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HYBRID GEAR PRELIMINARY RESULTS—APPLICATION OF COMPOSITES TO DYNAMIC MECHANICAL COMPONENTS

ASK THE EXPERT:
PRESSURE ANGLE/OPERATING PRESSURE ANGLE — WHAT'S THE DIFFERENCE?

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GT VIDEOS

The *GT* website currently features a video on DMG/Mori Seiki's gear milling capabilities. Gear-milling operations have remained virtually unchanged for decades—often requiring slow, tedious processes, expensive equipment and time-consuming setups. DMG/Mori Seiki USA and its partners are shaking things up with creative cutting strategies, standard, multipurpose milling machines, and off-the-shelf tooling.

To browse the archive visit: *www.geartechnology.com/issues*

E-Newsletter

Upcoming E-News topics for *Gear Technology* include the following:

June — Raw Materials
July — Gear Education and Training
August — EMO pre-show coverage
Contact *wrs@geartechnology.com* with editorial ideas.

Kapp-Niles Rocky Mountain Gear Finishing School: This can't miss event will be held October 16–18 in Boulder, Colorado and is designed for both classroom and shop floor lessons. Visit *www.kapp-usa.com* or check our technical calendar for more information.

Brian Langenberg, CFA and *PTE* contributor, will occasionally share market information within our social media networks. Check our *GT* and *PTE* LinkedIn Groups as he monitors global insights to support your business (*www.langenberg-LLC.com*).

Ask the Expert

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

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Coordinating Efforts

Publisher & Editor-in-Chief
Michael Goldstein

Like many Americans, I've been trained with the idea that those who see a problem should be the ones responsible for helping to solve it. If you see that something is broken, and you know how to fix it, don't wait for your dad, your boss or the government to tell you what to do. Just fix it.

Unfortunately, the bigger or more pervasive the problem, the more difficult it is for an individual or small group to fix it. No amount of gung-ho attitude and determination can solve it.

One such problem is the public perception of what takes place in a factory. Students, parents and advisors often think that manufacturing operations are dark, dirty and dangerous—and that working in a factory is a good way to come home with fewer than 10 fingers. They think manufacturing requires more brawn than brains. In truth, manufacturing today offers a clean, bright workplace that requires a solid education in math and science. Manufacturing is an interesting and challenging vocation that offers enormous opportunities. Just ask any of those gray-haired old men who are currently working in manufacturing.

But ask them soon, because if you wait much longer, they'll all be gone.

Too many workers are getting near the end of their careers. But even though manufacturing has been one of our economy's bright spots, between 600,000 and 800,000 manufacturing jobs remain unfilled in the United States. If we don't solve manufacturing's image problem—and get bright young people interested in it—America may lose a lot of very important expertise.

It's well past time that we reinforce the idea that a strong manufacturing base is essential to a productive economy and strategically vital to our nation's welfare.

Many of you are aware that I serve on the board of directors of Citizens for American Manufacturing (CAM). The nonprofit group was founded by Joe Arvin, president of Arrow Gear. Joe has written extensively on the importance of manufacturing to the welfare of our nation. We're a group that banded together because we saw some problems, and we wanted to be part of the solution.

Recently, CAM board members met with newly elected Representative Brad Schneider from the 10th Congressional District in Illinois. Congressman Schneider also happens to be an industrial engineer. As it turns out, he and his staff understand these problems and are interested in solving them, too.

In order to learn more about specific manufacturers' needs, he asked me to recommend manufacturing companies in his district that would be good candidates for him to visit.

So I called a number of gear manufacturers in the area, to talk about the things that we, as Americans, should be doing to solve the problems we see.

Those I talked were more than just receptive to the idea of problem-sharing. In many cases, they were also taking action, working with local associations, educational institutions and government agencies.

For example, one manufacturer I talked to works very closely with a local community college, in order to develop an educational program geared specifically towards manufacturing careers. In fact, this individual has pledged that anyone who completes the program at this community college is guaranteed job placement at his company.

A number of others indicated a strong interest in meeting with Congressman Schneider and exploring ways they could help.

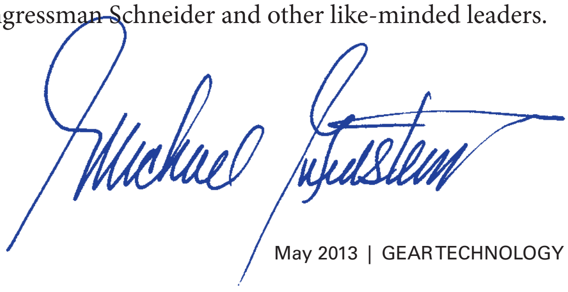
Interestingly, nobody asked what political party Congressman Schneider belongs to. They only saw a leader who was interested in their problems, and they're willing to work to help him better understand their needs and concerns. Nobody saw this as a Democratic problem or a Republican problem. They all saw it as an American problem.

And it's not just in the 10th District of Illinois that people are doing something. I also recently spoke with a gear manufacturer in Ohio, who told me that he belongs to an Ohio-based manufacturing association whose goals are to tackle many of the same problems identified by CAM and Congressman Schneider. Clearly, all across America, various individuals and groups are working toward common goals.

But it occurs to me that if we're all interested in solving the same problems, we should be working together, rather than independently. We should know what other groups and individuals are doing, so we aren't duplicating efforts. I've got to believe that with the few phone calls I made, I've only scratched the surface. Many of you are probably involved with local associations, manufacturing groups and educational institutions. You've probably got programs in place that others would benefit from learning about.

And perhaps this is what CAM's role should be: coordinating efforts.

So I'm asking you, our readers. Are these topics of interest to you? Do you think they're important? More to the point, are you involved in solving these problems, or are you aware of others near you who are doing so? If so, tell me at *publisher@geartechnology.com* about your group. Give me your web address. Give me a leader's name so we can contact them, so I can help CAM build a network of like-minded groups and individuals. Let's make this a coordinated national effort rather than a collection of local efforts, and let's also present a loud voice to Congressman Schneider and other like-minded leaders.



Feedback: My Gear Is Bigger than Your Gear

I read your article "My Gear is Bigger than Your Gear" in the March/April issue. I worked in engineering at Philadelphia Gear from 1963 until 1984. In the mid-1960s we built the drive systems for the JPL/NASA 210 ft. radio telescope. I remember the azimuth drive gear was approx. 80 ft. in diameter [24 meters]. The two elevation gears were sectors of 110 to 120 degrees with a radius of approximately 37.5 ft. The gears have a smooth track on the inner diameter of the gear rims. The drive reducers have a floating mount system so that the drives follow the gears and are not affected by the large thermal growth of the big gears. The gears were precision form cut in segments of about 10 ft. of circumference and assembled at the construction site. There were three systems built that I believe are still running. The first is at Goldstone in Mojave, California. The other two are near Madrid, Spain and in Australia. I have been at two of the sites, but not the one in Australia. That one in Australia was the subject of a movie for the general public 10 years ago or so.

You can see the elevation gear in the pictures at: *http://wikimapia.org/472151/Goldstone-DSS-14-Mars-Station*.

Leonard Haas
Consulting Engineer

I enjoyed your article "My Gear is Bigger than Your Gear" today and felt compelled to e-mail you. We are a machine shop in Rockford, Illinois and back in December my father and I were in Germany to see the runoff of the last of three large machining centers we ordered for our company in the town of Chemnitz. On our way back West to Frankfurt we had an open invitation to stop and visit the Waldrich Coburg plant in Coburg, Germany, where they build very large portal milling machines and vertical turning lathes. On our tour in the last assembly bay was the machine you mentioned for van der Wegen. We were able to stand on its rotary table and witness the size—absolutely gigantic—and a photo really doesn't do it justice. The machine is a gantry portal machine where the columns move across a stationary table to do milling work and then over the turning table that is pictured to turn and cut gears on the same table. We were told that Waldrich designed a special head to perform the gear cutting work. If I recall correctly the turning table is in the neighborhood of 9–10 meters diameter and the distance between columns was 13 meters; this is the widest machine that Waldrich Coburg has ever built. What is unique and what you pointed out in the article is that, because the columns can move and back off the turning table, this machine can cut up to a 17 meter diameter gear.

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Liebherr

LFG GRINDING MACHINE OFFERS PRECISION AND PRODUCTIVITY

This machine concept facilitates highly productive profile grinding for large workpieces. The range for external and internal gears comprises models for manufacturing workpieces up to 2,000 millimeters – for industrial gear units, wind power, and marine propulsion applications. Specific and controlled handling of twist in profile grinding solves production-related problems, and simultaneously opens new gear manufacturing doors. Various other solutions are available on the market for dealing with twist problems. Liebherr now introduces the five-axis LFG series profile grinding machines, with a novel machine design approach for twist-free profile grinding (or, if needed, the manufacture of specific twist designs) for single- and double-flank grinding.

Five Axes for Ultimate Precision

The machining concept works with five axes. LFG does not require a dressing axis, which rules out one potential source of inaccuracy. Another difference to comparable machines is the inversion of the shift and swivel axes. The mechanical limitation that results from the process of "first swivel, then shift" is overcome as a result. This special arrangement allows for the dimensioning of shift travel to be much larger than usual.

The machine's directly-driven table, featuring a highly dynamic wear-free torque motor, also delivers high precision throughout the machine's lifetime. It is a key component in allowing the machine to single- or double-flank grind precision- and custom-topographic tooth flanks.

Simultaneous Dressing Shortens Cycle Times

Because the machine also uses the shift and swivel axes to dress the grinding disks, the dressing axis can be eliminated. The basic LFG model's grinding disk is dressed by a single dresser in combination with the shift and swivel axes. The Syncdress design provides two dressing rolls that dress simultaneously left and right and greatly reduce dressing time. As a result of its increased importance, the LFG relies greatly on the permanently active swivel axis for profile grinding. Traditionally, the swivel axis was a set-up axis that was pivoted and clamped for grinding purposes. The grinding head for producing internal gears is mounted over the outer grinding head. No contact is made with the outer grinding head. Only the grinding disk must be removed. The dressing process for the internal grinding disks is consecutive, with the aid of the shift axis.

Twist Problems under Control

Crowning could only be performed via the X-axis in conventional grinding machines. Twist, however, occurs when this type of crowning is employed in profile-grinding. The result is an altered profile angle over the entire face width. The problem of twist due to this crowning method has played a rather minor role in gear manufacturing development for quite some time.

"Minimizing twist is one thing, incorporating specific twist designs is yet another. LFG series machines can grind anything required," explains Dr. Hansjörg Geiser, manager de-velopment and design gear cutting machines at Liebherr-Verzahntechnik.

The axes of the LFG facilitate additional movements and generate the opportunity to create the desired degree of crowning and prevent twists, even if double-flank grinding is involved, by overlapping the axis movements. By using the V, C and A-axes in addition to the × and Y-axes, the profile angle can be modified and the twist problem can be solved for both single- and double-flank grinding. In this way the operator can completely avoid tooth flank twist or intentionally produce it in compliance with the narrowest of tolerances.

Topological Modifications

Certainly the opportunities that the 5-axes create with respect to twist are limited by mathematics. Additional clearance allows for precision topological grinding. The division of the topography into multiple strip-shaped areas and corresponding processing with multiple strokes provide a multitude of specific options, for example, for prototype development or academic applications. The operator no longer has to concentrate on $f_{H\alpha}$ and C_α corrections, but rather can target individual points for processing.

Removal-Optimized Grinding through 5-Axis Infeeding

The figure shows how, during radial infeeding, the removed material near the tooth head is greatest at three infeeds during the final strokes. The workpiece is subjected to unnecessarily high loads as a result of variable grinding steps. Micro-structure damage occurs frequently.

Five-axis infeeding produces a (as far as possible) constant allowance distribution over the course of the strokes. The principal

material for this wear-optimized grinding is no longer left to wear-out on the tip; as a result the risk of grinder-burn is minimized, and the workpiece is protected. Number of strokes and production time can be reduced as a result, depending on application.

The different involute gear profiles (pinion/planet/cylindrical) show the distinction between the three tested gears, which lies primarily in the curvature in the involute gear profiles. Thus in the case of a pinion with maximum curvature the maximum benefit can be derived by using the 5-axis infeed method.

The number of infeed steps is reduced from 15 to 9 as a result of the 5-axis infeed. The curvature of the spur gear is small (due to the number of teeth, among other things) and, therefore, the savings in infeed steps is smaller (9 to 8).

Production Controls Profit from Large Shift Travel

The measuring sensor swivels laterally along the grinding disk. It uses the large shift travel (±300 millimeters) and, like a dedicated measuring machine, measures the gear. This leads to an additional acceleration of the process. Table rotation and radial infeed are not required for measuring, which contributes to additional precision of the measurement results.

With calibration in mind, conventional methods of measurements usually focus on a very sensitive $f_{H\alpha}$ profile angle. There is additional potential for inaccuracy when a machine radially retracts and extends its stylus. The sensitivity is considerably lower and, accordingly, the results more accurate when retracting laterally (shifting). There is a lot to be said for the precise measuring methods that can be achieved right on the production machine, and specifically this 5-axis LFG.

For more information:
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KISSsoft

RELEASES 03/2013 SOFTWARE

KISSsoft is a modular calculation system for the verification, optimization and sizing of machine elements. The scope of the application ranges from a single machine element up to the automatic sizing of complete gearboxes. *KISSsoft Release 03/2013* once again contains a wide range of new functions, including the following highlights:

The contact analysis has been greatly extended for planetary gear units. It is now possible to take into account the exact deflections of the shafts on the sun wheel, planet gear and internal gear. The planet carrier position is also determined during 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. This ensures that tooth trace modifications can be specified accurately, on the basis of the planet carrier torsion and sun wheel deformation.

The contact analysis for cylindrical gears has also been extended and improved. Experience gained following a comparison between various different commercial contact analysis programs, carried out in fall 2012, has also left its mark on the calculation. For example, additional correction factors (including one for Hertzian flattening) have been implemented, providing the user with even more detailed setting options. Of course, as you would expect, appropriate standard values are also set where suitable.

Thanks to improvements in calculation algorithms, the cylindrical gear contact analysis is now faster and more robust, and so enables the contact pattern for cylindrical gears to be analyzed more accurately.

Another highlight is the extended setting and evaluation options for optimizing modifications for cylindrical and planet gears. A new feature is that the face load factor $K_{H\beta}$ 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.Some new features have also been added to the plas-

tics calculations. The draft of the new VDI guideline 2736 is especially worthy of mention. After many years work, with contributions from KISSsoft, this guideline has now been released in draft form and so is also available in *KISSsoft*.

Freely configurable manufacturing drawings have now also been made available for all cylindrical gears. The toothing data and a range of different graphics — such as flank modifications, etc. — can now be displayed as graphics, output to screen or paper, and sent to the gear manufacturer.

Fine sizing functions have been added to the worm gear and spiral toothed gear wheel calculations. You can now vary the macro geometry within specific ranges and select the best possible solution. These modules, along with the cylindrical and bevel gears, now cover the sizing options for any tooth type. This latest functionality can be viewed in the shaft editor: Shafts and bearings are now displayed with shadowing (optional). Bearings are displayed according to their attainable service life. The new versions of the DIN 743 shaft calculation analyses and the FKM Guideline (6th edition) are also implemented in the *03/2013 KISSsoft* release.

As before, the CAD interfaces are designed to reflect the very latest version of each particular CAD system. In addition to the calculations for machine elements, there are now additional software features which make *KISSsoft* even more powerful and effective in handling real life situations. For example, you can create rules which check specified parameters before and after the calculation and output messages if required. 3-D models can now also be generated via a COM interface.

Finally, the current release includes a completely restructured user interface for *KISSsys*: the most commonly used elements are now available as icons. To generate a model, a user can simply drag and drop icons to add elements directly to the diagram window and link them up. The new *KISSsys Gear Unit Assistant* guides users through the process for generating models of planetary gears step by step. After the relevant kinematics have been defined, the bevel gear and worm wheel stages can now be rough sized directly in *KISSsys*.

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EMAG

OFFERS HARD TURNING AND GRINDING ADVANTAGES

The advantages of the process combination hard turning + grinding lie in process stream consolidation, improved component quality and greater flexibility. But process combinations can also be used to great effect for the shortening of cycle times. Where all the hard fine-machining operations can be carried out on a single machine, throughput, transport times and storage periods can be drastically reduced. There are also benefits to be had in the reduction of time and effort spent on setting up the machine.

An important requirement for combination machines is the unhindered fall of the turning and grinding chips. The VLC 250 DS with its vertical work spindle and its tools positioned below the workpiece offers the best possible chip flow conditions. All machine modules are mechanically sturdy and particularly vibration resistant. This is augmented by the machine base in Mineralit polymer concrete, with its great vibration damping properties, and by the design of the work spindle, which forms an integral part of a sturdy quill that carries out its Z-axis movement in a high-precision, hydrostatic guideway — also a design particularity that has a highly effective vibration damping effect.

The tooling systems are firmly anchored in the machine base and provide a stable basis for demanding turning and grinding operations — an important precondition for time-saving hard pre-turning work and for achieving the best surface finish with a hard finish-turning or grinding operation. Number and design of the stationary tooling systems can be chosen to suit the individual machining requirement. Continuous monitoring of the machine temperature ensures a high degree of thermal stability. The operating temperature is quickly reached and maintained within tight limits of the ambient temperature by a powerful cooling unit. The pick-up technique employed on the VLC 250 DS Turning and Grinding Center ensures that the machine loads itself. Gantry loaders — or other cost-intensive, space-devouring loading devices that involve time-consuming resetting work — can be eliminated.

The VLC 250 DS can handle complex manufacturing processes. Whether there is a call for turning work at high chip removal rates or for the somewhat gentler grinding operation — the machine covers a wide range of applications. The

advantage is obvious: complete-machining in a single setup, and thus the elimination of reclamping errors. Measuring operations too can be included. This would ensure optimal integration of a quality control function into the overall process. The measuring probe is located between machining area and pick-up station, where it is safe from the ingress of chips and coolant. As the workpiece remains clamped during the gauging process, intermediate measurements can also be taken.

A typical example of successful combination machining is the manufacture of gearwheels. The end face is hard finish-turned, whilst bore and cone are pre-turned and then finish-ground to ensure that the high quality requirements are met. For this purpose the machine is equipped with two grinding spindles, whereby one spindle machines the bores and the other carries out the external grinding work. As the amount to be ground is only a few hundredths of a millimeter, the grinding wheels need only be designed for finishing operations.

The advantages offered by the VLC 250 DS:

- Vertical hard turning and finish-grinding on a single machine and in one setup
- All sectors of the workpiece that can be turned with process integrity are hard finish-turned, and only those are ground (after hard pre-turning) where quality requirements and process integrity demand it.
- Improved workpiece quality and higher productivity rates, as the workpiece is complete-machined in a single setup, whereby the hard pre-turning process leaves an allowance of just a few microns for the subsequent grinding process.
- The grinding process needs to remove only very little material. The wear and tear on the grinding wheel is therefore minimal and it needs to be dressed only infrequently, and only by a fraction. This is of considerable advantage where cycle times are a concern.
- The grinding wheel specification can be fixed as "finishing quality," as only a very small allowance needs to be removed. This produces process-capable surface finishes in the Rz < 1.2 µm range.
- Unlike hard turning processes, the grinding operation will, on the same machine, generate absolutely scroll-free surfaces.
- Rear end faces are difficult to reach with a grinding wheel — a problem that is easily solved with hard turning.

The cross-operational machine design provides exceptionally easy access.

For more information:

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Sandvik Coromant

OFFERS COOLING TECHNOLOGY SOLUTIONS

Accurate targeting of coolant during machining provides maximum effectiveness in chip evacuation. However, precision and pressure are two equally important aspects of coolant. A high precision coolant requires lower pressure. The higher the pressure, the more demanding applications can be machined with excellent results.

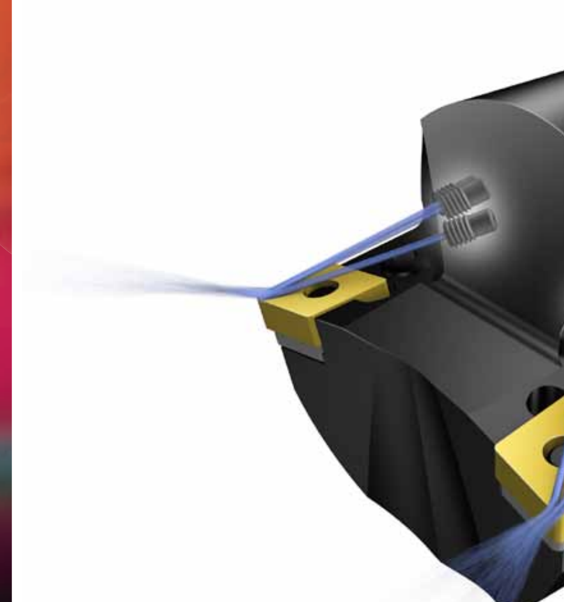
Sandvik Coromant offers cooling technology solutions through advanced nozzle technology and dedicated insert geometries for steel, stainless steel and HRSA material for all machining applications. The company recently announced additions to the growing range of options to apply coolant in the machining process. The range of new insert geometries and customized tool holders feature fixed nozzles that guarantee a precise coolant jet flow accurately hitting the center of the cutting zone target.

Advanced Nozzle Technology

The coolant flows from the pump to the tool through nozzles directed exactly at the cutting zone. This produces a wedge of coolant that efficiently removes the heat from the cutting zone and forms the chip. Improved chip control and longer tool life are just two of the benefits that contribute to secure and predictable machining, preventing unplanned machine stoppages. Increased productivity can even be achieved in tricky applications, and in difficult to machine materials, regardless of the pressure you use.

Low pressure 7–10 bar (100–150 psi)

When using low pressure, the new Sandvik Coromant CoroTurn HP holders, with high precision nozzles, outperform regular tool holders that can have a tendency to flood coolant. This makes for improved chip control and better process security in steel and other common materials. Substantially higher cutting data can also be applied, as well.



70–80 bar (1,000–1,200 psi)

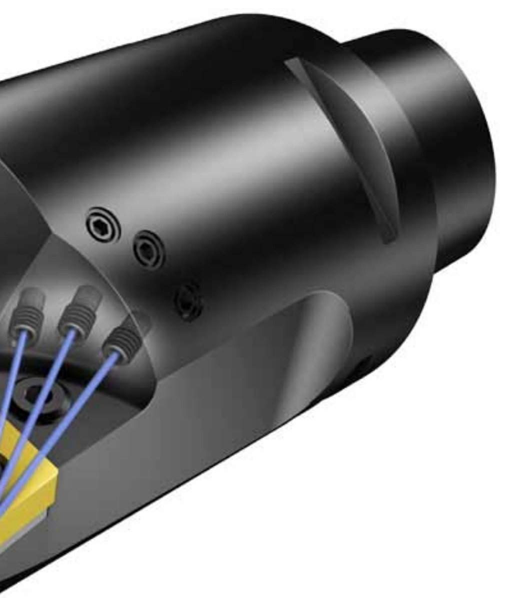
For demanding materials, such as duplex stainless steel and HRSA material, higher coolant pressures are needed. The unique CoroTurn HP nozzle technology in combination with the new-SMC, -MMC, -PMC insert geometries provides greater productivity.

150–200 bar (2,200–2,900 psi)

Few machines provide solutions for these pressures, however Sandvik Coromant offers standard holders and inserts that allow for up to 275 bar (3,900 psi) of coolant pressure. Coromant Capto clamping units for high-pressure coolant with 200 bar (2,900 psi) coolant pressure capability provide unrivalled performance ensuring that machine utilization is optimized through reduced set-up and production time.

Tool holders

The Sandvik Coromant advanced cooling technology has been a solution primarily for customers using quick change with Coromant Capto, SL- and QS holding system. Now, the same premium technology can be applied with general shank tools, making it possible for everyone working with wet machining to utilize this highly productive coolant solution, even in small lathes.



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Gleason Corporation

INSTALLS 10 METER CAPACITY GEAR HOBBER IN CHINA

Gleason Corporation recently announced the successful installation of a P 8000/10000 Gear Hobber at Changzhou Tianshan Heavy Industry Machinery Co. Ltd., in Changzhou, China. The machine has the capacity to produce spur and helical gears up to 10 meters in outside diameter, and has been fully demonstrated to consistently produce large gears at DIN 7 quality or better, reducing cutting times from as much as a week on older machines to as little as 10 hours. Founded in 2002, Changzhou Tianshan is a producer of approximately 35,000 gears per year ranging in size from 100 mm to 10,000 mm in diameter. Through investment in the most advanced gear production machines, Changzhou Tianshan has expanded rapidly and is today a factory of nearly 87,000 m^2, with 300 employees. The acquisition of the Gleason-Pfauter P 8000/10000 hobber has opened the doors for new projects in mining equipment, port mechanical equipment and large industrial applications, as well as with several of the world's leading wind turbine manufacturers, producing planetary gears, sun gears and eccentric gears for wind turbine gearboxes. When asked "Why Gleason" Jiang Wenge, chairman of Changzou Tianshan said, "The efficiency and accuracy of similar equipment on the market is low, but customer expectations are increasingly high, and the trend is to higher and higher accuracies and reduced lead times. Gleason-Pfauter has the experience in gear technology, service and support, so a high-quality production machine is assured. Among the manufacturers of high-accuracy large gear equipment, Gleason-Pfauter is the industry leader. There really is no competitor."

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Heavy-Duty Demands

Modern Coating Technology Examined

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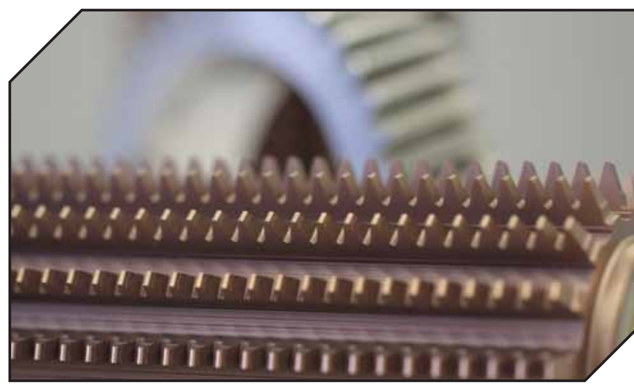
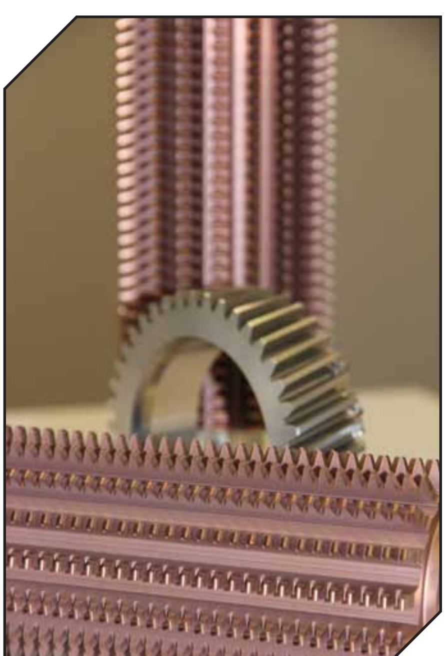
Matthew Jaster, Senior Editor

The hob is a perfect example of how a little manufacturing ingenuity can make a reliable, highly productive cutting tool. It's an engineering specimen that creates higher cutting speeds, better wear resistance and increases rigidity. The cutting tool alone, however, can't take all the credit for its resourcefulness. Advanced coating technology from companies like Sulzer, Oerlikon Balzers, Ionbond, Seco Tools and Cemecon helps improve cutting tools by reducing overall costs, increasing tool life and maintaining the highest levels of productivity. The following is a quick recap of new technologies and the latest information in the coating market.

Coating Technology with Sulzer

Sulzer offers a variety of coating equipment, material and services for the most complex surface applications. The company's custom solutions based on PVD and diamond coating technologies reduce production costs, increase tool cutting rates, reduce use of lubricants, prolong tool life and improve wear resistance. Significant for gear cutting is the company's new M.Power coating technology. "M.Power is a micro-alloyed TiSiXN-based coating that offers smooth surfaces; high hardness; high oxidation resistance; high wear resistance; low coefficient of friction; high tool quality; prevention of cold welding; and formation of built up edges," says Annette Norin at Sulzer Metaplas GmbH.





The key strengths of the coating are its dramatic reduction of the sticking material on the cutting edge due to reduction of the surface roughness. It also boasts extremely high heat resistance.

According to Norin, Sulzer provides custom solutions through the combination of pre and post treatment of the tool surface coating material, layer architecture and system/equipment technology with which the coating will be applied. "We focus on advanced plasma-assisted/arc evaporator technology for innovative coatings," Norin says. "APA is based on the cathodic vacuum arc and offers diverse development possibilities for new layer architectures in terms of morphology, stoichiometry, doping, multiple layers and nano layers."

The benefits of APA include excellent coating adhesion and smooth coatings through the reduction of macro-particles. APA is also the basis for new hybrid technology.

"Customers are willing to test new coatings to determine the benefits and also to come up with specific problems and we develop solutions together," Norin adds. "We develop coatings on our own R&D equipment and test new coating/layer designs together with our customers."

Norin believes the hybrids mentioned earlier will play a significant role in coating technology in the future. "This technology will include hybrids based on HI3 technology, a combination of AEGD (arc-enhanced glow discharge), a plasma etching process for layer adhesion; HIPAC (high-ionization plasma assisted coating), a highly ionized sputter process; and APA Arc (advanced plasma-assisted arc), a highly ionized arc process."

For more information:
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Hyperlox by CemeCon

Hyperlox is a new generation magnetron sputtering TiAlN coating produced by Cemecon technology. It has been developed with extremely low internal stresses, maintaining high values of hardness and oxidation resistance. Hyperlox works for HSS hobs operating in wet (oil) conditions but can be used also in dry conditions on material with hardness over 50 to 70 HRC.

Hyperlox offers a more stable performance vs. standard CrAlN coatings in medium speed and wet cutting conditions. Furthermore the de-coating operations of this layer do not cause the productions of chromium (CrVI) in the stripping baths. For its low tensional stress, together with specific preparation of cutting edges, Hyperlox allows extremely high chip thickness in hobbing (tests have been run up to 0.48 mm) with a very stable and limited flank wear. With these properties it is possible to offer stable and reliable conditions of production.

Hyperlox is best utilized for hobbing operations with medium and low cutting speeds, in both dry and wet conditions; it is becoming widely used in Europe by major automotive groups such as VW and ZF. It is used also in milling applications on milling cutters of hard metal (HM) and high-speed steel (HSS).

CemeCon has been supplying in-house coating technology for 25 years. Drawing on experience from Europe's largest coating production operation, CemeCon has now tailored its system technology to meet the needs of its customers with its CC800/9 series of coating systems. Both existing and new coating materials can be implemented on all models.

The benefits of CemeCon coating technology include:

Economically sustainable, future-proof coating technology due to easy upgrade (capacity, processes and new developments). Option for modern high-tech coatings; adaptations and upgrades can be carried out quickly and at low cost.

A single coating system for diverse coating processes; all models in the CC800/9 series are based on the same platform and are available at various configuration levels to fulfill different requirements.

Fast, low-impact coating or sputtering with extremely high metal ionization; booster technology and high-power impulse magnetron sputtering (HiPIMS), high ionization sputtering (HIS) for depositing numerous types of ultra-smooth composite coatings on any desired substrate geometry.

Transfer of know-how to the customer.

Expansion of customer's product portfolio with versatile options for coating design (outstanding friction characteristics, surface quality, color, etc.).

Quality benefits by designing the production chain to suit the customer's range of products.

For more information:
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Oerlikon Balzers

EXPANDS COATING OPERATIONS

Many in the gear market are familiar with Oerlikon Balzers' coating technology. Balinit coatings, for example, are just a few thousandths of a millimeter thick, but harder than steel; these low-friction coatings are extremely wear-resistant and chemically inert. The optimum coating is determined on the basis of both conditions of use and economic considerations. The material and properties of Balinit coatings can be selected to match customer-specific requirements. The typical coating thicknesses that can be reproduced in mass-production lie between 0.5 µm and 4 µm. Sharp edges, textured or mirror surface finishes and close production tolerances remain unaltered. Therefore no finishing work is required and the coating can be carried out as the final production step.

In order to meet the ever-increasing demands of its customers, Oerlikon Balzers continues its global expansion. The company recently opened its eighth coating center in India to establish a stronger presence in Chandigarth (Punjab).

"Despite current economic uncertainties, we further invest proactively in our global footprint," explains Dr. Hans Brandle, CEO at Oerlikon Balzers. "We believe in the growing demand of mobility in India and therefore increased our presence in one of the automotive parts and tractor industry hubs of the country."

To date, the company has 90 coating centers worldwide.

In line with its global growth strategy, Oerlikon is also expanding its global service offerings. Increasingly, the company will be able to provide complete solutions for the reconditioning of high-performance round tools to its customers, particularly in emerging regions. To this purpose Oerlikon Balzers is adopting a standardized concept by the brand "rox" for the setup and operation of regrinding centers from the Austrian Tool Management provider, TCM International, in addition to taking over the "rox" training facility in Stainz (Austria). Coated high-performance tools such as drills and milling cutters are crucial for high productivity in present-day metal processing. If correctly reground and recoated, they reach the same performance as if in new condition.

Adds Manfred Kainz, CEO of TCM International, "We are pleased that the concept developed by us has convinced Oerlikon Balzers. I am sure that the company will see to its global and professional implementation."

Additionally, Oerlikon Balzer's Ingenia coating system recently won the German International Forum (iF) Design Award 2013 in the industry/skilled trade category. The award-winning Ingenia system made its world premiere in September 2011 at the EMO fair in Hannover, Germany. With Ingenia, Balzers' engineers and physicists succeeded in extending the company's technological lead by developing a coating system that has the highest level of power densities and takes up a minimal amount of space.

Helmut Rudigier, head of research and development at Oerlikon Balzers, adds, "We were able to cut the cycle times in half and thus significantly increase productivity. And we accomplished this while doubling the precision of the coating thickness."

The system can also be equipped with the new S3p technology, a system developed by Oerlikon Balzers that produces uncommonly smooth, thick coatings that are both extremely hard and wear-resistant. The award-winning system has already been successfully implemented in its first coating centers and by third-party customers. The network is being constantly expanded.

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www.oerlikon.com

Seco Tools

DURATOMIC TECHNOLOGY

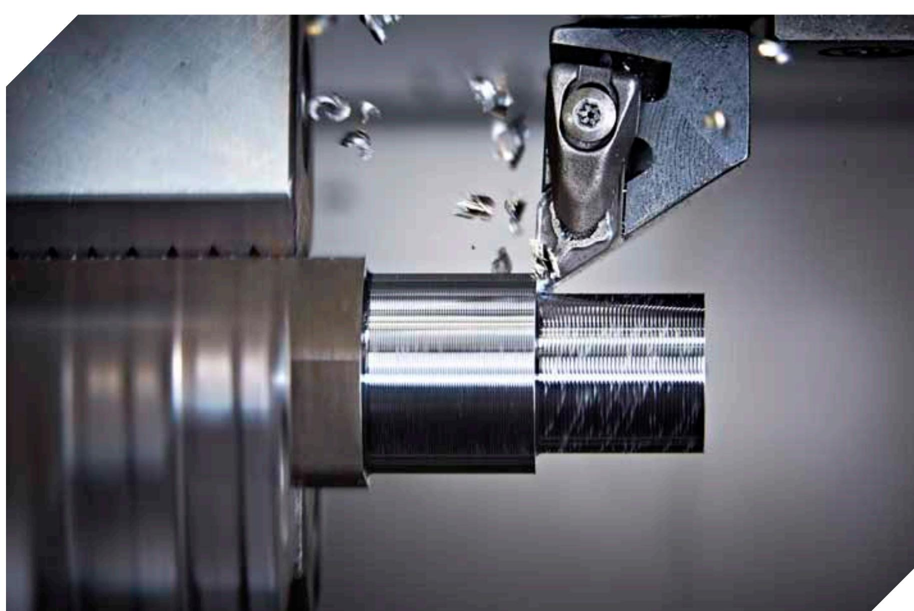
The Duratomic technology from Seco produces a durable coating by arranging aluminum and oxygen atoms in a unique way to provide increased toughness and abrasion resistance. The importance of atomic arrangement can be understood by one extreme illustration. Both graphite and diamond are made from carbon atoms; but the properties of those two materials are dramatically different because of the way the atoms are arranged. In a somewhat similar way, the Duratomic coating is more valuable than traditional coatings because of its atomic structure.

Controlling the structure of the aluminum oxide coating leads to several benefits for the user. First, it brings a harder and tougher atomic structure into the cut. Just as wood can be easily split with—but not against—the grain, aluminum oxide is more brittle in some atomic directions than others. Seco builds the coating in a controlled way to ensure the best structure is engaged in the cut.

Secondly, controlling the structure produces a smoother surface, resulting in less friction and heat during the cut. This translates directly to less build-up, a better surface finish, less tool wear, greater tool life and speed capability.

The flat facets on the Duratomic coating prevent built up edge and improve surface finish. These benefits are particularly important in stainless steel machining. The hardness and toughness of the Duratomic coating dramatically reduce insert wear. The result of these properties is dramatic. Inserts coated using the Duratomic process show less wear, less deformation and much greater tool life.

For more information:
Seco Tools
Phone: (248) 528-5200
www.secotools.com



IHI Acquires Ionbond

Last fall, IHI Corporation of Japan entered into an agreement to acquire 100 percent of the shares of Ionbond, a manufacturer of wear protection coatings headquartered in Switzerland. IHI provides thin-film technology to industrial customers through its physical vapor deposition (PVD) equipment and services, and together with its subsidiary, Hauzer Techno Coating B.V. in the Netherlands, acquired in 2008, is involved in diamond like carbon (DLC) technology.

Joe Haggerty, CEO of Ionbond, saw the opportunity to combine Ionbond's process engineering and coating network with the coating machinery at Hauzer. "This will lead to many innovations and advantages for our customers in the coming years. In addition, Ionbond's strength in CVD products complements the current PVD and PACVD offerings within Hauzer and the IHI Corporation."

Hardcut is a multilayer coating for high speed and high efficiency machining in minimum or zero lubrication conditions. It is a TiSiN-based coating with a support layer. Optimal performance is possible by means of a patented process that forms a true nano-composite material whereby nano-crystallites of Si3N4 are embedded in a TiN matrix. The coating properties protect the cutting edge from heat transfer, oxidation and abrasion. It offers ultra-high cutting speeds, gear cutting with carbide hobs, finishing and semi-finishing milling, low lubrication and dry machining, very hard and abrasive work piece materials and titanium and exotic alloys.

Crosscut's AlCrN structure exhibits reduced flank and cutting edge wear in a wide range of cutting conditions. As the most versatile high-performance coating, it closes the gap between Maximizer and Hardcut. It offers medium to high cutting speeds; milling and gear cutting with HSS and carbide tools; reduced flank wear and cutting edge wear for a wide range of cutting conditions; predictable abrasive wear by continuous wear instead of chipping; a high quality machined surface achieved throughout the lifetime of the coating; low to medium lubrication; and is suitable for machining a wide range of materials.

Maximizer is an AlTiN-based coating suitable for medium cutting speeds. The average crystallite size and stress have been optimized, resulting in increased cutting performance. Crack propagation is reduced by compositional fluctuations, and excellent ductility guarantees that coated tools are less susceptible to chipping. It offers medium cutting speeds, drilling, milling, and gear cutting with HSS and cemented carbide tools, a wide range of lubrication conditions, a broad range of work piece materials including stainless steels and nickel alloys.

For more information:
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Reinventing Cutting Tool Production at Gleason

Gleason Cutting Tools facility in Loves Park, IL, where production processes for spiral bevel gear cutting systems, as well as coarse-pitch hobs, have been reinvented (all photos courtesy Gleason Corp.).

Investment in advanced new manufacturing technologies is helping to reinvent production processes for bevel gear cutters and coarse-pitch hobs at Gleason— delivering significant benefits downstream to customers seeking shorter deliveries, longer tool life and better results.

Manufacturers of bevel and cylindrical gear cutting tools have made enormous strides in recent years to improve the performance, quality, and tool life of their products. New substrates, advanced coatings and new designs have converged with faster, more robust direct-drive CNC machines to revolutionize bevel and cylindrical gear production. But there is another "revolution" underway as well, taking place on the shop floors of some of the leaders in this industry. This revolution has less to do with *invention*, and more to do with *investment*, says Bob Phillips, senior vice president of Gleason Corporation's tooling products group.

"Highly productive new products are a big part of our 'solutions' approach, but of equal importance are the new processes we're putting into place on every Gleason factory floor," says Phillips. "Take a tour of our facility here in Loves Park, IL, and you'll find older machines sitting idle, with all the work they once did now being done much faster and more accurately by far fewer, advanced new machines. That's good news for our customers seeking shorter deliveries on superior product. Two of the best recent examples are our bevel gear cutters and coarse-pitch hobs."

A single Gleason IBG (inserted blade grinder) out-performs many older manual grinders, raising quality and productivity on inserted blade production to unprecedented new levels.

Changes in Spiral Bevel Gear Cutter Production

Spiral bevel and hypoid gear cutting has changed significantly over the years. Many high-volume producers have made the transition from mechanical machines performing traditional, single-index, five-cut face milling or, more recently, the completing process, to much more productive CNC machines performing carbide dry cutting completing as face milling or face hobbing.

However, for a significant number of bevel gear "jobbers" around the world, these older machines and processes still get the job done. These jobbers rely on a system of different cutter types still very much in production today: e.g., integral blade (solid-body) type, and segmental or inserted blade type. Gleason has long been a source for a variety of product in each of these families of cutter systems, as well as the machines that run them.

For example, the company manufactures well-known brands such as its Ridg-Ac and Wedge-Ac inserted blade cutter systems for gear roughing and pinion roughing, respectively; its Helixform and Hardac cutter systems, also with inserted blades,

Gleason's coarse pitch hob cell machines tools complete from barstock, even on hobs as large as 450 mm diameter, 530 mm in length and up to 40 module, to achieve 6-week deliveries.

For jobbers still using five-cut or completing processes to produce spiral bevel gearsets, Gleason's inserted-blade and solid cutters are now available with much shorter delivery times and greatly improved accuracy and repeatability.

for gear and pinion completing and finishing; and a variety of solid cutters for roughing, completing and finishing.

Until very recently, most of these cutter systems were produced by Gleason at its Plymouth, England facility on dozens of circa 1950s manual machines. According to Gleason's Paul Chadwick, production manager at the Loves Park facility, the production process relied heavily on the skills of highly experienced machine operators and their ability to coax the best possible productivity and quality out of these machines. "Even an operator with 30 years of experience would be hard- pressed to produce from blank a set of blades for a Hardac cutter in less than six hours on these machines, and blades for a particularly large diameter cutter might take 18 to 20 hours," Chadwick explains. "The process was extremely laborious."

The drawbacks inherent in this process were immediately obvious to Gleason's Phillips and his team when bevel gear cutter production was moved to the Loves Park facility. In a manufacturing environment where waste is abhorred and lean manufacturing and Kanban systems have cut delivery time on every product to well below the industry average, the older machines simply weren't relevant any longer, Chadwick recalls. "While the 'soft blanking' operations for these blades had been modernized with new CNC machining centers in Plymouth, the technology didn't exist at the time to make similar improvements in the hard finishing operations. No one could have guessed that today we would be producing the same inserted blades and solid cutters many times faster, with substantially better quality, and with an operator with just weeks of training versus the many years required previously."

New grinding machines and processes help produce finishing hobs with AGMA Class AA accuracies, precision ground with any desired profile or special involute modification.

An intensive, multi-year effort involving a team of Gleason engineers on two continents has today resulted in the development of two revolutionary, special-design 6-axis CNC grinders — a Gleason IBG (inserted blade grinder) and a Gleason SBG (solid blade grinder) — both employing proprietary technologies and processes to cut production times to a fraction of what was possible in Plymouth. Blanks now are produced complete in one fully automated setup, taking just minutes per blade.

While faster throughputs translate into shorter delivery times for customers, Chadwick says, of equal importance to the customer are the accuracy and repeatability levels now being achieved by these new machines. "We're already hearing very positive reports from customers in the U.S., Japan and Europe who are the first to receive product produced by these machines," he says. "You can imagine how difficult it was to maintain consistent, repeatable accuracies on the blades coming off the old machines, given their age, all the manual steps required, and the reliance on operator experience to get it right. For the end user, the quality of the blade, particularly the critical edge-rounding radius dimension and the blending between the edge rounding, the pressure angles and the front face where cutting occurs, are critical to achieving lower cutting forces and optimum chip shearing action — and longer tool life as a result." Chadwick points out that a better quality blade also makes the initial process of "truing" the blades to the cutter body within a certain assembly tolerance faster, because the tolerances of each blade are essentially identical.

Coarse-Pitch Hobs: Bigger, Faster, Better

On the opposite end of the gear cutting tools spectrum are the new manufacturing technologies being employed by Gleason for the production of coarse-pitch hobs — some as large as half a meter in length and diameter, and up to 40 module. While the end product and production methods are completely different, says Phillips, the strategic objectives are very similar. "Part of it is attributable to growth in the wind power market, part to our fast-expanding presence in markets like China and India, but suffice to say, global demand for our large roughing and finishing hobs has never been greater. Again, investment in new technology was the solution to meet our customers' needs for faster delivery on superior product."

Gleason's declared 6-week delivery from barstock on its coarse-pitch hobs today stands in stark contrast to an industry average of around 12 weeks. Older machines, long queues and a lot of non-productive time have given way to a new coarse pitch hob manufacturing cell at Gleason that produces hobs complete from barstock, even including on-site final inspection of all critical hob features. Now, all the "soft" manufacturing operations such as gashing, threading and turning that previously required multiple machines are done in one stop on the cell's single large turning center. Heat treat is performed in close proximity to the cell, and then new grinding machines perform the finish grinding operations many times faster and more accurately than what was possible before. Most importantly, the cell has greatly reduced the costly non-productive time that characterizes most large hob production, where many machines and setups are required to perform all the necessary operations.

"The cell is certainly much more productive than the machines it replaced, and it also ties nicely to our lean manufacturing practices, which eliminates much of the typical time wasted while product waits to be worked on," Phillips says.

The hob cell has also enabled Gleason to expand its product range to include hobs as large as 450 mm in diameter, 530 mm in length, and up to 40 module. These product offerings include Gleason's popular E-Z Cut hob, which features a unique flute design that adds extra cutting edges and delivers rough cutting feed rates up to 70 percent faster than conventional hobs.

In addition, the hob cell affords Gleason the ability to produce more accurate finishing hobs, ground to AGMA Class AA classification and with any desired profile or special involute modification.

Every operation is totally integrated, even the final step: complete inspection of all critical features on a Gleason GMM analytical gear inspection system.

"Yes, we're busy *inventing* the next generation of advanced new products, but in the meantime we never stop *investing* in existing product," concludes Phillips. "Ultimately, we're helping our customers get better results faster, even from cutting tool designs that have been around awhile."


Global demand from wind energy, mining, construction and other industries has stretched the world's large cylindrical gear making capacity, creating unprecedented demand for products like Gleason's EZ Cut hob (front), and the company's other roughing and finishing hobs.

The SBG (solid blade grinder) machine performs one-stop blade grinding on Gleason solid body bevel gear cutters.

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Delivering Big Gears Fast

When a customer needed gears delivered in three weeks, here's how Brevini Wind got it done.

Randy Stott, Managing Editor

Recently a South American manufacturer needed four large, double-internal replacement ring gears for its sugar mill, and the OEM who provided the originals was quoting eight months lead time. Unfortunately, they needed their parts faster—much faster. Looking for alternative manufacturers, they called on Brevini Wind, in Yorktown, IN.

"We were challenged to produce four large, double-internal ring gears in three weeks," says Dale Harder, director of facility operations at Brevini Wind USA. Each of the large planetary components contained two internal gears. On one end was a 12-module, 76-tooth, 282 mm face width internal gear. On the other end was an 8-module, 116-tooth, 140 mm face width internal gear.

The biggest challenge in producing these gears so quickly was figuring out the tooling, Harder says. Getting new cutting tools would have taken too long, so they looked at previous projects for parts with similar geometry to see if they could re-use existing tools. As it turned out, they had gashing cutters for previous internal gears with modules of about 12.1 and 7.3. But could these tools be used on *this* part? To find out, Brevini turned to its cutting tool supplier, Banyan Global Technologies LLC.

Even though Banyan wasn't going to be able to sell any additional cutting tools for this project, they were happy to help, says Banyan's Darryl Witte, VP of sales. "We have a fantastic relationship with those guys, and they're a great customer."

Banyan prepared CAD drawings of both internal gear elements, and then analyzed the existing cutting tools and stock conditions that would result. After their analysis, Witte had good news and bad news. They'd be able to cut the 12-module gear with existing tools, but not the 8-module.

The large planetary component contained multiple internal gears of different geometry. In this view, the 12-module, 76-tooth, 282 mm face width gear geometry is shown. For semi-finishing this gear, Brevini Wind was able to use a duplex milling tool provided by Banyan Global Technologies for a previous ring gear application

Machining Leader Tim Root removes one of the approximately 3,000 lb. planetary components from the Youji 1200 CNC vertical turning center, which Brevini Wind acquired and installed in the third quarter of 2012.

"For the larger internal gear element, we were fortunate enough to have a duplex profile milling tool for an application whose geometry was close enough to semi-finish the internal gear," Harder says. "Banyan Global provided Brevini Wind with a CAD model of the cutter profile versus the finished tooth profile, illustrating the maximum depth of cut that could be made while maintaining sufficient stock for finishing the gear teeth via a subsequent internal gear grinding process."

But they still had some work to do. Even though Banyan demonstrated that they could produce the geometry they needed with the existing cutting tools, Brevini Wind still needed a little bit of ingenuity to make it work, Harder says. "Because there wasn't sufficient room for the cutter radius to break out without hitting an adjacent shoulder in the part, our gear machining leader, Chris Hayes, devised a process to first radially in-feed utilizing our Gleason-Pfauter P2400 hobber at the furthest possible point on the facewidth before beginning to feed axially up the facewidth."

So Brevini Wind could make the 12-module internal gear with existing cutters. But what about the other side? Unfortunately, Banyan's analysis revealed they had no cutting tools available with close enough geometry. "So we elected to grind the gear teeth from solid using our Gleason-Pfauter P1600G gear grinder," Harder says.

A rendering of the duplex profile milling cutter used to generate the semi-finished gear geometry of the 12-module gear. Profile milling using the duplex cutter resulted in a total cutting time of under 55 minutes for the 76-tooth, 282 mm face width gear. (image courtesy of Banyan Global Technologies)

"This permitted us to generate the required gear geometry relatively quickly."

Harder explains that even though grinding from solid is a much more time-consuming process—in this case six hours versus the one hour that would have been required for gashing—it could be done using inexpensive, off-the-shelf grinding wheels that didn't require any additional wait time.

After rough machining, the parts were inspected, stress relieved and inspected again in Brevini's climate-controlled inspection lab. Having heat treating and metallurgical facilities in-house greatly enhances Brevini Wind's ability to turn parts around quickly, Harder says, and it also allows them tight control over every process.

"Due to considerable material removal from the required machining processes, Brevini Wind elected to stress relieve all of the large planetary components prior to finish machining critical dimensional characteristics and gear geometries," Harder says.

"Brevini Wind performed analytical inspections on the internal gear tooth geometries before and after the stress-relieving process to determine the level of dimensional movements that occurred," Harder says. "The information was utilized to confirm green machining dimensional targets that will provide minimal stock removals for the post-heat treating finish machining processes."

Without an available cutting tool to semi-finish the 8-module, 116-tooth 145 mm face width internal gear, Brevini Wind chose to grind the teeth from solid in order to facilitate delivering the large planetary component to their customer in the shortest possible time. The part is shown inside Brevini Wind's Gleason-Pfauter P1600G gear grinder, which is equipped to grind both internal and external gears.

Those finish machining processes included not only final gear machining, but also finish turning on the company's newly acquired Youji 1200 ATC CNC vertical turning center. With the live tooling capabilities of the Youji, it was also possible to process the numerous M36 threaded holes that were required around the part end face. The holes were drilled and the M36 threads were generated using circular interpolating thread milling technology instead of conventional taps.

Machining Leader Tim Root prepares one of the large planetary ring gears for the final turning process on a Youji 1200 ATC CNC vertical turning center. The machine is equipped with live tooling, allowing Brevini to machine threaded holes in the end face.

"The result was very precise threads, excellent size repeatability and no broken taps," Harder says.

In the end, Brevini was able to provide these parts on schedule for a customer with a very tight deadline. "Because of our equipment, expertise, innovative thinking and some very dedicated employees, we accomplished the mission," Harder says.

Inspection of components was completed in Brevini Wind's climate-controlled inspection lab.

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A brief history of Brevini Wind USA

Brevini Wind USA was built from the ground up with wind turbine gearboxes in mind. The company broke ground in 2009 and began hiring staff in 2010. Brand new machine tools began arriving late in 2010.

All told, the company spent over $35 million on the new factory. During 2011, the processing equipment was installed, staffing was hired, and the factory was prepared for operations.

"We made a lot of Brevini standard industrial parts to begin with in order to give the machining personnel experience and to do run-off acceptance of the machines," says Dale Harder, director of facility operations. In late 2011, Brevini Wind began producing precision planetary components for one of its wind turbine customer's gearboxes. Unfortunately, the business of making main drive gearboxes for the wind market began to slow, leaving Brevini Wind with unutilized capacity, Harder says.

But having extra capacity at a brand new, state-of-the-art facility, custom-built for manufacturing large planetary components wasn't all bad, Harder says. "We would hope that a lot of customers would want their parts made in a facility with this kind of capabilities."

In fact, it allowed the company to attract new customers, particularly in the heavy equipment industry. "Throughout 2012 we manufactured a lot of ring gears for Caterpillar," Harder says. "What makes us unique is our process efficiency. We cut a gear for Caterpillar in 39 minutes utilizing the profile milling "gashing" process that would take a competitor, utilizing a typical gear shaping process, 6–8 hours."

Despite that additional business, the company still has plenty of capacity and can offer exceptional turnaround time on planetary gearbox components, Harder says.

And the company is in it for the long haul. They're confident the wind turbine business will return and that demand for their capacity will be strong for many years to come. "The economy is in some sort of degree of uncertainty," Harder says. "Nobody seems to want to move very quickly. I think when things do rebound, particularly for things that require large gears, we're going to be well positioned, because everywhere you look out there [on our factory floor], you see the latest technologies available for the manufacturing of large, precision coarse-pitch gears."

A partial view of the 105,000 square foot Brevini Wind manufacturing facility. The company broke ground on the facility in 2009 and began installing equipment by late 2010/early 2011. The facility also houses a 6.4 MW capacity back-to-back test bench for full load testing of large planetary gearboxes.

JOB SHOP LEAN

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Ed's Note: This is the third 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.

Dr. Shahrukh Irani, Director IE Research, at Hoerbiger Corporation of America

The Tiger Team

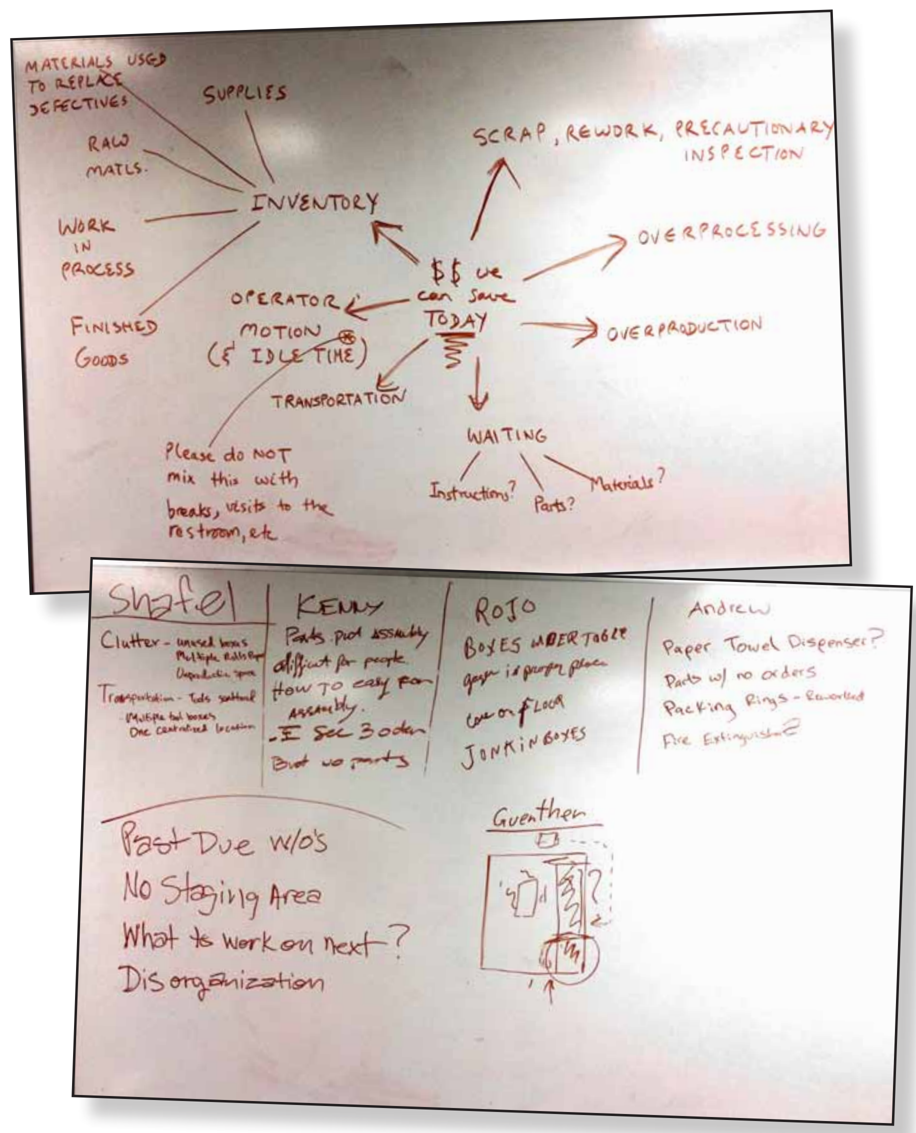
The initial approach to engage the workforce in implementing their own continuous improvement (CI) projects consisted of a weekly one-hour training session delivered to supervisors and team leaders. This approach was ineffective because considerable time was needed to conduct weekly audits of each department/cell to assess if the attendees had applied what they had just been taught. A different approach was needed. This led to the creation of the Tiger Team. Why Tiger? Because we wanted to take big bites out of the waste that existed in the shop and in the front office.

The team was designed to include (i) managers who are well-versed in the concepts, methods and CI tools, (ii) shop employees who have demonstrated an enthusiasm and/or prior expertise in implementing CI and (iii) office staff who expressed interest in initiating CI projects in departments that are "above the shop floor," such as Customer Service, Purchasing, Design, Engineering and Sales/Marketing.

Schedule of Activity

The initial plan called for the Tiger Team to meet at least once a week for a period of three months. Each meeting usually consisted of two parts:

- First, the SME (Subject Matter Expert) in the team would make a presentation to the rest of the team on a basic



Tiger Team members each received a notepad to record every instance of waste in the CA Cell.

problem-solving method/tool that is frequently used by CI teams.
- Next, the team would go to a particular area in the shop where they would engage and collaborate with the employees in that area to apply the method/tool they had just learned to improve the workspace and/or the work processes performed in that area.

This weekly routine continued in that particular area for the entire period of three months, or until sufficient improvements had been made to justify ceasing work in that area.

Focus of the Tiger Team's First Project

Our group was a mix of talented individuals drawn from different departments who wanted the team to impact any project at many levels. The team was confident that it could (i) re-engineer the daily work processes and (ii) re-design the work system to eliminate waste in any manufacturing cell or department that was assigned to us. Where should we do our first project such that waste elimination would have a clear-cut impact on the business? That dilemma was quickly solved for us. As part of a massive supply chain reorganization, corporate decided that HCA-TX would build a certain family of products in the existing "CA Cell." Currently, this cell built assemblies using machined parts that were being sourced from our sister plant in Florida. Now that HCA-TX would be responsible for the entire "CA Value Stream," the Tiger Team had found just the right project. Our goal was to observe and understand how the CA Cell worked, document and map how it really operated and determine what it would take to fit the existing pieces together into a more efficient and effective production system.

Ground Rules for the Tiger Team

- Everyone has an equal say — No pulling rank or position.
- There is no single answer for any problem.
- Learn by doing — It is okay to fail as long as you try and try again to get a better result.
- Every idea is good — Just prove that it is really good.
- Ask "Why?" five times if you think that the work system cannot be improved.

Every surface in the room was crammed, stuffed or stacked with junk.

- Maintain a positive attitude — Avoid blaming anyone or anything.
- Keep an open mind to change.
- Practice mutual respect — Treat others the same way that you would have them treat you.

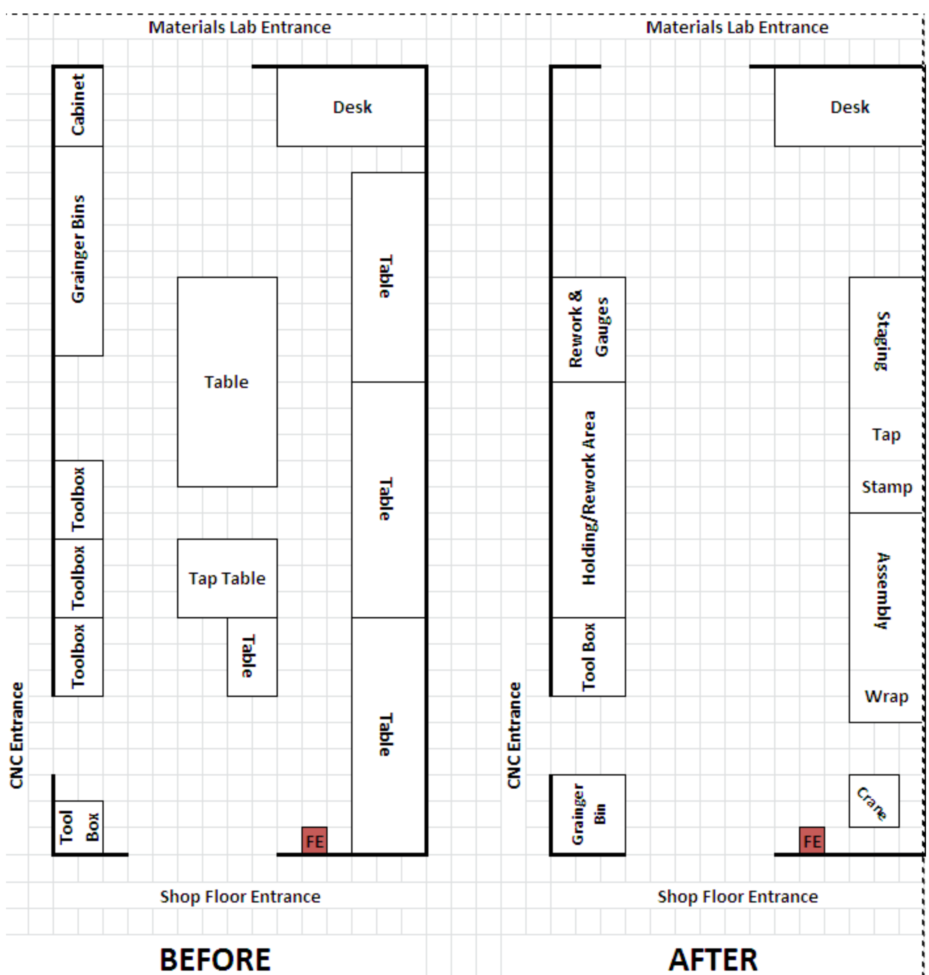
Subsequent meetings covered Value Stream Mapping (VSM), Process Mapping, Flow Diagrams, Operations Process Charts built from Bills Of Materials (BOMs), Problem-solving Tools (Five Why's, Ishikawa Diagram, etc.).

What We Did

Sort (The First S in 5S): The CA Cell hosts one full-time operator, and the room that houses it measures just 30' x 15'. Just about every surface in the room was crammed.It really was no wonder that the team could claim resounding success on that day when it undertook the removal of any and all junk from the room housing the CA Cell. Teaming up with the full-time operator and the floater from the machine shop, we achieved this goal by filling up countless trash cans and quarantining items for other departments to review, especially if they were going to be disposed of. This phase of 5S was sorely needed given the mess that cell was in, almost as if it had been used as a dumping ground by other departments. The removal of unused or unneeded tooling helped to consolidate the remaining tooling into the single mobile toolbox that was purchased for the cell.

Shine (The Second S in 5S): We wanted the cell to project a visual appeal that would not only make us proud but also impress customers and visitors touring our facility. Among the many enhancements that our maintenance department helped to make were several coats of epoxy for the floor, fresh new paint for the walls, the ceiling tiles were fixed and an array of bright ceiling lights were mounted right above the re-located assembly tables. Later, we would like to install a synchronized digital clock inside the cell and, outside the entrance, mount a framed photograph of the main product that the cell assembles. Beside that product's photograph, we hope to post the autographed photographs of the two employees who work in the cell, mainly to reinforce their pride and identity working in the cell.

Set (The Third S in 5S): There is a reason why the layout of any production system is essential for Lean, regardless of whether it is a single workstation, a single machine, a cell, a machine shop or an entire factory. Flow happens (or fails) primarily because of a good (or bad) layout. In the case of our CA Cell, the initial layout of the cell had tables and shelves lined along all the walls. A large table with lighting and racks on it sat in the middle of the room. Several small tables and benches were scattered all over the room. Assembly was not dedicated to a single table; instead, multiple in-process assemblies, rework, and projects in different phases of completion were strewn throughout the room. The Tiger Team spent several consecutive weekly meetings just standing around the cell and watching how work was done (or delayed) in the cell. During one meeting, we mapped the movements of the full-time assembly operator from start to finish around the cell (Flow Diagram aka Spaghetti Diagram). After every session inside the cell, the team would reconvene upstairs. The good ideas started pouring in! The large table in the middle had become a crutch. It had good lighting and that was the only reason it was being used. Next, we found that about half of the steps were being performed against one wall, and the rest of the process along the other wall. A couple of steps were even being done on the small tables in between! All of these problems were solved simply by implementing an assembly line/cell that required placement of two tables side-by-side and moving the toolbox, fixtures and gauges onto them, or adjacent to them at POU (point-of-use) locations. In turn, this freed up space inside the cell. Now, material that was earlier staged in carts kept outside the cell could be positioned in a 2-cart "Kanban queue" just inside the entrance to the cell. We also knew that other departments, particularly our supervisors, needed an area inside



Before and After layouts of the CA Cell.

the cell to work on special projects. To address this need, we added a rework/project table, as well as a staging rack for jobs and parts needing further attention. Thereby, anyone doing support work inside the CA Cell no longer needs to worry about interfering with the core assembly work being done in it.

Safety and Ergonomics in the Workplace: Watching the operator lift each heavy final assembly and hold it up during shrink-wrapping, often turning it around while doing that, raised a red flag. The new layout includes a jib crane and an automatic shrink-wrapping machine to wrap each final assembly before it is placed on a cart and rolled into the Shipping department. Anti-fatigue mats have been bought to reduce standing fatigue for the operator. The ceiling drop for the air hose has been repositioned to reduce the travel time and effort that the operator had to exert yanking on the hose whenever he required to blow air to clean an assembled unit.

Inventory Rationalization: Several pockets of inventory were stored in the cell, all used in the final products. We found that these items were poorly maintained and controlled. BOMs, drawings, or both, would be wrong. Fortunately, our expert operator was self-correcting these issues. To ensure accuracy and quality, we pulled all of our gaskets, O-rings, and tie rod stock out of the cell into the Receiving department. Now, only the correct items are delivered to the cell at the time of assembly. This also allows our operator to know if a BOM or drawing is incorrect, which permits us to fix it immediately at that time, making it accurate for the next time that BOM configuration is pulled. After a few months, not only were our inventories accurate, but we could also ensure better quality of our final product.

The products assembled in the CA Cell also require fasteners. Our part number Rolodex contained about 50 different nuts, bolts, washers and plugs. What we found was that we were actually stocking 150 different part numbers. Obviously something was wrong! To eliminate this issue, we teamed up with our MRO supplier (Grainger). We started from scratch and built our inventory from our current drawings, ensuring that our engineering group had a feedback loop to us if revisions were made or new fasteners created. We set acceptable minimum/maximum levels for each fastener and labeled the fastener bins with a picture of the part, dimensions, Grainger reference number, and most importantly, our ERP reference number. This way there is no room left for error, ensuring that we procure and use the correct fasteners.

Where Do We Go From Here?

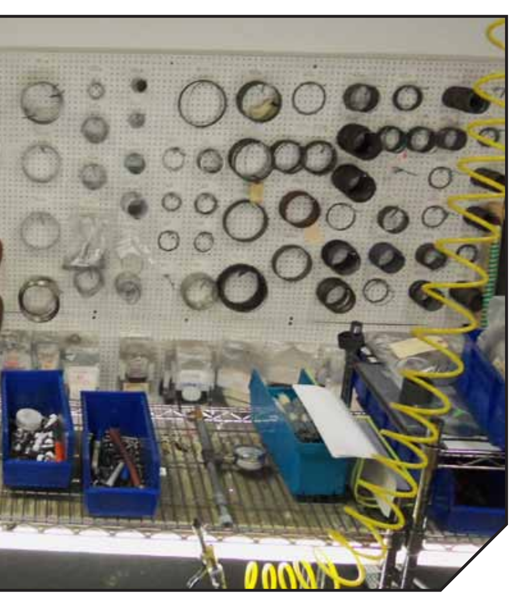
Integrated Product and Process Design (IPPD): Each assembly uses threaded tie rods for shipping and installation purposes. We found that we were calling out for and procuring smooth rods, threading them ourselves then cutting them down to size. This was all being done during assembly, thereby wasting the operator's time as follows: The operator would start assembly, see that he needed tie rods, stop work, thread the rod and cut it to specification, then complete the assembly. Today, we procure threaded tie rod, which has eliminated the threading and sawing operations. The threaded rod is less expensive than the smooth variant. Next, we plan to locate the saw used to cut the tie rod to size adjacent to the CA Cell; thereby, the operator will use his idle time to cut and fill a buffer of tie rods which would allow him to work uninterrupted during assembly periods.

WIP Reduction and Continuous Flow using Transfer Batches: Transfer batches are not as good as one-piece flow. But at least they are smaller than the shipment batch (aka process batch, if you are familiar with Eliyahu Goldratt's Theory of Constraints (TOC). We realized that for the CA product, most of our order quantities are small (less than 10 units), although on occasion we receive large orders of 50 or more. So, all these years, just to hold those ***occasional*** large orders we had packed all those tables into the single room that housed

Several pockets of inventory were stored in the cell, all used in the final product/s.

the CA Cell. That is not going to happen anymore! Now, instead of running a large order as a single batch, we are using our ERP system's capability to split an order. Okay, so we still do not know the optimal number of transfer batches that a shipment batch should be broken into. At least we plan to allow transfer batches up to a maximum size, and no more. This will make all the in-house activities related to the Value Stream for the "CA Cell" product family more manageable ex. we could start building an order using on-hand parts even as additional parts are on order. Or even give the Shipping department a heads-up so they can ready a table to package a particular CA order, even as the CA Cell is sending more completed assemblies on the next push cart from across the aisle that separates them.

"Kitbans" Help to Simplify Supply Chain Management: Everyone is familiar with a kanban (card) being associated with a batch quantity for a single part number. A "kitban" is simply extending the same idea to ensure completeness of all the components that will be required to assemble a single, or batch, of products. In the short term, we will continue to receive machined parts (the cups and flanges that go into the final product assembly) from Florida. Each case is built from a specific list of parts, i.e. X pieces of Cup X and 1 piece of Flange Y. However, analysis of our ERP records showed that we may get one cup on Monday, one cup on Tuesday, another on Thursday and the last one next Monday. Guess when assembly of that particular unit began? Only when that last cup arrived next Monday! Consequently, we are discussing with our sister plant in Florida how their machining cells could coordinate the completion times of the components in the kit of components that comprises a particular CA assembly, and ship that complete kit to our plant early enough so we can assemble and ship the assembly on time. This sup-



ply chain nightmare sound familiar to those of you who make gear assemblies? Besides, this will streamline our material handling and labor costs for the same activity.

Ratcheting Up by Several Notches the Training Given to Tiger Team Members: Management has been requested to consider allowing team members to receive more training. Currently, the training that is being offered to the team is loosely drawn from the training program developed to teach the *Quick-Start Approach to JobshopLean*. In addition, a simple training program on CI has been developed that will be offered only to the really interested and motivated employees, especially targeting those who first "did a tour of duty" on the Tiger Team! Please email *shahrukhirani1023@yahoo.com* to receive a copy of this curriculum. It utilizes Productivity Press's (now CRC Press) *Lean for Operators (Shopfloor Series)* and popular videos available from Society of Manufacturing Engineers, Greater Boston Manufacturing Partnership and Lean Enterprise Institute.

Compensation for Team Members: Rewards and incentives are under discussion. Of course, the usual ideas are being thrown around (shirts, lunches, "honor parking spots," etc.). But, it is heartening that management has taken a very serious view of those who do, and do not, actively participate in one of more Tiger Team projects. There has been talk of linking promotions, overtime and bonuses to active and valuable participation in our CI program!

(Toyota) Lean will meet Job Shop Lean: It is but natural that these two flavors of Lean, primarily developed for **low**-mix **high**-volume manufacturing and **high**-mix **low**-volume manufacturing, respectively, come together at HCA-TX. The CA Cell will need to become more flexible as it begins to make a wider range of products in the same product family. Heijunka (mixed model production) will have to be implemented. The CA Cell will pull kits of parts from a supermarket which will have to be sized and configured to carry inventories of different parts that get used in popular product configurations. This supermarket will be replenished with parts that will be machined in a FLEAN (Flexible and Lean) machining cell that will be designed and scheduled using Drum-Buffer-Rope or Finite Capacity Scheduling logic.

The current state of the CA Cell. Upper management has begun to take notice of the Tiger Team's activities.

Cell Performance Display Board: This is going to be a standard display with a focus on Quality, Cost, Delivery, Improvement Ideas, and possibly an area where the cell members can post some personal details.

The Word is Spreading among the Employees

The next Tiger Team project is being done in the MPC Cell. Kenny Pham and Dhananjay Patil (a graduate intern from the University of Texas at Arlington) have already started working with the cell's team. Having a Tiger Team member who has already worked on the CA Cell project has fired up the employees in the MPC Cell. They have already completed the Sort and Shine phases of the standard 5S effort!

Upper management has got a whiff of the activities of the Tiger Team. We may be asked to make a presentation at the Global Production Conference scheduled to be held later this year. We hope to include a short video documenting the work that we did in the CA Cell.

Andrew Reynolds has been the inventory and warehouse supervisor at HCA-TX for two years. Previously, he had been a production supervisor in the machining cells. While in college, he worked for two years in Hoerbiger Service, Greenville, SC. He is an accounting graduate from Furman University.

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 JobshopLean in HCA's U.S. plants.

If You (Re)build It, They Will Buy It

Retrofit, re-control, re-build, re-manufacture: It's all good.

Jack McGuinn, Senior Editor

It's been said that the best ideas are often someone else's. But with rebuilt/retrofitted/re-controlled/or re-manufactured—pick one — machine tools — buyer beware and hold onto your wallet. Sourcing re-work vendors and their services can require just as much homework—if not necessarily dollars—as with just-off-the-showroom-floor machines.

According to Jerry Adamski, global customer service director for Gleason Corporation (Rochester, New York), "Many factors can influence this decision, including machine condition, cost to upgrade, project timing, operator knowledge, machine quality history, existing tooling, rebuild vs. new productivity improvements, etc."

And Ken Flowers, owner and vice president of sales of Machine Tool Builders (Machesney Park, IL), elaborates on the points Adamski raises.

"It starts with the machine type and machine issues. For example, a machine which is currently CNC that has an antiquated/unsupportable control, but is producing good quality parts, is a likely candidate for a full re-control for about one-quarter to one-third (the price) of a new machine price. Re-controlled machines can last another 10-15 years if the right candidate is chosen for the upgrade. Gear cutting machines lend themselves well to re-building and re-controlling because, in general, these types of machines are more valuable than machines like mills and lathes. However, size matters; generally machines in the size range of 300 mm diameter and larger provide a larger savings than machines with smaller diameters; this is due largely to the prices of new machines in the smaller size ranges.

A mechanical shaper that was fully re-built, modified and converted to CNC control. It has five axes under CNC control, using a Siemens 840D CNC. It was modified to use a 2000 Nm water -cooled torque motor to generate the up/down stroking motions. The upgrade also provided CNC-controlled elevation adjustment and high-speed return of the cutter, helping to reduce cycle time from seven to two hours on most parts (Courtesy MTB).

A fully re-built Lorenz LS-180 gear shaping machine that had a custom tailstock/face gear table assembly added to it during the re-build. This machine has five axes of CNC control and one spindle — all controlled by a Siemens 840D CNC (Courtesy MTB).

"Depending upon the machine type, re-building and re-controlling can produce benefits in the accuracy achieved; the speed; the flexibility; features and functions; lower set-up times; and lower cycle times."

David Goodfellow, Star-SU LLC (Hoffman Estates, Illinois) president, puts things in an economic law of diminishing returns context.

"A re-build averages between 50-60 percent, and a full CNC upgrade re-manufacturing is 70 percent of a new machine price and is generally more applicable to larger machine tools, since there are more parts of the machine that can be reused. CNC re-manufacturing of old mechanical machines is often less expensive than trying to rebuild a machine to the OEM's original specifications for a mechanical machine."

Also doing some math for us is Jim Vosmik, Drake Manufacturing (Warren, OH) president. "Where the machine itself is no longer able to be brought into tolerance by adjusting gibbs, leveling and aligning the base, and other 'heavy' preventative maintenance, a tougher decision needs to be made. If re-manufacturing will cost more than 75 percent of a new machine of similar function *and* the re-manufactured machine is not guaranteed to produce at 100 percent of the speed and quality of the new machine, you are likely better off with the new machine on a total lifetime cost analysis that looks at initial, as well as productivity, operating and maintenance costs.

"Of course, when a new machine of the same function is not available, the math becomes more forgiving. The upfront cost is only one consideration. Over the life of a machine the operating, consumables, and manpower costs generally dwarf the initial, upfront costs of the iron. The main driver of those lifetime costs is stiffness in the cut/grind—stiffness drives productivity—either through cycle time directly or through diminished tool life.

"Another consideration is whether or not the carcass can be automated. Does the physical layout of the machine allow for automation to be utilized in a safe and efficient manner without doubling the footprint of the machine on the shop floor?"

Indeed, carcass hunting today can be a daunting task. Depending what you are shopping for, it's not like there exists a Happy Hunting Bone Yard where one can be readily purchased.

"Many of the carcasses result from plant closures and auctions," says Flowers. "Small machines are easily found on the market, but larger machines are becoming rare."

"Yes, (carcasses are) definitely harder to find," Vosmik affirms. "The large gear equipment has been used to exhaustion to keep up with demand, until a couple of years ago. There are just not too many large thread grinders still out there that have not been CNC-retrofitted."

Adamski says that "Carcasses are found at existing and new customer (locations), on the used machine market and at auctions," but concedes that "Popular models can be difficult or costly to find."

Of course it's ultimately all about — aside from trying to save some money—re-doing a machine to update its technical capabilities and thus make its owner more competitive in the market. But is that a double-edged sword scenario? Is it possible that machine tool technology is advancing at a pace that renders re-dos almost superfluous? The reality is that the risk of sudden obsolescence is minimal. Or is it? Fact is — it depends.

Adamski reasonably points out that "Again, it depends on a number of factors, the most significant of which is the level of re-build, i.e., basic re-build vs. retrofit vs. re-contol, etc. A re-control with new controls, motors, drives, etc., can bring the machine up to current technology levels."

Those stipulations addressed, Flowers maintains that "Actually, there is little risk at all — especially when you couple the re-build with a full re-control or conversion to CNC." He explains that in the case of re-making a machine for its current user, "If his process (has not dramatically changed), we

A mechanical (change gear-driven) Modul ZFWZ800 gear hobbing machine that was fully rebuilt and re-controlled to have four axes and one spindle under CNC control. The CNC was Fanuc model 0i-MD (Courtesy MTB).

can assume that the original proven machine castings will work perfectly for (his) re-build project. The re-control or CNC conversion can use all the latest state-of-the-art controls and, as such, can provide many of the newest technological features and the proper software."

And yet, pulling no punches, Goodfellow allows that in re-purposing, "There is significant risk," but balances that in adding that "the cost savings may be justified — especially with multiple machines and engineering utilized across more than one machine. It is always about the money cost."

The mention of software gets right at one of the crucial elements of a successful, worthwhile re-do. The machine's original capabilities must be considered, and more. For instance — who writes the software? That can be tricky — and time-consuming. The good news, however, is that today's sophisticated programs can actually increase the likelihood that a re-do is economically justified.

As Adamski points out, "A re-control will allow the machine to use the most current software and features, which essentially imparts new-machine capabilities," and Goodfellow adds that "Applying a full CNC re-manufacture allows the latest CNC technology to be applied to an old carcass, and often proves cost-effective." But as to sourcing such software, he maintains that "Relatively few rebuilders have good software capabilities, while machine tool re-manufacturers usually do."

"Good, flexible process software can overcome quite a few engineering challenges and help make a marginally productive, manual machine a winner as a CNC machine," says Vosmik. "But again, the original process must have been stable on the machine—the software and CNC retrofit can overcome the inefficiencies of movement, but generally do not add cutting/grinding stiffness."

Flowers says that "Sometimes (software) is outsourced; but two main issues occur there—namely, lack of support going forward, and difficulty finding an expert in the subject matter. After all, many programmers are not machine tool people. It is best to choose a vendor that has a proven track record, because it can take years to develop a robust, proven software package that embodies all the features and functions that a modern machine would possess."

We've addressed some of the critical considerations, but deciding to go the re-do route also requires finding a supplier who knows where the "bodies" (parts) are buried — or not (no longer available). There is indeed a machine age-related tipping point.

As Gleason's Adamski puts it, "Generally speaking, the older the machine, the harder it is to rebuild. This is particularly true when original components need replacement but become more difficult to obtain, and substitutes require a high degree of engineering."

"The single most difficult challenge is to determine how far to update to what would be considered comparable to a new machine," Goodfellow explains. "There are limitations that exist; you can (for example) replace ball screws, but the machine may call for linear guides that create significant challenges."

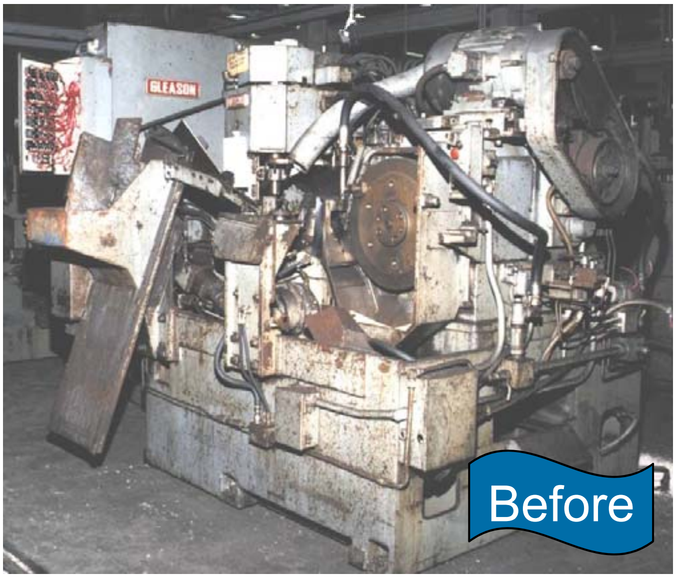
On the other hand, MTB's Flowers maintains that the question's premise is off-base, in that it is not the age of the machine, as it is the beauty of its original design capabilities.

"A machine might never be too old," he counters. "But the machine design could be such that it does not make a good candidate for the re-control or re-build process. For example, the castings (which we always reuse) may not be suitable for the modifications required to implement the conversion to CNC. Another problem may be the structure of the machine is too odd and flimsy, or the machine is simply not going to be rigid enough to provide sufficient process improvements to justify the re-build."

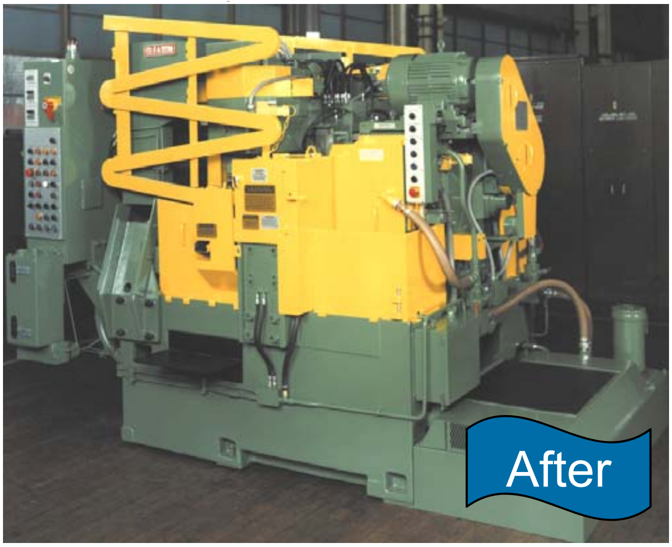
Staying with that point, Drake's Vosmik agrees that "Physical age is not too important. Go back to productivity—it does not matter how old or new the iron is, so long as it is stiff enough to use today's cutting tools and abrasives."

OK: age—not so important. But the market is now flooded with machinery boasting a much smaller footprint to accommodate today's factories, job shops and their lean manufacturing cells. Is a "lean machine" always the answer? Not so much, actually, if you know your cutting machines.

"Ironically, the older gear cutting machines have smaller footprints," Flowers reminds, following with a point that may surprise. "It's the newer machines that are larger and consume more floor space."



Gleason straight bevel REVACYCLE machine



These before-and-after photos from Gleason demonstrate the dramatic results of a machine update (courtesy Gleason Corp.).

For Vosmik (addressing machinery in a broader context), gear cutters aside, "(Size) is another driver of the economics. In the past, stiffness was often achieved by mass and over-engineering the statics. Today, the dynamics can be achieved by other means and one can have a small, compact machine that performs better than the old, massive machine."

But Adamski makes the point that "It can be (a problem), but in many cases the rebuilt product is returned to the same space it came from."

Three other points not yet addressed are biggies: price, warranty, and delivery.

Regarding what you'll pay, know this — it varies. As one might expect, cost depends on what you are buying and what you will use it for; logistics are key as well.

"It depends on the customer's requirements, Adamski says, also pointing out that "(Another) major consideration is the transportation expense to send the machine to Gleason and to have returned to them when the rebuild has been completed."

Flowers stresses that "(Cost) depends on the (carcass) price. Rare, hard-to-find machines can fetch a steep price, even if bought as a carcass." But he also says that some creative horse —or is it carcass? — trading can help. "Taking the customer's machine in trade can offset the additional expense of the carcass purchase, provided the customer has a machine to trade in."

As for warranty, one year is the typical industry standard.

As for delivery time—there's nothing "typical" about it. And up to a year is *not* atypical.

"It depends on many things, including the complexity of the product, condition you start with, customer requirements, and availability of parts and resources that may be hard to find." says Adamski.

Up to a year is accurate, Flowers allows, while managing to somehow creatively invoke Henry Ford in his response. "The main difference lies in the roots of the mass production concept laid down by Henry Ford. Once it is designed, you just build many duplicates of it — you can benefit from economies of scale; familiarity; JIT (just-in-time) manufacturing and stock; optimized production facilities, etc. Re-building is just a very time-consuming process."

The bottom line here, according to Goodfellow, is that CNC work will require the most time, "due to the stripping out of the old mechanical and re-designing and building into the carcass the new technology."

All of the above reflects the presence of a mature market here in the U.S. for machine re-builds and their variations. We've been doing it here for a very long time and doing it well. But how about, say, Asian countries?—China, for example.

We'll defer to Vosmik on this one, given that he happened to be in China on business when we caught up with him for this article.

"Almost (no market exists) in China—they want new," he states flatly. "They want productive; and, as important, the Chinese government makes it difficult to import used equipment — even retrofitted and remanufactured.

"While 'they want new' sounds like a fashion statement, those demands actually helped us (Drake) to discover how much more productive our new machine designs could be vs. the CNC retrofits and remanufactured machines. The dynam-

Metrology Products Help Repurpose Rebuilds, etc.

Supplier provides machine tool users assistance for retrofit and upgrade.

Frank Powell, product manager, Marposs Corp.

Marposs supplies precision metrology equipment for improving productivity and reducing cost in manufacturing. And while the company's products—such as gauges, sensors and probing systems—are used on new machines, the same products are also widely used for the retrofit and upgrade of existing machines. Marposs supports individual machine tool users with hardware, software and service where a retrofit or upgrade may be accomplished on-site and in coordination with the customer's in-house maintenance staff. Marposs also serves as a supplier to many machine tool OEMs and integrators, but, as with the above, companies that specialize in rebuilding and remanufacturing machines as well.

In some cases, it is possible to incorporate these products in existing machine tools without machine modification, as Marposs products are designed specifically for the machine tool environment.

When a retrofit application is presented, the machine needs to be evaluated—both mechanically and electrically—to understand the capability of the existing machine. For example:

- Is there a place to mount the new device?
- Is the machine control capable of working with the new device?
- What will be impact on the machine operation?
- Most importantly, how much will this affect the machine operator's job?

When looking at the machine to decide what would be used in a gauge retrofit, we start with the machine itself. Some of the things that we evaluate include:

- Determining available space within the tooling to install the gauge
- Accessibility to the feature of the part to be gauged
- Available clearance to load and unload the part in the machine

That last item is very important, especially when the machine is manually loaded. If a new device is added to an existing machine, and it impedes the operator's normal routine, the

ic performance gains we were able to achieve with our new designs—designs initially made for the China market—drove new productivity advancements around the globe."

As for re-doing thread and form grinding machines, Vosmik believes that "The productivity of our new machines vs. the retrofits has basically led our customers — and, consequently, us — out of the re-manufacturing business. The productivity of a new thread grinder is in its stiffness and the ability to utilize modern abrasives. The productivity and finish gains from a new thread grinder far outweigh the savings from a remanufacture and CNC retrofit, in most situations. (But) we still perform in-plant CNC replacements where a machine's electrical system is outdated and unreliable but the machine is still productive."

Will the re-build industry remain economical—and in demand—a decade from now? And what will it look like?

"(It is) moving toward CNC replacements and linear rail/truck replacements — almost a heavy-maintenance type of approach," says Vosmik.

As for Adamski, "As the price point for new machines continues to drop it may be more challenging for the re-build market to sustain growth. Re-controls and machines with unique capabilities where there are not newer alternatives will have the greatest success."

As for MTB (where re-working is its predominant business model), Flowers acknowledges an awareness of a landscape that is rapidly changing while projecting an eagerness and ability to adapt to it. In not too many years hence, re-builders will be incorporating the newest "wine" (technology) into what will by then be older "bottles" — OK, carcasses.

"Re-building will not go away," he states. "But the machines that are being rebuilt will have a different mix. The technology has advanced so much that the re-builders will have to step up their game to stay current and be able to tackle the problems associated with direct-drive systems and torque motors; gear grinders with on-board inspection capabilities; shapers with electronic guides, etc. All these candidates will at some point become targets for re-building and re-controlling."

Goodfellow couches his answer in a historical perspective.

"It will always be with us, as it has for the last 60 years."

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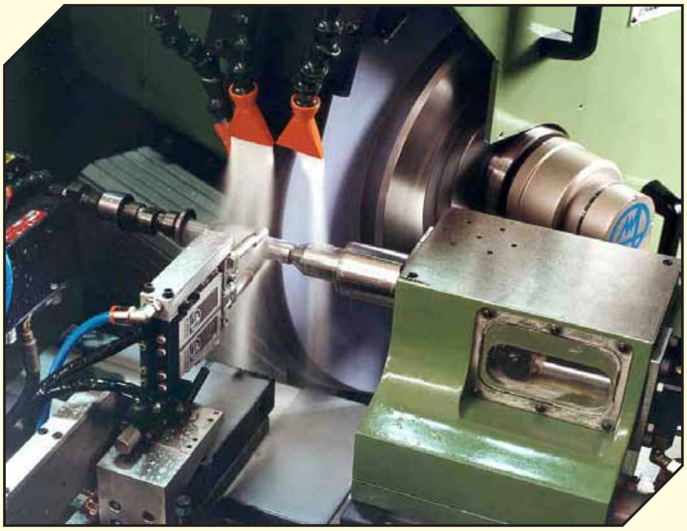

The grinder shown was originally upgraded by Marposs in the 1970's, using an in-process gauge for automating the original, manually operated machine. It is an example of an existing machine that could be a candidate for modernizing again, using the latest state-of-the-art technology to add renewed life and performance.

system will never work. The best possible scenario for installation of a new gauge on a machine is that it is transparent to the machine operator. Once it is determined that there is a place for the gauge, the next step is to evaluate the machine's control capability.

If the machine has an existing device that we are upgrading, we need to see if it is possible to connect to the existing interface; this way there are no requirements to change the machine as it is currently running. If we are adding a new device to a machine that never had one, then we must make sure the machine control has the support systems in place for the new device. This may require modifying software in the machine, and/or adding solenoids, flow controls, piping, etc. to operate the device. In some older machines with OEM proprietary controls, the OEM would need to be consulted on possible modifications before proceeding with the upgrade.

Unfortunately, many OEMs of older machines are no longer in business, so a new control may be required. In that case, Marposs will work with an integrator of the customer's choice.

Once the machine environment, function and customer needs and expectations are established, Marposs application engineers will design the proper system that will work with the machine and process. Through numerous applications annually, many manufacturers find that new life can be put back into an existing machine by installing modern gauges, sensors and/or probing systems as part of a retrofit, rebuild or remanufacture program.

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Gear Research Institute: A Big Part of Small World of U.S. Gear Research

Jack McGuinn, Senior Editor

The essence of designing gears is often by necessity risk-averse, given that many of them are used in applications where loss of life is a distinct possibility. The Gear Research Institute (GRI) at The Pennsylvania State University conducts "risk reduction testing" with the same goal in mind—whether it be gears in fighter jets, Ferris wheels, tanks, or countless other gear-reliant vehicles and machinery.

The institute, founded in 1982, exists to "provide and supplement gear and related technological needs by conducting research and development, consulting, analysis and testing." GRI has long prided itself on being "a leading proponent of cooperative pre-competitive research," but is also quite active in working with individual companies in their R&D projects. *(Ed.'s Note: An interesting historical fact regarding the GRI is that it was in fact founded in Illinois, in a Chicago suburb, by a group of gear engineers from International Harvester and a few other companies. GRI maintains its registration there to this day.)*

GRI also shares DNA with several other Penn State centers of research. Suren Rao, senior scientist and longtime managing director at GRI, explains.

"ARL was started in 1945 and is an inter-disciplinary research institute of Penn State, sponsored by the Navy. The Drivetrain Technology Center (DTC) was started in 1992 as a division of ARL with support from the Navy ManTech program. GRI, started in 1982, became a long-term sponsor of the DTC in 1996 because of the synergy between the activities of DTC and GRI."

GRI also boasts close ties with the American Gear Manufacturing Association (AGMA) and the American Society of Mechanical Engineers (ASME). How close? Six of the 10 members comprising GRI's board of trustees are nominated by ASME and AGMA.

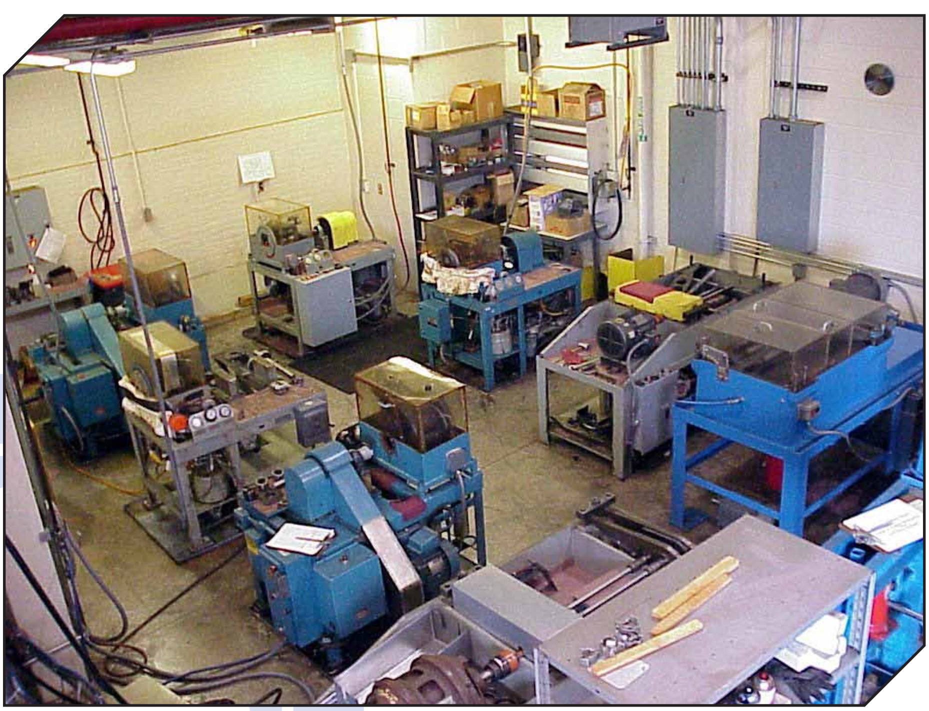
As for trying to single out a particular area of expertise relative to GRI, you might say consider them something akin to generalists in the gear world.

Or as Rao puts it: "The common theme is to improve the performance of geared systems. Performance can be many things like durability/life/power density/noise, etc."

For non-profit entities such as GRI, it's all about developing—and maintaining—close corporate relationships. Without them, the institute could not exist. And that existence is based in part on the required $600 annual membership fee. Some of those dollars are used to support post- and undergraduate programs for Penn State students with engineering careers in mind.

"Undergraduates will work on any research activity that needs support. A graduate program will focus on a more formal defined topic that would constitute their thesis," says Rao.

Great idea! Right?



Some of the machinery used in GRI's research and testing efforts (photos courtesy GRI).

Unfortunately—if not surprisingly—the level of participation thus far has been rather dismal.

"To date, we have had only one company, John Deere, sponsor and recruit an undergraduate through GRI's program," Rao says. "We have had a few other enquires, but no other 'bites' so far."

Not to point fingers, but this is the reality despite the continual hand-wringing and lamentations we read and hear about on the part of corporations/manufacturers bemoaning the dearth of talented young people pursuing engineering and manufacturing careers. Why this disconnect? Could it be that published reports and opinion pieces claiming that, despite American Business's dire need for these new workers, they expect government to foot the entire bill? Just asking.

Returning to the subject of cooperative pre-competitive research, we asked Rao for his own, non-Harvard Business School definition.

"The term 'cooperative' is derived from the fact that the cost of the research effort is shared among several companies. Since the research results are shared between several competitors, without any restraint, the effort is generally classified as pre-competitive."

But eventually, real-world reality reigns and "cooperation" reverts to "competitive."

"The individual sponsors generally stop the research effort once they realize that any further sharing would erode their competitive position," Rao says.

And speaking of individual sponsor research, the funding behind it is oftentimes anything but "individual."

"Sometimes the single-client effort is funded by the sponsor's internal R&D funds," Rao explains. "In many instances GRI supports a larger corporate program that is funded by the Federal Government (e.g., DoD, DoC, DoE), in which case GRI's funding is termed a 'federal flow-thru' through the corporate sponsor."

One might think another type of funding—from the Dept. of Defense, for example—might be drying up, given the "sequester."

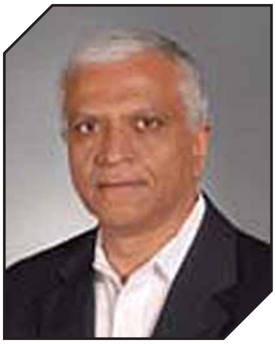
Surprisingly, however, "At the moment (early 2013), we have not seen the funding stream affected," says Rao. "It is tight; but it has always been tight."

Which leads us back again to GRI's cooperative pre-competitive research business model. Things look pretty good in the aerospace sector for the institute, but in other areas—less so.

Rao explains that "At its heyday (1980s), GRI had three or four research groups conducting research in the category of 'cooperative, pre-competitive research.' Only two survived the relocation of GRI's activities to central Pennsylvania. I would consider this reduction as a result of geographical obstacles. In the early 2000s the Vehicle Research Bloc (GM, Ford, New Venture Gear, etc.) went into a steep financial decline and decided not to continue to support GRI."

That response prompted asking Rao to compare what GRI does with the work done at the Gear and Power Transmission Research Laboratory (GearLab). Coincidentally—and it is in fact only coincidence—both institutions began around the same time.

"Until about five years ago, GearLab at OSU focused its efforts on gear noise, and GRI focused (its) efforts on gear materials and fatigue evaluation," he points out. "Apparently OSU's GearLab



Suren Rao, GRI managing director.

"To be honest locating sufficient funding to keep GRI alive, in spite of the minimal competition, is a herculean task."

Suren Rao

(For their $600 gift) "the corporate sponsor (of Penn State graduates and undergraduates) gets the satisfaction that they are helping educating the next generation of gear engineers."

Suren Rao

has expanded into fatigue testing in the recent past."

In our March-April *Gear Technology* we asked GearLab director Ahmet Kahraman why there are so few institutions like his the U.S. And so we asked Rao the same question. In some ways his answer creates more questions than answers.

"To be honest, locating sufficient funding to keep GRI alive, *in spite of the minimal competition*, is a herculean task. Maybe I am a lousy salesman; but marketing research for a technology that most consider ancient, is difficult enough with just two or three players (i.e., GRI, OSU Gear Lab, NASA-Gear Research Center). If there were more, some of us would have to close."

Rao's candid response compels us to ask of him the same question we pose to virtually anyone with an enduring stake in the gear industry and—more importantly—the country's future: Given the dwindling number of aspiring engineers and skilled workers, do you fear for the future of high-tech manufacturing in the U.S.?

"That is a real concern," Rao allows. "However, I am an optimist. As a nation of immigrants, we will attract the best the world has to offer if we can give them a better life than they have in their native land."

Single-tooth fixture equipment used for bending fatigue testing

Good answer. But then there's this: during lunch recently with a young management person working for a major company in the power transmission component industry, he said that while he was in school (a well-known private university in Chicago), professors went out of their way to dissuade their students from pursuing a career in engineering/manufacturing.

Rao's reaction:

"I am very saddened by this. No wonder everything we utilize in our daily lives comes from China or Taiwan. I am also of the opinion that manufacturing is a very significant component of the 'wealth creation' activity of any nation. We are all poorer as a result."

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Operating Pressure Angle

QUESTION

What is the difference between "pressure angle" and "operating" pressure angle?

Answer provided by John Mayhan, Xtek, Inc.

The *pressure angle* of a standard gear is defined as the angle formed by a line tangent to the pitch circle, and the line normal to the tooth profile at the pitch circle. The profile angle is defined as the angle formed by the line tangent to the tooth surface, and the line normal to the pitch surface at a *specified* pitch point. The profile angle is determined by the tool used to form the involute curvature of the gear teeth. For a standard gear profile, these angles are equal (Fig. 1).

The *operating* pressure angle is defined as the angle formed by the line tangent to both base circle diameters of the mating gears, and the line normal to their intersecting pitch circles. It is common to design mating gears with base circles that differ from the standard dimensions, and that operate at center distances different from the standard center distance. In these cases the pressure angle generated by the tool will differ from the pressure angle at which the gears will operate (Fig. 2).

John Mayhan, vice president, engineering for Xtek Inc.; 11451 Reading Road; Cincinnati, Ohio 45241; Phone: (513) 733-7993.

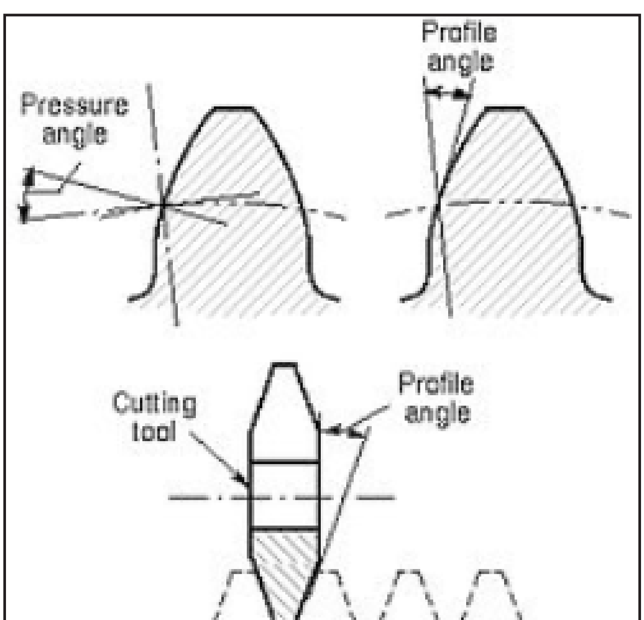


Figure 1 Standard gear profile with equal angles (Figures courtesy Xtek, Inc.).

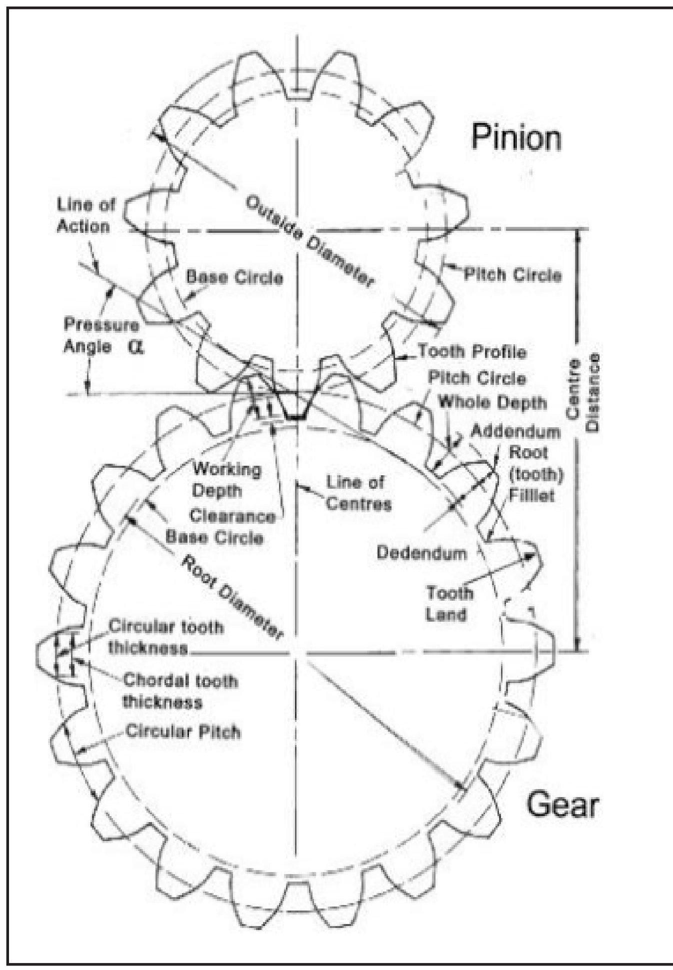


Figure 2 A pressure angle generated by the tool will differ from the pressure angle at which the gears will operate.

Answer provided by Dr. Hermann J. Stadtfeld, Gleason Corp.

If a cylindrical gear with a certain positive addendum modification is mated with a cylindrical gear having the same amount of negative addendum modification (*V0* gearing), then the center distance will be the same as that of a gear set with no modifications (module times half the sum of pinion and gear teeth). The pitch lines in both cases (no modification or a V0 profile shift) will be the same, and the pitch diameter is, in both cases, calculated as module times the number of teeth. The relationship between the two pitch diameters (or the pitch radii) is equal to the relationship of the tooth count of the two members (ratio). For involute gearing, the pitch circle is defined from the location, where the two interacting surfaces show no sliding, but pure rolling. This is where the line of engagement intersects the center connecting line, as shown in the involute development in Figure 1. R_{1a} (Fig. 1) is the pitch radius, and the pressure angle is defined between the orthogonal to the line of engagement and the pitch radius R_{1a} in the pitch point.

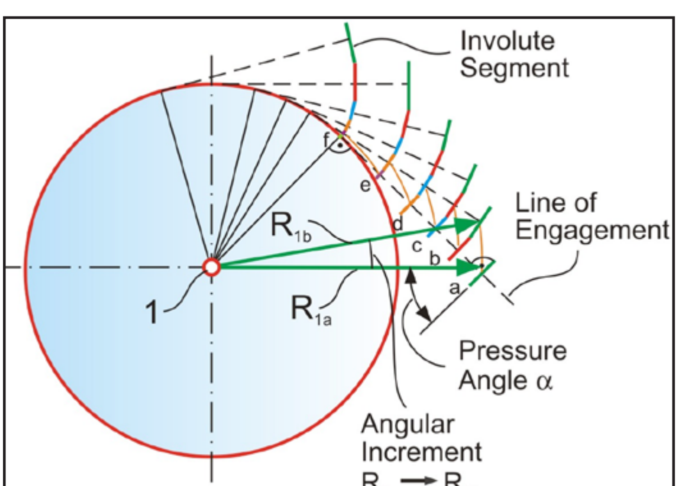


Figure 1 Line of engagement and pressure angle (Figures courtesy Gleason Corp.).

If one of the two cylindrical gears has an addendum modification (Fig. 2) and the mate does not, then the center distance changes. It is calculated as module times half the sum of pinion and gear teeth, plus module times $\times$ (where $\times$ is the addendum modification factor or profile shift factor). It is interesting that in such a scenario the original pitch circles of the two gears "lose their function." The interaction of the involutes of two differently profile-shifted gears (not V0 gearing) will lead to a new line of engagement (Fig. 3; red line of engagement for $a+\Delta a$) and a new working pitch point between them where the sliding velocity is zero and the relationship between the radii from the center of the two gears to that point is again equal to the relationship of the tooth count of the two members (ratio).

The new profile dividing line is called the operating pitch line. The pressure angle, which was based on the nominal pitch lines during the manufacturing of the individual gears, can now be determined at the operating pitch line location. In Figure 2, the pressure angle can be found in the pitch point, and the operating (or working) pressure angle is defined in the working pitch point. Figure 3 clearly shows the difference between the two lines of engagement (which is equal to the difference between the pressure angle and the operating pressure angle). The operating pressure angle is more relevant to the gear set's operating performance and is also required to calculate the bearing forces. The pressure angles of the tools are independent from operating conditions, but reflect the nominal pressure angles.

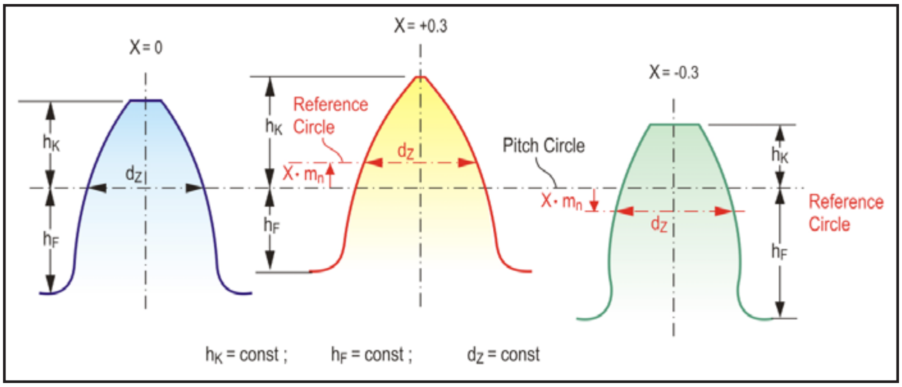


Figure 2 Principle of addendum modification (or profile shift X).

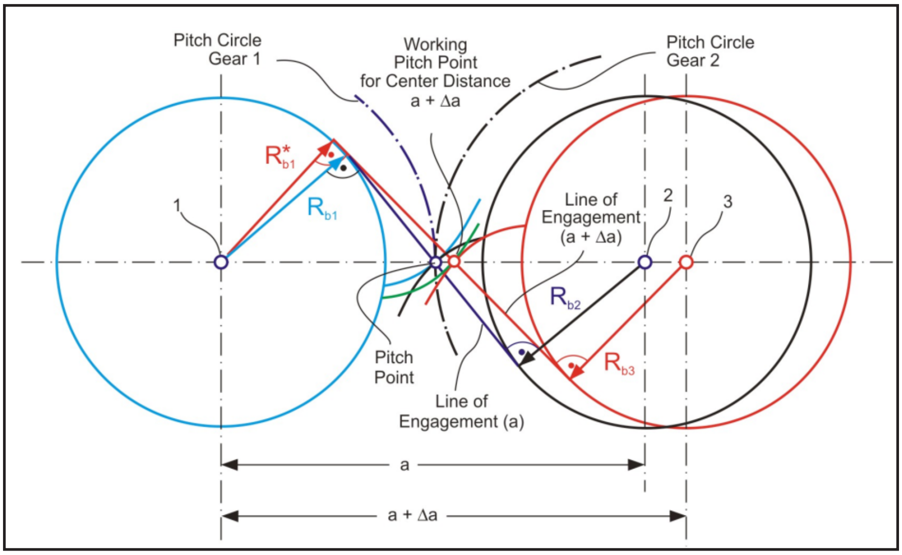
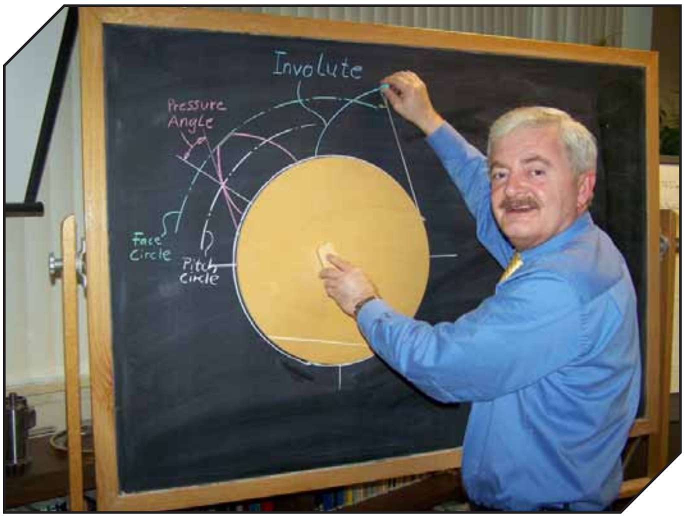


Figure 3 Pitch point and working pitch point after center distance change.

Dr. Stadtfeld is Gleason Corp. vice president, bevel gear technology, R&D



Dr. Hermann "The Expert" Stadtfeld, drawing involute and pitch line.

Gear Design Optimization for Low-Contact Temperature of a High-Speed, Non-Lubricated Spur Gear Pair

Carlos H. Wink and Nandkishor S. Mantri

A gear design optimization approach applied to reduce tooth contact temperature and noise excitation of a high-speed spur gear pair running without lubricant. Optimum gear design search was done using the *Run Many Cases* software program. Thirty-one of over 480,000 possible gear designs were considered, based on low contact temperature and low transmission error. The best gear design was selected considering its manufacturability.

Introduction

Eliminating lubricant in geared systems is both cost-saving and environmentally sound, but does pose some technical challenges. Metal-to-metal contact of tooth surfaces sliding and rolling against each other under contact pressure causes high tooth temperature that may result in material microstructure changes. Tooth surfaces can severely wear away and even deform plastically. Tooth-sliding velocity and contact pressure can be reduced by changing the gear design. However, such design changes may adversely affect gear dynamics and noise—critical parameters of high-speed gears. This paper presents a gear design optimization approach that was applied to reduce both tooth contact temperature and noise excitation of a high-speed spur gear pair running without lubricant. After defining upper and lower boundaries of the main design parameters, and the problem constraints, an exhaustive search within the feasible design region was done using the *RMC* (*Run Many Cases*) software program from The Ohio State University (OSU) GearLab (Ref. 1). Each one of the designs was critically analyzed in terms of manufacturability. The selected optimum gear design was compared to an existing gearset using *LDP* (*Load Distribution Program*) software—also from OSU (Ref. 2)—which was also used to optimize microgeometry modification of profile and lead. Tooth contact temperature was calculated by *LDP* for both the existing and optimum design, and with a dry, steel-on-steel coefficient-of-friction. A favorable correlation between predicted tooth contact temperature of the existing gearset and test results was realized. A 48 percent reduction of tooth contact temperature and a 79 percent reduction of transmission error were achieved with the optimized gear design. The low contact temperature of the optimized design can significantly contribute to preventing tooth surface damage under "no-lubricant" operating conditions.

Tooth Contact Temperature

Conjugate action of gear teeth in mesh consists primarily of sliding and rolling motions. At the pitch line, sliding velocity is zero; however, sliding velocity increases when the conjugated tooth contact line travels away from the pitch line in both directions. Contact pressure of gear teeth in mesh also changes along the line of action (Ref. 3). Heat is generated by sliding friction of tooth surfaces. The temperature distribution is proportional to the distribution of contact pressure and sliding velocity. The instantaneous (or flash) temperature of tooth contact along the line of action is calculated by Blok's contact temperature theory (Ref. 4). The contact temperature is the sum of maximum flash temperature along the line-of-action and the tooth temperature, which is the temperature of the tooth surface before it enters the contact zone (Ref. 4).

The maximum contact temperature is obtained by Equation 1:

$$\theta_{B\,max} = \theta_M + \theta_{fl\,max} \tag{1}$$

where:

θ_M is tooth temperature, °C

$\theta_{fl\,max}$ is maximum flash temperature along the line-of-action which is calculated by Blok's equation:

$$\theta_{fl_{(i)}} = 3162\,K\,\mu_{m(i)}\,\frac{X_{\Gamma_{(i)}}\,w_n}{\left(b_{H_{(i)}}\right)^{0.5}}\,\frac{v_{r1_{(i)}} - v_{r2_{(i)}}}{B_{M1}\left(v_{r1_{(i)}}\right)^{0.5} B_{M2}\left(v_{r2_{(i)}}\right)^{0.5}} \tag{2}$$

where:

K is 0.80—a numerical factor for the Hertzian distribution of frictional heat over the instantaneous contact band width;

$\mu_{m(i)}$ is mean coefficient-of-friction;

$X_{\Gamma_{(i)}}$ is load-sharing factor;

wn is normal-unit-load, N/mm;

$X_{\Gamma_{(i)}}$ is semi-width of the Hertzian contact band, mm;

B_{M1} is thermal contact coefficients of the pinion, and given by $B_M = 10^{-3}\,(\lambda_M\,\rho_M\,C_M)^{0.5}$

B_{M2} is thermal contact coefficients of the gear, and given by $B_M = 10^{-3}\,(\lambda_M\,\rho_M\,C_M)^{0.5}$

λ_M is heat conductivity, $W/(m.K)$

ρ_M is material density in kg/m^3

C_M is specific heat-per-unit-of-mass in $J/(kg.K)$.

$v_{r1_{(i)}}$ is rolling tangential velocities in m/s of the pinion;

$v_{r2_{(i)}}$ is rolling tangential velocities in m/s of the gear;

i is a subscript of line-of-action points.

Gear Dynamics and Noise

Transmission error (TE) is widely accepted in the gear community as one of the major excitation sources of noise and vibration of geared systems (Refs. 3 and 5).

TE can be described as irregularities of the motion transmitted by gear pairs caused by deviations from the ideal tooth contact; these irregularities stem from tooth topological modifications, manufacturing deviations, shaft deflections, tooth deflections and mesh stiffness variation along the line-of-action. Relative accelerations between the gears caused by TE result in vibration of gear masses and dynamic tooth forces (Ref. 6).

Transmission error may be expressed as a linear displacement along the line-of-actions by Equation 3.

$$TE = R_b \left(\delta_2 - \frac{z_2}{z_1}\delta_1\right) \tag{3}$$

where:

TE is transmission error, mm,

R_b is gear base radius

δ_1, δ_2 are the angular rotation of pinion (input) and output gear, respectively,

z_1, z_2 are the number of teeth of pinion (input) and output gear, respectively.

The dynamic response of the geared system to TE excitation is influenced by the mass and stiffness of gears, shaft and other major internal components, and by damping characteristics (Ref. 6).

Gear Design Optimization Approach

The challenge is a multi-objective optimization to minimize tooth contact temperature and transmission error, subject to maximum contact and tooth root stresses below allowable stresses values; and also subject to constraints related to packaging size, such as mounting center distance and maximum face width; and manufacturability such as undercut condition, minimum topland, and root clearance. There are many design variables to be determined as part of the problem solution; these variables refer to the gear geometrical parameters—e.g., module, pressure angle, addendum modifications and outside diameter.

One convenient and robust approach for solving this optimization challenge is to combine the gear design knowledge and computational power of modern computers to completely "sweep" or search the feasible design region to find the optimum design.

Using the *RMC* program developed by the GearLab (Ref. 1), thousands of potential gear design candidates are quickly generated and analyzed based on the gear designer's input. The gearset that best meets the objective functions and constraints can be identified using range reduction methods that select design candidates within defined ranges and parameter prioritization (Ref. 7).

Application Example

An existing spur gear set of an automotive timing gear application that runs at high speed was tested without lubrication; results of this exploratory test were used to create a baseline for comparison with the optimized design.

The gears were made of SAE 4100 (Cr-Mo) series steel and induction-hardened to 56–61 HRC surface hardness. Tooth flanks were ground to achieve AGMA grade A4 (Ref. 8). The gear samples were submitted to a dynamometer cycle of rotational speeds up to 16,000 rpm (pitch line velocity up to 36.3 m/s), and light loads (up to 0.86 N-m/mm of face width). The outlet air temperature recorded during the test was 150°C. Figure 1 shows the baseline gearset after over 100 hours of testing.

The drive-side of the teeth of both gears was severely worn, and material plastically flowed out toward the two faces (Fig. 2). The amount of wear measured on tooth profile of the driver gear (Figs. 1 and 2) was 0.130 mm, and the driven gear was 0.115 mm.

Both gears were metallurgically analyzed. Microhardness-measured results on the gear teeth indicated that the gears were exposed to a temperature range of 450°C and 510°C, which was estimated using the material tempering curve.

In parallel with the metallurgical analysis, the tooth contact temperature was calculated using the *LDP* program (Table 1).

The results of tooth contact temperature are shown (Fig. 3) for the baseline gear set, which is close to the lower limit estimated from the metallurgical analysis. In addition to the tooth contact temperature prediction at nominal design condition, a robustness

Figure 1 Baseline gear set after test.

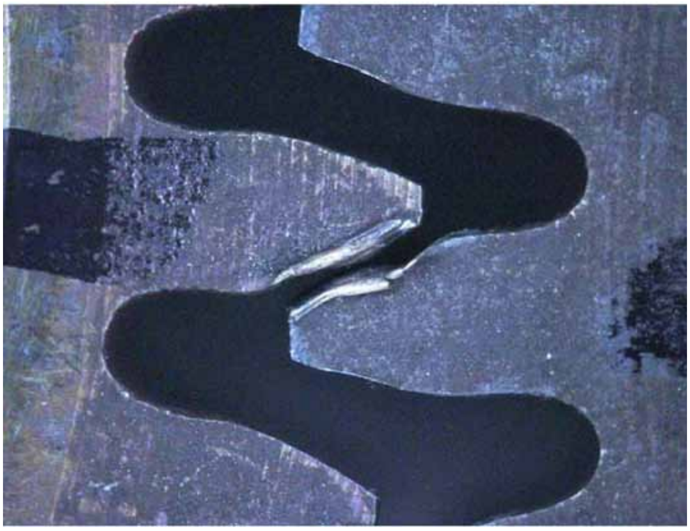


Figure 2 Base gear teeth after test.

analysis was also performed over deviations and tolerances specified on the gear drawings (Fig. 4).

The robustness analysis results indicate that the tooth contact temperature prediction for the baseline gearset falls in a range of 411°C–543°C — with an average of 475°C and standard deviation of 23.78°C. As such, excellent correlation was established for the baseline gear set.

The boundary conditions were then established for the optimum design search in *RMC*, along with upper and lower limits for the design parameters (Table 2). The last column in Table 2 is the number of points between the lower and upper limits. Center distance and gear face width were kept the same as the current design; gear ratio is 1.0.

A total of 483,372 good gear design candidates were generated under those conditions (Fig. 5).

RMC uses a modified equation to calculate tooth contact temperature that is different from Equations 1 and 2; thus *RMC* results were used as directional values only.

The *Range Reduction Method* in *RMC* was used to eliminate candidates with bending and contact stresses that exceed the allowable stresses for the application—despite the acceptable contact temperature and transmission error. The 31 candidates that met the given restrictions are displayed (Fig. 6). The differences among them in terms of tooth contact temperature and transmission errors are minor. (*The point identified with a star was the one selected as the best design because of its manufacturability.*)

Table 1 Temperature parameters used for the calculation

Parameter	Value
Coefficient of friction	0.5
Inlet bulk temperature	150°C
Thermal conductivity	48 W/(m K)
Density	7860 kg/m^3
Specific heat	544 J/(kg K)

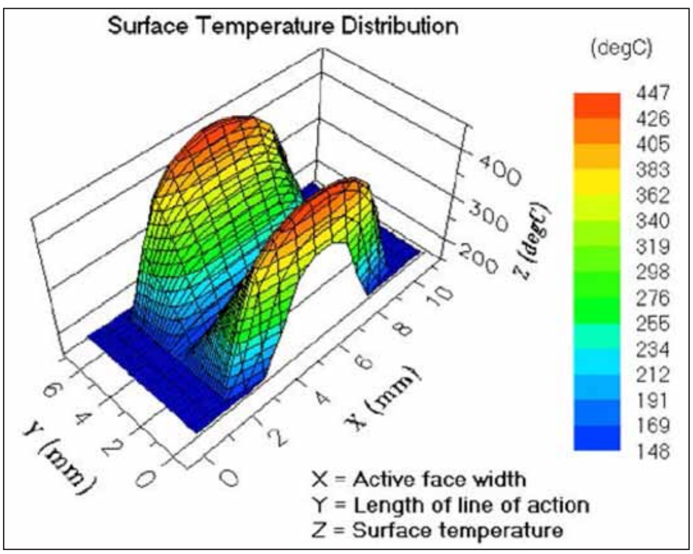


Figure 3 Predicted tooth contact temperature of baseline gear set.

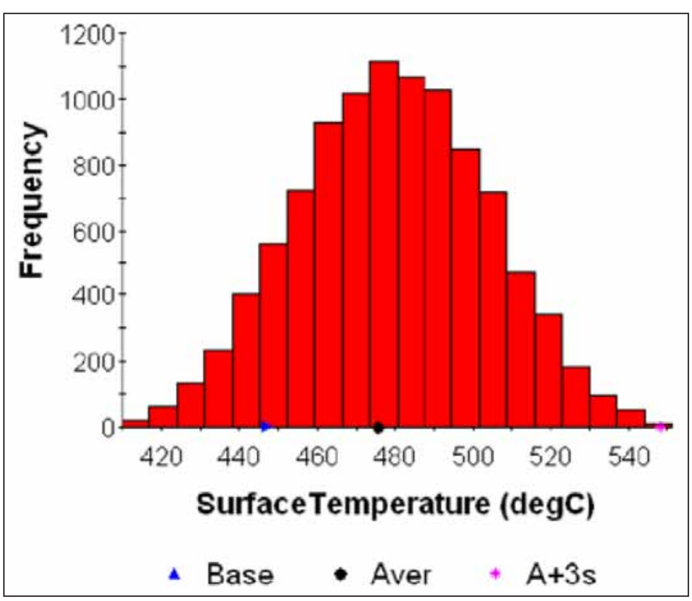


Figure 4 Robustness analysis of baseline gear set.

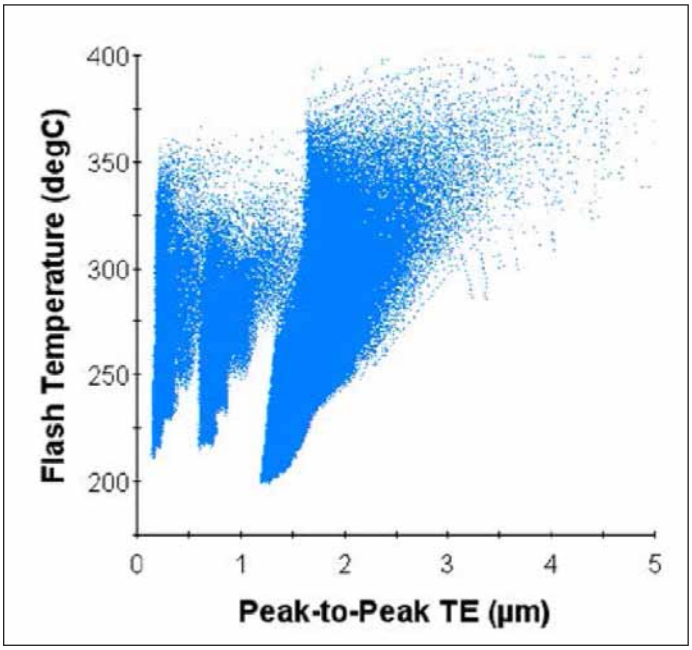


Figure 5 RMC transmission error vs. tooth contact temperature results.

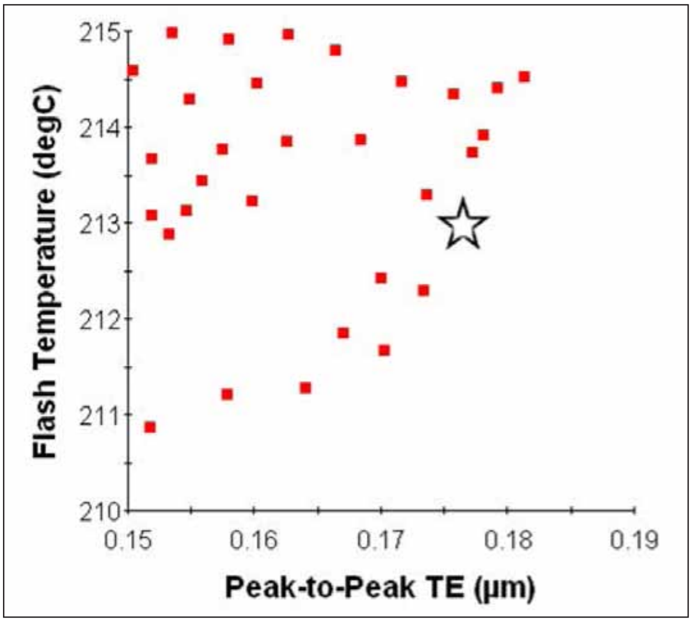


Figure 6 RMC best results (* identifies the selected design).

Table 2 Variable limits for optimization		
Design parameter	**Value**	**Levels**
Number of teeth	10 - 60	51
Pressure angle, degrees	12.5 - 25	20
Tool dedendum coefficient	1 - 1.2	10
Hob shift level	-	10
Backlash coefficient	0.048	-
Minimum topland coefficient	0.20	-
Minimum root clearance	0.15	-
Minimum SAP roll angle, degrees	4	-

Table 3 Results before and after optimization		
Parameter	**Current gear set**	**Optimized gear set**
Number of teeth	41	57
Module, mm	1.06	0.75
Pressure angle, degrees	14	18
Contact ratio	52.24	2.15
Slide to roll ratio	1.32	0.63
Contact stress, MPa	7.97	752
Tooth root stress, MPa	1.31	198
PPTE, µm	0.59	0.12
Contact temperature, °C	447	232

The best design geometry was then transferred into *LDP* to confirm the calculation results, optimize micro-geometry modifications, and do robustness analysis. Microgeometry modifications were defined using the *LDP 3D Microgeometry Analysis* module as 2–6 mm profile crown, and 0–4 mm lead crown. Table 3 shows a comparison of the current design and the optimized design for low contact temperature and transmission error (PPTE).

The robustness analysis also showed that the optimized design is less sensitive to manufacturing deviations than the current one. Predicted tooth contact temperature ranges from 233°C–262°C—with a standard deviation of 6.16°C; compared to the 411°C–543°C—with a standard deviation of 23.78°C for the current design.

Gear samples were made for validation testing (Fig. 7). Two heat treatment processes were considered: 1) induction hardening (current process) and 2) nitriding—which may provide additional wear resistance because of high surface hardness and a white, nitrided layer; in this case the gears were finished before nitriding.

The gear samples of the optimized design were tested with the same dynamometer cycle used for the current gear endurance testing, and results will be compared to the current gear set test results.

Figure 7 Gear samples of optimized design.

Summary

Favorable agreement between the predicted tooth contact temperature using *LDP* and the temperature estimated from microhardness and material tempering curve was obtained to an existing gear set that was tested at high speed and without lubrication. The gear design was then optimized using both the *RMC* and *LDP* programs. The best gear design for low contact temperature and low transmission error was selected from more than 480,000 designs. A 48 percent reduction of tooth contact temperature and a 79 percent reduction of transmission error were achieved with the optimized gear design, which is also more robust to manufacturing deviations than the current design. The main reason for the reduction in contact temperature of the optimized design was the slip-to-roll ratio reduction, which was proportional to the reduction in temperature. The low contact temperature of the optimized design can significantly contribute to prevent tooth surface damage under no-lubricant operating conditions, which will be confirmed through dynamometer endurance testing.

Acknowledgments

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Light-Weight Assembled Gears: A Green Design Solution for Passenger and Commercial Vehicles

Thales Sardinha Garcia Souza, Dr.-Ing. Mauro Moraes de Souza and Juliano Savoy

Introduction

Discussions on climate change have been posing automotive industry challenges, as carmakers have to meet tight emission standards from different countries. The European Commission established through Regulations 443/2009 and 510/2011 the goal of limiting average CO_2 emissions from new passenger cars to 130 grams-per-km by 2012—a reduction of around 25% from 2006 levels (Ref. 1). This trend also exists in other countries—Brazil, for one—which through Regulations 418/2011 and 315/2002 set new emissions limits for CO (carbon monoxide), HC (hydrocarbon) and NOx (nitric/nitrogen oxides) (Ref. 2). According to Steinberg (Ref. 3), the cost of reducing each gram of CO_2/km has already risen from $17.03 (€13) to $65.50 (€50)—before the 2020 target of 159 g of CO_2/km has even been reached.

It is widely recognized that the reduction of CO_2 requires consistent light-weight design of the entire vehicle. Likewise, the trend towards electric cars requires light-weight design to compensate for the additional weight of battery systems. The need for weight reduction is also present regarding vehicle transmissions. Besides the design of the gearbox housing, rotating masses such as gear wheels and shafts have a significant impact on fuel consumption. The current technology shows little potential of gear weight reduction due to the trade-off between mass optimization and the manufacturing process. Gears are usually forged followed or not by teeth cutting operation. Due to the elasticity of the equipment, current presses must operate with a minimum distance between punch and die in order to avoid tool failure when operating with no working piece. Also, the press force is determined by this gap in cases where some flash is formed during forging; and a minimum flash is required for a forgeable part using the available press. This issue constrains the minimum wall thickness of a final product; e.g.—the body of an automotive gear. Therefore, some gear designs must have a more robust wall thickness than is usually needed due to this conceptual restriction. This applies even if a thinner wall thickness were approved by accepted criteria such as stiffness, permissible stress and NVH (noise/vibration/harshness). For these reasons, a gear that achieves the abovementioned goals is greatly coveted and will in fact be presented here. Existing technology affords only limited weight optimization potential, due to the manufacturing process trade-off. Therefore, this challenge must be met through innovation.

Existing Technology

Gears are an elementary component of vehicle transmissions. The manufacturing and machining of gears is therefore a central task in the transmission production. There is, on one hand, the possibility of giving the tooth contour its final geometry already in the soft state, in which case the gear only need be hardened. The advantage of this method is the short process chain and resultant lower costs. On the other hand, inaccuracies caused by distortion due to hardening are usually unacceptable, in which case hard machining must follow the hardening process. Figure 1 shows a planetary gear in various machining steps (Ref. 4).

The current manufacturing process trade-off is presents itself in the forging operation, where, the higher the forging effort, the lower the wall thickness. Presses must operate with a minimum distance between punch and die in order to keep the press force under workable levels. Moreover, tool failure may be expected if this gap is not big enough to accommodate machine elasticity while operating with no working piece. Figure 2 shows the minimum thickness achievable for a gear body, and the shaft elasticity during the forging process.

As a result, the wall thickness of the final product will be constrained by this gap, which leads to a limited light-weight design. Figure 3 presents (*Gear* 1) the minimum wall thickness required for structural approval for a typical gear for a manual transmission; (*Gear* 2) exhibits the minimum wall thickness possible in the forging. One can see that a reduction of 30% on the gear body width would lead to a 14% mass reduction on the finished gear.

A B C

Figure 1 Machining steps of a planetary gear: 1) forging; 2) turned blank; 3) soft- hobbed gear; 4) hardened and finished gear (Ref. 4).

Some versions are designed with an asymmetric gear body in order to optimize the stiffness in a certain direction; also available are versions with holes which will reduce the weight. Nevertheless, these versions are weight-constrained by their own process requiring initial forging. That being the reality, further optimization must be achieved through an innovative solution.

Light-Weight Assembled Gear

The method/process used in attaining the necessary optimization is grounded in the idea of redistributed mass combined with an assembly process that maintains the system under radial pre-load. Figure 4 describes each part of the light-weight assembled gear: plate A is mounted on the gear ring B and on the inner part C by radial deformation in the elastic field. The system is axially locked when the plate reaches the existing "steps" for B and C. It is tangentially locked due to D, and by the radial pre-load that results from the plate deformation during the assembly process.

The new concept requires a customized manufacturing process (Fig. 5). It starts with forging and machining of the inner and outer part, followed by heat treatment, assembly and teeth grinding in order to eliminate potential concentricity errors deriving from the assembly process. The advantages of this process are:

- Different materials can be used for the inner and outer part. In other words, a more substantial and more expensive steel is restricted to the outer part—which must present the highest mechanical strength—while the other parts can be manufactured with lesser steels or alternative materials.
- The heat treatment can be applied locally. For instance, the carburizing would be applied only to the outer region, while the inner region can be conventionally quenched and tempered. According to the geometry of the inner hub, shape of the splines, and transmitted torque, the heat treatment can in fact be eliminated. Both characteristics lead to cost advantages for the final product.

Design advantages are achieved by moving the gear body material farther from the neutral line, leading to a section that presents a higher moment-of-inertia on the axial direction. Comparing this proposed design with a standard gear, it can be seen (Fig. 6) that an increase of 43.4% of axial stiffness is attained—with 0% weight alteration.

The stiffness advantage results in a lower axial displacement variation of the gear teeth during a transient torque, leading to enhanced NVH behavior. By designing the articulation point

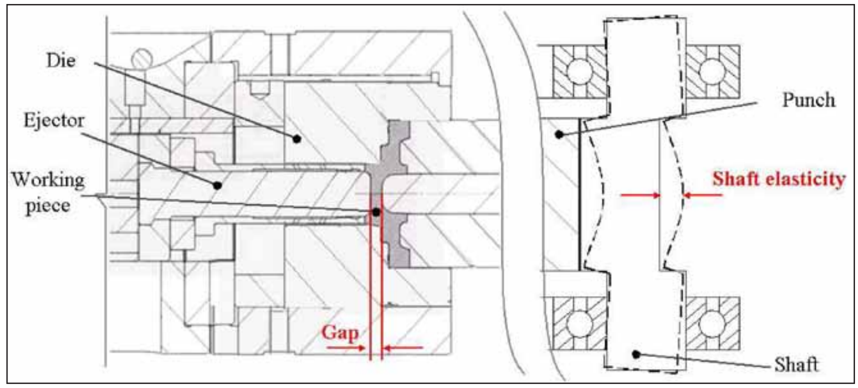


Figure 2 Minimum gap and shaft deformation for a typical horizontal press.

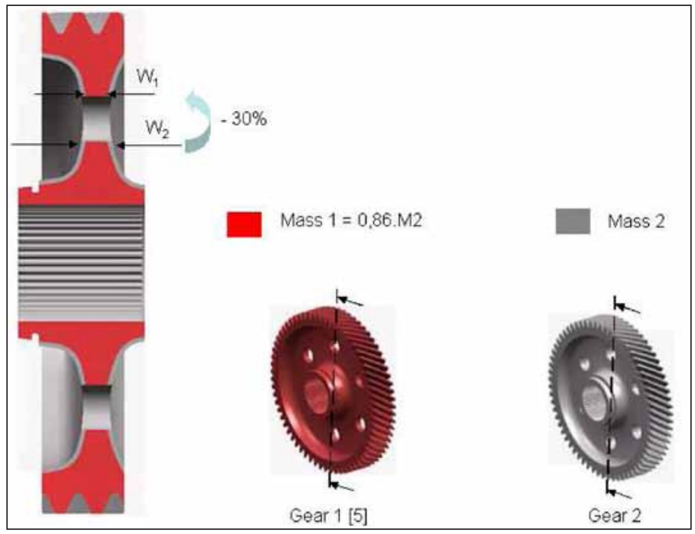


Figure 3 Body width difference for a conventional forged gear of manual transmissions (Ref. 5).

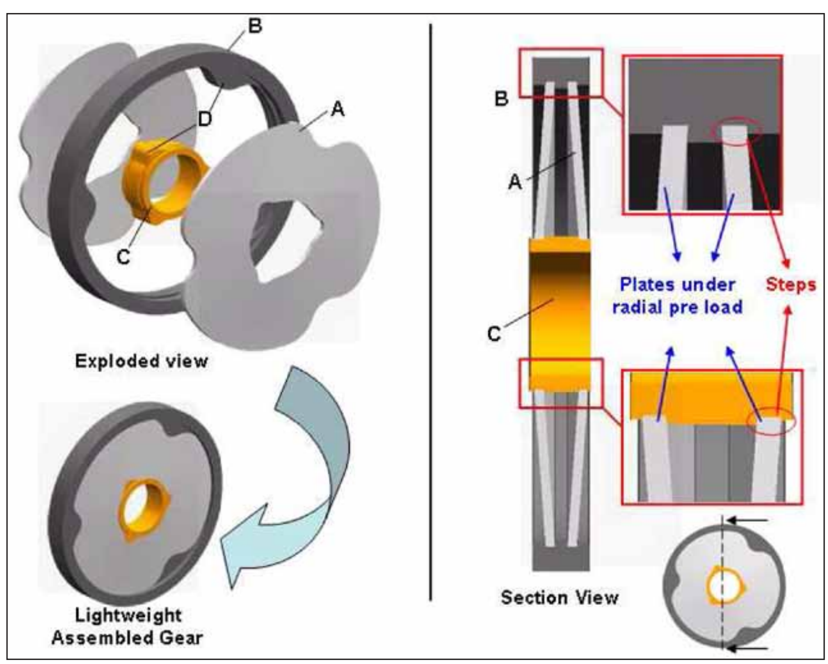


Figure 4 Light weight assembled gear concept.

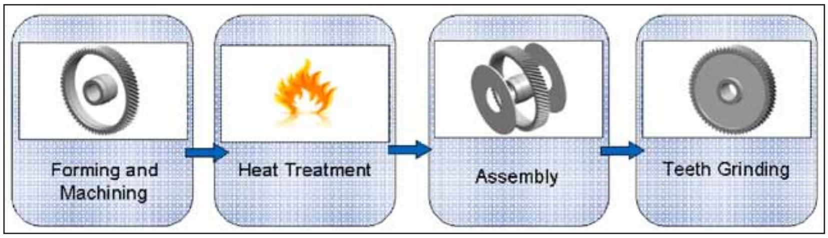


Figure 5 **Customized manufacturing process.**

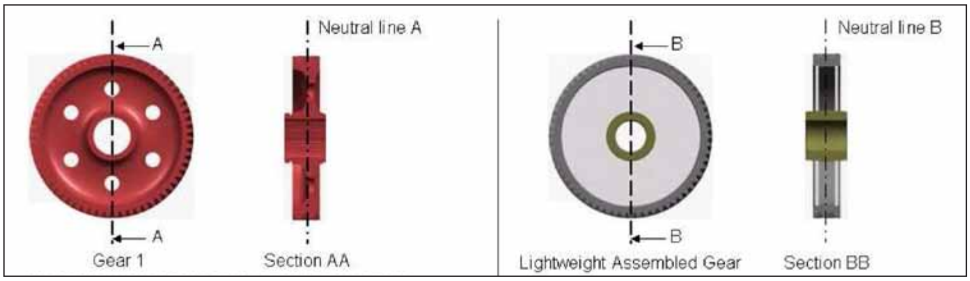


Figure 6 **CAD data comparison between the light-weight assembled gear and the current state of the art.**

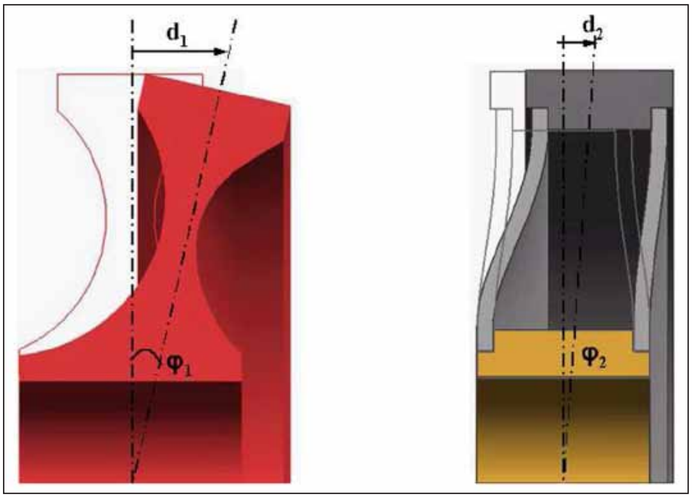


Figure 7 **Expected displacement behavior.**

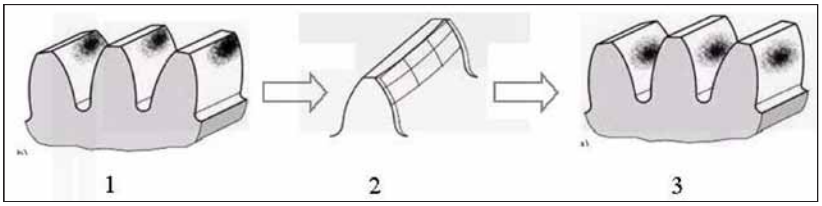


Figure 8 **1) one-sided contact path; 2) longitudinal profile correction for removing local load increases; 3) homogeneous pressure distribution possible to be eliminated on the light-weight assembled gear (adapted from Ref. 4).**

Figure 9 **Modes of a gear failure: 1) vibration fatigue; 2) macropitting; 3) scuffing; 4) wear; 5) spalling; 6) crack at the root diameter due to bending stress (Refs. 4 and 8).**

farther away from the neutral line, a lower angular variation of the gear body is realized (Fig. 7).

In addition to the lower angular variation, the teeth contact area is positively affected. A homogeneous contact path between the input pinion gear and the output light-weight gear during alternating loads now exists. In other words, the gear wheel performance is enhanced while the profile correction effort is reduced—if not eliminated entirely (Fig. 8).

The performance limit for gear wheel designs is basically determined by tooth failure resistance. Vibration fatigue, pitting, scuffing, wear, spalling and bending stress at the root diameter are the main causes for tooth damage (Ref. 8).

Shown damage types (Fig. 9) limit the load capacity of the gear wheels; according to Naunheimer (Ref. 4), the major factors that lead to these failures are:

- Operating conditions (type of load; tooth forces and additional forces; circumferential speed; temperature)
- Selection of materials
- Gear geometry
- Manufacturing accuracy
- Surface treatment/surface roughness
- Selection of lubricant (chemical and physical characteristics)

Assuming that the proposed light-weight gear works in the same environment and under the same load conditions as Gear 1 (Fig. 3), the gear geometry factor is the only point that requires careful study. A virtual and experimental investigation of the above-mentioned issues follows.

Development and Validation

The following is intended to present a complete explanation of the development process for the light-weight assembled gear. This explanation does not involve the use of sophisticated calculations, such as the German standard DIN 3990 gear wheel calculation; rather, an attempt is made to present the fundamentals of structural calculation by merging the finite element method (FEM) with experimental engineering procedures.

The light-weight assembled gear was substituted for a customer application. By analyzing the maximum engine torque times, the highest transmission ratio available for the adopted powertrain, and the maximum tractive effort limited by the tires of the vehicle used, a maximum torque of 900 Nm was calculated for the transmission output shaft. An assumption of load distribution on the teeth contact area is not required, because the contact algorithm of the general computer program is used to calculate the contact area and stresses by application of torque to the pinion gear, while the light-weight gear is considered at rest. Figure 10 shows the FEM model discretization, the boundary conditions, and the types of elements used for stress analysis. Element sizes were assured by a convergence study.

The structural analysis resulted in the stress distribution shown (Fig. 11); the variation of contact and bending stresses along the path of contact has also been studied (Fig. 12).

Next, natural frequencies and vibration modes were also investigated. Considering a four-stroke engine with four cylinders for mid-size cars that achieves a maximum revolution of 7,000 rpm, a frequency of 72 Hz may excite the gear system. Proving ground data acquisition shows that the excitation level from suspension systems is lower than that reached by the engine. Thus the first vibration mode of the proposed solution must be above the critical excitation level imposed by the engine in order to assure a safe working condition (Fig. 13).

The last step in the virtual development is the life prediction of the component. The failure modes for a gear have been presented (Fig. 9). According to Stephens (Ref. 9), failure due to fatigue is the most common cause of mechanical failure. Although the number of mechanical failures compared to successes is minimal, zero defect tolerance is required due to the potential for fatalities, injuries and other major concerns. Proper fatigue design can reduce these undesirable losses; following are some Dos and Don'ts (Ref. 9):

- *Do* recognize that the closer the simulated analysis and testing are to the real product and its usage, the greater the confidence in the engineering results.
- *Do* recognize that proper fatigue design methods exist and must be incorporated into the overall design when cyclic loading is involved.
- *Don't* rely on safety factors in attempting to overcome poor design procedures.
- *Do* consider that good fatigue design—with or without computer-aided design—incorporates synthesis, analysis and testing.
- *Do* consider that fatigue design durability testing should be used as a design verification tool, not as a design development tool.
- *Don't* overlook the additive or synergistic effects of load, environment, geometry, residual stress, time and material microstructure.

The maximum torque to be transmitted by the light weight gear was calculated at 900 Nm for a maximum acceleration case. As cyclic loading can be expected for the component, a proper

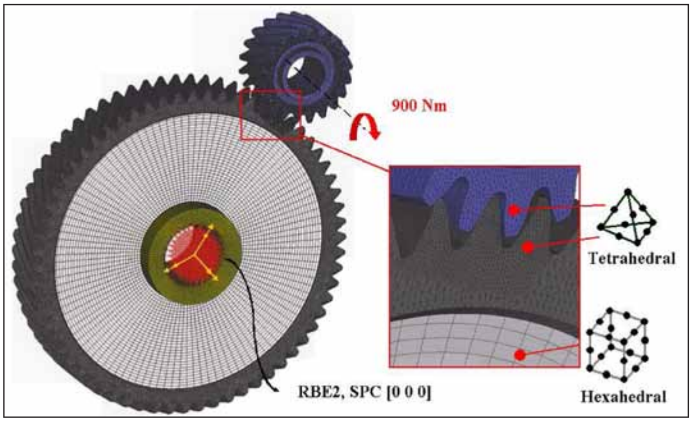


Figure 10 Finite element model discretization, boundary conditions and element types.

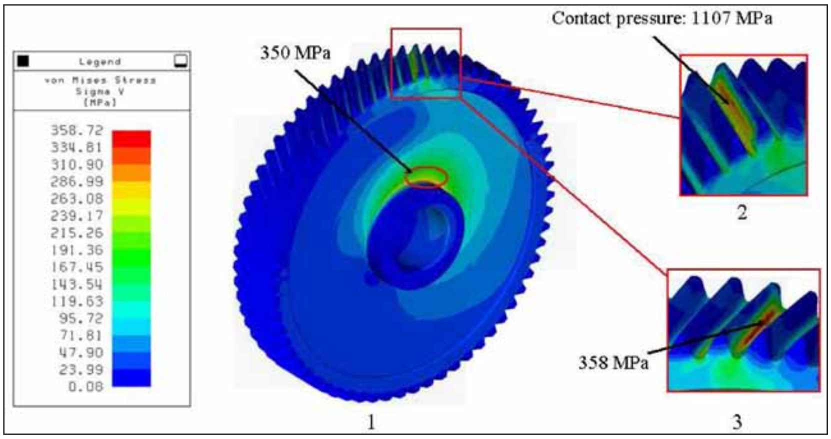


Figure 11 1) Overall von Mises stress; 2) contact pressure at the tooth contact path; 3) bending stress on the root diameter.

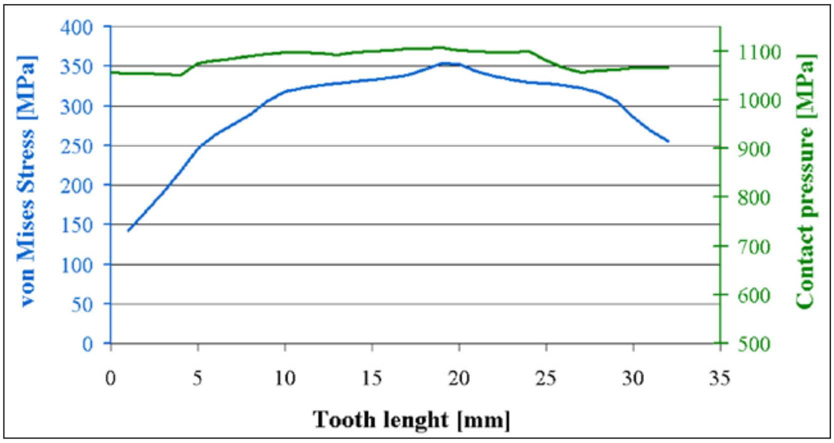


Figure 12 Magnitude of the contact and bending stresses along the contact path.

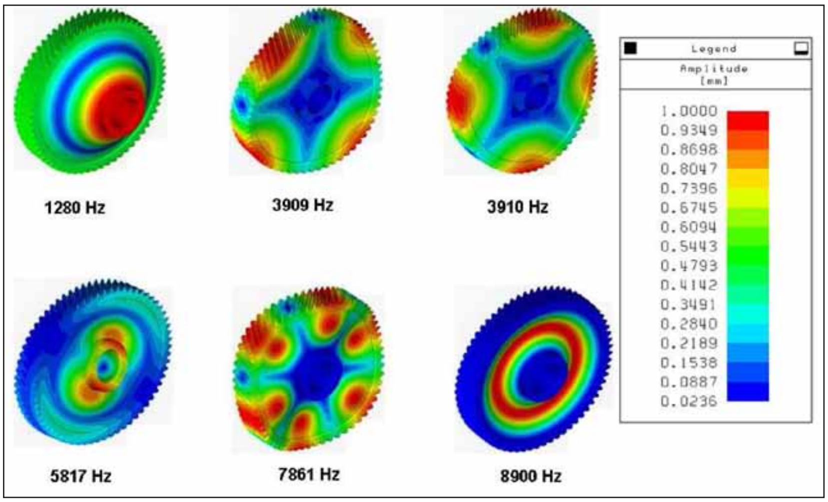
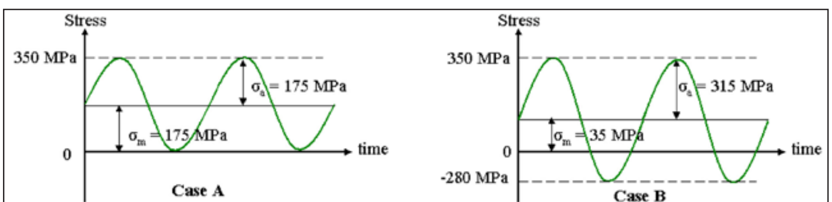


Figure 13 **Natural frequencies and vibration modes for the light-weight assembled gear.**



Case A:

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} \quad [9]$$

$$\sigma_a = \frac{350-0}{2} \longrightarrow \sigma_a = 175MPa$$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \quad [9]$$

$$\sigma_m = \frac{350+0}{2} \longrightarrow \sigma_m = 175MPa$$

Case B:

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} \quad [9]$$

$$\sigma_a = \frac{350-(-280)}{2} \longrightarrow \sigma_a = 315MPa$$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \quad [9]$$

$$\sigma_m = \frac{350+(-280)}{2} \longrightarrow \sigma_m = 35MPa$$

Figure 14 **Case A) maximum acceleration followed by torque interruption; Case B) maximum acceleration followed by brake engine torque.**

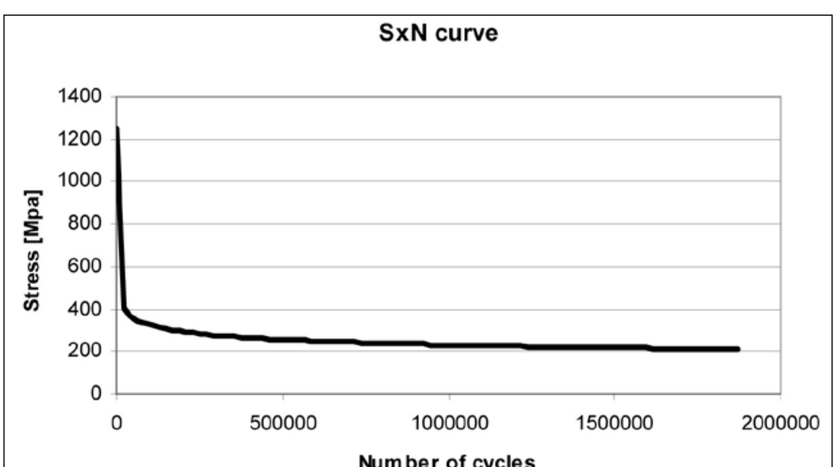


Figure 15—Curve SxN (Ref. 10).

fatigue design must be evaluated. Dynamic loads for a given vehicle can be achieved through collected data acquisition on the proving ground. However, the random behavior of those loads may lead to a very complex test bench in some cases, rendering it unfeasible due to the huge amount of data to be studied. Durability testing laboratories often adopt severe load cycles with a regular pattern in order to determine the life of a component. Figure 14 presents the adopted critical cycles for the light weight gear; they represent—through case A—constant, maximum acceleration followed by torque interruption, and—through case B—a maximum acceleration followed by a brake engine torque of 80% of the maximum acceleration torque. The stress values on the gear body shown on the vertical axis were reached through the same static structural analysis presented (Fig. 11), and they will be used as input data for the life determination.

The analysis of the cycles presented (Fig. 14) are necessary in order to verify the effect of the higher tractive-mean-stress in A—despite knowing that the alternating stress is much higher in B. The effect of a *tractive*-mean-stress is always damaging to the life of the component—once it collaborates with crack propagation—while a *compressive*-mean-stress allows load transfer and so would not jeopardize fatigue life.

Having defined proper load cycles, a good understanding of material properties, size effects, microstructural aspects and surface finishing are essential for the success of the fatigue design. Mechanical properties of solids modeled in a virtual environment are often considered homogeneous, isotropic and linearly elastic. But at the microscopic level, none of these assumptions may exist, and metal fatigue is significantly influenced by microstructure; this includes chemistry, heat treatment, grain size, anisotropy, inclusions, porosity, flow lines and other discontinuities or imperfections (Ref. 9). The S-N curve presented (Fig. 15) is available in fatigue software, and it was achieved through experimental tests on the actual material. Here microstructural effects are inherently accounted for and therefore do not have to be considered again for life prediction. Size effects, frequency and surface finishing were incorporated with the S-N behavior in order to represent the real fatigue limit of the component.

Figure 16 presents the ratio between the expected number of cycles for failure of the component and the documented number of cycles during which the component actually failed.

Considering that the state-of-stress on the teeth area of the light-weight assembled gear is either equal or lower than that of the reference gear, the fatigue analysis shows that both cases not only reach the minimum life of 106 cycles, but also exceed it, reaching 3.09.106 for case A and 1.28.106 for case B.

The high durability of the light weight assembled gear in the virtual development phase allowed for moving on to some validation procedures. The extensive time and effort invested during the virtual development process paid dividends in the experimental phase. As the results of the finite element analysis (FEA) didn't demonstrate "worst-case" stress behavior in the teeth contact area when compared with a standard gear, the goal of the stress investigation presented here is to validate the von Mises stress level on the gear body. An alpha prototype of the light-weight assembled gear was machined and assembled on a torque test bench through several devices; parts were assembled (Fig. 17). The torque was applied manually through the crank wheel and then amplified by the reducer in order to reach 900 Nm. The torque was recorded by the load cell placed after the reducer. Devices are responsible to transfer the torque from the load cell into the gear by a single tooth. Because the main stress directions are unknown, a strain gauge rosette was connected to the data acquisition equipment in order to determine deformations at 0°, 45°, and 90°. Thus, via analytical calculation, it was possible to calculate the von Mises equivalent stress on the gear body. Also, the use of terminals was essential in guaranteeing the gauge integrity, thus protecting it from possible impacts that may jeopardize the test result.

The expected linear behavior was verified for deformations in directions 1, 2 and 3 (Fig. 18).

According to (Ref. 11), the relation between deformations and main stresses for a rectangular rosette is given by Equation 1.

$$\sigma_{1,2} = \frac{E}{2}\cdot\left[\left(\frac{\varepsilon_1+\varepsilon_3}{1-\nu}\right)\pm\left(\frac{\sqrt{2}}{1+\nu}\right)\cdot\sqrt{(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2}\right] \qquad (1)$$

where:

E = Young modulus

ν = Poison coefficient

Finally, the von Mises equivalent stress is calculated by Equation 2 (Ref. 12):

$$\sigma_{vM} = \frac{1}{\sqrt{2}}\cdot\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2} \qquad (2)$$

Equations 1 and 2 lead to the stress evolution shown (Fig. 19).

A difference of 5.7% was found when comparing the experimental von Mises stress with the FEA result. As the stress level on the gear body is much lower than that of the ring gear, a solution that considers a less-substantial material for the gear body may indeed lead to cost savings. Given the current

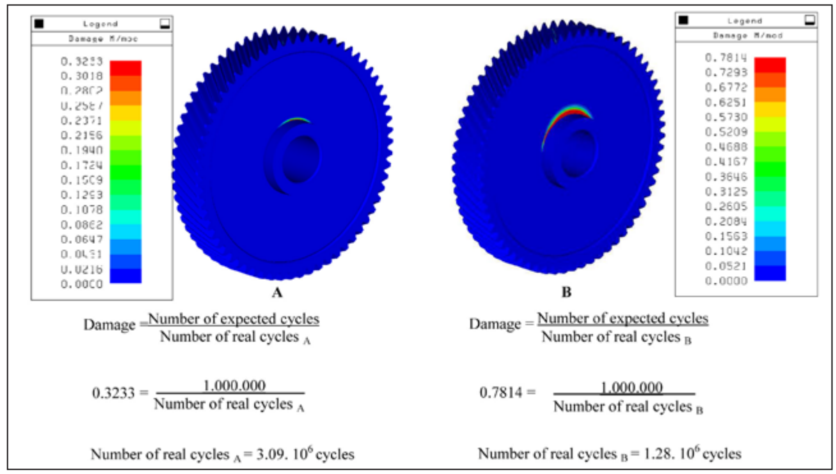


Figure 16 Fatigue damage of the light-weight gear for an expected life of 106 cycles.

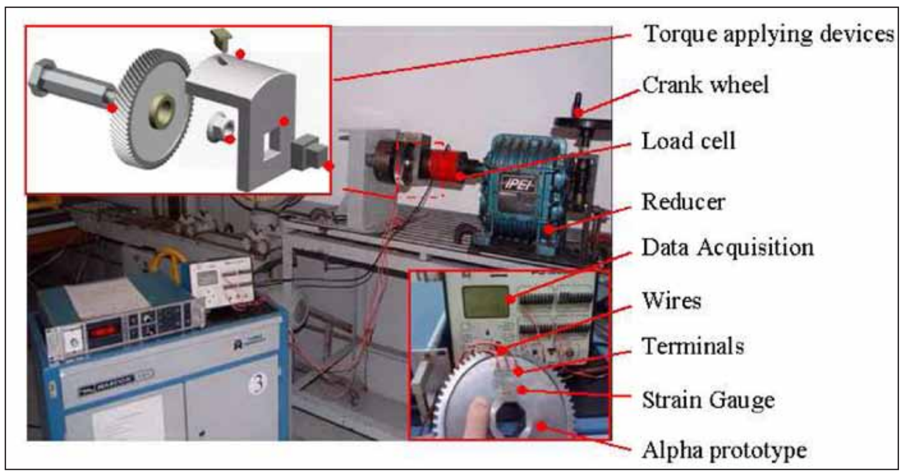


Figure 17 Stress validation test bench.

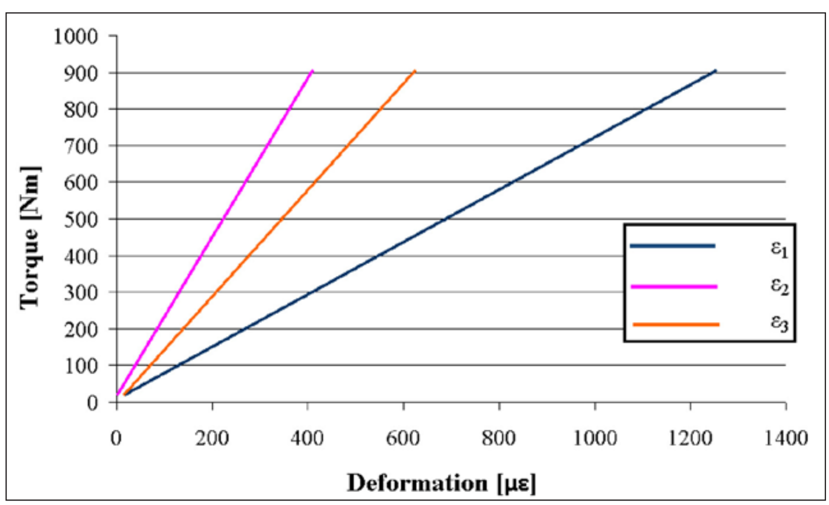


Figure 18 Stress test output data.

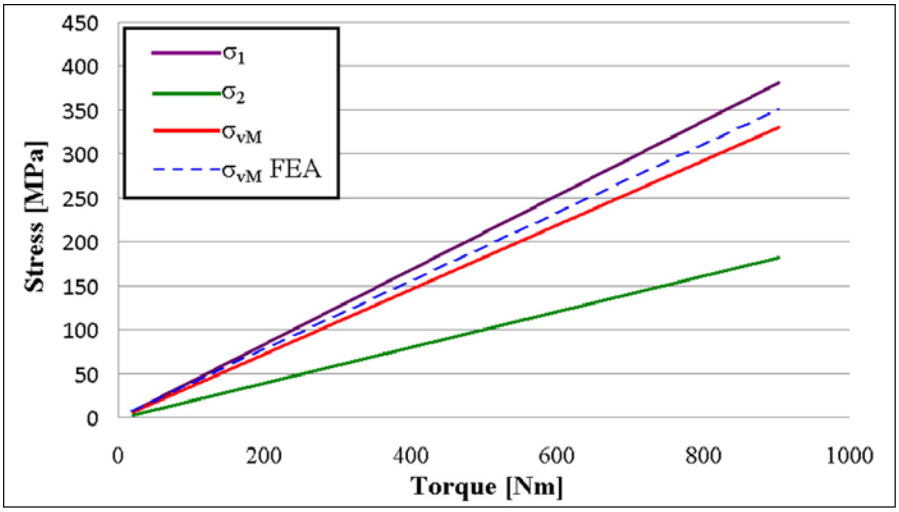


Figure 19 **Stresses evolution on the gear body.**

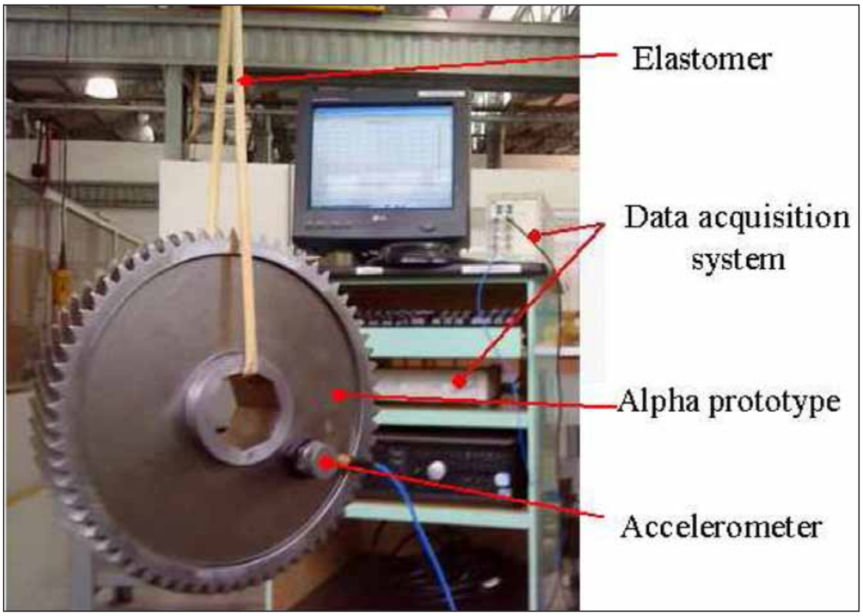


Figure 20 **Natural frequencies and vibration modes validation.**

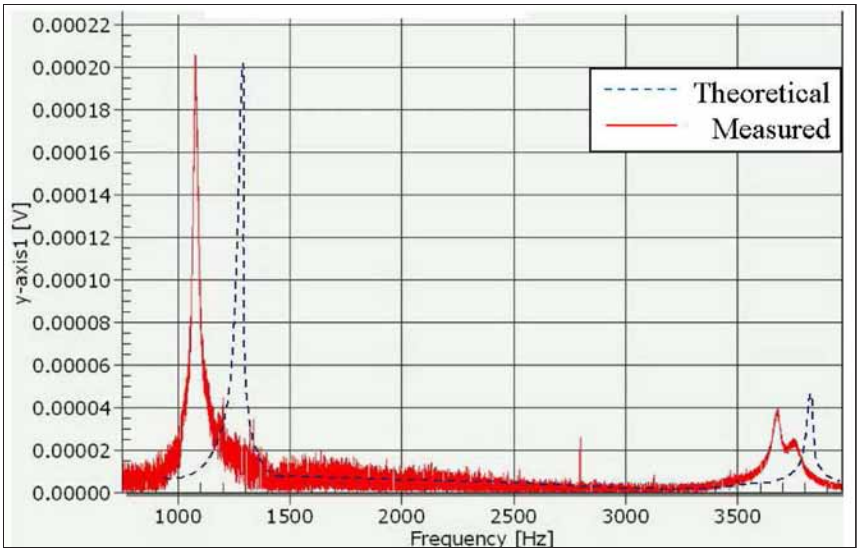


Figure 21 **Natural frequencies.**

state of stress, spoke designs are also possible.

Figure 20 describes the methodology used for NVH investigation. The gear was suspended by an elastomer in order to isolate possible external interference on the vibration results. An accelerometer was placed on the gear body and connected to a data acquisition system through flexible cable. The software provides a wealth of mathematical and graphical functions for quick analyzing and evaluating the measured data.

Several excitations were performed, combined with different accelerometer positions, in order to reach good test accuracy; all excitations lead to similar responses (Fig. 21).

The difference between the theoretical and measured data for the first vibration mode may be considered high for a validation that presents stiffness and mass as the only parameters. However, both cases demonstrate natural frequency levels 17 times higher when compared to the excitation source frequency of 72 Hz. According to Olley (Ref. 13), a system that presents a working condition twice as low as the first natural frequency is considered safe.

Conclusions

- In validating the results of the FEA, the alpha prototype showed good accuracy with the mathematical model. Comparing both models, the difference found on the stress test and natural frequency validation precludes the need for a beta prototype at this stage of the development.
- The concept of the solution presented here allows different material combinations for the inner and outer parts. Therefore, forging heat treatment can be applied locally in order to guarantee the local properties required by the component application. The flexibility introduced by this new manufacturing process leads to a rational application of the raw materials, as well as the available energy matrix, and thus leads to a green design and manufacturing chain.
- The light-weight assembled gear proved to be a high-performance solution. Combining high efficiency with the proper manufacturing process appears to be critical in attaining mandated CO_2 emission reduction. Nevertheless, durability and NVH tests should be done as a next step in order to assure a reliable design.

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Hybrid Gear Preliminary Results — Application of Composites to Dynamic Mechanical Components

Robert F. Handschuh, Gary D. Roberts, Ryan R. Sinnamon, David B. Stringer, Brian D. Dykas and Lee W. Kohlman

Composite spur gears were designed, fabricated and tested at NASA Glenn Research Center. The composite web was bonded only to the inner and outer hexagonal features that were machined from an initially all-metallic aerospace quality spur gear. The hybrid gear was tested against an all-steel gear and against a mating hybrid gear. Initial results indicate that this type of hybrid design may have a dramatic effect on drive system weight without sacrificing strength.

Introduction

The components used in rotorcraft applications are designed such that the minimum weight is attained without sacrificing reliability or safety. Since the drive system is an appreciable percentage of the overall rotorcraft vehicle weight (~10 percent), many approaches have been applied to improve the power to weight ratio of these components.

Past and current government-funded efforts for drive system technology (Refs. 1–2) have used power to weight ratio as the most critical performance metric. Through clever design modifications, configuration arrangements and advanced materials, great progress has been made.

Material properties of composites make them very desirable. Having a very low density and high strength are two important properties that directly impact power to weight ratio. Therefore application of these materials to rotorcraft transmission static and dynamic components can have a drastic effect on overall drive system weight (Refs. 3–4).

The use of composites has been mostly limited in drive systems to housings and shafts (Ref. 5). A number of critical issues were identified and addressed in these applications. These issues include metal—composite attachment, corrosion, strength, etc. The objective of this research reported herein is to expand the use of composite materials to gears and to identify critical issues that may result in this application. Several tests were performed on the composite gears to identify the issues that need to be addressed to allow this technology to be suitable for rotorcraft drive systems.

Composite Material—Metallic Gear Hybrid

Components that are lightweight and high-strength are very important for aerospace drive systems. The composite portion of the hybrid gear was fabricated using a tri-axial braid prepreg (*Ed.'s Note: A fibrous material pre-impregnated with a particular synthetic resin, used in making reinforced plastics*) material made with T700SC 12K carbon fiber tows and a 350°F epoxy matrix material. A 0 ± 60 braid architecture was used so that in-plane stiffness properties would be nearly equal in all directions. Representative composite material properties are compared to that of the typical gear material AISI 9310 (Table 1). Materials with these characteristics have the potential to produce a design with a very high power-to-weight ratio.

There are other reasons for using a hybrid of composite and metallic elements in a gear. For example, gear meshing vibration and noise should benefit from this configuration by altering the acoustic path between the gear mesh generating the noise and the housing that re-radiates the vibration and noise.

In theory it may be possible to produce a hybrid gear at reduced cost, as a portion of the machining required to reduce component weight would be eliminated. But the manufacturing process would have to be altered when making a hybrid gear to attain aerospace precision of the components.

Unfortunately, for all the positive implications of using this technology for dynamic drive system components, there are also some negative aspects. Some of these include:

Attachment to the metallic features to produce a hybrid gear (gear teeth-to-web, web-to-shaft, and bearings-to-shaft)

Heat conduction issues—composite material through thickness conductivity

Operation during extreme thermal events such as loss-of-lubrication. In current drive system component design, the

Table 1 Materials as used in the test gears

	Composite Material	AISI 9310 Gear Steel
Modulus of elasticity (psi)	Tensile - 6.4×10^6 Compression - 6.1×10^6	29×10^6
Poisson's ratio	0.3	0.29
Density (kg/m3)	1800	7861
Thermal conductivity (W/(m°C))	9.4 (T700 fiber – axial)	55
Useful maximum temperature (°C) as gear material	150	175
Coefficient of thermal expansion (micro-m/m)	2 (in-plane)	13.0
	Failure Strain (%) Tension - 1.89 Compression - 0.94	Elongation (%) 15

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gears and shafts are one piece and the bearing inner raceway is typically part of the gear shaft component. Use of a hybrid gear would require attachment in some manner from the composite material web shaft to the gear teeth.

Hybrid Gear Design and Manufacturing

The basic gear design used for this study is summarized (Table 2). These gears have been used in the past for loss-of-lubrication testing and other experimental work within NASA (Refs. 6–8). Gears used were representative of aerospace precision prior to modification to a hybrid configuration.

Turning the gears into a hybrid configuration started with a portion of the web being machined away; the metallic teeth and attachment regions were kept. A hexagonal region was removed; this arrangement was chosen due to the number of teeth (42) on the gear to be modified. By using a six-sided feature, no sharp edge was located near a tooth fillet/root region where the highest bending stress is reached.

Two unique ply stacks were used for this configuration. The first ply stack was larger than the metallic portion that was machined away and had a circular, outside geometry. This created an overlap onto the surface of the outer rim. This overlap created a bonding surface that was critical for proper composite-to-metal adhesion. The second ply stack configuration was cut to match the hexagonal region that was machined away from the metal gear. This tight fit provided a load path from the outer rim to the metallic inner hub.

An epoxy prepreg, in conjunction with a quasi-isotropic braided fabric, was chosen as the composite material. The fabric provides nearly in-plane isotropic properties that react similarly to that of the metallic features.

Prior to molding, any portion of the metallic features that was to come in contact with the composite was sandblasted and surface-primed to promote good adhesion and increase bond-line strength.

A special fixture was then designed and fabricated to locate the gear rim and the gear hub prior to composite material layup. The gear teeth outer rim was located using "measurement-over-pins" (Ref. 9). The inner metallic hub was located via its inner bore.

The first step in the lay-up process was to place the inner metallic hub by locating it around the feature in the mold center. During the assembly process the larger ply stack was created by 12 layers of the prepreg; each layer was rotated 60° in one direction to encourage the best isotropic behavior. With the first ply stack positioned and debulked, a film adhesive was added and the outer metallic ring was placed on top. The second ply stack was created in the void between the two metal features. The same "clocking" procedure was performed on these plies. Another layer of film adhesive was added and the final ply stack was added in the same fashion as the first. The composite material lay-up process is shown (Fig. 1).

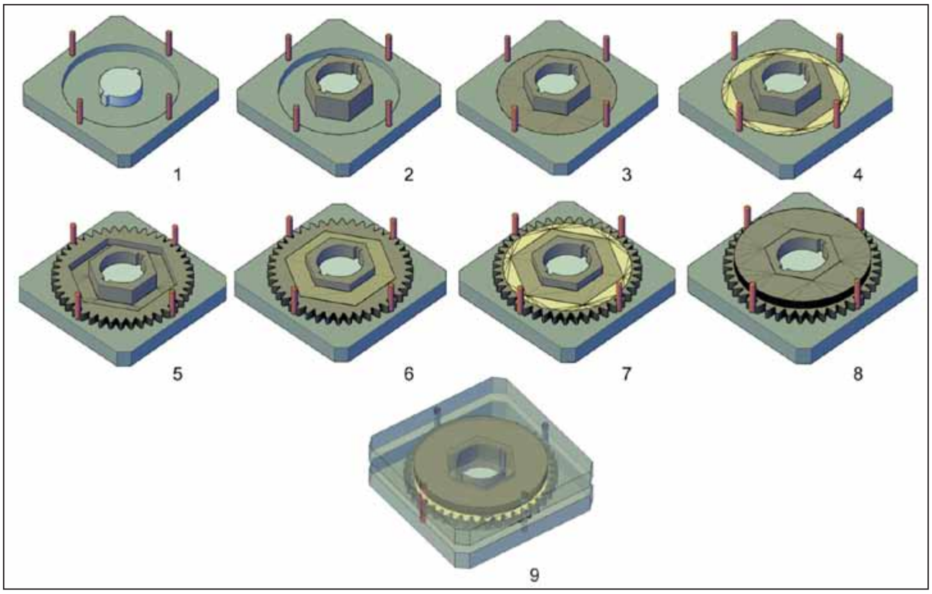

Figure 1 Hybrid gear assembly steps.

Table 2 Basic gear data for components tested

Number of teeth	42
Diametral pitch	12
Circular pitch	0.2618
Whole depth	0.196
Addendum (in.)	0.083
Chordal tooth thickness (in.)	0.1279
Pressure angle (deg)	25
Pitch diameter (in.)	3.5
Outside diameter (in.)	3.667
Root fillet (in.)	0.04 to 0.06
Measurement over pins (in.)	3.6956
Pin diameter (in.)	0.144
Backlash ref. (in.)	0.006
Tip relief (in.)	0.0005 to 0.0007
Weight all-steel gear (lbf)	0.8375
Weight hybrid gear (lbf)	0.7147

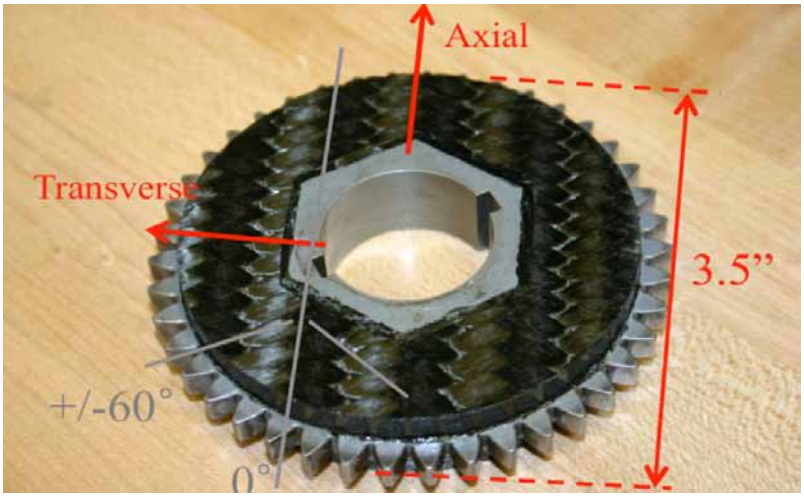

Figure 2 Hybrid gear.

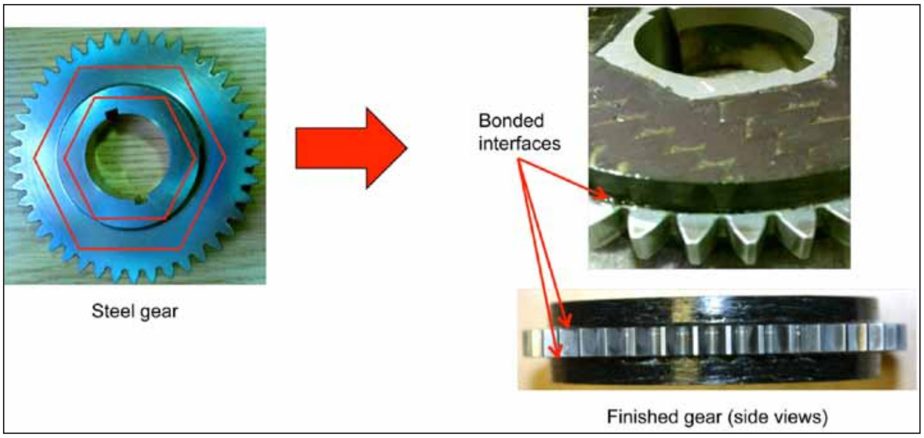

Figure 3 Hybrid gear manufacturing details.

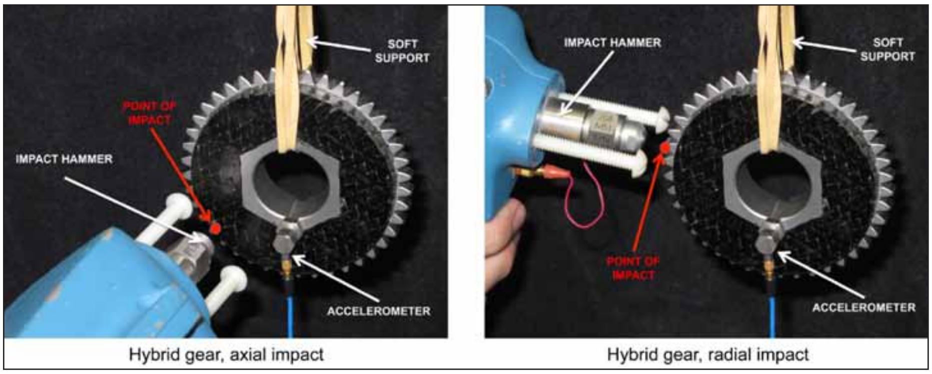

Figure 4. Impact locations shown for hybrid gears (similar for all-steel gear).

This figure shows the assembly procedure used prior to curing the finished part.

The gear mold assembly was placed into a press and subjected to a 100 psi load. The press was then heated at a ramp rate of 4°F-per-minute to a temperature of 250°F. A one-hour dwell was held at 250°F to allow time for the metal and composite to reach a consistent temperature. The temperature was then increased to 350°F using the same ramp rate. The temperature was held at 350°F to fully cure the composite prepreg. After the cure cycle was complete the part was removed from the mold and any excess resin flashing was removed.

The finished hybrid gear is shown (Figs. 2–3). There was no optimization of the arrangement at this point, but the gear produced was still on the order of 20 percent lighter than the all-metal one.

Free/Free Vibration Modes

A series of experiments using a modal impact hammer was conducted on a standard AISI 9310 steel spur gear and a hybrid spur gear specimen. The objective was to experimentally determine the modal properties of the hybrid spur gear and compare them to those of its conventional steel counterpart.

Additionally, a model of the conventional spur gear was generated using finite element software and subsequently compared with experimental data obtained from the test specimen. A further effort is underway to include hybrid material parameters into the model and correlate with modal data acquired from these experiments.

A series of modal experiments was conducted on a baseline steel gear and the hybrid gear to identify natural frequencies and calculate modal damping. An electric impact hammer was used to impact the gears in multiple orientations, with an accelerometer at the tip of hammer providing a trigger for the acquisition of acceleration data from the gear. In all cases, the single accelerometer was placed on the metal hub of the test gear with the accelerometer axis parallel to the rotational axis of the gear. This placement was chosen for convenience because it was accessible on both test specimens. Finite element analysis (FEA) demonstrated that most displacement would be in the axial direction for the modes of interest.

Figure 4 shows the experimental configurations in which the impact experiments were performed. The test gear was suspended on rubber bands hanging on a rubber cord, with this soft support at the twelve o'clock position. The accelerometer was mounted on the metal hub in the six o'clock position. Both the steel gear and the composite gear were subjected to a series of impacts in the radial direction and a series of impacts in the axial direction. Axial impacts were concentrated at approximately the seven o'clock position on the gear, at a radius just inboard of the teeth. For the composite gear, this location was at the edge of the composite portion of the gear. For radial impacts, a tooth near the ten o'clock position was impacted at the tip. A nylon bolt on either side of the tip was used to more effectively set the standoff distance between the tip and the gear, enabling more consistent impacts between tests. A total of 10 impacts were performed in each of these four configurations.

Impact Study

The time-domain data signal was imported into an automated signal analysis and filtering software package. The data was then filtered to isolate the signal associated with the natural frequency corresponding to the first non-rigid body

Table 3 Specimen modal property estimates

	Impact position	Axial		Radial	
	Gear specimen	9310-T42	Hybrid 42	9310-T42	Hybrid 42
Log decrement (δ)	Mean	0.0145	0.1296	0.0261	0.0543
	Standard deviation	0.0004	0.0263	0.0028	0.0122
Damping ratio (ζ)	Mean	0.0023	0.0206	0.0042	0.0086
	Standard deviation	0.0001	0.0042	0.0004	0.0019
General damping constant (c) (lbf-sec/in.)	Mean	0.4843	2.9887	0.8725	1.2520
	Standard deviation	0.0143	0.6053	0.0928	0.2821
Natural frequency (ω_n) (Hz)	9310-T42	7219 ± 43		n=19 data samples	
	Hybrid 42	6236 ± 62		n=14 data samples	

mode. The log decrement was calculated for each filtered data set. From this calculation modal parameters of the hybrid specimen and its steel counterpart were estimated and compared. Figure 5 depicts an example of both a raw and filtered data set.

Additionally, the unfiltered results of each impact were viewed in the frequency domain to compare results within configuration groups (Fig. 6). These figures each show the frequency data from four of the 10 impacts for each configuration.

Using the basic log decrement relationships, modal properties of the gears were estimated (Table 3). As expected, the hybrid gear exhibits higher damping properties than its steel counterpart. This has the potential to reduce transmitted vibration as compared to all-steel gears. Note that the damping properties vary somewhat, depending upon the impact position. The experimentally determined mean and standard deviation of the natural frequency corresponding to the first non-rigid mode are also provided.

FEA Modal Study: Steel Gear

A modal analysis was conducted for the 42-tooth steel gear to verify natural frequencies identified in the experiment and to provide information on the associated mode shapes. The solid model of the gear captures the tooth geometry to a reasonable extent but does not include subtle, geometric features such as tip relief. For the purposes of a modal analysis however, the solid model is a close approximation to the test specimens.

The finite element mesh is a solid mesh consisting of 19,152 linear tetrahedron elements and having a total of 31,002 nodes. The characteristic element size is approximately 0.10 in. The gear specimens are made from AISI 9310 steel, which is represented in the analysis as a linear isotropic material with Young's modulus of 29×10^6 psi (2.0×10^{11} Pa), Poisson's ratio of 0.29, and mass density of 0.284 lbm/in^3 (7,861 kg/m^3). The anal-

Table 4 All-steel gear frequencies for modes 7–12

Mode number	Frequency, Hz
7	7187
8	7270
9	12304
10	12853
11	12924
12	15237

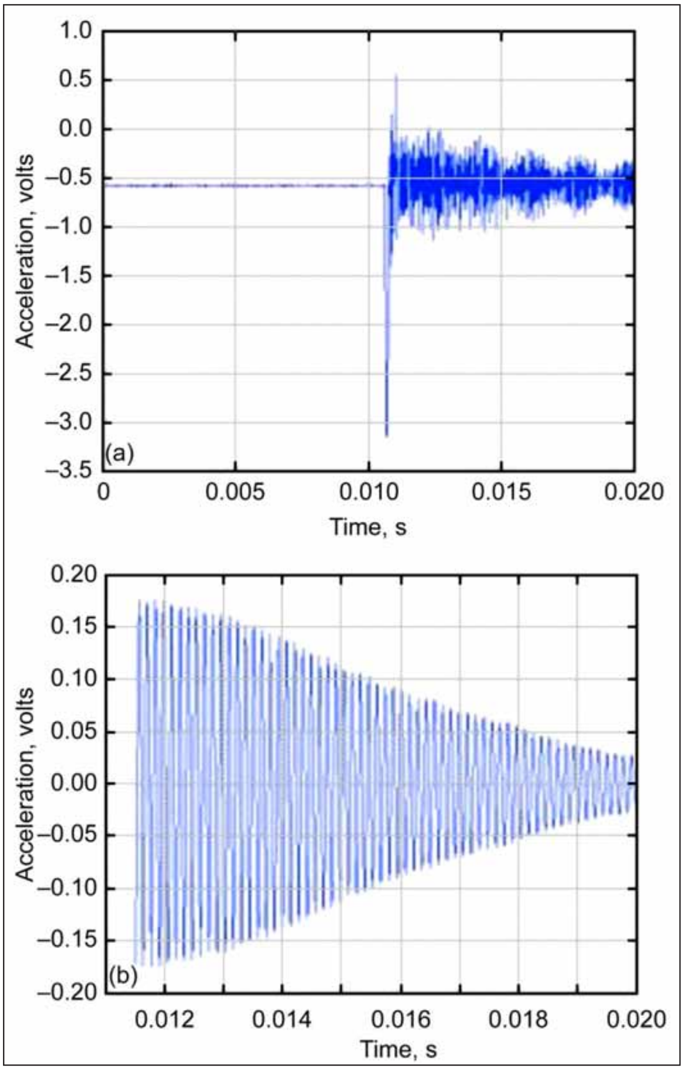

Figure 5 Sample, raw data raw: (a) time domain signal; (b) filtered data.

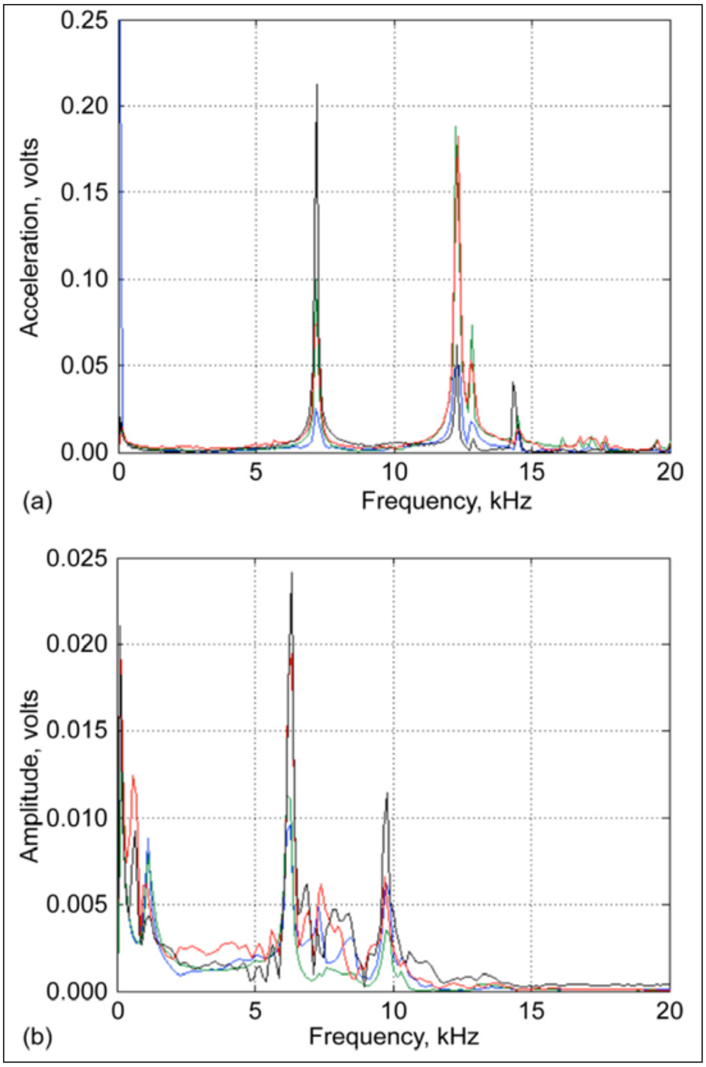

Figure 6 Frequency domain results—axial location impacts: (a) all-steel gear; (b) hybrid gear.

ysis is conducted on the unconstrained gear (free-free).

The first six modes identified in the analysis are rigid body translations and rigid body rotations; one mode is associated with each translational- or rotational-degree-of- freedom. Therefore, starting at mode 7 to 12, the frequencies associated with these modes are shown (Table 4); the mode shape for mode 7 is shown (Fig. 7). The mode shapes found illustrated that the modal displacements are primarily in the axial direction for the modes of interest, guiding accelerometer placement.

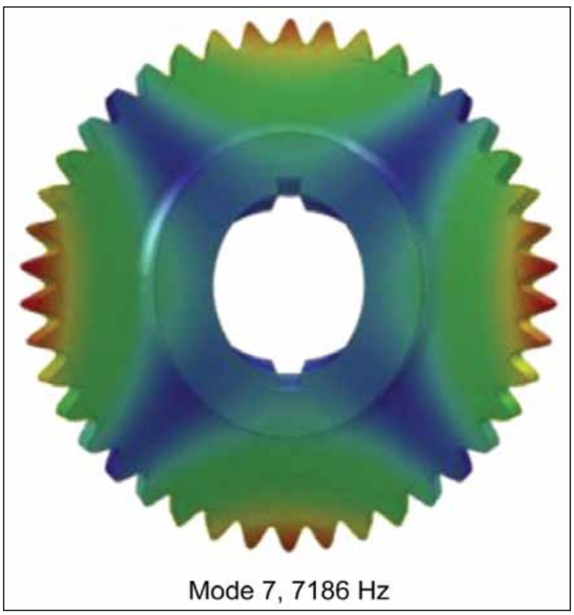

Figure 7 **All-metallic gear mode shape.**

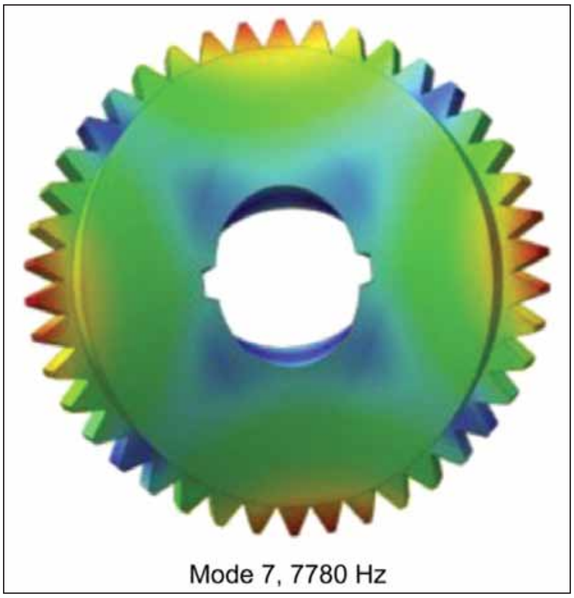

Figure 8 **Hybrid gear mode shape.**

FEA Modal Study: Hybrid Gear

A modal analysis was also conducted for the 42-tooth hybrid gear to verify natural frequencies identified in the experiment and to determine the associated mode shapes. As in the case of the steel gear, the tooth geometry is a reasonable representation but does not include all subtle features of the teeth. The deviation of the model geometry from the physical specimens is expected to have a negligible effect on the modal results.

The finite element mesh is a solid mesh consisting of 25,672 linear tetrahedron elements and having a total of 39,166 nodes. The characteristic element size is approximately 0.10 in. The composite portion of the gear is constructed of prepreg triaxial-braided carbon fiber with alternating orientation between adjacent layers, and resin. Due to the anisotropic nature of the material, consideration was given to modeling each individual ply with orthotropic properties. However, due to the large number of plies, it was determined that the composite portion of the gear could be modeled using isotropic properties.

The hub and ring portions of the gear were modeled using properties of AISI 9310 steel, which is represented in the analysis as a linear isotropic material with Young's modulus of 29×10^6 psi (2.0×10^{11} Pa), Poisson's ratio of 0.29 and mass density of 0.284 lbm/in^3 (7,861 kg/m^3). The composite portion of the gear is modeled as a linear isotropic material with Young's modulus of 6.4×10^6 psi (4.4×10^{10} Pa), Poisson's ratio of 0.30 and mass density of 0.055 lbm/in^3 (1,522 kg/m^3). The analysis is conducted on the unconstrained gear (free-free); the components are treated as welded together (node-to-node constraint at the interfaces). It is notable that the calculated bulk modulus properties for the composite are not linear, as the tensile elastic modulus of 6.4×10^6 psi compares to a compressive elastic modulus of 6.1×10^6 psi when using bulk properties—a difference of 5 percent. Based on the relatively minor difference and the square-root- dependence-of-frequency on stiffness, the bulk tensile modulus was used in this simplified case. Based on these small differences it was decided to use the bulk properties to simplify the analysis.

Modes 7–12, identified in the analysis, are shown (Table 5). The first six modes are related to the rigid body translations and rigid body rotations. The mode shape for mode 7 is shown (Fig. 8).

Comparison of FEA to Experiment: Natural Frequencies

A comparison between the FE output and the experimental results was conducted in the first step of validating the FEA model. Figure 9 depicts a comparison between the measured frequencies of the steel spur gear specimen and the predicted frequencies of the FE model; an exact frequency match falls directly on the diagonal. The result shows good agreement between model predictions and the experimental results.

For the hybrid gear, however, modes identified in the experiment generally shifted to lower frequencies, whereas the *model* predicted a shift to higher frequencies. In the model, this is an expected result since the composite has a higher ratio of elastic-modulus-to-density than steel, and the area moment of inertia is considerably larger for the cross sec-

Table 5 **Hybrid gear finite element vibration modes and frequencies**

Mode number	Frequency, Hz
7	7,780
8	7,913
9	13,745
10	14,592
11	15,725
12	16,483

tion of the hybrid gear. However, the FE model assumes adjacent surfaces in the components are bonded together.

Based on actual construction methods the interfaces may have a lower effective stiffness such that the experiment would produce modes at frequencies lower than predicted. Changes to the interfaces can be made in the model to bring the natural frequencies within the ranges of the experiment, but this may not provide additional physical insight to the properties of the interface. However, such an approach may be employed to improve the model for subsequent stress analysis.

Unlike the steel gear, a comparison between the hybrid gear finite element results and the experimental results did not produce similar mode frequencies as the all steel gear. From the experiments, the hybrid gear exhibits two significant peaks: approximately 6,270 and 9,743 Hz. The modes found from FEA did not compare well to the experiments. It is expected that further model development will reduce some of these inconsistencies with the experimental data.

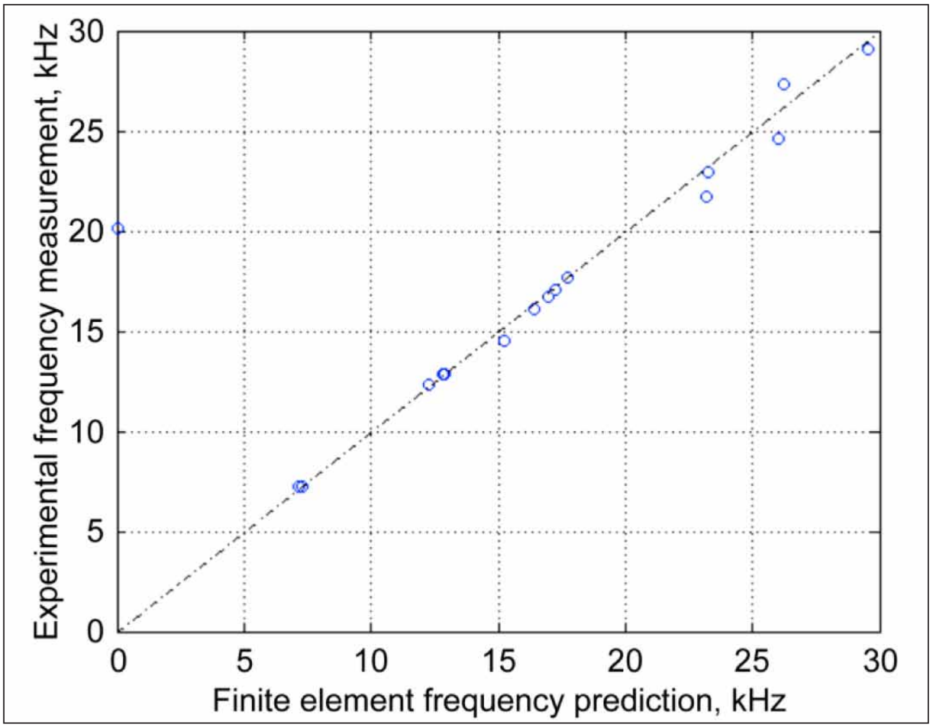

Figure 9 Comparison of experimental and finite element natural frequencies.

Dynamic Testing

Two types of dynamic tests were conducted to determine if gears could be considered as possible composite candidates in future rotorcraft drive systems. The first set of tests measured vibration and noise at four speeds and four levels of torque. The second test was an operational endurance test.

The dynamic tests for noise and vibration were conducted with four different gear arrangements, at four different rotational speeds, and four different levels of load. The gears were installed in the test rig in the following configurations: (1) all-steel both sides; (2) hybrid gear left side; all-steel gear right side; (3) all-steel gear left side, hybrid gear right side; and (4) hybrid gear, both sides. When the facility is operating, the left- side gear is the driving gear and the right-side is the driven gear. All vibration measurements were made on the driven side support bearing housing (Fig. 10).

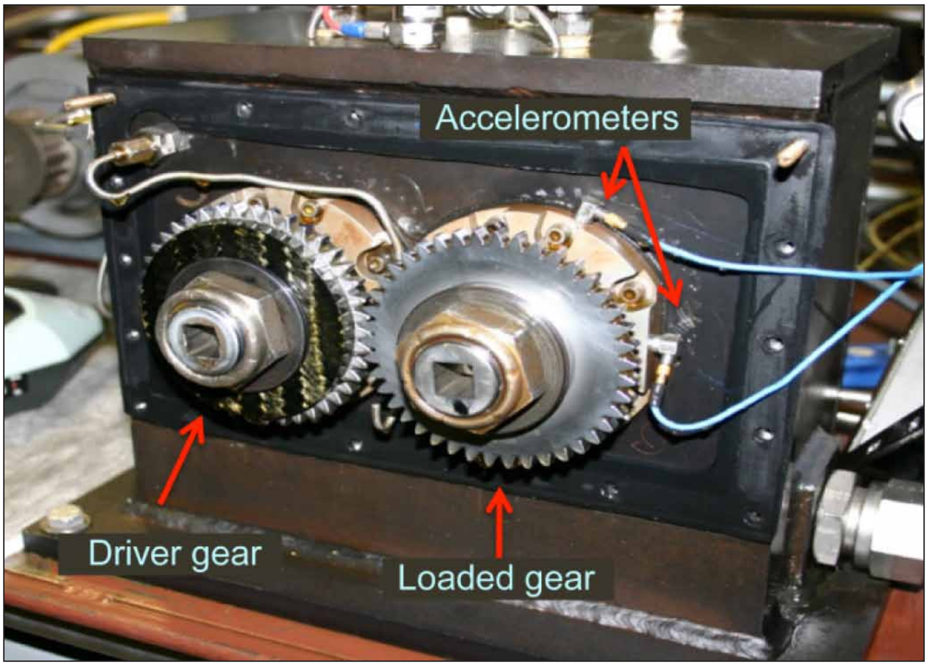

Figure 10 Test facility shown with cover removed.

For the four configurations mentioned above tests were run at 2,500, 5,000, 7,500 and 10,000 rpm and at 133, 238, 448 and 658 in.*lb torque. The vibration level in "gs" is shown (Fig. 11). The noise level was measured via a hand-held sound level meter at a distance of one in. from the test gearbox cover. The sound level was recorded on an A-weighted scale. The results of the sound level data are shown (Fig. 12). The four test rig configurations are shown at four speed and load conditions.

From the vibration data shown (Fig. 11) the hybrid gear generally reduced the overall vibration level with mixed- or all-hybrid configurations. For the noise data (Fig. 12) the mixed-hybrid gear arrangement and all hybrid arrangement produced less noise for the two higher speed conditions.

Although some vibration and noise reduction were seen with the hybrid gears, the results were not as dramatic as expected. There are several reasons why noise and vibration had only modest reduction. First, the manufacturing process used to fabricate the hybrid gear did not result in aerospace-quality accuracy. The composite curing actually reduced the backlash of the components due to stretching of the metal outside rim. The backlash also was not consistent around the gear. Both of these "manufacturing errors" could be corrected by post-composite-attachment, final grinding of the gear teeth. The noise data is related to how well the teeth mesh during operation. In effect, the noise measured at a small distance from the cover is a combination of airborne and structure-borne from the meshing gear teeth being reradiated from the test facility cover.

Long-Term Testing

An endurance test was conducted on the hybrid gears in NASA's spur gear test facility. The hybrid gear arrangement was run for over 300×10^6 cycles (gear revolutions) at 10,000 rpm, 250 psi torque load (553 in.*lb torque) with an oil inlet temperature of ~120°F. The hybrid gears operated without any problem during this extended test period. The gears did not show any signs of fatigue during post-test inspection.

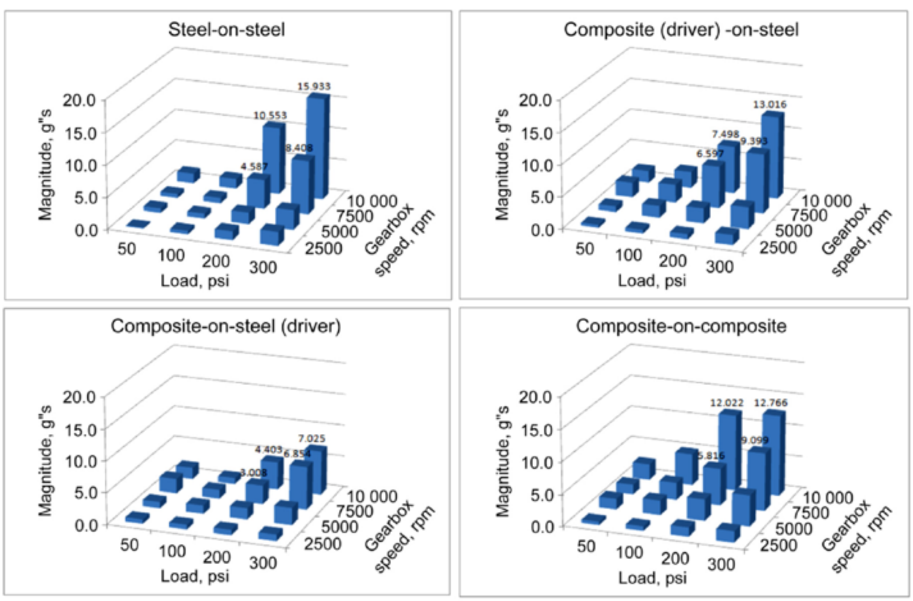

Figure 11 Vibration data taken for four speeds and four load levels.

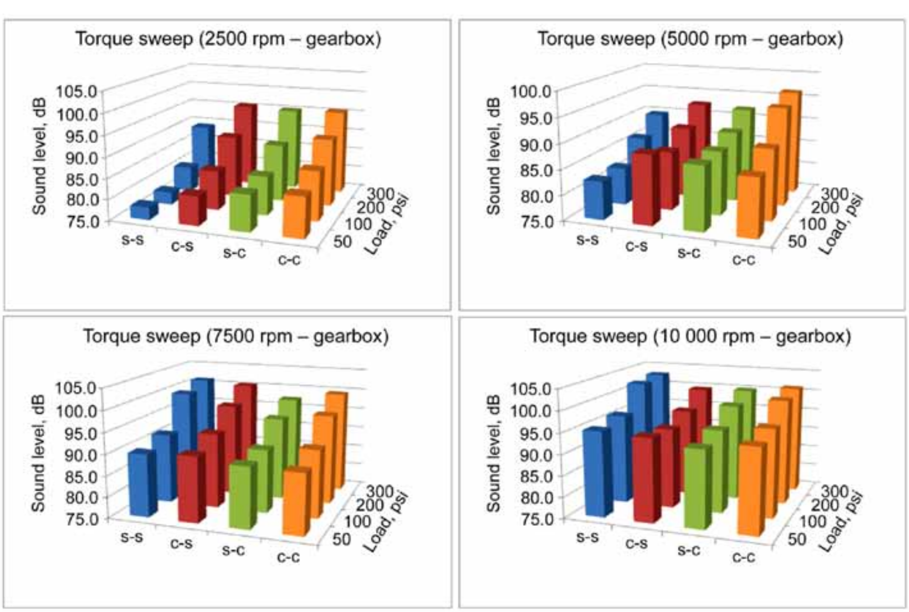

Figure 12 Sound level measurements made for the four different test arrangements, made at four different speed and load conditions.

Conclusions

Based on the results attained in this study the following conclusions can be made:

Hybrid gear arrangement shows promise, as the gears were operated for an extended period of time at a relatively high speed and torque.

Power-to-weight improvement could be possible, as steel webs could be replaced by lightweight, composite material. For the gears tested, a ~20 percent decrease in weight was realized without optimization of the components.

Reduced noise and vibration would be expected, when manufacturing processing produces aerospace quality gears; the hybrid gears tested show only modest improvements in vibration and noise. More significant improvements are possible with improved manufacturing processes and possible material tailoring through the composite structure.

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Ryan Sinnamon is a graduate student studying mechanical engineering at Wright State University (WSU) in Dayton, Ohio, where he also received his bachelor of science degree in mechanical engineering. He is a member of the National Engineering Honor Society/Tau Beta Pi. Sinnamon's previous professional experience includes working on advanced composite mechanical components at NASA Glenn. Since 2012, he has started a master's thesis researching hybrid fuel cell/gas turbine power systems under Dr. Rory Roberts, WSU.

Lieutenant Colonel Blake Stringer, PhD.,

is an active-duty army officer with 19 years of military experience as an army aviator and research engineer. He has a bachelor of science degree in aerospace engineering from the U.S. Military, a master of science in aerospace engineering from Georgia Tech University, and a doctorate in mechanical and aerospace engineering from the University of Virginia. Colonel Blake has performed fundamental research on aerospace mechanical components, focusing on gear fatigue, health monitoring and the rotor-dynamic modeling of transmission systems. He has also served as instructor and assistant professor on the engineering faculty at West Point. As a military aviator, he has over 1,000 flight hours of rotary-wing and fixed-wing experience, and is rated in the UH-1 and CH-7D helicopters and C-12 airplane. Colonel Blake also holds a FAA commercial airman's certificate.

Brian Dykas is presently a research engineer with the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, Maryland. Dykas has a PhD in mechanical engineering from Case Western Reserve University in Cleveland, Ohio and over 10 years of research experience in tribology of propulsion mechanical components.

Dr. Lee W. Kohlman

has a bachelor of science degree (physics) and a PhD (engineering) from the University of Akron, Akron, Ohio. He has been at NASA for two years, following two years under NASA's GSRP program. His primary area of research is composite materials, including testing and failure mechanics. Kohlman's more recent research is focused on composite and hybrid structure for rotorcraft drive systems. In addition, he is working on material concepts for thin and adaptive fan blades, ballistic penetration of cryogenic water ice, and electrospun, thermoplastic nanofiber deposition for composite toughening.

Stanley Miles Sitta

1930-2013

Stanley 'Stan the Man' Sitta passed away peacefully April 7, 2013 at the age of 82 in Bradenton, Florida. He was born May 22, 1930 in Chicago, Illinois to Czech immigrants Stanley Sitta and Camille Blaha Sitta. He resided for 40 years in Wheaton, Illinois before moving to Bradenton, Florida 2½ years ago.

Sitta graduated from Morton High school and Morton Jr. College in Cicero, Illinois. He received a bachelor's degree from Loyola University in biology and chemistry and graduated from Harvard's 52nd AMP Business School.

Sitta began his business career at U.S. Rubber. He moved to Marion, Virginia in 1958, joining Brunswick's defense division and eventually becoming the plant manager. After a transfer to Muskegon, Michigan, he brought his family back to the Chicago area. Sitta became president of the Foote-Jones Gear Division of Dresser Industries in Downers Grove and Chicago, Illinois.

He was involved with Illinois Benedictine University and was a patron of St. Michael's Catholic Church. He served as president of the Downers Grove Chamber of Commerce and national Chairman of the American Gear Manufacturers Association. Sitta is survived by his loving wife of 61½ years, Zdenka (Vrla) Sitta, four children: Ellen (John) Hoefer of Kansas City, KS, Janet (Mike) Schraer of Bradenton, FL, Stanley J. (Donna) of VA Beach, VA, and James M. (Liz) of St. Charles, Illinois., ten grandchildren and four great grandchildren, nieces Jenny Smith, Karyn (Chuck) Fischer, and Nina (Larry) Biddinger. Sitta has one sibling, Camille (Yarmil) Pekarek of Sun City, Arizona.

Sitta was greatly influenced by his father, who taught him an appreciation of nature, particularly for birds, plants and fish. He was an avid collector of coins, stamps, postcards, model trains and antique toys. He enjoyed hunting and traveled extensively. Some of his favorite times were spent enjoying the woods of Marion, Virginia and the lakes of Montello, Wisconsin.

The memorial service was held at Williams-Kampp Funeral Home, 430 E. Roosevelt Rd., Wheaton, Illinois on Saturday April 13. Donations can be made in his name to St. Michael's Catholic Church in Wheaton, Illinois or can be sent to the National Parkinson Foundation.

Wenzel America

PARTNERS WITH LIEBHERR GEAR TECHNOLOGY

Wenzel America proudly announces their new partnership with Liebherr Gear Technology, Inc. Liebherr will exclusively represent the Wenzel GearTec product line in the United States and Canada. Liebherr Gear Technology, Inc. is based in Saline, MI and manufactures, sells, and supports a wide range of gear hobbing, shaping and grinding machines. The Saline, MI facility is also home of Liebherr Automation Systems, Co., a global supplier and integrator of automation for advanced manufacturing systems.

The Wenzel GearTec product line includes a range of granite, air-bearing horizontal gear testing machines named WGT and can also offer 4-axis gear measuring technology on any Wenzel CMM frame to give customers gear and traditional CMM measurement on the same platform.

Andy Woodward, president of Wenzel America, summed up the new relationship: "We are very excited at the prospect of working with Liebherr. Their knowledge of the gear manufacturing customer base in North America is second to none and we are certain that they will be able to introduce our gear testing product line to many more prospective customers in our market. Also, joining our forces will produce an unrivalled customer support team going forward. This agreement represents the first of many between the two companies around the world."

Peter Wiedemann, president of Liebherr Gear Technology, Inc., added: "We have a history of providing our customers with turnkey solutions in gear production and inspection. The Wenzel GearTec product line enables us to continue to offer our customers the best products and services available."

Wenzel Group has been manufacturing metrology equipment for over 45 years and celebrates their 10th anniversary of supplying gear testing systems to some of the world's most

prestigious gear manufacturers, including some very large machines to Liebherr. Wenzel remains a family owned company and prides itself on its long-term relationships with its customers.

Since 1949, the Liebherr Group has been a family-owned business. Today, the entire organization consists of over 39,000 employees in more than 130 companies across all continents.

Gleason Cutting Tools

RECOGNIZED AS JOHN DEERE PARTNER-LEVEL SUPPLIER

Gleason Corporation recently announced that its Gleason Cutting Tools Corporation facility in Rockford, Illinois has earned Partner-level status in the John Deere Achieving Excellence Program. This status is Deere & Company's highest supplier rating. Suppliers who participate in Deere & Company's Achieving Excellence program are evaluated annually in several key performance categories including quality, cost management, delivery, technical support and wavelength, which is a measure of responsiveness. John Deere created the program in 1991 to provide a supplier evaluation and feedback process that promotes continuous improvement. Robert P. Phillips, senior vice president, Tooling Products Group and Gleason Cutting Tools Corporation said "Gleason Cutting Tools Corporation is proud to be a supplier to John Deere, and are honored to have our performance recognized at such a high level." Partner-level status was awarded to Gleason Cutting Tools Corporation for all cutting tool products and services provided by Gleason to the John Deere operations in Waterloo and Des Moines, Iowa.

Liebherr Gear Technology

APPOINTS SERVICE MANAGER FOR NORTH AMERICA

Liebherr Gear Technology, Inc., Saline, Michigan, has appointed **Robert (Bob) Jelic** service manager overseeing North American operations for machine tool and automation systems, announced Peter Wiedemann, president, Liebherr Gear Technology, Inc. and Liebherr Automation Systems, Co. Jelic is a 1996 graduate of Michigan Technological University and since then has been designing, building and installing automated manufacturing systems. For the last seven years, he has been employed by Liebherr Automation Systems Co., a subsidiary of Liebherr Gear Technology in Saline, MI. "During his time at Liebherr, Bob has designed gantry and automation systems, managed their installation, and supervised complete projects from concept to implementation," said Wiedemann. "His customer interaction and site management has provided Liebherr with a level of customer satisfaction that has resulted in success and growth.Bob now brings his practical knowledge and desire for excellence to the service and installation team to continue to insure the quality, timing, and customer satisfaction that our customers deserve and expect from all Liebherr installations," Wiedemann added.

Drake Manufacturing

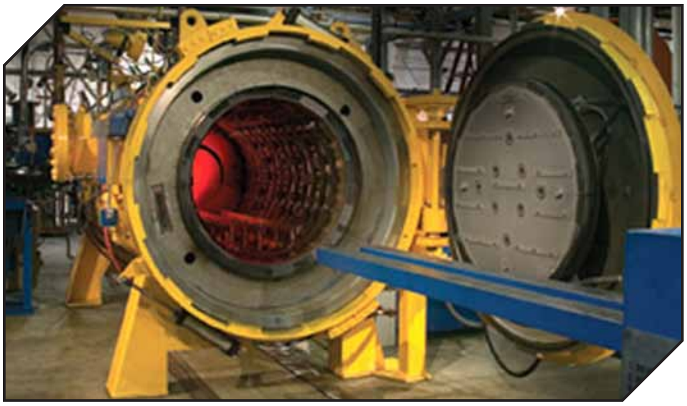
WELCOMES KENNETH LONSBERRY

Drake Manufacturing Services Co., a Warren, Ohio, precision machine tool builder, has recently hired **Kenneth Lonsberry** as vice president operations. Lonsberry will be responsible for managing and driving improvements in engineering; materials management (purchasing and inventory control); manufacturing and assembly; and the new start-up, warranty, and service group. He comes to Drake with 14 years of operations experience and 16 years in engineering management, design and product support. He is very adept at working on the manufacturing floor and has broad knowledge of manufacturing processes. His experience includes the role of vice president of operations for Horsburgh & Scott, in Cleveland, a maker of large gears and gear drive systems. At Horsburgh, He was in several positions of increasing responsibility ultimately accountable for the entire operating structure of the organization of 135 individuals, including procurement, quality, product engineering, manufacturing engineering and all facets of the manufacturing organization. Before Horsburgh, Lonsberry had his own business, was manager of engineering and manager of operations at Parker Hannifin (Youngstown), and held other engineering and engineering management positions in Michigan and Ohio. He has a B.S. in Manufacturing Engineering, holds two patents, and is well versed in the Lean and Six Sigma tool kits.

Solar Atmospheres

DONATES VACUUM FURNACE TO ASM

In commemoration of ASM International's 100th anniversary, Solar Atmospheres Inc. is donating a vacuum furnace to ASM for use in its Teaching Lab at their headquarters in Materials Park, Ohio. William R. Jones, CEO of Solar Atmospheres, Inc. states, "This gift, valued at $250,000, is being provided to educate future technical personnel on the latest design and capabilities of the modern vacuum furnace." This new furnace is expected to ship in June 2013 and be operational in July.



The furnace is being built by Solar Manufacturing, a Solar Atmospheres company. Currently under construction is a Model HFL-2018-IQ horizontal, internal quenching furnace with a hot zone that measures 12" wide × 12" high × 18" deep and is capable of operation to 2,400°F. The hearth will accept a load of 250 pounds. The hot zone insulation package will consist of a heavy graphite foil hot face backed by 4 layers of ½» inch graphite felt, all supported in a stainless steel ring. The elements will be curved solid machined graphite.

The vacuum system will incorporate an Alcatel mechanical pump, a Varian 6» VHS-6 diffusion pump and an Alcatel holding pump to allow the furnace to operate in the 10^{-6} Torr range. Gas quenching will be via an internal 5 HP blower/heat exchanger combination that recirculates the cooling gas through fixed gas nozzles located throughout the hot zone. Instrumentation will include a Honeywell DCP100 programmer/controller, a Eurotherm 6100 temperature/vacuum recorder, a Honeywell UDC2500 overtemperature controller and an Allen Bradley Micrologix 1500 programmable logic controller.

Featuring state-of-the-art vacuum furnace technology, this furnace will allow students to perform a wide variety of tests and experiments relating to vacuum heat treating, brazing and sintering processes. It will also give them a hands-on understanding of the value and advantages of using vacuum over other heat treating equipment.

Burkhardt+Weber

START SALES OPERATIONS IN UNITED STATES

Romi Machine Tools Ltd. is pleased to announce the opening of the North American office of Burkhardt+Weber Fertigungssysteme GmbH. The combination of Romi and Burkhardt+Weber will strengthen both companies to efficiently serve customers in the North American market. The mutual office will be opened in February 2013. The Premium Quality Machining Centers and Special Machines, made in germany, deliver premium performance and are serving all industries that need accurately machined parts weighting up to 44 tons. These industries include power generation, gearbox manufacturing, diesel engine technology, mining, machine tools, alternative energy, paper processing, wood/plastics, industrial pumps and more. Burkhardt+Weber manufactures three basic lines of large CNC Machine Tools: The BW MCX - Series — for reliable production, speed, accuracy and precision from a strong roller bearing design. The BW MCR - Series — for the extreme demanding applications, combining high capacity roughing with longevity and precision from a superior slideway design.The BW µ - Series — for ultra-precision machining with repetitive micron accuracy.

SDP/SI

DONATE COMPONENTS TO TEAM SPACEPRIDE

Stock Drive Products/Sterling Instrument (SDP/SI) recently announced the donation of components to Team SpacePRIDE for the NASA Lunar Rover Challenge 2013, enabling the team to better compete by improving robotic and automation technology for space applications. Their space rover will traverse up to 80,000 sq. meters, avoid obstacles, navigate, and locate different samples autonomously. The rovers' drive trains consist of two wheel pods, each having two sets of XL pulleys and belts which are powered by a 100W DC gearmotor. The motors each drive a 90-degree miter gear arrangement, which allows them to sit inside each wheel pod. The belt drive expansion allows more reduction capability and shock absorption. Members of Team SpacePRIDE will compete in June at Worcester Polytechnic Institute. Details of the competition can be found at *www.spacepride.com*.

May 22–23—AGMA Marketing and Forecasting Conference 2013. Crowne Plaza, Chicago O'Hare Hotel and Conference Center, Rosemont, Illinois. What's going on in the gear market? What is happening in the end user market that will affect next year? How can you better prepare your company for the ups and downs of the current economic climate? The Marketing and Forecasting Conference will present a comprehensive report on the U.S. Economic Conditions, Industry Conditions for Gears, Gear Market Bookings and Gear Market Shipments. This will be broken down into a series of end user markets including total gears, industrial machinery gears, construction machinery gears, farm machinery gears, power transmission equipment, mining, ship and offshore, railroad and aerospace gears. IHS Global Insight has developed news reports that will forecast these various markets. This AGMA member-only event includes a reception and dinner for networking opportunities. For more information, visit *www.agma.org*.

June 3–6—HxGN Live. Las Vegas. Formerly known as Hexagon 2013, HxGN Live is the international conference from Hexagon Metrology that offers an opportunity to preview technologies, attend presentations and participate in targeted tracks/breakout sessions. This year's theme, "Great Stories Start Here," empowers attendees to do great things that have a global impact. The metrology track will offer opportunities to hear experts discuss industry trends and challenges on 3-D scanning, automation/robotics, emerging metrology techniques, metrology in the supply chain, temperature compensation and more. Other tracks include geosystems; process, power and marine; and security, government and infrastructure. For registration information, visit *www.hexagonmetrology.com*.

June 3–6—Gleason Cutting Tools Gear School. Loves Park, IL Fundamentals: This comprehensive 3-1/2 day program is a blend of shop time and classroom study. A coordinated series of lectures is presented by engineering, production, inspection and sales staff members averaging 27 years' experience. It's an ideal course for those individuals seeking to understand the fundamentals of involute gear geometry, nomenclature, manufacturing and inspection. Training groups are kept small so that individual concerns may be fully addressed. Students are welcome to bring sample gear prints and inspection charts for discussion and interpretation. Shop tours and demonstrations are conducted to visually enhance the understanding of classroom discussions. For more information: Phone: (815) 639-4201 or *GCTC@gleason.com*.

June 3–June 7—ASME Turbo Expo 2013. San Antonio Convention Center, San Antonio, Texas. Connect and reconnect with turbomachinery colleagues from around the world at the ASME's premier turbine technical conference and exposition. The scope of the conference has now expanded to include fans and blowers, steam and wind turbines, solar energy, and supercritical CO_2 power cycles. Highlights include a five-day technical conference, organized to meet the needs of growing participation; a three-day exposition of gas turbine products and services supported by leading companies in the industry; and a keynote session featuring prominent industry leaders. The registration package includes proceedings, access to all activities and abundant networking opportunities, including receptions and lunch as well as in-depth training workshops providing fundamental study on selected subjects. For more information, visit *www.asmeconferences.org*.

June 10–14—NAMRC 41. Monona Terrace Community and Convention Center, Madison, Wisconsin. The North American Manufacturing Research Conference is sponsored by the North American Manufacturing Institution of the Society of Manufacturing Engineers (NAMRI/SME). It is co-located with the 8th Annual ASME International Manufacturing Science and Engineering Conference. The conference schedule will include keynote presentations, technical presentations, expert panels, student poster presentations, an early career forum, university lab tours and more. The purpose is to disseminate the most recent manufacturing research and development through both technical presentations and panel sessions. For more information, visit *www.sme.org*.

June 24–27—PowderMet2013. Sheraton, Chicago. More than 200 worldwide industry experts will present the latest in powder metallurgy and particulate materials. 100 booths will showcase leading suppliers of powder metallurgy and particulate materials processing equipment, powders and products. The event will feature special guest speakers, award luncheons and a main social event where you can relax, network and talk powder metal business. The MPIF/APMI sponsor this conference and exhibition aimed at powder metallurgy and particulate materials engineers, technical staff, and sales and management personnel. Held in late spring, and located each year in a different first-tier city in North America, the conference presents the latest industry technical advances through technical papers and presentations, posters, special interest programs, and general sessions. For more information, visit *www.mpif.org*.

July 7–11—ICME 2013. Salt Lake Marriott Downtown at City Creek, Salt Lake City, Utah. Integrated Computational Materials Engineering (ICME) has received international attention due to its potential to shorten product and process development time, while lowering cost and improving outcome. Building on the success of the 2011 conference, the 2nd World Congress on ICME will bring together researchers, educators and engineers to examine topics relevant to the global advancement of ICME as an engineering discipline. This conference will provide a forum for presentations and discussions on the ICME approach, challenges of integrating models, data management issues, engineering education and set the stage for further growth in the worldwide application of ICME. The event is sponsored by Ford Motor Company, University of Michigan, Carnegie Mellon University, NIST and Fraunhofer Institute for Mechanics of Materials. For more information, visit *www.tms.org*.

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4

What is your primary JOB FUNCTION (check ONLY one)

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

____

5

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

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

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Hardness Testing

Specifying the hardness of finished gears is just one way that gear engineers can ensure they are made of the right material and properly heat treated. However, a wide variety of hardness testing methods exists. Here is a brief introduction to those most commonly used in gear manufacturing.

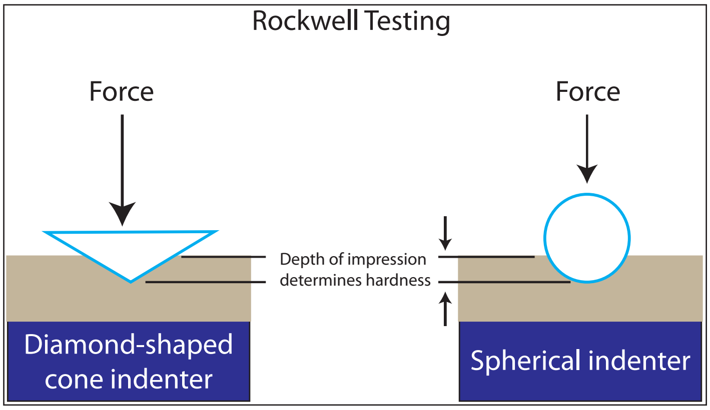
Rockwell. The Rockwell hardness test was invented in 1919 by Stanley P. Rockwell, who developed his method as a nondestructive way to quickly, repeatably and reliably test the hardness of the bearing races made by his company.

Like all of the other major testing methods, the Rockwell test determines hardness based on the results of an indentation test, wherein a hard material is pressed into the test piece under a specified load.

Rockwell testing is done in two phases. First, a minor load is applied. This reduces the effects of surface asperities and establishes a zero reference point. Then, a major load is applied for a set time period, and released, leaving an indentation in the test piece. The testing device determines hardness based on the depth of the penetration.

There are many variables involved in Rockwell testing. The indenter can be either a diamond cone or a steel ball, and steel balls of varying diameters can be used, depending on the material to be tested. Also, different materials require different minor and major forces to be applied, resulting in 30 different Rockwell scales (named A, B, C, etc.). The scale most widely used for gearing is the Rockwell C scale, which covers most steels. In addition, there is a Rockwell superficial test, which uses light loads and which is meant for thin or easily damaged surfaces.

ASTM E18 and ISO 6508 cover Rockwell hardness testing for metals. According to ASTM E18, Rockwell C hardness should be specified using the designation HRC along with the hardness number. The "H" stands for hardness, the "R" for Rockwell, and the "C" corresponds to the appropriate hardness scale. Thus, HRC 55 might be the Rockwell C hardness of 4140 steel.



Brinell. Swedish engineer Johan August Brinell invented the Brinell hardness test in 1900. It is often used on large parts, particularly castings or forgings whose grain structure is too coarse for testing via the Rockwell or Vickers methods.

With Brinell testing, a spherical indenter is pressed into the test piece and held for a specified time under a controlled force. The hardness of the piece is calculated based on the surface area of the indentation, which must be measured optically, either by microscope or by an optical device integrated with the tester.

Brinell testing is very much dependent upon the specific force applied as well as the material used for the indenter. Today, Brinell testing is typically done using 3,000 kgf and a 10 mm tungsten carbide ball.

ASTM E10 and ISO 6506 are the relevant standards for Brinell testing of metals. According to ASTM E10, Brinell hardness should be specified using the designation HBW, where "H" stands for hardness, "B" stands for Brinell, and "W" stands for tungsten carbide, the material used for the indenter. In addition, the size of the ball and the force applied should be included with the specification. Thus, an HBW 10/3000 hardness of 187 would indicate a Brinell hardness of 187 was achieved using a 10 mm tungsten carbide ball, applied at 3,000 kgf. Often materials suppliers and manufacturers leave out this important information, even though Brinell hardness numbers obtained using different forces or indenter materials are not comparable.

Vickers. The Vickers hardness test was developed in England in 1921 as an easier alternative to Brinell testing. It uses a standardized indenter, and the results are largely force independent (although there are special considerations for microindentation tests done at forces of less than 200 g).

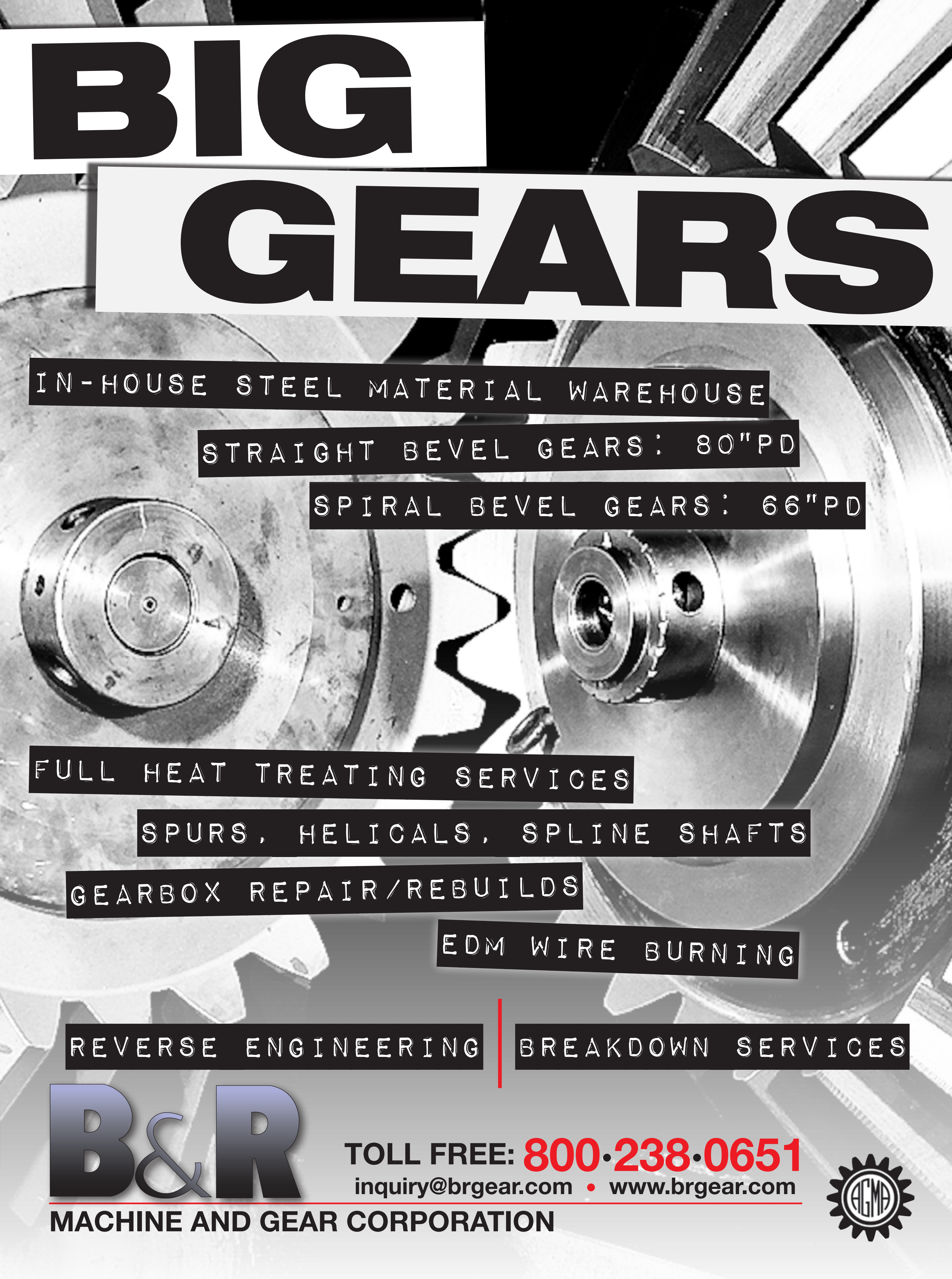
Like the Brinell test, the Vickers test calculates hardness based on the surface area of the indentation. However, the Vickers indenter is a pyramid-shaped diamond rather than a ball. The diamond tip is pressed into the test surface under controlled force for a specified period of time. The Vickers hardness is a function of the test force divided by the surface area of the indent.

The Vickers test has two distinct force ranges: macro (1 kg–100 kg) and micro (10 g to 1,000 g). ASTM E384 covers the micro force ranges, while ASTM E92 covers the macro force ranges. ISO 6507 covers both ranges.

Knoop. The Knoop hardness test is used for particularly thin or brittle materials, where only a small indentation can be made. The Knoop test is similar to the Vickers test, except that it uses an elongated pyramid indenter and is reserved for microindentation testing.

Because the indentation is very small, and optical identification of the surface area is required, the Knoop test requires a highly polished, flat surface. This often means the test piece must be destroyed in the process.

Knoop testing is described by ASTM E384. Because it is force-dependent, it is crucial that the Knoop hardness specification include the testing force. Thus, HKN50 500 is the proper designation for a Knoop hardness of 500, achieved at 50 grams testing load.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