June 2009

GEAR TECHNOLOGY

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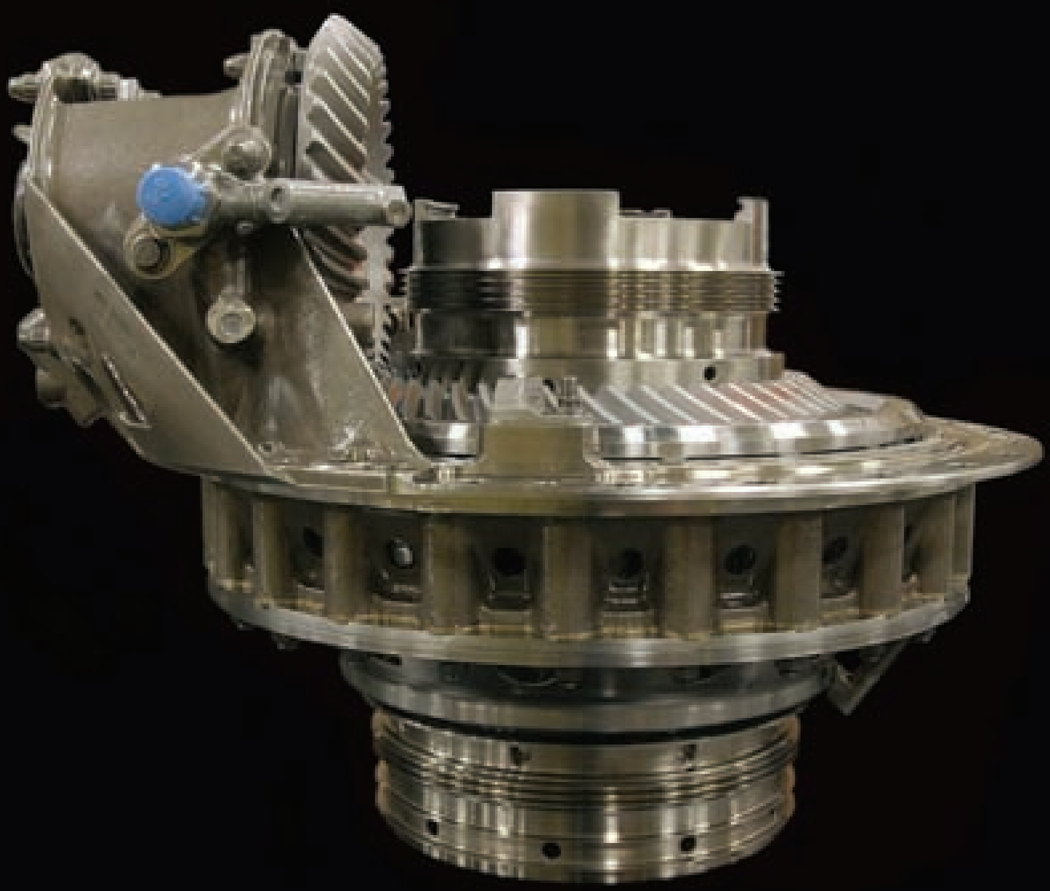
The Journal of Gear Manufacturing

25 YEARS 1984-2009



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Features

- Want Aero and Defense Contracts? Be Careful What You Wish For
- Cutting-Edge Aero Research Update

Technical Articles

- Faster Wind Power Gear Grindings
- How Start-Up Load Conditions Affect Gearbox Performance and Life Failure Analysis

Plus

- Addendum: Economic Stimulus Logo Revisited

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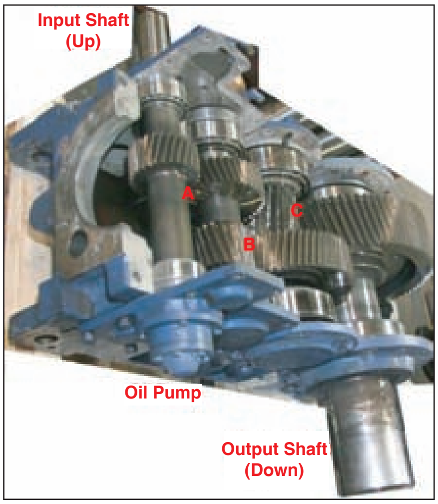

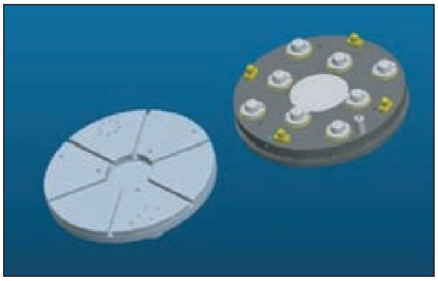

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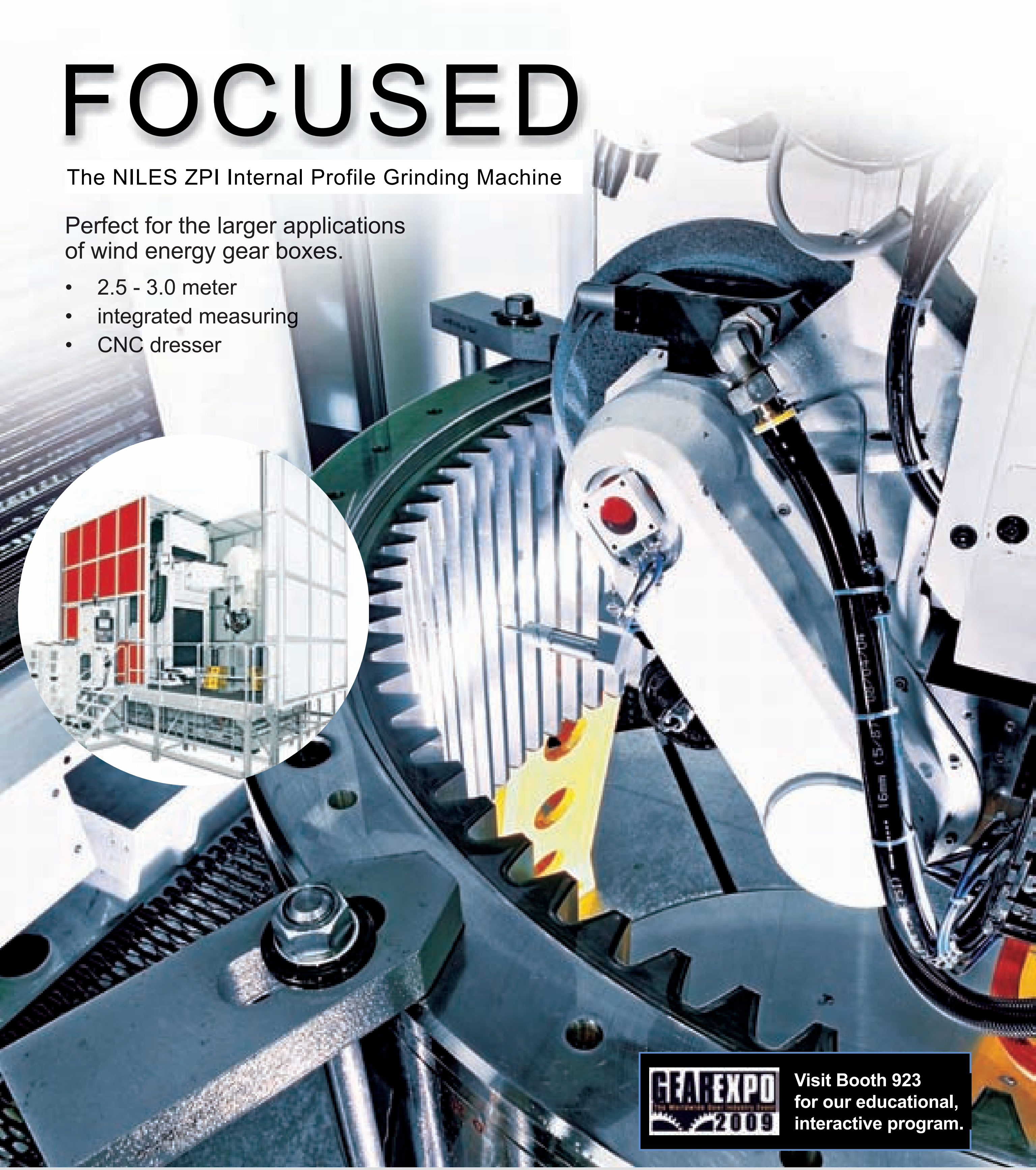
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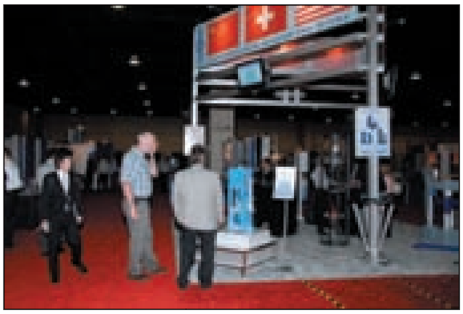

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Cover courtesy of Triumph Gears.

Paying the Tab

The U.S. economy has been out of kilter for some time. As a nation, we've been behaving irresponsibly—both individually and collectively. As consumers, we've spent and borrowed to the point where our houses are worth less than our debt. Despite the obvious crises looming with issues such as Medicare, Social Security, the rising cost of healthcare, etc., we've put off the difficult issues time and again. "Just put it on my tab," we've been telling the bartender. But instead of paying the bill, both Republican and Democratic administrations have been sneaking out the back door and leaving the tab for their successors. But it's not their successors I'm worried about, it's ours—our children and grandchildren are the ones who will be stuck with the bill.

On top of all that, the economy went kerflooey, and we've had to face some real economic emergencies. As a result, a lot of attention has been paid to the financial sector. Had to bail out all those bankers, mortgage resellers and so on. Then the auto industry collapsed after years of everyone saying it was coming. Had to bail them out too.

Most everyone agrees that our government had to do something to protect our economy and our nation from catastrophe. When the building is on fire, you have to put out the flames. So we loaded up our industrial strength fire extinguisher with lots of economic stimulus money and aimed for the hot spots.

But those other problems—those looming crises—are still out there. After the current fires are put out, how much longer will the building support its own weight?

Even worse, we face crises besides those already mentioned that may not be as visible or newsworthy, but which are just as important to the long-term health of America. With two out of the Big Three going through bankruptcy, America's biggest manufacturing industry has gotten a lot of attention. But what about the rest of American manufacturing, which is quietly suffering? What about the smaller companies and smaller industries whose problems are not so collectively large nor so easily focused on? The small- to mid-size American manufacturer also needs help.

If you work in one of these smaller industries or in one of these smaller companies, you already know that the work you do is a terribly important—even critical—part of our economy. You provide America with jobs. You drive invention and progress. You create wealth. You also provide America with the ability to make things under our own control and within our own borders.

And you already know that the government probably isn't going to notice you. No red, white and blue-caped hero is going to swoop in to save the day with a stimulus check or the tax credits.

So what should you do?

In the past, I've talked about using these economic down times to search for ways to improve your company, looking at lean principles and similar tools and ideologies to minimize waste, increase productivity and improve the bottom line. Continuous improvement has to be continuous, even in the worst of times.

While you may not be in a position to compete for the Shingo Award (given to organizations best exemplifying lean principles), now is the perfect time to look at ways you can seize the crisis and turn it into an opportunity to reanalyze all facets of your business.

Each of our companies has key employees with knowledge and experience that's critical to our success. These are the people no company can afford to lose, no matter what the economic situation. Although they may not be busy today, they're definitely going to be needed when things turn around.

If you're the boss, don't be tempted to let these valuable resources go. Instead, use this opportunity to redirect their energies. Use their knowledge and experience to participate in or lead the teams that will research, reanalyze and redirect every aspect of how your business operates, how information is exchanged and how material flows through your company.

If you're one of those knowledgeable and experienced employees, now is the time to step up and prove your worth. Your boss isn't going to figure this out. You are. You know your job. You have the ideas about how to do things faster, more efficiently and more economically. Technology has changed, communication has changed, machines have changed, etc. How can you change to take advantage of all these new opportunities?

There are doubtless many ways you can improve your operations that you haven't yet explored.

But one thing is certain. It doesn't look like your Uncle Sam is going to bail you out. You're going to have to do it yourself.

Sincerely,

Michael Goldstein,
Publisher & Editor-in-Chief


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Accelerating Together.
With over a century of history, Mitsubishi Heavy Industries has had plenty of time to grow. Today the numerous MHI divisions worldwide lead in many fields such as transportation, power systems, environmental systems, and more. All our divisions share their unique understanding of diverse customer needs to leverage unparalleled synergies and unrivaled capabilities, thus making Mitsubishi Heavy Industries America a truly innovative company with a steadfast network of proven expertise.
This fully integrated corporate culture enables the MHIA Machine Tool division and their technically advanced gear cutting machines to offer inventive solutions for every industry, despite the short-term changes in any one market. At a time when others slow down and fall behind, you can continue to depend on our growing strength and long-term reliability.
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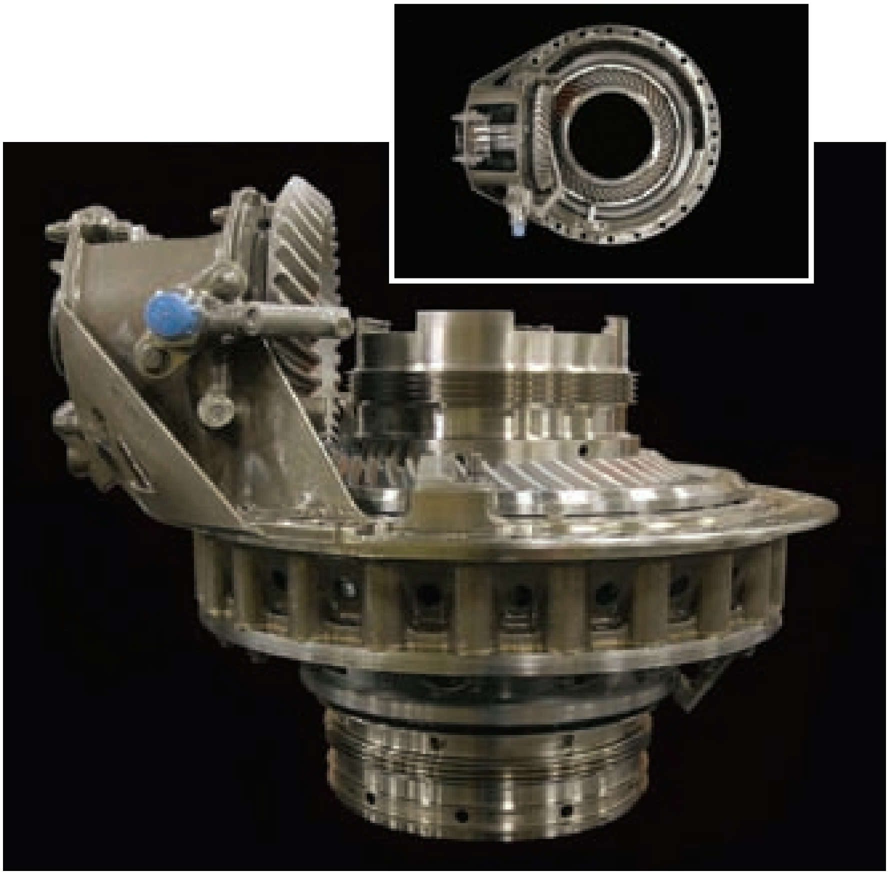
For Aerospace, the Proper Tool for the Proper Job is Key

TRIUMPH GEAR SYSTEMS-MACOMB BUILDS CUSTOM INFRASTRUCTURE FOR MANUFACTURING LARGE, HIGH-PRECISION AEROSPACE GEARBOX AND ASSEMBLY HOUSINGS.



To ensure a long and trouble-free operating life for its gearboxes, Triumph manufactures the housings on Mitsui Seiki horizontal CNCs capable of holding critical dimensions within 0.0003" (courtesy Triumph Gear-Macomb).

Late in 2006, Triumph Group Inc. negotiated an agreement with GE Engine Systems that would allow its Michigan-based subsidiary, Triumph Gear Systems-Macomb, Inc., to supply the critical CFM56 engine inlet gearbox and related parts for the life of the program. The CFM56 engine, which propels the Boeing 737 and many Airbus models, is the most popular in aviation history.

Based on the volume and cost/performance requirements of this business, as well as other opportunities on the horizon, Triumph has made substantial investments in CNC manufacturing cells, tooling, modular fixturing and software to further streamline the manufacturing of housings for gearboxes and complete assemblies.

At the heart of the new additions are two large pallet-loading Mitsui Seiki CNC horizontal machines—a 4-axis (HS6A) and 5-axis system (HS6A 5-axis) capable of manufacturing housing components up to 1,000 x 900 x 750 mm. These machines, mounted on 5-foot-deep cement foundations to ensure ultra-precision cutting at high speeds, are in addition to the six other machining centers (six Mitsui Seiki's and one Toyoda) that Triumph already operates.

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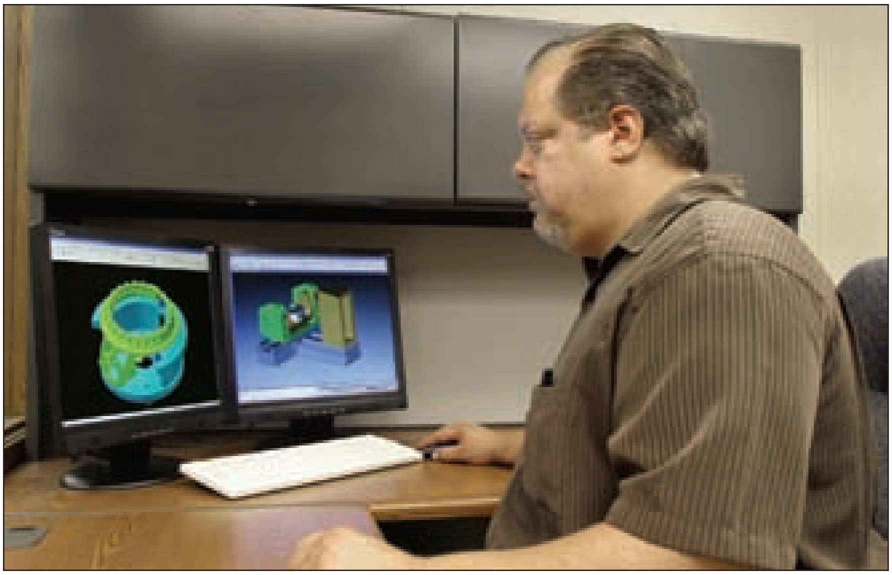


Triumph's Dave Czerw uses *Mastercam X3* software (left) along with an integrated *Vericut* software package to generate and analyze tool paths for manufacturing gearbox housings (courtesy Triumph Gear-Macomb).

Opportunity Driven

"Things have changed a lot in the 26 years I have been with this company," says Bob Maggetti, director of engineering. "When I started out, we were privately owned and the only milling we did was to drill lightening holes in the web of a gear. But our customers wanted us to do more, so in the mid-'80s we started making simple gearboxes. Today, ones like the CFM56 inlet gearbox are very complex. But that's not the end of it. In the near future we will be partnering with our sister company, Triumph Gear Systems-Park City (UT), to manufacture complete assemblies. Many of these will be larger than anything we have made previously, and that business is likely to be driven by the demand for helicopters and the offshore oil industry. These new directions demand that we simultaneously make improvements in both our precision and high throughput manufacturing capabilities."

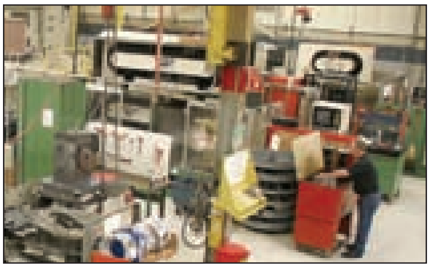
Indeed, Maggetti says the helicopter project was one of the reasons his company purchased the new CNC machines.

Supporting Systems

Milling was the most heavily burdened department in the shop. The purchase of the two large machining cells was justified, based on the volume of work and a fast payback of only two to three years, thanks to increased productivity. According to Dave Czerw, milling department manager, "We were looking for larger machines for our larger work. We selected horizontal Mitsui Seiki machining centers because of the accuracy, repeatability and dependability they provide."

The new manufacturing cells would be a further extension of an ongoing, specialized system for high-precision,

Triumph Gear Macomb's veteran staff is exploiting CNC capabilities for automatically manufacturing challenging parts and assemblies with high levels of precision and productivity. Shown here is Brent Berger (courtesy Triumph Gear-Macomb).



The four 4- and 5-axis Mitsui Seiki horizontal CNC machining centers are staged with custom modular fixtures to ensure exceptionally fast setups and secure workholding for gearbox manufacturing precision (courtesy Triumph Gear-Macomb).

high-volume manufacturing of housings that has evolved at Triumph in recent years. Major elements of the system include:

Robust horizontal CNC. The new Mitsui Seiki 4- and 5-axis pallet-loading CNCs have a 1,000 mm cube work area, glass scales for high precision and 240 and 360 tool carousels, respectively. The 5-axis machine is particularly important for single-setup manufacturing of parts, which should be set up in the fixture only once to preserve positional accuracy. For example, in the case of housings made of magnesium that are very temperature sensitive, single setup manufacturing on the 5-axis avoids positioning errors due to clampout (minor changes in the part's shape when it is released from the fixture).

Parts like those made for the CFM56 engine inlet gearbox have many exceptionally tight tolerances. "For example," says Czerw, "we have a couple of bores with diameters that must be held to within 0.0003". As for positional accuracy, the two bores have to be in-line within 0.0005", and they must be positionally located to other features 90 degrees from them to within 0.0002". So that's why we bought the milling machines that we did."

The CNC machining centers must meet these requirements with "error budget" to spare to compensate for such things as tool and fixture variability.

CAM capabilities. For programming all of its CNC machining centers, Triumph uses *Mastercam X3* software. This package allows the company to tap into all of the capabilities of the equipment, including large tool libraries and 5-axis capabilities, as well as 90 degrees and indexable heads. "Surfacing" allows rapid creation of sculptured toolpaths from surface modeling.

Custom modular fixturing. A key to productive manufacturing of gearbox and assembly housings is minimization of setups. To achieve that, Triumph uses Stevens Engineering Inc. modular

continued

fixturing systems, which it uses on all of its Mitsui Seikis and are virtually resident in its *Mastercam* libraries. Each machine is fitted with a grid plate of dowels so that fixturing plates can be moved and accurately located on any machine. This gives the shop the flexibility to use a variety of machines for the same part with exceptional repeatability of dimensions.

In the past, making a part that required 150 tools to manufacture might have required a day and a half of setup time. With this system, Czerw says his shop has whittled the setup content of these jobs down to a couple of hours.

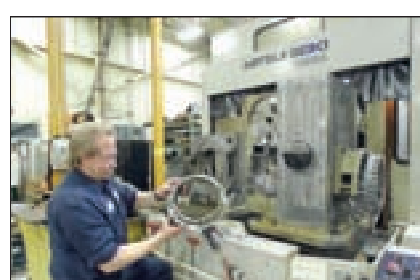
Toolpath verification. *Mastercam* allows Triumph to manually fine-tune any cutting operation. However, a given part can have hundreds of these, so Triumph uses *Vericut* software in interaction with the CAM software via proprietary "C-Hook" technology to automatically analyze geometries and toolpaths and modify them to improve cutting efficiencies and check accuracy. The part is observed being made in a realistic virtual machining environment in *Vericut* before posting it to the CNC machining centers for efficient real-world manufacturing.

Czerw says he is continually using the program's verification feature to avoid potential tool and toolholder crashes.

Keep Chips Flying

Czrew says that, 15 years ago, it would take his company several days to set up and perform as many as 20 operations on eight machines to make housings similar to the ones they make today. Now all of these operations, including bores that used to be ground, are being performed on a single 4-axis CNC, with one or two fast setups using the modular tooling. Today, CFM56 inlet gearbox housings are being manufactured at a rate of better than three a day.

With the high rpm and rotational stresses placed on helicopter assemblies, high-precision, single-setup manufacturing with the 5-axis system will become even more important. Even so, Czerw says the name of the game is to still "Keep the chips flying."



Steven Bisson checks a part that 15 years ago would take Triumph several days to set up and manufacture (courtesy Triumph Gear-Macomb).

"We get paid for doing that and nothing else," he adds. "My programming is overhead. The guy setting tools is overhead. We get paid for cutting chips. That's our main goal—to keep the machines making chips. That's what we are investing in."

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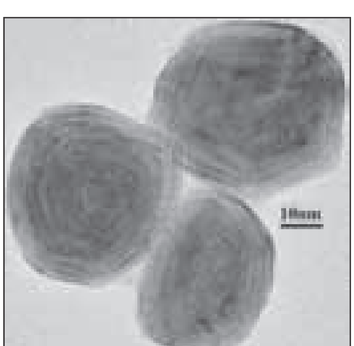
Nano-technology-Based Lubricant

TESTED TO REDUCE GEAR WEAR



ApNano Materials's NanoLub lubricant was demonstrated to significantly decrease wear pits on gear teeth in a test conducted by the FZG Gear Research Centre of the Technical University of Munich, Germany.

NanoLub uses nano-sized particles of tungsten disulfide structured as nested spheres, known as inorganic fullerenes. Layers of the fullerenes slip off under loads to form an adherent film, which reduces friction and wear. The particles are added to liquid oil or grease to increase the lubricating properties. NanoLub also "wraps" moving parts with a thin lubricating film, referred to as tribofilm, which

continued

serves as an uninterruptable lubrication source during severe oil leakages.

"The test proves that NanoLub significantly enhances automotive and industrial gear oils, improving pitting resistance," says Dr. Menachem Genut, ApNano Materials' president and CEO. "Gear teeth are especially vulnerable to micropitting, and reducing this damage can save high costs of replacement and repair, making the gears operational 24/7. For example, Anglo-American, one of the largest mining companies in the world, has begun to use NanoLub in its heavy mining equipment in Chile."

The FZG Gear Research Centre test follows other tests performed on gears with heavy duty gear oil blended with NanoLub powder. No wear damage was observed with an optical microscope on the steel lubricated by NanoLub, but significant wear was detected when using reference oil. Tribofilm was noticed on the NanoLub lubricated gears. The tribofilm lubricates the moving parts even in circumstances where oil supply is interrupted.

"The new test further enhances NanoLub's position in the automotive and industrial markets, opening new horizons for our innovative lubricant as a necessary additive to gear oils," says Aharon Feuerstein, ApNano Materials' chairman and CFO. "NanoLub is distributed worldwide in Europe, Asia and the Americas by local agents and distributors. Due to the large demand, we have increased the capacity of our production plant."

For more information:
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Fax: (212) 719-0893
hq@apnano.com
www.apnano.com

Expanding Twist Mandrel

PERFORMS WIDER RANGE OF APPLICATIONS

Gleason Corporation has grown the LeCount expanding mandrel line

with the Type G Twist Mandrel, which can accommodate a wider range of applications, including O.D. and face grinding operations where parts have a smooth bore, as well as non-gear grinding processes like cylindrical grinding.

The LeCount Type G Twist Mandrel uses a sliding-jaw design that features a mechanical rotary device for clamping workpieces. The mandrel provides 0.0050 mm (0.0002 in) TIR accuracy, considerable holding power torsionally and axially and a wide expansion range that fits bore sizes from 25.40 mm (1 in) to 76.20 mm (3 in).

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Semi-Synthetic Metal Cutting Fluids

RESIST BACTERIA AND FOAM

Henkel Corporation introduced two water-soluble metal removal lubricants designed to generate minimal foam for years with little biological degradation.

The Multan B 236 and B 414 are for machining and grinding ferrous and non-ferrous alloys. They are intended for applications in which soft water or process requirements make controlling foam difficult.

The Multan B 236 is appropriate for most water conditions and multi-metal applications. It performs well on cast iron and steel applications that require rapid cooling, corrosion protection

continued

and moderate lubrication. The fluid rejects tramp oil and maximizes fluid life without using routine additives, according to a Henkel press release.

The Multan B 414 offers the same advantages as the B 236, but it also contains more oils and contains more extreme pressure additives. It acts as a universal lubricant on soft metals and more exotic alloys like aluminum, stainless steel, titanium, inconel, brass or copper.

Once machining or grinding is finished, both products leave behind a very light film residue to protect parts during storage. They eliminate smut and buildup on a machine's interior, tools and the finished parts.

For more information:
Henkel Corporation
1001 Trout Brook Crossing
Rocky Hill, CT 06067
Phone: (860) 571-5100
www.henkelna.com

Ipsen VFS Furnaces

SHIPPED TO NORTHEAST, MIDWEST AND SOUTHWEST

The Ipsen HIQ2624-10 horizontal internal quench (HIQ) vacuum furnace was shipped to a customer in the Northeast. The furnace was designed to accommodate the customer's sintering process requirements. It is the second

VFS vacuum furnace this customer has purchased.

The furnace features a 10-bar nitrogen quench system with an energy efficient graphite hot zone that can process temperatures up to 2,400 degrees; Graform curved graphite heating elements, a CompuVac supervisory control system and a TruLock autoclave door. The unit hot zone is 18" x 14" x 24", and the unit handles loads up to 750 lbs.

Ipsen also shipped a HEQ3836-2VDS horizontal external quench furnace to a Midwest medical device manufacturer. The furnace is capable of both vacuum debinding and vacuum sintering. It includes a two-bar argon quench system with a similar graphite hot zone, molybdenum heating elements, the CompuVac control system and TruLock autoclave door. This is the 19th VFS furnace this customer has bought over the course of 25 years.

The HEQ3836-VDS horizontal external quench furnace also achieves both vacuum debinding and vacuum sintering in a single vacuum furnace, and it was recently shipped to a new customer in the Southeast United States.

The furnace features a two-door design with a pneumatically activated clamping system. A -5 HG argon quench system is included along with an energy efficient all metal hot zone that can process temperatures up to 2,500 degrees, all molybdenum heating elements and the CompuVac supervisory control system. The unit hot zone is 24" x 24" x 36" (610 mm x 610 mm x 914 mm), and it can be loaded from either end with loads up to 1,000 lbs.

Ipsen's HIQ2624-10 horizontal internal quench vacuum furnace shipped to a customer in the Northeast.

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Rockford, IL 61125
Phone: (815) 332-4941
Fax: (815) 332-4549
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Omega Portable

OPTIMIZED FOR REVERSE ENGINEERING

Romer Inc. is calling the Omega portable measuring arm their most economical tool to date for multi-purpose non-contact measurement. The system is packaged for 3-D scanning applications like reverse engineering, rapid prototyping and no-contact inspection. The entire package includes the Omega articulating arm, the R-Scan line laser scanning probe and *PC-DMIS Reshaper* software.

The metrology device is lightweight due to a seven-axis arm comprised of advanced carbon fiber and aluminum construction. The R-Scan non-contact laser scanner has infinite rotation to scan areas difficult to reach. The system also features large capacity inspection, repeatability, automatic color recognition and real-time display of point clouds and point data.

The *PC-DMIS Reshaper* software uses a 3D point-cloud processing program to handle quickly generated point clouds and produce quality 3D meshes. The software collects live data from the measurement arm and creates 3D polygon mesh models, which users can export in various formats to bring into a CAD program or STL files for printing. Arm, probe and software all come with a Romer warrantee.

"The Omega arm is tailor made for the engineer or designer who wants a contemporary solution for the age-old problem of quickly acquiring accurate surface data from the most complex forms," says Jeff Freeman, Romer product line manager. "In the past, reverse engineering systems have either been very expensive, hard to use, or lacked a well-rounded toolset of both hardware and software to get the

job done. Omega is our cost-effective answer to this market need. We are confident that Omega's advanced features and ease of use will render efficiencies for a very broad range of reverse engineering and quality control applications."

For more information:

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Wixom, MI 48393
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www.romer.com

Wind Energizer

EXTENDS GEARBOX LIFE

Leviathan Energy has officially begun sales and marketing in the U.S. market for its Wind Energizer, a patented technology that increases the power output of large wind turbines.

The Wind Energizer is a passive, land-based structure that can be used with a wind turbine from any manufacturer. The product directs surrounding wind flow to the most important areas of a turbine's blades, which increases wind velocity to the blades. Power output jumps 20–40 percent when the turbine is moving and over 100 percent in marginal or poor wind speed. The Wind Energizer balances wind velocity load and shearing forces, so the blade and gearbox lifespan are both extended by 2–3 years, Leviathan estimates.

"We expect that with the very fast return on investment the Wind Energizer can deliver, sales will be quite strong," says Dr. Daniel Farb, CEO of

continued

Leviathan Energy. "We look forward to witnessing the transformative effects our technology will have on the wind industry throughout the country."

For more information:
Leviathan Energy
Phone: (323) 281-4070,
+972-77-2285111
sales@leviathanenergy.com
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GE Turbines

CONVERT TO MOBIL GEAR OIL

North American wind turbine owner and operator enXco has converted 32 of its 1.5 MW GE turbines to Mobilgear SHC XMP 320 synthetic gear oil at the Chanerambie and Viking Wind Farms in Minnesota. These sites generate energy to power thousands of homes in the southwest region of the state.

"enXco's selection of our premium Mobilgear SHC XMP 320 gear oil for many of its GE wind turbines is just another example of how our first-rate application expertise and lubricant technologies continue to help our customers maximize productivity and gain a competitive edge," says Brad Prickett, industrial sales engineer for Mobil Industrial Lubricants.

ExxonMobil's exclusive service provider, COT-PURITECH, executed the four-week conversion process with help from ExxonMobil field engineering and analytical support. Existing contamination and residual oil from the gearbox and lube system was removed by COT-PURITECH's proprietary gearbox flushing procedure.

"Developed through years of experience and working closely with leading gearbox and turbine OEMs, COT-PURITECH's proprietary gearbox flushing procedure was performed for enXco to help ensure optimal gearbox performance and to minimize possible compatibility issues," says George Mazzaro, market manager for COT-PURITECH Wind.

For more information:
Mobil Industrial Lubricants
Phone: (800) MOBIL25
www.mobilindustrial.com

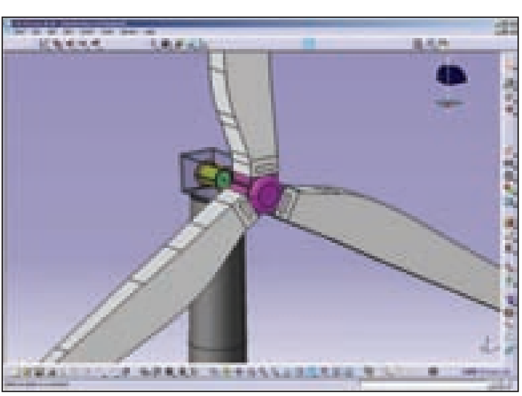
LMS Software

PREDICTS WIND TURBINE FATIGUE LIFE

The latest software release from LMS International, the *LMS Virtual.Lab Rev 8B*, features the Motion Aerodyn Wind Loads feature, which allows users to predict transient dynamic loads and input the information for fatigue life and radiated noise emission calculations. The software can create the wind turbine blade and its structural flexibility and wind behavioral traits while incorporating the modeling of the other critical elements, including the gearboxes, bearings and controls.

Pre-processing options help create formatted wind input data and include wind behavior traits. IEC wind standards are used to validate the turbine design. Based on wind information and blade orientation and speed during each time step, the *LMS Virtual.Lab Aerodyn* calculates the apparent wind speed on the blades and the subsequent wind load for each blade section for dynamic simulation studies.

"We integrated the Aerodyn functionality used to apply accurate loads on a turbine into our advanced 3-D multi-body code to model the entire wind turbine interaction with the wind in a much more scalable way," says Guillaume Lethé, product manager. "An easily accessible 3-D environment for cross-attribute multi-disciplinary simulations, *LMS Virtual.Lab* is the only 3-D CAE environment that addresses the specific challenges of wind turbine design, including precise blade-wind interaction and load cascading, thanks to the new Aerodyn Wind Loads feature."



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KEEPING THE WORLD IN MOTION™

Military fighter jets, including the F-22 Raptor, require high-precision/high-quality products from gear manufacturers (courtesy of Airman 1st Class Amanda Grabiec).

Several programs involving the Joint Strike Fighter, including an alternate engine and reliable replacement warhead, could potentially be cut under Defense Secretary Robert M. Gates' 2010 defense budget (courtesy of Senior Airman Julianne Showalter).

High-Tech Risks and Rewards

AEROSPACE/DEFENSE CONTRACTS OFFER UNIQUE CHALLENGES FOR GEAR MANUFACTURERS

Matthew Jaster, Associate Editor

There's always pressure on gear companies to deliver high-quality products to customers, but the pressure increases slightly when Uncle Sam is involved and the United States' global interests are at stake. Decorated generals might drop by the manufacturing floor for an update, contracts may be more stringent and delivery/quality expectations are heightened.

Aerospace/defense gears aren't exactly your run-of-the-mill, garden variety type of equipment. For these applications, companies seek high-precision, high-quality and highly-inspected gears that are placed in vehicles or equipment that costs millions. What sort of preparation and expertise separates those working on a $45,000 automobile from those working on an $80 million fighter jet?

In order to land contracts in these industries, a gear manufacturer must have complete manufacturing and design capabilities in-house and an experienced workforce in place to meet the demands of these fields. Despite all the added pressure, aerospace/defense contracts can be extremely profitable for gear manufacturers that have the right systems and processes in place to handle the workload.

"Primary contractors are very demanding in the aerospace and military industries," says Tony Werschky, sales and marketing representative at Tifco Gage & Gear and Delta Research. "A traditional automotive company needs to have a 'come to Jesus' [moment] when they determine whether they have the ability to conduct business profitably in this industry and whether they can handle the stress, competition and responsibility that it encompasses."

For 25 years Delta and Tifco have been supporting the military through primary and secondary contractors,

continued

amounting to approximately 51 percent of business.

"We have built steering systems for the Navy since the '70s," Werschky says. "Since then, we've also provided all kinds of products from fuel metering units to parts on the Tomahawk Cruise Missile and complete gearboxes that go on satellites into space to precision optical parts."

"We also machine the transmission and engine adaptor housings for the Expeditionary Fighting Vehicle—an amphibious tank," Werschky says.

Werschky says the defense business is good if you can get it, but it is tremendously different than servicing other industries. "There is more accountability, more process control and little to no room to deviate from the part requirements."

Reputation is a huge factor in determining future business for companies seeking aerospace/defense work.

"Developing new customers takes time, but once you're in the system and accepted, these companies get into the habit of using you," Werschky says. "Margins can be higher if quality is attained without significant rework or overextended processes."

Werschky says that quality and delivery are more important than price for many aerospace and defense customers.

"They may not come out and say it—they don't have the time and resources to develop a new supplier every time a product change comes along. Additionally, some aerospace/military contractors are still buried by demands from the Iraq and Afghanistan wars and are looking for suppliers who may be able to help them with capacity issues," Werschky says.

Delta and Tifco's business comes primarily from the aerospace/defense and automotive markets, though Werschky notes that the automotive business is only a fraction of what it has been in the past.

"With Tifco's heritage being a master gear and gage producer, our teams produce their aerospace gears to gage quality tolerances. We continue to review alternate industries like wind, mining, medical and off-highway projects," Werschky says. "Although we are involved in these industries, we maintain a focus in automotive, military and aerospace based on market direction, current and future industry demands and risk-to-reward relationships."

Arrow Gear has provided gearing products for Armored Personnel Carriers (APCs), Landing Craft Air Cushion (LCAC) Hovercrafts, guidance systems for a tank gunner, missiles, military drones, as well as fighter jets including the F-18, F-22 and Joint Strike Fighter (JSF).

As commercial work was moving offshore in the 1980s, many gear companies were looking to other industries for new business. Arrow's President, Joe Arvin, had a background in the aerospace industry when he first joined Arrow and was already helping to steer the company in that direction. At the time, the specialized work involved in aerospace projects remained a viable sector for the company, thanks to its established gear expertise.

The aerospace industry accounts for roughly 65 percent of Arrow's business today. In addition to supplying various parts and services for military equipment, Arrow Gear has been an innovator in new technology and gear advancements for aerospace applications.

"Most aerospace companies are divesting themselves of gear design engineering—it's not a core competency—and we have taken up the slack," Arvin says.

As an example, Arvin explains that Arrow performed the gear design and prototype development for the power-take-off and the accessory drive bevel gears for the jet engine on the JSF as well as the lift-fan gears used on the STOVL version. Utilizing advanced computer aided technology, Arrow's engineers produced a design that accurately predicted how the contact pattern of the gears would move under full load — achieving optimal results on the first attempt.

Arvin said, to his knowledge Arrow Gear produces more jet engine gears and bevel gears for helicopters, than any other non-captive gear manufacturer in the world.

Arvin agrees that the work done in the aerospace/defense field is far different than other areas and the challenges are extremely specific; this has required Arrow to triple their engineering and quality overhead.

"There are many more quality and documentation requirements. In some instances, the paperwork required to ship the parts actually weighs more than the gears."

Arvin notes that there is more pressure on delivery of a complicated part that can take up to 120 different operations for a lot size of one or 20 gears.

"If it is a military DX rating, someone from the military will be in your factory making sure you're running their part," Arvin says.

Precipart Corporation, founded in 1979 in Farmingdale, NY, has worked in the aerospace/defense industry for more than 20 years. These industries have contributed to approximately 25 percent of the company's business.

Don Weinzimer, vice president of special projects, says the company is always looking for new opportunities throughout the aerospace and defense markets. Through its engineering and manufacturing expertise, Precipart has designed and produced components and motion control devices that have been incorporated on commercial and military aircraft, the Hubble Telescope and the Mars Rover.

"Contracts in this field typically are more sensitive to economic turns up or down. These contracts require special process controls, specify tighter requirements overall and mandate adherence to the National Aerospace and Defense Contractors Accreditation Program (NADCAP) performance standards for suppliers."

While the aerospace/defense industries present many manufacturing challenges, it's equally demanding for these organizations to seek new business opportunities.

"The question we continued to ask ourselves is how do you become more diversified as an organization when 85 percent of your business involves aerospace and defense?" asks Adam Nelson, general manager at Nelson Engineering.

"It's a matter of finding other industries that need the same type of high-quality products, focusing on areas such as industrial gearboxes, the automotive aftermarket and maintenance/repair and overhaul."

Nelson says the precision and machining knowhow needed to satisfy these fields can be utilized for other areas of the gear industry.

"Customers always value experience and the knowledge you bring to the table," Nelson says. "This positions us to satisfy other markets that expect the same high-quality and high-precision products."

Nelson Engineering recently brought in 10 outside sales representatives to aggressively seek business in industrial gearboxes with wind generation a key focal point.

"The benefits of working in aerospace and defense are that the work you do ends up creating robust systems and processes, and this allows you to really stand behind the products that are being manufactured," Nelson says.

Products at Nelson Engineering include gearboxes in nuclear missile silos, high-end gear products for the Multifunction Utility/Logistics and Equipment (MULE) vehicles for the U.S. Army and work involving the next generation of catapults for aircraft carriers (the device used to assist military jets in launching from ships).

Nelson adds that the pressure that comes with manufacturing highly critical components is not much different than other types of components.

"The interesting thing about working in aerospace and defense is that you're not the only one holding the part. It might go through 12 different companies before you reach the finished product. It's as much about program management as everything else," Nelson says.

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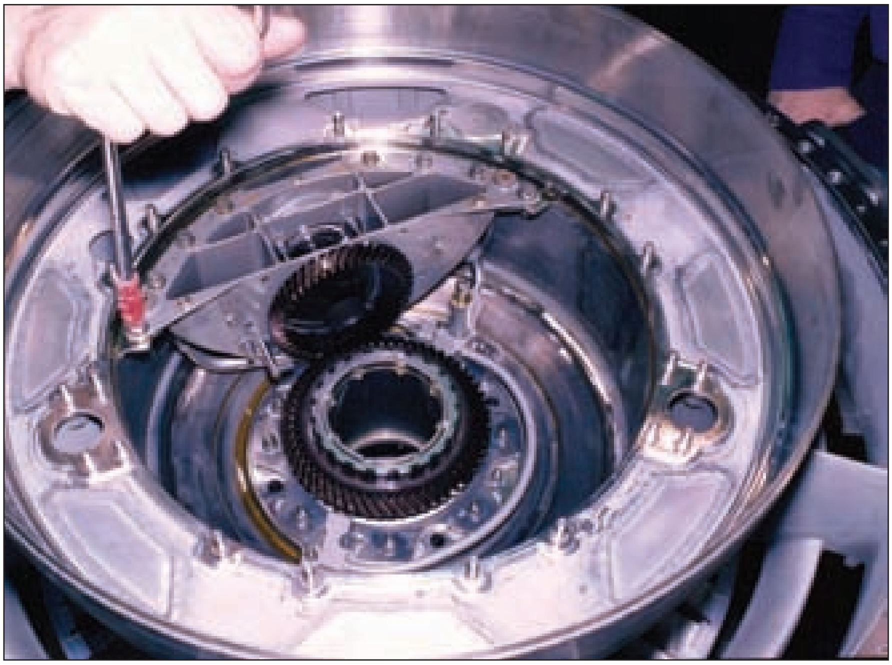
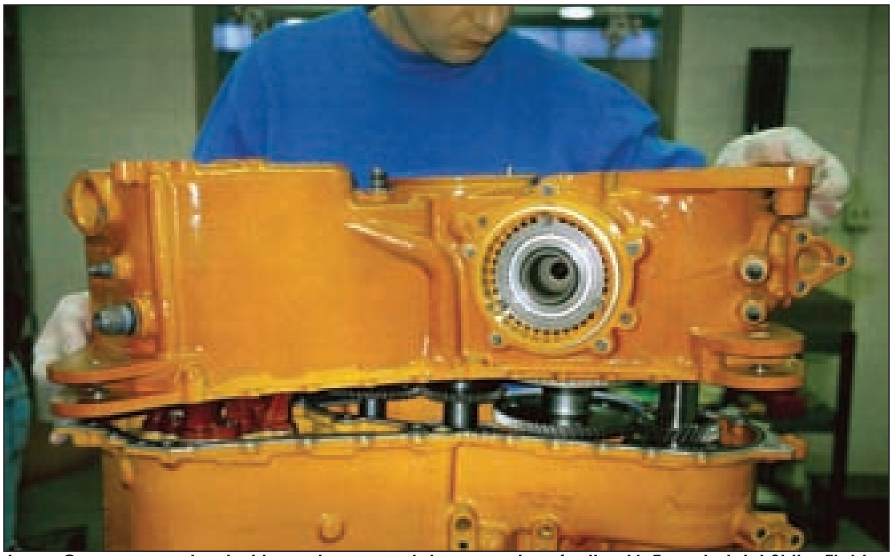


Arrow Gear provided components for the F-18 404 engine power takeoff shaft (courtesy of Arrow Gear).



Arrow Gear was contracted to work on a prototype gearbox for the Air Force's Joint Strike Fighter (courtesy of Arrow Gear).

Nelson Engineering has worked with the U.S. Army on components for the Multifunction Utility/Logistics and Equipment vehicles (courtesy of the U.S. Army).

as everything else," Nelson says.

And is there any added pressure when military organizations are keeping a close eye on your work?

"We're one of only a dozen or so companies with a DX-rated contract, meaning that the only one who can issue the purchase order is the President of the United States," Nelson says. "It has been made clear to us numerous times that if we make any hiccups, the government would get involved very quickly."

As it stands now, it's the manufacturers that are paying close attention to Washington. As *Gear Technology* went to press, Defense Secretary Robert M. Gates was pleading his case before Congress for the 2010 defense budget. Although base funding is projected at $534 billion, Gates announced billions of dollars in cutbacks to programs in all four military branches.

In his opening statement to the House Armed Services Committee on May 13, 2009, Secretary Gates expressed the principles of his budget plan.

"This budget aims to alter many programs, and many of the fundamental ways that the DOD runs its budgeting, acquisition and procurement processes," Gates said. "The responsibility of this department first and foremost is to fight and win wars—not just constantly prepare for them."

The rampant debate on how U.S. dollars should be spent on defense projects is making headlines due to Gates' plan to "remake" the U.S. military, shifting the focus to unconventional war items like mine-resistant vehicles, surveillance drones and medical helicopters while cutting back on fighter jets, bombers, tanks and aircraft carriers.

Gates wants to focus on "irregular" warfare issues instead of spending billions of dollars on expensive future weapon systems while the fighting in Iraq and Afghanistan continues.

"These recommendations are less about budget numbers than they are about how the U.S. military thinks about and prepares for the future. Fundamentally, the proposals are about how we think about the nature of warfare."

It remains to be seen what projects will be terminated and how the budget under the Obama Administration will affect future contracts. Nevertheless, gear manufacturers are keeping tabs on the outcome of this debate.

"We are concerned about these cutbacks as it would be a major loss of jobs," Arvin at Arrow Gear says.

Nelson adds, "The market will pick up in some areas and slow down in others. You have to be really prudent and yet at the same time, it's necessary to expand your reach to see what other

Delta Research and Tifco Gage and Gear machine the transmission and engine adaptor housings for the U.S. Marine Expeditionary Fighting Vehicles (courtesy of the EFV Program Office).

opportunities are out there.”

Time will tell how manufacturers will cope with terminated contracts in industries that account for more than half of their business.

“We are ever vigilant as to how to evolve as a company in order to provide the products that are needed in the future,” Werschky says. “What we have found is when you produce outstanding quality products, on-time and at a reasonable price, there will always be a place for you in this business.”

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Aerospace Gearing Research— An update

Jack McGuinn, Senior Editor

As this is being written, an msnbc.com *headline asks: "Defense Jobs—Recession-Resistant No More?" The story goes on to point out that defense/aerospace spending has always meant good, well-paying jobs for job shops and OEMs throughout the country. And like Chrysler's recent nationwide shuttering of many of its locally owned dealer showrooms, the loss of defense contracts can have devastating effects on cities and towns, and attendant collateral damage. Indeed, national defense has—until this Great Recession—always proven to be recession-resistant. No more. These days, and for some time now, it is outer space that is attracting the dollars and generating contracts. Which, in a very limited sense, is good, except for the fact that deep space research—though admittedly sexier—occupies a very limited niche, where aerospace/defense boasts a much wider, guns-and-butter impact, affecting more jobs and companies. And yet, the work does in fact go on—at least in terms of invaluable research. With that in mind, we talked to three institutions long-respected in the gearing community—The Ohio State University Gear Dynamics and Gear and Power Transmission Laboratory (GearLab), the Gear Research Institute (GRI) and Applied Research Laboratory at The Pennsylvania State University and the Cleveland-based NASA Glenn Research Center, all with the idea of getting their take on the state of aerospace/defense research.*

Sophisticated gear test rigs facilitate the often complex research projects at the GearLab (courtesy GearLab).

GearLab and Gear Research Institute at Head of the (Gear) Class

At Ohio State's GearLab, founded in 1980 by "Gear Professor Emeritus" Donald R. Houser, the roster of sponsoring companies and government agencies has grown steadily since its inception, now numbering approximately 50. In 2003, the GearLab partnered with a research group led by (current GearLab director) Professor Ahmet Kahraman, thus widening its breadth of research in gear and power transmission. Areas of GearLab's research focus include:

- geometry, kinematics, design and analysis
- dynamics, vibrations, acoustics and noise control
- contact mechanics, load distribution models and FEA
- power losses and efficiency
- contact and bending fatigue
- metrology and test methodologies

At Penn State's GRI, founded in 1982 and led by managing director Dr. Suren Rao, the areas of focus differ, but are just as valuable:

- high-hot hardness gear steels
- utilization of Boron-toughened steels
- technology surveys
- durability testing of gears
- effect of lubricants on durability
- heat treat distortion
- gear noise prediction
- design allowable for gear steels
- effect of the ISF (isotropic surface finishing) process on gear durability

One thing the two institutions have in common is an A-list roster of sponsors, including Avio Group (Italy), Dana, Ford, Timken and Sikorsky Aircraft, among others.

We started off by asking Rao to what degree AGMA/ISO standards affect the status of GRI's research

continued

activities. Turns out, it's sort of a good–beter–best situation.

"Designing gears utilizing AGMA/ISO methods and procedures will give you a very functional gear with a long operating life," he says. "However, the aerospace industry has to design optimal gears because these gears have to fly in an aircraft and weight is a major consideration. That is where research groups (like GRI) come in. We work with the aerospace companies to support them in developing proprietary methods to design optimal gears for their applications."

As for Kahraman, he demurs to AGMA's aerospace committee on that question, but adds that "The aerospace community essentially has their own design methods that are related, but not identical, to the AGMA standards."

As cited in the MSNBC story, aerospace/defense funding and contracts are the lifeblood of not only good manufacturing jobs, but state-of-the-art research as well. Ever wonder how that works in other countries vs. United States? For many of them, think government assistance and sponsorship.

All of which begs the question—What, exactly, is the state of the nation's aerospace-related gearing research? It's a mixed review, in most respects.

But first, some perspective. Take Germany, for example, as explained by the GearLab's Kahraman.

"In Germany, the FVA (*www.fva-net.de*) is an industrial organization that funds as much gearing research as goes on in literally the rest of the world. Their government subsidizes this activity to a certain extent. It also supports universities with salaries (for professors). The FVA has about 190 members, all from Germany."

Kahraman goes on to point out the enviable fact that for the JSME's (Japan Society for Mechanical Engineers) motion and power transmission conference, their government sponsored 14 Japanese universities.

"Our number of universities involved with our ASME gearing conferences is only about five or six," but, he adds, "Our estimate is that little of the Japanese research has an aerospace motivation."

On the other hand, says GRI's Rao, "I do not believe that most European gear research is government-funded, and OEM funding is evident. The one venue of support for European gear research that is not very active here is their respective national trade associations."

Indeed, perhaps surprisingly to some, Rao prefers that government take a hands-off stance in most circumstances.

Apparently differentiating between the general revenue funds and the DOD budget, Rao says, "I do not believe that the federal government should get involved in funding research unless it directly relates to solving a problem that it needs solved. It is hard to say where that might go, under the current political climate."

Asked if GRI would like to see more government involvement, Rao states: "Gear research, especially as it relates to defense, is already U.S. government-funded. I do not see a more active role in the immediate future."

The GearLab's Kahraman agrees, adding by way of explanation that "We do not see (more U. S. funding) happening beyond the current funding that is driven by the Army and relates mainly to helicopters. Quite frankly, NSF (National Science Foundation) tends to steer the direction of university research, which in turn drives the types of faculty hired at (schools). NSF's priorities change quite often, but topics related to gears are not viewed as high priority. We think that the U.S. government, by and large, considers gearing to be a 'mature' technology and that all research should be paid for by industry."

Returning to the state of U.S. aerospace research, Kahraman responds, "The answer to this one is pretty subjective. When compared with the research going on at the German universities, there is only a pittance of U.S. gearing research going on. However, if one is speaking more of aerospace research, little of the German research appears to be directed towards the aerospace industry, as the main driver is the automotive sector.

"Another way to answer this question is to look at how little academic gearing research is being performed in the U.S. Other than Ohio State and The University of Cincinnati, there are an extremely low number of graduate theses being written in gear-related areas in the past few years."

For GRI's Rao, the evaluation depends upon various application and industry sector issues.

"Thankfully, the aerospace industry is constantly pushing the gear design and performance envelope, with the aid of research," he says. "The automotive sector appreciates the value of gear research but cannot afford it at this time. While what constitutes research is in the eye of the beholder, most other industry sectors do not even realize they need research, simply because their gears work and the basic technology has been around forever. Consequently, my characterization of the state of gear research in the United States is just 'poor-to-fair'—a C-."

And when asked to identify the hottest areas of gear research here, the answers seems to depend on each institute's areas of emphasis.

"We are not sure that there is one area that is 'hotter' than any other," says the GearLab's Kahraman. "Our activities extend across a broad range of areas such as efficiency, durability, noise, etc. We have been active in all these fields, with some increases in our gear efficiency gear research due to fuel economy and carbon emissions issues."

For Rao's GRI, it's "Exploring new gear materials to improve performance (H3 i.e.—high strength, low carbon stainless steels and titanium) or to reduce costs (powder metal) are the 'hot' areas that we are involved in."

In closing, given the dismal, daily news reports on the economy, one might assume that aerospace research is taking a funding hit. And that is true—but only to an extent; i.e., it could be worse.

"The economy has killed off research support from the non-defense sectors," says Rao. "While some discretionary projects have been terminated—even from the aerospace industry—research funding continues to be strong from this sector, at this time."

At the GearLab, "We do not think that the economy has affected the aerospace companies that deal heavily with gearing like (the economy) has the rest of the country," says Kahraman. "Our sponsorship has not lost any of our aerospace participants, and, in fact, we have seen a rise in sponsorship from aerospace companies."

Despite Lean Crew, NASA Glenn Continues Grinding Out the Work

The Cleveland-based NASA Glenn Research Center (GRC) boasts research efforts that are cutting-edge. Originally founded in 1941 as the Aircraft Engine Research Lab of the National Advisors Committee for Aeronautics—and changed in 1999 to its present name—the facility works to: develop "a national resource capable of providing innovations in aircraft engine technology, and transitioning these innovations to U.S. industry for use in future propulsion system designs for commercial and military applications."

Complementing the work done at the GearLab and GRI, GRC's mission includes aeronautics, space research and fealty to tax payers. The GRC includes in its focus the following:

- to be valued as a leader in space flight systems development
- to be known for excellence in project management
- to excel in aeronautics and space research
- to become an integral part of the Ohio community and the nation

As done previously, we asked about the relevance of standards to what they do at Glenn.

In general, says Phil Abel, deputy branch chief of the tribology and components branch for Glenn, "Yes, we are very interested in the standards-setting process. I've seen in other areas the importance of establishing good standards. We've begun exploratory talks in getting involved. It's a question of what would be our most appropriate role at this point."

We then asked about funding support for aerospace specific to gearing and received a less-than-optimistic response.

"I think, unfortunately, it's pretty thin," says Handschuh. "There's us here at Glenn, and we're talking about less than 10 people; and then there are a few universities—there's (the GRI and Applied Research Lab) at Penn State University. You've got Ohio State University—the GearLab, which is really doing very well—and they have quite a few sponsors."

But, Handschuh relates, (As opposed to the deep space side of things) "The (aerospace) budget is always tight, and aero has been getting squeezed for the last 10-plus years. There's a few reasons: One is the NASA program in general stayed fairly constant for quite a few years. If you think about it—if you never got a pay raise for 10 years, what does that do to your possibilities for doing research? If NASA had kept up with inflation, the budget would probably be double what it is now.

"Now, there's been this shift to get rid of the shuttle, and with that shift there's a lot of money going into the space-related side. And then there's other competing things even within NASA—like the Hubble (telescope), earth science, etc."

Says Abel, "The budget pressures within NASA have been fairly chronicled. The aero program within NASA has been receiving less emphasis over the last decade or so, (but) it sounds as if that may be reversing. But that's at a policy level."

Putting aside for now money issues, we got down to the nuts-and-bolts of the work being done at Glenn, especially currently. Handschuh lists a few projects:

"We are doing work in what they call 'windage,' he says. "Windage is the gears beating up the environment inside the gearbox—air and lubricant. But that is something we are trying to put some science to; there's been a minimal amount of empirical work done, and we actually have a NASA-funded NRA (NASA research announcement). We have an in-house experimental effort ongoing in that area and we're looking to apply some very modern CFD (computational fluid dynamics) tools to this problem.

"People have done things like CFD around a rotor and inside a gas turbine engine; we're taking it one notch farther because gearing presents some real problems. We found a professor at (Penn State's GRI and Applied

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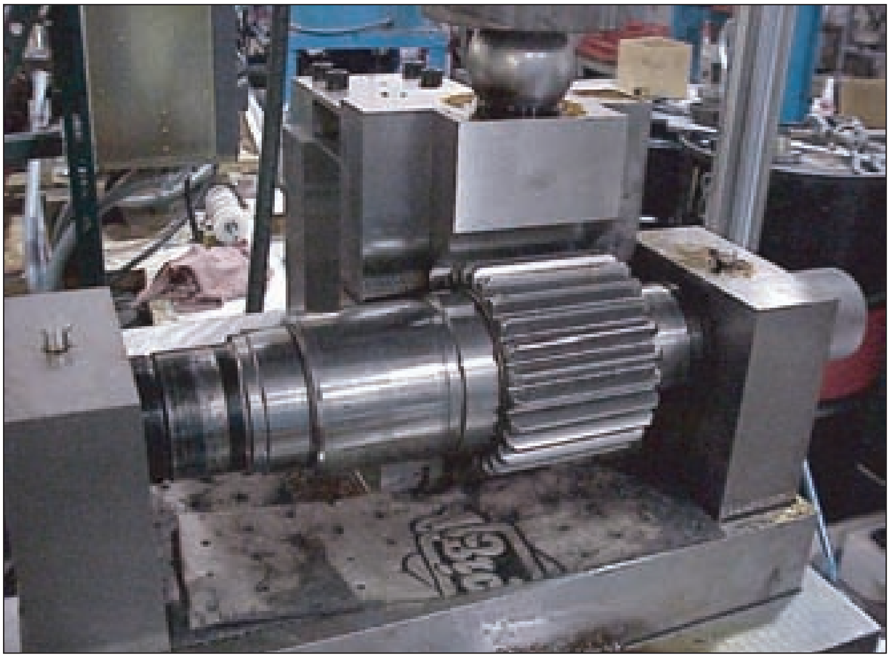


Single-tooth bending fatigue test on a helicopter main transmission gear is performed at the Gear Research Institute (courtesy Gear Research Institute).

Research Lab), and I think he's made some very valuable contributions, just from the way you grid a problem like this. What we're really aiming for is not so much a tool, but to have direction on how to minimize windage losses in gearboxes."

"It's a hot area of research," adds Rosen. "(Another one) of the exciting things we are currently working on is a new bearing material, and it was just recently announced, so I can talk about it now. It's a nickel titanium alloy which goes through a proprietary (heat treating) processing that suppresses the shape memory alloy properties and makes it machinable before processing and very hard afterwards. We have some samples which have the unique combination of properties being non-magnetic and highly corrosion-resistant—like silicon nitride, but conductive. For a niche application in, for example, instrumentation bearings, this may be just the thing that's needed."


The Glenn Research Center's supersonic wind tunnel is used for state-of-the-art aerodynamics/aerospace research (courtesy NASA).

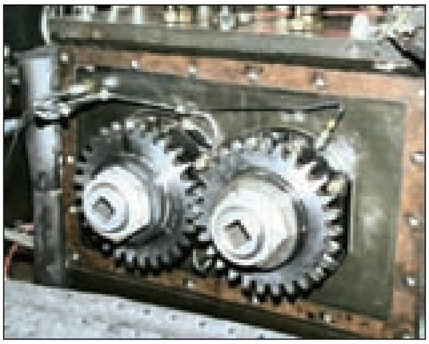
That said, we asked Handschuh for his evaluation of gearing research in this country—i.e., is the U.S. still No. 1?

"If you asked me that 20 years ago, I'd have said yes. Now I'd say that in some areas we're doing pretty well, but I see all the other countries at least being equal or surpassing us, (especially) Germany for gearing research.

"In the mechanical components area there's quite a concerted effort—in Germany, I know for sure—and probably Japan—that has been ongoing for a long time. The technical University of Munich has a large staff that dwarfs our team here, along with the professors and students that are working mechanical component-related research there. So that's a little disheartening. They're making good progress, but they have a lot of manpower."

We last asked about how OEM and other sponsorships work with Glenn on projects.

"We've worked directly with companies," says Handschuh, "but we're not going to test a widget because somebody says 'I'll pay you $100,000 to test a widget.' It's more like if there's


Gearbox-related windage research is a priority at NASA Glenn (courtesy NASA).

something we think is appropriate for us to work on for our charter. Sometimes they (sponsors, etc.) might supply us with test hardware, and our contribution and what we get paid to do is write papers and present our research. On one hand, they may be getting some testing done for almost nothing, but what we get out of it is (papers) and trying to provide information for U.S. technology."

Adds Rosen: "Another form of cooperative research is where we're both bringing resources to the table. If the company is interested in holding onto the data—keeping something proprietary—then NASA requires that it be essentially funded by the company. So there may be some situations where we enter into a fully refundable research agreement—but you won't hear about those."

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Innovative Concepts for Grinding Wind Power Energy Gears

A. Türich, C. Kobialka, and D. Vucetic

Management Summary

Over recent years, wind power energy has gained recognition as a way to reduce CO_2 emissions and thus counteract global warming. The development of wind power technology is driven by increased performance, which requires larger wind turbines and gearboxes. The quality demands of those gears are increasing while the production costs must decrease. This requires new production methods to grind the gears at low cost and at a high quality level. Profile grinding is known as a process to achieve the highest possible quality, even for complex flank modifications, while threaded wheel grinding is known for high productivity. New machine concepts now make it possible to use both advantages at the same time. The reduction of non-productive auxiliary time is a key aspect to becoming more productive.

This paper will show the newest developments to reduce the overall cycle time, including aspects to reduce setup time, idle time, productive time and dressing time.

Productivity in Profile Grinding

The gears used in wind turbine gearboxes have to transfer high loads, which requires hardened material on one hand and an exact geometry on the other. Thus, those gears have to be hard-finished. Discontinuous profile grinding with dressable wheels is an effective process to hard-finish gears of large modules (m > 8 mm:DP < 3). Due to the ongoing boom in the wind energy market, gearbox manufacturers are focusing on increasing the capacity and productivity of existing machine tools.

In profile grinding, the total cycle time to grind a gear consists of idle time and main production time. Many efforts at optimizing cycle time simply concentrate on improving the production time itself, without considering the idle time. The idle time, which can cover up to 50% of the total cycle time, consists of setup time, centering time, dressing time, time for over travel and pitch movements during grinding, as well as on-machine measuring time.

Figure 1 shows typical times for profile grinding large gears. The effective grinding time in rough grinding (41 min) is only 34%, or just 17% of the total cycle time (240 min). This example shows a dramatic inefficiency of the process.

The grinding time can be calculated with the specific material removal rate $Q'w$, which represents the productivity of a grinding process—the higher the $Q'w$, the shorter the grinding time. Figure 2 shows the definition of $Q'w$ for discontinuous profile grinding. $Q'w$ is the product of radial infeed Δx and axial feed speed f_a. To reduce the grinding time, $Q'w$ has to be increased either by larger radial infeed or faster axial feed speed, or even both. The limiting factor for such an increase is usually the appearance of grinding burn.

Figure 3 shows the principal relation between the radial infeed Δx and the axial feed speed f_a. As an example, a specific material removal rate of $Q'ww$ = 10 mm³/mms can be achieved by using a radial infeed of $\Delta x = 0.15$ mm, and an axial feed speed of f_a = 4,000 mm/min as well as using a radial infeed of Δx = 0.05 mm and an axial feed speed of

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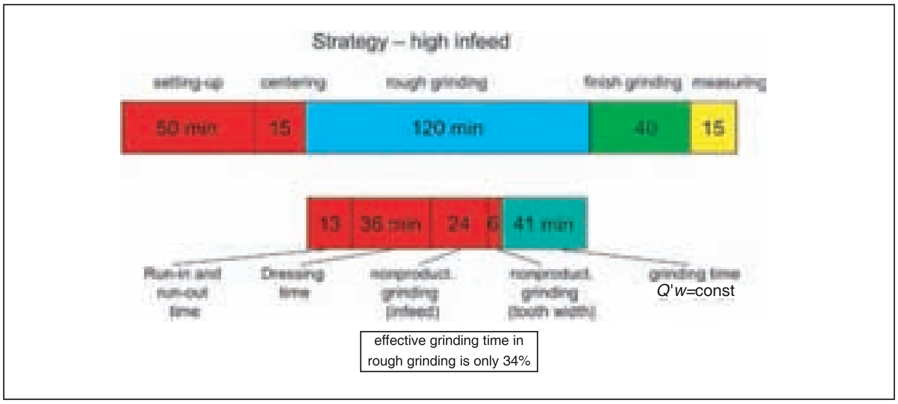

Figure 1—Typical cycle time in profile grinding of large gears.

f_a = 12,000 mm/min. In principle, there are two strategies to reduce the total amount of stock Δxx_{total}. One is using high feed speeds, and the other is using a high radial feed. It is obvious that using a higher axial feed, for example, by a factor of three, results in an increase of strokes by a factor of three as well. Running more strokes effects a longer cycle time because each stroke needs an approach travel to accelerate the axis to the axial feed speed as well as an over travel to decelerate as shown in figure 4.

Table 1 shows a cycle time comparison for different grinding strategies. The first strategy is running the cycle with a high radial infeed. For a given specific material removal rate of 10 mm^3/mms, and an axial feed speed of 4,000 mm/min, the radial infeed per stroke results in 0.15 mm. To remove the total amount of radial infeed Δx_{total} of 3.0 mm, 20 strokes are necessary. The second strategy is running the cycle with an axial feed speed of 12,000 mm/min, which effects 60 necessary strokes to remove the total amount of stock. The idle-time-per-stroke depends on the acceleration and deceleration time of the axial axis. Figure 5 explains the relation between the acceleration and deceleration time per stroke in dependency of the acceleration rate of the axis. The accelerating and decelerating time per stroke at a typical axis acceleration rate of 1 m/s^2 for 4,000 mm/min axial feed speed takes about 0.35 s, while this time increases to 0.6 s at a speed level of 12,000 mm/min. The effect of this increase can be seen in Table 1. The pure grinding time for both strategies is still the same, but the idle time is getting much longer. This is the reason for a total cycle time that is 34% longer compared to the strategy of high infeed. Even when running the machine at an acceleration rate of 2 m/s^2 (strategy No. 3 "high speed 2"), the total cycle time is still increased by 23%.

Furthermore, an increase of axis acceleration has limitations due to the higher load of all mechanical components such as bearings, spindles and guide ways.

The strategy of grinding at higher axial feed speeds finally results in longer idle times, although the specific material removal rate stays constant and thus is not appropriate. Experimental trials done at Gleason Pfauter have shown that grinding typical wind turbine gears at 12,000 mm/min axial feed speed have 36% longer idle times (Table 1) than grinding at 4,000 mm/min axial feed speed and higher radial infeed. To offset this time delay, an increase of the specific material removal rate from $Q'w$ = 10 mm^3/mms to $Q'w$ = 14 mm^3/mms would be necessary. But this would tremendously increase the risk of grinding burn. In other words, it is not possible to achieve a higher productivity by higher feed speeds without an increased risk of burn. In addition, such an increased material removal rate would just affect the 41-min effective grinding time as shown in Figure 1, which again is just 17% of the total cycle time. Increased mechanical load on axis components and increased electrical power consumption are disadvantages at this comparison.

Thus, focusing on other strategies to increase the productivity on both sides is needed, i.e.:

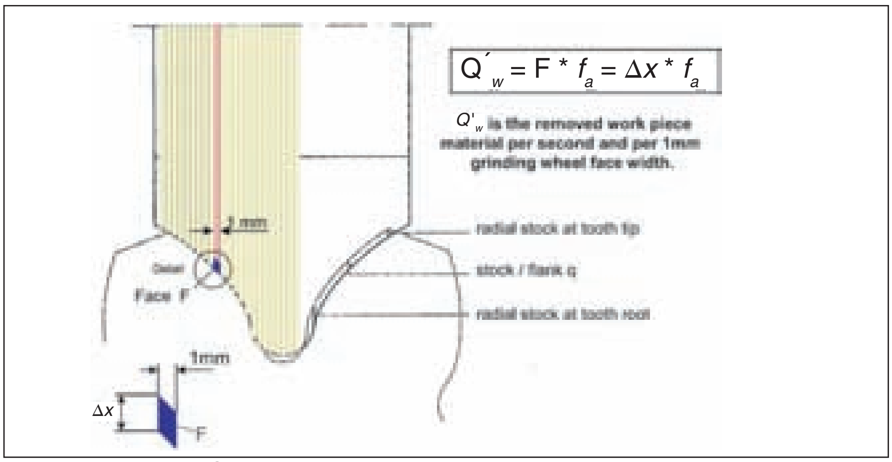

Figure 2—Definition of *Q'w* in discontinuous profile grinding.

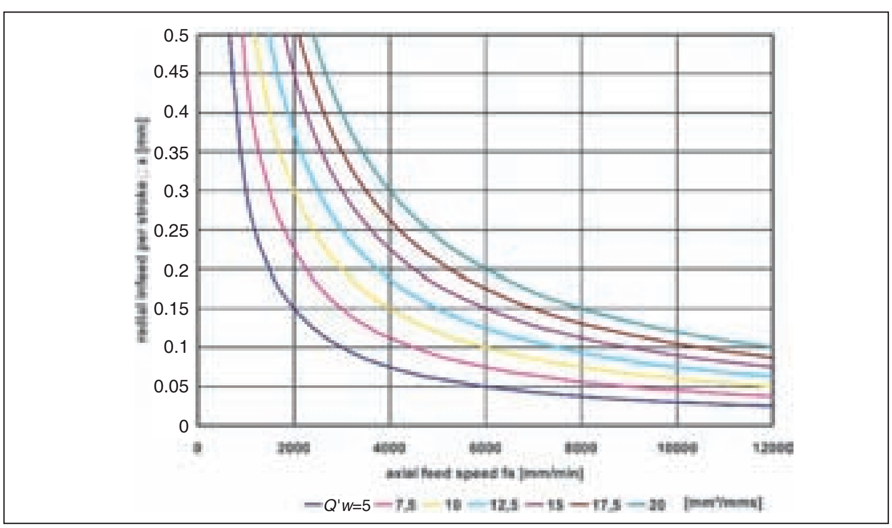

Figure 3—Relation between radial infeed and axial feed speed at constant *Q'w*.

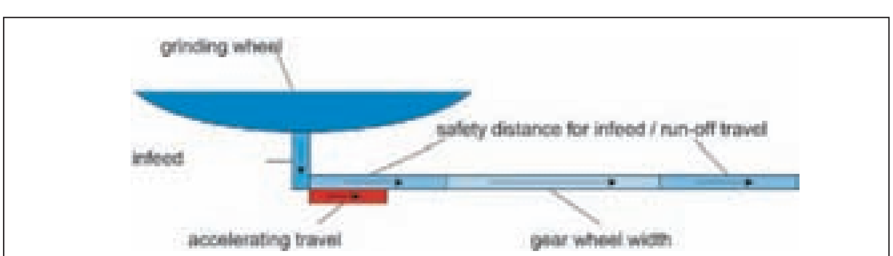

Figure 4—Approach and overtravel in profile grinding.

- The main grinding time
- The non productive times

Multiple-Wheel Profile Grinding

The use of multiple-wheel profile grinding offers several possibilities to increase the performance or the workpiece quality. In a case where the teeth have no special profile modifications, four instead of two flanks can be ground simultaneously in roughing and finishing operations, which will reduce the grinding time by a factor of two. Just as well, it is possible to reduce the risk of burn significantly without impacting the productivity when compared to conventional profile grinding. Therefore, just the two external wheels are grinding and the middle one is not touching the teeth. This affects a smaller contact angle between the grinding wheels and the tooth flanks. Schlattmeier (Ref. 3) describes the risk of grinding burn as becoming lower the smaller the contact angle gets. The reverse conclusion allows an increase of the specific material removal rate at the same burning risk when grinding with just the external wheels; thus the cycle time will be reduced.

Another possibility is to grind four instead of two flanks at a time with a lower *Q'w*; thus the productivity is the same but at a much lower burning risk.

An attendant important point for ground gears is the surface finish. Investigations (Ref. 6) have shown that the load capacity of a ground gear can be tremendously increased by a very good surface finish of Ra < 0.2 µm. In conventional profile grinding, using just one grinding wheel, such a good surface finish is not achievable because the grinding wheel is designed as a compromise for rough and finish cutting. Therefore, for high-quality gears an additional process called barrel finishing is used to achieve this surface finish. The use of multiple wheels as shown in Figure 6 allows the use of different grinding wheel specifications for rough and finish operation, thus providing the capability to achieve a good surface finish of Ra < 0.2 µm without the additional barrel finishing process. To realize such good surface finish, the two external wheels are only used for the roughing operation; and the middle one, with a fine grit size, is used for the finish operation. During roughing, the middle wheel is dressed to a smaller diameter in order to avoid touching the flanks, while during finishing the two external wheels are dressed to a smaller diameter.

Last—but not least—it is even possible to increase performance when using the anti-twist grinding method. The unique point in this method is to achieve the twist modification in dual-flank grinding, as opposed to doing it flank-by-flank, which doubles the grinding time. With the use of multiple grinding wheels, it is now even possible to further enhance performance by using four flanks for roughing and two flanks for finish grinding—including the anti-twist modification.

continued

Table 1—Cycle time comparison for different grinding strategies.

			High Infeed	High speed 1	High Speed 2
Total radial infeed	Δx_{total}	mm	300	300	300
Axial feed speed	f_a	mm/min	4,000	12,000	12,000
Spec. material removal rate	$Q'w$	mm3/min	10	10	10
Radial infeed per stroke	ΔX	mm	0.05	0.05	0.05
Face width	b_{eff}	mm	278	278	278
Grinding time per stroke	$t_{h\ stroke}$	s	4.17	1.39	1.39
Axis acceleration rate	a	m/s²	1	1	2
Acceleration and deceleration time per stroke	t_{n1}	s	0.35	0.6	0.4
Idle time for radial infeed and pitch movement	t_{n2}	s	0.1	0.1	0.1
Number of strokes	n	--	20	60	60
Total grinding time	t_h	s	83.4	83.4	83.4
Total idle time	t_n	s	9	42	30
Total time per tooth slot	t_{total}	**s**	**92.4**	**125.4**	**113.4**
				+36%	+23%
Time ratio (idle time/grinding time	t_n/t_h	--	11%	50%	36%

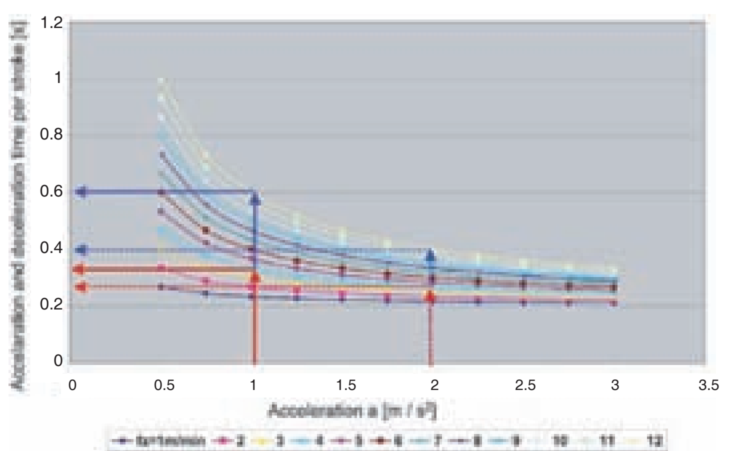

Figure 5—Acceleration and deceleration time per stroke.

Threaded wheel and profile grinding in combination. Threaded wheel grinding is known as a much faster grinding process because there are no idle times for pitch movements between the teeth, and it is thus appropriate for grinding gears with a large number of teeth. But threaded wheel grinding of large-module gears has limitations regarding the achievable quality.

The highest quality level can still be achieved by profile grinding, but a lot of investigations are being made to use threaded wheel grinding for rough- and finish-grinding of large-module gears (Ref. 5). One new strategy is to use threaded wheel grinding as a fast roughing cycle and profile grinding to achieve a high quality level, which for high-module gears is typically in the range of DIN 1–2. But this technology requires new machine concepts capable of running both cycles. New machine series are in development capable of combining the advantages of both cycles. The grinding head of that machine is designed to use threaded grinding wheels, as well as profile grinding wheels, as shown in Figure 7. In addition, the machine is capable of changing those wheels automatically within a grinding cycle via a special tool changer.

Figure 8 shows an example for cycle time reduction when using threaded-wheel grinding for roughing, and profile grinding for finishing. The total cycle time can be reduced from 127 to 77 min.—a reduction of 40%.

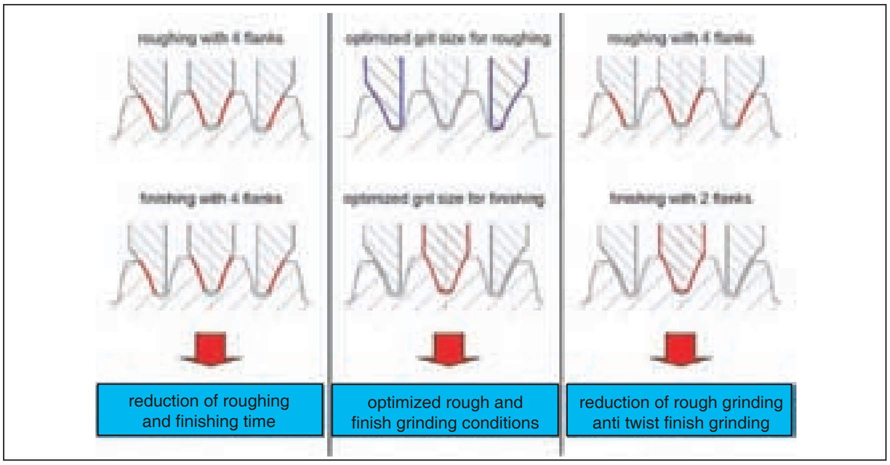

Figure 6—Multiple wheel profile grinding.

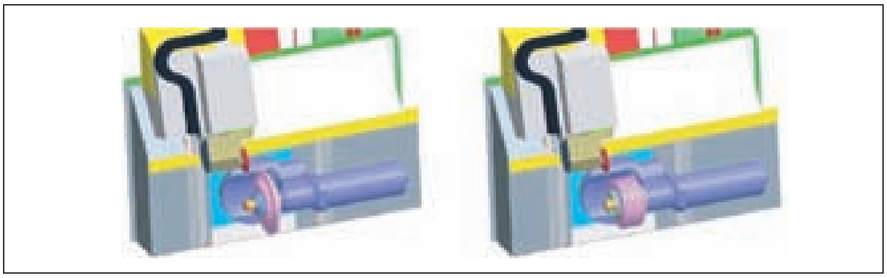

Figure 7—Grind head for profile and threaded wheel grinding.

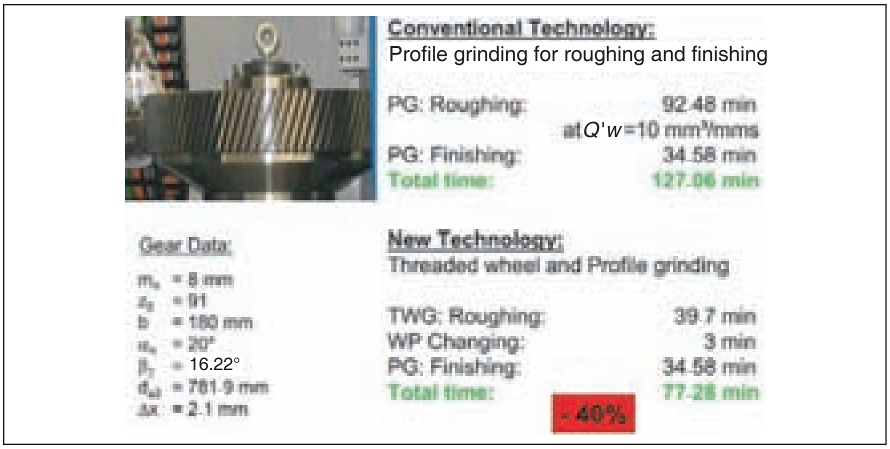

Figure 8—Comparison between conventional and new technology.

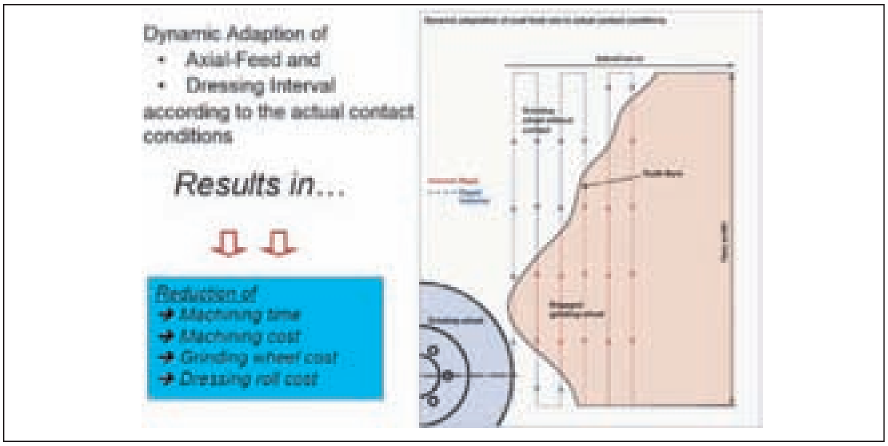

Figure 9—Adaptive technology to reduce cycle time and dressing time.

Adaptive Grinding Technology

Another important aspect in reducing main grinding time is to avoid so-called "air grinding." If using the conventional technology as described above, the maximum amount of stock is subdivided into a certain number of strokes, which will be passed through with the programmed axial feed speed. But due to hardening distortions, the amount of stock is not constant over the tooth flanks and around the gear, as shown in Figures 9 and 10, resulting in a considerable amount of stroke length not grinding the gear.

To avoid this unproductive air grinding, an acoustic emission sensor technique is used to detect whether the grinding wheel has contact with the workpiece. In case the wheel is running without contact, the axial feed speed is increased to a maximum speed, effecting time savings. Additionally, the dressing intervals can be increased as well. Instead of dressing the wheel after a certain number of strokes, the wheel is dressed after a certain amount of effectively ground stroke length. This is reducing dressing time as well as tool cost, i.e., grinding wheel and dresser. The adaptive technology allows time savings up to 33%. So the more critical the hardening distortions, the more effective the adaptive technology.

Power Dressing

The reduction of dressing time is another important aspect for productivity improvement. When mounting a new grinding wheel, the shape does not fit to the required profile and thus has to be dressed.

In conventional dressing, the target profile (red line) is dressed as shown in Figure 11. The dresser is starting to follow path No. 1, then 2, and so on until it reaches the final profile. This means that the dresser is covering a volume (blue), which is shown on the right-hand side of Figure 11. This volume is much higher than the real dressed volume, showing that this dressing method is not very efficient.

To avoid this ineffective dressing volume, Gleason has developed the so-called "power dressing" method (Fig. 12). Instead of dressing pass-by-pass, parallel to the target profile, the dresser works in the radial direction. Therefore, the raw profile of the wheel is programmed to the machine, which allows starting the dressing cycle just outside the wheel and infeeding in the radial direction until the target profile is reached. The effect is that the processed volume (blue) is almost the same as the real dressed volume, representing the high efficiency of this method.

Depending on the raw profile of the grinding wheels, as well as the gear data, the dressing time compared to conventional dressing can be nine times faster, as shown in Table 2.

Workpiece Clamping System to Reduce Setup Time

As shown in Figure 1, setting up the workpiece consumes a large portion of the overall cycle time. This is caused by the workpiece weight, which can easily be up to several tons. Aligning such big gears in order to avoid eccentricity and wobble, which would effect an increase of air grinding, is time consuming.

In order to reduce this time, two technologies exist. The first one is the wobble and eccentricity compensation, which is patented by Gleason. The idea behind this is to avoid the time-consuming alignment of the workpiece and to instead measure the eccentricity and runout. Once these two values are known, the machine software can compensate for this with special machine movements resulting in a ground gear without runout and wobble. Figure 13 shows the possibilities by which to measure the eccentricity and runout. Depending on the application,

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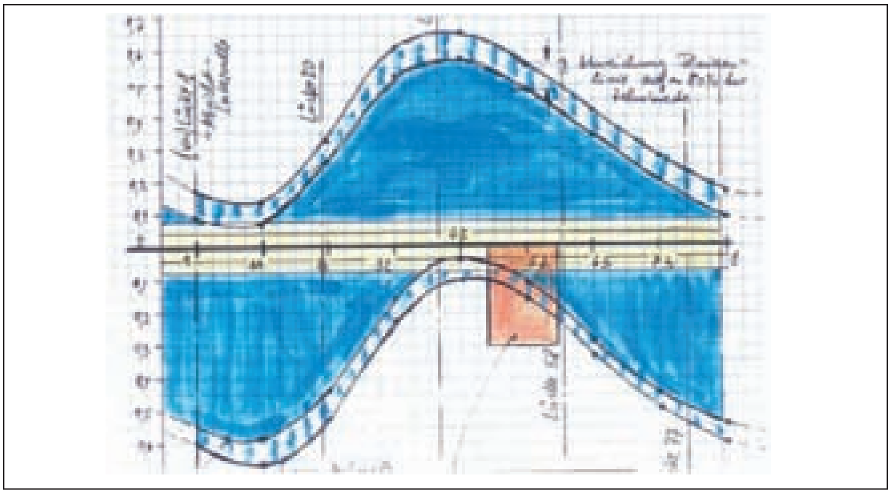

Figure 10—Typical runout of hardened gears.

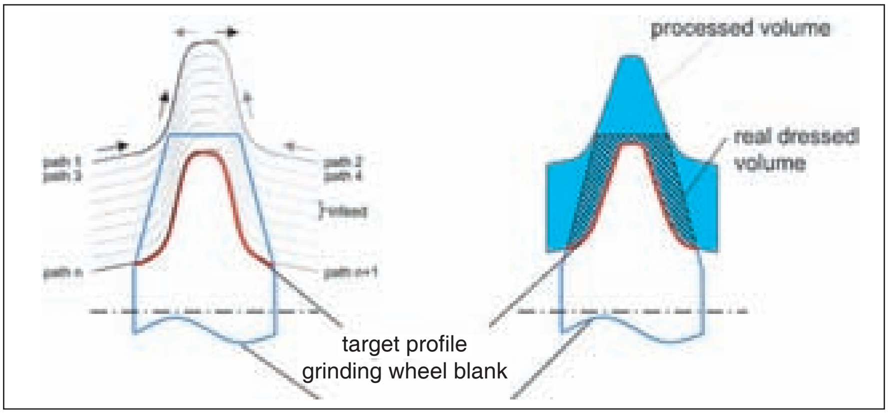

Figure 11—Conventional dressing.

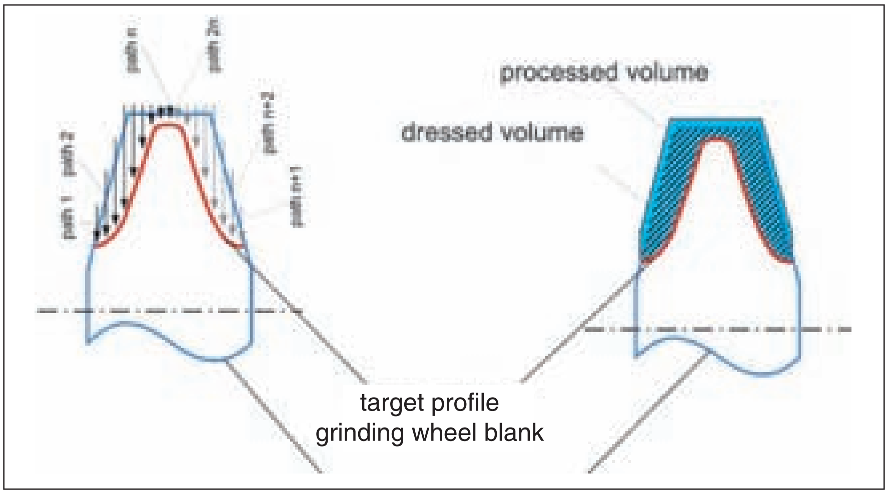

Figure 12—Power dressing.

there are four different possibilities to get these values.

The second possibility to avoid non-productive time for setting up the workpiece is the use of so- called "zero-point clamping systems." Instead of fixing the workpiece directly to the machine table, the workpiece is prepared outside the machine using a special-designed pallet. The workpiece still has to be aligned to this pallet, but this does not consume machining time since it can be done parallel to the grinding operation. When grinding a new gear, this pallet has to be loaded to the machine table, which has a special adaptor ensuring that the workpiece is centered correctly to the machine axis. Both systems help to reduce non-productive setup time tremendously.

Table 2—Performance Comparison of Power Dressing vs Conventional Dressing

Module	14		10		8		5	
No. of teeth	15		10		34		18	
Wheel width	50		40		30		20	
Convention (mm:ss)	20:27	55:37	k.A.	k.A.	9:47	31:30	4:48	13:12
Powerdressing (mm:ss)	4:40	6:16	3:10	4:30	3:48	3:55	2:11	2:48
Performance factor	4.4	8.9	k.A.	k.A.	2.6	8.0	2.2	4.7

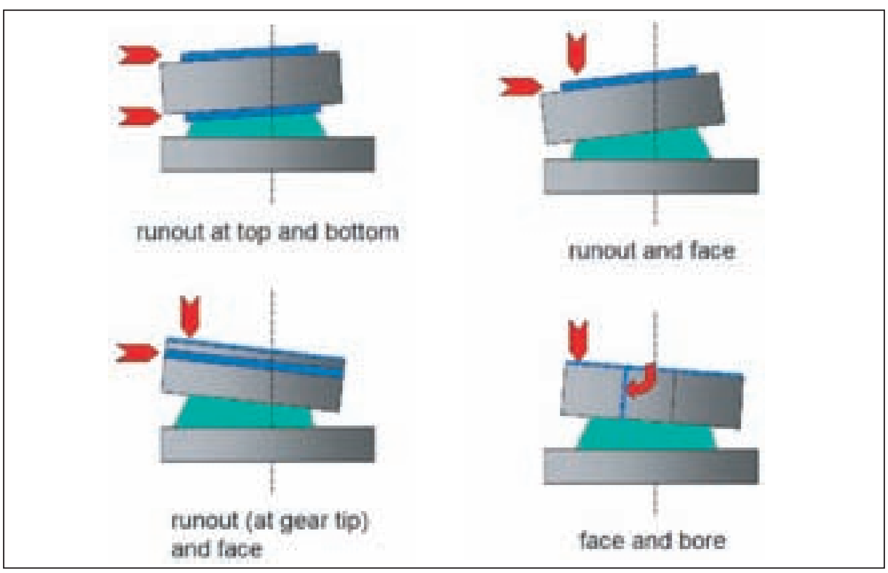

Figure 13—Possibilities to measure eccentricity and runout.

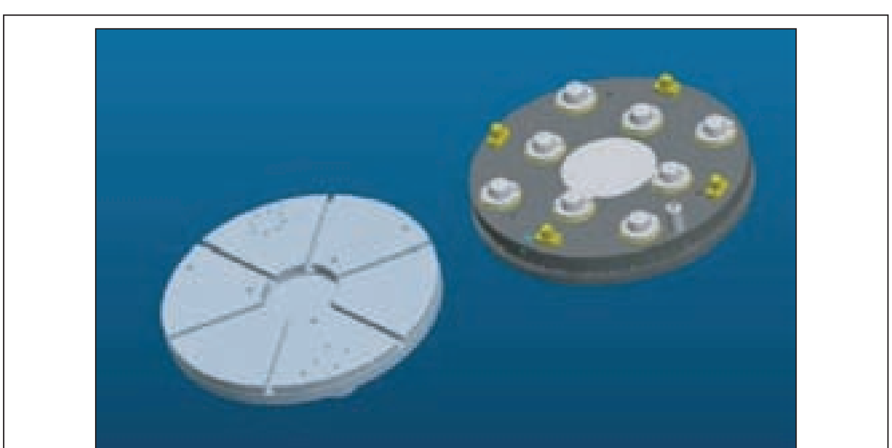
Figure 14—Zero-point clamping palette to reduce setup time in the machine.

Conclusion

Due to the boom in wind power energy, the request for ground gears has increased significantly. Those large-module gears are usually ground using profile grinding. But this process, which produces the highest possible quality, is not very productive compared to other processes such as threaded-wheel grinding. This paper provides an overview of the newest developments to reduce the overall cycle time, including aspects to reduce setup time, idle time and productive time, as well as dressing time.

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The Effect of Start-Up Load Conditions on Gearbox Performance and Life Failure Analysis, with Supporting Case Study

R. J. Drago

Management Summary

Most gearboxes are rated based on one or more of several criteria, such as peak applied load, nominal operating load, prime mover rated power, driven machine load spectrum, maximum expected overload, etc. These load conditions are used to predict the expected operating life of the gear and bearing system. In many cases—especially where the load and/or speed vary significantly during the normal operational cycle of the gear system—a great deal of attention is paid to the spectrum of load conditions, often resulting in the definition of extensive load/time tables, which are used in a Miner's rule (cumulative damage theory) or Weibull approach to the calculation of the expected life for gear systems under these widely varying, load-speed-time conditions. However, one important factor is very often neglected—the starting load.

If a gear system is run continuously for long periods of time—or if the starting loads are very low and within the normal operating spectrum—the effect of the start-up conditions may often be insignificant in the determination of the life of the gear system. Conversely, if the starting load is significantly higher than any of the normal operating conditions, and the gear system is started and stopped frequently, the start-up load may, depending on its magnitude and frequency, actually be the overriding, limiting design condition. In these cases, failure to account for the start-up load (Ref. 1) conditions in both the basic design of the gear system and in the proper attention to detail of tooth modification, can lead to premature, seemingly unfathomable failures.

This paper addresses the issue of start-up loading and its effect on the performance of a series of gearboxes in an industrial application by virtue of a specific case study. A description of the failures that occurred, and the test program and results that led to a definition of the root cause of the failures and a path of correction, are also presented.

While not addressed in this paper, it should be noted that shut-down load can, in rare cases, also be extremely significant in the design of the gear system due to the very high, short-term loads that can be applied in certain applications. In one case in the author's experience, a gearbox that was used in a high-speed turbo compressor application failed due to very high loads that were caused by an improper shut-down procedure on the driven machine that generated high back pressures and inertial forces sufficient to damage the gears.

Introduction

When gearboxes are used in applications where the connected load has high inertia, the starting torque transmitted by the gearbox can be a great deal higher than the rated load of the prime mover. Power plants often require several evaporative cooling towers or large banks of air-cooled condensers (ACC) to discharge waste heat (Fig. 1). Because of the very large size of the fans used in these applications, they fall into this category of high-inertia starting load devices.

The typical evaporative cooling tower or air-cooled condenser unit is composed of an electric motor that drives a large fan through a gearbox. This assemblage generates air flow for the purpose of removing the waste heat from the power-generation process. In a typical air-cooled condenser application, many identical units (typically 20 to 40) are installed in an array to provide the total cooling required for a large facility. Depending on its type, these geared fan units may operate almost constantly ("base load" plants, e.g.) or very intermittently ("peaking" plants).

The fans in these units are generally very large, and thus have significant inertia (Fig. 3). When started from zero speed, a very high torque is required to accelerate the fan to normal operating speed. If the fan is started infrequently yet run continuously for long periods of time, this high starting torque is of minimal significance. However, when the fan is started and stopped frequently, the number of cycles at the high starting torque can accumulate to a point where they can cause extensive fatigue damage—even if the gear system is adequately rated. Where the gear unit is marginally rated, very early, catastrophic gear failure often results.

As part of the overall investigation of several failures in such gearboxes, we measured starting torque on a typical installation, examined many failed gears and calculated the load capacity ratings for the gearboxes under actual operating conditions. This paper describes the failures observed, the testing conducted, the data analyses and the effect of the high measured starting torque on the life and performance of the gear systems. The test results were surprising, especially during starts where the fan was already windmilling due to natural air flow in the ACC bank. In the final analysis, the importance of appropriate profile modifications is also clearly demonstrated (Fig. 4).

The Initial Incident

A failure was reported in the low-speed gear set of a triple-reduction, single-helical gearbox (Fig. 5). The gearboxes are used in an air-cooled condenser (ACC) facility at a power plant, and had been in service for about four years at the time this investigation was initiated.

The initial failed unit is one of 30 identical units at the same facility, Site A. An identical bank of units, Site B, is also in service for a similar time period at a "sister" power plant in the same state. The first failed Site A unit that we examined had accumulated just over 13,000 hours of loaded service, and during that time had been subjected to more than 7,000 start/stop cycles. All of the gears in these units are carburized, hardened and profile-ground.

Subsequent to this first failure, several additional, very similar failures were also discovered on Site A gearboxes. Additional, ongoing periodic visual inspections of the remaining gearboxes at Site A continue to reveal additional failures. Careful evaluation of the additional low-speed gears showed them to have very similar damage characteristics. It is clear at this point that all of the units at Site A are very likely to eventually suffer similar failures over time.

It was initially reported that, though the systems

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Figure 1—Air-cooled condenser bank.

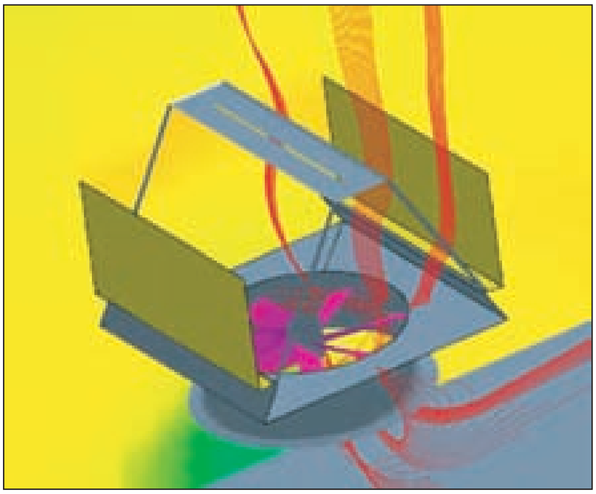

Figure 2—Air-cooled condenser schematic.

Figure 3—Installed air-cooled fan.

Figure 4—Spalled single tooth.

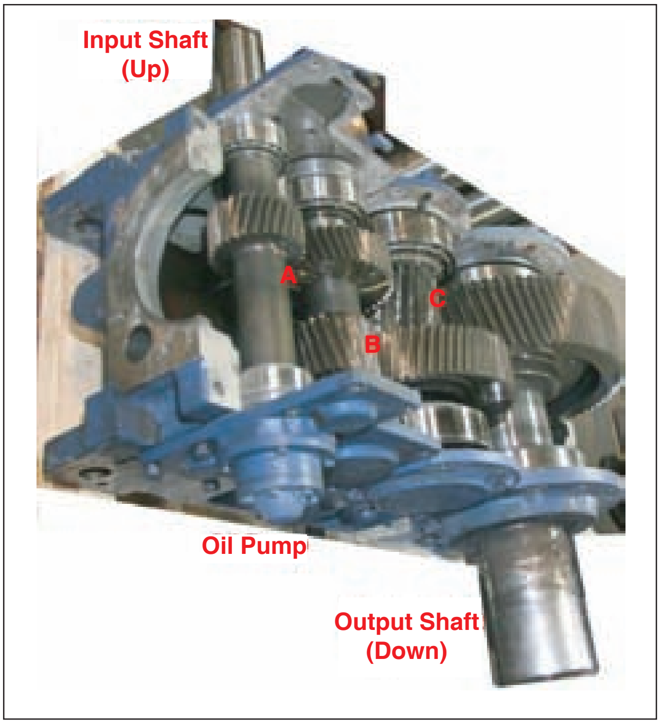

Figure 5—Triple-reduction gearbox (shown in normally installed attitude).

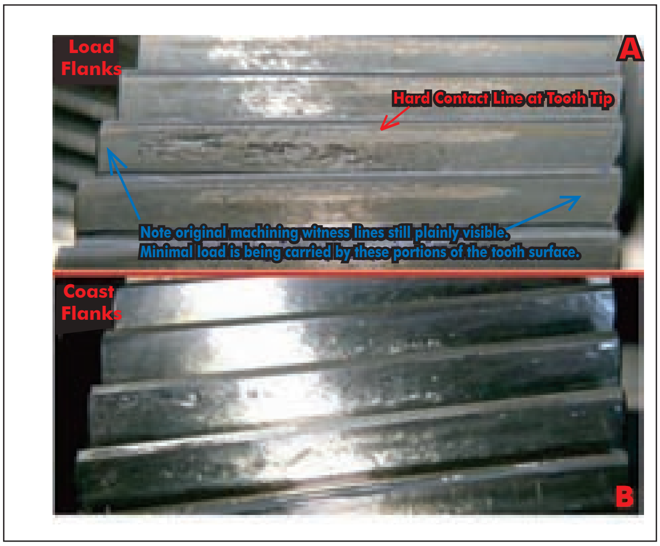

Figure 6—Low-speed gear.

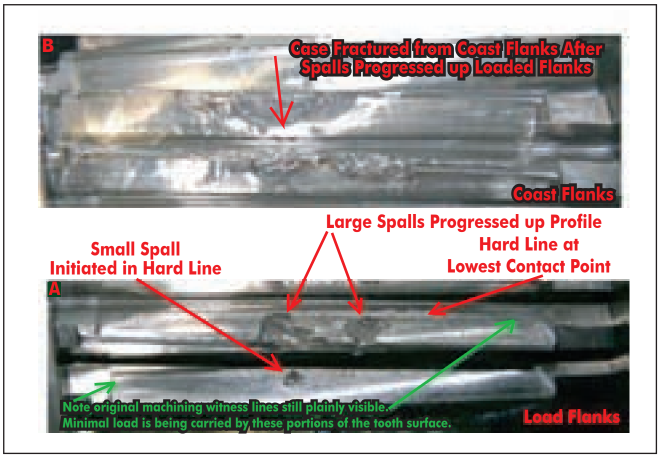

Figure 7—Low-speed pinion.

(gearboxes, fans, motors, controllers, etc.) were identical at the two sites, the gearboxes at Site B had not experienced any failures. As the investigation progressed, however, we did find some indications of very early stage failures of low-speed gears at Site B which were very similar in nature to those observed on Site A. The extent of the damage observed on the Site B low-speed gears was much less than that observed on the low-speed gears on the Site A gearboxes, and to date none of the Site B gearboxes has actually been removed from service due to low-speed gear damage.

Obviously, since the units are identical at both sites, this concentration of failures at Site A and the lack of any apparent failures at Site B was something of a puzzle. Even with the discovery of some very early stage damage on the Site B low-speed gears, it is clear that something is different between the two sites.

After in-depth evaluation of the characteristics of the sites, the only significant difference identified was the fact that Site A was operated as a "peak load" plant, while Site B was operated as a "base load" plant. In the operation of a base load plant, the fans would run almost continuously, with very limited start/stop cycles. In contrast, the operation of a peaking plant involves multiple, frequent start-stop cycles.

While the number of start-stop cycles is different between the two sites, the nominal power draw on the motors at both sites A and B during normal, full-speed, steady-state operation was found to be very much the same.

The Failure

Initial evaluation of the gearbox indicated that the primary damage was on the low-speed gear set. The high-speed and intermediate gear sets did show some damage, but it was largely inconsequential. The low-speed gear (Fig. 6), exhibited a very hard line of contact near the tip of the tooth. This hard, localized region of contact indicates that the tooth did not have sufficient profile modification for the applied loading. The shape of the damaged area suggests that the gear set had some crowning (probably applied to the pinion) to accommodate misalignment. The damage pattern observed on the gear tooth-loaded flanks, however, is slightly heavier on the left end of the face (Fig. 6). The relatively short area of damage indicates that the crown applied to the low-speed gear mesh is likely too large for the applied loading. This tends to concentrate the load in the center portion of the face while unloading its ends. This increases the localized stresses in the heavy-contact region. This is very apparent on the loaded tooth flanks shown in Figure 6.

The location of the damage observed on the low-speed pinion (Fig. 7) corresponds to the damage observed on its mating gear. However, the level of damage on the low-speed pinion is much more severe than that on the mating, low-speed gear. Since the pinion sees many more cycles than the gear, the disparity in the level of damage is expected. The location of the very hard line of contact near the tips of the gear teeth corresponds closely to the similar hard line of contact at the lowest contact point on the pinion teeth. As noted above, this hard contact indicates a lack of adequate profile modification on the pinion or gear or both.

The specific failure mode observed on the pinion is spalling, or surface durability distress. Specifically, spalling is a fatigue mechanism that occurs when very high, local stresses initiate cracks at or near the tooth surface. These cracks progress into the hard case on the tooth surface and progress up along the tooth surface, from the lowest contact point, in the direction of sliding on the tooth surface. As the cracks progress, material on the tooth surface is undermined, and eventually relatively large, somewhat fan-shaped pieces of tooth surface are liberated. This mechanism is clearly shown in Figure 7. As the cracking progresses through the carburized case on the loaded flanks of the teeth, it eventually propagates across the tooth thickness—generally fairly close to the tips of the teeth—and fractures the entire case off the tooth, even extending back onto the coast flanks. Essentially, the carburized case is "peeled" from the loaded and unloaded tooth flanks. (More detail on this failure mode is presented below.)

In addition to the hard line at the lowest contact point, the pinion distress also suggests that the teeth are somewhat over-crowned. This condition is similar to that observed on the mating, low-speed gear, as noted above. Careful examination of both Figures 6 and 7 also shows small areas of the loaded tooth surfaces at both ends of the face width, where the original witness marks from the tooth-finish grinding operation are plainly visible. These areas of relatively light loading further indicate the possible over-crowned condition. In addition, they also indicate that misalignment across this gear mesh is not a major factor in the occurrence of the low-speed gear set failure. While it may be more of a factor on other low-speed sets, it is not the primary causative agent, though it is certainly contributory.

Load Capacity Evaluation

In order to better understand the cause of the failures observed, we calculated the basic load capacity rating of each gear set in the gearbox. The load capacities are best understood by looking at the service factors for each gear mesh, as summarized in Table 1.

As shown by the data in Table 1, although the strength ratings are above the applied power, the durability ratings of the low-speed pinion and gear are less than the applied power. These low power ratings result in durability service factors that are less than unity (1). In an application such as this, we would normally recommend a minimum service factor of at least 2.00. The lower service factor on the low-speed pinion relative to the higher (but still below the recommended minimum) service factor on the mating low-speed gear is consistent with the relatively greater damage experienced by the pinion, as compared to the gear. Based on these ratings, premature durability failures of the low-speed pinion and gear would be expected. The relatively high-strength service factors would allow the units to continue operating for a long period of time after the spalling damage had initiated and progressed, though tooth fracture would ultimately be expected. In this particular application, the power supplied by the motor during normal, steady-state operation is slightly less than the motor nameplate rating; thus the durability service factors for the low-speed gear set are actually slightly higher than shown in Table 1 (and very close to unity).

While the low-durability service factors are certainly of significant concern, of and by themselves they do not fully explain the rather catastrophic failures that occur on the low-speed gear sets at Site A—especially in view of the fact that the durability service factors for the intermediate and high-speed gear sets are only slightly higher (there were no reports of catastrophic failure or even significant surface damage), and there were no catastrophic failures of any of the gears at Site B.

In order to better understand just what is happening, we had to first develop the actual failure scenario explaining the catastrophic damage that occurs on the low-speed gears of the Site A gearboxes.

Failure Scenario

While it may seem obvious that the low durability ratings of the low-speed gear set, particularly the pinion, are fully responsible for the failures observed, they are not the sole cause. Some evidence of a small amount of misalignment is apparent, and this certainly plays a role in the failure as well by generating a load misdistribution across the face that results in high, localized stress levels. Further, it appears that there may be too much crowning on the low-speed set (either by error or design), which also results in load concentration toward the midsection of the face width that increases the unit stress levels in that region. Each of these factors exacerbates the problem of relatively low durability ratings.

Another major factor, however, is at work and is the primary compounding cause, acting in concert with the low durability ratings, of the relatively short-term occurrence of the failures observed.

The specific initiating failure mode observed is spalling (not pitting). The spalling initiated at, or very near, the lowest contact point on the pinion tooth where the loads should be very low and, ideally, virtually zero. This is the point at which the mating gear first makes contact with the pinion. In the case of the subject pinion, the high applied loading on the teeth, relative to their inherent, basic capacity, results in tooth

continued

Table 1—Service Factors

Parameter		Strength	Durability
High Speed	Pinion	2.6	1.2
	Gear	2.9	1.2
Intermediate	Pinion	2.0	1.0
	Gear	2.6	1.1
Low Speed	Pinion	1.5	0.8
	Gear	2.1	0.9

Note:
Ratings based on 175,000 hour required life (24 hours/day, 365 days/year, 20 years) using AGMA Grade 1 materials to motor nameplate power, per AGMA 2001-C95.

deflections, which cause very high loads to exist locally as the tip of the gear makes contact with the pinion. This condition is shown schematically in Figure 8.

These very high local loads, combined with the normal, very high sliding that exists at the lowest contact point on the pinion, cause an abnormal, very high, local stress condition.

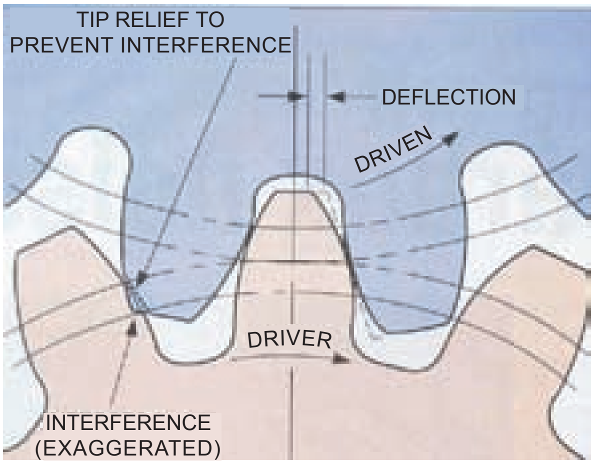

Figure 8—Tip interference due to tooth deflection causes high local loading at lowest contact point.

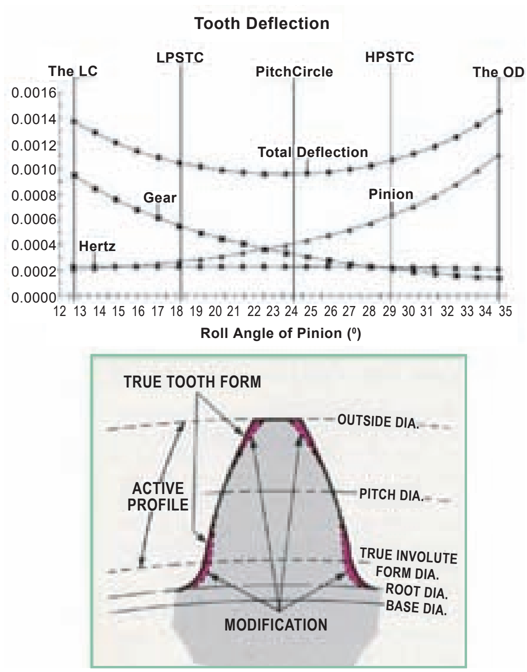

Figure 9—Schematic showing the application of profile modifications to a gear tooth to avoid deflection-induced, high local loading.

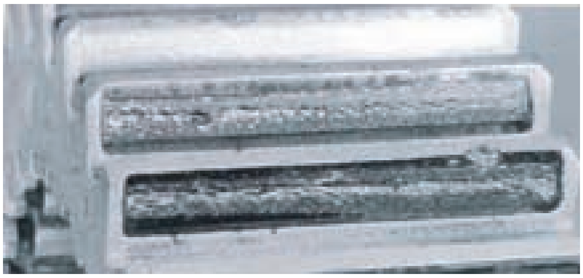

Figure 10—Typical gear tooth pitting failure.

High starting loads, even though applied for a short duration, greatly aggravate this condition because the tooth deflections (and thus the amount of interference) are increased as compared to normal operation. Though normal operation under the conditions depicted in Figure 8 will eventually result in the formation of a "hard" line near the lowest contact point, frequent high-inertia starts shorten the time required to reach failure. This very high load concentration at the tooth tips and tooth flanks is alleviated by applying appropriate modifications to the tooth profile. Typical profile modifications, which are based on the actual deflected shape of the gear tooth, are shown schematically in Figure 9. The deflection curve shown in Figure 9 is for the low-speed gear set and was calculated at the motor nameplate power. Starting loads, which are significantly higher than the motor nameplate-equivalent torque, will result in proportionately larger tooth deflections.

The application of profile modifications does not improve the basic load rating of a gear tooth; however, they do make the tooth much less sensitive to spalling failures, thus allowing the gear set to achieve its inherent life. While the theory is far beyond the scope of our discussion here, spalling failures are not adequately addressed by the durability ratings calculated through the use of the AGMA rating standard. The durability ratings calculated by the standard refer to the pitting failure mode, an example of which is shown in Figure 10, for reference—not the spalling failure mode.

Careful evaluation of the failed pinion (Fig. 7) shows that it did not suffer a pitting failure at all, but rather a spalling failure induced by very high loads at the lowest contact point on the pinion. Note that the damage on the tooth shown in Figure 10 occurs mainly away from the lowest point of contact, and generally in the midsection of the tooth height. This is the typical appearance of classical gear tooth pitting. Conversely, the spalling damage shown on the pinion in Figure 7 starts at the very bottom of the contact zone—in the region of the hard line at the bottom of the tooth—and progresses upward along the tooth profile. This difference is especially significant regarding the remedial actions that are practical for this gear system, as will be explained further below.

As previously noted, spalling is due, among other causes, to inadequate or improper involute profile. The specific nature of the progression of a spalling failure from initiation to complete failure is shown in Figure 11. It is important to note that the very first sign of spalling failure is a relatively innocuous hard line in the region of highest loading, deep in the pinion tooth root. This initial damage is very difficult to see (Figure 11 is shown at high-magnification; thus the damage is obvious). It is possible for the initial stages of spalling to go undetected by a casual observer. The early stages may only be apparent to an experienced, skilled gear engineer. This is an important consideration for Site B (peaking plant), as those gears are subjected to far fewer start-stop cycles, and thus may be in a much earlier stage of progression.

As is the case with the low-speed pinion shown in Figure 7, the initiation of the spalling failure shown in Figure 11 resulted from inadequate profile modification that led to very high loads at the lowest contact point. While spalling is the primary failure mode, its occurrence at a relatively early point in the expected life of these gears was aided by what appears to be excessive crowning, some misalignment across the face width and the inherently low durability rating of the low-speed gear set.

The low-speed pinion also exhibits considerable damage on the coast flanks of the gear teeth (see the top portion of Figure 7). This damage, too, is characteristic of spalling that has progressed to catastrophic failure. To better understand this mechanism, Figure 12 shows a photomicrograph of the cross section of a tooth that has experienced a spalling failure. The cracks—"a"—initiate at or near the surface (Figure 12A) and propagate at an acute angle into the tooth and up along the profile in the direction of sliding. After cracks "a" have propagated sufficiently, the tooth surface is undermined locally, and a relatively large piece of the tooth surface breaks away as the crack "b" progresses to the tooth surface (Fig. 12B). This results in the liberation of relatively large, generally flat chips of tooth material (pitting debris, in contrast, is relatively fine, roundish, small particles) and the characteristic fan-shaped appearance of the damage on the tooth surface (Fig. 12C). As the cracking "a" and "b" progresses, the damaged region on the tooth surface grows ever larger, and the remaining, undamaged, surrounding tooth surface is subjected to ever-increasing unit loads (as the damaged surface spalls away, the remaining surface must carry the full load; thus the unit loading applied to the remaining sound surface increases).

After sufficient surface is destroyed—if the inherent load capacity of the tooth, including especially its bending load capacity, is relatively low (as is the case for the low-speed pinion)—the cracking below the surface will turn in the direction "c," and large portions of the coast tooth flanks will be cracked away relatively quickly. This is the final stage of spalling crack progression, after which the teeth will be

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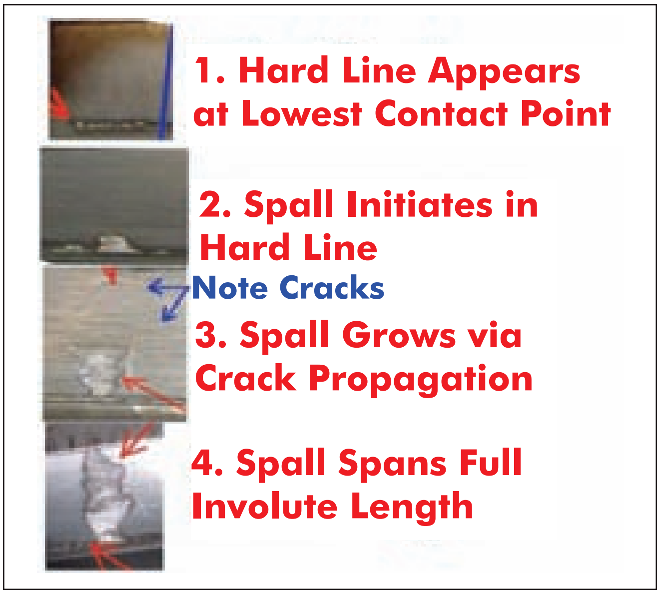

Figure 11—Typical spalling failure progression.

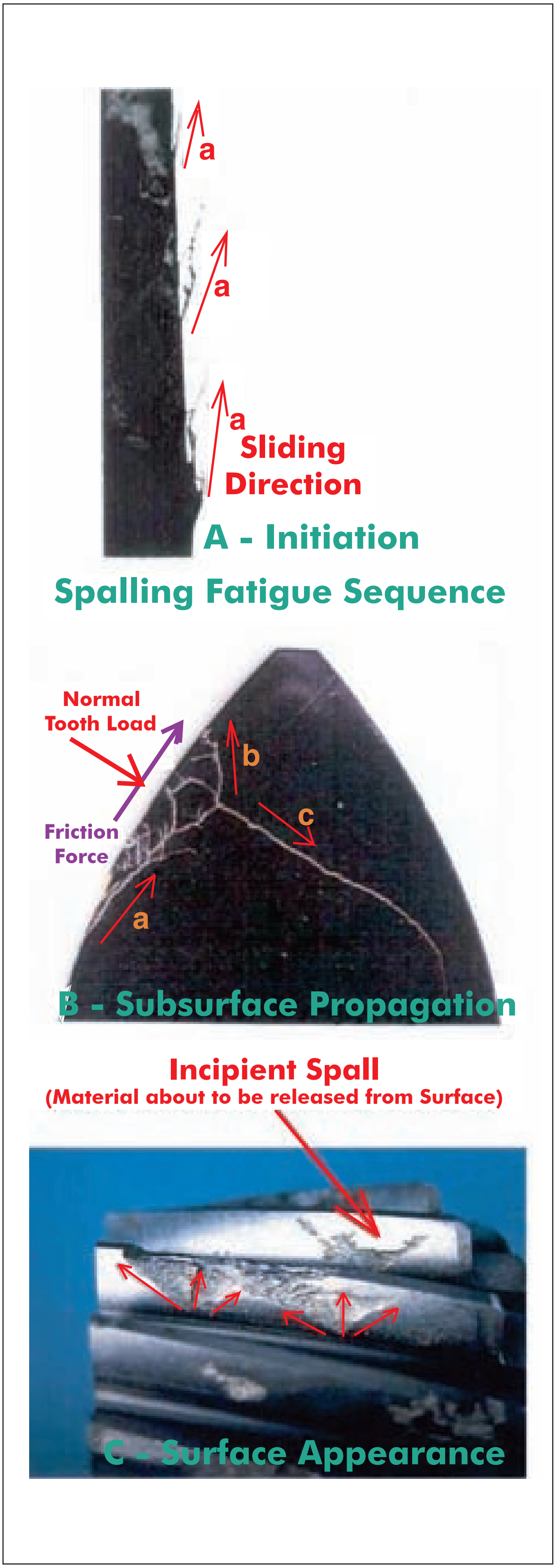

Figure 12—Spalling progression sequence.

completely stripped from the gear. The spalling on the low-speed pinion progressed completely up the loaded flanks (Fig. 7A), wrapped over the tooth tip and down the coast flanks (Fig. 7B). As a result, the low-speed pinion teeth were close to complete tooth fracture and, ultimately, total loss of torque transmission capability.

In order to be sure that our observations on this low-speed gear set were typical of the failures that have occurred on these gearboxes, rather than an isolated incident, we examined another failed low-speed gear set that was selected (by others, randomly) from the "stock" of failed gear sets. A section was removed from approximately the center of the face width of this low-speed pinion (Fig. 13), for laboratory examination.

Careful, close-up examination of a tooth (A) in Figure 15 shows the same mechanism that is presented in Figure 14.

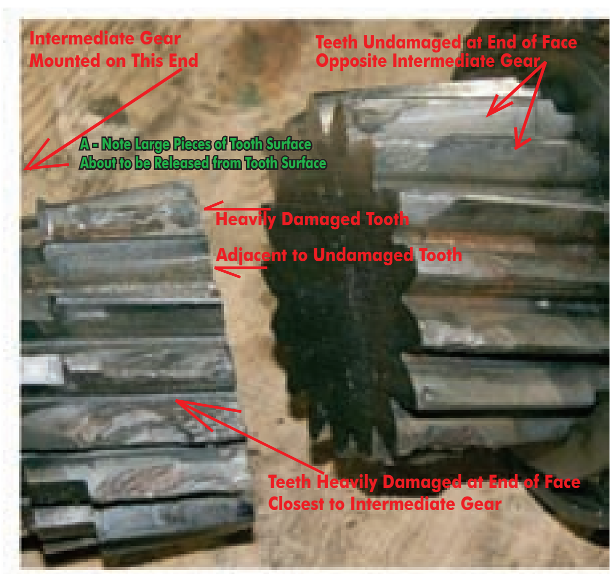

Figure 13—Second low-speed pinion. (Photo taken after section removed for laboratory analysis.)

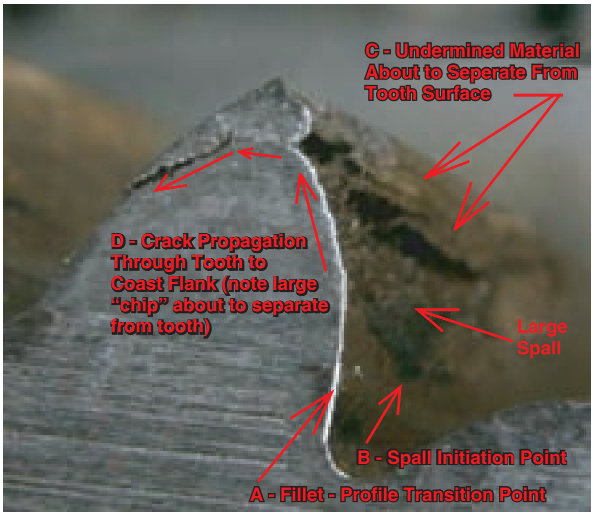

Figure 14—Spall initiation and progression on the pinion tooth (A), enlarged from Figure 11. (Note: Loaded tooth flanks are on the right in this view.)

Because the failure scenario clearly points toward inadequate profile modifications in the presence of high tooth deflections, we had a local vendor conduct a complete inspection (i.e., lead, profile, pitch and pitch diameter runout) of a new, OEM, low-speed gear set before it was installed as a replacement for the damaged, low-speed gear set described above. Of these inspections, the involute chart of the low-speed gear, Figure 15, is of most interest.

This chart shows the gear involute profile to be virtually straight, with no profile modification (the sharp drop-off at the tooth tip is more chamfer than actual tip relief).

The involute chart of the pinion (Fig. 16) shows very similar characteristics. While the pinion does have a very slight amount of tip relief, the flank is completely straight.

Clearly, the same mechanism is at work on the pinion tooth (A) shown in Figures 13 and 14, as that shown in a composite DST image shown in Figure 12. Figure 14 also shows the location of the spall initiation (B) on this tooth in relation to the profile-to-fillet.

The very straight involute chart on the low-speed gear at its tip, combined with the very straight involute chart of the pinion at its flank would, under sufficient load, generate the hard line that was observed at the root of the pinion (Fig. 7). At this critical contact point, there would be about 0.0014 inch of interference due to the total tooth deflection (Fig. 9). Under starting loads, which would be significantly higher than normal operating loads, the amount of interference would be substantially greater.

As noted earlier, the low-speed pinion also appeared to be over-crowned. The lead chart shown in Figure 17 shows this condition as well. Crowning is a very valuable feature, and should be included in any gearbox in an application where some supporting structural deflection can reasonably be expected. This is certainly true of the framework in which these gearboxes are mounted. In addition, some misalignment can also be expected from internal sources, such as bearing clearances and shaft deflections. Still, the amount of crowning and the offset of the crown must all be carefully designed for the specific application. In this case, the crown applied was slightly excessive for the conditions encountered. While this is contributory to the failures observed, it was not a major driving factor.

While all of the pieces of the puzzle fall fairly well into place and point to the combination of a low basic durability rating and lack of adequate profile modification—as the root cause of the failures observed—the significant difference in damage level observed on the low-speed gears at Site A and Site B is still of concern.

As noted above, the most important difference between the two sites involves the number of start-stop cycles experienced by the gearboxes at each site. In order to investigate the loading question further, a program was developed to measure the torque applied to the gearboxes during the start-up cycle and normal loading.

Measured Torque

Site conditions during the testing were what could be called "normal." Wind velocity was not excessive (about 5 knots) and was out of the normal direction. Ambient air temperature was about 68° F. As will be discussed below, the worst-case scenario would be a no-wind condition since this would likely result in a start-up from zero speed. The fans are fitted with an anti-rotation device that prevents them from turning backward, so the worst condition would be a stopped fan condition.

Due to time constraints, only four test runs were made; however, these runs yielded very valuable data.

Test 1 was initiated after the drive had been shut down for several hours. Despite this several-hour down period, when the motor was engaged at the start of test 1, the fan was still turning slowly (windmilling) due to normal cross airflow in the system. Speed at motor engagement was 20.06 RPM for test 1.

Test 2 was conducted quickly after test 1. The power was removed from the drive for several minutes and the fan was allowed to coast down in speed, but the fan did NOT come to zero speed. At the start of test 2, the fan was still turning at a speed of 69.25 RPM when the motor was engaged.

Test 3 was conducted quickly after test 2. After power was removed from the drive for several minutes, the fan was allowed to coast down in speed, but the fan did NOT come to zero speed. At the start of test 3, the fan was still turning at a speed of 24.93 RPM when the motor was engaged.

Test 4 was conducted quickly after test 3 after power was removed from the drive for several minutes and the fan was allowed to coast down in speed, but NOT to zero. At the start of test 4, the fan was still turning at a speed of 26.23 RPM when the motor was engaged.

We examined the data in detail and conducted further analysis so that the results could be presented in graphical form. The results are very interesting and provide a great deal of insight into the loads that are applied to the gearbox during the start-up portion of the cycle.

Figure 18 shows the instantaneous motor torque applied to the gearbox during the motor engagement, while Figure 19 shows the instantaneous motor power delivered to the gearbox during the start cycles measured.

Although the motor comes up to speed relatively quickly, this data shows that during this short period of time, very high torque levels are applied to the gear system. Since the system was not started from zero speed during this testing, we still do not know what the actual "start from zero speed" load would be, but we can make a projection using the data available to us. In order to do so, we plotted starting torque as a function of system speed at engagement (Fig. 20).

We also plotted three straight lines on this figure to represent the most pessimistic (blue), the most optimistic (green), and "nominal" (red) projections to a zero engagement speed starting torque level. (While we have plotted a straight line for simplicity, the actual starting torque will be somewhat exponential, but we do not have enough data to make a better projection at this time. In any case, the data does provide good

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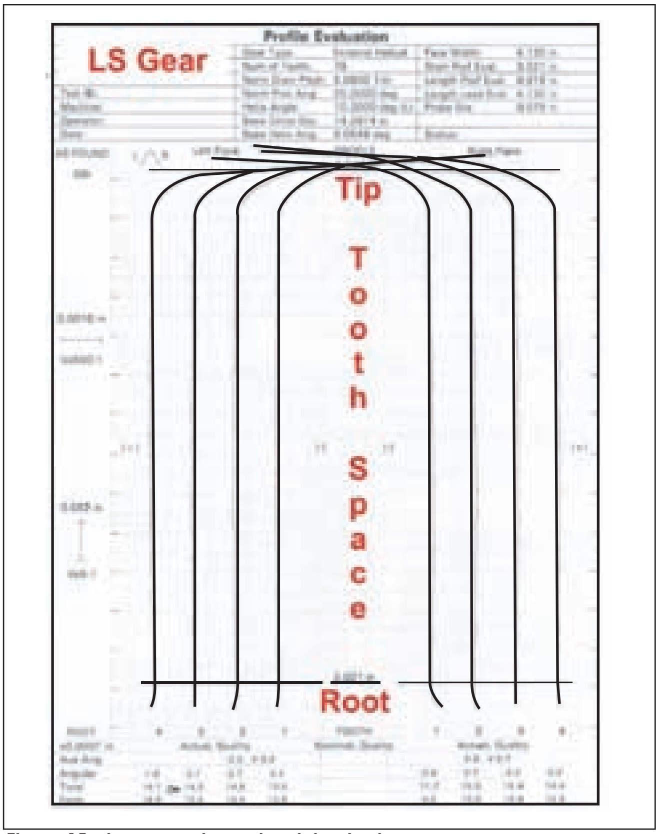


Figure 15—Low-speed gear involute chart.

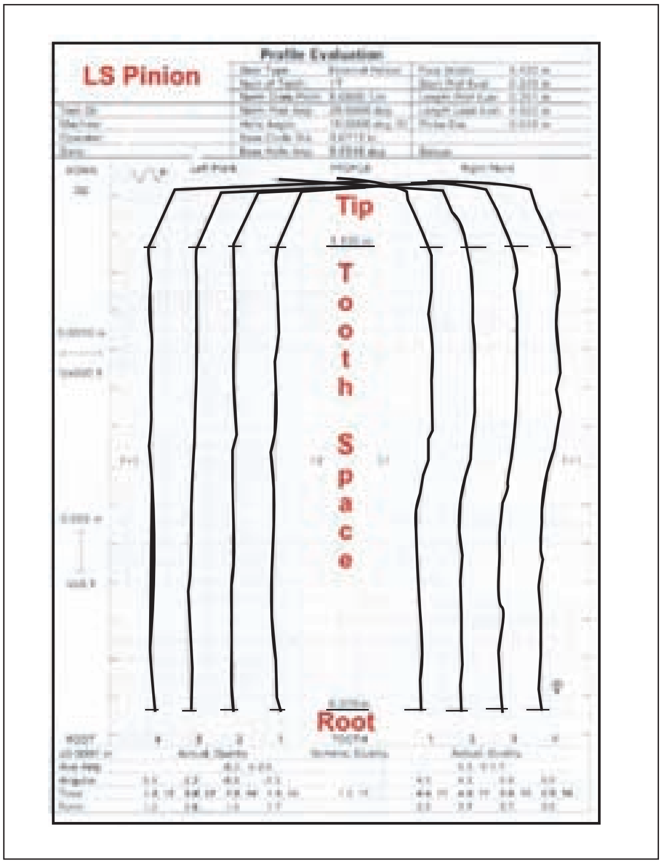


Figure 16—Low-speed pinion involute chart.

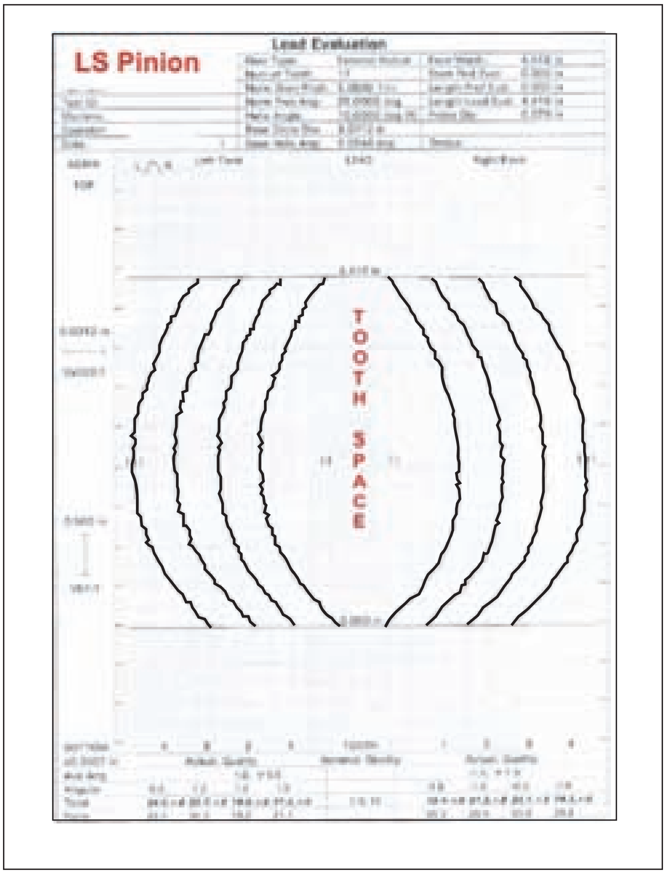


Figure 17—Low-speed pinion lead chart.

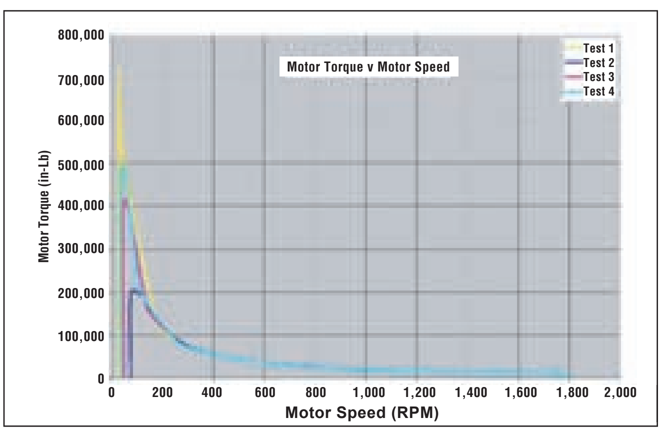


Figure 18—Instantaneous motor torque applied to the gearbox during start-up.

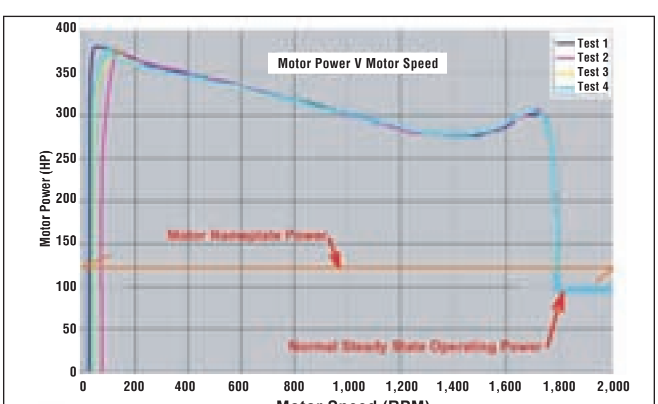


Figure 19—Instantaneous motor power applied to the gearbox during start-up.

insight into the basic operation of the system.) It is possible, but very unlikely, that the zero speed engagement torque might be represented by the pessimistic blue line in Figure 20. We believe that the real value would be somewhere between the most optimistic (green) and the nominal (red) lines. In any case, however, the starting torque is very much higher than the nominal, full-speed running torque provided by the motor. While it is not possible to predict the exact zero engagement speed from the small amount of data available, the data does show that, by any estimate, the start-up loads are very much higher than the operating loads.

It is also both interesting and important to note that, based on the data obtained from this small test program, it may not be the zero speed starting loads that are of most importance. The peripheral observation that the conditions at the site during the testing were relatively benign (no significant wind conditions, 60° F), and that the motor was found to be free-wheeling at about 20 RPM, even after having been shut down for several hours (certainly enough time to coast to a full stop if no other factors were at work), the start-up loads of most interest may be those that occur when the motor is coasting at or above 20 RPM. Even a small amount of freewheeling speed at motor engagement can dramatically reduce the starting torque, as Figure 18 clearly shows. This is a very important observation since it is clear that a consistent starting torque of 1,000,000 in-lbs. (the "pessimistic" projection at zero speed) would most likely have destroyed the gears much sooner than the four years reported here. As the wind velocity increases, I would expect that an unrestrained system would windmill at speeds somewhat higher than the 20 RPM. From the data in Figure 18, even a free wheel speed of 70 RPM (only 4% of full motor speed) drops the zero speed engagement starting torque to 200,000 in-lbs. While this value is still very high relative to the 4,347 in-lbs. normal torque, it correlates better with the observed, approximate four-year "life" of the current gears—especially in view of the very fast, observed ramp time to full speed.

It is also very important to note that the number of cycles that the gears experience during start-up is also relatively low. The data provided is not fine enough to calculate with certainty the number of cycles the gears would experience during typical starts, but based on the information available, the number of motor shaft rotations is probably in the range of 1,000 to 3,000 revolutions between a 'typical" free-wheeling start and full speed. Since the gearbox total ratio is about 22:1, the low-speed pinion would experience somewhere between 45 and 136 revolutions during each start cycle. In addition, the applied torque during start-up decreases as the motor comes up to speed (Fig. 18); thus the maximum start-up load is only applied to the gears for a small portion of the estimated 45–136 revolutions (about 10% to 15%, based on the data available). Over the course of thousands of starts, of course, these cycles would certainly add up; but the total would still be relatively low. The number of recorded starts on the gearbox from which the low-speed gear set detailed in this paper was removed was 7,102 at the time the damage was discovered. Using the estimates developed above, the low-speed pinion teeth in this unit would have been subjected to between 32,000 and 150,000 peak-load, start-up load cycles. (These are rough estimates, but I believe that they are reasonable representations of true numbers.)

These very high starting torque levels cause the involute interference shown in Figure 8, which leads to the spall initiation and progression observed on the low-speed gear set. If these high starting loads are applied very infrequently, they will not significantly reduce the expected life of the gears. If, however, they are applied very frequently—as appears to be the case for the subject drive—they can lead to extremely premature failure of the gear system, as we seem to be observing here.

Additionally, the much lower number of start cycles which the gearboxes at Site B experience explains their significantly longer "life" before damage was observed. And yet, after about six years of operation, the Site B gearboxes did begin to exhibit the early signs of spalling failure that are very similar to those experienced by the gearboxes at Site A. While prediction of "life" based on observed gear condition is difficult at the very best, we estimate that the practical life expectancy of the gearboxes at Site B (base load, infrequent start-stop cycles) is about double that of the gearboxes at Site A (peaking, very frequent start-stop cycles).

Conclusions

This investigation demonstrates the importance of proper involute profile modifications and the extreme influence starting loads can have under certain operating conditions. This is particularly true where the driven load has high inertia characteristics and the number of start cycles is more than trivial.

While the gearboxes were of and by themselves of adequate overall design, the application of these gearboxes in this high starting load environment required special tooth modifications in the form of involute profile modifications of sufficient magnitude to avoid interference at the very high starting load condition.

The gearboxes used in this application are standard "catalogue" type units that have been very successfully used in a variety of applications. In this regard, perhaps the overriding conclusion that can be drawn from this investigation is the need to fully understand the loading and overall operating conditions of any application before selecting a gearbox for use. Often, these conditions require the use of either a custom-designed, single-purpose gearbox or the modification of an available "standard" design to tailor it for use in a particular environment.

The Plan

Work is currently underway to design and manufacture new, set-wise-interchangeable, advanced technology gear sets that will have optimized tooth geometry, improved material characteristics and quality. And, most especially, fully tailored, modified (barrel shaped, tip and flank relief) involute profiles. These gears sets will be used to rebuild all of the gearboxes at Site A and Site B in a phased program over the next several years. While this replacement program will not fully "cure" the problems that have been experienced, it will extend the time to failure for all gearboxes significantly.

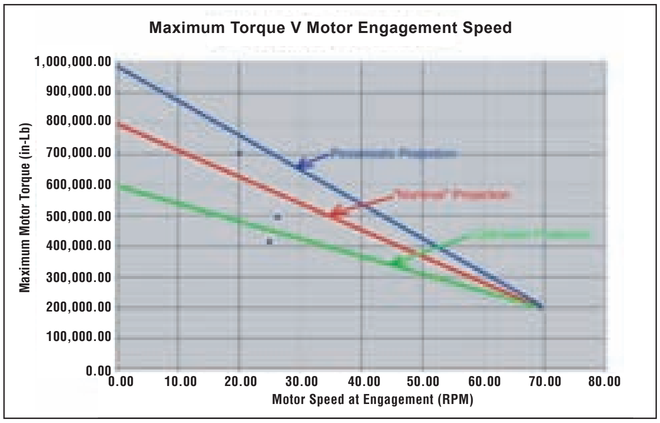


Figure 20—Motor torque vs. motor speed at engagement.

Closing Comment

Obviously, the data provided here is very limited. It would have been very desirable to obtain more extensive data related to other gearbox configurations, operating conditions and environmental variables (wind speed, direction, temperature, effect of operation of units in adjacent cells, etc.). This was, however, a failure analysis effort rather than a research project; thus, the main goal was to understand the root cause of the failures and to develop a reasonable, cost-effective solution. This was accomplished, and the implementation is ongoing. Our purpose in presenting this information in this forum is not the definition of a fully researched study of starting load effects (as welcome as such a study would be), but rather to present useful design and application information in the spirit of the Chinese proverb, "It is better to light a single candle than to curse the darkness." The author hopes that the greater design community reads this material with this limitation in mind.

I can only imagine how much brighter the world of gearing would be if we lit more single candles

In his role as chief engineer of Drive Systems Technology, Inc., **Ray Drago** *is active in all areas of mechanical power transmission. These activities include the design and analysis of drive systems for such diverse areas as large, high-speed paper, printing and cardboard machinery; commercial marine drives; heart pumps; large oil field valves; high-speed cable climbing devices; high-speed gas turbine/generator sets; special automotive racing gearboxes; artificial limbs; mine shaft hoists; air- and water-cooled condensers; miniature gear motors (120 in-oz torque range); automatic bolt torquing devices; very large mining and mill gears; municipal and industrial water and waste water processing system drives and small private helicopter conversions (piston to turbine engines).*

PowderMet2009 features a trade exhibition, 46 technical sessions, six special interest programs and a technical poster program.

Long-Term PM Industry Growth

AFFIRMED BY POWDERMET CONFERENCE PROGRAM

Schedules will be jam packed for attendees of PowderMet2009, the International Conference on Powder Metallurgy and Particulate Materials, where there is no shortage of special events, activities and technical presentations. This is not to mention all the usual attractions the PM industry will find in Las Vegas.

Sponsored by the Metal Powder Industries Federation (MPIF) in cooperation with APMI International, PowderMet features a 100-booth trade exhibition of the latest PM products, raw materials and process equipment. International industry experts will offer more than 200 technical presentations in 46 sessions, six special interest programs and a technical poster program. "The collection of high-quality contributions, coming from both the industrial and research communities, will give those attending PowderMet2009 an opportunity to gain insight into the ongoing evolution of the PM industry," says Stephen J. Mashl, co-chairman of the program committee and global director of research and development for Bodycote plc.

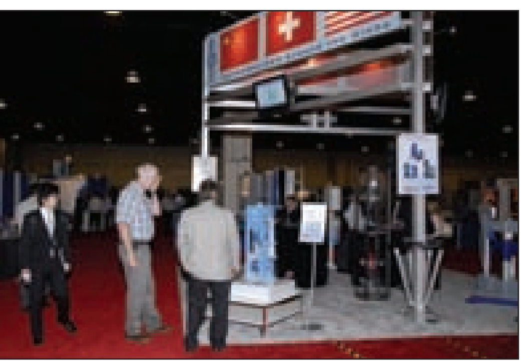
Some topics the technical session will cover include advanced powder production techniques, nanostructured materials, thermal management materials, functionally gradient materials, biomedical applications in powder injection molding, advanced gear processing, foams and structured sandwich materials, titanium-boron materials, trends in metal powders, PM process equipment and PM parts making.

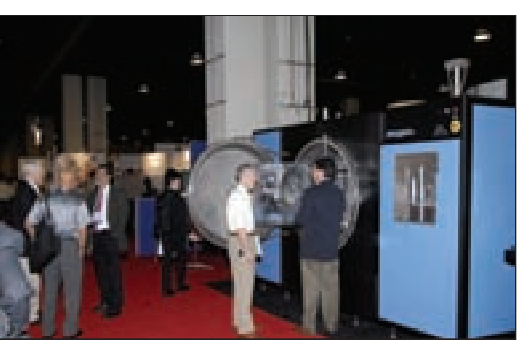
"The program reflects good sound interest in PM, despite tough condition in the national economy, and shows there is still confidence in PM's long-term growth," says Thomas J. Jesberger, co-chairman of the program committee and chief technical officer of Abbott Furnace Co.

The keynote presentation for the opening general session, held first thing Monday morning, also addresses a timely topic: "Tough Driving Ahead: the Future of the U.S. Automotive

continued

Attendees scope out some gears featured in the PM design excellence awards.





Visitors walk the show floor at 2008's PM World Congress browsing the latest PM products, raw materials and process equipment.

Market in the Next Decade." The address will be given by Sean McAlinden, executive vice president and chief economist for the non-profit Center for Automotive Research. Dr. McAlinden will assess the current economic and competitive positions of North American automotive companies, and he will discuss the prospects for market recovery, what industries will be a part of it, and his expectations for the role of powder metallurgy in the kinds of cars, regulations and technologies that will develop in the long-term.

In addition to the technical sessions, there are six special interest programs. "SIPs, as they are called, are created by the Conference Program Committee and MPIF Technical Board, and [they] are based on current technical or hot topics utilizing invited presentations, as opposed to the open 'call for papers,' which fill the technical session program," explains Sandra Leatherman, manager of meetings and conferences for MPIF.

At last year's World Congress, the international PM community's biennial event, which was hosted in Washington D.C., there was an SIP devoted to "Gears—The Next PM Frontier."

"The three-session SIP contained nine presentations and was the best attended technical session at PM2008," Leatherman says. "There was an excellent exchange of technology through the interaction of the attendees during the presentations and scheduled speaker interact.

"Due to the overwhelming interest and subsequent discussions after each session of the 'Gears-The Next PM Frontier,' the Center for Powder Metallurgy Technology (CPMT) has launched a new program 'Advanced Gear Processing,'" Leatherman says. "The program objectives are to understand the contribution of post-PM processes on performance characteristics—contact fatigue, bending fatigue, wear and dimensional accuracy."

The Advanced Gear Processing session (number 39) will take place Wednesday morning from 10:45–12:15. The session is chaired by Jeffrey R. Hamilton of Cloyes Gear and Products, Inc. Two German papers are being presented, titled "Gear-Rolling Study" and "Rollability of Case-Hardening PM Steel." An American paper titled "Surface Durability of Ausformed Powder Metal Gears" is also part of the session.

Also of interest to gear makers is a paper called "High-Speed Gear Hobbing—HSS or Carbide?" being presented in the Wear session (number 43), held Wednesday afternoon, 1:30–3:00. The High-Density Applications session (number 33), on Wednesday morning from 8:00–9:30, includes a paper on "Investigation of a Cogging Process for Surface Densification of PM Gears by FEM Simulation."

PowderMet2009 takes place June 28–July 1 at the Mirage Hotel in Las Vegas. For more information, visit *www.mpif.com*.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CALENDAR

July 8–10—Gear Manufacturing Troubleshooting Course. Liebherr America, Saline, MI. This training school for gear manufacturing is a basic course offered by the Gear Consulting Group in regional versions throughout the year to reduce the time employees spend out of the office while training. Other sessions this year will take place in California, September 7–9 and Ontario, Canada, dates to be announced. Instructors Geoff Ashcroft and Ron Green teach participants both theory and practical aspects of gear manufacturing while imparting knowledge of everyday problems and understanding how to think through troubleshooting. Tuition is $750 and includes a reference manual and certificate of completion from AGMA. For more information, call (269) 623-4993, or email *gearconsulting@aol.com*.

July 20–24—Coordinate Metrology Systems Conference. Louisville Marriott Downtown, Louisville, KY. The 25th annual CMSC will bring together professional and novice users of portable 3-D coordinate measurement technology. White papers will be presented by expert users from leading companies and universities; workshops, user group meetings and an exhibition highlight portable coordinate measurement systems, software, accessories, peripherals, inspection and measurement service providers. The CMS also hosts networking events, a membership banquet, entertainment and a local tour. For more information, visit *www.cmsc.org*.

July 27–29—Powder Metallurgy Basic Short Course. Penn Stater Conference Center Hotel, State College, PA. This three-day course is designed for people starting out in the PM field looking for an introduction, looking to learn about recent developments in the industry, trying to broaden a PM background and users of PM parts. Attendees will learn the history of PM, why it is viable, why use is so widespread, design points, production, injection molding, standards and the latest technologies. It is not required that attendees have a technical background. It is designed specifically for engineers, tool designers, product designers, metallurgists, technicians, QC personnel and more. For more information, visit *http://www.mpif.org/meetings/2009/2009_basic_sc.pdf* or call the MPIF at (609) 452-7700.

September 15–17—Gear Expo. Indianapolis, IN. For the first time since 1995 the gear industry's premier trade event returns to Indianapolis featuring five pavilions on the show floor: aerospace, breakdown, energy, powder metal/plastics and tooling. AGMA anticipates more than 175 exhibitors and 3,000 attendees from 43 states and 36 countries. This year's Gear Expo is co-located with the Heat Treating Society's Conference and Exposition, which is expected to add another 3,000 attendees and 180 exhibitors. For more information, go to *www.gearexpo.com* or visit our *Gear Technology* Gear Expo Showroom at *www.geartechnology.com/gearexpo*.

Siemens

CHOOSES KANSAS FOR FIRST U.S. NACELLE PLANT

Hutchinson, KS is the proud new home of Siemens Energy's first U.S. nacelle production facility, which will consist of a 300,000-square-foot plant and an adjacent 80,000-square-foot service and repair facility. The operation represents the first major wind turbine equipment factory in Kansas, which is ranked third in the country for its wind energy resource potential. Siemens estimates the factory will create 400 jobs.

"The United States already is and will continue to be one of the world's fastest growing wind energy markets. We are thus intensifying our commitment to this green technology to further expand our leading global position in this field," says Peter Loscher, CEO of Siemens AG. "We are already the leading green infrastructure giant. And by making these investments, we will become even greener."

Hutchinson, located in Reno County, northwest of Wichita on the Arkansas River, was chosen after a broad-ranging search in which several finalist locations competed for selection. Being near the geographic center of the lower 48 states, Hutchinson offers a viable workforce and transportation logistics. The factory will provide direct loading onto rail, so project locations throughout the United States and Canada will be easily accessible.

"We are excited to welcome Siemens to Hutchinson, Kansas," said Kansas Governor Mark Parkinson at the official announcement May 5, at the Windpower show in Chicago. "Siemens is a global leader and innovator in the production of wind turbines. Any time a company of this magnitude chooses Kansas, it speaks volumes about our business climate, our workforce and our prime location in the nation's wind corridor."

Groundbreaking is anticipated for August this year, and the first nacelle is expected to ship from the factory in December 2010. The nacelles from this facility will be used in Siemens' 2.3 MW turbines. The factory's planned annual output is 650 nacelles or 1,500 megawatts initially. The service and repair facility plans to begin service earlier in a temporary space in the area until the facility is finished.

Siemens Wind Power has grown from zero to 800 employees in the United States since 2005. The company plans to double that in the next two to three years. U.S. operations include a wind turbine service operation in Houston, a 600,000-square-foot blade manufacturing facility in Ft. Madison, IA, an R&D center in Boulder, CO and the Americas headquarters in Orlando, FL.

"This nacelle facility in Kansas means we are able to further expand U.S. dollar-based sourcing from qualified suppliers," says Rene Umlauft, CEO of the Siemens Energy Renewables Division. "It is our goal to reach greater than 90 percent U.S. dollar-based content by 2012 in order to better and more cost-efficiently meet the demand for our high-quality wind turbines in the United States. Also, the expanded service presence will improve our responsiveness by being centrally located to key customers, and it will add capabilities in larger component repair."

Siemens also announced the first U.S. order from Minnesota Power for 33 units of the SWT-t.3-101 wind turbine set for deployment at the Bison I wind project near Center, ND. The first 16 turbines are planned for installation in 2010 with the remainder following in 2011. At its completion, Bison I is expected to generate up to 75 MW and provide power for more than 22,500 homes in Minnesota.

Nixon Gear

CERTIFIED WITH NEW ISO QUALITY STANDARD

ISO 9001:2008, the latest edition of the quality standard, was established two months before Syracuse, NY-based Nixon Gear, a subsidiary of Gear Motions, Inc., received the certification. The standard endorses that a company or organization is applying formalized business processes. The standard requires the continual improvement of a company management team, and as stated in the standard's introduction, "This standard promotes the adoption of a process approach. An advantage of the process approach is the ongoing

Onandaga County executive Joanie Mahoney presents the ISO 9001:2008 certification to Nixon Gear employees.

control that it provides over the linkage between individual processes within the system of processes, as well as over their combination and interaction."

According to Mark Bechteler, manager of quality and continuous improvement at Nixon Gear, "We've been a 'process company' for many years, and this registration validates how mature and robust the quality system we use every day to build our high precision gears is already operating."

Brevini Wind

ACCELERATES INDIANA OPERATION PLANS

Due to increased market demands, Brevini Wind's proposed main drive manufacturing operation in Muncie, IN has been pushed ahead of the original schedule by six months. Brevini expects to start manufacturing gearboxes in Muncie by late in the third quarter of 2010 instead of the first quarter 2011.

"We have reached the point with new original equipment manufacturer customer contracts and ongoing conversations where we must move up our scheduled start of production to serve the needs or our customers," says Dr. Jacopo Tozzi, CEO of Brevini Wind, in a press release.

Brevini chose GDI Construction as the design firm responsible for building the gearbox production facility. Groundbreaking on the site is anticipated to start in July and be completed in March 2010. Brevini will produce 1,000 gearboxes per year, ranging in size from 1.5 MW to 3.65 MW, and a second phase expansion is tentatively planned to double the manufacturing capacity by 2015.

The groundbreaking event will feature a supply chain conference to help potential local, state and regional suppliers meet Brevini's needs, This is being coordinated with local and state officials from the Indiana Economic Development Corporation, Indiana Office of Energy Development, WorkOne, Ball State University and Ivy Tech Community College.

"The Brevini Company values the close working relationship and tremendous support it has received from each of these organizations with the preparation of the perspective workforce and supplier base," says Greg Winkler, director of project development for Brevini Wind.

Work is already under way on the previously announced relocation of Brevini USA's North American headquarters, which is scheduled for completion in July.

GE Drivetrain Technologies

LAUNCHES GENERATOR AND CONTROL SYSTEM DIVISION

GE Drivetrain Technologies, a unit of GE Transportation, is expanding its wind industry portfolio by introducing a wind generator and control systems division specifically aimed at serving GE wind turbine customers worldwide. The formal announcement was made at AWEA's Windpower show in Chicago.

continued

"GE Transportation has a proud tradition of designing and building complete drive train systems, including electrical components, for rugged environments," says Prescott Logan, business leader for GE Drivetrain Technologies. "Our objective is to apply the full range of GE Transportation's capability to advance the state of the art in wind energy generation technology."

Last year, GE introduced the IntegraDrive integrated geared generator for the wind industry. Combining the gearbox, generator and power controls, GE has essentially taken off the gearbox's third stage and attached the generator directly to it. GE produces more than 3,000 generators annually, mostly between 2 and 6 MW.

Despite the current softness of the market due to the global economic crisis, Logan remains optimistic about the wind industry. "We feel really good about wind. It's here to stay. Renewables are an important part of the new energy future," he says. "We're finding ways to continually grow."

Newcomer GBE

PARTNERS WITH DONTYNE

A group of mechanical transmission design engineers that formerly worked for a leading aircraft engine manufacturer formally established GBE, or Gears and Bearings Engineering, operating out of Oakville, Ontario. GBE is managed by Nasr Kenawy, who spent over three decades working for Pratt & Whitney Canada.

GBE works on mechanical transmission technologies that include tailored industrial transmissions, oil industry transmissions for drilling and extraction (top-drive gearboxes), main and accessory gearboxes for experimental and general aviation, renewable energy equipment such as wind turbine gearboxes and solar tracking mechanisms, gearing for aircraft landing, robotics transmissions, advanced concepts for experimental equipment and gear systems for test rigs.

Services GBE provides include sales and support for Dontyne Systems' gear design software, optimization studies and concept selection, detail design for customer concepts and specification, analysis of optimization of customer design, modification and adaptation of existing designs, technical reports for designs as well as technical support for manufacturing testing prototypes and production.

The agreement with Dontyne targets the North American sales market. "We will be working very closely with the company on the sale of our gear design and analysis products in North America. The support will be improved for our existing customers in the region," says Mike Fish, co-director of Dontyne Systems.

"We believe the agreement we have in place with GBE will be beneficial beyond simply the improved support for our software product," Fish says. "Their engineering knowledge will help us to address a certain growing requirement to use the software in a consultancy capacity."

Kenawy says GBE also works closely with a few manufacturing houses in Ontario, providing the possibility to prototype and produce hardware of GBE designs. The company was officially registered in November 2008, and its website, *www.gbengineering.ca*, was launched at the end of May. General inquiries can be made to *contact@gbengineering.ca*.

Although less than a year in operation, the company is actively pursuing various endeavors. "Our first project was a design of a top drive gearbox for an oil exploration company," Kenawy says. "Since then, we are bidding on three projects in various applications, namely aerospace, oil drilling and wind turbine."

Bosch Rexroth

OPENS WIND TURBINE GEARBOX PLANT IN NUREMBERG

Nuremberg, Germany is the new home to Bosch Rexroth's latest wind turbine gearbox manufacturing facility. Spanning

continued

five football fields, the plant is expected to produce 300 large gearboxes this year. By 2013, Bosch Rexroth expects to invest a total of $246 million (180 million euros) into the plant.

"The long-term forecasts continue to predict global growth for the wind power market," says Reiner Leipold-Büttner, a member of the Bosch Rexroth AG executive board responsible for engineering and manufacturing at the parent company. "As the world's largest independent supplier of gearboxes and automation solutions for wind turbines, Bosch Rexroth will benefit from this market development."

Sandvik

ESTABLISHES AEROSPACE APPLICATION CENTER

Sandvik Coromant's aerospace application center opened in Fairlawn, NJ to focus on customers readdressing current processes.

Sandvik Coromant opened the doors to the Aerospace Application Center in Fair Lawn, NJ April 28. The center focuses on machining projects for high temperature and titanium alloys for engine components and aero frame structural parts. Sandvik's goal is to concentrate on customers interested in readdressing their current processes.

Equipped with the latest machines for developing highly productive processes for aerospace applications, the center is supported by a team of industry specialists, process and development engineers and CAM programmers.

Gildemeister, Mori Seiki

SIGN COOPERATION AGREEMENT

Gildemeister formed a strategic partnership with Mori Seiki Co. covering production, purchasing and machine development in addition to sales and services in select markets. The agreement allows both companies to extend business activities with short- and long-term mutual advantages. The goal is to achieve synergies of 15 million euros a year for both companies.

A cross shareholding was agreed upon, with each investing in 5 percent shares. Gildemeister purchased two million Mori Seiki shares and plans to increase this to 4.4 million shares, while Mori Seiki will purchase 2.3 million shares. This makes Mori Seiki the largest, single Gildemeister shareholder.

"The world of machine tools has become global. Meeting and overcoming the challenges of the international economic crisis demands strong alliances," says Dr. Rüdinger Kapitza, chairman of the Gildemeister executive board. "We will bundle our resources in order to achieve joint efficiency advantages."

Xspect Solutions

LAUNCHES RENT2MEASURE PROGRAM

Manufacturers can rent brand new Wenzel X-Orbit CMMs with no long-term purchase commitment in Xspect Solution's Rent2Measure program. Users have the opportunity to apply 65 percent of the rental payments to offset the purchase price of the CMM at any time during the rental period.

"A rental program for CMMs is a first for a U.S.-based CMM manufacturer," says Keith Mills, president of Xspect Solutions. "As the nature of U.S. manufacturing evolves in these uncertain times, equipment suppliers like Xspect Solutions have to be more creative in the way they market

continued

Correction

The May issue of *Gear Technology* featured an industry news item "Gear Technology Recognized by Boeing for Excellence," on page 61. Gear Technology was mistakenly identified as being located in Newport Beach, CA. The company is actually based out of Rancho Cucamonga, CA. We offer our sincere regret for this mistake.

—The Editorial Staff

their products as well. As program schedules and quantities for parts suppliers shrink, the need for quality still remains very high. However, the ability to justify new capital equipment in support of these smaller programs has been reduced. For that reason, Xspect Solutions created the new Rent2Measure CMM rental program that allows manufacturers to have a new Wenzel X-Orbit 8.10.7 with a Renishaw PH10T/TP20 probe on their shop floor for six to 36 months, depending on the need.

"Additional features for the CMM include a complete suite of *OpenDMIS* software, a MCR20 styli change rack, installation and CMM calibration program as well as three days of operator training for two operators. Also, we will provide the CMM XtraCare package, which covers all breakdowns, *OpenDMIS* software upgrades as released, on-site Dell PC warranty, Renishaw probing warranty and help-desk applications and software support up to the maximum rental period of 36 months. The cost of a typical CMM under the Rent2Measure program is $2,975 per month."

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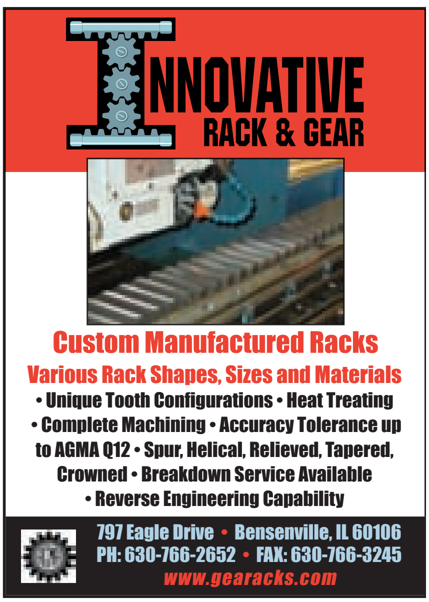

loopy logo or symbolically superior?

(**logo** n. a symbol or other small design adopted by an organization to identify its products, uniform, vehicles, etc.—(Origin 1930's: abbreviation of logogram or logotype. *The Oxford American College Dictionary)*

Have you seen the newly created logo symbolizing the scope of President Obama's $787 billion American Recovery and Reinvestment Act? The Addendum staff has—and is, at best, underwhelmed. We're not graphic artistes, but we know what we like.

Apparently, we're not alone in our reaction.

"I don't think it is a particularly attractive logo, but I've never been accused of being an art critic," was the logo lowdown from Pennsylvania Gov. Ed Rendell (D–PA) in the March 12th U.S. News & World Report. And yet, the Gov then went on to explain the origins of his own logo love: "I had seen on TV the night before (while in D.C. for Obama's first governors' conference) that when (President Franklin D. Roosevelt) did the CCC (Civilian Conservation Corps) program, every project had a CCC logo on it, and I said to the President, 'We need a logo so that every time a citizen passes a bridge or road that's being worked on, they know it's coming from the stimulus itself.' " Another logo relic of the New Deal was the NRA (National Recovery Act).

Given the Oxford gang's definition, a logo is meant to identify an organization's (read federal government's) products, services, etc. The big question—does the stimulus logo accomplish that?

Let's discuss.

What we have is a red-white-green-and-blue circular graphic design. The bisected circle shows eight stars—widely interpreted to depict the 50 states—along with the Recovery Act Web address, *RECOVERY.GOV*. The bottom portion of the circle shows a three-leafed plant on the left to signify either some Americans' marijuana cravings (we're kidding!) or, more realistically, alternative energy initiatives.

AND—on the right—what does one see?—GEARS!

Well, sort of. The "gears" look more like toy-variety sprockets—not gears that might be instrumental in powering, say, wind turbines. Admittedly, readers of this publication may have more of a parochial interest in promoting manufacturing, especially manufacturing that includes gears. Given all the talk that we as nation have to get back to "making things" again, one can reasonably assert that industry in general received short shrift from the logo designers (Chicago-based Mode Project).

But there is a silver logo lining.

We can take solace from the fact that the logo design does at least seem to impart the notion that manufacturing, environmentalism and our populace can co-exist in perfect harmony—symbolically, at least.

(*Ed.'s Note: The Addendum staff welcomes submissions from our readers of either their interpretation of the logo's meaning or a new graphic design of what the stimulus logo should look like. We will then present them to our readers in a later issue for their vote on either the best logo or interpretation.*)

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