varepsilon\beta = 1$ (Figure 15). Thus the absolute value issued is not precise in this case, but the course of the curve is accurate; thus giving a correct value for $K_{H\beta}$. We are actually investigating further this topic, comparing some examples also with results from the FE method.

Thus a good design technique is: First use AGMA 927 to find near to optimum flank line modification, then use contact analysis to find the optimum flank and profile modification combination. We have used this technique for some years in different engineering projects and could reduce the time to find the best profile modification considerably (up to 70%). We never encountered a case where the results of AGMA 927 were contradictory to the results of contact analysis; thus the outcome of the algorithm as defined in AGMA 927 is typically very satisfying.

As explained, the line load in AGMA 927 is higher (w_{max} = 192 N/mm, 1,096 lbf/in) than in contact analysis (approx. 140 N/mm, 799 lbf/in), due to εβ; but the course of the load distribution is the same.

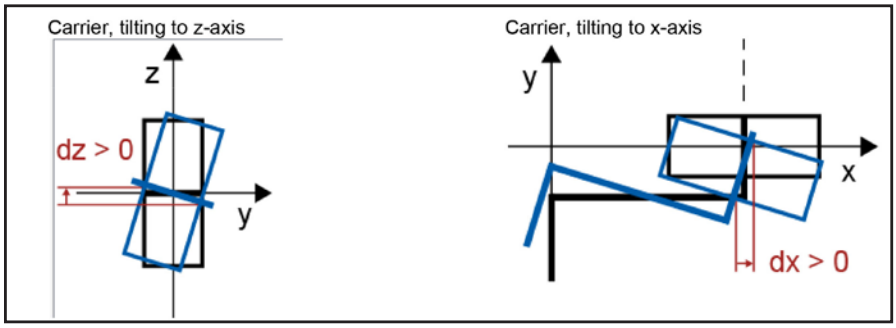

Figure 13 Definition of carrier tilting.

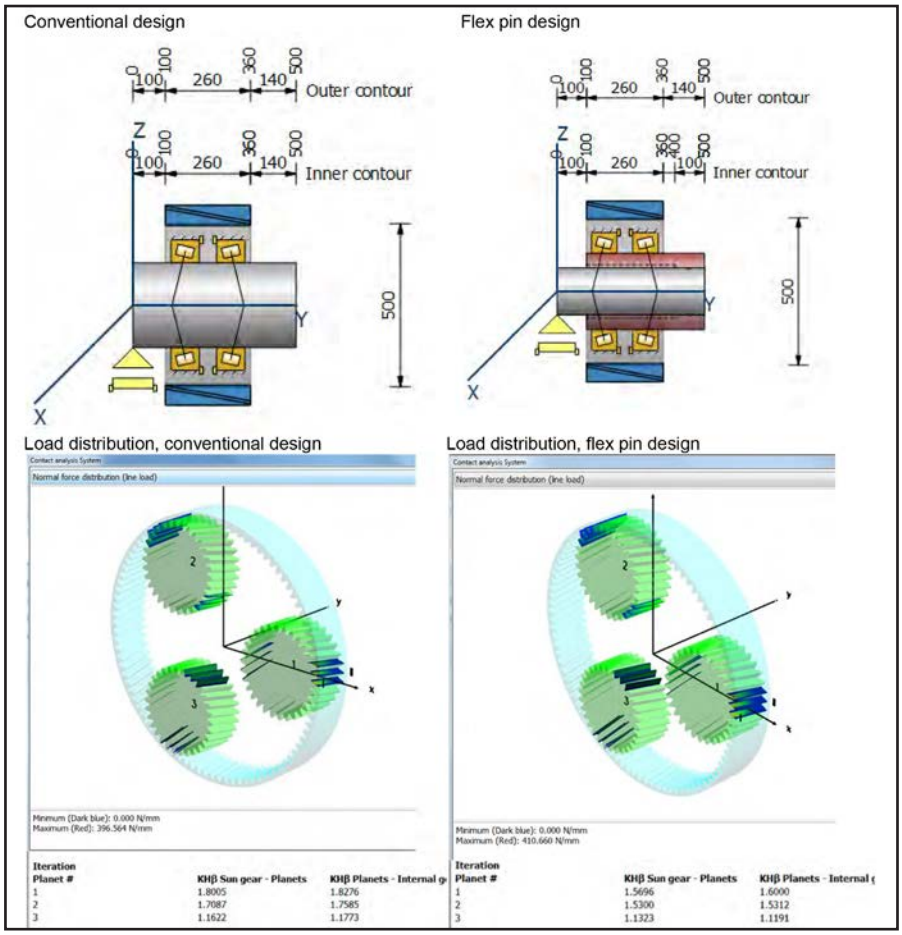

Figure 14 Load distribution in a planetary stage with two different planet bearing support designs.

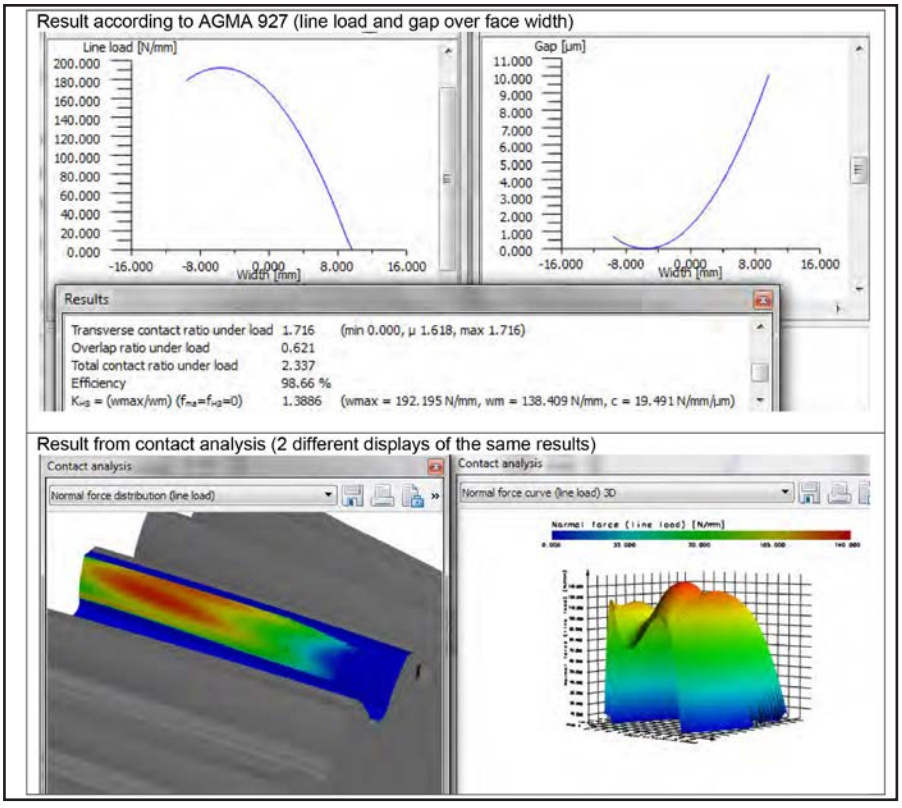

Figure 15 Helical gear pair (14° helix angle, εβ = 1.02, εα = 1.57).

Conclusion

Annex E in ISO 6336 — "Analytical Determination of Load Distribution" — is entirely based on the AGMA 927-A01 standard. It is a very useful method to get a realistic value for the face load factor $K_{H\beta}$, and much faster than using contact analysis. Basically, the algorithm is a one-dimensional contact analysis, providing good information about the load distribution over the face width. For helical gear sets, depending on the overlap ratio εβ, the absolute value of the line load is too high; but the course of the curve is still accurate.

As input, the geometry of both shafts (including bearings and loads) is needed. The trend today in gear software is to use system programs able to handle a complete power transmission chain. In these applications all data needed to perform a load distribution analysis according AGMA 927 are available.

Thus the method is easy to use and provides a fast and accurate value for $K_{H\beta}$ — as needed in calculations according to the ISO 6336 standard.

The result of this method is the line load distribution over the face width; this information is very helpful in the gear design process to quickly find a nearly perfect proposition for best flank line modification. As shown by example, even for complicated duty cycles it is possible to find the best modification — hence improving overall lifetime considerably.

For planetary gear sets, the application of the ISO 6336, Annex E algorithm must be adapted to the specific properties of the combination of sun shaft, planet carrier — with pin and planet — and annulus gear. It is explained how this can be performed using an additional iteration on a system level. For planetary stages, it is much more difficult to design best flank line modification and to get accurate information about the load distribution factor in the different meshings, thus use of this method is very helpful in planetary gearbox design.

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Ulrich Kissling studied mechanical engineering at the Swiss Federal Institute of Zurich (ETH). His Ph.D. thesis, in collaboration with a leading Swiss textile machines company, was completed in 1980. From 1981-2001 he worked as a calculation engineer, technical director and then as managing director of Kissling Co., a Swiss gearbox company located in Zurich, focusing on planetary, turbo and bevel-helical gearboxes for industrial applications and the ski industry. In 1998 he founded KISSsoft AG and acts as CEO. Since then, KISSsoft AG has sold to more than 2,200 companies their software, making the *KISSsoft* program one of the most successful gear software programs worldwide. Dr. Kissling is chairman of the NK25 committee (Gears) of the Swiss Standards Association (SNV) and voting member for Switzerland in the ISO TC 60 committee. He has published over 60 works on calculation procedures plastic gears to large open gears, and has made numerous presentations at the major international gearing conferences. His areas of interest are on lifetime calculation of gears, non-circular gears, and special gears such as face gears. His practical experience, combined with his theoretical know-how, allows him to provide leading software tools, sound engineering advice and fascinating seminars.

Metallurgical Investigation of "Tiger Stripes" on a Carburized High Speed Pinion

March Li, Phil Terry and R. Eckert

"Tiger stripes" on a high-speed pinion made of a carburized SAE 9310 steel were investigated. The morphology of the damage was typical of electric discharge damage. The cause of the stripes and potential damage to the gear tooth were analyzed and are presented in this report.

Introduction

There are many gear failure modes, depending on the material and related strengthening and/or hardening processing, working condition (power, speed and load) and environment (temperature, lubrication, corrosion, etc.). It is important to identify the failure mode in order to take necessary measures to mitigate it or to prevent it from occurring.

Among the various failure modes, electric discharge is a common one. It is caused by electric arc discharge across the oil film between mating gear teeth. This discharge may produce temperature high enough to locally melt the gear tooth surface (Ref. 1). Electric discharge also causes bearing failures. It has been reported (Ref. 2) that electric discharge pits initiated spalling on a bearing, which in turn created vibration and overheating, which ultimately led to fatigue failure of the bearing.

The electric current typically originates from electric motors — especially variable frequency drives (VFDs) — sources of rapidly switching electric currents such as electric clutches, or accumulation of static charge and subsequent discharge. Accordingly, this can be prevented by providing adequate electrical insulation or grounding.

To the unaided eye, a surface damaged by electric discharge appears as an arc burn, i.e., similar to a spot weld. The density of the spots on the affected surface increases with the increase of the electric current intensity. On a microscopic level, small hemispherical craters can be observed. The edges of the crater are smooth, and they may be surrounded by burned or fused metal in the form of rounded particles that were once molten.

ANSI/AGMA 1010-E95 includes some macro- and micrographs showing the morphology of this failure mode. However, it does not mention any other surface appearance or property change. This paper introduces a specific appearance of electric discharge — tiger stripes — on a high-speed pinion made of carburized SAE 9310 steel. Morphology characterization was performed by means of scanning electron microscopy (SEM). The hardness profile across the carburized case depth was measured with a microhardness tester to reveal the damage due to electric discharge.

Application, Chemistry and Material Tensile Properties

The application is a speed increaser gearbox with a 4.735:1 ratio driven by an 1,800 rpm VFD electric motor and driving a centrifugal compressor. The

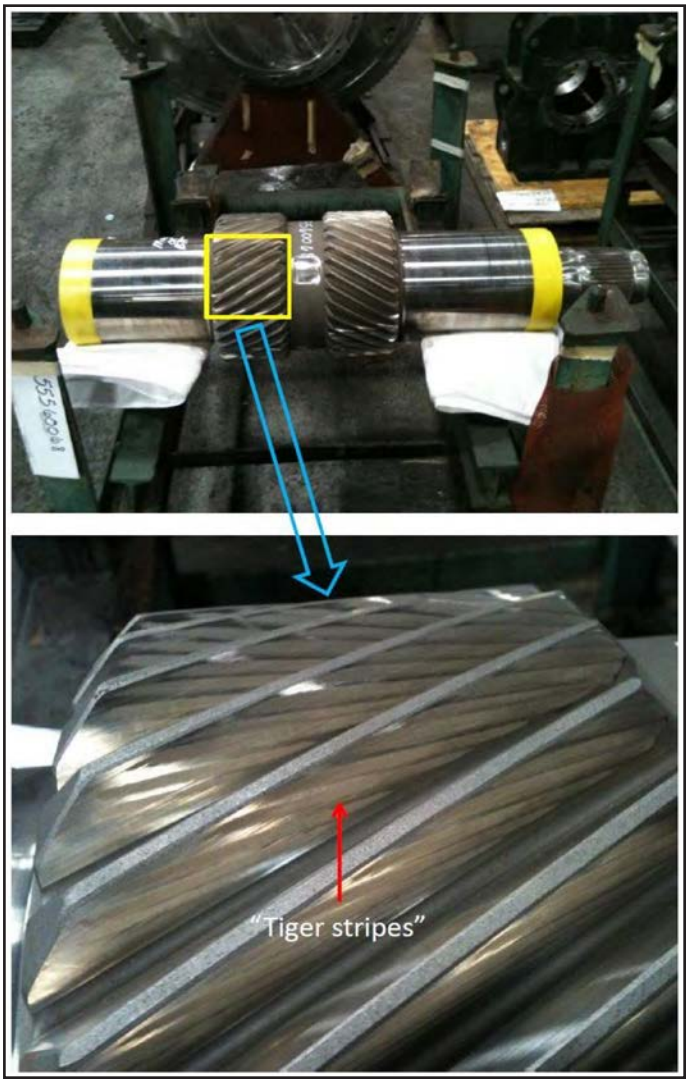

Figure 1 Tiger stripes on the pinion.

Table 1 Chemistry of the sample, wt. %

Chemistry	C	Si	Mn	Cr	Mo	Ni	S	P
Sample	0.14	0.26	0.66	1.32	0.12	3.28	0.011	0.007
SAE 9310	0.07 0.13	0.15 0.35	0.40 0.70	1.00 1.45	0.08 0.15	2.95 3.55	0.040 max	0.030 max

Table 2 Mechanical properties of the samples

	Ultimate tensile strength, psi	Yield strength, psi	Elongation, %	Area reduction, %
Sample 1	148,300	107,500	17.7	58.1
Sample 2	148,700	110,700	16.8	58.3

high-speed pinion has 34 teeth and a normal diametral pitch of four.

A sample of material was cut from the pinion shaft and analyzed using a mass spectrometer. The results of the analysis are shown (Table 1) along with ranges specified for SAE 9310 steel. It shows that the carbon content is a little high, but all other elements are within specification.

Two tensile test specimens were prepared from the pinion shaft, and the measured mechanical properties are shown (Table 2).

The manufacturing records show that the surface hardness of the pinion teeth is 59-60 HRC, with 10% retained austenite and dispersed carbides.

Visual Examination

Figure 1 shows the tiger stripes on the pinion. These stripes appeared to be along lines of contact of one (load) side of the pinion teeth and distributed at different rotational positions of the pinion. Also, it was noted that the tiger stripes occurred on the pinion only; the mating gear didn't show any stripes.

Microstructure Investigation

One pinion tooth was cut for morphological characterization by scanning electron microscopy (SEM) (Fig. 2).

The SEM showed clearly that each stripe was composed of a high density of craters (Fig. 2c). Under higher magnification it revealed these craters were caused by electric discharge, indicated by the typical fused metal particles and gas pockets (Figs. 2d and 2e). The particles were about 1-3 micron in diameter. For comparison, Figure 3f is cited from ANSI/AGMA 1010-E95

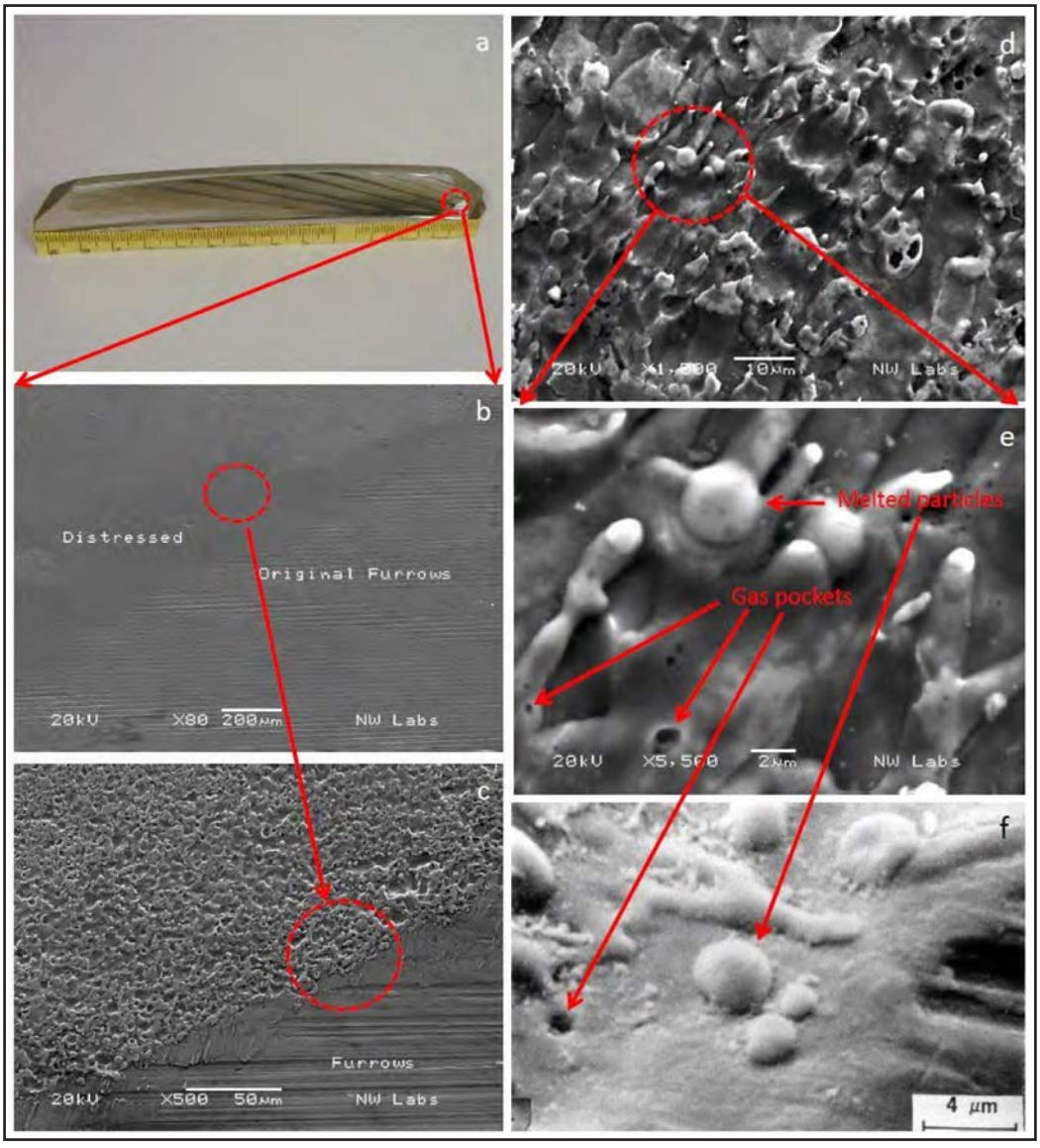

Figure 2 Morphology of tiger stripes revealing electric discharge: a – e were taken from the sample; f is cited from ANSI/AGMA 1010-E95. Note they are under different magnifications, as indicated by scale bars.

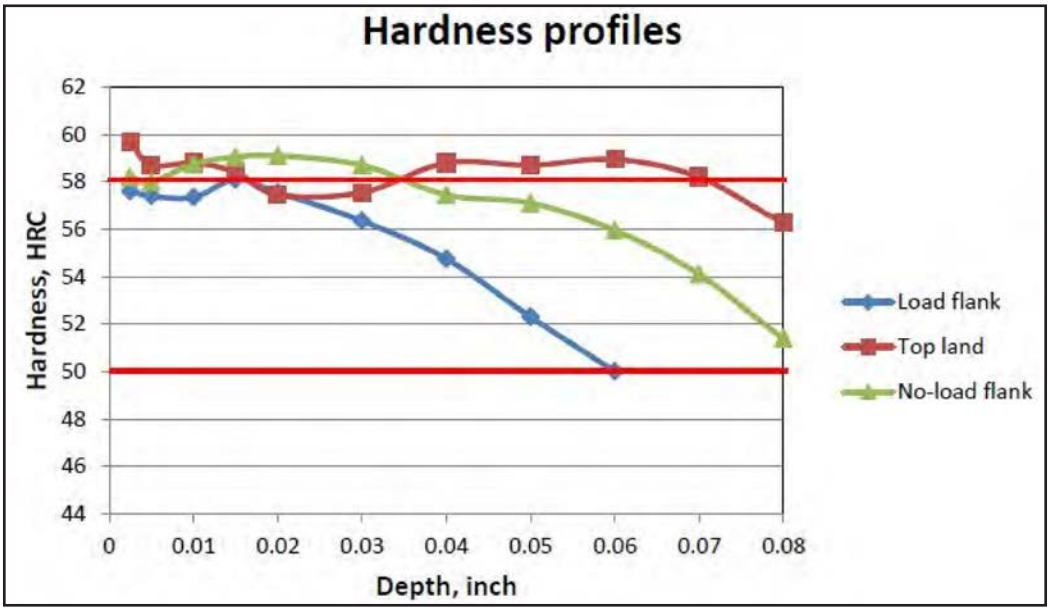

Figure 3 Case hardness profiles of the pinion tooth.

as an example of electric discharge. Figures 2b and 2c show the original machining marks outside of the tiger stripes.

Hardness Profile

In order to evaluate the extent of damage caused by electric discharge, one pinion tooth was sectioned for microhardness profile checks across the gear flanks (load and no-load sides), and the top land from the surface to the hardened case depth (Fig. 3).

The load flank hardness profile revealed that although the depth between the surface and the location where the hardness number is 50 HRC reached 0.060" and is deeper than the specified minimum effective case depth (in this case 0.036"), both the load flank and top land lost some hardness below the surface due to the tiger stripes — especially on the load flank of the teeth. For example, the hardness was only 57.6 HRC on the load flank surface, which is lower than the required minimum 58 HRC. This made the pinion soft and lowered its contact fatigue resistance. As a matter of fact, except at 0.015", its hardness is lower than 58 HRC at any other depth. Even the top land showed some degree of hardness drop. The tiger stripes had the least negative influence on the no-load flank of the pinion teeth. Since the original manufacturing records show that the surface hardness on any flank of the pinion was 59 - 60 HRC, the hardness loss of the inspected pinion was due to the tiger stripes; i.e., electric discharge.

Discussion

The chemical analysis confirmed the material is SAE 9310 carburizing steel. Mechanical properties were in the normal range.

The hardness profiles exhibited hardness loss due to the tiger stripes. The load flank surface hardness was even lower than 58 HRC, the minimum hardness required by the AGMA standard. SEM analysis revealed that these stripes were electric discharge defects. The electric discharge generated very high local temperature and local melting of the pinion teeth. As a result, some areas of the pinion were re-tempered at high temperature. This gave rise to lowered hardness and jeopardized the contact fatigue resistance. Furthermore, as the surface hardness is lower than 58 HRC, the original gear rating is not valid. It is recommended that a new pinion should be manufactured to replace this damaged one if the user wants to keep the initial rating.

It should be noted that this tiger stripe pattern is different from normal electric discharge. While the latter shows random spots on the gear tooth, tiger stripe takes on regular patterns. Obviously, these stripes came from periodic discharge between the mating flanks. Although some composite bearings have been introduced to minimize this type of damage, proper operating grounding such as brushes is still considered to be the best solution to prevent this from happening (Ref. 3).

Conclusions

- The steel for this pinion was confirmed to be SAE 9310.
- Tensile test showed its mechanical properties met the requirements.
- SEM analysis confirmed the tiger stripes are electric discharge damage.
- It generated high temperature and locally melted the pinion surface, giving rise to low surface hardness.

Acknowledgement. *The authors are thankful to Bob Errichello for his discussion and review of this paper.*

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Rainer Eckert is a forensic engineer and director of the metallurgical services department for Northwest Laboratories in Seattle, WA. In that role he has conducted several thousand failure analyses of industrial components and has served as an expert witness in several hundred court cases. Eckert has also assisted manufacturers in basic research, design improvement, quality control, and root cause failure analysis. His expertise also extends to wind turbines, thus he serves as Northwest Labs' technical advisor to domestic and international wind turbine manufacturers. Eckert holds a BS in science and engineering (1983) from the Technical University of Berlin; a BS of science and engineering in welding engineering (1983) from the Welding Institute of Berlin; and a Masters of science and engineering in materials science (1985) from the University of Pennsylvania. As a graduate research assistant there, he studied monotonic and cyclic fracture (fatigue) behavior of various copper alloys by means of optical microscopy, scanning electron microscopy (SEM) and auger spectroscopy. He has authored a number of technical papers for various associations such as AGMA and STLE. And finally, and of equal importance, Eckert is one damned good auto mechanic.

Prior to his recent retirement, **Phil Terry** was chief metallurgist for Lufkin Industries, responsible for the direction of materials technology across the company, covering the Power Transmission and Oil Field Divisions in the U.S. and their various overseas facilities. He graduated with a degree in metallurgy from the University of Aston in Birmingham, England, and continued academic research in the field of fracture mechanics before receiving his Ph.D. in 1972. Terry worked for the United Kingdom Atomic Energy Authority (UKAEA) on the UK Prototype Fast Reactor program and the installation of the first UK Pressurized Water Reactor. He joined Houston-based oil company Cameron at their Leeds, UK facility and held several positions, including chief engineer R&D, technical manager, and director of central services. Terry has served as Chair of the Leeds Engineering Initiative NGO and continues to work with TWI and BSI standards development. Terry is also a member of the Institute of Minerals, Materials and Mining; a Fellow of the Institute of Mechanical Engineers; a Chartered Professional Engineer; and a member of the American Gear Manufacturers Association, serving in various capacities and on several committees. He has presented numerous technical papers and taught courses on metallurgy and material related subjects in Europe, the Middle East and U.S.

March Li is currently a lead metallurgist at Power Transmission Division, Lufkin Industries, Inc., where he is responsible for material selection, evaluation and application in gearbox, heat treatment (through-hardening and surface hardening), materials characterization and failure analysis, etc. He has Bachelor, Master and Ph.D. degrees in materials science and engineering. Li worked at different universities, research institutes and manufacturing facilities in the U.S., Germany and Japan before joining Lufkin. Li is an active member of the Metallurgy and Materials Committee and Nomenclature Committee of AGMA.

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Topological Gearing Modifications: Optimization of Complex Systems Capable of Oscillation

Johannes W. Vriesen, Daniel Lütfrenk and Klaus Dünck-Kerst

Vibration and noise from wind turbines can be significantly influenced — and therefore reduced — by selecting suitable gearing modifications. New options provided by manufacturers of machine tools and grinding machines, and especially state-of-the-art machines and controls, provide combined gearing modifications — or "topological gearing corrections" — that can now be reliably machined. Theoretical investigations of topological modifications are discussed here with the actual machining and their possible use.

Introduction

Regulations relating to noise emission of wind turbine systems are becoming increasingly stringent worldwide, especially close to residential areas. When generating electric power with offshore wind turbine systems, the excitation of vibration of towers and other wind turbine components plays a special role, and component manufacturers must also take this into account. Standard IEC 61400–11 (Ref. 1) also specifies noise levels that must be complied with.

For wind turbine systems equipped with a main gearbox used to convert torque and speed, vibration and noise are excited as a result of meshing gears under load in the gearbox. This vibration and noise can be significantly influenced — i.e. *reduced* — if suitable gearing modifications are selected.

Gearing Corrections

In practice, a significant differentiation has always been made between specific tooth width and tooth height modifications when modifying gearing (Fig. 2). Excluding the topological modifications, specific profile modifications are frequently orientated to the roll distance or the corresponding gearwheel diameters (Fig. 3), and they apply to each width coordinate of the gear wheel. Previously, many modifications involved a linear gradient; today, parabolic-shaped gradients are employed that enable a continuous-function transition. For helical gear wheels which, in principle, have slight advantages over gear wheels with straight teeth regarding noise, this type of separate modification also has disadvantages. This is because in the tooth meshing area — in particular segments — modifications are made that are actually not required. These unnecessarily increase the maximum pressure when meshing. However, this disadvantage can be resolved by applying specific topological modifications; at the tooth flank, the modified flank shapes shown in Figure 4 are derived from the standard shapes shown in Figure 3 as differences to the theoretical involutes.

The basic relationship between the profile angle modifications and the pressure gradient in the profile direction is shown

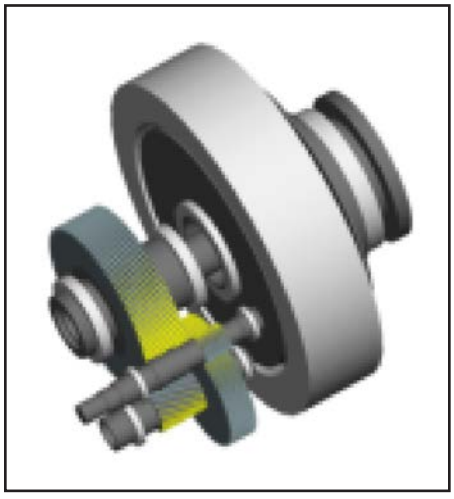

Figure 1 Principle design of a main gearbox for a 2 MW wind turbine (Ref. 2).

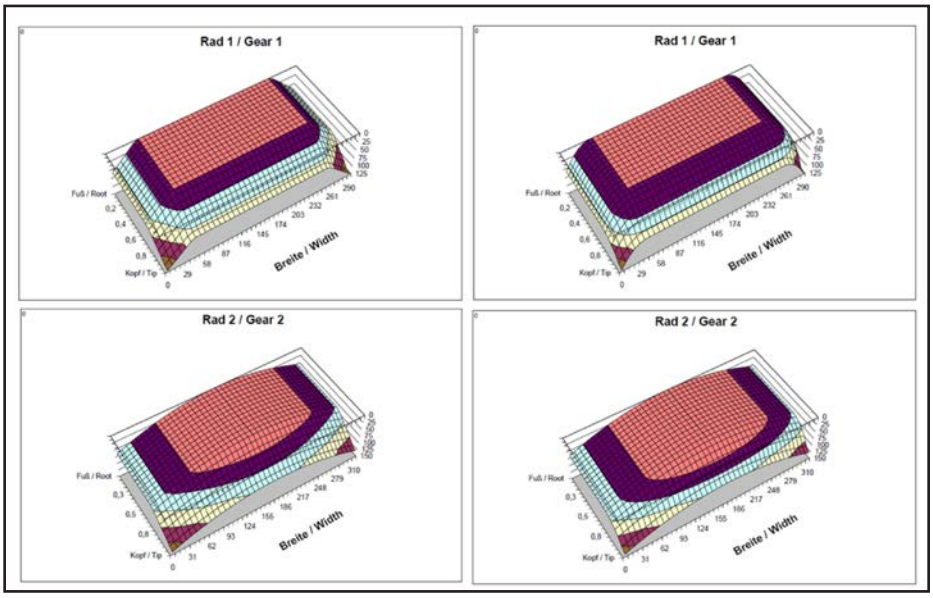

Figure 2 Gearing modifications (Ref. 9).

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(Fig. 5). If the exit impact is reduced by using the appropriate profile angle modification, the maximum pressure level is reduced. If the approach impact is reduced, noise excitation can be further reduced. However, the maximum pressure level is increased when compared to the version without profile angle modification. As a consequence, the profile angle modification must be variably defined over the tooth width.

Influence of the Modification in Tooth Meshing

As a result of new options provided by manufacturers of machine tools/grinding machines — and especially state-of-the-art machines and controls — freely defined gearing modifications can now be reliably machined. These can be applied more specifically to reduce the excitation of vibration and noise without necessarily having to have a negative impact on the load-carrying capacity.

In theory, a distinction can be made between the topological modifications possible in such a first and second generation. For the first generation the profile angle modification is specifically varied across the gearing width. For the second generation a variable modification gradient is incorporated in the tooth width and tooth height directions. For example: For the "Forschungsvereinigung Antriebstechnik (FVA)" Research Association for Drive Technology (FVA), in the form of modification versions known as "generated end/tip relief." For the first generation, in some instances, existing machines with expanded or new control systems can be used. However, this is not possible for the second generation; however 5-axis machines may be used for this purpose.

Two examples of possible variable profile angle modification gradients over the tooth width are shown (Fig. 6). For helical gearing the definitions at the left-hand and right-hand end of the tooth are decisive for influencing impact at both tooth approach and exit. Depending on the design, modified profile angle modification gradients over the tooth width can influence harmonics within specific limits. In principle, the first-generation profile angle modification according to Equation 1 comprises a constant component and a variable component over the tooth width with coordinate x_b.

The functional chain of the excitation effects in the gearbox is shown (Fig. 7), as is the associated formula (Equation 2). One can see that excitation from the meshing gear wheels can normally only be indirectly detected with measurements when the gearbox is operational.

$$C_H\alpha(x_b) = C_H\alpha_{,k} + C_H\alpha_{,v}(x_b) \quad (1)$$

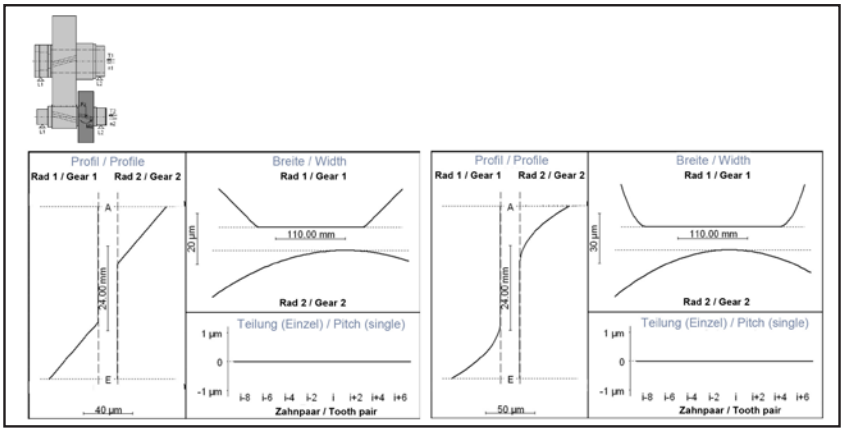

Figure 3 Gearing modifications, separately made in the tooth width and tooth height directions (Ref. 3).

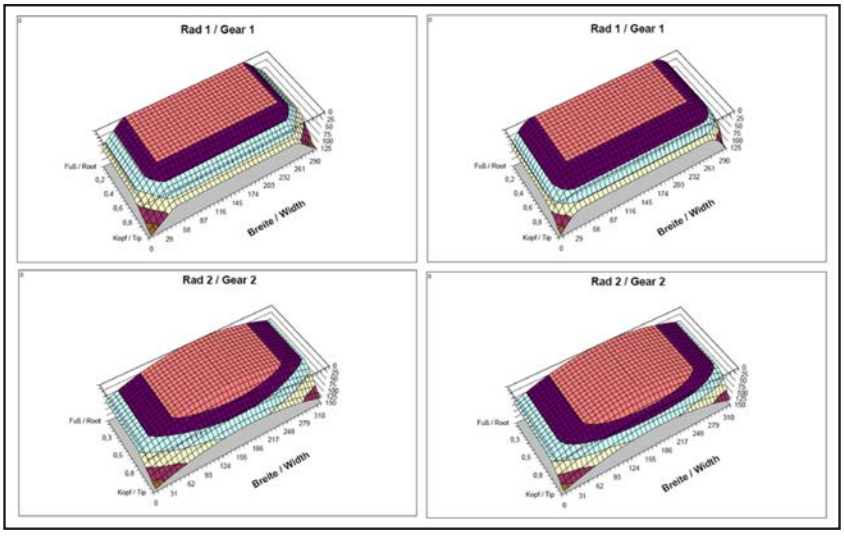

Figure 4 Gearing modifications when combining tooth width and tooth height modifications.

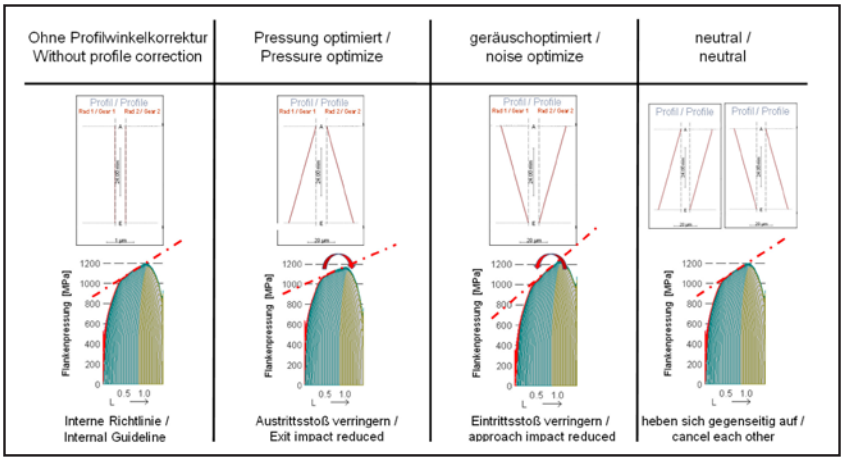

Figure 5 Principal correlation between profile angle modification and pressure gradient.

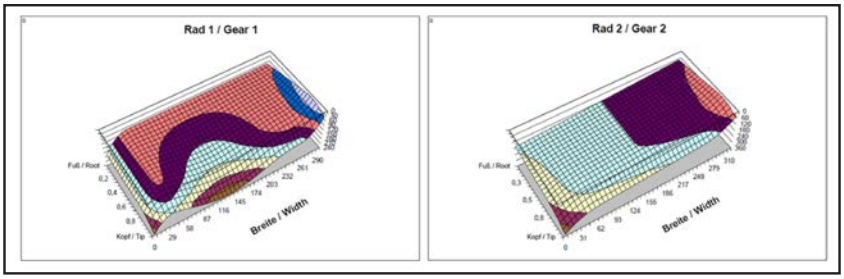

Figure 6 Examples of topological first generation gearing modifications.

$$L_W(f) = L_F(f) + L_h(f) + L_\sigma(f) \quad (2)$$

Gearbox Behavior on the Test Stand

Every wind turbine gearbox manufactured in our company is tested up to its rated load and rated speed. The gearboxes are driven along a ramp-up curve, which is then evaluated to identify possible resonance points and excessive excitation levels. The evaluation of the vibration measurement is shown (Fig. 8) and it also includes the effects of excitation generated as a result of gear wheels meshing. The measured values can be allocated to the sources of excitation based on the gear meshing frequencies.

Figure 9 documents actual examples for reduced excitation levels that have been achieved by optimizing the profile modification when excited with the gear meshing frequencies f_{zE}. From Figure 9 — in conjunction with the principle from Columns 2 and 3 from Figure 5 — it can be concluded that it makes sense to relieve the approach impact at the beginning and to relieve the exit impact at the end of a meshing operation. Following the principle from Figure 6 and Equation 1, this is illustrated by the example in Figure 10, in which the constant component is set to zero. This type of modification allows the excitation to be specifically reduced and, at the same time, uses other areas to increase the load-carrying capacity by reducing the maximum pressure in the meshing area.

When making the design, possible deviations as a result of statistically defined deviation levels for the tooth trace can be taken into consideration. In so doing, the various combinations should be checked with plus and minus ($+f_{ma,ß}$, $-f_{ma,ß}$, $+f_{ma}α$, $-f_{ma}α$). In addition to optimizing the rotation path, the speed-dependent excitation level should also be observed when designing the gearbox.

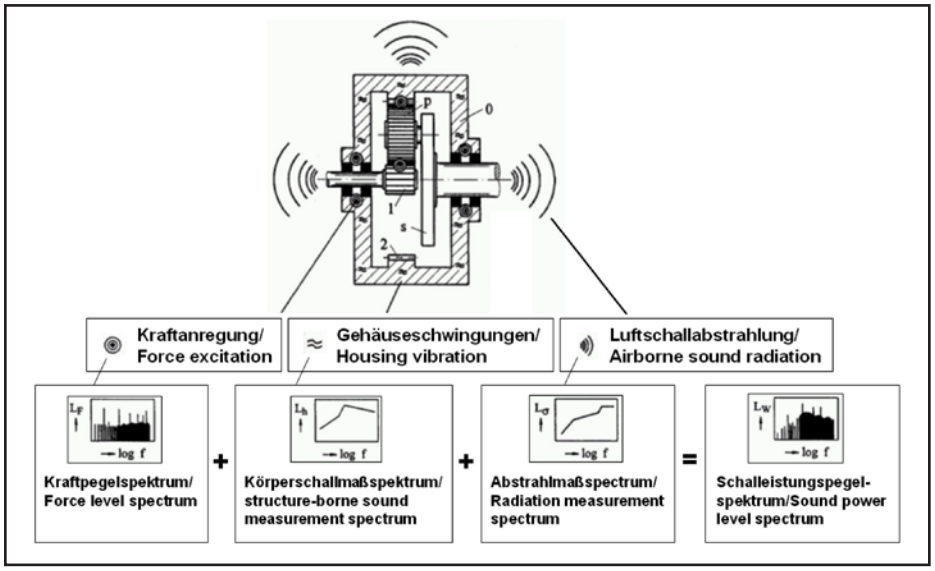

Figure 7 Functional sound transmission chain for a planetary gearbox with continuous estimated curves for L_h and L_σ (Ref. 10).

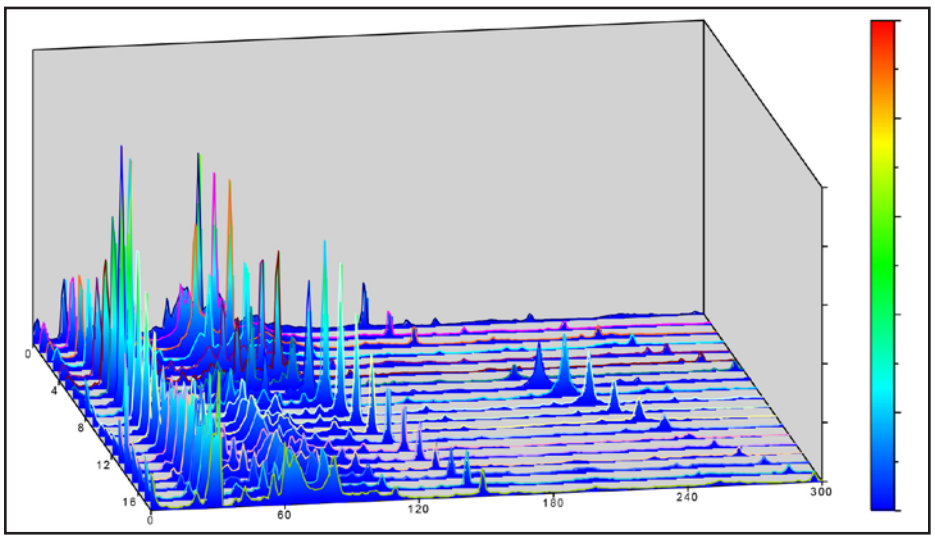

Figure 8 Vibration measurements when ramping up speed.

Manufacturing Prototype Parts

When machining the tooth flanks, deviations are obtained with respect to the theoretically required topology. The differences between the left and right tooth flank topologies of a gear wheel used as example can be identified in Figure 11. The highest deviations with respect to the theoretical topology are at the sides; the differences for the pinion can be taken from Figure 12. For the pinion it can be seen that the left-hand and right-hand flanks are almost identical.

The deviations from the theoretical specification and between the left-hand and right-hand edges are predominantly defined in production by the magnitude of the modification specified. If, for instance, only the pinion is to be modified, then for larger modification, correspondingly higher deviations are obtained. Whether these deviations can be tolerated can be determined when checking the rotation path.

Summary and Outlook

For gearing modifications, a very significant differentiation has always been made in practice between tooth width and tooth height modifications.

- As a result of new options available to manufacturers, topological gearing modifications can be established reliably during the production process — and can be specifically used to reduce vibration and noise excitation sources.
- Using first-generation, topological gearing modifications as examples, it has been shown that it is possible to reduce the approach and exit impact levels without losing load-carrying capacity.
- The deviations in production with respect to the theoretically designed modification topology depend on production technique.
- As a consequence, it also makes sense to take production technique into account when designing and checking gearing modifications.

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Dr. Johannes W. Vriesen began his studies in mechanical engineering in 1992 at Ruhr University Bochum, where he also earned his doctorate and worked as a scientific assistant until 2001. He went to work for Winergy AG in 2001 as a development engineer; later (2003) as project leader for multi-megawatt gearboxes for wind turbines; then (2008) was responsible for technology in the engineering department; and is now (since 2012) senior key expert for gear components at Siemens.

Daniel Lütfrenk is an authority in mechatronics, receiving in 2010 his bachelor's degree at the University of Applied Sciences, Gelsenkirchen, and his master's at Westphalian University of Applied Sciences in 2012—both degrees concentrating on mechatronics. From 2006 until 2010 he apprenticed as a draftsman in the engineering department at Winergy AG and Siemens AG, respectively, before becoming in 2010 a calculation engineer in the engineering/technology department at Winergy AG. He assumed his current position—project engineer for FLUDEX couplings, at Siemens AG—in 2012.

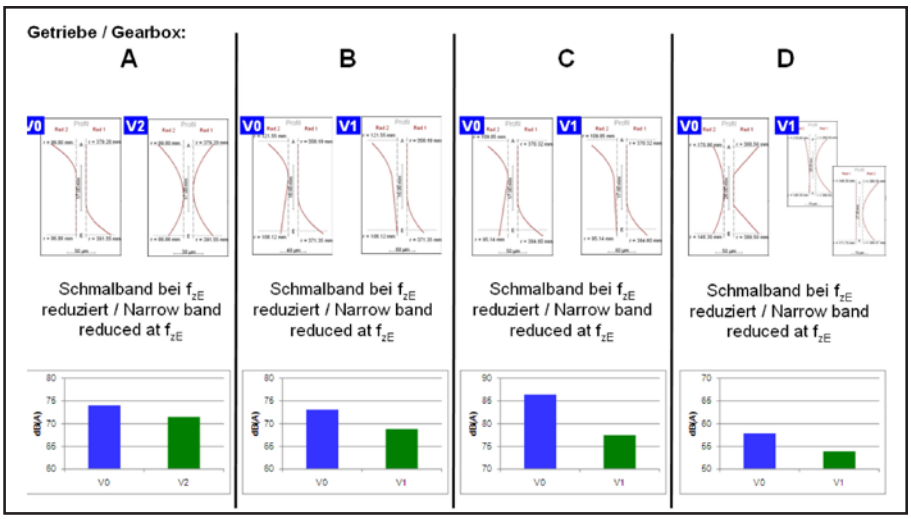


Figure 9 Real examples for specifically reducing excitation by adapting the profile modifications a) pinion; b) wheel.

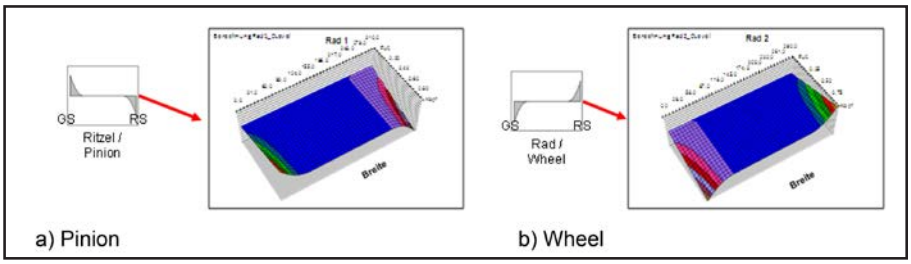


Figure 10 Gear wheel flanks with varying profile angle over the tooth width.

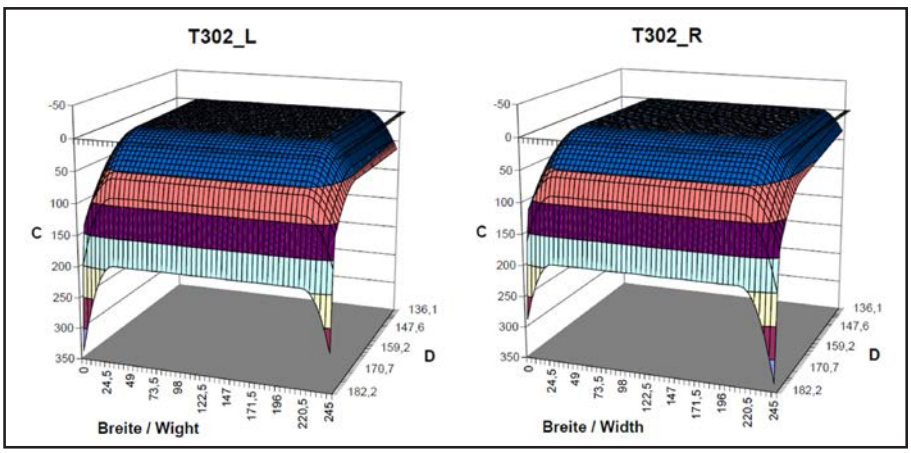


Figure 11 Topology of the production simulation of the left-hand and right-hand gear wheel flanks.

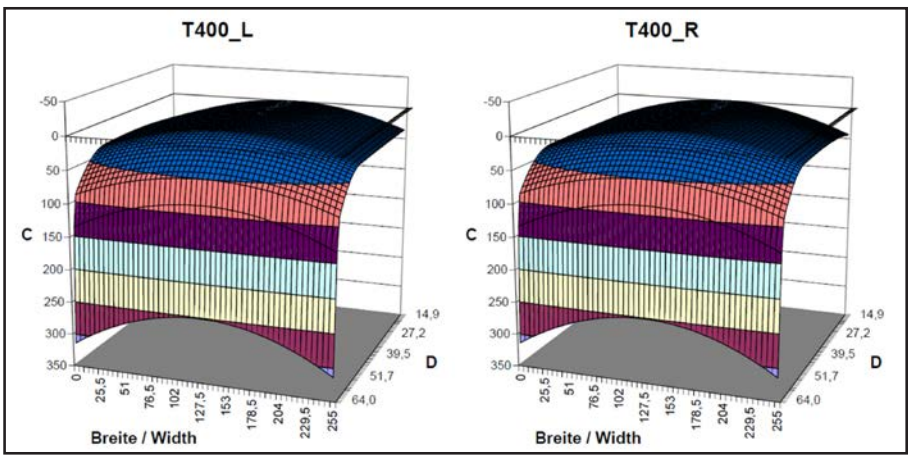


Figure 12 Topology of the production simulation of the left-hand and right-hand pinion flanks.

United Grinding

ANNOUNCES NEW PRESIDENT

United Grinding North America, Inc. recently announced that current president and CEO, Rodger Pinney, has been elected as vice chairman of the company's board of directors in conjunction with his retirement on April 1, 2014. **Terry Derrico** will join United Grinding North America, Inc. as its new president and CEO and assume complete responsibility for leading the company's strategic, tactical, operational and administrative functions in North America. Derrico will report directly to Stephan Nell, CEO, United Grinding Group AG.

"United Grinding North America is enjoying unprecedented growth and the company's future also looks very promising" Pinney said. "I look forward to continuing to serve the organization as vice chairman." In addition to his board member duties, Pinney plans to actively promote North America based manufacturing.

Nell commended Pinney for successfully leading United Grinding North America for 16 years. "Rodger guided the company through various economic climates and market transitions, positioning the company as the best and strongest in the North American grinding business. His unwavering service to the company and its people and passion for the industry will be a continued asset to us as he moves into this new advisory role," he concluded.

Derrico's overall executive and management-based career spans 27 years, and he has a proven track record in the successful growth of the companies for which he has worked. "I am excited to join this highly dynamic company and the incredibly talented and passionate team that drives it," Derrico said. "United Grinding is a visionary company and I look forward to leading the next stage of its growth and development, both horizontally and vertically in the total grinding solutions market. We will continue to develop innovative technological solutions and responsive services to keep our customers productive and profitable, and most of all, competitive."

Derrico spent the past decade in key leadership roles at The Marmon Group LLC, a global Fortune 500 organization with numerous diverse business units that is part of Berkshire-Hathaway, Inc. Most recently, he served as president of the Construction Fasteners Group, having full profit and loss responsibility for the industrial business unit.

Prior to The Marmon Group LLC, Derrico worked for Proton Energy Systems, a manufacturer of hydrogen generators and regenerative fuel cell systems, as senior vice president of sales, marketing and business development. He was also president and CEO of Swiss Industrial Group Holdings, Inc., a global packaging organization; chief operating officer of TMC, a manufacturer of automated packaging equipment; and national sales manager for General Electric Fanuc Automation, an industrial computer and software company specializing in factory automation. Early in his career, Derrico served as an apprenticeship toolmaker and worked his way into tool and manufacturing applications engineering positions.

According to Nell, Derrico is a perfect fit to lead United Grinding North America, Inc. into the future. "Terry applies a hands-on, results-focused leadership approach and believes in motivating teams around a shared vision," he said. "We look forward to continued success and growth under his leadership together with his team."

GMTA

ADDS PERSONNEL AND WELCOMES GERMAN LANGUAGE STUDENTS

GMTA (German Machine Tools of America) represents various top-quality German metalworking machine builders, including Wera Profilator, Pittler, Praewema and WMZ. These machines are sold to the North American market by GMTA primarily for gear and spline production, as well as other power transmission applications. The company's target markets include automotive, off-highway, energy and other heavy equipment manufacturing. Machines are provided for gear honing, gear grinding, the patented Scudding process for gearmaking, polygon milling, turning, gear tooth pointing and multi-task machining operations. GMTA recently announced the addition of **Stefan Kloos** as product manager. Kloos will handle the Pittler vertical turning lathes and WMZ centerdrive lathes. He will be based in Ann Arbor, Michigan, North American Headquarters for GMTA.

In addition, German Language and International Careers (LIC) students from Eastern Michigan University visited GMTA on March 12, 2014. Students were given a tour of GMTA facilities and a presentation in German by GMTA President, Walter Friedrich. As EMU Department of World Languages Professor Margrit Zinggeler Ph.D. pointed out, "Eastern Michigan was one of the first universities to combine foreign language with a practical business component. The EMU major in language and international careers (LIC)

is designed to integrate the study of modern foreign languages and cultures with preparation for an international business career. The major objective of the program is to provide students with the skills, knowledge and understanding needed to function in a foreign environment and in professional dealings with people and clients who speak a foreign language. It is a very useful course of study in today's global economy, especially with so many foreign companies setting up shop in the U.S."

After the presentation and questions, students were invited to a typical German "Brotzeit" (evening meal of German bread and coldcuts) and, of course, ample quantities of German beer Reissdorf Koelsc.GMTA is proud to support young people in the community and help provide them with (German) language opportunities in a business environment.

Gleason Cutting Tools

RECOGNIZED AS JOHN DEERE PARTNER-LEVEL SUPPLIER

Gleason Corporation announced that its Gleason Cutting Tools Corporation facility in Rockford, Illinois has for the second year in a row earned Partner-level status in the John Deere Achieving Excellence Program. This status is Deere & Company's highest supplier rating. Suppliers who participate in Deere & Company's Achieving Excellence program are evaluated annually in several key performance categories including quality, cost management, delivery, technical support and wavelength, which is a measure of responsiveness. John Deere created the program in 1991 to provide a supplier evaluation and feedback process that promotes continuous improvement.

Robert P. Phillips, senior vice president – tooling products group and Gleason Cutting Tools Corporation said "Gleason Cutting Tools Corporation is proud to be a supplier to John Deere, and are honored to have our performance recognized at such a high level for the second year in a row." Partner-level status was awarded to Gleason Cutting Tools Corporation for all cutting tool products and services provided by Gleason to the John Deere operations in Waterloo and Des Moines, Iowa.

Dowding

RECEIVES MPIF VANGUARD AWARD

Robert J. Dowding, research manager for materials and manufacturing science at the U.S. Army Research Laboratory (ARL), Adelphi, Md., has received the first-ever Vanguard Award from the Metal Powder Industries Federation (MPIF). The award recognizes powder metallurgy (PM) industry champions from the end-user community whose long-time promotion of the technology has contributed to the expansion of powder metal applications.

Over the course of Dowding's tenure at ARL, much of his PM-based research and development work has been related to, or in support of, material and process development for tungsten and tungsten alloys. He has performed research examining strain aging in tungsten heavy alloys (WHA), the processing of novel tungsten-based compositions, and the re-spheroidisation of tungsten grains in heavily cold-worked WHAs.

Dowding has been a strong leader in and supporter of the Army's Small Business Innovative Research (SBIR) program since the mid-1980s. As the contracting officer's technical representative (COTR) for more than 35 Phase I and Phase II contracts, his efforts have been leveraged to support multiple mission programs in the materials science and manufacturing of protection- and lethality-related applications. He has also promoted missile programs focusing on powder metallurgy, tungsten research, nanomaterials, armour ceramics, and powder injection molding. Dowding will be presented with the award at the PM2014 World Congress that takes place from May 18–22 in Orlando, Florida.

Gleason Forum

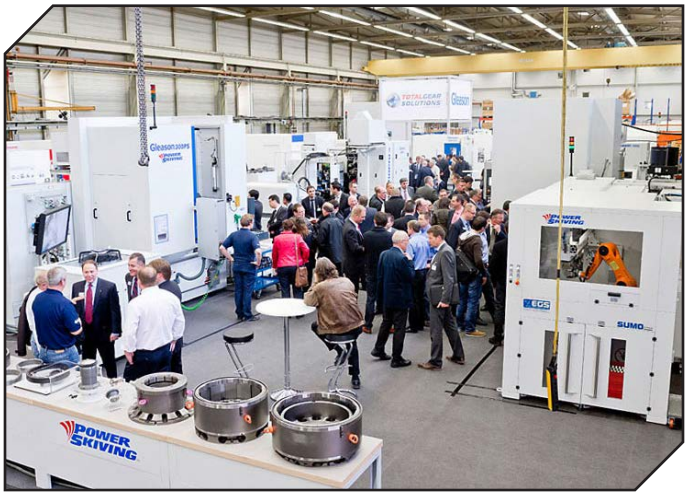
ATTRACTS VISITORS FROM 30 COUNTRIES

Gleason Corporation announced the completion of the Gear Solutions Forum at its Gleason-Pfauter facility in Ludwigsburg Germany, April 1-3, 2014. Gleason hosted approximately 600 visitors from 30 countries over a three day period with a comprehensive display of the latest technologies in gear production and a series of leading experts from the gear industry and academia presenting on significant trends and developments in gearing.

Introduced were brand new machine developments and technologies including the Genesis 200GX double spindle threaded wheel gear grinder, the Genesis 210HCD gear hobber with dual loading stations and integrated chamfering and deburring, and the 100S small gear shaping machine, which was dry shaping with capability up to 3000 strokes/minute. Demonstrated were new gear production processes like Power Skiving, on-board part inspection using Gleason's own *GAMA* metrology software, the new Phoenix 280G bevel gear grinding machine and the 300GMS analytical gear inspection machine. In total were more than 15 gear production machines providing live demonstrations, along with the industry's largest and most diverse offering of gear cutting tools and workholding. Complementing products and processes were service and support capabilities, including machine rebuilds and retrofits, training and service programs.

Joining Gleason at the event was a host of partners and technology providers to the gear industry who exhibited at the Forum. This included companies providing software, heat treatment, coatings and machining solutions.

Also introduced for the first time was Gleason 4.0, Gleason's vision and systems architecture for digital manufacturing for the future. This topic stimulated significant interest from the attendees as they consider the next major step in design and production of gear systems.



Said John J. Perrotti, president and chief executive officer of Gleason Corporation, "This was the third time we have hosted this event and customer response just continues to grow. The Gear Solutions Forum has truly evolved into the global gear industry's most comprehensive educational event of the year". The next Gear Solutions Forum is scheduled to be held in September 2015 in Rochester New York, home of the Company's corporate headquarters and of The Gleason Works facility. 2015 will be the 150th anniversary of the company.

EMAG

LAUNCHES APPRENTICE PROGRAM

EMAG has an ongoing interest in providing job opportunities for highly skilled, specialized machine tool technicians. To encourage continuing growth in Michigan's mechatronics manufacturing industry and ensure an advanced workforce to close the sector's skills gap, EMAG has launched an apprentice training program, together with the Michigan Economic Development Corporation, Oakland Community College and Henry Ford Community College. The program offers high-school graduates a career in machine Mechatronics, a discipline

Rebekka Neumann and Matthew Combs, apprentice mechatronics technicians on the EMAG shop floor.

incorporating electrical, electronic and mechanical studies, providing all graduates an Advanced Associate's Degree.

Over the course of three years, the students will rotate educational semesters at the colleges with practical learning on the shop floor of EMAG. "This program is unique in that it is the first of its kind here in the U.S. that will develop a talent pipeline for the manufacturing industry," stated Mike Kjorli, EMAG shop floor manager and designated mentor to the company's apprentices. "The participating colleges asked companies for their input to develop a real world curriculum, making it truly tailored to the needs of the industry," Kjorli added. All tuition and student fees, as well as supplies are provided by the EMAG. The combined classroom and work curriculum offers the students with both paid employment during their studies and a guaranteed position with the company upon successful graduation. Rebekka Neumann, hired by EMAG as an Apprentice Mechatronics Technician, stated, "This program takes a different approach. You apply everything you learn at your job then graduate with a degree, a job and no student loan debt."

The apprenticeship program's goal is to introduce more people to the mechatronics technician field, providing critical support to engineers, increasing the sector's economic strength and ability to attract and retain desirable jobs. "This will prepare them for many work opportunities in the mechatronics field, not only at EMAG, but in the whole industry," stated Kjorli. Two applicants, Matthew Combs and Neumann, were hired by EMAG at the start of the program. After completing their first educational semester, both joined the EMAG team in January 2014 to begin the practical rotation of their apprenticeship.

A substantial investment by the EMAG management team helped to launch the apprenticeship program in Fall 2013. It has received recognition from U.S. Senators, State of Michigan officials and extensive support from college representatives. "This program is very special for me, as I studied the then-new area of Mechatronics in school myself," stated EMAG CEO Peter Loetzner. "I have always believed it is necessary that we help educate and train the next generation of engineering, operator and maintenance personnel. Nothing happens in industry if the machines are not working properly. We at EMAG are very proud to participate in this important program, which not only benefits us, but Michigan and the Detroit area, in particular."

Mitsubishi Heavy Industries

WELCOMES WEGRYN-JONES TO SALES TEAM

Mitsubishi Heavy Industries – Machine Tool Division is pleased to announce the employment of **Ross Wegryn-Jones** as regional sales manager for gear machines. Wegryn-Jones has vast experience in the gear industry including gear, spline & shaft products to print, gear grinding and measuring machine tools and workholding. He has over 24 years' experience in the machine tool & manufacturing industries. Wegryn-Jones holds a BA from Michigan State University in Marketing & Advertising and an MBA in Management from Western Michigan University. His passions include family, radio controlled aircraft, sailing and soccer when he's not keeping up with his four daughters.

KISSsoft

HOSTS ISO WORKGROUPS

During the week of April 7 to 11, several meetings of ISO Workgroups took place at KISSsoft AG headquarters. Workgroup 6, chaired by Professor Höhn, is intensively engaged in the development of a Technical Report, in which for the first time eight examples of calculations according to ISO 6336 will be documented. This work is very important for KISSsoft, because it can demonstrate that the software correctly implements the ISO 6336 and gets the same results, as they will be published in the standard.

After concluding the new issue of the ISO 1328-1 for cylindrical gear tolerances, Workgroup 2 works now on the Technical Report 10064: Code of inspection practice. The ISO 1328-1 was published in 2013 and is included in the new

KISSsoft Release 03/2014. Since the differences compared to 1995 are considerable, both versions of Part 1 are now available in *KISSsoft*. It will most likely take time until the new tolerance values are generally considered. Workgroup 7, chaired by Dr. Octrue, is concerned with the geometry and strength of worm wheels. The different flank forms of the ISO TR 10828 are implemented in the 3-D worm models of *KISSsoft*.

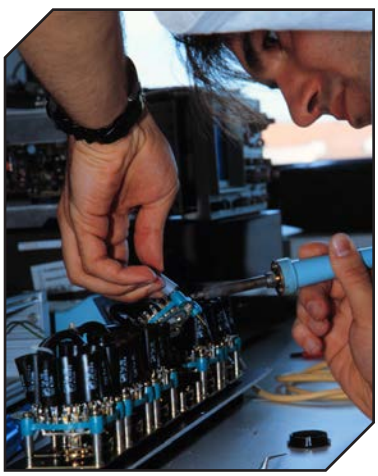
Trescal

ACQUIRES INSTRUMENT CALIBRATION SERVICES

Trescal recently announced that it has acquired Instrument Calibration Services and Test Equipment Repair Corporation, two companies that provide calibration and repair services for a wide variety of measurement and test equipment. The two transactions consolidate Trescal's geographical footprint and enhance its calibration and repair capabilities in North America.

The deals were completed with the support of Trescal's majority shareholder, Ardian, the premium independent private investment company, and underscore Trescal's position as a leading global provider of calibration services through its global network of over 67 owned calibration laboratories. This is the fourth expansion since Ardian acquired Trescal in July 2013.

Instrument Calibration Services and Test Equipment Repair Corporation — both based in Atlanta, GA, and A2LA accredited — generated roughly $4.2 million in sales last year and have 24 employees including 18 engineers. The terms of the deals are not disclosed.



"The acquisition furthers our growth strategy in North America, and marks another significant step towards our goal of dominating the market within two years," Guillaume Caroit, general secretary of Trescal said. "Once again, the expertise of the teams and the reputation of these companies were critical aspects of both acquisitions."

Britt Myers, president and founder of both Instrument Calibration Services and Test Equipment Repair Corporation, said joining Trescal, a market leader in test and measurement equipment services, was an extraordinary opportunity.

"I am happy to transfer my teams to Trescal, as this group is a pure player and specialist in calibration services strengthening its leadership position as a comprehensive test equipment solutions provider. I am confident that this transaction will be beneficial for both parties and their customers. Also, I would like to thank Guillaume Caroit and Lonnie Spires for their efforts and their professionalism," Myers said.

Thibault Basquin, managing director of Mid Cap Buyout at Ardian, also applauded the deal, noting the strong prospects for Trescal as it continues to work closely with Ardian. "This latest acquisition fits perfectly with the strategy we laid out when we acquired Trescal," Basquin said. "Both the Ardian and Trescal teams have implemented an ambitious roadmap with a view to accelerate external growth and we are confident that new transactions will be announced in the coming months."

PTG

COLLABORATES WITH UNIVERSITY OF HUDDERSFIELD

Committed to the advancement of machine tool technologies, Precision Technologies Group (PTG) has signed a 'Memorandum of Understanding' with The Center of Precision Technologies at the University of Huddersfield.

PTG and the University of Huddersfield have worked together on a range of projects over a number of years. In signing the agreement, both parties have shown their commitment to collaborate with the aim of creating a Research and Development Center in Machine Tool Technology at the University.

As part of the agreement, the position of 'Chair in Machine Tool Technology' will be created and, in the first instance, held by Professor Alan Myers of the University of Huddersfield. Additionally, 'Visiting Researcher' status will be granted to an individual nominated by PTG and approved by the University.

In the first instance, this role will be held by Professor Christopher Holmes, general manager of PTG division, Holroyd Advanced Developments. As a further benefit of the agreement, PTG will be given access to the University's on-campus, high-performance computing resources, which will make intensive simulations very much faster.

"Professor Myers has taken part in meetings with our designers and advised us on thermal behaviour," comments PTG's Professor Holmes. "The work we plan to do is ambitious. We are discussing software modelling of machine tools to predict static deflections, dynamic responses, and thermal behavior, all of which have an effect on accuracy. By modelling these factors in advance, we can assist our designers. We also hope to have a software model of a machine, which will permit virtual parts to be machined and control software to be developed, without the need for a real machine to be available."

"We are delighted to have embarked on this exciting partnership with the University of Huddersfield," comments PTG Group Business Development Director, Neil Jones. "At Precision Technologies Group, we have a reputation for not only embracing the very latest manufacturing technologies, but also for innovation. Consequently, we look forward to the ben-

From left to right: Dr. Tony Bannan (PTG), Professor Alan Myers (University of Huddersfield), and Professor Christopher Holmes (PTG).

efits that working with the University of Huddersfield can bring to our global customer base."

Professor Myers, who recently visited CHMTI (the machine tool division of PTG's Chinese parent company) with PTG Chief Executive Officer, Dr. Tony Bannan, added: "The Center for Precision Technologies at the University of Huddersfield has established a growing relationship with PTG over a number of years now and has also welcomed several Chinese executives and engineers. The Memorandum of Understanding will take our partnership with PTG to a new level as we seek to push the boundaries of machine tool technology. Additionally, I am delighted to welcome Professor Christopher Holmes as a Visiting Researcher at the University. His vast experience will bring that specialist industrial knowledge to our work that will be crucial in what we hope to accomplish."

Dedicated to the advancement of technology, PTG is also platinum sponsor for City University London's biennial International Conference on Compressors and their Systems. The conference is widely regarded as one of the world's leading events in compressor technology, and City University London is globally recognised as a premier center of excellence for compressor design and development. PTG has sponsored the event since it was first held in 1999.

Renishaw

ACQUIRES ADVANCED CONSULTING AND ENGINEERING

Renishaw has purchased the business of Advanced Consulting & Engineering, Inc. (ACE), a U.S.-based supplier of dimensional measurement products and services focused on the automotive industry.

The acquisition of family-owned ACE, based in Rochester Hills, Michigan, provides Renishaw further specialized programming capabilities using leading industry packages, and will help to support Renishaw's sales of coordinate measuring machine (CMM) probing systems and Equator gauges in the USA.

For over 15 years ACE has provided a range of in-house and on-site measurement services to its customers including contract inspection, CMM fixture design, machine retrofits, CMM programming, training and full turnkey solutions from concept to completion. Since 2011 the company has also been a distributor of Renishaw's CMM and gauging products, including REVO, PH20 and Equator. ACE has A2LA lab accreditation.

"We are very excited at becoming a part of the Renishaw Group, which is globally respected in the metrology industry," said Ken Bergler, founder of ACE."This is a great opportunity to expand our existing operations, and I believe that we can make a significant contribution to Renishaw's U.S. operations through the specialized skills we have developed servicing our high quality customer base."

Leo Somerville, president of Renishaw Inc, added: "This is an excellent acquisition for Renishaw and further underlines our commitment to invest in the development of our metrology business. We have known Ken and his team for many years, over which time ACE has built an excellent reputation for delivering high quality measurement solutions, particularly for demanding applications in the automotive sector. As Renishaw continues to focus on supplying end-user metrology solutions, including CMM retrofits and installations of our Equator gauge, the specialized programming and applications knowledge of the ACE team will be particularly valuable."

From left, Jeff Keller, Jeremy Holbrook, Ken Bergler, Kristin Monahan, Jason Christensen, Kurt VonLinsowe.

H-D Advanced Manufacturing

APPOINTS DON BROWN PRESIDENT AT OVERTON

H-D Advanced Manufacturing Company (H-D), a heavy duty industrial company focused on high-precision manufactured products used in motion control and other applications, announced today that Donald A. Brown has been appointed president and CEO of its subsidiary, Overton Chicago Gear Corporation (OCG or the Company), a leading manufacturer and provider of large, custom, mission-critical gears, gearboxes and repair services. Mr. Brown brings to OCG more than 20 years of management experience in the global manufacturing sector. Former OCG Chief Executive Officer Lou Ertel will remain Chairman of the Company's board, in addition to his duties as chairman of the American Gear Manufacturers Association.

Brown joins OCG from Carlisle Brake & Friction, a $350m division of Carlisle Companies (formerly Wellman Products Group) where he was vice president of Global Operations and Carlisle Operating Systems (COS). During his eight-year tenure at Carlisle Brake & Friction, he was responsible for the company's global operations, including sourcing, purchasing, engineering, quality and quality systems, COS, and Environmental, Health and Safety functions.

Christopher DiSantis, CEO of H-D Advanced Manufacturing Company, said, "We are proud to have attracted an executive of Don's caliber to lead OCG. Don is a highly accomplished manufacturing executive and a proven leader. He is widely known for his uncompromising drive for operational excellence, and his hire is a great development for our customers who will benefit from his relentless focus on customer service. We look forward to OCG's successful future under his leadership."

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Procurement
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3

GOAL FOR IMTS 2014
I look forward to seeing firsthand what emerging technologies are available for the manufacturing sector, and bringing that information back to my own facility. What I learn at IMTS often leads to improvements on a local level, but it also helps me bring quality information back to our global sites.

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Where else can you meet the minds that are moving manufacturing forward? Nowhere but IMTS 2014. With a focus on success through cooperation, the week will be filled with technology, education, and ideas that we can all benefit from. Join us at McCormick Place Chicago, September 8–13, 2014. Learn more at IMTS.com.

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IMTS 2014

**COME TOGETHER.
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May 18–22—PM2014 World Congress. Orlando. PM2014 World Congress boasts more than 450 experts presenting the latest in PM, particulate materials, tungsten, refractory and hard materials. An inaugural conference on additive manufacturing will feature worldwide industry experts presenting the latest developments in this fast-growing field. It is an essential meeting for anyone interested in metal components produced via additive manufacturing. The trade exhibition will include 175+ booths from suppliers in the PM industry. Special conference events include global trends sessions, three luncheons, a welcome dinner and a closing dinner. Conference session topics include composites, mechanical properties, sintering, magnetics, heat treatment and more. For more information, visit *www.mpif.org*.

May 21–22—AGMA Spring Marketing & Forecasting Conference 2014. Crowne Plaza O'Hare, Rosemont, Illinois. Growing automotive production, housing construction and capital spending are positive indicators for gearing in the near term. But, our industry faces risks from uncertain government policies, a slowing energy sector and weak markets in Europe and Asia. The AGMA Marketing & Forecasting Conference will have a line-up of presenters to help make sense of these competing forces: AGMA's economists (IHS Global Insight) will give their assessment and forecast for the industry and 10 end user markets; two experts representing sales channels for manufacturers' representatives and agent and industrial distributors will discuss how to improve your sales through these two channels; special speaker on the evening of May 22 from the Chicago Federal Reserve. For more information, visit *www.agma.org*.

June 9–12—The Big M 2014. The Big M is not only devoted to answering the big questions about the future of manufacturing. It's also focused on the entire manufacturing process – from design to production to quality to sustainability, and much more. The Big M is ultimately about helping you find the solutions you need here and now. The Big M takes networking to a whole new level. Real working sessions provide a level of collaboration you've never experienced before – with real results. "Connection Stations" throughout the exhibit area encourage impromptu meetings. Small group networking sessions, matchmaking opportunities and social events will help you make connections and build alliances across multiple industries. The Big M includes Rapid 2014, SME Annual Meeting and NAMRC. For more information, visit *www.sme.org*.

June 9–11—Gear Failure Analysis Software. Big Sky Resort, Big Sky, Montana. In AGMA's Gear Failure Analysis Seminar, attendees will examine the various types of gear failure, such as macropitting, micropitting, scuffing, tooth wear and breakage. Possible causes of these failures will be presented, along with some suggested ways to avoid them. A gear failure analysis expert will use a variety of tools and methods – lectures, slide presentations, hands-on workshops with failed gears and Q&A sessions – to give you a comprehensive understanding of the reasons for gear failure. Participants are encouraged to bring their own failed gears or photographs and discuss them during the Q&A sessions. The seminar brings together a vast amount of knowledge not available elsewhere. It will help you solve everyday problems whether you are a gear engineer, user, researcher, maintenance technician, lubricant expert, or manager. Attendees will treasure the course manual as a permanent reference and guide for failure analysis. It offers over 100 color photos, dozens of illustrations, a textbook and failure atlas. The course is instructed by Robert Errichello from Geartech. For more information, visit *www.agma,org*.

June 10–11—NAM 2014 Manufacturing Summit. Washington, D.C. The National Association of Manufacturers asks you to join your fellow manufacturers from across the country to meet with legislators and advocate policies that play a critical role in our nation's economic growth. Last year, over 550 manufacturers of all sizes from across the country attended this two-day Manufacturing Summit and made over 210 visits to congressional offices to highlight their personal stories and concerns about key manufacturing issues. The Manufacturing Summit is the perfect time for you to connect with freshman members, as well as other key members of Congress to discuss a host of issues that impact not only the business community but your company, your workers and your bottom line in a meaningful and impactful way. It's time for manufacturers to lead. For more information, visit *www.nam.org*.

June 17–19—Gear Manufacturing & Inspection. In this seminar, attendees can gain a broad understanding of the methods used to manufacture and inspect gears – and much more. They will take it one step further, learning how the resultant information can be applied and interpreted in the design process. First, learn about methods behind a variety of gears, including external and internal spur, single and double helical gears, as well as bevel and worm gears. A description of each basic manufacturing and inspection method is provided. Both the methodology and underlying theory are explained. The seminar also covers the methods of specifying the data required to control both the manufacturing and inspection processes on an engineering drawing and in a specification. This includes both the data to be defined and the presentation of the data on the engineering drawing. The course is instructed by Raymond Drago, chief engineer - gear technologist, Drive Systems Technology, Inc. For more information, visit *www.agma.org*.

June 24–25—International VDI Congress Drivetrain for Vehicles. Friedrichshafen, Germany. The 14th Congress allows attendees to discuss with over 1,200 experts on topics such as hybrid, MT, AMT, AT, CVT and AWD. Companies participating in various lectures include ZF, BMW, Getrag, Jatco, Ford Motor Company and more. Topics include NVH, components, clutches, transmission control, hybrid drives, mobile machines, testing drivelines. Rene Borbonus will give an evening presentation (Respect! How to gain prestige with friends and foes) that deals with professional communication. Current exhibitors include KISSsoft, Getrag, GKN Driveline, Liebherr, Oerlikon Graziano, Romax Technology, Schaeffler, SKF, Victrex, ZF and more. *Gear Technology* is a media sponsor of the event. For more information, visit *www.getriebekongress.de*.

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❑ Product Design, R&D Management (H)
❑ Product Design, R&D Department (I)
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5 → How are YOU involved with gears (check all that apply)?

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☐ My company BUYS gears (22)
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In Aviation, Pants Are Optional

The long and colorful history of aviation is comprised of many chapters and giants. The chapter we're reviewing in this installment of Addendum is the invention and development of the retractable landing gear. We'll also touch wings with a couple of those "giants" — i.e., Jack Northrup and Leroy Grumman — both of whom played key early roles in determining a most critical design element for the critical landing gear: Pants or no pants?

That is the question. But first some much needed context.

It was the Roaring Twenties and by then the flyboys were pretty sure the aviation thing was a winner, so of course the American thing to do was to make it even better. One immediate goal was — of course — *more speed* with *less fuel*. Serious testing began. Indeed, the National Advisory Committee for Aeronautics (NACA) in 1927 debuted its Propeller Research Tunnel (PRT) at Langley Memorial Aeronautical Laboratory in Virginia. The wind tunnel — unique for its time — could accommodate an entire airplane for testing. NACA engineers suspected that aircraft landing gear contributed to much of the drag of an airplane, and the PRT was the first wind tunnel that would allow them to confirm their suspicions.

Tests in the outsize tunnel immediately confirmed that landing gear contributed nearly 40% of fuselage drag. This shocked the researchers — and handed them a "eureka moment."

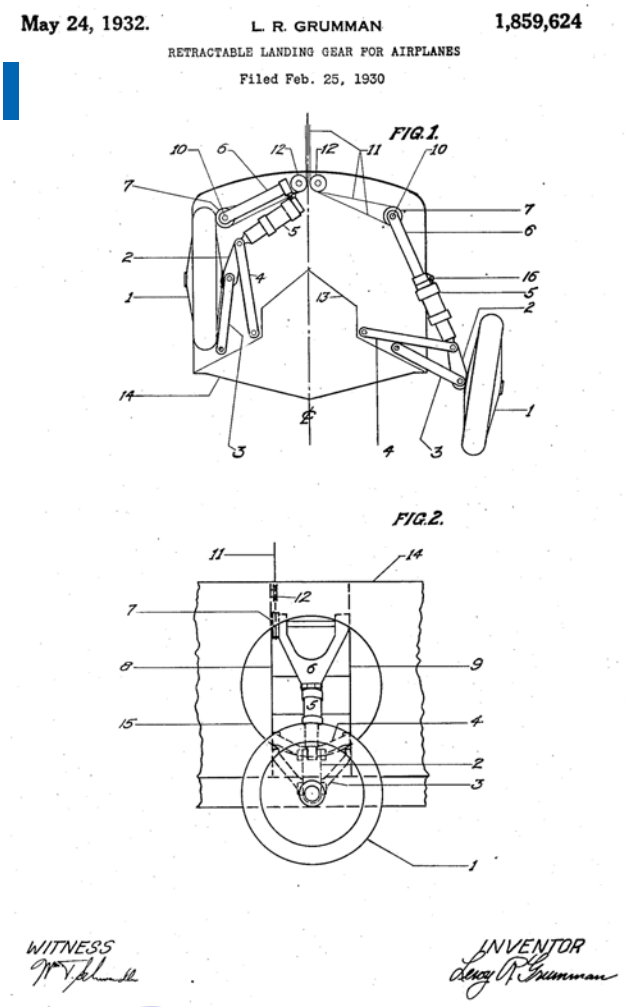
They now realized that reducing drag produced by landing gear would significantly improve the overall performance of the airplane in flight. And, they were aware of several ways to reduce the drag of the landing gear. The two most obvious methods were to either retract the landing gear inside the aircraft, or to redesign a fixed landing gear so that it produced less drag while still protruding below an aircraft. At the end of the day, the bottom line for designers is — as mentioned — overall performance. Which, in turn, led designers of that period to a consensus that landing gear should be brought up into the fuselage, thus removing all resistance and accompanying drag.

(In fact, it was determining this delicate balance between the extra weight of the gear and the reduced drag that was most important for the overall acceptance of retractable landing gear.)

But consensus is not unanimity. There remained many who felt fixed landing gear were the best approach, an approach that could be improved aerodynamically with the addition to the landing struts of something never seen on landing gear before: *"pants."*

It's true. That is what the designers came to call the metal shrouds that enwrapped the fixed landing gear. These streamlined coverings that extended down from the fuselage with the wheels sticking out at the bottom, were also known — somewhat more elegantly — as "trouser gear." Jack Northrup, a leading proponent and one of the last holdouts for gear pants (but he called them "cowls") — clung to his design — until the late 1930s.

For it was in 1937 that the humble yet now irreplaceable O-ring (as we remember the Space Shuttle Challenger) was born, making simple hydraulic systems suddenly possible for moving retractable gearing into place. (Early iterations were either hand-cranked or driven by inefficient electric motors.) When the O-ring came online, the improved hydraulic systems became practical for retracting wheels.



And since the outbreak of WWII, the rule has been fixed wheels for light planes flying less than 200 mph; retractable gear for fast commercial and combat planes.

To get to the end of the story, we need to retrace a bit.

The first U.S. patent for retractable landing gear was awarded in 1925 to American Paul G. Zimmerman and Russian Boris V. Korvin-Kroukovsky, both of Monmouth, New Jersey. And the Boeing Monomail (1930), along with the Lockheed Model 9 Orion (1931), are generally considered pioneers in the development of retractable landing gear, proving that it was practical.

In 1932, aware of the U.S. Navy's desire for retractable landing gear, Leroy Grumman was awarded U.S. Patent 1,859,624, *Retractable Landing Gear for Airplanes,* based on an earlier design of his. The innovative, manually operated landing gear helped win a number of Navy defense contracts for his company.

But it was after the outbreak of World War II in Europe that Grumman's still scuffling company realized almost overnight success as the war prompted France and Britain to order a skyful of F4F Wildcats — Grumman's first monoplane fighter design and still bearing his original signature design element — the retractable undercarriage that had been created in 1932 — *with pants*. (Sources*: www.century-of-flight.net; Googlepatents.com; www.uh.edu/engines.*)

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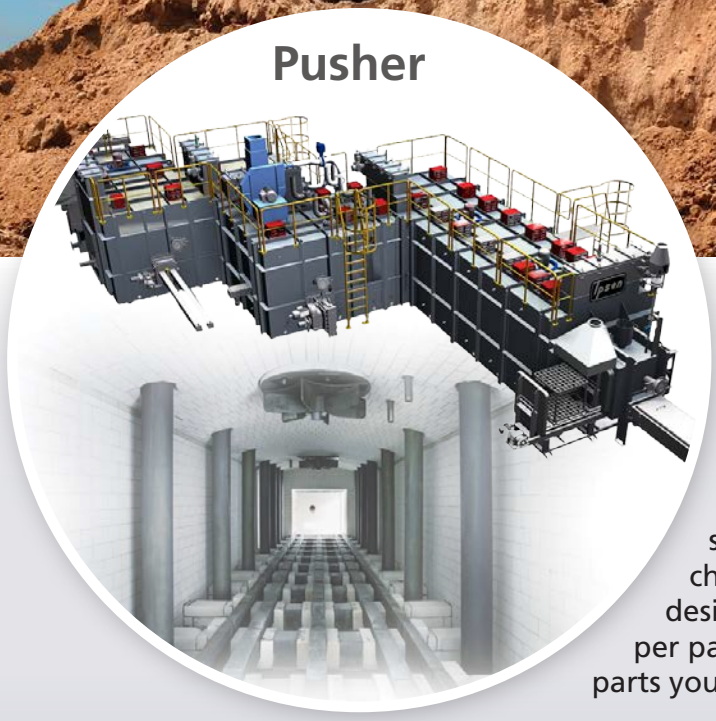

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