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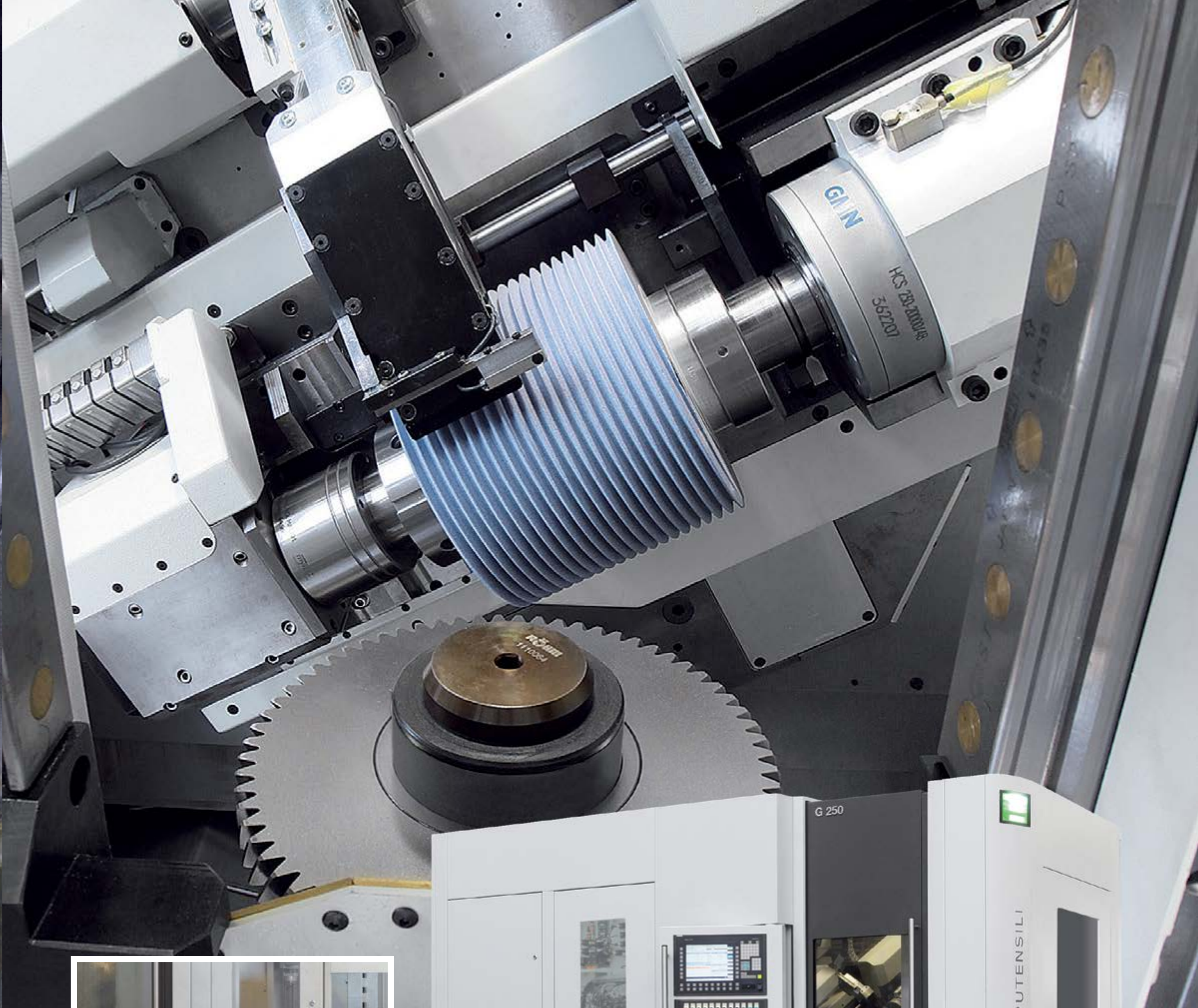

The G 250 / G 450 can be easily equipped with various automation solutions

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features

technical

Vol. 30, No. 7 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, July and December by Randall Publications LLC, 1840 Jarvis Avenue, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). Randall Publications makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1840 Jarvis Avenue, Elk Grove Village, IL, 60007. Contents of ads are subject to Publisher's approval. Canadian Agreement No. 40038760.

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departments

Gear Grinding on a Kapp Niles machine
Photo by David Ropinski

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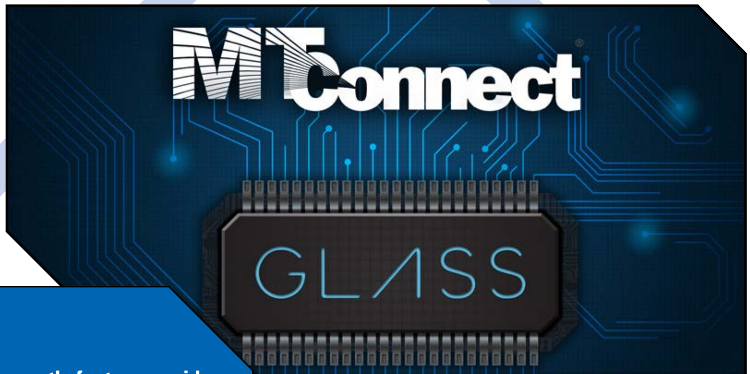

GT VIDEOS

The *GT* website currently features a video on how the MTConnect+Google Glass app works from ITAMCO. For more information, visit *www.itamco.com/glass.html.*

Gear Expo Coverage

Gear Technology and *Power Transmission Engineering* hosted two successful events during Gear Expo. Check out the Gear Expo photo album on our Facebook page at *https://www.facebook.com/pages/Power-Transmission-Engineering/109042075794176?ref=hl#* .

LinkedIn

Check out our LinkedIn page for upcoming trade shows, seminars or educational events like the 12th International CTI Symposium and its flanking specialist exhibition aimed at people seeking the latest developments in automotive transmissions and drives for passenger and commercial vehicles.

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BPA WORLDWIDE


Hunting For
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US Navy MH-60S Seahawk helicopters patrolling for mines out ahead of surface vessels use a powerful and precise Carriage Stream Tow and Recovery System (CSTRS) to quickly raise and lower mine-hunting and destruction equipment. Very high-precision gears from Forest City Gear help to ensure that the mission goes as planned. In this and many other aerospace and defense applications, Forest City Gear is helping customers meet their gear challenges – no matter how difficult to detect.
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NAVY

Opportunity Knocked

Publisher & Editor-in-Chief
Michael Goldstein

For anyone involved in gear manufacturing, Gear Expo is an absolute treasure. In 2013, it was bigger and more varied than it's been in a decade. With 226 exhibitors covering every conceivable gear-related technology, Gear Expo offered visitors unparalleled opportunities to interview potential new suppliers. More importantly, many exhibitors were showing new technology—in some cases, game-changing technology with the potential to improve your productivity, not just incrementally, but by an order of magnitude. 3M's Cubitron II and Gleason's power skiving were just two examples.

Gear Expo was equally impressive from a gear buyer's perspective. With more than 50 of the world's leading suppliers of gears and gear drives exhibiting, gear buyers had a wide variety of potential suppliers to visit, including manufacturers of plastic, powder metal and cut steel gears for aerospace, industrial, automotive and many other industry sectors.

On top of all that, the exhibition was once again co-located with ASM's Heat Treating Conference and Exposition, as well as AGMA's Fall Technical Meeting, providing even more learning opportunities for visitors.

The folks over at AGMA put on quite a show, and overall attendance was up considerably. The final tally was 3,466, according to Jenny Blackford, AGMA director of marketing communications. This is up nearly 12% compared to the show in Cincinnati two years ago.

Although some exhibitors expressed concern that the foot traffic is still light, many were pleased with the quality and motivation of the attendees who came with projects in hand and intentions to buy. We saw visitors from companies like General Motors, Chrysler, American Axle, Caterpillar, Eaton and so forth—the types of visitors that exhibitors like to see. And although they didn't come in large groups, they came with specific needs.

So overall, Gear Expo 2013 was a very good show. I just wish more of you had been able to take advantage of it. It continues to amaze me that this show doesn't attract far more visitors.

As for us at the *Gear Technology* family, we considered Gear Expo 2013 to be a resounding success. As has become our custom over the last several shows, we transformed our booth into a gourmet coffee bar with freshly made espresso, cappuccino and latte drinks served to visitors and exhibitors alike, many of whom came back for seconds or thirds and told us we had "the best coffee at the show."

We also expanded on an idea we started two years ago hosting a dinner for our technical editors; this year we also broke bread with a number of authors who have been significant contributors to the magazine over the years. In attendance were some of the leading minds in gear technology, whose work continues to inform the gear industry through their research and writing (see our news item on pp. 70 for a full list of attendees).

The dinner was a great opportunity for our staff to get to know many of these contributors on a more personal level, and to learn more about the work of these important individuals. In addition, by fostering and developing these relationships, *Gear Technology* will continue to provide the most relevant, accurate and significant technical articles available for your educational benefit.

Our sister publication, *Power Transmission Engineering*, held a marketing seminar and breakfast for gear manufacturers, in which some of the key concepts of branding that help differentiate one gear manufacturer from another were explained. The seminar was extremely well attended, with more than 50 in the audience and the crowd spilling into the aisles around our booth. If you'd like more information about the presentation, contact Associate Publisher/Advertising Sales Manager Dave Friedman via e-mail at *dave@powertransmission.com*.

Finally, our booth included a wide-screen TV with a display of video recordings "starring" *Gear Technology* readers, who talked not only about what they do and how they're involved in the gear industry, but also about what *Gear Technology* means to them. The video presentation included many of the leading manufacturers in our industry, and we thank them for their participation. The video was so well-received—and our readers so enthusiastic about what we do—that several visitors volunteered to have their own videos recorded right there on the spot.

Thank you to all who came and visited us during the show. We appreciate your support and feedback, and we promise we'll keep working on ways to improve *Gear Technology* to suit your needs even better than we've done so far.

We look forward to seeing even *more* of you at Gear Expo 2015.

To Be Emphatically Clear —The Devil (and the Standard) is in the Details

Bill Bradley

I read with great interest Buzz Maiuri's article in the September 2013 issue of Gear Technology—"How Gear Standards are Written."

I feel Buzz did a good job of outlining the process. There are a couple of things where I would like to add emphasis. The committee membership and the ballot comment resolution process are extremely important for developing good standards.

The committee membership needs to be made up of competent and knowledgeable individuals that represent all aspects and views that are covered by the scope of the proposed standard. They must be able to find compromise. If not, the standard may end up being biased to a segment of industry, a company, or misleading in its application. The committee membership is perceived as being "the experts" in the technology and, therefore, are not generally challenged when a committee draft is balloted within the whole organization—be it ANSI/AGMA or ISO.

Also, the ballot comment resolution process is extremely important. The AGMA procedures require that all comments be addressed and resolved by the developing committee. An extremely important AGMA requirement is that if the resolution of a comment results in a substantive change in the standard, the draft must be re-balloted at either the committee comment or general ballot stage. The procedures require a 75 percent approval of all those voting at each stage. These requirements help assure the development of a consensus standard.

The ISO ballot comment resolution requirements are different. The ISO/IEC directives allow for the resolution of comments to be proposed by the Secretariat "in consultation with the

agma voices

How Gear Standards are Written

T.J. "Buzz" Maiuri, Sr. Product/Project Manager, The Gleason Works

Several years ago my friend, colleague and past Technical Division Executive Committee (TDEC) Chairman Doctor Phil Terry (retired chief metallurgist, Lufkin Industries and now owner of P. Terry and Associates) wrote a very good article titled "Raising the Standards" about the AGMA Technical Division and the AGMA TDEC. Doctor Phil's words are still applicable today, and I'd like to revisit some parts of the article with a few updates, as well as explain the AGMA Standard and Information Sheet writing process.

The AGMA mission statement is "To help members compete more effectively in today's global marketplace." A large part of that mission has to do with the standards and information sheets created by the 26 committees in the Technical Division.

The Technical Division of AGMA is overseen by the TDEC. The TDEC has the responsibility to supervise the development and maintenance of AGMA Standards and other technical publications, as well as supervising the division's activities and coordinating them with the Administrative Division. The TDEC also organizes and conducts the annual Fall Technical Meeting.

The TDEC consists of a chairman (myself – T.J. "Buzz" Maiuri of The Gleason Works) and 7 voting members: John B. Amendola, Sr. of Artec Machine Systems; Terry Klaves of Milwaukee Gear Company; Bob Wasilewski of Arrow Gear Company; Dan Phebus of Fairfield Manufacturing Company; Todd Schatzka of Rexnord Corporation; Todd Praneis of Cotta Transmission Company and Bill Hankes of A-C Equipment Services. We meet face to face two to three times a year, once online via WebEx. As necessary, we use conference calls and e-mails throughout the year to take care of any business that needs to be addressed between meetings.

All TDEC meetings are attended by AGMA headquarters personnel Charlie Fischer – VP Technical Division and Amir Aboutaleb – staff engineer. Joe Franklin Jr. – president of AGMA also attends the meetings, as does the AGMA chairman of the board. The new chairman is Lou Ertel of Overton Chicago Gear Corporation, and the chairman emeritus is Matt Mondek of Reliance Gear Corporation.

Each member of the TDEC is also the liaison to several of the technical committees. As the liaison, he helps the committee chairman evaluate new projects and prepare proposals to the TDEC for the committees, as well as submit progress reports, completed work and committee problems to the TDEC.

The technical committees are responsible for the timely development, maintenance and theoretical accuracy of the technical publications of AGMA. Each committee has a chairman and vice chairman.

Several of the technical committees also serve as the United States Technical Advisory Group to programs within ISO TC 60 and ISO TC 14 (International Organization for Standardization – Technical Committee). The scope for ISO TC 60 is the standardization in the field of gears, including terminology, nominal dimensions, tolerances and tools for manufacturing and control. The scope for ISO TC 14 is the standardization in the field of shafts for machines, their keys and keyways, splines and serrations and their accessories such as couplings, flanges, etc.

AGMA is the secretary of ISO TC 60 and procedurally oversees all the standards programs that are undertaken.

All AGMA standards have the status of being American national standards as defined by the American National Standards Institute (ANSI). To maintain this status, AGMA's Technical Division operations are audited by ANSI every five years to ensure compliance with our own policy and practices, and with ANSI's requirements. The next audit will be in 2014.

There are currently 53 AGMA standards and 30 information sheets.

Information sheets are similar to standards, but are different in a few major ways. ANSI/AGMA standards comprise proven, reliable information. Information sheets, however, often contain material that is still being tested and proven. Information sheets are also a forum for setting new material before the industry so that they can be used and refined. ANSI/AGMA standards require balloting before the entire membership of AGMA, as well as any other interested parties. An information sheet requires only approval of the technical committee that prepared it, and permission to publish from the TDEC. One advantage to preparing an information sheet is that it can be published more quickly, since it does not go through the general ballot process. However, information sheets are not standards and do not carry the authority of consensus standards.

New standards and information sheet projects can originate from within an AGMA technical committee, the AGMA Business Management Executive Committee (BMEC), from AGMA membership, or from sources outside of AGMA.

The whole process from the proposal of a new standard or information sheet to its publication will take some time, and there are a number steps along the way. AGMA headquarters with the guidance of the TDEC has prepared a document titled "Operating Instructions for AGMA Committee Chairmen and Vice Chairman," which outlines the procedures for writing standards and information sheets. As an example, the document contains an extensive flow chart as well as a checklist with 30 task items for standards development. In addition, the manual contains other useful information in the "Policy and Practice Guide" portion of the document. (Note that the TDEC is in the process of reviewing the document for necessary updates to reflect current procedures.)

In brief, the process for a proposed standard will go something like this:

If the proposed standard originates from within a Technical Committee, the proposal will contain a written scope and justification for the standard. It

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Chair of the technical committee or subcommittee and, if necessary, the project leader, for proceeding with the project." This can result in unilateral resolutions. The directives require committee resolution of comments only if two or more participating countries file a timely objection (within two months) to the leadership's proposals. Also, the directives only require two-thirds acceptance and less than one-fourth rejection of participating countries to become an ISO or IEC standard. In addition, in a 2013 directive change, committee draft ballots may be skipped if a committee so decides on the recommendation of the developing working group. Although there is some rhetoric paid to developing consensus, it is easier to develop an ISO or IEC standard than an ANSI/AGMA standard — especially if there is no policing of the decisions by committee leadership. (*Note: While the U.S. [AGMA] has been the Secretariat of the ISO/TC60 Committee for Gears, all ballot comments on TC60 standards, by agreement in 1994, have been resolved by the developing working group(in order) to promote consensus.*)

One last comment is that a standard should be short in volume, with specific requirements, (and shall) contain few recommendations (should doing so) tend to make compliance difficult to discern. The recommendations or textbook statements belong in AGMA Information Sheets or ISO Technical Reports.

Bill Bradley, a longtime, distinguished AGMA member — and former vice president of the AGMA Technical Division — was in 2006 awarded AGMA's Lifetime Achievement Award. He has, over the years, also graciously volunteered his time and expertise to serve as a *Gear Technology* technical editor.

KISSsoft

OFFERS LATEST SOFTWARE UPGRADES

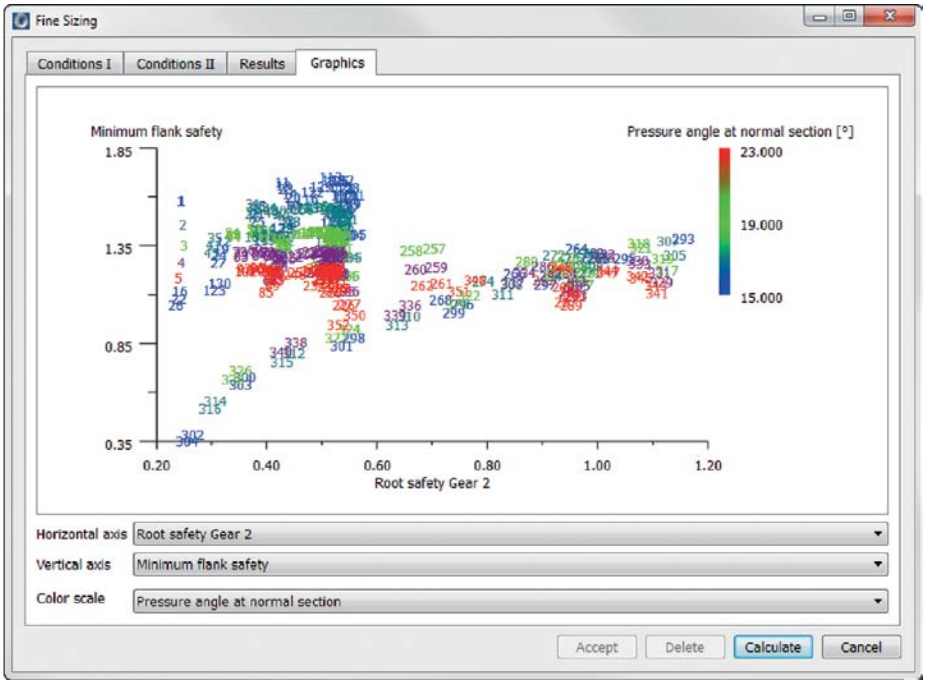
KISSsoft covers a broad range of applications in a single software package. The latest release of *KISSsoft (Version 03/2013)* incorporates the newest advances in contact analysis for both cylindrical gearing and planetary geared systems as well as fine sizing for worm wheels and crossed helical gears.

Fine Sizing for Worm Wheels and Crossed Helical Gears

For the calculation of worm wheels and crossed helical gears, fine sizing modules are now available (module ZD5 and ZE6). The *KISSsoft* fine sizing is applied to gear optimizations of all kinds — from static strength to noise optimization. Thereby, the macro geometry is varied in desired areas and the optimal solution according to various criteria is selected from the calculated variants. Plastic helical gears can be directly calculated according to the new draft of VDI 2736. After the cylindrical and bevel gears, these fine sizing modules complete the sizing process for all teeth.

Configurable Manufacturing Drawings for Cylindrical Gears

For all cylindrical gears, custom configurable manufacturing drawings are now available in *KISSsoft* (module ZPK). The gear data and a range of different graphics–such as flank modifications, etc.–can now be displayed in one graphic, output to screen or paper, and sent to the gear manufacturer. At the same time, graphic position and scale can be set by the user on his own. Now gear data can be easily arranged and placed on the graphic. The settings are saved in a separate file and thereby adopted for all gears. This approach favors also the definition of company standards. Those interested can look at the manufacturing drawing examples in a *KISSsoft* test license by e-mailing *info@KISSsoftAG.com*.



Evaluation of Gear Modifications in the Radar Chart

Another highlight in the *KISSsoft Release 03/2013* is the extended settings and evaluation options for optimizing modifications of cylindrical and planet gears. A new feature is that the face load factor KHβ can now also be calculated. This therefore reveals the direct influence of the tooth trace modification on the safeties of the classic tooth root and flank load capacities.

Modifications are evaluated in the radar chart, which also provides a very clear comparison, especially within different partial loads.

Contact Analysis for Planetary Units

The contact analysis has been greatly extended for planetary gear units (module ZA30). It is now possible to take into account the exact deflections of the shafts on the sun, the planet, and the internal gear. The planet carrier position is also determined by a shaft calculation, or can alternatively be specified as a displacement. The results are finally displayed in the 3-D system, ensuring maximum clarity. This provides a powerful analysis tool for the planet system. New dimensioning suggestions are now calculated for modifications, especially for planetary gear units (module ZA5). This ensures that tooth trace modifications can be specified accurately, on the basis of the planet carrier torsion and sun gear deformation.

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

MHI

TOUTS GEAR SHAPING TECHNOLOGY

Mitsubishi Heavy Industries, Ltd. (MHI) has completed the development of a new gear shaping machine, the ST40A, capable of cutting a broad array of gears, including helical and cluster gears, with one system. The ST40A's significantly expanded range of cutting applications derives from the first application in Japan of NC programming technology to the relieving motion that prevents interference between the cutter and the workpiece. The machine made its international debut in the United States with a live demonstration of its capabilities at Gear Expo 2013, in Indianapolis. The ST40A is a totally upgraded version of the ST40, a helical gear shaping machine requiring no helical guide for each workpiece. The ST40A has extended the ST40's cutting flexibility even further by incorporating Japan's first NC-programmable relieving mechanism and making all seven of the machine's axes fully NC-programmable. This new capability enables the ST40A to accommodate various high-precision cutting applications such as crowning and tapering. In addition, stroke speed has been increased by 20 percent, from the earlier 500 strokes per minute to 600, enabling high-speed cutting with a focus on productivity. Stroke speed when machining at lower speeds meanwhile has been reduced by 50 percent, from 60 strokes per minute to 30, enabling secure cutting of hard workpieces. The new machine is also capable of tapering up to 0.3 degrees without use of a tilt table. In these ways, the ST40A has been designed to fully address diverse user needs, including demand for a broader range of optional devices and functions, and enhanced operability, safety and energy savings. The company intends to market the ST40A for a wide spectrum of gear cutting applications for various products including automobiles, construction machinery and aircraft.

For more information:
Mitsubishi Heavy Industries America
Phone: (248) 669-6136
www.mitsubishigearcenter.com

Sandvik Coromant

EXPANDS GEAR MILLING FAMILY

The CoroMill 172 range was recently extended on October 1st. This disc cutting concept adapted for gears, splines and racks will now be available in module 3-10 (DP 8.467-2.540) with gear profiles in accordance with DIN 867 for gears and DIN 5480 for splines. CoroMill 172 disc cutters offer a versatile and time saving solution for milling of high-quality gear profiles. Thanks to the new indexable carbide insert technology and powerful iLock interface, the component can be machined in flexible, non-dedicated machines, such as multitask machines and machining centers, as well as in hobbing machines. CoroMill 172 is designed to be able to hold a range of inserts, offering flexibility for customers producing gears and splines of close module size and similar tooth profiles. CoroMill 172 is an attractive alternative for milling of high-precision profiles in a wide range of applications. Diameters range from 2.480-10.000 in. (63 to 254 mm).

For more information:
Sandvik Coromant
Phone: (800) SANDVIK
www.sandvik.coromant.com

Saint-Gobain

INTRODUCES NORTON FINIUM FILM ROLLS

Saint-Gobain Abrasives, Inc. has introduced Norton Finium abrasive microfinishing film rolls for precision applications. Norton Finium products are designed with a new, patented topside resin system alongside two new backing types and an innovative grit size color coding. This combination is specifically engineered to deliver high material removal and exceptional surface finish uniformity, while positioning Norton Finium film products as the most advanced in the market. The new Norton Finium line, designated Q351R and Q351S, features either a Rough (R) back or Smooth (S) back film, to meet any application requirement and equipment type. These microfinishing film rolls are used in powertrain polishing operations in the automotive, truck, marine, small engine, and very large engine manufacturing operations around the world. Film rolls are made in extremely fine grit sizes, available in 80 – 9 micron/μ or 180 – 1,000 grit of straight and scalloped edge. The micron size is so fine that it can be difficult to distinguish visibly one from the other, which is critical in selection process. “We have added a color code by grit size as visible identity verification to simplify selection to avoid mistakes inside our customers manufacturing plants,” says Alexandre Pecora, product manager for film for Saint-Gobain.

For more information:
Norton (Saint-Gobain)
Phone: (508) 795-2833
www.nortonabrasives.com

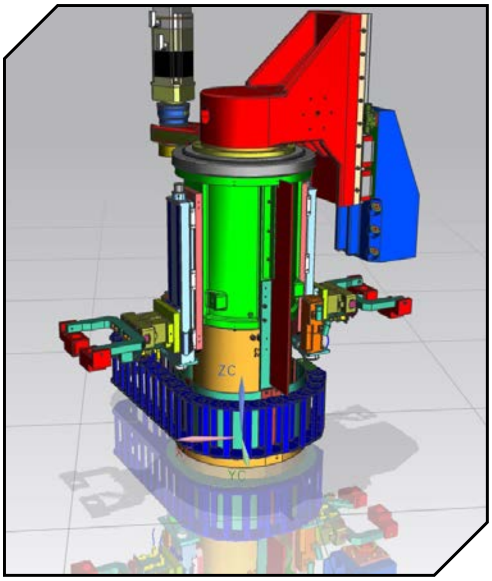
Siemens

ENHANCES PLM SOFTWARE

Siemens recently introduced a new series of industry-specific offerings at its annual PLM Software Analyst Conference in Boston. The *Industry Catalyst Series* offerings consist of a pre-packaged combination of industry best practice guides, templates and software aimed at accelerating PLM deployment and tailoring the system to the needs of specific industries. The series is designed to increase a company's overall return on its PLM investment, as well as the speed at which ROI is realized. The new offerings will also make it faster and easier to adopt, and gain value from, the latest PLM technology. The *Industry Catalyst Series* will work with one or more Siemens PLM Software offerings and – in accordance with the company's open business model – in combination with third party PLM solutions. Individual Industry Catalyst Series offerings will be announced over the next several months.

"Two years ago we began our transition from a product-focused organization to one focused on the unique requirements of industries," said Chuck Grindstaff, president and CEO, Siemens PLM Software. "This announcement represents a pivotal step forward in that transition. Each offering in the *Industry Catalyst Series* will be built around a specific industry's best practices, based on in-depth knowledge we have collected over more than 30 years of working with customers. By embedding that knowledge and experience in each offering, our customers will not only experience accelerated PLM implementations, but those implementations will be tailored to each company's business in a way that facilitates the adoption of new technology. The result is more business value, faster ROI, and the ability to benefit from the latest technology as soon as it becomes available."

Over the past several years, most organizations have come to appreciate how PLM technology and processes can help them increase productivity and efficiency. At the same time, however, many of these organizations have been slow to implement a full-scope PLM solution, or



to adopt the latest technology for their existing PLM system. This often stems from concern about costs and business disruptions associated with the need to customize standard PLM technology to their specific processes, data structures and workflow.

The *Industry Catalyst Series* minimizes that disruption by delivering an industry-tailored deployment more quickly. As the name implies, each individual *Industry Catalyst Series* offering will work like an industry-specific "agent" to accelerate a PLM implementation.

"Building interfaces and custom coding can add significantly to the cost of a PLM system," said Georg Vogl, executive program manager PLM at BSH, a Siemens PLM Software customer. "Over the past several years, Siemens has evolved its PLM software solutions to minimize these efforts by allowing us to configure the system to our needs rather than developing custom software. This has already helped us reduce our total cost of PLM ownership by 25 to 35 percent. Now with the introduction of the *Industry Catalyst Series*, we see the potential to implement new PLM technology even faster and reduce costs even further."

For more information:
Siemens PLM Software
Phone: (800) 498-5351
www.plm.automation.siemens.com

Northfield Precision

INTRODUCES MODEL 1025 AIR CHUCK

Northfield Precision Instrument Corporation, a designer and manufacturer of precision workholding chucks, introduces their Model 1025 air chuck. This chuck is used to grip on the pitch diameter of a large ring gear. A pin cage with integral axial locator is mounted to the chuck face as a subassembly. When accomplished, the jaws push the pins inward to grip the gear's pitch diameter. Northfield Precision designs and manufactures accurate air chucks for any lathe, boring machine, grinder or VMC. Models include through-hole, high-speed and quick-change. Chucks are available in SAE or metric, in sizes from 3" (76 mm) to 18" (457 mm). Accuracies of 0.001" to 0.00001" (0.254 m) are guaranteed. Custom workholding chucks and jaws are available, and free engineering assistance is offered.

For more information:
Northfield Precision
Phone: (800) 810-2482
www.northfield.com

Blaser Swisslube

RELEASES BLASOCUT BC935SW

Blaser Swisslube Inc., a manufacturer of Swiss quality metalworking fluids, is pleased to announce the release of Blasocut BC935SW. Blasocut BC935SW is formulated with the latest in state-of-the-art metalworking fluid components. Blasocut emulsions provide excellent bio-chemical stability and long sump life. This is due to the unique bio-concept of Blasocut emulsions and is accomplished without the use of bactericides, while maintaining a high level of environmental health and safety. Blasocut BC935SW is chlorine free yet provides high cutting performance and long tool life in cast iron, steel, aluminum and exotic alloys and is formulated for use in machining applications over a wide range of materials. Blasocut BC935SW has excellent washing action and low misting properties, thus providing a high level of machine and shop cleanliness. Blasocut BC935SW exhibits suitable bio and chemical stability and is formulated for use in water with a maximum hardness of 140 ppm. Blasocut BC935SW provides foam control in moderate to high coolant pressure applications.

For more information:
Blaser Swisslube
Phone: (845) 294-3200
mailboxusa@blaser.com
www.blaser.com

Hardinge

OFFERS C-SERIES COLLET AND COLLET STOPS

Hardinge Inc., a manufacturer of spindle tooling, began production of collets in the 1890s for use on bench lathes making parts for the watchmaking and lens industries. It is believed that the "C" designation for their first 5C collets came from the name of the Cataract waterfalls that could be viewed from the factory grounds of the Hardinge Brothers Company in Chicago, Illinois where they manufactured precision Cataract bench lathes.

Incredibly, the Hardinge C-series design has not changed since the early use in the 1890s, even in light of the rapidly changing technology in machine tool design. A collet has the capability to accurately grip a workpiece or a tool, resisting both rotational forces and multi-directional cutting loads with the ability to rapidly release the workpiece or the tool. A collet has the capability to amplify the actuation force, converting it into workpiece gripping or tool gripping with the ability to operate at high repetition levels without loss of accuracy or material failure. It also has the ability to operate at a wide range of rotational speeds with minimal loss of gripping force.

Hardinge C-Series collets, in sizes ranging from 1C up to 25C, are used in manual and CNC lathes, mills, grinding machines, collet blocks and closers, indexers, rotary tables and tool holders. The Hardinge collet is manufactured to exacting standards from special alloy steel. Threads are heat treated and the body is spring tempered to assure accuracy and durability. Hardinge C-series collets are available in fractional sizes of round, hexagon and square to capacity. In addition, many round collets are stocked in metric, decimal, letter and number sizes. Most of the popular sizes of round serrated, taper hole and regular collets are available from stock. Special accuracy 5C collets with a guaranteed maximum TIR of .0002" are available. Collet variations include emergency collets, step collets, extended-nose collets, step chucks (stepped out collets that hold larger diameters), and Dead-Length collet systems for controlling workpiece lengths.

The standard Hardinge 5C-series collet, with an order hole of .9843" or less includes precision internal threads to permit the use of Hardinge positive solid and ejector stops. The Hardinge stops are threaded into and positively locked against the end of the collet and are adjustable and machineable for the desired part length to accommodate a wide variety of chucking work. Once locked in place, the stop cannot move even under heavy drilling or other end-working pressures. Universal stops are available for 5C collets and 16C spindles. A variety of Hardinge Dead-Length systems are also available for producing consistent work pieces, including through-hole style for bar work.

For more information:
Hardinge Inc.
Phone: (607) 734-2281
www.hardinge.com

Dillon Manufacturing

INTRODUCES HPG500 LUBRICANT

Dillon Chucks and Jaws introduces HPG500 – a boundary lubricant that prevents metal-to-metal contact under high load and slow speed conditions for either high-end manual chucks or power chucks. This premium, high-performance NLDI Grade 2, lubricating grease has suitable mechanical stability, very high load carrying capacity, and water and moisture resistance. It has a water washout rating of less than three percent. Plus, its unique formulation gives it rust and corrosion resistance, even in the presence of a synthetic and oil based coolant environment. This chuck lubricating grease handles high loads, and provides long term corrosion protection under the most hostile conditions.

The environmentally friendly formulation contains no heavy metals or other environmentally undesirable materials such as compounds containing antimony, barium, lead, chlorine, phenols, or phosphorus. This lithium-free formula does not react negatively when contacting the water contained in water based coolants – as opposed to lubricants with lithium which cause lithium build-up on the internal workings of the chuck.

An all-purpose industrial lubricant, HPG500 can be used in bearings, bushings, slides, pivots, tracks, etc., — all important engineering components of manual and power chucks. It is recommended wherever high lubricity, EP (Extreme Pressure) properties, mechanical stability, rust and corrosion protection, water washout protection, and good oxidation stability are required.

Essential for the safe operation, and maintaining maximum gripping pressure of chucks, HPG500 is available in 14 oz. tubes. It can be purchased by the tube, in cases of 10 or 50 each. A greasing set, consisting of a grease gun, 2 tubes of grease and one grease adaptor fitting, is also available. HPG500 is also safe to use in your machine centers that require EPI grease.

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

Oelheld

INTRODUCES NEW FLUID LINES

Oelheld U.S. introduces IonoGrind, a multifunction fluid that is equally suitable for spark erosion and as a grinding oil. It has been designed for the use in combination machines (two-in-one systems). IonoGrind combines the advantages of a high-performance dielectric allowing for high rates of metal removal with suitable surface quality and that of a high-speed grinding oil which displays low foaming and misting properties. Additionally, Oelheld U.S. has introduced DiaCut CP, a new line of punching oils which have been developed especially for fast punching machines. They effectively prevent the formation of built-ups and allow for punching without burrs. DiaCut CP punching oils are rolled or sprayed onto the workpiece. Finished parts are practically free of residue. DiaCut CP punching oils contain no chlorines and heavy metals and are practically free of aromatic compounds.

For more information:
Oelheld U.S.
Phone: (847) 531-8501
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The Art of Versatility

Grinding technology on display at Gear Expo and EMO

Matthew Jaster, Senior Editor

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Whether you spent time at Gear Expo in Indianapolis or EMO in Hannover, there was certainly new technology attracting attention. Machine tools are faster, more efficient and can integrate numerous functions in a single setup. Grinding technology is turning science upside down and inside out with high-speed removal rates and increased throughput. The mad scientists (engineering wizards) have been hard at work in their labs to make gear production more flexible in the coming years. The future of some of this technology is just getting started. How fast and efficient will gear grinding become in the coming years? How will gear manufacturers adapt to some of these new technologies? While we don't have the answers, it's safe to say productivity is definitely increasing and the versatility in machining processes continue to add value for both job shops and OEMs.

Klingelnberg Viper 500 Series

The Höfler Viper 500 series from Klingelnberg offers pre-finishing and finishing of complex gears including process design, cutting, measuring, deburring, grinding and quality control. "We offer three machining configurations including the Viper 500 (profile and internal grinding), Viper 500 K (profile, internal grinding and spindle option K) and Viper 500 W (profile, internal and generating grinding)," says Ralf-George Eitel, managing director, sales and service at Klingelnberg. "These machines are highly adaptable, offer a quick changeover, low maintenance and optimal energy efficiency."

The Viper 500 series can go from generation grinding to profile grinding by swapping out the grinding wheel, grinding wheel flank and dressing wheel in less than five minutes on the 500 W (which was on display during Gear Expo). "We're offering the customer high productivity with the lowest possible cost per piece," adds Eitel. "This is made possible with our comprehensive service offerings and the technical expertise and support from the Klingelnberg engineers."

Eitel is also proud of the energy efficiency highlights on the machine including cooling units, optimal axis weight compensation and energy-optimized grinding oil nozzles. This overall modular approach gives gear manufacturers the tools necessary to succeed in areas like agriculture, mining, material handling, aerospace, wind power and maritime propulsion technology, Eitel says.

Overall, the Viper series allows optimized five-axis machining of an entire range of modifications in the shortest possible grinding time. The proprietary *GearPro* software offers routine operation for the attendant even when the applications are complex. *GearPro* includes many module options for best-fit, high-speed and adaptive grinding as well as dressing to enable significant reductions in production times.

Gleason Presents Titan 1200G

The concept behind the Titan 1200G began when engineers toyed with the idea of combining multiple grinding configurations to increase productivity and throughput. "Let's combine some of the established grinding technologies like profile grinding, known for its excellent quality and threaded wheel grinding, known for its high productivity. The combination of both is what we call Power-Grind to provide more flexibility and productivity to our customers," says Dr. Antoine Türich, director of product management, grinding solutions at Gleason. "This is now possible with our new Titan 1200G including a fully-automatic tool changer, something that is not new in the general machining industry but is totally new to the gear industry."

The Titan 1200G offers a high surface finish quality combined with high productivity utilizing the automatic tool changer. The machine can be individually configured to suit customer requirements and provides maximum productivity, flexibility and quality.

"In conventional grinding there is always a compromise when selecting the grinding wheel specification to match the opposing requirements of roughing and finishing stroke," Türich says. "I compare it to tires on your car; you need certain tires for driving in the summer and certain tires for managing harsh winters. The same can be said about grinding wheels. Some are better for one process than another. With the tool changer we are now able to solve the conflict in the wheel selection and use a dedicated grinding wheel specification for the roughing operation and another smoother specification for the finishing operation. Of course the Titan 1200G can run without the tool changer as well, becoming a conventional profile grinding machine."

Türich adds that the Titan 1200G exhibited during EMO was set up to manufacture a sun shaft of a planetary gearbox with two gear sets. "We wanted to demonstrate to attendees how the machine concept worked when you needed two different grinding wheels. The process is quite simple. We exchanged the wheel without interference and it produced excellent surface finish qualities."

"Besides the mechanical development of the new Titan 1200G machine, we have made some significant improvements in the grinding technology as well," says Türich. "Our new infeed strategies—called: A(X) and degressive infeed—allow a much better and intelligent partitioning of the total stock removal into the different grinding strokes, resulting in a much shorter cycle time and a higher process reliability."

Additionally, the Titan 1200G includes wobble compensation, requiring less time to align large and heavy workpieces while improving quality and reducing fixture costs. "Conventional methods can require significant time to manually align the workpiece," Türich adds. "This technology was first used on gear inspection machines. In some cases, we've reduced the alignment process from one hour to five minutes using wobble compensation."

Sustainability, an important aspect of manufacturing, remains a priority with Gleason. The Titan 1200G consumes up to 40 percent less energy than older machines and is 35 percent smaller in footprint. "During setup the machine can be set into a standby mode in order to save energy, for example," Türich says. "We've reviewed all energy consuming components and reduced sizes wherever possible without a loss in machine performance. In addition the machine requires much less floor space, for which our customers thank us."

The Titan 1200G was a key point of interest for our customers at EMO. "Overall, we had 20 percent more visitors to this show than the last EMO," Türich says. "We collected leads from every customer, took some machine orders and we're extremely happy with our presence and with the customer experience we provided this year."

Star SU/Samp Gear Grinding Technology

Based on established concepts from previous Samputensili models, the G 250 is an innovative, compact and extremely flexible gear grinding machine. It has been developed for very low cycle times and for top-quality and efficient mass production of gears with outside diameters up to 250 mm and shafts with lengths up to 500 mm. The dual work spindle concept efficiently eliminates non-productive auxiliary times. Additionally, the loading/unloading process of a workpiece is carried out in masked time, while the G 250 manufactures another workpiece simultaneously.

The grinding spindle allows the use of long grinding worms to raise the tool life of single or combination worms. The extremely high rotational and linear accelerations offer appropriate cycle times, and the G 250 is suited for future developments in the grinding tool sector. The profile dressing unit consists of a standard profile diamond dressing roll mounted on a dedicated spindle, which is located on the rotating table structure. An optional diamond OD dressing stick can be mounted on the dressing unit structure, in order to have the necessary flexibility to dress the OD of the grinding wheel.

If the tooth root diameter must be ground as well, a tip radius dressing roll is applied to create the required tip radius on the grinding tool. When required, the dressing unit is automatically brought into the working position by the rotating movement of the worktable. This guarantees an extremely precise and rigid positioning, which is of fundamental importance in order to obtain an excellent result. The dressing movements are actuated by the interpolation of the axes. The possibility to use generic profile dressing rolls on the machine allows you to save money and guarantees a fast supply of dressing tools. You may employ both single- and double-flank dressing rolls, as well as multi-rib type.

Non-productive dressing times can be reduced considerably by dressing via a diamond-plated dressing gear. With its total length in contact and its ten times larger diamond-plated surface, the dressing gear dresses a lot faster and with less wear, thus much more productively than a single dressing roll. Moreover, dressing tool changes are reduced as well. For the dressing cycle, the dressing master is transferred like a workpiece from an external station into the work area. Consequently it always stays clean and is not affected by swarf or heat.

Depending on your application, the G 250 machine can be easily equipped with various automation solutions to produce parts in small and large quantities, with shorter lead times, preserving high quality at lower costs. The G 250 can be linked, for example, to a robotic arm, which is normally installed next to the machine and manages the loading and unloading process of workpieces. Optionally a pallet storage solution can be integrated for a continuous workflow without any interruptions.

Liebherr: Short Grinding Times with High-Production Quality

The newly designed gear grinding machine LGG 180 for profile and generating grinding offers compact dimensions and is suited to handle the high production demands of vehicle and transmission manufacturers. "The advantage is higher quality throughout the entire production. It gives users fast processing combined with the advances of a one-table solution," says Dr.-Ing. Andreas Mehr, grinding and shaping technology development and consultancy at Liebherr.

The machines for 180 mm and 280 mm contain the same dimensions, making it easy to develop a complete high quality production line in which all the gears are produced using a one-table solution. Manufacturers can ground planetary and sun gears, bore-type gears as well as drive and pinion shafts with lengths of up to 500 mm. New features on the LGG 180 include a new grinding head, (speeds up to 10,000 rpm and a spindle power of 35 kW), a thermally stable machine bed and reserve capacities for future grinding developments. The LGG 180 can also utilize the abrasive Cubitron II from 3M.

In addition, the machine will enable undulations to be applied specifically to gear wheel flanks for noise optimization purposes for the first time. The ability to produce sub-μ range waviness cost-effectively gives designers a whole new range of options. Features under consideration include twist-free grinding, grinding of stimulus-optimized corrections (amplitude, wavelength, phase, orientation), trueing up of lines and grinding of conical gear teeth (beveloids). The newly designed user interface is individually configurable, enables intuitive operation via touch panel, and allows for mathematical analysis of waviness and twist. It also provides user guidance for process cycles and conversion cycles.

Luren Looks to Job Shops with Universal Grinding Machines

Luren Precision established itself in the industry for manufacturing and engineering gear cutting tools but has expanded in the market to provide gear grinding machines. "The LUG-3040 is a great example of Luren's machining versatility," says Darian Ditzler, sales and service manager at Luren. "This machine is perfect for job shops. It utilizes a Fanuc controller and direct drive motor for the workpiece spindle and a built-in motor for grinding. It offers a wide range of specifications and software capabilities for multifunctional machining."

In addition to the LUG-3040, Ditzler says the LWT-3080 attracted interest during Gear Expo. "This is our best-selling machine in the States, thanks to its competitive price and the direct drive motor and linear motor." Luren's *Smart Dialogue* software offers flexibility as well as management of the grinding/dressing cycle without the need for the external PC.

The company plans to bring more machines to the States that are being utilized in Asia in the near future. Currently, Luren offers hob sharpening, worm thread grinding, horizontal and vertical grinding, and CNC universal gear tool grinding machines.

Ditzler was happy with the concentrated traffic that visited Luren's booth during Gear Expo in Indianapolis. "We've received some great feedback this week. We're walking away with a couple of prospects for our universal grinding machine. While it's a small show, it's a much better focus than you'll find at IMTS or the larger trade shows. I think we're going to get a larger booth in Detroit in two years and focus on bringing more engineering personnel to talk about our increasing machine capabilities."

3M Offers Grinding Strength and Precision with Cubitron II

Made of precision shaped grain (PSG), the Cubitron II offers a more uniform surface finish, no grinding burn (if used properly) and can cut production time, dressing amounts and dressing cycles in half. It was also widely discussed on the exhibition floor during Gear Expo. Walter Graf, 3M, invented this gear grinding technique and plans to contribute more information to *Gear Technology* magazine in future issues. What we do know is that Cubitron II has been demonstrated on some of the latest and most advanced gear machine tools. Those involved in the demonstrations agree that the abrasive offers great potential to reduce machining time, the number of passes can be significantly reduced

and the possibility of soft/green generating grinding will be examined in the future. Graf presented a technical paper titled "Precision Shaped Grains Turn the Concept of Gear Grinding Upside Down" during the AGMA Fall Technical Meeting (FTM).

Meanwhile, 3M grinding solutions were also exhibited at EMO, including a full range of the Cubitron II abrasives. These are used for the profile grinding of gears as well as for the continuous rolling and bevel gear grinding. According to a company press release, 3M also exhibited prototypes for the external and internal cylindrical grinding of automotive and industrial bearings. Application testing in industrial production has shown that the processing time can be reduced by up to half using these products — and at the highest surface quality. The lifetime increased to three to four times without risk of burning. Initial calculations show that in the future about a quarter of the production costs can be saved when using this innovative abrasive.

Erwin Junker Promotes Grinding Flexibility at EMO

Erwin Junker provided several grinding technologies during EMO, including the Lean Selection series and the Jupiter series. The Lean Selection all-round, with a grinding length of 800 mm and a center height of 150 mm, is designed for the complete grinding of workpieces used in prototype production, mold and tool making, pneumatic and hydraulic applications, precision mechanics, gear manufacture and medical technology. The machine makes short work of wide-ranging different workpiece geometries, including cylindrical diameters, tapers and radii, shoulders using angular infeed grinding, OD and ID threads as well as punches. The machine can be equipped with corundum, CBN or diamond grinding wheels and lends itself to a wide variety of uses. The multifunctional OD and ID grinding machine is flexible for small batch runs through to large-scale series, and is used predominantly by small and medium-sized enterprises. As it offers scope for individual automation, it can also be used in production lines.

With the Jupiter series, grinding means centerless cylindrical grinding — depending on the application with corundum or CBN. The Junker CBN high-speed technology enables high grinding performance with a simultaneous, long grinding wheel service life and provides considerable production advantages for high-volume applications as well as smaller lot sizes and a broad range of variants. The high axial feed rate, with through grinding, makes the process remarkably fast and delivers exceptionally high output performance. The Jupiter machines enable straight infeed grinding for the centerless grinding process, in addition to angled infeed grinding made possible by the Jupiter 125. The Jupiter 125, 250 and 500 machines offer a large number of functions, which considerably reduces the effort required for set-up and conversion as well as overall production time. The settings on the patented height-adjustable supporting rail are automatically calculated by a software tool. While the regulating wheel is worn down, both the position of the regulating wheel and supporting ruler are automatically adjusted by the patented height adjustment of the ruler. The Junker control electronics compensate this change in position with corresponding tracking of

the grinding and regulating wheel, ensuring precise, constant grinding at all times. Following each dressing process, the position is automatically re-calculated and the grinding wheel is immediately corrected. The quality of the concentricity remains constant while requiring less time to adjust the centerless grinding process without compromising performance. Depending on the workpiece requirements, the Jupiter series can be offered with an internal or external loading system. The loading systems can be combined with various feeding and discharge systems, such as conveyor belts, vibration conveyors or systems adapted to customer-specific requirements. The measuring systems are individually adapted to the workpieces and customer specifications. Junker offers a wide range of options for the Jupiter series, such as retrofitting for CBN grinding.

Gear Grinding 2014

As mentioned earlier, many of these new grinding concepts are in early production runs and will continue to add capabilities and features in the near future. *Gear Technology* will check back in around IMTS next year to see how these gear grinding technologies continue to evolve.

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www.3M.com/cubitron2/geargrinding

Untraditional Gear Machining

Ingersoll and Allied Precision Make Gears by Not Making Gears

Doc Ardrey, Ardrey Inc.

"Long story short: the company dramatically improved the material removal rate and yield while reducing fixture cost and delivery lead time on a family of gears by not treating them as gears."

Look beyond the obvious, and you may well find a better way to machine a part, and serve your customer better. That's the lesson illustrated in a gear machining application at Allied Specialty Precision Inc. (ASPI), located in Mishawaka, Indiana.

Long story short: the company dramatically improved the material removal rate and yield while reducing fixture cost and delivery lead time on a family of gears by *not* treating them as gears. First, they moved the tooth forming operation from a traditional gear shaper to a CNC multitasking center. Next, they treated the tooth throat as a short slot rather than the usual tooth throat, using a form-matched Ingersoll Chip-Surfer replaceable-tip carbide slotting tool.

Although it's a gear in the spindle, Allied Specialty Precision Inc. treats this part as something else to achieve "done-in-one" production from 17-4 PH cut-off bar stock, to deliver sooner and to cut machining costs (all photos courtesy of Ingersoll and Allied).

Step one enabled "done-in-one" machining, which led to simpler in-process parts handling and shorter delivery lead times, as well as reduced total machining cycle time by more than 2 to 1. Step two streamlined the tooth-cutting operation itself, the longest operation on the part, by about 3 to 1.

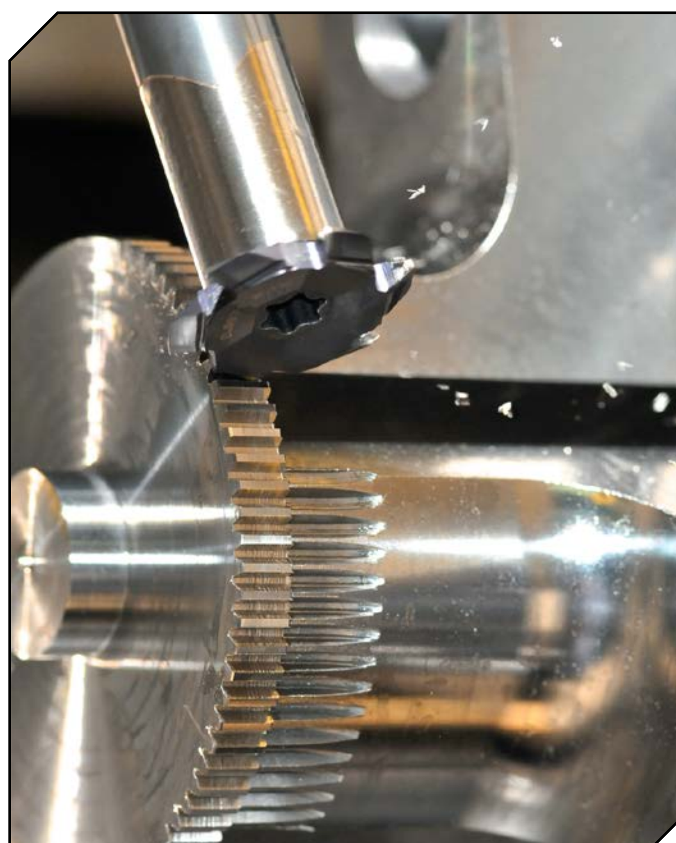
Running 24/6 with 60 employees in the shop, the company has earned a reputation as, in the words of CEO Pam Rubenstein, "the 'go-to' guys for challenging manufacturing projects." Because of its location and that reputation, ASPI has become a preferred supplier for aerospace manufacturers.

"When you see a gear, you naturally think of a stroker-type gear shaper, equipped with the familiar single point high-speed steel form tool," says Todd Stoddard, ASPI manufacturing engineer. "But completing this particular part is more about machining the web, hub and stepped shaft bore—seven operations in all—than just cutting the teeth. Now we grab the part once and complete all seven."

Done-in-one machining

The sector gear, machined from solid 17-4 PH bar stock, looks like half a gear with a lever arm attached. Measuring about 3½ inches diameter with 46 teeth over a 180° arc, the gear goes into helicopter flight controls. Annual volume for the earliest orders was just 100 pieces, all similar.

Back in 2008, ASPI moved strongly toward the "done-in-one" approach on a plant-wide basis. To that end, the company moved the job to a new Mazak Integrex CNC multitasking center with all available auxiliary axes. "In effect it's a nine-axis machine," says Stoddard.



Modified standard Chip-Surfer slotting tool forms teeth in just two passes, shaving 20 minutes off tooth-forming cycle time for this sector gear at by Allied Specialty Precision.

Originally on the new Integrex, teeth were formed with a two-inch high-speed steel (HSS) gear gasher – essentially a slitter with form-matched teeth. It completed the teeth in two roughing and one finishing pass. Total cycle time for tooth machining was 28 minutes, the same as before on the shaper. The big savings were in the other operations and in less part handling.

Orders for the sector gears started to increase in 2011, and expanded into a family of about a dozen different part numbers. Total annual volume grew to around 500 pieces. The parts varied in diameter, arc, number of teeth and extra features like linkage arms, but used just two different tooth forms. In other words, the job became a big enough piece of business to warrant some additional optimizing. Tooth formation, the most time consuming of the seven operations, naturally became a prime target.

Stoddard reached out immediately to Ingersoll's Andy Thornburg, who, in Stoddard's words, "knew more about gear machining than I did—especially non-traditional gear machining. It's a pretty specialized area."

Teeth as slots

Thornburg suggested treating the teeth as short slots and machining them with a one inch form-matched Chip-Surfer T slotting mill oriented like a slitting tool. The cutter features a small replaceable tungsten carbide tip mounted on a threaded carbide shank. By itself, moving from HSS to carbide would enable much higher machining rates and extend edge life, Thornburg reasoned. The replaceable tip design, moreover, would minimize the amount of carbide used and enable in-spindle tip replacement. The carbide shank, which was reusable, would stiffen the cutting system for a better finish on the wear surfaces of the teeth.

ASPI's CEO Pam Rubenstein and Todd Stoddard (far right) explore fresh ideas for faster gear production with Ingersoll's Andy Thornburg (center). "Andy knows more about gear machining than we do," says Stoddard, "so his application support is invaluable."

Faster machining

During trials, Stoddard and Thornburg worked together to optimize parameters for the new process. Conclusion was to quadruple the surface speed and double the feed rate, and to take just one roughing and one finishing pass. Final settings for the 1 inch tool are 1,500 RPM, 0.060 in. depth of cut for roughing and 0.010 in. for finishing. This process change reduced cycle time for the teeth from 28 minutes to eleven.

"In one recent case here in the United States, an Ingersoll one-start indexable carbide insert (ICI) hobber has reduced "from the round" tooth-generation cycle time from 34 hours to five on big 8 AGMA shaft gears for mining equipment while actually improving surface finish."

Once the new process went operational for a couple of months, tool life could be compared. The Chip-Surfer tips typically last through 50 pieces in this application, while the gear gasher needed a regrind every 10-20 pieces. "So ASPI reduces stoppages for tool replacement and cuts tool inventory costs as well," says Thornburg.

Even though it is form matched, each Chip-Surfer tip costs about $125, the same as one regrind on the gasher. Keeping spares is much more economical, too, since a single gasher can cost more than $400 to buy and $100 a pop to regrind, and can take weeks for delivery. Bottom line: tooling cost per part dropped from $20 to $2.56, an 8 to 1 reduction

ASPI's gear tooth tooling typifies the many Ingersoll Chip-Surfer modified standard slotting tools in service today. Ingersoll stocks the standard blanks (left) and simply grinds them to required form.

Slotting tool, close up

The improvement in throughput stems from the proven capability of carbide over HSS, plus the Chip-Surfer's free-cutting presentation geometry that enables higher feeds and speeds without chatter, according to Thornburg. The Ingersoll Chip-Surfer mill features a replaceable carbide chip that screws onto a threaded shaft with 0.0002" repeatability to datum. Tips can be swapped out right in the spindle. The shaft can be either alloy steel or carbide depending on stiffness requirements and impact loads. "Even with the carbide shaft, the only throwaway carbide is the tip," explains Thornburg. Ingersoll custom-grinds a standard Chip-Surfer T-Slot tip to match ASPI's required form.

Modified Standards

What about the supply-chain risks of depending on a "special" tool? "Virtually all gear tooling is a special anyway," says Stoddard. "The lead time on the previous slitter was weeks or months. And here, the customization is so simple that we regard it as a modified standard tool, not a full special. We can get them in a couple of days."

"When you see a gear, you naturally think of a stroker-type gear shaper, equipped with the familiar single point high-speed steel form tool," says Todd Stoddard, ASPI manufacturing engineer. "But completing this particular part is more about machining the web, hub and stepped shaft bore—seven operations in all—than just cutting the teeth. Now we grab the part once and complete all seven."

Ingersoll national milling product manager Konrad Forman adds that modified standard Chip-Surfers are very common for slotting and T-slotting and die and mold applications. "As in the ASPI case, it's a simple matter of a custom grind on a standard Chip-Surfer T-slot tip, which is always available off the shelf."

Sector gear, machined from solid 17-4 PH bar stock, looks like half a gear with a lever arm attached. Measuring about 3½" (89 mm) diameter with 46 teeth over a 180° arc, the gears produced by ASPI go into helicopter flight controls.

No more of the tooling baggage usually associated with gear-tooth machining. No swapping out gear gashers or dealing with regrinds. Operator simply changes tips in seconds and starts up again.

ICI Tooling wins gearmakers' trust

The ASPI application typifies a global trend toward indexable carbide (ICI) tooling in gearmaking, according to Frank Berardi, Ingersoll product manager for gear machining. "Gearmakers have always recognized the potential of ICI tooling to outproduce and outlast high speed steel by wide margins, but were deterred by concerns about repeatability in multi-tooth compound cutters and hobbers," he says.

In one recent case here in the United States, an Ingersoll one-start indexable carbide insert (ICI) hobber has reduced "from the round" tooth-generation cycle time from 34 hours to five on big 8 AGMA shaft gears for mining equipment while actually improving surface finish. Now the surface reads 80 RMS all the way to the root, vs. 135 RMS partway down before. The company, a familiar name in off-road equipment, has also standardized on Ingersoll ICI hobbers for a host of whip gears, where surface quality is more critical.

"Several European gear manufacturers report similar successes with both one- and two-start ICI hobbers," Berardi added. "ICI tooling technology is definitely winning converts in gearmaking."

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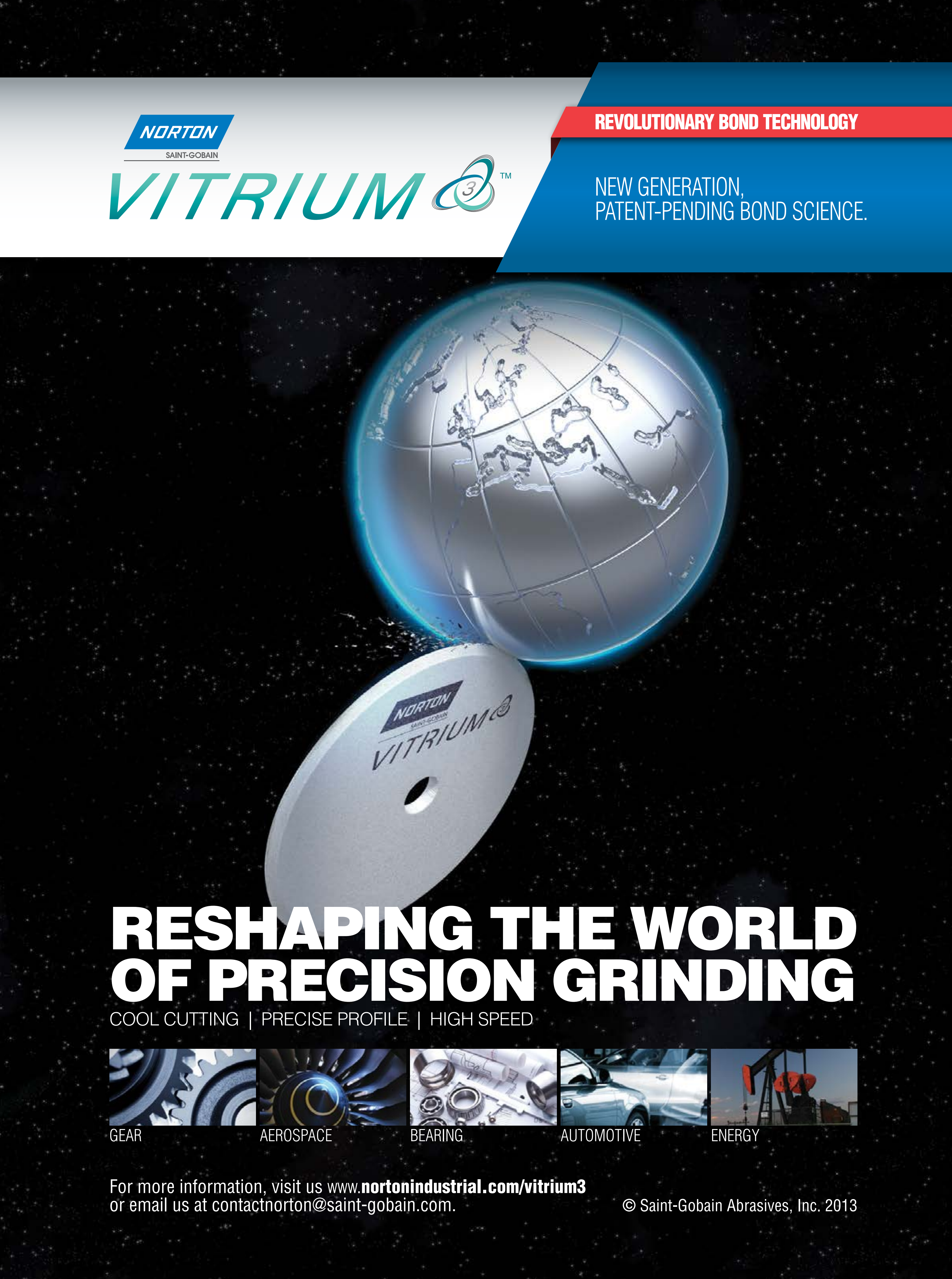
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THE LATEST GEAR GENERATION

Interview with Jan Klingelnberg

This the first of a new series of *Gear Technology* profiles of individuals you should know in the gear industry.

Q:Tell us a little bit about the history of Klingelnberg. When was Klingelnberg originally founded? When and why did the company get involved in the gear industry?

A:Klingelnberg was founded in 1863—originally as a metal trading company. We have been located in Hückeswagen, Germany since 1916. Having started with the production of tools and machine knives in 1908, the company moved to Hückeswagen and eventually became involved with gearing technology. Consequently, in the 1920s we started designing and producing machines for bevel gear manufacturing based on the palloid system.

Q:Please describe how Heinrich Schicht invented Klingelnberg gearing and the challenges he originally faced with his invention.

A:Heinrich Schicht converted the basic principle of hobbing from cylindrical gears to spiral bevel gears. Instead of a cylindrical hob used for cylindrical gears, he applied a conical hob for bevel gears. His idea remains the basis for all further developments in this industry. The patent for his idea was applied for in 1921. It allowed the company to grow and go global from that point on.

Q:For historical perspective, please describe the significance of the Klingelnberg cyclo-palloid tooth form and its development; i.e., why was it developed, how does it fit in the overall scheme of spiral bevel gear production, and, historically, how has it competed with other tooth forms?

A:First of all, cyclo-palloid is a widely used, universal gearing principle. The cutting tool is not specifically designed for a dedicated gear set. Rather, it is applicable for any ratio in a defined module range. This makes cyclo-palloid profitable and thus competitive, especially when the customer has small batch sizes and a high variety of gear designs.

Q:From a gear design perspective, cyclo-palloid always creates parallel tooth heights. This is important to mention since there are other gearing systems that apply a tapered tooth height. The lengthwise shape of the teeth, combined with the optimal tool diameter, provide the best conditions for maximum strength of a cyclo-palloid gear.

A:One important feature of cyclo-palloid is the hard finishing option. The machine executing the soft cutting operation is able to perform a hard cutting process called "HPG skiving"— resulting in very geometrically precise gears to meet the highest quality demands.

Q:What were the significant technology contributions of Oerlikon, and how does that technology fit with today's operations?

A:Klingelnberg has always been very strong in the market of universal applications in industrial gear boxes. But decades ago, on the other hand, Oerlikon introduced the face hobbing principle to produce gears for automotive applications. This latter process provided significantly higher productivity, but every individual design required a dedicated tool.

Oerlikon has been the market leader in lapping technology from the beginning of the 1990s. Since bevel gears for industrial gear boxes are mainly ground or skived, Klingelnberg did not initially have enough expertise in the area of high-volume products and lapping. But, by combining Oerlikon's market knowhow and Klingelnberg's experience in CNC machine design, the group became a full-service supplier for bevel gear manufacturing in the automotive industry.

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

A: There are some valuable, inherent advantages to being a family-run business. Time, for example, is one key factor:we take our time—in both marketing new developments and patiently striving for continuity—even in tough periods. On the other hand, our independence allows us to make quick decisions, even concerning strategic matters. Another factor that must not be underestimated is our commitment to our local community and our heritage—important values that contribute to our staff's identification with the company.

Q: How has the gear industry evolved since you took over as CEO in 2004?

A: With regard to the markets in general, what stands out is the increasing quality demands for gears, especially in the automotive industry. For us as a company in particular, it is the transition from machine tool supplier to solutions provider for technology partnerships. Application support along the entire process chain is what customers demand today.

Q: Why was the recent acquisition of Höfler important for Klingelnberg?

A: Put simply, it was the logical completion of Klingelnberg's product range, adding cutting and grinding machines for cylindrical gears—both in terms of application areas and customer industries served. The addition of Höfler Maschinenbau allows us to significantly advance in reaching our strategic goal of being able to provide all gear technologies as a one-stop shop.

Q: What synergies have been achieved in the takeover of Höfler?

A: Of course we benefit from certain technological expertise, and the complementary product range of the two partners. Höfler's strong R&D focus is a major asset to our company.

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

A: One main factor that drives demand in the industry is, of course, the growth of the automotive sector in certain countries such as Russia, India, China and Brazil. This is nothing unique to gear manufacturing, of course, as it applies to several other industries as well.

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

A: The development of electric drives vs. combustion engines in automotive engineering will have a growing impact on our industry, for sure. Other than that, efficiency, noise reduction, unit costs and stable manufacturing processes will be the focus of development work—both for us and our customers.

Q: What are your goals for the Klingelnberg group over the next five years? Can you discuss your expansion plans in Germany? Do you have plans to expand manufacturing outside of Germany?

A: Certainly one important step is relocating our site in Hückeswagen to new, nearby facilities; this will take place gradually during the next decade. In general, we will keep striving to deliver product innovations, just as we have been doing in the past or at an even higher level.

Q: How have your customers' demands changed in recent years?

A: What sticks out is the ever-growing demand for more efficiency in production. For this reason we introduced our trademarked 2 E efficiency label. The label stands both for high-performance and energy-efficient machines. In this context we are an active member of the sustainability initiative, Blue Competence (*Ed.'s Note:The* Blue Competence *machine tools initiative increases awareness and knowledge of sustainability and raises the energy efficiency bar in the European machine tools industry. The initiative offers a common platform to European machine tool companies and coordinates efforts for the development of energy and resource-efficient solutions*). Another important factor is making our machines easy to operate while providing ever more complex technologies. With our customers being globally active, they need to rely on reproducible quality worldwide—no matter who operates the machine. Easy operation of our machines minimizes costly human errors and, in the final analysis, reduces costs per unit.

Q: What is Klingelnberg doing to accommodate those demands?

A: We listen to the markets and develop our solutions accordingly. This is, in our view, the only viable way to develop products that help customers reduce cost-per-unit and at the same time provide high quality—certainly two of their main goals.

Q: How has your North American distribution, sales and service organization changed over the last several years?

A: We have established new sales capacities and have expanded our network through Höfler based on their already strong presence in the USA.

Q: Describe the importance of Klingelnberg's unique gear manufacturing capabilities. (Specifically, regarding delivery time; quality; price; materials; new-application designs, etc.)

A: Customer satisfaction is the result of the optimal interplay between factors such as delivery time and reliability, quality of materials and service, and pricing. We are convinced that cheap "solutions" go against this interplay and thus against customer satisfaction. Furthermore, our team of innovative engineers lays the groundwork for refined solutions and new developments.

Q: Given your reputation for recruiting and retaining skilled workers, do you have any concerns in that regard?

A: In this context we find two trends especially important:first, we cooperate closely with local and regional schools and universities; second, we continuously invest in internal training and further education to strengthen our staff. This is something that will be of growing importance in our market, so we are well-prepared for future developments.

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VL 8
Work-piece-Ø max. 15.7 in
Workpiece height max. 11.8 in

The Halls of Ivy (Tech) Are Humming With Precision (Tooling)

By Jack McGuinn, Senior Editor

> "We are continually trying to raise the bar of excellence at our company to better serve our customers. We decided to help launch this program so that we could get students excited about manufacturing, give them a solid technical skillset, and ultimately develop future employees."
> Mark A. Neidig II

If you've been following this space with any regularity, you know that grassroots efforts among industry and academia are springing up around the country to help win the hearts, minds and talents of young people in nudging them towards a career in manufacturing.

Add another partnership to the list.

Students at Indiana-based Plymouth High School (PHS) — with a generous boost up by ITAMCO, the machining services, open gearing and large-part assembly company — now have available to them the opportunity to pursue "precision tool manufacturing training courses." ITAMCO, also based in the Hoosier state, has partnered with Ivy Tech Community College (ITCC) and the Plymouth Community School Corporation in the creation of "dual credit" manufacturing courses intended to help and inspire students to continue their post-high school education.

As Ivy Tech North Central Chancellor Thomas Coley puts it, "Ivy Tech's role in training a skilled workforce is vitally important to the economic stability of our region. Manufacturers in the Marshall County area communicated to both Ivy Tech and the Plymouth Community School Corporation the desire to partner with us to provide training opportunities to high school students that will lead to jobs immediately after graduation."

Readers familiar with these kinds of partnerships also know that it requires a good deal of heavy pulling to make it happen. Just ask ITAMCO's Mark A. Neidig II, purchasing manager for the family-owned business.

"There were a lot of moving parts with having multiple partners engaged," he acknowledges. "Plymouth High School had to get school corporation board approval for budgeting the funds and executing the building renovations for the host site. Ivy Tech had to find an instructor able and willing to teach the course. And Jerry Hollenbaugh, director of the North Central Area Vocational Cooperative (NCAVC), put together an advisory committee of local manufacturers and educators to help establish the curriculum."

In addition, pre-engineering STEM courses are already available at PHS, courtesy of the nationwide Project Lead the Way program (*http://www.pltw.org/about-us/who-we-are*). This affords students the luxury of attending egg-headed STEM classes and then heading over to ITCC for some hands-on precision machining experience.

Since the program began in August, the outcome has been "terrific," according to Neidig. And that is despite the fact that, says Neidig, "The program was not officially advertised, because we weren't sure if the facility and equipment would be ready on time."

Speaking of equipment, ITAMCO contributed $100,000 worth of machinery for the venture, as well as invaluable technical assistance. As for the program's scope, Neidig says that "While any student in the state may attend, we're targeting students in 12 area high schools that participate in the North Central Area Vocational Cooperative"

So why now? What inspired ITAMCO to help spearhead this program? When you think about it, and if you own a manufacturing company, by now the answer should become obvious.

"Ultimately, (the reason) was our customers, Neidig says. "We are continually trying to raise the bar of excellence at

ITAMCO donated $100,000 in machinery for the new Ivy Tech dual credit program (all photos courtesy NCAVC).

our company to better serve our customers. One barrier to doing so was the time it would take us to bring new employees up to technical competence. We decided to help launch this program so that we could get students excited about manufacturing, give them a solid technical skillset, and ultimately develop future employees."

But remember—these things take time.

Says Plymouth Community School Corporation Superintendent Daniel Tyree, "Marshall County Industrial Corporation Association has been working on this for over a year now. We are excited to finally be seeing the course offering come to fruition. Not only will high school students be able to earn a valuable skill and get college credit for their work, we will be helping our existing manufacturing firms fill much-needed jobs."

Adds Neidig, "I see this program as being critical in sparking an interest with students for manufacturing, and in turn accelerating their interest in STEM courses. Getting more high school graduates with solid STEM knowledge is important."

The Ivy Tech program offers students dual-credit manufacturing courses to motivate them to continue their post-high school education.

Of course the skills gap dynamic has been with us for longer than we care to admit, making insidious and largely unremarked "progress"—from grade school to grad school. And if we are honest with ourselves, we know where the blame lays. As Neidig points out, two of the reasons are "School budgets getting tighter and a lack of industry engagement with local high schools. When schools started cutting their vocational budgets, manufacturing companies did not step up and say how important the training was or try to find more innovative solutions to bridge the funding gaps."

Another is the now outdated mantra embedded in kids' brains that without a college degree, you're toast. You'll be parking cars or wrangling burgers or worse. Which begs the question: a degree in *what*? It can be safely stipulated that countless kids go off to college each year with absolutely no clue to what they are going to do if or when they graduate. But what about kids who like working with their minds *and* their hands? Short of being a surgeon, college doesn't offer much.

Or as Neidig states, "I think the paradigm of 'college vs. vocational trade' is outdated and doesn't reflect reality. The reality is that college is very expensive and learning a skilled trade early in life is a great way to earn a living. It also gives students who are pursuing engineering or management careers a practical, skills-based foundation."

The Precision Tool Manufacturing Training Center is an outlet for high school students to earn a valuable skill and get college credit for their work, while also benefiting manufacturers in Indiana.

If you'd care to help out in any way, by volunteering your time, expertise, cash, etc., please see right.

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JOB SHOP LEAN

Ed's Note: This is the sixth article in an eight-part "reality" series on implementing Continuous Improvement at Hoerbiger Corporation. Throughout 2013, Dr. Shahrukh Irani will report on his progress applying the job shop lean strategies he developed during his time at The Ohio State University. These lean methods focus on high-mix, low-volume, small-to-medium enterprises and can easily be applied to most gear manufacturing operations.

Clement Peng and Shahrukh A. Irani, Hoerbiger Corporation of America, Inc.

Computer-Aided Finite Capacity Scheduling of a FLEAN Machining Cell

Background

An earlier column (*Gear Technology*, August 2012) described the process shown in Figure 1 that is followed for implementing Job Shop Lean in a comprehensive manner in any high-mix, low-volume discrete manufacturing facility, such as machine shops, forge shops, fabrication shops, mold shops, etc. At the core of this iterative approach is the expectation that (i) a job shop will utilize production flow analysis and/or group technology to identify the stable part families in its product mix, (ii) will implement a FLEAN (Flexible+Lean) manufacturing cell to produce each part family that has a stable demand and (iii) utilize finite capacity scheduling to schedule each cell on a daily shift-by-shift basis.

In theory, every time that one loop of the process shown in Figure 1 is completed, it will result in the implementation of a stand-alone FLEAN manufacturing cell dedicated to producing a family of parts whose manufacturing requirements are completely satisfied by the cell, except for vendor processes that simply could not be brought in-house. *In reality*, numerous constraints will either need to be broken (Example: Operators will need to be trained to operate multiple machines in a cell and suitable group incentives put in place to ensure that the cell's team becomes autonomous) or can't be broken (Example: Heat treatment furnaces cannot be placed inside a cell next to a CNC grinder).

Typically, after several iterations of the process in Figure 1, a job shop will end up being divided into at least two areas: (1) One area consisting of several FLEAN manufacturing cells with each cell dedicated to a product family and (2) Another area being a "remainder job shop" that produces the "cats and dogs" (parts with low volume, low value, and infrequent demand) in the product mix, spare parts, prototypes for emergent business and one-off orders. By dividing the job shop into these two areas, the following benefits are gained: (1) The FLEAN cells provide unquestionable

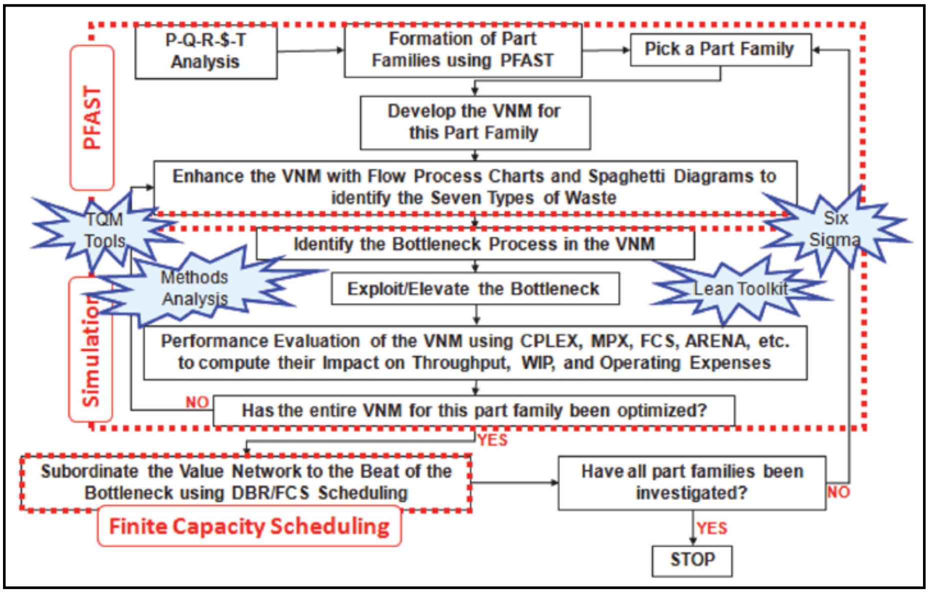


Figure 1 Comprehensive approach for implementing Job Shop Lean.

quick response, high quality, teamwork and other benefits that are guaranteed with flexible cellular manufacturing and (2) Instead of the entire business being managed as a complex job shop, only the smaller non-cellular portion of the shop now remains a complex job shop.

What Follows the Layout Design of a FLEAN Cell?

Having implemented a new layout for a FLEAN cell, it is then necessary to schedule daily operations in the cell. In this column, I will support the implementation of finite capacity scheduling software. Depending on the complexity of the part family and the demand patterns for the parts produced in a cell, a manual/visual system of pull scheduling just could suffice. For example, I know of at least one precision machine shop that uses a DBR (drum-buffer-rope) scheduling tool. One of our own cells, the QRC, makes do with a manual scheduling board that is populated with orders by an office manager who can guesstimate work content and overall cell workload. Possibly even an ERP system's schedule adjusted by experienced cell operators who can eyeball capacity requirements by just looking at the queue of parts.

Why Computer-aided Cell Scheduling?

Personally, I just do not wish to learn and implement questionable ad-hoc manual cell scheduling strategies when a solution of the future was already being successfully used in one of our sister facilities in Pompano Beach, FL, prior to my joining HCA. Especially if there are other cells that share resources with this cell, then the schedules of those cells (and outside vendors too), must be coordinated with this cell's schedule. Nor is visual management sacrificed at all. The complete daily schedule for a shop can be visualized using a Gantt chart, such as the one shown in Figure 2 which was produced by *Preactor* (*www.preactor.com*), the FCS (finite capacity scheduling) tool that is used by our sister facility in Pompano Beach, FL. The firm orders and their due dates quoted to customers are downloaded from *SAP* (which is our ERP system) into *Preactor*. After the schedule is generated by *Preactor*, it is input to our MES (manufacturing execution system), *FactoryViewer*, which then publishes twice daily a machine-by-machine sequence for producing orders loaded on every machine in the facility. Since every machine's operator must record the start/stop times for each order processed on his machine, the MES closes the loop between the daily schedule and the real-time execution of that schedule.

Scheduling a Single High-Mix, Low-Volume Cell – But Why?

The MP cell in our HCA-TX (HARP) facility is essentially a small job shop. Therefore, effective scheduling would improve its performance and employee utilization. The complexity of scheduling even a small job shop with four or more machines used in various combinations makes its schedule hard to generate, revise and maintain it manually. Ask any IE graduate who has taken a course in scheduling about how much time it took him/her to produce the schedule for a job shop consisting of just three machines producing four parts with different routings. Similarly, in the case of the MP cell, it has different equipment types, and in some cases, two machines of the same type that are unique, yet capable of processing the same parts if the tools and fixtures are available. In order to complete the implementation of the Job Shop Lean process shown in Figure 1, we undertook an exploratory proof-of-concept project to demonstrate the following "What if?" scenario for the MP cell: *If the daily schedule that was issued to the cell at the start of the day was subject to change due to one or more reasons, such as changing order priorities, machine breakdowns, rush orders, operator taken sick during the shift, due date changes forced by customers, etc., could we rapidly revise and re-generate a new schedule for the cell?*

Why *Schedlyzer Lite* was Chosen over *Preactor* for this Project

Like all other ERP systems on the market, our ERP system (*SAP*) uses MRP (material requirements planning) for production planning and operations scheduling. MRP uses assumptions of infinite capacity, backward scheduling from customer due dates using fixed lead times, batch production, etc. So it was decided not to use *SAP* for scheduling the MP cell.

Although *Preactor* is being used successfully in our Pompano Beach facility, our current license and implementation there is for a factory-wide installation. Due to time constraints, it was difficult to obtain a stand-alone license for the MP cell that would run on a desktop computer dedicated to the cell. Also, our director of manufacturing systems, Paul Mittendorff, who is the architect of the *Preactor+FactoryViewer* integrated system that we use in Pompano Beach, had prior commitments that made him

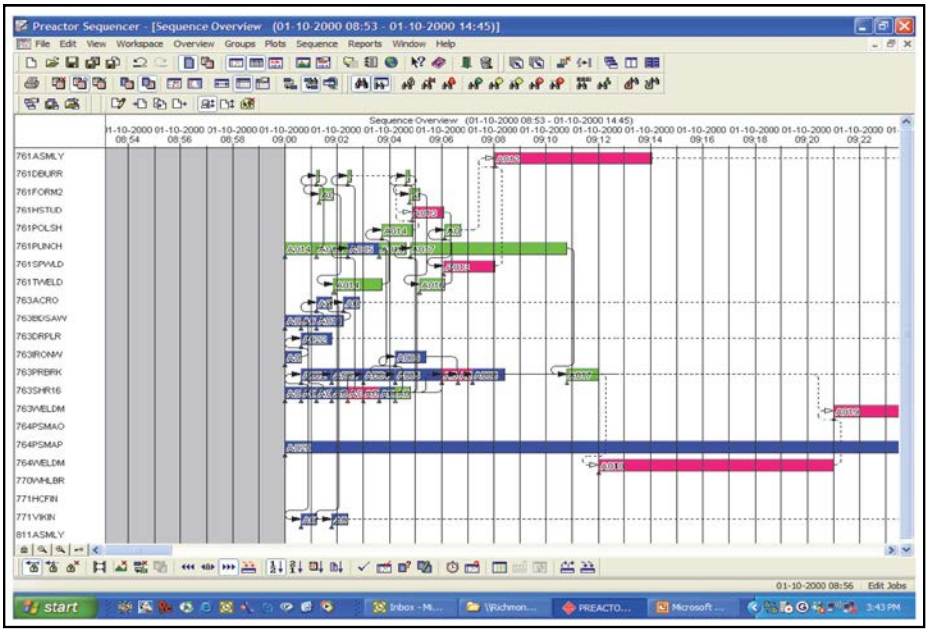


Figure 2 Gantt chart representation of a production schedule for visual management.

unavailable during the period when we wanted to do this project.

Therefore, we decided to work with another FCS vendor, Optisol Inc. (*www.Optisol.biz*) and use their *Schedlyzer Lite* tool for the project. *Schedlyzer Lite* is easy-to-learn and allows a user-friendly VBA (Visual Basic) interface to be developed for shop floor employees. Its price tag easily makes it affordable to purchase a single license for a computer that will be dedicated to a cell. It is well-supported by a local vendor resident in Bryan, TX, who boasts a track record of successful implementations in several job shops.

Figure 3 shows the VBA interface between *SAP* and *Schedlyzer Lite* that was developed by Clement Peng, the graduate intern we hired to work on this project. Since *SAP* query authorization was not allowed for our project, a macro in *SAP* was adapted to automatically generate data for daily orders. First you would click on the button highlighted in red then click on the button highlighted in yellow. Voila, the input data file for *Schedlyzer* would be ready with data extracted from *SAP*.

Next, as shown in Figure 4, we would open the input data file for *Schedlyzer* that was produced from *SAP* and, with one click on the "Schedule" button, we would schedule all jobs for production in the MP cell. By default, *Schedlyzer Lite* releases all jobs to complete by earliest due date (EDD) subject to labor and machine capacity constraints. Queues of jobs at individual machines are prioritized using the same dispatching rule (EDD).

Figure 5 shows the cell schedule summary screen in *Schedlyzer Lite* with detailed information on every job (Job ID, Job Start Time, Job Finish Time, Relative Earliness/ Lateness compared to Due Date, etc.). In the case of our pilot project, 30 jobs and 139 operations were scheduled to minimize the average # of in-process jobs to 8.2 orders. Some immediate benefits of this report are (i) it would help customer service to decide whether a new order can be done by its customer-specified due date and (ii) when the shipping department can expect the order to begin packaging it for shipment.

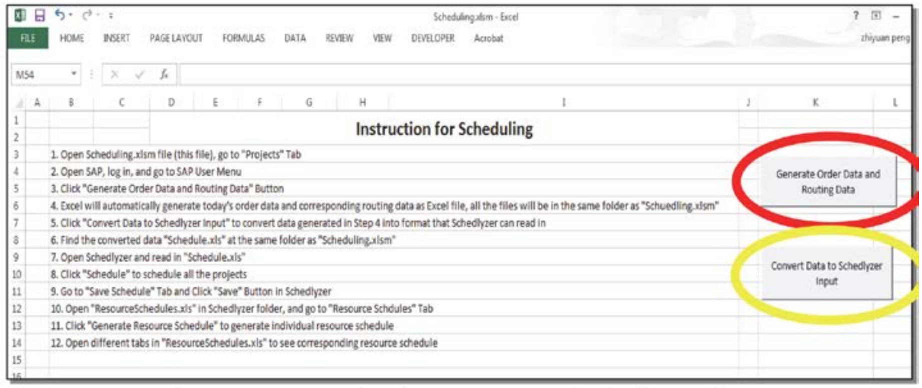


Figure 3 VBA interface between SAP and Schedlyzer Lite.

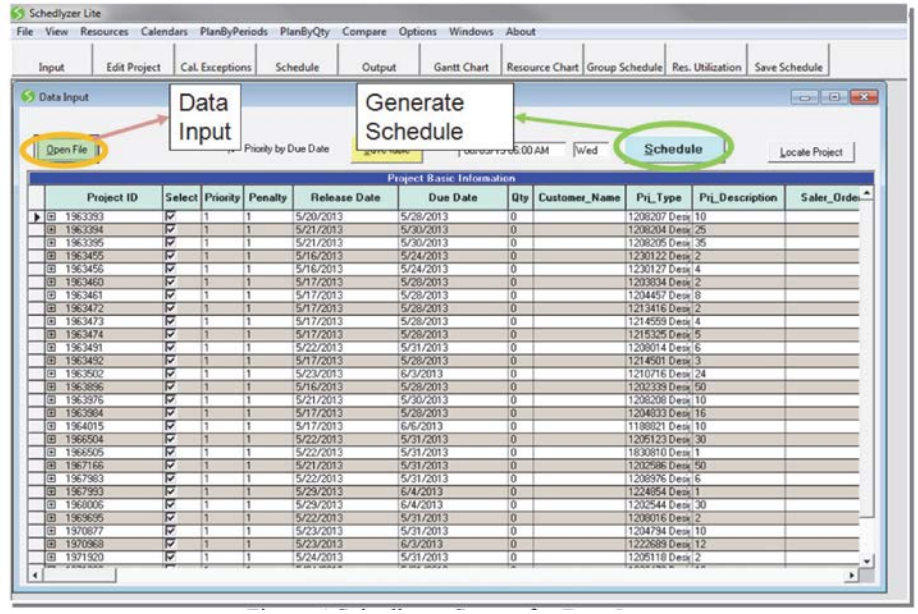


Figure 4 Schedlyzer screen for data input.

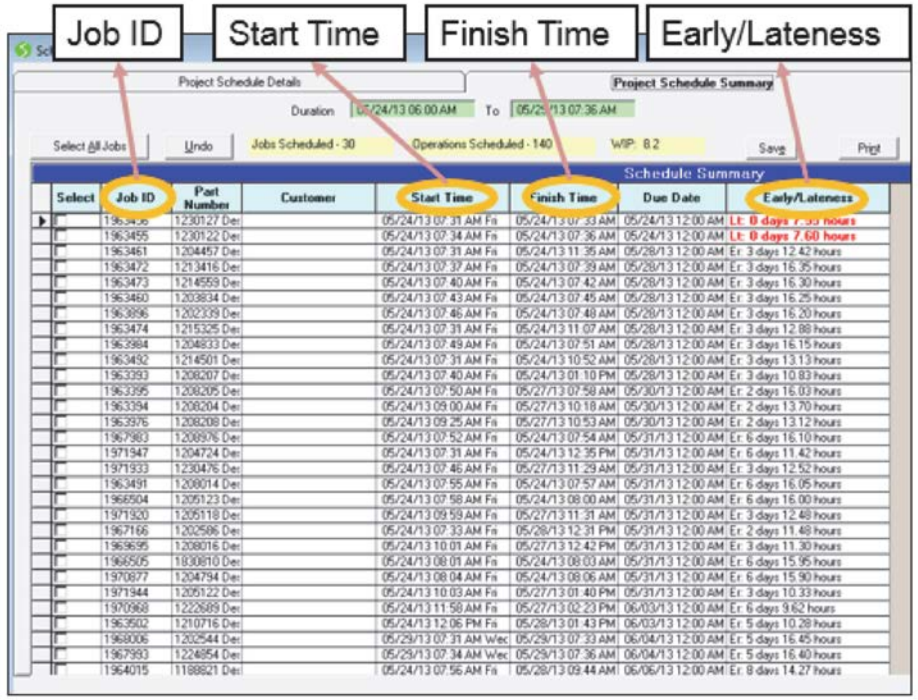


Figure 5 Cell schedule summary.

Figure 6 displays the schedule for a particular machine. This is the preferred sequence in which jobs should be worked on by that machine on any given day. For each job, its Job ID, Material Number, Operation # (with its expected Operation Start Time and Operation End Time), etc. is displayed. Thereby, the machine operator cannot have a doubt as to which jobs absolutely must be ready to run before/after another job. Like the powerful beam that emits from a lighthouse that can be seen by far-away ships, this schedule is the "beat" to which everybody (such as the machine operator, material handler, the cell leader, office manager, etc.) walks. Every violation of this daily sequence would be noted and become a kaizen that the continuous improvement team could solve by first asking, "Why? Why? Why? Why? Why did this happen?" This is a how the core problem-solving tools of lean are essential even in an IT-aided FLEAN manufacturing cell.

Schedlyzer can also generate the complete schedule for all active jobs run on all machines in the cell, either in a standard Gantt chart format or produce an *Excel* spreadsheet version for that chart. Although not as visually pleasing, the spreadsheet showing the sequence of jobs, start/finish times, waiting times, etc. is more effective for use by shop floor employees, the plant manager, or even the president of the company.

Here in our Houston, TX, facility we have a pilot implementation of the *Preactor+FactoryViewer (FV)* integrated system in the PoR Cell. The cell operators are familiar with the FV screen to guide schedule execution and on-time delivery tracking. The FV screen is superior to a simple tabular version of a Gantt chart.

For those readers who are familiar with the takt time counters that are mounted above assembly lines, the Gantt chart, or equivalent display, of the schedule for a high-mix, low-volume job shop cell is equivalent to the "pacemaker" in an assembly line.

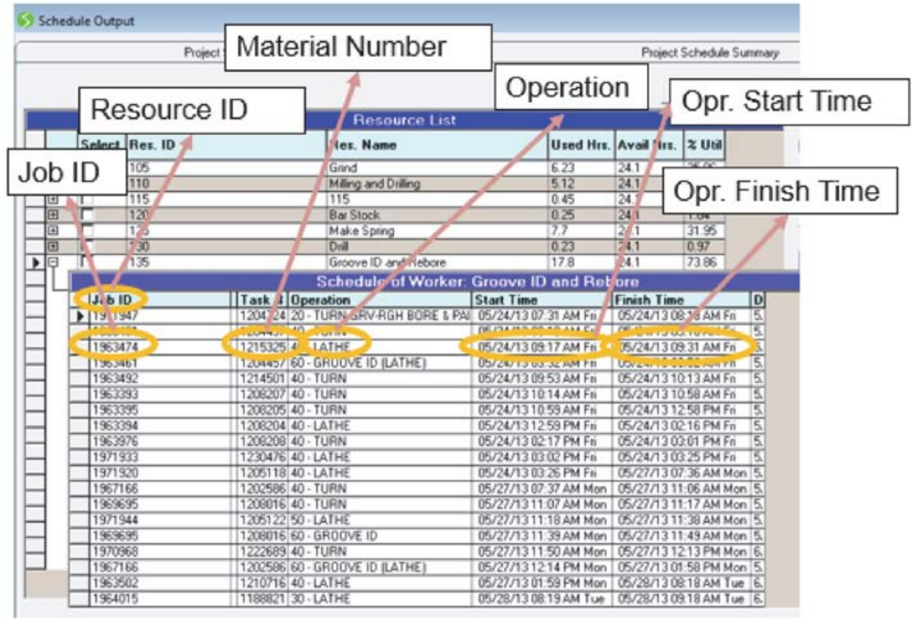


Figure 6 Schedule for a specific machine.

FCS does Facilitate Waste Elimination, Too

Scheduling using *Schedlyzer*, or any good FCS tool for that matter, would help to reduce WIP, minimize job waiting, plan on-hand inventories of raw materials, anticipate short-term overtime needs, etc. for any cell. For example, in this pilot project involving the MP cell, the *Schedlyzer* schedule projected that we could reduce the WIP of in-process orders from 59 orders to 15, which was equivalent to about $12,000 based on the prices of those orders. Why? Because a schedule based on finite capacity constraints automatically defers pre-mature release of orders that will simply end up in queue in front of the bottleneck machine when it is NOT the first machine being used to process the orders. Similarly, there are additional benefits of effective scheduling using an FCS tool that are prominently displayed on any vendor's website or listed in textbooks. But beware the hidden pitfalls and dangers of wanting to have those benefits without investing in the personnel and support systems essential for the success of FCS and MES.

Who Will Implement, Deploy and Manage your Implementation of FCS?

In *Preactor* (*www.preactor.com*), like *Schedlyzer* (*www.optisol.biz*) and *Tactic* (*www.waterloo-software.com*), high-mix, low-volume job shop-like manufacturers have a choice of powerful, widely-used and well-supported FCS tools. For example, in the case of *Schedlyzer Lite*, Dr. Prasad Velaga, president of Optisol Inc., ensured that being able to use his software was never a bottleneck during the execution of our project.

However, besides its weaponry, a good army needs a good general and many good soldiers, too. I will unequivocally state that the success of this pilot project can be attributed to Clement Peng, the graduate intern from the Department of Industrial and Systems Engineering at Texas A&M University. He single-handedly did this project in partnership with Dr. Velaga, the software vendor. His computer-skills, prior IE coursework related to scheduling, work ethic, ability and willingness to learn *SAP* and *Schedlyzer* on his own, driven nature, determination to make an idea work in practice, desire to learn real-world implementation of Job Shop Lean using computer tools like *PFAST* and *Schedlyzer* — he made the difference! As is the case with any lean implementation, people like him will make the implementation of FCS a success in any company like ours.

Now the Hard Work Must Begin

In order to take the next step towards computer-aided daily scheduling of each of our cells, we must now undertake the following essential tasks:

We must implement the new layout that we proposed for the cell. The new layout will co-locate almost ALL the machines and their operators who will be responsible for completing orders loaded on the MP cell. In my experience, not a single high-mix, low-volume facility that I have assisted has ever been designed correctly. Due to poorly-designed layouts, even in the case of an individual cell, whenever there is a distance of separation between two consecutive operations *that exceeds three feet*, the inter-operation transfer delays can, and will, destroy the best schedules generated by an FCS software resident on someone's computer in an office removed from the shop floor.

Next, we must conduct time studies (else rely on pre-determined standard times based on group technology) to populate the routers in *SAP* with reasonably accurate setup and machining cycle times for all the unique parts produced in the MP cell. Any software, be it an ERP system, FCS tool or MES, will produce garbage output if it receives garbage input, aka GIGO (garbage in, garbage out).

Finally, we will need to engage our IT staff to develop a professional communication interface between *Schedlyzer* (preferably *Preactor*) and our MES (*FactoryViewer*) to standardize how our schedules and employees interact.

Achieving FLEAN (Flexible and Lean) with People First, and IT Next

Lean, IT and flexible automation will co-exist with a motivated, talented and well-trained workforce in the Hoerbiger Production System (HPS). The HPS is in its infancy but it is intended to become a viable production system model for high-mix, low-volume manufacturing environments. Despite the incorporation of computer-aided data analysis and systems optimization, flexible automation, IT-aided production planning and control, etc., people and the standard lean tools are going to be the foundation of the Hoerbiger Production System. In fact, IT-enabled production systems demand an even greater reliance on employees and managers who can undertake continuous improvement projects to eliminate the myriad problems that arise when, say, computer-aided demand forecasts and daily shop schedules are disrupted by the vagaries

Resource ID	Project ID	Material Number	Operation Desciption	Start Time	Finish Time	Ring Type
105	1971947	120472	30 - GRIND	05/31/13 08:19 AM	05/31/13 08:53 AM	Design:PACKING RING
105	1963461	120445	50 - GRIND	05/31/13 09:17 AM	05/31/13 09:27 AM	Design:OIL SCRAPER
105	1963474	121532	50 - GRIND	05/31/13 09:32 AM	05/31/13 09:41 AM	Design:PACKING RING
105	1963393	120820	50 - GRIND	05/31/13 10:59 AM	05/31/13 11:18 AM	Design:PACKING RING
105	1963395	120820	50 - GRIND	05/31/13 12:59 PM	05/31/13 02:08 PM	Design:PACKING RING
105	1963394	120820	50 - GRIND	05/31/13 02:17 PM	05/31/13 03:06 PM	Design:PACKING RING
105	1963976	120820	50 - GRIND	05/31/13 03:07 PM	05/31/13 03:26 PM	Design:PACKING RING
105	1971933	123047	50 - GRIND	05/31/13 03:27 PM	06/03/13 07:43 AM	Design:PACKING RING
105	1971920	120511	50 - GRIND	06/03/13 07:44 AM	06/03/13 07:50 AM	Design:PACKING RING
105	1969695	120801	50 - GRIND	06/03/13 11:18 AM	06/03/13 11:24 AM	Design:PACKING RING
105	1971944	120512	60 - GRIND	06/03/13 11:39 AM	06/03/13 11:53 AM	Design:PACKING RING
105	1970968	122268	50 - GRIND	06/03/13 12:14 PM	06/03/13 12:19 PM	Design:PACKING RING
105	1963502	121071	50 - GRIND	06/04/13 08:19 AM	06/04/13 10:04 AM	Design:PACKING RING

Resource Schedules | 105 | 110 | 115 | 120 | 125 | 130 | 135 | 145 | 150 | 155 | 180 | ...

Figure 7 Detailed machine schedule output.

of the dynamic shop floor. For example, if a machine operator needs to take a restroom break, do you forbid him/her because the schedule generated by *Preactor* shows that he/she should be running Job X at that time?

Further, no ERP, FCS or MES system could ever match the flexibility and response time that good cell operators can provide when any number of unscheduled disruptions (machine breakdowns, missing tools, defective parts requiring rework, scrapped parts, vendor delivery failures, etc.) render the current computer-generated schedule for a cell useless. Will the computer be willing to report to work on a Saturday to get a rush order done and shipped to a key customer?

Sure, *Preactor* or *Schedlyzer* could quickly generate a new schedule but it would still have to be the cell leader who would provide it the data to accommodate and/or override the existing schedule! Specifically, our director of manufacturing systems, Paul Mittendorff, has teamed with our plant managers – Mark Ellis (Plant 3) and Christoph Magnet (Plant 1) – to stress to the shop floor that the dispatch lists that *FactoryViewer* presents them at their machines *must* be followed, that cherry-picking jobs out of the global schedule is *not* allowed. This teaming partnership has already produced results in Pompano Beach.

For Further Information on HCA's Projects Related to Scheduling

Joshi, P. & Irani, S.A. *A Tutorial on Job Shop Scheduling (JSS) using LEKIN Academic Scheduling Software.* Presentation made at the First Lean and Flexible Conference in Houston, TX, on April 1, 2013.

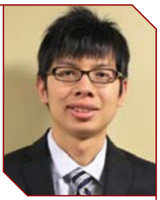
Mittendorff, P. *The Water Strider: How To Get the Right Material to the Right Machine at the Right Time per the Daily Schedule.* Presentation made at the First Lean and Flexible Conference in Houston, TX, on April 1, 2013.

Irani, S.A. *What are the Wastes created by a Jobshop's ERP System?* Presentation made at the First Lean and Flexible Conference in Houston, TX, on April 1, 2013.

Ellis, M. & Mittendorff, P. *Integration of MES (Manufacturing Execution System) with Material and Inventory Management.* Presentation made at the Second Lean and Flexible Conference in Houston, TX, on September 5, 2013.

Irani, S.A. & Velaga, P. *Revisiting Time and Motion Studies: Implementing Lean Improvements for a High-Mix Low-Volume Flexible Manufacturing Cell.* Presentation made at the Second Lean and Flexible Conference in Houston, TX, on September 5, 2013.

Please e-mail either *Paul.Mittendorff@hoerbiger.com* or *Shahrukh.Irani@hoerbiger.com* to receive electronic versions of these presentations, subject to permission from our higher-ups.



Zhiyuan (Clement) Peng is a graduate student at the Texas A&M University, where he is pursuing his Master's degree in industrial engineering (IE). He is currently working as an industrial engineering intern at Hoerbiger Corporation of America (www.hoerbiger.com). In his current job, he is supporting continuous improvement and inventory control projects in the shipping department and designing a new layout for that department. Previously, he worked as a quality engineering intern in TPT Electronics to apply six sigma skills to increase product quality. His other areas of expertise are data-driven justification of projects related to lean manufacturing, inventory control, and quality control. In the true spirit of continuous improvement, he continues to develop his expertise and work experience in other related areas.

Dr. Shahrukh Irani is the Director of Industrial Engineering (IE) Research at Hoerbiger Corporation of America (www.hoerbiger.com). In his current job, he has two concurrent responsibilities: (1) To undertake continuous improvement projects in partnership with employees as well as provide them on-the-job training relevant to those projects and (2) To facilitate the implementation of Job Shop Lean in HCA's U.S. plants. Previously, he was an associate professor in the Department of Integrated Systems Engineering at The Ohio State University (OSU). There his research focused on the development of new IE methods to adapt and scale lean for use by high-mix, low-volume SMEs (small and medium enterprises). His research group created *PFAST* (Production Flow Analysis and Simplification Toolkit) which is software for material flow analysis and facility layout to implement Job Shop Lean. At OSU, he received the Outstanding Faculty Award for excellence in teaching from the graduating classes of 2002, 2003, 2004, 2005, 2006 and 2009. In 2002, he received the Charles E. MacQuigg Student Award for Outstanding Teaching from the College of Engineering. He is a member of IIE.

Worm Gears

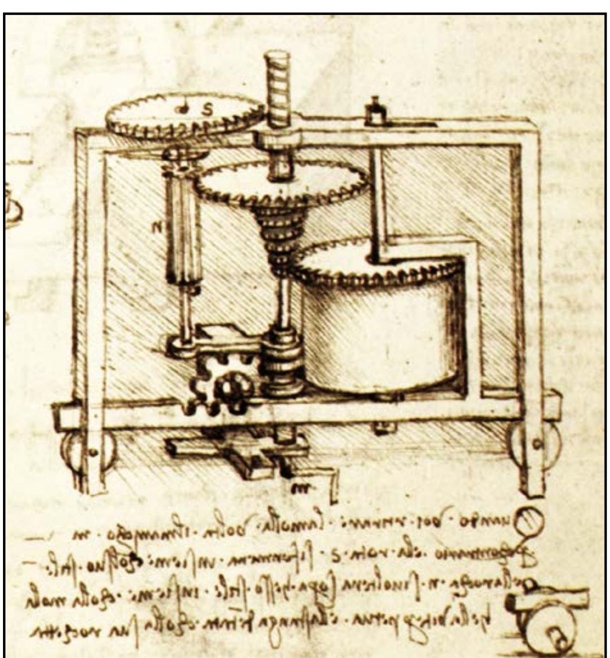
Email your question—along with your name, job title and company name (if you wish to remain anonymous, no problem) to: *jmcguinn@geartechnology.com*; or submit your question by visiting *geartechnology.com*.

QUESTION #1

How does one determine the center of a worm and a worm wheel?

First response provided by Joe Mihelick, *Gear Technology* Technical Editor:

The center of the single enveloping worm is straightforward, as it is at a plane passing through the axis of the worm at its outside diameter. The center of a double enveloping worm gear is a bit more involved. It is nominally located at a plane passing through the worm gear at its root diameter. If the worm gear is throated, the location of the minimum diameter of the throat will locate the nominal center of the worm gear. This is more useful for the manufacturing process but is less important in the successful operation or the worm – worm gear pair. The successful operation of worm gearing involves the actual contact pattern between them. The observed contact pattern is to be from the nominal center of the worm gear towards the leaving side of the worm gear as determined by the direction of the worm rotation.



The study of worm gears has come a long way: 16th century worm gear illustration (courtesy Leonardo daVinci).

Second response provided by Charles D. Schultz, PE, Chief Engineer for Beyta Gear Service, and *Gear Technology* Technical Editor *(gearmanx52@gmail.com):*

Short answer: It depends upon who is asking and what the intended application is. If you are specifying an off-the-shelf solution, you can rapidly determine the appropriate size from supplier catalogs. Commercially supplied worm gear speed reducers are available in a wide range of sizes, ratios and assembly configurations — from both U.S.-based and off-shore companies.

Worm gearing is not as standardized as spur, helical and bevel gearing. Several different 'systems' coexist in the marketplace, and each has its proponents. In the smaller gearbox sizes (less than 4-inch center distance), exterior and mounting dimensions have become 'standard' and users can easily interchange between brands. Larger units have no such commonality, and users are well advised to carefully consider all factors of supply (initial cost, availability, service factor and after-sales support) before selecting a vendor. Published ratings can be based on AGMA, DIN, ISO or other methods, and have generally been applied with few problems.

While each manufacturer will tout their particular tooth design as having performance advantages, the key factor in power capacity remains the physical size of the parts and the mechanical properties of the materials used to make them. Worm gears have some unique capabilities that can be used to good advantage in machinery design. They are the only gear system where gear ratio does not affect the outside diameter of the rotating parts; this means a machine can easily be supplied with a wide range of ratios — say 5:1 to 70:1 — without a center distance change or multiple reductions. Another capability — self-locking — can be a boon or a bane, depending upon your goals. Understanding these aspects of worm gearing can be a lifelong project, but users should ask the suppliers about it before ordering.

The long answer: Many 'systems' have been developed for worm gearing over the past 100 years. Each of them has its proponents and, oddly enough in the normally polite world of gear engineering, opponents. If off-the-shelf components won't work for your applications, you have to pick one of these competing systems and wade through the often confusing recommendations to develop your gear set. Custom-made tooling is expensive and takes critical lead time to obtain, so designers are encouraged to use existing hobs and fly cutters. I recommend the design system found in Daryl Dudley's *Gear Handbook,* along with the worm hob charts on Ash Gear and Supply's web site. AGMA's standards are the most reliable rating method for the independent designer.

If your requirement is for instrument gearing or plastic gearing, it is recommended that you work with a supplier of such parts or an experienced design engineer. Tooling costs can be very high, and the performance of prototype sets can vary depending upon manufacturing method. Molded plastic teeth do not have exactly the same topography as cut gears; veteran suppliers of plastic gearing understand the changes needed to make sample parts that will work reliably without skewing test results.

Worm gearing design is an iterative process which can be frustrating the first few times you work through it. Standard worm hobs may not converge on the solution you would prefer. Some suppliers can make worm gears using 'fly tools'—a custom single-point cutter that allows more flexibility in design than the standard hobs. The cutting process is, by necessity, much slower than hobbing, but for one-off or low-volume requirements it is often the best solution. Regardless of the tooling ultimately employed, custom worm gearing design requires compromises on center distance, face width and numbers of teeth/threads. More than any other gear type, 'your results may vary' is an appropriate disclaimer.

QUESTION #2

A gear handbook in my possession states: The ZI worm is identical to an involute helical gear whose tooth number is the number of worm threads. Equations of tooth surfaces of an involute helical gear are the same as for an involute worm. Knowing that a ZI hob cutter is identical to a ZI worm, I conclude that the mesh of the ZI worm and involute helical gear is identical to a cross involute helical gear mesh; and even identical to the hobbing process of an involute helical gear with a ZI hob cutter.

I would like to know whether I am correct and what is their difference.

Response provided by Hermann J. Stadtfeld, vice president - bevel gear technology - R&D for Gleason Corporation.

Worm Gear Generation and their Manufacturing Tools

The question will be answered considering the different possibilities in profile form, kind of mesh, and type of tools. Figure 1 contains the general nomenclature used to define the geometry parameters.

Worm gear drives can be separated in three categories:
Case A. Crossed helical worm gear drives
Case B. Cylindrical worm gear drives
Case C. Double-enveloping worm gear drives

Cylindrical worm gear drives "B" are the most common form. Their tooth profiles of the worms depend on the manufacturing method. The different profile forms according to DIN 3975 are:

ZI: Tooth profile in face section is an involute; manufactured, for example, by hobbing, like a cylindrical pinion. The hob for the worm gear manufacturing is a "duplicate" of the worm (however serrated and considering clearance and backlash).

ZA: Profile is a trapezoid in an axial section; manufactured, for example, by turning.

ZN: Profile is a trapezoid in a normal section; manufactured, for example, by turning with cutting blade tilted to lead angle of worm.

ZK: Profile with crowning. Tool is disk cutter with trapezoidal profile, which is tilted to lead angle of worm. Profile crown generated depending on disk cutter diameter.

ZH: Disk cutter with convex cutting edges, causing hollow flank profiles in axial section on worm teeth. Disk cutter axis is parallel to worm axis (not tilted like ZK).

A. Crossed helical worm gear drive. This is a special case of crossed helical gears, where the worm is a helical gear with one to six teeth, and the worm gear has a high number of teeth (e.g., above 30). The pitch elements of a crossed helical worm and worm gear are cylinders (Fig. 2). Both members—worm and worm gear—are manufactured like helical gears, with standard hobs, for example. The profile of both members is involute. The hobbing tool in Case A is not identical to

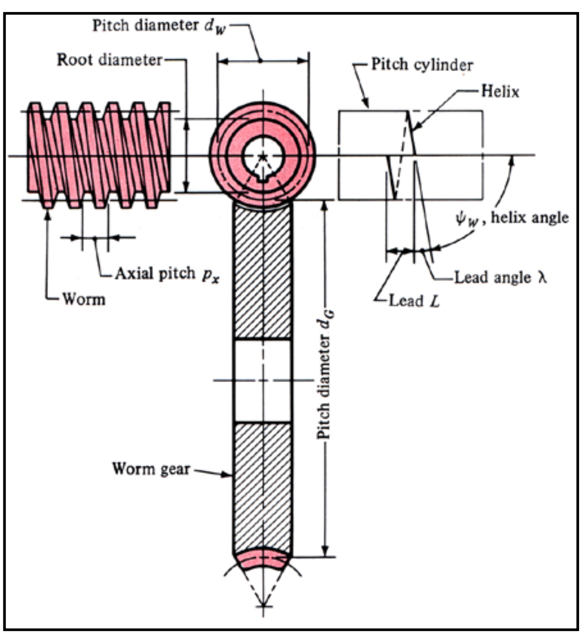


Figure 1 Worm gear drive nomenclature, single-throat example (graphics courtesy of Gleason)

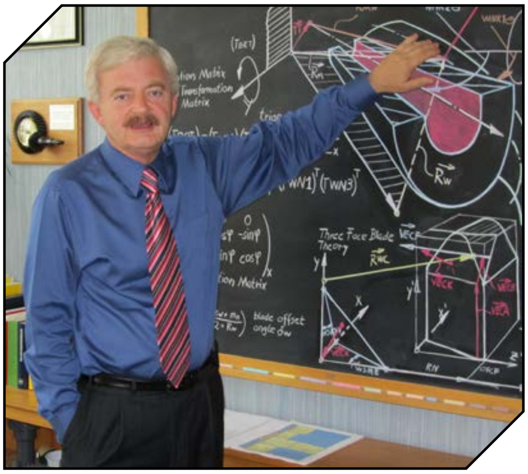
the worm. The two members have line contact, which appear instead as point or small contacting zones.

B. Cylindrical worm gear drives (single-throat worm gear drives). A typical worm gear drive; here the worm also has one to six teeth (starts), and the worm gear has a high number of teeth (e.g., 30 to 300). The pitch elements of a single-throated worm and worm gear are shown in Figure 3. The worm is manufactured on a lathe or with a disk milling cutter. The profile is not a generated involute but a straight line. The geometry of a cylindrical worm therefore is similar to an ACME screw. The worm gear is manufactured with a hob and the hob's enveloping surface *is identical to the mating worm*. This enveloping surface generates the same involute profile on the worm teeth as seen in Case A. However, the tooth thickness of the hob is thicker by the desired backlash amount. The difference in the gear in Case A is the shape of the pitch element, which in Case B has a hyperbolic form known as "throat." The throat is formed merely by plunging the hob cutter at the center of the face width. The two members have line contact that appears on the worm gear member like slim ellipses with a major orientation (if projected in an axial plane) parallel to the worm gear axis.

C. Double-enveloping worm gear drives (double-throated worm gear drives). These are special types of worm gear drives with a very high contact ratio and high torque transmission abilities. Again, here the worm has one to six teeth (starts) and the worm gear has a high number of teeth (e.g. 30 to 300). The pitch elements of worm gear and worm have a hyperbolic appearance which is why Case C is called "double-throated" (Fig. 4). The worm is manufactured on a lathe, where the cutting blade profile rotates around a center point while it moves along the face width. The distance between the cutting blade pitch point and the center of blade rotation is identical to the pitch radius of the worm gear. The profile is not a generated involute, but in a straight line. The worm gear is manufactured with a hob that has the pitch diameter of the worm at the center of the throat and the same number of starts, unlike the number of worm teeth. Also, here the worm gear is cut (as in Case B) by plunging with the hob cutter at the center of the worm gear's face width. The two members have line contact that appears even under light load, as with large elliptical zones—even in single angular positions.

It should be mentioned that in Case B, where the worm gear tool resembles the mating member within the flank surfaces, there remain several differences. The tool face is extended in order to machine sufficient top-root clearance, and the top-land corners to the flanks are rounded with the desired root fillet radius. The dedendum depth of the tool is equal to the addendum of the worm, plus an excess amount to prevent any cutting action at the worm gear top-lands.

The short answer to all conclusions the questioner has posed is "yes."



Hermann J. Stadtfeld

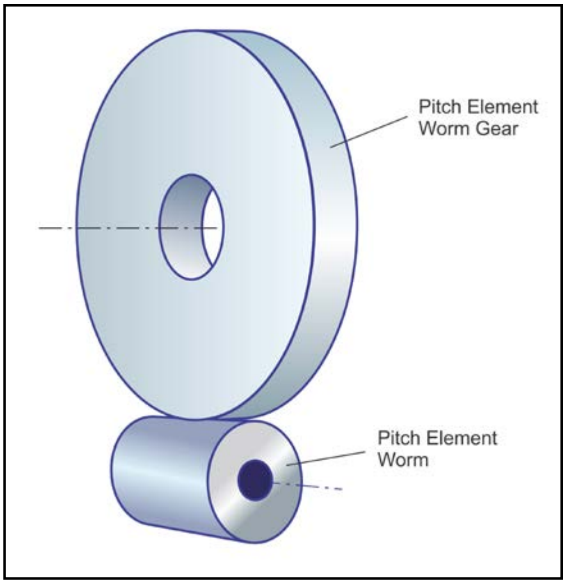


Figure 2 Pitch elements of crossed helical worm gear pair.

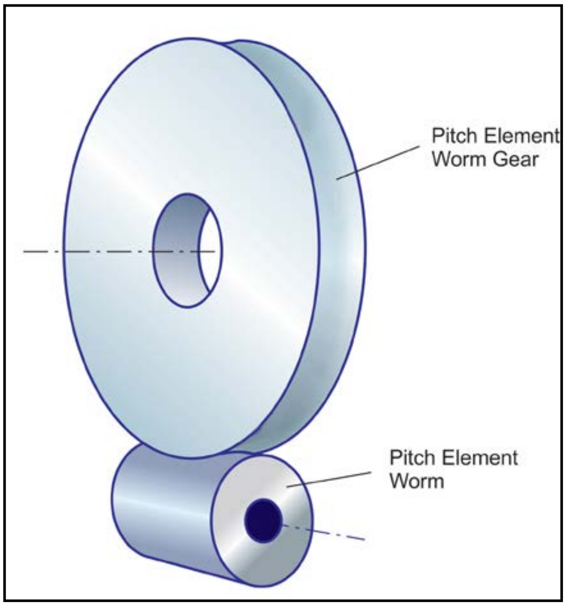


Figure 3 Pitch elements of single-throat worm gear pair.

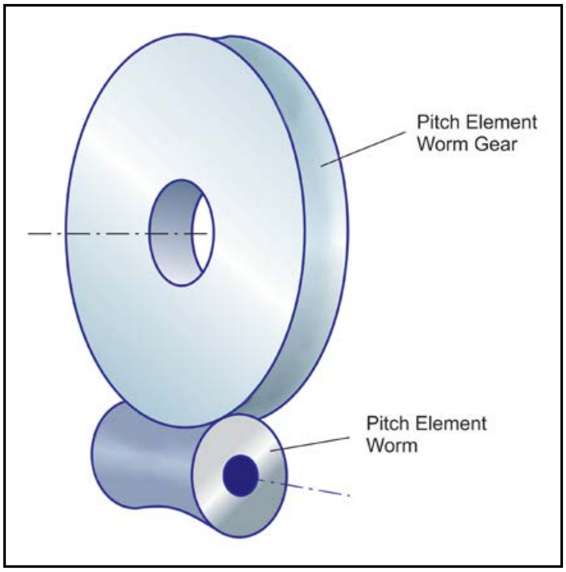


Figure 4 Pitch elements of double-throat worm gear pair.

Gear Standards and ISO GPS

Michele Deni

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standards
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In today's globalized manufacturing, all industrial products having dimensional constraints must undergo conformity specifications assessments on a regular basis. Consequently, (standardization) associated with GD&T (geometrical dimensioning and tolerancing) should be un-ambiguous and based on common, accepted rules. Of course gears — and their mechanical assemblies — are special items, widely present in industrial applications where energy conversion and power transmission are involved.

The ISO (International Standards Organization) GPS (geometrical product specifications) standard is a new approach to providing the basic tools and developing a common language supported by mathematical formalisms for acceptance in:

- Design geometrical definitions
- Specification limits for (tolerancing) classification
- Inspection methods
- Conformity assessment rules for acceptance

Upon general consensus between experts, the following basic, GPS-related documents should be considered in the future development and revision of gear standards:

- ISO/TR 14638
- ISO/TS 17450–1
- ISO/TS 17450–2
- ISO/14253–1
- ISO/TS 14253–2

The need for a GPS standard became apparent near the end of 1992, about the same time that the newest-generation tools were becoming available in the field of industrial products design. The development chain was going to be increasingly based on "virtual development" — right up to the physical realization of the single parts constituting the final product.

In this chain are involved:

- Basic design idea
- CAD implementation of drawings
- CAM programming for machine tools, robots, etc.
- CNC machining

At this stage, *everything* is "virtual" (i.e., numbers, codes) until the "physical" part is realized. There is then need of an interface able to compare the "real part" with the "virtual data," — thus capturing feedback for eventual modifications, corrections and final acceptance.

This "interface" is the aforementioned, modern measuring tool-set, possessing a certain degree of "intelligence"; e.g., computerized, electronic metrology devices (GMMs, CMMs, etc.).

Soon upon (the new devices') implementation came the realization that the traditional design specification methods (ISO1101, et al.) were no longer sufficient, and now operative only for the old-metrology tools like dial comparators, gauges, etc.

And so 1968 presented major problems for (manufacturers) like myself and others who were involved in the design and manufacturing of those new measuring tools (CMMs, GMMs); i.e., where the dimensional characteristics of measured parts are derived by reversing the mathematics of analytical geometry (from points to mathematical synthesis of geometrical features), and not comparing an artificial feature (artifact, reference frame, etc.) with a real one, as done in traditional metrology.

But despite some uncertainty over new processes of product development, (I found that) the uncertainty will diminish if:

Figure 1 Gears are special items — widely present in industrial applications where energy conversion and power transmission are involved.

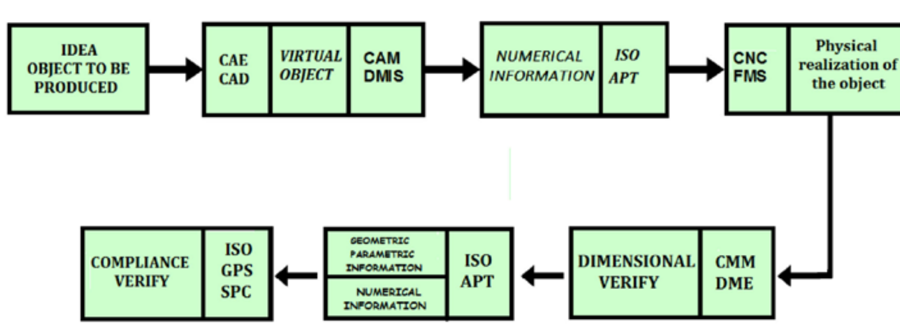

Figure 2 With ISO GPS, the manufacturing process is based increasingly upon "virtual development" — right up to the physical realization of the single parts constituting the final product.

Figure 3a and 3b (GMM 70) **This "interface" is the aforementioned, modern measuring tool-set, possessing a certain degree of "intelligence"; e.g., computerized, electronic metrology devices (GMMs, CMMs, etc.).**

The GD&T (geometric dimensioning and tolerancing) specifications implemented in the CAD drawings have the best "correlation" with the final functionality of the product, or "low correlation uncertainty."

- The GD&T specifications are self-consistent with an intrinsic low "specification uncertainty."
- The adopted verification method is at least "compliant" with the specifications in the drawing, or "compliance uncertainty."
- The conformity assessment for acceptance is based on "traceable" measurements.
- Following are some tecnical reports and technical standards containing conceptions of GPS systems:

ISO/TR 14638. This technical report contains the "master plan" of the hierarchy in which the GPS standards are organized, consisting of the fundamental, global, general and complementary standards containing the basic principles and general tenets.

ISO/TS 17450–1. This technical specification, which is part of global GPS documents, contains the model for geometrical specification used in the design of assemblies and individual parts that will deal with compliant measurement procedures.

These tools are based on the characteristics of features, on the constraints between features, and on operations used for the creation of different geometrical features. The aim is to define the fundamental concepts for the geometrical specification of a part (workpiece), and provide a mathematization of those concepts in order to have common, standardized rules for CAD users, developers of metrology algorithms, and conformity verification methods.

Some observations and perspective are necessary in order to better understand the philosophy of this ISO/TS. With the advent of new design tools like CAD, CAM, CNC and coordinate metrology, there was the need to change a way of thinking. The parts designed in a drawing represent an assembly of ideal geometric features, and the GD&T is related to the geometric parameters that define those features. So in the drawing we have dimensions and tolerances relative to ideal-perfect, geometrical elements.

The machined parts derived from the same drawing are imperfect, with errors relative to size, form, deviation and position. Here we have the problem of how to get a set of parameters for each feature present on the workpiece that might be comparable to the "ideal" ones on the drawing.

Utilizing coordinate metrology, the problem was solved with the introduction of a new "substitute geometrical feature." This is another perfect ideal feature "extracted" from the workpiece by means of the measuring procedure (probing or scanning points on the part). The parameters of this "substitute feature" can be compared with those represented in the drawing, and hence be able to reveal errors of size, deviation and position; but not form errors — they are not contained in the "substitute feature."

This approach is possible only in the case of what I call "metrology in predefined geometry," as the mathematical formalization of the measured part must be known "a priori" and constitutes a "target feature" for the "best-fit" mathematical algorithm that will produce the aforesaid substitute geometrical feature.

From this situation derives one of the most important principles of GPS — the "independency principle" — or ISO/8015 ISO/14659.

For this principle, any tolerance specification reported in a drawing must be independent of all other specifications. So if the substitute feature is introduced, eventual form errors must not influence the size, deviation or position errors. In my experience I have seen this principle violated very frequently in many blueprint specifications; e.g.: size tolerance specifications smaller than the admitted — or practically achievable — form errors. All of the concepts and definitions reported in this document are operative in the practice of the design and tolerancing specifications of gears.

The designer first defines a part of perfect ideal form with shape and dimensions, and with tolerance specifications that best fit the functionality of the final product. Let's call this defined part the "nominal model."

It is evident that the final realization of this part may not fit completely the ideal requirements of funcionality. This will be, in the end, an economic factor pertaining to the realization of the product. This economic factor is the "correlation uncertainty" in the GPS system. It is only the first step in the complete process of conformance assessment for the acceptance of the product in terms of economic finalization, evaluation of risk in case of acceptance or rejection, quality assurance and, not the least, security conformance.

In this document (ISO/TS 17450–1) all the definitions related to geometrical features and their geometrical characteristics are reported. It must be said that the majority of those definitions are pertaining more to specification and verification of pre-defined, geometrical features like line plane, cylinder, etc., and leave it to the tools to compare the real with the ideal geometrical characteristics, thus avoiding the form errors.

But this may not be the case of a gear's characteristics where the form error is relevant and best-fit algorithms for gear surfaces, where "transcendent" mathematical geometries are involved, are at present in an early stage of develpment, and, sometimes, cannot be applied.

The GPS may well need in the near future a contribution from the "gear people" with an international project tasked to the "fusion" of the two cultures. Some terms and definitions of this TS are particularly useful for the future work, like:

- ***Feature.*** Geometric feature: point, line, surface (involute, helix, worm and bevel in our case)
- ***Ideal feature.*** Feature defined by a parametrized equation
- ***Characteristic.*** Single property of one or more features expressed in linear or angular
- ***Specification.*** Expression of permissible limits on a characteristic
- ***Deviation.*** Difference between the value of a characteristic obtained from the non-ideal surface model (skin) and the corresponding nominal value
- ***Extraction.*** Operation used to identify specific points from a non-ideal surface
- ***Filtration.*** Operation used to create the non-ideal feature by reducing the level of information of an extracted non-ideal feature
- ***Association.*** Operation used to fit ideal features to non-ideal features according to a criterion (metrologic operator)
- ***Associated feature.*** Ideal feature established from a non-ideal surface model (skin model), or from a real surface through an association operation

A practical consequence of these definitions is the "conformity assessment" procedure, normally adopted for a machined part, that follows five steps:

1. Partition
2. Extraction
3. Filtration
4. Association
5. Evaluation

We think that there are more definitions that may occur in the future development or revision of gear standards.

ISO/TS 17450–2. This TS is another global GPS document and contains the basic issues for the development of the overall system that is based on the four tenets listed as A,B,C and D.

A. Simply states that GPS specifications on a drawing and functionality of the final product derived from those specifications are correlated at a certain degree (correlation uncertainty).
B. If a product is realized using a product documentation (blueprint) where GPS geometrical characteristics are reported, this product is acceptable if GPS specifications are fulfilled and measures are compliant, at a certain degree, to the same specifications (compliance uncertainty). The GPS specification itself may be "incomplete" (leading to bad functionality or difficult assembling), so an eventual specification uncertainty has to be accounted for regarding acceptance or rejection purposes.
C. Here the document points out that the process of realization of the product is independent from the GPS specification, and the GPS specification does not deal with the choice of the verification operator (measurement method). The lowest specification and measuring uncertainties obtainable dictate the best choice: ISO/TR 14253–2 PUMA method.
D. Here the document states that the implementation of the best selected verification process always leads to imperfections, and the implementation uncertainty has to be accounted for (compliance uncertainty).

(*Author's Note*: *In offering justification for this way of thinking in the GPS environment,a philosophical approach contends that in the community of metrologists recently, two schools of thinking have evolved, similar to what happened at the beginning of the last century for the communities of logicians and mathematicians.* Of *the two schools, one accepted the postulate of "completeness" posed from* ***Hilbert****, the other one, by contrast, belived in the Godel theorem of "incompleteness."*)

Thus on one side we have metrologists that believe that specifications on the blueprint are self-evident, and if those specifications are completely fullfilled there are no problems (principle of completeness). On the other side there are metrologists (GPS) that think this is not the case and specifications are incomplete (principle of incompleteness).

The problem is that for every specification there must be a verification — with a preventive measurement at the final stage of assembly or at the stage of functionality proof.

So it can be stated that a specification is complete only if all the intended functions are perfectly described and controlled with the specified characteristics. Unfortunately, most of the specifications will be incomplete because some funcions are imperfectly described and controlled — and sometimes not at all. The consequence is that there may be a more or less good — or bad — connection, between the function and the relative specification. Correlation uncertainty refers to the case of imperfect control, while specification uncertainty implies absence of control. Consequently, we can say that a measurement with low uncertainty is of little value when correlation or specification uncertainty is large. For metrologists the GPS is a good thing, as finally the responsibility of designers will be strongly accounted for in the production process.

The specfication process is step one, and is the responsibility of the designer.

The verification process follows the specification and is done by implementing the actual specification operator in an actual verification operation.

Some definitions:

Operator-ordered set of operations :

- ***Specification operations***. Operation formulated using only mathematical and/or geometrical expressions and/or algorithms
- ***Specification operator***. Made up of specifications operations
- ***Verification operator.*** Operator made up of verification operations (derived from specification operator)

ISO/14253-1. This standard is now well known by experts, and will soon gain in global importance and acceptance in the industrial environment, as the rules for the conformity assessment become clearly defined.

The role of uncertainty as an economic factor is evident, and the decision rules for who is going to pay are clear. The uncertainty contributions are introduced at different levels of the conformity assessment, going from the final level of the measurement uncertainty up to the level of the correlation uncertainty finalized to the functionality proof, passing through the specification uncertainty.

ISO/TS 14253–2. This technical specification provides a general rule of how to find the best specification and verification operators, known as the "PUMA" method.

Conclusion

In the future development and revision of existing standards dealing with technical specifications for gears, it should be mandatory to consider that any specification tool must be uniquivically associated to a corresponding verification operator.

Unfortunately, it seems that, given a particular specification, there is not much freedom for implementing a verification procedure that must be, at best, compliant witrh this specification, if relevant economic fallouts are to be avoided in a global production environment.

It is also suggested to take in account the following normative tools:

- The "VIM" for basic terminology. (*Editor's Note: This document gives guidance on the concepts and terms used in various approaches to measurement*).
- The GPS principles for specifications and verification items
- The "GUM" for measurement uncertainty evaluation . (*A series of documents establishing general rules for evaluating and expressing uncertainty in measurement that can be followed at various levels of accuracy and in many fields — from the shop floor to fundamental research for measurement uncertainty evaluation*).
- The ISO/14253–1 for conformity acceptance, activities.

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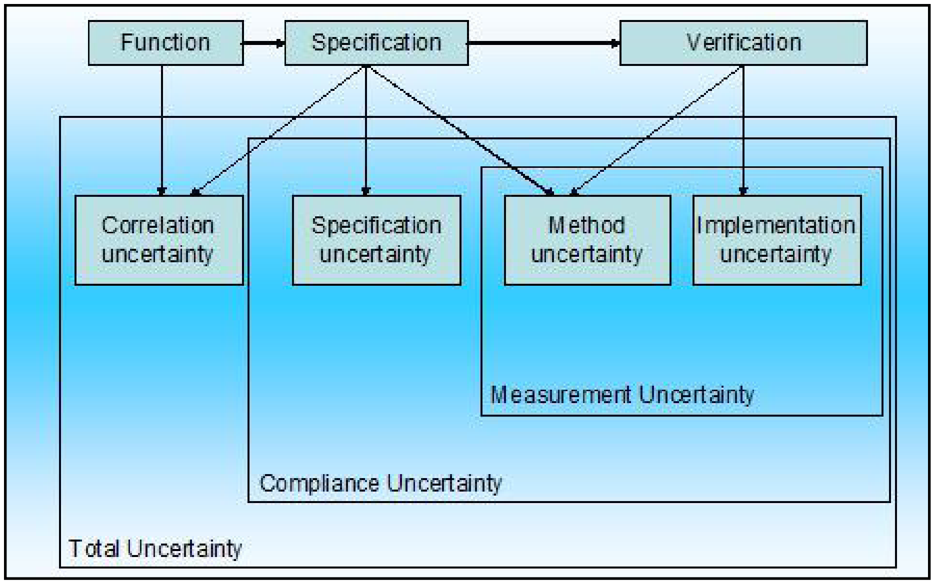

Figure 4 The verification operator is the basis for the conformity assessment procedure.

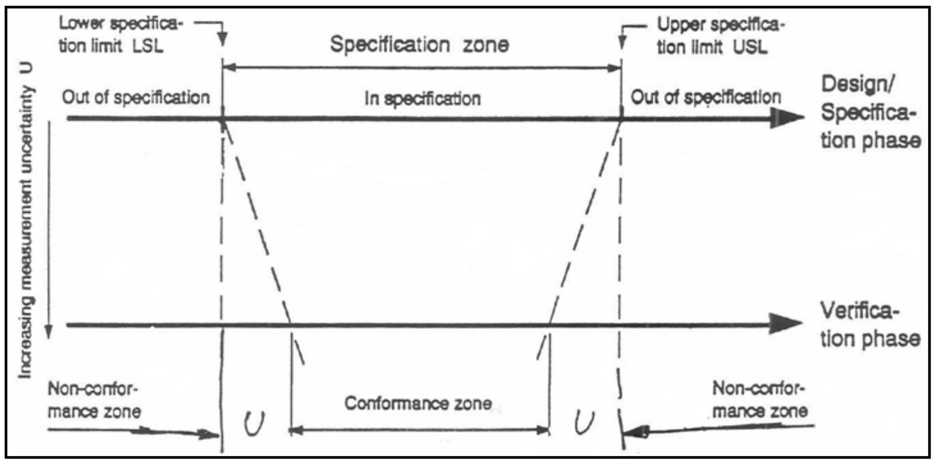

Figure 5 Uncertainty—cost unknowns—present at different levels throughout conformity assessment—from measurement uncertainty to correlation uncertainty, and finalized at functionality proof level.

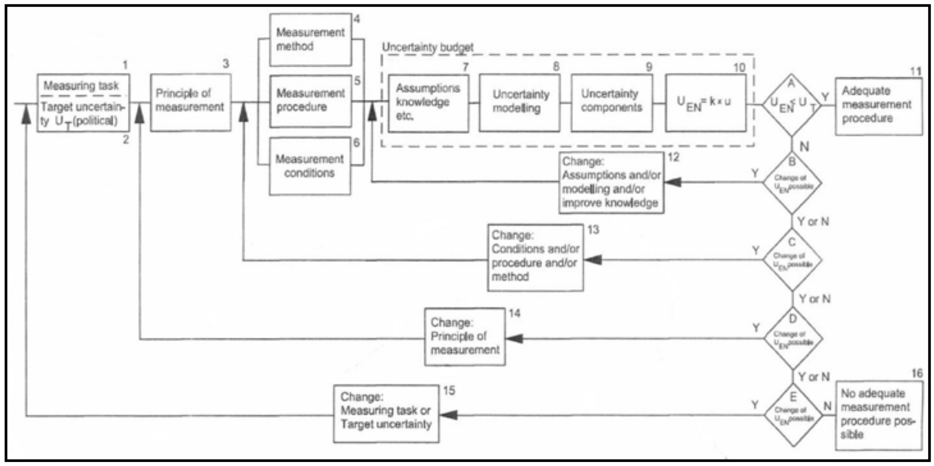

Figure 6 ISO/TS 14253–2's general rule—the "PUMA" method—shows how to find the best specification and verification operators.

Minimal Tooth Number of Flexspline in Harmonic Gear Drive with External Wave Generator

Hai-Lin Zhu, Hong-nen Wu, Min Zou, Xing-pei Qin,
Pei-yi Song and Jun Pan

Wave generators are located inside of flexsplines in most harmonic gear drive devices.

Because the teeth on the wheel rim of the flexspline are distributed radially, there is a bigger stress concentration on the tooth root of the flexspline meshing with a circular spline, where a fatigue fracture is more likely to occur under the alternating force exerted by the wave generator.

Our solution to this problem is to place the wave generator outside of the flexspline, which is a scheme named harmonic gear drive (HGD) with external wave generator (EWG). A formula to calculate the minimal tooth number of a flexspline that satisfies the requirement in fatigue strength for the flexspline is derived in this paper.

Nomenclature

- Z_R Tooth number of flexspline
- Z_G Tooth number of circular spline
- m Module of flexspline and circular spline (mm)
- r_m Radius of middle circle in flexspline (mm)
- d_m Diameter of middle circle in flexspline (mm)
- d_R Diameter of reference circle on flexspline before its deformation (mm)
- d_G Diameter of reference circle on circular spline (mm)
- h_{fR} Dedendum of flexspline tooth (mm)
- h^*_{fr} Coefficient dedendum for flexspline
- d Wall thickness of the flexspline's rim (mm)
- E Material elastic modulus of the flexspline (MPa)
- I Moment of inertia for cross section in the flexspline to mid-axis (mm^4)
- B Axial width of the flexspline (mm)
- W_0 Radial maximum deformation of the flexspline (mm)
- b Length of short semi-axis of elliptic mid-layer (mm)
- a Length of major semi-axis of elliptic mid-layer (mm)
- n_s Safety coefficient under bending normal stress
- n_τ Safety coefficient under torsional shear stress
- $[n]$ Permissible safety coefficient
- σ_{-1} Fatigue strength limit in bending for flexspline's material (MPa)
- K_σ Factor of stress concentration in the gear's root influence of average stress on fatigue strength
- ψ_σ Influence of average stress on fatigue strength

Introduction

It is via the elastic deformation of the flexspline that a harmonic gear drive (HGD) transfers motion and power. Unlike a conventional gear drive, which is based on the concept of rigid bodies, HGD, operated by the elastic theory, is mainly composed of three basic components: a non-rigid "flexspline," a rigid "circular spline" and an elliptical "wave generator." The wave generator produces and controls the deformation of the flexspline. It is called the harmonic drive since the wave form presented in the flexspline is a simple harmonic wave which is symmetric by and large (Refs. 1 and 2).

Harmonic gear drives have advantages that other drives do not, such as simpler structure; higher drive ratio with a wide range of variation, which is capable of producing speed ratios up to 300 in a single stage (Ref. 2); larger load-carrying capacity resulting from more teeth meshing and supporting load simultaneously; tooth contacts of about 10-30% of the total tooth number (Ref. 3); and smooth transmission with no impact between gears. Because of these advantages, HGD has promising applications in fields such as aerospace, machine tools, instruments, electronic equipment, mining equipment, transport and communication facilities, hoisting machinery, petrochemical machinery, textile machines, agricultural machinery, medical apparatus and instruments (Refs. 1–3).

A flexspline in operation undergoes alternating stress; its life determines the service life of the entire harmonic gear device. The wave generators are mostly located inside of flexsplines in current HGD devices. Because the teeth of the flexspline are distributed radially on the gear rim, the mouth of the tooth socket in the flexspline meshing with the circular spline will open wider under the action of wave generator. Higher stress concentration is caused in the tooth root of the flexspline, where a fatigue crack occurs easily under the periodically alternating force of the wave generator.

If the wave generator is set outside of the flexspline — known as an HGD/EWG (harmonic gear drive with external wave generator) — the teeth on the rim of the flexspline are distributed in a form of convergence on this occasion. The stress concentration in the tooth root of the flexspline is lightened, thus enhancing the strength of the flexspline and, in turn, prolonging the service life of the device.

The structure size of two key gears — the flexspline and the circular spline — must be determined first in order to design an HGD mechanism with EWG. Unfortunately, HGD-with-EWG is rarely discussed in mechanical design literature, nor mentioned in reference material.

In an attempt to address the problem, this paper presents a formula to calculate the minimal tooth number of flexspline in double-wave HGD-with-EWG. The formula is rooted in the concept of a mid-layer in the flexspline and the analysis of the radial deformation of the mid-layer, section stress and fatigue strength of the flexspline under the action of EWG. The tooth number of the circular spline can then be settled; if its tooth number is determined, a theoretical foundation is thus laid for structural design and strength analysis on a harmonic gear device with EWG.

Principle of HGD-with-EWG

An HGD mechanism with EWG (Ref. 4) is also composed of three basic parts: 1) flexspline; 2) circular spline; and 3) wave generator (Fig.1). The circular spline is an external gear; the flexspline is a thin-wall gear ring with internal teeth, and its tooth number is slightly more than that of the circular spline. Most harmonic gear devices are of double waves, and, in this case, the tooth number of the flexspline is usually two more than that of the circular spline.

Initially, the profile of the flexspline is circular in shape (Figs. 1 and 2) before the flexspline is compressed by the EWG. The inner side diameter of the wave generator is slightly less than the outside diameter (equal to $2r_m$) of the flexspline before it is deformed. The flexspline is squeezed into an oval under the action of EWG, which contacts with the flexspline. Teeth near both ends of the minor axis of the ellipse for the flexspline mesh completely with the teeth in the circular spline, and the teeth near the major axis of the ellipse separate completely from those in the circular spline; teeth on other segments are in transition states of coming into or out of mesh gradually.

The circular pitches for the two gears are the same. In the pitch circle of the circular spline, the meshing process for teeth of the flexspline and circular spline looks like two pure rolling (no sliding) rings. The arc length rolled in the pitch circle must be equal at any moment for two gears. The deformation position on the flexspline is ever changing; EWG turns continuously as the teeth of the two gears are in mesh, and then out of mesh; in turn, the engagement transmission is thereby realized.

Radial Deformation of a Flexspline

The concept of mid-layer in flexspline. Elastic deformation of the flexspline emerges periodically under the action of EWG. The deformation of the flexspline is usually represented by the deformation of the mid-layer. The so-called mid-layer, a hypothesis in material mechanics (Ref. 5), refers to the middle layer in the interior of the flexspline's rim, which is neither elongated nor shortened while the flexspline is undergoing bending deformation. The middle face through the rim thickness of the ring-flexspline is usually considered as the mid-layer because the degree of bending deformation for the flexspline is less (Ref. 6). The line intersection of mid-layer and cross-section is called the neutral axis; i.e. — a line on the cross-section connecting every point where its normal stress is zero. The elliptic mid-layer in the flexspline will rotate as EWG turns.

The mid-layer of the flexspline before it is deformed is a circle, or middle circle. If the flexspline is a standard gear (no addendum modification), the radius of the middle circle in the flexspline (Figs. 1 and Fig. 2) is determined by the equation:

$$r_m = 0.5d_R + h_{fR} + 0.5\delta \quad (1)$$

where:

the diameter of the reference circle on the flexspline before its deformation $d_R = mZ_R$, the dedendum of flexspline tooth $h_{fR} = mh^*_{fR}$, coefficient of dedendum $h^*_{fR} = 1.35$ (Ref. 7) for the normal tooth of the flexspline with a pressure angle of 20 on the reference circle according to the standard of involute tooth profile in harmonic gear universally.

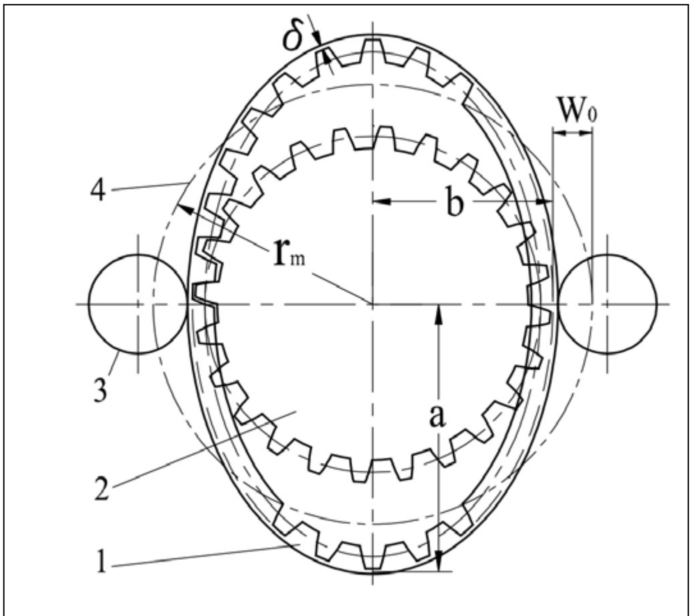

Figure 1 Generalized drawing of HGD with EWG.

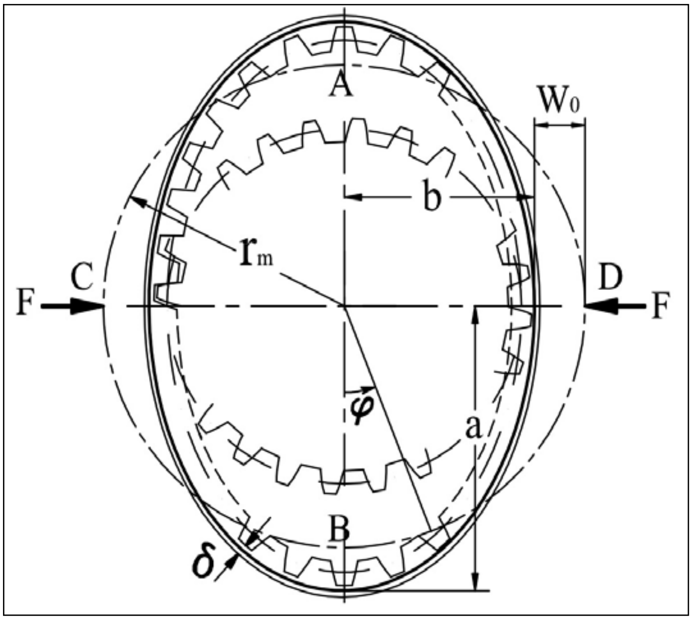

Figure 2 Shape change of mid-layer in flexspline — from circle to ellipse.

Bending moment on section in flexspline. The flexspline in Figure 1 — a cylindrical shell with teeth inside — is an orthotropic anisotropic shell (for the flange or rim of the flexspline) in structure. There exist structural nonlinearities, since the teeth on the rim are equivalent to longitudinal reinforcing ribs, and geometric nonlinearities of large deflection because the ratio of radial maximum deformation to rim's wall-thickness of the flexspline is bigger than 0.2. It is therefore difficult to obtain an exact solution in internal force, deformation and stress distribution on the flexspline's rim under the action of EWG.

Some simplification is necessary in order to study the internal force and strength of the flexspline. Influence of a flexspline's teeth could be left out first, so that the flexspline is simplified as a smooth, thin-walled cylindrical shell with a rim thickness δ, since it is far less than r_m, the radius of the middle circle (Ref. 8). After obtaining the deformation and stress of the flexspline shell using the shell theory in elastic-plastic mechanics, the influence of teeth on stress in smooth shell is then considered and reflected in the calculation formula as a tooth influence coefficient (Ref. 9).

Assuming that the EWG exerts concentrated forces on the flexspline, a mid-layer ring of flexspline which bears a pair of equal pressures *F* in opposite directions is taken as a research model. As shown in Figure 3a, it is a statically indeterminate structure (Ref. 5).

Just one-quarter of the ring-flexspline (Fig. 3b) need be studied, considering the symmetry of the ring's geometry and load. There is only axial force and moment on section B because of the symmetry. The axial force is equal to 0.5 *F* using equilibrium condition, and bending moment *Mx* is a redundant constraint to be solved. Since the turn-angles on sections B and D are zeroes, section D could be regarded as a fixed end, and the zero turn-angle on section B is taken as deformation coordination condition. Thus a force-method based canonical equation (Ref. 5) can be written (the derivation process is omitted here due to limited length of this article), redundant constraint (bending moment) $Mx = F_{rm}$ (0.5-1/π) is then gotten, and from which the bending moment on any section for the ring-flexspline is determined by the formula:

$$Mx = F_{rm}\,(0.5\cos(\varphi) - 1/\pi) \tag{2}$$

where:
F is the extruding force pressed on the ring-flexspline by EWG; φreflects the position of the ring section starting from vertical section B, φ = 0 ~ 90, and the counterclockwise angle is considered positive.

Radial deformation of mid-layer in the flexspline. Radial deformation in major and short axes of elliptic mid-layer on the flexspline has the greatest influence on meshing quality between the flexspline and the circular spline, so the fluctuations in length must be analyzed for vertical diameter AB and horizontal diameter *CD* on the mid-layer (Figs. 2 and 3).

The length of horizontal diameter *CD* on the ring-flexspline will be shortened under a pair of extruding forces *F*. From Equation 2 we apply Moore's theorem (Ref. 5) and integrate along the entire circle of the ring, the reduction of diameter *CD* that is the relative displacement δ_{CD} between *C* and *D* on which the forces *F* act can be obtained:

$$\delta_{CD} = \frac{F r_m^3 \left(\frac{\pi}{4} - \frac{2}{\pi}\right)}{EI} \tag{3}$$

where:
E is material elastic modulus of the flexspline; *I* is the moment of inertia for cross-section in the flexspline torus to mid-axis $I = B^3/12$; *B* is the axial width of the flexspline; *EI* means flexural rigidity of the torus, which reflects material's ability of resistance to bending deformation.

The length of vertical diameter AB for the ring-flexspline will surely be elongated when the length of horizontal diameter *CD* becomes shorter. According to Equation 2, applying Moore's theorem (Ref. 5) again along the entire circle of the ring, the amount of elongation δ_{AB} for diameter AB can also be obtained:

$$\delta_{AB} = \frac{F r_m^3 \left(\frac{2}{\pi} - \frac{1}{2}\right)}{EI} \tag{4}$$

It can be seen that $\delta_{CD} > \delta_{AB}$ from Equations 3 and 4 means that the maximum radial displacement among points on the mid-layer appears in the short axis of ellipse; i.e., in the direction of extruding forces.

From Figure 2, it is directly seen that the radial maximum deformation

$$W_0 = \frac{\delta_{CD}}{2} \tag{5}$$

To simplify the discussion, assume that the flexspline and circular spline are two standard gears. From the point of view for proper meshing between two gears, the reference circle on the circular spline should coincide with the reference line near the short axis of the elliptic mid-layer of the flexspline (Fig. 1). In other words, the length of short semi-axis *b* should satisfy the following relationship:

$$b = 0.5\,d_G + h_{fR} + 0.5\delta \tag{6}$$

where:
the diameter of the reference circle on a circular spline $d_G = mZ_G$. The thickness of the flexspline's rim $\delta = (0.01 \sim 0.015)\,d_R$ is generally taken (Ref. 9).

Obviously, $W_0 = r_m - b$ (Figs. 1 and 2). We obtain $r_m - b = 0.5m\,(Z_R - Z_G)$ by subtracting Equation 6 from Equation 1. Parameters of W_0, *m*, Z_G and Z_R must obey the following expression:

$$W_0 = 0.5m\Delta Z \tag{7}$$

where:
D*Z* is the tooth number difference of the flexspline and the circular spline; $DZ = (Z_R - Z_G)$.

Stress on Cross-Section in the Rim of a Flexspline

The scholar M. H. Ivanov considered that HGD is one having initial pre-stress (Ref. 8). After the wave generator is assembled outside of the flexspline, the flexspline is force-deformed and subjected to preliminary load because of the extrusion effect by EWG — thus pre-stress occurs in the cross-section of the flexspline's rim.

The maximum and minimum stresses in section of flexspline. It is known (Eq. 2) that the biggest bending moment occurs on sections D of φ = 90 in the ring-flexspline (Fig. 3); its value $M_{max} = -Fr_m/\pi$ (minus sign means that this bending moment decreases the curvature of the elliptic mid-layer). The stress at the outermost end (away from the center of the middle circle) on section D is the maximum compressive stress in cross-sections of the ring-flexspline, its value $\sigma_{max} = 0.5\,M_{max}\delta/I = -0.5Fr_m\delta/(\pi I)$. The maximum compressive stress could be calculated from Equations 3 and 5:

$$\sigma_{max} = \text{-}8.5580 \frac{W_0 E\delta}{d_m^2} \quad (8)$$

Here the minus sign indicates a compressive stress; the diameter of the middle circle in the flexspline is $d_m = 2r_m$.

Also from Equation 2, it is obvious that the minimal bending moment appears on sections B of $\varphi = 0$ in the ring-flexspline; its value is $M_{min} = Fr_m\,(0.5\text{-}1/\pi)$. The stress at the outermost end (away from the center of the middle circle) on section B (it is a tensile stress) $\sigma_{min} = 0.5\ M_{min}\delta/I = 0.5\ Fr_m\ (0.5\text{-}1/\pi)\ \delta/I$, which is also the minimum tensile stress of all sections in the ring-flexspline. The minimum tension stress can be calculated as follows:

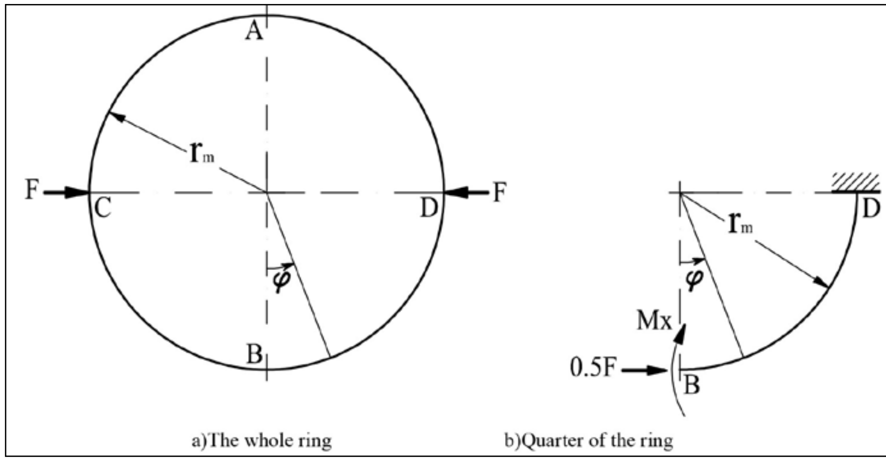

Figure 3 Force analysis on mid-layer of flex-spline.

$$\sigma_{min} = 4.8849 \frac{W_0 E\delta}{d_m^2} \quad (9)$$

Cycle characteristic of alternating stress on section in ring-flexspline. As mentioned above, the stress at outermost end on section D (Fig. 3) in the ring-flexspline is biggest (maximum compressive stresses), and smallest on section B (that is, minimum tensile stresses). Therefore, the stress on the ring's section is an alternating stress in an asymmetric cycle, which is a reason leading to fatigue failure for the flexspline.

Combining Equations 8 and 9, and considering the influence of teeth in the flexspline on stress, will derive a general formula to calculate the average stress in sections of flexspline in one cycle.

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = 1.8366 \frac{K_\delta W_0 E\delta}{d_m^2} \quad (10)$$

where:

K_δ is a factor reflecting the influence of teeth in flexspline on stress (Ref. 9), $K_\delta = 1.05 \sim 1.10$, in most cases.

Alternating stress amplitude, namely, the difference of maximum and minimum stresses on the ring's section, is:

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = 6.7214 \frac{K_\delta W_0 E\delta}{d_m^2} \quad (11)$$

Determining Minimal Tooth Number of Flexspline

The performance of the flexspline depends on its fatigue strength. Stress on a section in a ring-flexspline is in cyclical change (an asymmetric cycle), as described. We thus must calculate the fatigue strength of the flexspline (Ref. 6).

According to Refs. 5 and 8, the safety coefficient n in fatigue strength under alternating stress of the combination of bending and twisting is:

$$n = \frac{n_\sigma n_\tau}{\sqrt{n_\sigma^2 + n_\tau^2}} \geq [n] \quad (12)$$

where:

the permissible safety coefficient $[n] = 1.3 \sim 1.5$ (Refs. 8 and 9), as a rule.

Usually, the influence of normal bending stress is only considered in approximate calculation, since it is quite small for the influence of torsional shear stress on the fatigue strength of the flexspline (Ref. 8). That is, the following equation on safety coefficient in fatigue strength of flexspline should meet:

$$n_\sigma = \frac{\sigma_{-1}}{K_\sigma \sigma_a + \psi_\sigma \sigma_m} \geq [n] \quad (13)$$

where:

the factor of stress concentration in the gear's root $K_\sigma = 1.8 \sim 2.0$, influence factor of average stress on fatigue strength $\psi_\sigma = 0.10 \sim 0.15$ are reasonable ranges (Refs. 6 and 8).

The minimal tooth number of a flexspline satisfying the requirement in fatigue strength is then obtained from equations 1, 7, 10, 11 and 13.

In general, let's take $K_\delta = 1.07$; $K_\sigma = 1.9$, $\psi_\sigma = 0.12$; $\delta = 0.012$; $d_R = 0.012\ mZ_R$ in the recommended ranges. Substituting relevant data into Equations 1, 7, 10, 11 and 13 yields the following relationship:

$$n_\sigma = 12.2795 \frac{\sigma_{-1}\,(Z_R + 2.668)^2}{K_\sigma \sigma_a + \psi_\sigma \sigma_m} \geq [n] \quad (14)$$

Equation 14 is the condition under which the tooth number of the flexspline should be satisfied. And ΔZ, the tooth number difference for two gears, should be integral times of the wave number for HGD (Refs. 8 and 9). Double-wave HGD with a tooth number difference of two has been widely used at present, and double-wave HGD with a tooth difference of four also has application on specific occasions; thus ΔZ could be 2 or 4 in different applications.

Tooth number Z_G of the circular spline could then be calculated using the formula:

$$Z_G = Z_R - \Delta Z \quad (15)$$

where:

if the tooth number Z_R of the flexspline and tooth number difference ΔZ of two gears are determined.

Example: Suppose we are to design a double-wave harmonic gear assembly with EWG. A steel 30CrMnSiA, quenched and nitrided, is selected as material for the flexspline; its bending fatigue limit $\sigma_{-1}$is 625 MPa; elastic modulus E is 2.1 10^5

MPa. Let $[n] = 1.4$ and $\Delta Z = 2$; solution of inequality (Ref. 14) is $Z_R \geq 71.2765$; it means that the tooth number of the flexspline should be at least 72, a satisfaction of condition $n_\sigma \geq [n]$ guarantees that fatigue strength of the flexspline is enough. If $\Delta Z = 4$ is taken, the result from inequality 14 is $Z_R \geq 148.0406$; the tooth number of the flexspline should be more than 148. In this case, the flexspline could meet requirement for fatigue life.

Conclusions

Stress concentration near the tooth root of a flexspline is alleviated in HGD-with-EWG. The strength of the flexspline is improved and service life of the device can thus be extended, compared to HGD with built-in wave generator—today's accepted system. Therefore foundational study on HGD-with-EWG has both theoretical and practical significance.

The basic features in HGD are that the flexspline bends periodically and repeatedly under the action of the wave generator, and is in a working condition of alternating stress. HGD failure is thus mainly caused by fatigue fracture of the flexspline. Many of the benefits of HGD — such as reliability, kinematic accuracy and bearing capacity — are chiefly affected by the flexspline. Striking that delicate balance between flexspline strength and elasticity has been the focus of HGD research for a long time. For HGD-with-EWG, the flexspline is also the weakest link; its deformation and stress have critical impact upon transmission precision and the life of the entire device.

The authors analyzed the radial deformation of the mid-layer and section stress of the flexspline under the action of EWG based on the research model of a smooth cylindrical shell. It showed that the stress in the flexspline at work is an alternating one of asymmetric cycle; the stresses of cross-sections in the flexspline's rim are larger at major axis and short axis of elliptical mid-layer; those between the major axis and short axis are smaller; and the stress in the short axis is bigger than that in the major axis. The most dangerous section, vulnerable to damage, is the contact zones (sections C and D, Fig. 3) of the wave generator and the flexspline.

The strength of the flexspline is closely related to its structure parameters — especially to its number of teeth

Determination of tooth number of the flexspline must comprehensively consider such factors as the deformation, fatigue strength of the flexspline and its proper gearing with the circular spline.

The formula on the minimal tooth number of the flexspline derived in this paper provides a basis for tooth number selection and structure design on the flexspline and the circular spline in HGD-with-EWG and engineering application of this kind of device, which changes the present situation that little research is done on relationship between the strength of flexspline and its tooth number, and remedies a shortage in reference to devise HGD device with EWG.

Acknowledgment. *The authors wish to acknowledge the financial support of the National Natural Science Foundation of P.R. China under Contract No. 51075046. This project is supported by the National Natural Science Foundation of China No. 51075046.*

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Purchasing Gear Lubricants: Be Careful When Playing the Numbers Game

John Sander

Introduction

When it comes to purchasing gear lubricants, many people on both the sales and purchasing side decide to play the numbers game. The person with the most numbers, or the biggest numbers, or the lowest numbers, must have the best product — right? Wrong; gear oil selection is not a game, and numbers alone cannot determine the right product for an application. Too much information can be just as much a problem as too little. A purchaser can be tricked into selecting the wrong oil if he does not completely understand what the numbers mean.

As the old saying goes, "Figures don't lie, but liars do figure." This is not to suggest that gear lubricant sales representatives are liars, but rather that too often neither the sales rep nor the purchaser completely understands what the numbers on a technical sheet or price list really mean. An attempt will be made here to explain what you should consider when choosing a gear lubricant for a specific application and to show why choosing based solely on the numbers is not the best bet.

Background

Gears are a unique application for lubrication in that they provide a different challenge than other lubricant applications. In non-gear applications, the moving surfaces are in sliding motion or rolling motion. Gear teeth, however, experience both rolling and sliding motion at the same time. With these interesting conditions in mind, the formulator has numerous ingredients available to build a gear lubricant that provides proper protection. See Table 1 for a list of common ingredients used in various combinations for gear oil formulas. A formula does not have to contain every one of these additives, and there are multiple additives available to provide specific functions. As seen in Figure 1, gear oils are categorized first based upon the application, as either an open gear lubricant or an enclosed gear lubricant. As these names would suggest, an open gear lubricant is not enclosed in a gearbox or oil sump. As such, open gear lubricants are generally formulated as either high-viscosity fluids or greases. This paper will focus on enclosed gears only.

Enclosed gears are generally contained within a gearbox or some other device in which the gears can be bathed or showered with a coating of fluid lubricant. Enclosed gear oils are categorized next as either automotive or industrial gear oils. Both types can be subcategorized as synthetic or mineral oil, which describes the base fluid. Automotive gear oils are then broken down into a final set of subcategories that describe the application in which it will be used, while industrial oils are subcategorized based upon the type of additives used in the formula.

10-Step Gear Oil Selection Process

For years, many have stated that when selecting a gear lubricant — or any lubricant for that matter — one need consider only temperature, speed and load. More recently, however, this advice has been expanded to include environment. An easy way to remember this is L-E-T-S, i.e.: load, environment, temperature and speed. While this advice is simple and easy to remember, it still doesn't provide

Table 1 Gear oil ingredients

Ingredient	Function
Base Fluid	Mineral oil or synthetic fluid (PAO, ester, PAG) makes up 50-98% of the formula.
Viscosity Modifiers	Viscosity index improvers or polybutene polymers used to increase the base fluid viscosity; becoming very common today to replace high viscosity bright stocks often used in gear oil formulas.
Rust & Oxidation Inhibitors (R&O)	Rust inhibitors coat metal surfaces to protect against rusting. Oxidation inhibitors defend the oil against degradation due to reactions with oxygen in the air when the lubricant is exposed to elevated temperatures.
Copper Deactivators	Gear systems can contain some yellow, copper-containing metal elements that can be tarnished by gear oil ingredients. These additives protect the metal.
Anti-wear Additives (AW)	Some gear applications operate in the mixed film lubrication regime, meaning slight metal-to-metal contact. The base fluid isn't sufficient to protect the surfaces from wear, so additives are included to form a sacrificial surface that decreases the friction between two metal surfaces.
Extreme Pressure (EP)	Heavily loaded gear applications can operate in the boundary wear regime, meaning the oil film is squeezed out completely. EP additives put down an aggressive coating that carries the load and protects the metal surfaces in lieu of the lost oil film.
Dispersants	These surface-active additives grab onto and disperse contaminants in bulk oil so that they do not collect in the gearbox, but instead can be carried to the oil filter for removal. They are used more often in automotive gear oil than in industrial gear oil.
Emulsifiers	These are not common, but some gear oils are formulated to mix with water and stay mixed, such as when water contamination is impossible to avoid.
Demulsifiers	Surface-modifying components are used to promote the separation of water.
Defoamants	Surface-tension-reducing polymeric compounds are used to inhibit the formation of foam on the surface of the oil that could result in housekeeping, oxidation and wear issues.
Tackifiers	Sticky polymers with high molecular weight are added to increase a gear oil's ability to climb and cling to gears.
Solid Lubricants	These are not common in lower viscosity enclosed gear applications, but are often used for lubrication of open gears. EP additives lay down a layer of solids that keep the metal surfaces from rubbing. Common examples include molybdenum disulfide and graphite.
Pour Point Depressants	Polymeric ingredients are added to modify wax crystals that form in oils at low temperatures. They keep the oil from gelling up, thereby expanding the oil's operability range on the low end.
Compounding Additives	A vegetable or animal fatty acid is put into formulations as a friction modifier in formulas for gear applications sensitive to most EP additives.

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sufficient direction to make an educated decision. Instead, the following 10-step process is recommended to anyone who is responsible for purchasing enclosed gear lubricants.

1. Set lubrication goals. As with most things in life, it is very important to have a goal. This is even important when it comes to selecting a gear lubricant for use in a specific piece of equipment. Most maintenance groups have a broad goal of increasing the reliability of the equipment for which they are responsible. In trying to improve reliability, one thing that is often reviewed is "uptime." The higher the percentage of uptime, the more reliable it is considered. Lubrication has often been traced to reliability. Also, many maintenance individuals would like to reduce the amount of time they have to spend performing lubricant-related maintenance projects. High-performance lubricants are available that can be used to help improve reliability. Lubrication has also been traced to improved energy efficiency, an area that has been given much attention in recent years. Improved heat removal and friction reduction in a gear application can result in decreased energy consumption.

So the question remains, what is the goal for selecting a gear lubricant for a specific application? Is the one currently in use not performing as needed? Is there a desire to change from one supplier to another? Is it a new piece of equipment that needs to be filled for the first time? Are there availability issues with the lubricant currently in use? Does the company have an edict to reduce energy consumption? Is there a desire to increase the maintenance intervals? Goals must be personalized and they must be specific. Without a specific goal, there is little reason to push ahead to steps 2–10.

2. Seek professional advice and consultation. Ideally, a lubricant sales professional or consultant is available to serve as a value-added member of the team. It used to be that many companies would employ a lubrication engineer or at the very least have a person whose job was focused on equipment lubrication. Today, most maintenance departments have been forced to work with fewer people. As a result, a lubrication specialist on staff is considered a luxury. Instead, lubrication duties have been added to the existing workload of maintenance staff. As a result, time spent on improving equipment reliability through lubrication has been decreased.

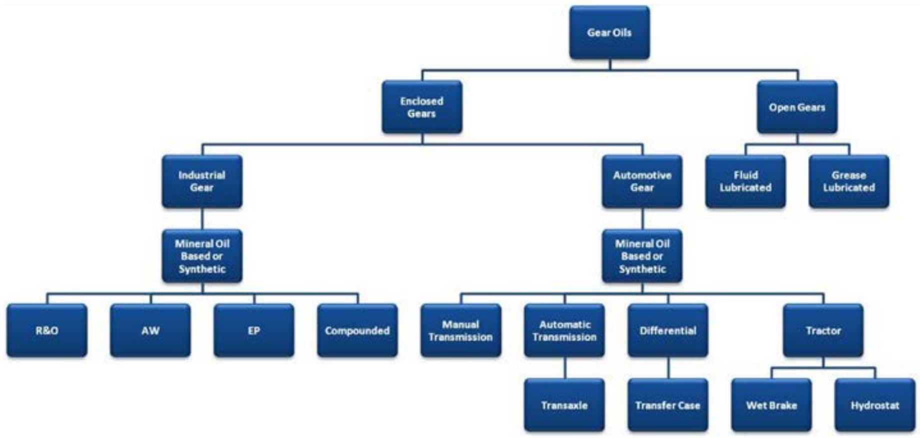

Figure 1 Gear oil categories.

The gear purchasing process should start with evaluating the experience, knowledge and services offered by the individual or company providing the lubricants. Today, groups like the International Council for Machinery Lubrication and the Society of Lubrication Engineers offer certification programs for lubrication professionals. It is a good idea to ask your lube provider whether they or somebody on their support staff has been certified by one of these organizations. If all your potential gear lubricant supplier can provide is a price list and specification sheet, it should raise an immediate red flag. The price paid for the lubricant should include the physical lubricant as well as professional service to go along with it. Ray Thibault, a lubricant consultant, trainer and author, provides this great segue from Step 2 to Step 3:

"While a product data sheet provides useful information, the true test of gear oil is how it works in the system. Adhere to OEM guidelines and consult your lubricant supplier for further information." (Ref. 1)

3. Review OEM recommendations, including compatibility. The next step is to consider the recommendations of the original manufacturer of the gear equipment. Ask any potential gear oil suppliers if they are able to provide evidence that their products are either approved by, or meet the requirements of, the OEM.

Often the OEM has determined — through field experience or extensive testing — what the lubricant requirements are for the equipment. Some will publish a specification that lists the physical and performance requirements for the gear lubricants. Some gear OEMs even take it a step further by creating their own approval system, including approvals and the publication of a list of approved products. It is important to become familiar with these specifications or approval lists so as not to void any warranties provided by the OEM and to maximize the reliability of the equipment.

Many lubricant purchasers fail to consider the compatibility of the lubricant with the equipment in which it is going to be installed. Some OEMs use coatings or paints to protect the insides of a gearbox from corrosion. Unfortunately, some lubricants can compromise these coatings. Another compatibility issue can be the use of certain elastomeric seals in a gearbox. If the lubricant is incompatible with these elastomers, the seals could start leaking. If not caught soon enough, these leaks can result in lubricant starvation. Oil leaks also can result in safety issues if the oil collects where it causes a slip hazard.

Based upon specific end uses of a gearbox, there are circumstances in which the OEM-recommended oil does not provide adequate protection. In these cases, it is extremely important that the professional advisor mentioned in Step 2 is consulted for other recommendations, and that proper testing be conducted to ensure a successful change to a new, better-performing product.

4. Determine type of load. Figure 1 illustrates how gear oils are characterized according to their formulation and/or usage application. It especially shows how industrial gear oils are characterized according to their additive type, specifically the wear-related chemistry used.

For example, a gear lubricant may be described as R&O, EP or AW. Certain enclosed gear applications have little to no load applied. The appropriate oil in this case might be R&O oil only. As the amount of loading increases, so will the amount of metal-to-metal contact between the gears. For gears operating in the mixed film wear regime, AW oil may be needed, while for those operating in the boundary regime, EP oil may be needed.

Sometimes the OEM specifically describes the type needed either in the equipment user's manual or on a plate attached directly to the gearbox itself. If not, then it is up to the user to determine whether the application subjects the gearbox to either heavy loads or shock loads during operation. In that case, it will require EP oil that contains active sulfur and phosphorous compounds that form a protective chemical layer on the gear surfaces when the fluid is compressed out of the meshed gears. In extreme loading cases, it might be helpful to use gear lubricant that contains solid EP additives. However, it is important to note whether fine filtration is in use, because it can remove solid additives and make this specific product ineffective. Some OEMs specifically recommend against the use of solid additives, so it is important to know this.

5. Know gearbox construction and capacity. A gearbox contains various components, including — but not limited to — the case, gears, bearings, shafts and seals. The construction of the gearbox, including its geometric configuration, is often contingent upon how the gearbox is required to transmit power within the given application. As described by Tim Cooper of Lubrizol:

"Today's gearboxes often are smaller and made from new materials; they are getting pushed to produce more power and at the same time be more durable and reliable than before. To meet these increasing demands, today's industrial gear oil must contain high-performance additive chemistry (Ref. 2)."

You must know the construction of the gearbox and use this information as part of the lubricant selection process. This includes the metallurgies, gear geometries and the cuts of the gears (rough or smooth). Table 2 illustrates the part that gear geometry plays in the lubricant selection process.

The gearbox capacity is a subcategory of construction that merits its own discussion. As noted previously by Cooper, many gearboxes are getting smaller. In a small gearbox, less oil is present. As such, it could run hotter, be sheared more by the gears and be affected more dramatically by contamination. The corollary is that in a large box, the oil may circulate less, run much cooler and last much longer. Although this sounds like an endorsement for larger gearboxes, they are not suitable — or even possible — with some applications.

Many lubricant additives activate at certain temperatures. With that in mind, it is possible that a large gear set might experience elevated wear because the oil never gets hot enough for the additives to activate. On the other hand, the wrong additive system employed in a small, hot gearbox could result in an aggressive gear additive prematurely activating, oxidizing and leaving behind deposits. The oil capacity of the gearbox can have a dramatic effect on the gear oil. As such, capacity must be considered as a part of the selection process. Also, if the goal determined in step 1 was to extend the interval between lubricant drains, the size of the gearbox case is very important. The more lubricant there is in the gear case, the more additive reserves there are to extend the life of the lubricant.

6. Minimize effects of operating environment. A gearbox could be operating in an environment that is hot, cold, dusty, wet or various combinations of these conditions, all of which can have significant effects on the gearbox. To minimize these effects, you can take precautions such as using air breathers, sight glasses and filtration devices. The lubricant itself also may be required to compensate for some of the challenges caused by the operating conditions.

Extreme temperatures. For an application operating at either extremely high or low temperatures, it may be necessary to choose a synthetic-based lubricant instead of a mineral-oil-based lubricant. For low temperatures, oil should have a pour point that is 5°C (9°F) below the startup temperature. Operating temperatures can also determine the chemistry needed in the gear oil. Very aggressive EP gear oils might result in heavy deposit formation in the gearbox during operation. Non-EP oil used in an EP oil application can result in high oil temperatures due to excess frictional heating of the oil.

Particulate contamination. In a coal or rock crushing plant, it is inevitable that dust and dirt will be in the air, and it is very difficult to keep the particles from finding their way into the gear oil. Filterable gear oil would allow filtration to remove harmful contaminants without removing valuable additives.

Water contamination. In water treatment facilities, it is nearly impossible to keep water out of some gearboxes, making it extremely important to choose a gear lubricant with excellent water separation properties.

7. Identify viscosity recommendation. The viscosity of a gear lubricant is a measurement of its ability to flow in an application. This is a very important consideration in selecting gear oil. If the oil is too thick, it will not flow into the gear contact zones. If the oil is too thin, it will be compressed out of the contact zones or fling off the gears while they are in motion. In either case, lubricant starvation will occur, which can result in premature wear-related failures. The primary means of gear lubricant selection, with regard to viscos-

Table 2 Effect of gear type on lubricant chemistry selection

Lubricant Chemistry	Gear Geometry Type				
	Spur	Helical	Worm	Bevel	Hypoid
R&O inhibited	Normal loads	Normal loads	Light loads & slow speeds only	Normal loads	Not recommended
EP gear lube	Heavy or shock loading	Heavy or shock loading	Satisfactory for use in most applications	Heavy or shock loading	Specified for most applications
Compounded	Not normally used	Not normally used	Preferred by most OEMs	Not normally used	Lightly loaded applications
Synthetic	Heavy or shock loading and/or extreme temps	Heavy or shock loading and/or extreme temps	Heavy or shock loading and/or extreme temps	Heavy or shock loading and/or extreme temps	Heavy or shock loading and/or extreme temps

ity, is to use the OEM requirement. If an OEM recommendation is not available, there are two other methods to obtain viscosity recommendations. The first is to use the viscosity ranges recommended by the American Gear Manufacturer's Association, per its 9005-E02 standard (Ref. 3), illustrated in Table 3.

The second method is attributed to renowned gear expert Robert Errichello (Ref. 4), and is based upon a calculation method that employs the following equation:

$$V_{40} = 7000 / \sqrt{V_1} \quad (1)$$

where:

V_{40} is the viscosity at 40°C, in cSt;
V_1 = pitchline velocity of the lowest speed gear in the gearbox in feet-per-minute = 0.262 × speed (pinion rpm) × pinion diameter (inches)

If there is no oil cooler on the industrial gear drive, it is best to determine the maximum expected ambient temperature during operation and:

a. Increase one ISO viscosity grade if the ambient temperature exceeds 35°C (95°F).
b. Increase two ISO viscosity grades if the ambient temperature exceeds 50°C (122°F).

If there is an oil cooler, the maximum ambient temperature is less important because the oil's temperature can be controlled. Therefore, the oil's temperature should determine the viscosity.

c. Increase one ISO viscosity grade if the oil temperature exceeds 65°C (150°F).
d. Increase two ISO viscosity grades if the oil temperature exceeds 85°C (185°F).

If the oil temperature exceeds 90°C (194°F), use a cooler such as a fan or a heat exchanger (Ref. 5).

8. Consider gear speed. Viscosity often is related proportionally to the speed at which the gearbox is operating. The general belief is that high-speed applications require low-viscosity lubricants, and low-speed applications require high-viscosity lubricants. AGMA provided a general guideline in its 9005–94 specification, which serves as a good rule of thumb. When referring to its viscosity grades shown in Table 3, AGMA stated:

"These guidelines are directly applicable to… gears that operate at or below 3,600 revolutions per minute, or a pitchline velocity of not more than 40 meters-per-second (8,000 feet per minute)… and worm gears that operate at or below 2,400 rpm worm speed or 10 meters-per-second (2,000 feet-per-minute) sliding velocity (Ref. 6)."

Table 3 AGMA viscosity grades for gear oils

AGMA Number	ISO Grade Equivalent	Kinematic Viscosity at 40°C min / max cSt		Kinematic Viscosity at 100°C min / max cSt	
0, 0S	32	28.8 /	35.2	- /	-
1, 15	46	41.4 /	50.6	- /	-
2EP, 25	68	61.2 /	74.8	- /	-
3EP, 3S	100	90 /	110	- /	-
4EP, 4S	150	135 /	165	- /	-
5EP, 5S	220	198 /	242		
6EP, 6S	320	288 /	352		
7 Comp, 7EP, 7S	460	141 /	506	- /	-
8 Comp, 8EP, 8S	680	612 /	748	- /	-
8A Comp, 8A EP	1000	900 /	1100	- /	-
9EP, 9S	1500	1350 /	1650	- /	-
10EP, 10S	-	2880 /	3520	- /	-
11EP, 11S	-	1440 /	5060	- /	-
12EP, 12S		6120 /	7480	- /	-
13EP, 13S				190 /	220
14R				428.5 /	857.0
15R	-			857.0 /	1714.0

Anything above these gear speeds is considered a high-speed gear, and it is best to consult the OEM recommendations for lubricant recommendations. Figure 2 is a simple schematic that summarizes how load, speed and viscosity come together during the lubricant selection process (Ref. 7).

9. Ensure fluid durability for extended drains. Today, people are realizing that there is a hidden cost to using inexpensive, lower performance lubricants. The less time a lubricant lasts during service, the more maintenance it takes to change the lubricant. In addition, the more frequently the lubricant is changed, the more waste lubricant there is to be disposed. While there are plenty of companies specializing in waste oil disposal, they do charge for their services. With these hidden costs in mind, many users are looking to extend their drain intervals.

Gear oil durability requires that a proper synergy exists between the base fluids and additives chosen for the gear product. The user must consider the gearbox application to know what type of stresses it will put on the lubricant. Improper selection will accelerate the demise of the lubricant's physical and chemical properties. For example, as mentioned in Step 6, filtration tools can overcome some of the issues caused by the operating environment. However, filters also might remove some of the additives, such as tackifiers and defoamants. Consult the manufacturer of the gear lubricant to verify if it has experience in these cases. If not, request testing or continue searching for another supplier.

10. Evaluate price. Evaluating the price is the last step in this process for a reason. Unfortunately, many gear oil purchasers evaluate price first, and sometimes it is the only number they evaluate. This can be a costly mistake. According to Mike Johnson, lubrication consultant, trainer and author:

"Performance lubricants are often not considered for use because of price objections. Maintenance costs range from 5–15 percent of a plant's cost of manufacturing, depending upon the industry. Lubricant purchases represent only 1–3 percent of maintenance expenses. Yet, the portion of the budget that can be directly impacted by lubricant expenditures can represent about 35 percent (20 percent from parts replacement, plus 15 percent from lube program routine and overtime repair labor). The cost-to-cost leverage fac-

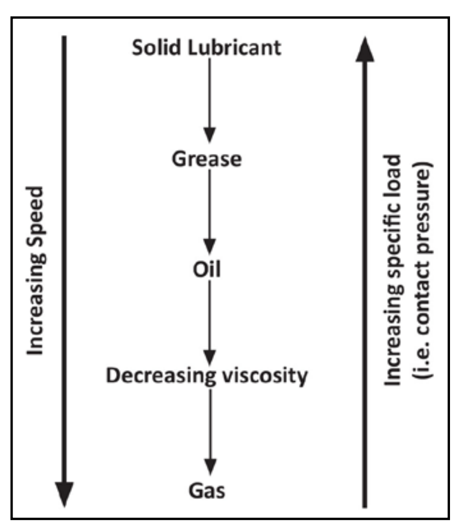

Figure 2 **Effect of speed and load on lubricant selection.**

tor for lubricant savings opportunity vs. lubricant expense is an astounding *35:1*. Investment in either process or product improvements can produce returns at several hundred percent investment with just a little effort (Fig. 3)." (Ref. 8)

While consideration of price is a valid part of the lubricant selection process, it should always be the last step.

By the time steps 1–9 have been completed, it is likely that the most appropriate lubricant for the gear application has become apparent. Yet, if there are still several products that appear to be equivalent, then price should play into the selection process. The highest-priced lubricant is not necessarily the best for a given application. For example, if a gearbox has leaking problems, it is not likely that an expensive synthetic lubricant will provide value. On the flip side, this does not mean you should purchase the least expensive gear oil and ignore the leaking gearbox. In a case such as this, it is a maintenance issue and not a lubricant issue. As described by Johnson, leaving a problem like this unresolved can cost the company much more in the long run than initiating good maintenance practices and choosing high-performance lubrication products.

Important numbers. Assuming that steps 1–10 have been considered, and that the final decision comes down to a comparison of data sheets, the question still remains: What numbers should one consider important? A review of various gear lubricant supplier data sheets will show that there can be dramatic differences between the claims made. Without knowledge, the tendency might be to go with the product with the most numbers and OEM claims on the data sheet. While this shows that the supplier was willing to put a sizeable investment into product development testing, it still doesn't necessarily prove that one product is better than the other for the application. Be wary of the lubricant sales person who just points out one specific data point and emphasizes this for the sale. There are other factors that affect the significance of those numbers, such as applicability to the application, test precision and units portrayed. Let's take a look at just a few.

Many companies will show the Timken test: ASTM D2782 (Ref. 9). What is not widely known outside of the laboratory is the precision of this test. Most ASTM test methods include a repeatability and reproducibility statement. Repeatability is a measure of error between multiple test runs, on the same sample, by the same operator running the same instrument, while reproducibility is the error between multiple test runs conducted on the same sample by different operators on different instruments.

For the Timken test, the repeatability is 30 percent of the mean on one of 20 samples and the reproducibility is 75 percent of the mean on one of 20 samples. This means that the error from the same lab on 20 runs will likely produce at least one run with up to 30 percent error. The rest of the runs may be somewhat better than that, but expect the possibility of at least 30 percent error. When different labs are running this test, it is even worse. Imagine a sample that has a 50 lb Timken result. If the same lab runs this test, at least one test in 20 will deviate by as much as 15 lb. Within the precision of this test, the same operator could produce a 35 lb Timken result or a 65 lb Timken result, and statistically these would be the same result. Now, seeing that the reproducibility is 75 percent, two different labs could produce a 12.5 lb result or 87.5 lb result —and these would be considered statistically the same result for the average of this imaginary 50 lb sample.

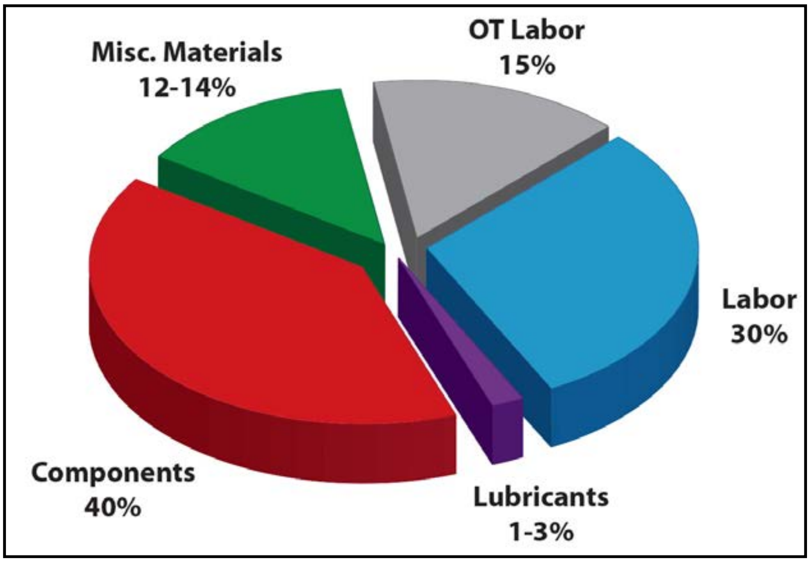

Figure 3 Typical maintenance budget divisions.

Next, it is a good idea to pay close attention to the units reported on a product data sheet. Once again using the fictitious 50 lb Timken result, a lab in the U.S. might report that data as 50 lb, while a lab in Europe might present it in metric units as 22.6 Kg. Both of these are correct, but the U.S. lab number looks much higher. One might mistake the U.S. result as a better result when they are actually the exact same number. As a sideline to this, there are various standards groups active throughout the world. They might publish very similar methods, yet there can be subtle differences. One cannot just assume that results published using the same instrument are comparable, because the various methods used can cause differences in results. For example, an ASTM method might produce different results than an ISO method on the same instrument.

There are two common corrosion tests used within the lubricant industry: ASTM D665 (Ref. 10) and ASTM D130 (Ref. 11). Both have nuances, depending upon the application. The D665 has an A and B version of the test method. The A version uses deionized water for the testing, while the B version uses standard saltwater. Traditionally, the saltwater version is more severe, so when considering results one should ensure that the same test conditions were employed. The D130 test employs two different test temperatures. This can make a big difference depending upon the EP package used in the gear oil's formulation. The same result published on two competitive data sheets might not mean the same thing if the temperature is not published.

The gear lubricant features that should be evaluated when comparing data sheets depend upon the application. See Table

Table 4 Important information to look for on product data sheets

Application	Lubricant Feature	Common Tests	Optimal Results
All	OEM Approvals		Check for any approval that is required.
All	Viscosity	Viscosity, ASTM D445	varies by grade
		Viscosity-Brookfield, ASTM D2983	varies by grade
Extreme temps (extremely low startup: <-26°C (-15°F) or continued exposure to extremely high: >82°C (180°F))	Synthetic	NA	NA
Lightly loaded or high-temp operation	R & O	Oxidation @121°C, ASTM D2893B	<6 max
		Oxidation Rig Test, viscosity increase, L60-1	<100%
		Rust Test, ASTM D665B	pass
Light-to-medium loading	Anti-Wear (AW)	Four-Ball Wear, ASTM D4172	<0.50 mm
Medium-to-heavy loading	Extreme Pressure (EP)	Four-Ball EP Weld Point, ASTM D2783	250 Kg
		Four-Ball EP LWI, ASTM D2783	>60
		FZG Scuffing, DIN 51354	>12
		FVA 54 Micropitfing Load Stage	>10
		Timken OK Load, ASTM D2782	>60 lb min
Release of air for lubrication or housekeeping issues	Anti-Foaming	Foaming Characteristics, ASTM D892	0/0/0
		Flender Foam Test	<10% increase
Water removal when necessary	Water Separability	Emulsion Characteristics @ 82°C, ASTM D1401	40-40-0 / 10
		Demulsibility Characteristics EP, ASTM D2711B	Max 2% H_2O in oil, 80 ml free $H_2$0, 1 ml of emulsion
Rust or yellow metal protection	Anti-Corrosive	Rust Test, ASTM D665B	pass
		Copper Corrosion, ASTM D130	1a or 1b

4 for a list of common lubricant features cross-referenced with application conditions and optimal test results indicating a lubricant's suitability for that application.

While the lubricant industry is considered a relatively mature industry, there are still areas of active research. The leading edge for lubricant manufacturers is to formulate products that can be used in the challenging wind turbine gearbox applications.

Over the years, wind turbine OEMs have found that their gear sets are notorious for micropitting, also sometimes called fatigue scoring, flecking, frosting, glazing, gray staining, microspalling, peeling or superficial spalling. (Ref. 12)

The FVA 54 test evaluates this phenomenon. This test, which is specific to base fluid, viscosity and additive chemistry, is not easy to pass. This is why some wind turbine OEMs have come to respect the data from this test and have now incorporated it into their specifications. Several OEMs also require a passing result for their general industrial gear specifications.

Conclusion

Several resources are available to help the end user select the right gear lubricant. Some have focused only on speed, temperature and load, while others have added operating environment to the mix. Still others have added lubricant and equipment compatibility. All of these tend to confuse the end user. The result is that many end users look to their lubricant suppliers for assistance. This is a good plan, but it can sometimes result in a mere comparison of price or data sheet numbers; in other words — a numbers game. Instead, try using this 10-step process for lubricant selection to make the process easier and more systematic, resulting in improved equipment reliability. Remember: Be careful when playing the numbers game. Most players end up losing.

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Gear Technology

HOSTS TECHNICAL DINNER DURING GEAR EXPO

Randall Publications LLC Publisher and Editor-in-Chief Michael Goldstein and the editing team at *Gear Technology* hosted a technical dinner at Lorenzo's Ristorante (Indianapolis), an authentic Italian restaurant a few blocks from Gear Expo 2013. The dinner included *Gear Technology* technical editors Robert Errichello (also Geartech president and long-

time AGMA training instructor), AGMA and industry veterans Octave Labath, Chuck Shultz and Robert Smith, as well as many key international gear authors and educators: Alex Kapelevich (AK Gears), Dr. Ulrich Kissling (KISSsoft), Frank Uherek, (Rexnord), Dr. Karsten Stahl (FZG), Dr. Michael Otto (FZG), Dr. Carlo Gorla (Politecnico di Milano), Jannik Henser (WZL), Dr. Carlos Wink (Eaton) and Jane Muller (Geartech). The evening provided an excellent opportunity to discuss the past, present and future of the gear industry as well as share dinner with old and new friends. *Gear Technology* thanks everyone for joining us, and we look forward to hosting our next industry event in Detroit.

GEAR AND GEAR DRIVE MARKETING

Power Transmission Engineering sponsored a free breakfast seminar on Wednesday September 18th during Gear Expo 2013. Dave Friedman, associate publisher and advertising sales manager, discussed how to build brand identity, print vs. online advertising and how to best use the tools *Power Transmission Engineering* has to offer the industrial marketplace. Randall Publications would like to thank the 50+ attendees who joined us for the breakfast seminar.

Holroyd Precision

INVESTS IN LOCAL WORKFORCE

When the latest cohort of craft apprentices joins Rochdale, U.K.-based Holroyd Precision Limited in September 2013, the individuals concerned will be continuing a tradition that goes back for almost as long as the 150-plus years that Holroyd has been in the region. "As a company, we are committed to investing in the local workforce," comments Don Whittle, human resource director. "Indeed, as part of our strategy to maintain the exacting engineering standards that we have become renowned for, every year we look to take on a number of young people; developing their skills through a strong, engineering-based modern apprenticeship program that typically takes up to four years to complete. This is in addition to offering summer placement opportunities to promising engineering degree students."

Very real career opportunities

"Perhaps most importantly," Whittle continues, "when interviewing for each year's apprentices, we look very carefully at where future skills gaps may exist in our business. This not only ensures solid succession planning by developing the core skills essential for the future of Holroyd, but also gives each apprentice a very real career opportunity to work towards."

Apprentices joining Holroyd only a few years ago would have completed their first year of training at the company's onsite training school. However, today's apprentices spend twelve months with the teaching partner to Holroyd, Rochdale Training Association. Having worked with Rochdale Training Association for many years, Whittle decided to move Holroyd's first year apprenticeship learning program off-site to the training provider in 2006. "We decided that it made good sense to pool our resources," he says. "As a result, Holroyd apprentices continue to receive the highest standards of initial training, Rochdale Training Association benefits from the government funding that our apprentices attract, while other apprentices are now able to see and experience the Holroyd way of doing things."

Developing key skills from day one

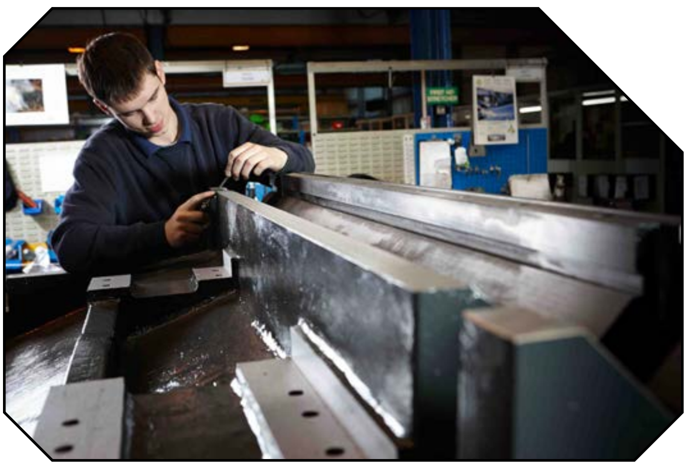
During year one, Holroyd apprentices learn a range of key engineering skills at Rochdale Training. This is in addition to attending college for one day each week to study towards the BTEC Ordinary National Certificate. With their first year completed, they then return to Holroyd's headquarters for on-the-job training. Ultimately working towards the NVQ Level 3, they continue with day release, progressing to the BTEC Higher National Certificate award.

Providing first-class progression

"Industry-recognized qualifications and a career with plenty of opportunities for progression, however, aren't necessarily where the story ends," adds Whittle. "Whenever we feel that an apprentice has the necessary ability and aptitude, we'll continue to support them through degree-level study – and beyond – if that's a route they're happy to pursue. We really do aim to provide our employees with the best opportunities available."

Long and successful careers

It's a testament to the quality of Holroyd's selection process and training that the majority of those awarded an apprenticeship with the company not only stay the course, but typically go on to enjoy long and successful careers with the machine tools and precision components specialist.



Former apprentice, Philip Hart, 32, is a perfect example of Holroyd's commitment to staff development. It was while Hart was working through his NVQ Level 3 in 1998 that it was decided to "fast track" him onto a university course instead. He went on to secure an honors degree in engineering at Salford University. Now a research and development engineer with Holroyd, Hart has recently achieved full membership of the Institute of Mechanical Engineers (IMechE) – quite possibly the highest accolade to his technical expertise so far.

Another example of Holroyd's commitment to employee development is Production Foreman, Steve Greenwood. After completing his apprenticeship in 1988, he gained experience across several areas of the business, including time working on multi-axis rotor grinding machines and a specialist supercharger production cell, before being promoted to the role of production foreman in the Precision Components Division.

Currently responsible for a team of 30 staff, Greenwood heads a department with an annual turnover of £6.5 million. He says: "The apprenticeship program at Holroyd is the best you can get. It provides first-rate training, incredible levels of support and encourages a real work ethos."

Perhaps the best person to ask about the opportunities provided by Holroyd, however, is current apprentice, Josh Mills. "I'm thoroughly enjoying what I'm doing and I'm getting paid for it," says Mills, 20, who began his engineering apprenticeship in 2011 after previously working in a car body shop. "I'm learning cutting-edge skills that will put me in good stead for the future."

Commenting on her organization's relationship with Holroyd Precision Limited, Rochdale Training Association's Chief Executive, Jill Nagy, adds:

"We have worked with Holroyd for over 25 years and immensely value the partnership we have developed. During this time we have helped recruit, develop and train their apprentices, many of whom are from the local community. "Only recently, Holroyd recruited a young person from one of our employability courses. That person not only completed an apprenticeship, but also progressed into higher education. Holroyd provides outstanding opportunities for local residents and young people. HR Director, Don Whittle, was also a board member of Rochdale Training for many years. As a result, we greatly benefited from Holroyd's advice and guidance, which enabled us to deliver our Apprenticeship Program according to employers' needs."

Eaton Corp.

BRINGS FORGING OPERATION IN-HOUSE

Diversified industrial manufacturer Eaton has announced that its South Bend, Indiana, facility has added a $1.9 million cross-wedge-rolling machine for use in the production of transmission shafts for heavy-duty trucks. The new machine improves manufacturing efficiency by completing a forging process in South Bend with the cross-wedge-rolling system. It replaces a hammering press operation that previously was outsourced. In a traditional hammering press, brute force is used to forge a hot piece of steel into the size and shape required by customers. With Eaton's new cross-wedge-rolling machine, steel is heated to 2,200 degrees Fahrenheit and rolled – rather than pressed – to form the transmission shafts.

Built in Belarus, Eaton's cross-wedge-rolling machine is one of fewer than 10 such systems in the world – and one of only a few in the United States. The South Bend plant currently is completing tests of the new machine, which is expected to be fully operational by mid-September.

"This is a unique process that will significantly improve our manufacturing efficiency," said David Larkins, South Bend plant manager. "We're very excited to have it here in South Bend."

The South Bend plant supplies gear forgings to three Eaton facilities – in Kings Mountain, North Carolina; Shenandoah, Iowa; and San Luis Potosi, Mexico – which assemble them into transmissions for leading global truck manufacturers. South Bend also supplies precision gear forgings for use in off-road and watercraft recreational vehicles.

In 1989, Eaton acquired the South Bend plant, which is part of the company's Vehicle Group business, and employs more than 110 people. The facility contributes nearly $200 million to the local economy through taxes, wages and supplier impact. In addition, Eaton South Bend and its employees donated $41,000 in 2012 to local community organizations such as the United Way of St. Joseph County, La Casa de Amistad Hispanic Community Center and the St. Margaret's House center for women and children.

Inductoheat

PROMOTES TARPINIAN TO PROCESS METALLURGIST/LABORATORY SUPERVISOR

Inductoheat, Inc. is pleased to announce the promotion of **Sean Tarpinian** to the new position of process metallurgist/laboratory supervisor. Tarpinian is a graduate of Schoolcraft College, where he earned his associate degree in metallurgy and welding technology. He most recently earned a Bachelor of Science in Applied Technologies from Eastern Michigan University. He is a native Michigander and has been employed at Inductoheat for two years as a process metallurgist. Tarpinian will supervise the lab personnel and allocate laboratory equipment as required to meet customer expectations. This position reports directly to the lab manager. "We are pleased to have Sean in this new role. He brings a wealth of technical, organizational and leadership skills that will continue to improve customer satisfaction," said Robert Madeira, vice president of heat treating at Inductoheat Inc.

Arrow Gear

ANNOUNCES NEW CHIEF FINANCIAL OFFICER

Arrow Gear is pleased to announce the appointment of **Andrew Mazzarella** as the company's new chief financial officer (CFO). Mazzarella joined Arrow Gear in mid-August. He has an extensive background in executive level finance for the manufacturing sector. A graduate of the University of Illinois in accounting, Mazzarella began his career working for a Fortune 200 company in the automotive replacement parts industry; eventually achieving the position of CFO. After moving on to CFO positions at several middle-market companies, he later became part of an ownership team that operated a manufacturing company which supplied products to the automotive industry. Here he performed the dual role of CFO and vice president of manufacturing; heading up the company's main manufacturing facility in Carson City, Nevada. Mazzarella's diverse experience in the financial requirements of manufacturing is a valued addition to the Arrow Gear executive team.

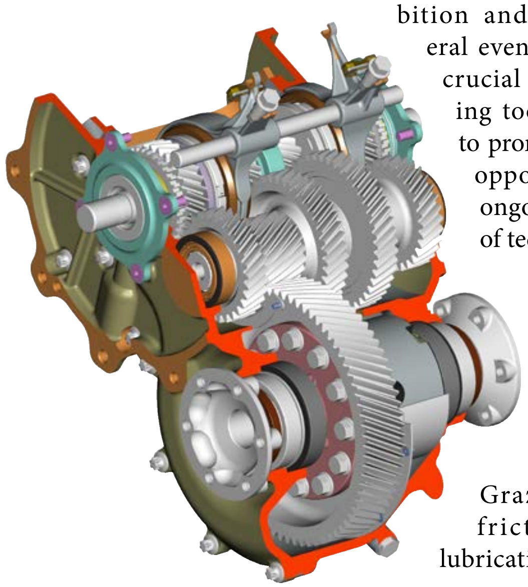
Oerlikon Graziano

DISCUSSES MEASUREMENT OF FRICTION COEFFICIENT

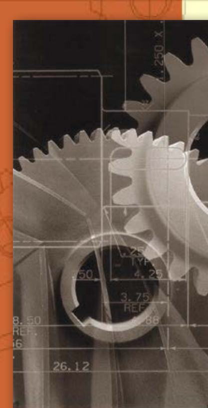
High-performance transmission specialist Oerlikon Graziano shared its extensive knowledge and innovative research techniques at the World Tribology Congress 2013, in Turin, from September 8-13, stand 56. The event, organized by the Italian Tribology Association (AIT), occurs every four years and provides a unique opportunity for discussion of recent developments in tribology and to strengthen the link between research organizations and industry.

"Creating low friction surfaces is a crucial factor in Oerlikon Graziano's development of market-leading transmission systems, and we intend to share our methods for measurement of the friction coefficient involved in cylindrical gear teeth meshing," says Oerlikon Graziano Chairman and Managing Director, Paolo Ramadori. "The effects of gear mesh on transmission efficiency have been estimated with an analytical approach that requires a suitable corrective coefficient calibration: using prototype development, intensive testing and statistical approach — DOE methodology — we are able to deliver a more accurate, proven efficiency model to predict the power losses of transmission systems."

Vincenzo Solimine, Oerlikon Graziano virtual validation engineer and Davide Crivello, Oerlikon Graziano testing engineer, delivered a speech on "Measurement of friction coefficient involved in cylindrical gear teeth meshing," at the Congress, which offered diverse scientific sessions on specific tribology-related topics, a broad exhibition and various collateral events. It is seen as a crucial knowledge sharing tool that continues to promote collaborative opportunities for the ongoing development of technologies.



Eco-tribology and sustainability were the primary focus in this year's Congress, and Oerlikon Graziano's study of friction, wear and lubrication in cylindrical



gear teeth meshing has been crucial to its development of gearboxes and drive systems for EVs and HEVs. Due to efficiency requirements and NVH expectations, this emerging market is the most demanding in terms of maximizing the operation of driveline components.

"Oerlikon Graziano's calculation code for the efficiency model is all-encompassing and considers both load dependent and load-independent contributions to power losses," explains Solimine. The activity is focused on the experimental evaluation of power losses due to cylindrical gears meshing to obtain a mathematical expression of the friction coefficient. In particular, the parameters under investigation are oil viscosity, the most important gear geometry sizes and working conditions."

Complete Heat Treating

ACQUIRES WISCONSIN STEEL INDUSTRIES, INC.

Complete Heat Treating, LLC announced the completion of its acquisition of all assets and equipment of the former Wisconsin Steel Industries, Inc. Complete co-owners Jake and TJ Dolhun made the announcement. The combined companies boast 75 years of service to the metalworking industry, with substantial heat treating and related capabilities. The purchase of Wisconsin Steel was made by Complete in 2011, with the relocation of all equipment and key personnel having now concluded.

All equipment from both companies has been consolidated at the 65,000 square foot Complete facility in Milwaukee, where the highlight is a gas-fired car bottom furnace with a 53' × 22' × 14' workspace, powered by 40,000,000 BTUs with a 1,000,000-pound load capacity and operating temperatures to 2,150°F max.

The equipment and services now offered include five car bottom furnaces, five box furnaces, heavy-duty polymer and water quench tanks, stress relieving, sand blasting, prime and finish painting, annealing, normalizing, BHN inspection, straightening, saw cutting of test specimens, tractor/trailer fleet and full compliance with ISO 9001 certification standards. Workpieces to 50 tons are routinely processed, using existing and new crane equipment recently installed.

Dana

EXPANDS GEAR MANUFACTURING CAPABILITIES IN THAILAND

Dana Holding Corporation recently announced it will construct a state-of-the-art gear manufacturing operation in Rayong, Thailand, to support growing customer demand for Spicer axles in the region. The new Dana facility, scheduled to open next year, will have the capacity to deliver 600,000 gear sets to the region. "Dana is committed to delivering differentiated innovations for growth markets such as Thailand," said Mark Wallace, president of Dana Light Vehicle Driveline Technologies. "By expanding our gear development and manufacturing capabilities in the region, Dana will deliver programs more efficiently, and be equipped to handle projected market growth." For more than two decades, Dana has supported major automakers in Thailand and the region with the production of axles and drive shafts. Major customers include Ford, Mazda, Nissan, Suzuki, and Tata. Dana currently employees 650 people at three facilities in the country. Approximately 125 new jobs will be created to support the expansion.

Gleason

ACQUIRES SAIKUNI MACHINERY

Gleason Corporation announced that it has acquired Saikuni Machinery Co., Ltd., located in Niigata City, Japan. Saikuni is a manufacturer of gear cutting tool sharpening equipment, cutting tool inspection equipment, rack milling machines and other metal cutting and finishing equipment. Saikuni has manufactured certain Gleason products, including Gleason's BPG Blade Profile Grinding Machine, for sale both in Japan and abroad, and Gleason has worked with Saikuni in selling certain of its products as well.

John J. Perrotti, president and CEO of Gleason Corporation, said "Given Gleason's strategic partnership with Saikuni since 1997, the significance of the Japanese market and our large customer base within Japan, the acquisition strengthens our ability to provide our customers in Japan and the broader region with effective local solutions and support."

Gleason has a long-standing presence in the Japanese market through its Gleason Asia Co., Ltd. subsidiary, with sales and service operations located in Tokyo, Nagoya and Osaka. Gleason will operate the Saikuni business with the current management team and approximately 25 employees under the name Gleason-Saikuni Co., Ltd.

October 28–31—Power Transmission and Control 2013. Shanghai New International Expo Centre, Shanghai, China. Organized by Deutsche Messe, PTC Asia is the continent's leading trade fair for electrical and mechanical power transmission, fluid power, compressed air technology, machine parts, bearings, linear motion systems, internal combustion engines and gas turbines. Sponsors include Bosch Rexroth, Emerson, DMG, Parker, Siemens, EMAG, SKF, Lenze, Tsubaki, ABB, NSK, SEW Eurodrive, Gates and others. An important part of PTC ASIA is the gathering of companies from industries including gears, chain transmission, belt transmission, couplings, brakes, electrical power transmission, fasteners, springs and powder metallurgy. It is held in combination with CEMAT Asia 2013, the international exhibition for material handling, automation technology, transport systems and logistics. For more information, visit *www.ptc-asia.com/EN/*.

October 29–31—South-Tec 2013. TD Convention Center, Greenville, South Carolina. South-Tec draws manufacturing suppliers, distributors and equipment builders from across North America and around the world. With hundreds of exhibitors, attendees will find all the products and services needed to streamline their various manufacturing processes. Automotive, advanced materials, energy, aerospace, biosciences plus many others are all represented. Over 34 percent of the jobs in the Greenville region are tied to manufacturing, drawing a skilled workforce that invigorates the area with new ideas and a strong entrepreneurial spirit. Panel discussions include workforce development, supply chain optimization and a brief manufacturing overview from the Department of Defense. The Additive Manufacturing/3-D Printing Resource Center will offer new technologies and designs that can help lower production expenses. For more information, visit *www.southteconline.com*.

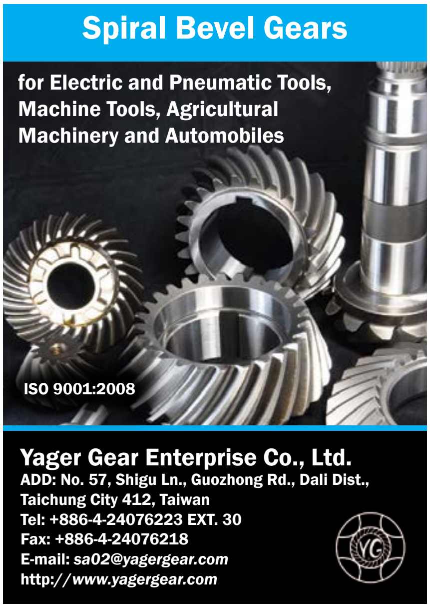
November 6–8—AWEA Wind Energy Fall Symposium. Colorado Springs, Colorado. The administration's recent commitment to renewable energy initiatives has arrived as the wind energy industry is emerging from a record year in new capacity additions and is moving to design a robust strategic direction for 2014 and beyond. With that, the AWEA Wind Energy Fall Symposium returns to offer a unique platform. In 2012 the AWEA Wind Energy Fall Symposium hosted hundreds of key decision makers, including over 20 CEOs, 50 vice presidents, and 55 directors. Now is the time to join fellow executives from across the industry for a stimulating and thought-provoking discussion on analyzing market challenges, examining potential solutions, and steering the industry towards a new phase of growth in America's successful form of renewable energy. For more information, visit *www.awea.org*.

November 12–15—AmCon 2013. Suburban Collection Showplace. Novi, Michigan. AmCon is a contract manufacturing expo for all job shops and contract manufacturers that provides custom metal, plastic, rubber or electronic parts and related manufacturing services to OEMs. Attendees include top level purchasing, engineering and production managers who are directly involved in buying custom contract manufacturing services. Representatives from companies of all sizes attend from a range of industries, often with blueprints in hand. The AmCon shows occur regionally throughout the year. Highlights this year include the Power of Persuasion video presentation, new technology seminars and new contract manufacturing services. For more information, visit *www.amconshows.com*.

November 12–15—Manufacturing Days. Davis, California. DMG/Mori Seiki's four-day, complimentary event centers around the company's new highly-automated factory, Mori Seiki Manufacturing, and its neighboring research and development hub, Digital Technology Laboratory (DTL). Similar in format to DMG/Mori Seiki's annual Innovation Days event held in the spring, Manufacturing Days offers machine demonstrations, industry seminars, tours of both the U.S. factory and DTL facilities, and California-style wine and dine events. "Our customers and partners can expect the same caliber of information and hospitality at Manufacturing Days as they've experienced at Innovation Days," says Mark Mohr, president of DMG/Mori Seiki USA. "However, Manufacturing Days is unique in that it's focused more on the latest applications in manufacturing." Seminars include presentations from industry and DMG/Mori Seiki experts. Topics include the latest in aerospace, automotive and medical machining, sustainability in manufacturing, and software and automation implementation. For more information, visit *www.mdays2013.com*.

November 15–21—ASME 2013. San Diego, California. The annual ASME International Mechanical Engineering Congress and Exposition is a premier global conference that focuses on today's technical challenges, research updates and breakthrough innovations that are shaping the future of engineering. The congress convenes engineers, scientists and technologists of all disciplines for the purposes of exploring solutions to global challenges and for the advancement of engineering excellence worldwide. The congress will feature a technical program that promises to be the most extensive and diverse in the history of the exhibition. In line with the national strategic initiatives, ASME and the organizers of IMECE have chosen advanced manufacturing as the overall theme for 2013. Technical presentations include aerospace technology, energy, heat transfer and thermal engineering, systems/design, advanced manufacturing, education and more. For more information, visit *www.asmeconference.org*.

November 18–21—Fabtech 2013. McCormick Place, Chicago. North America's largest metal forming, fabricating, welding and finishing event boasts more than 35,000 attendees and 1,500 exhibiting companies. Keynote presentations include "Navigating the Fiscal Reality," and "Accelerating Performance through Flawless Execution." Panel discussions include discussions of the state of the industry, solutions for a qualified workforce pipeline, a professional welders' competition and new product presentations. Pavilions include finishing, stamping, tube and pipe, forming, and fabrication and welding. Attendees can meet with suppliers, see the latest products/technologies and find the tools to improve productivity and increase profits. For more information, visit *www.fabtechexpo.com*.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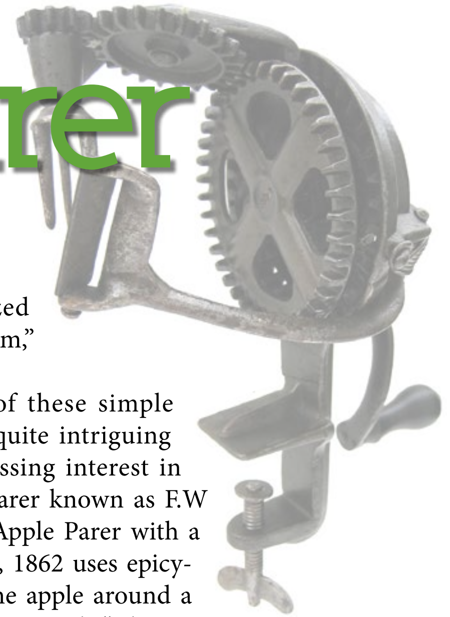
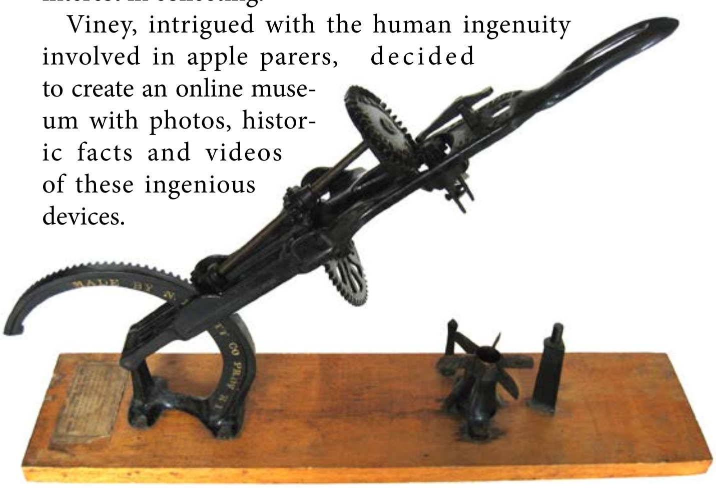
The Ever-Evolving Apple Parer



Mike Viney's curiosity about the evolving designs of apple parers began after reading the article, "There's a Fascination in Apple Parers" by Marion Levy, which appeared in the second edition of Linda Campbell's *300 Years of Kitchen Collectibles*.

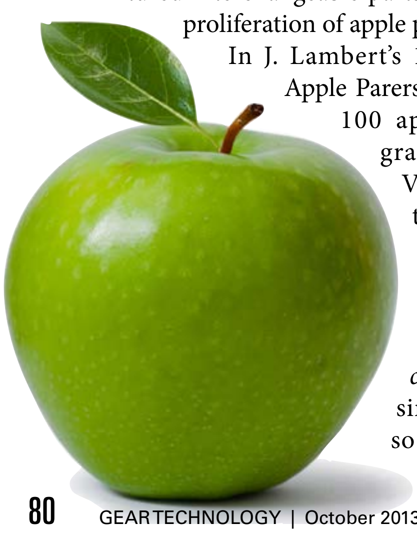
"I also have an early memory of seeing Levy on a PBS news program that highlighted early apple parer designs he had collected and categorized," Viney said. "My wife and I bought and sold antiques during college and this experience sparked my interest in collecting."

Viney, intrigued with the human ingenuity involved in apple parers, decided to create an online museum with photos, historic facts and videos of these ingenious devices.



"During the 18th and 19th centuries, apples were a critical winter staple in the United States. The apple was also a major U.S. export. During the fall season communities gathered in social get-togethers called apple bees to prepare large quantities of apples for winter storage. Preparing enough apples was a monumental task. Farmers created homemade apple paring devices made of wood and sometimes iron to make the job easier. Some of these early designs employed gears made of wood."

Viney continued, "As America underwent industrialization during the 19th century, the use of iron to produce manufactured interchangeable parts acted as a catalyst for the proliferation of apple parer designs."

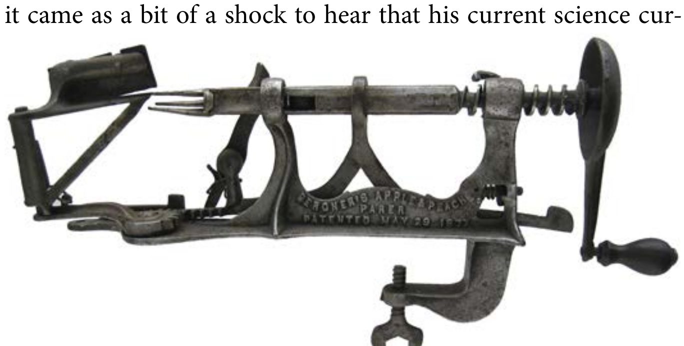


In J. Lambert's 1991 article, "Some Rare Apple Parers," he notes that more than 100 apple parer patents were granted from 1850 to 1890. Viney, a secondary science teacher for the past 27 years, has collected much of this information for the general public at his website, *appleparermuseum.com*. "Apple paring was a singular problem solved in so many different ways and undoubtedly catalyzed by a free market system," Viney added.

And the history of these simple machine designs is quite intriguing to anyone with a passing interest in gears. "A turntable parer known as F.W Hudson's Improved Apple Parer with a patent date of Dec. 2, 1862 uses epicyclic gears to rotate the apple around a stationary blade," Viney said. "The S.S. Hersey with patent dates of June 18, 1861 and Aug. 30, 1864 has a gear mechanism that allows the paring arm to switch between two bevel gears rotating in opposite directions. Thus, apples can be pared in two directions. The Bergner lathe apple parer with a patent date of Jan. 9, 1872, utilizes a rack and pinion gear to move the paring arm over the rotating apple (George Bergner was a gunsmith who served as a Union soldier in the Civil War)."

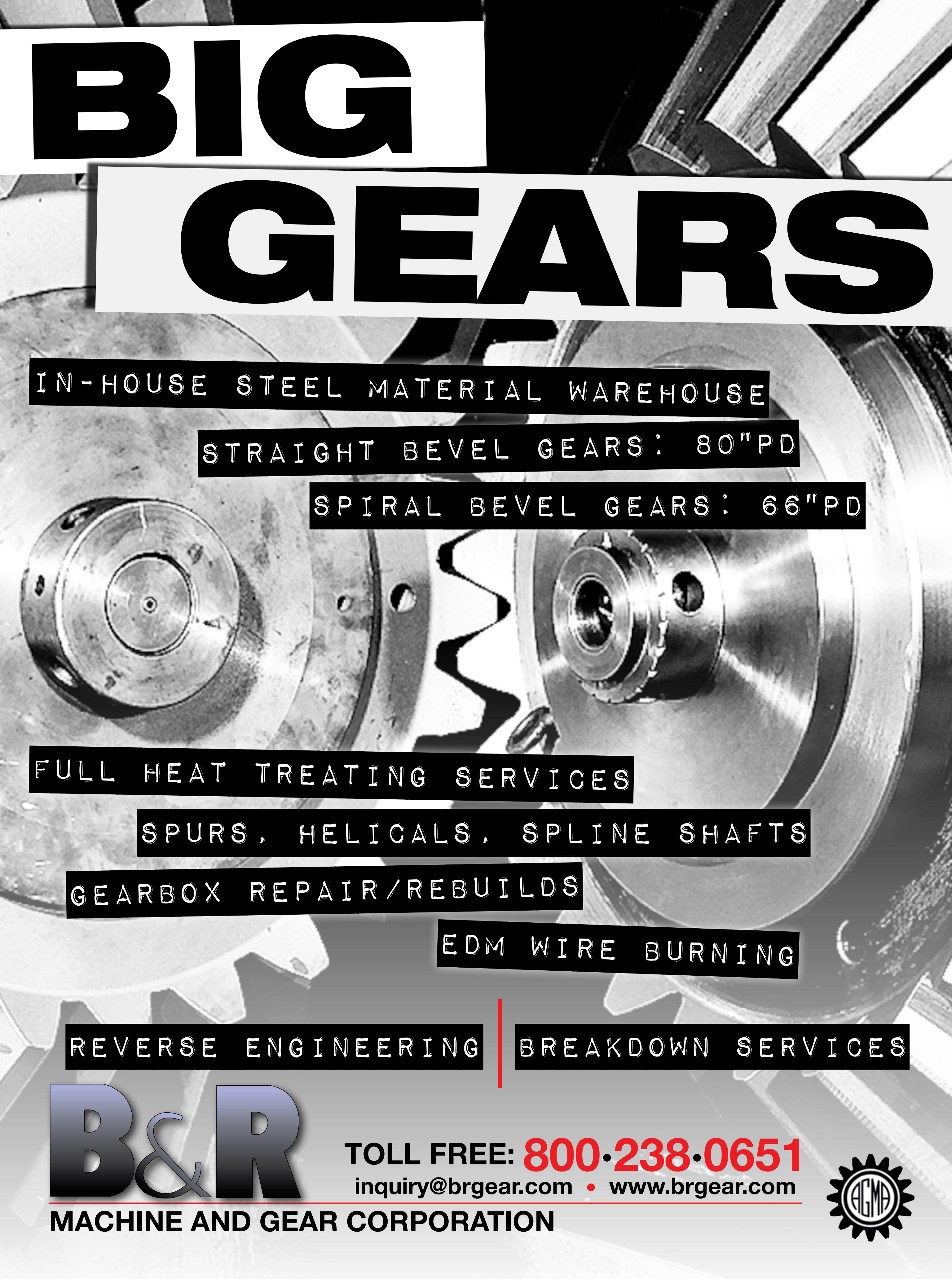
Viney receives many inquiries from his website, particularly from collectors seeking the estimated value of certain apple parers. It also attracts the interest of websites, magazines and publishers seeking apple parer photographs.

With so much information on the website dedicated to gears, it came as a bit of a shock to hear that his current science curriculum *doesn't* include a section on gearing mechanisms. "During my entire career, I have not helped students explore gears," Viney said. "My current curriculum does include simple machines, but I have to add information about gears."



We won't hold it against him, since Viney has put together a website that celebrates science, engineering *and* includes plenty of gears.

"It is my personal belief that those of us in industrialized nations live in a world of prepared immediacy. Everything from fine fitting clothes to food to technology is served to us on demand," Viney said. "How do companies know what sizes to make for clothing, what processes were involved in making my cheeseburger, how does my car engine work? For many technological devices, gears are a part of this mystery."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