GEAR TECHNOLOGY

MARCH/APRIL 2006

The Journal of Gear Manufacturing

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GROWING MARKETS FOR GEAR MANUFACTURERS

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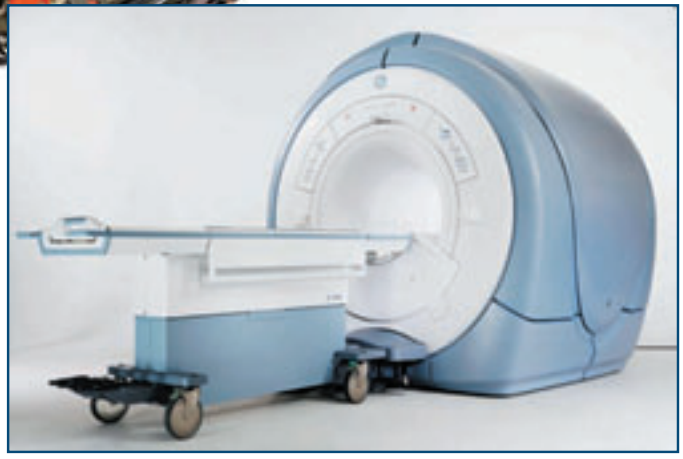
- Medical
- Wind Energy

TECHNICAL ARTICLES

- Tip Relief Modification
- What's the Right Tolerance?
- Detailed Computer Model of Gearbox Reduces Design Time



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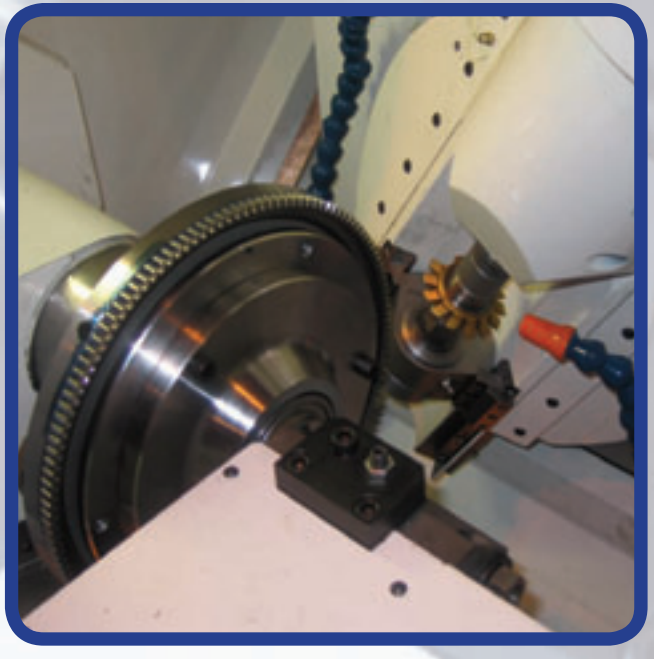

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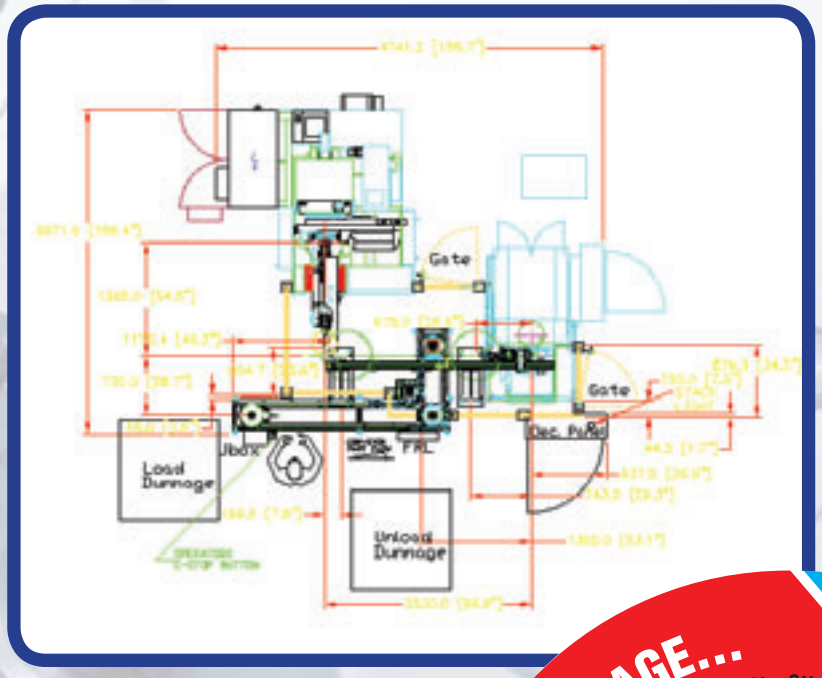

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The Journal of Gear Manufacturing

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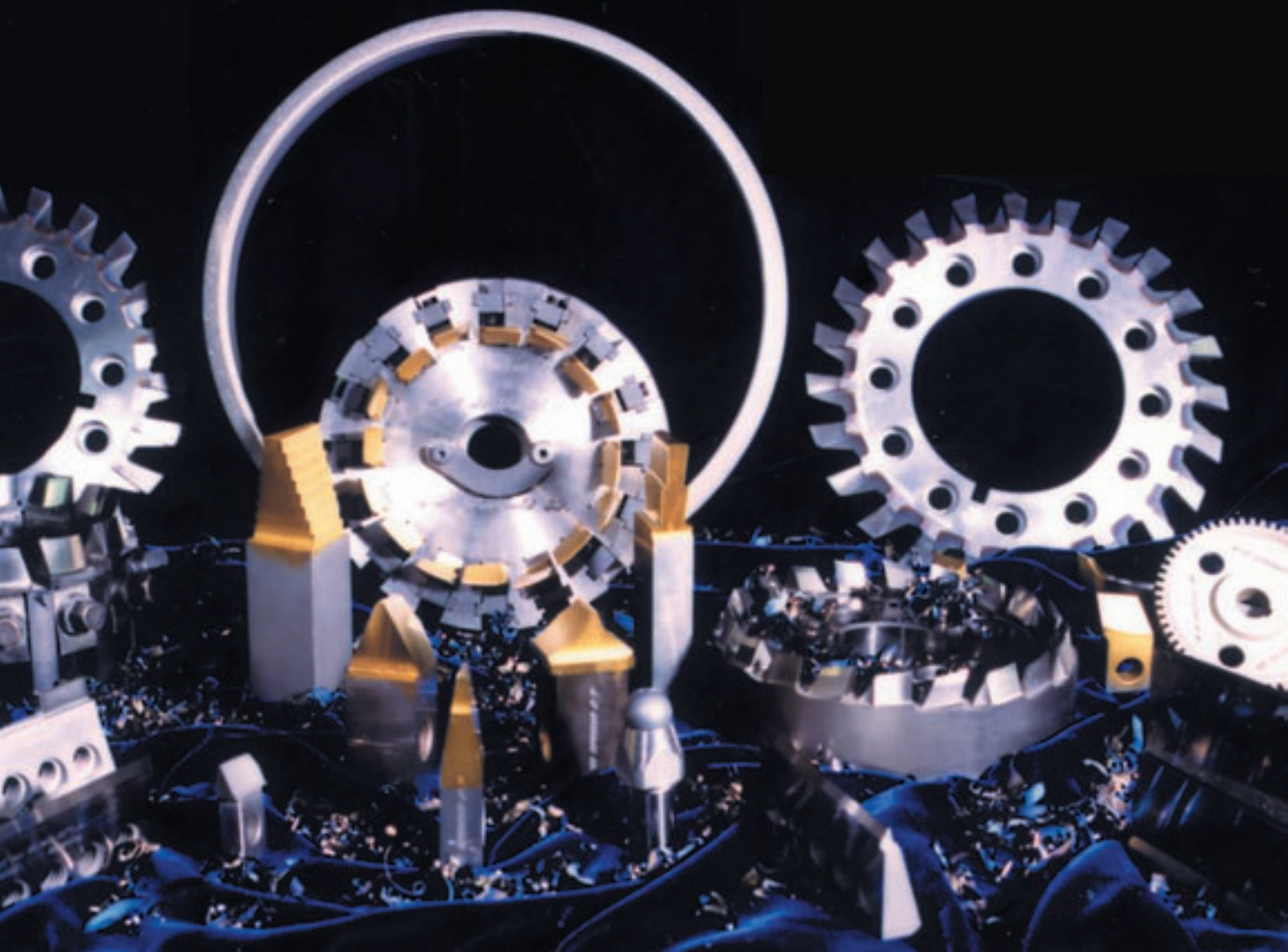

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The Premise *and* The Promise

Gear Technology was founded 22 years ago on a very simple principle: to provide the best possible educational articles and information for the gear industry. Since 1984, *Gear Technology* has provided you with relevant and practical information about the design, manufacturing, processing, inspection and use of gears.

Because of that focus—educating our readers—we place an extremely high value on our editorial integrity. Our job is to help you understand the technology of gears so that you can make informed decisions that will help your company become more productive, produce higher quality or deliver greater value to your customers—how to make better gears, faster, and at a lower cost.

Editorial integrity means we don't kowtow to our advertisers. It means we apply our own experience in the industry, and we have our own voice. It means I can ask questions like "Is Gear Expo Worth It?" as I did two issues ago. Judging by the amount of response that has been generated, it was a question worth asking.

Also, we spend a lot of effort to make sure our articles are both accurate and useful. Did you know that all of our technical articles are reviewed by experts not affiliated with the authors before they can be accepted in *Gear Technology*? Each article is rated by an expert for its technical merit, contribution to gear knowledge and practicality or usefulness. Usually, our reviewers request changes, edits and rewrites that make the articles better for you.

Very often, this process forces us to reject articles, even when they've been submitted by advertisers.

Some magazines make very little—if any—effort to separate editorial from advertising. You'll often find articles in other publications that feature a company on the same page as an advertisement for the company, making the reader unsure where the article ends and the advertising begins.

We have a much greater respect for our readers than that. That's why you'll find no advertising on the pages that include technical articles. These articles stand on their own, and their inclusion hasn't been influenced by anything other than their merit.

Our focus on serving the reader also means we keep in touch with our audience. We ask what you want, and we do our best to deliver it. Last fall we conducted a survey, to which more than 200 of you responded. In the survey, we asked what kinds of articles you'd most like to read about in 2006.

One of the hottest topics revealed in the survey was gear manufacturing in the Far East, and last issue's special focus on that subject was the result. This issue we're covering growing markets for gear manufacturers, with articles about gear manufacturing for aerospace, medical devices and wind turbines.

On our cover, we call ourselves "The Gear Industry's Information Source," and we like to think of the extra efforts we put in as fulfilling that promise.

But we also believe you can't rest on your laurels. Like a modern, lean manufacturer, we have to invest in continuous improvement, so I'd like to take this opportunity to make sure you're aware of some of the things we're doing in 2006 to keep that promise and expand upon it.

Late in 2005, we redesigned the *Gear Technology* website. We did so to make all the articles from the current issue available to our readers, right from the home page. You don't need a password, you don't need to register. You just have to know that if you need information about gears, you should come to *Gear Technology* and *geartechnology.com*, where we receive more than 35,000 visitors every month.

Also, we've always offered free subscriptions to the printed version of the magazine in the United States, but this year, we've expanded that offer to qualified readers in Canada and Mexico as well.

Of course, we'll be asking for your help with this, because we can only offer free subscriptions to qualified individuals. To become qualified, you have to fill out a subscription card.

Throughout the rest of 2006, we'll continue to expand our efforts to bring you the information you need. We hope that you'll continue to give us feedback to let us know if we've hit the mark, if there's something else you'd like to see covered or if you disagree with something we've written.

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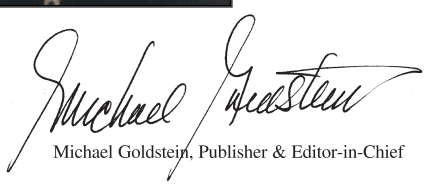

Michael Goldstein, Publisher & Editor-in-Chief

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The following letters were written in response to the Publisher's Page editorial, "Is Gear Expo Worth It?" which appeared in the November/December 2005 issue.

Dear Michael:

The question regarding the value, or lack of value, of industrial trade shows is not new. In your January/February issue, the response depended greatly upon whether you were sponsoring the show or attending it. It can also depend upon whether the cost of exhibiting comes out of your bottom line or is subsidized in some form or another by a foreign nation to promote trade.

Attendance at industrial shows has declined over the years. Many companies have limited or restricted attendance altogether, in view of the time and cost associated with attending—and [of the] questionable value.

However, I still believe there is a place for industrial shows, and that attendance is only one factor in evaluating their success. A trade show is the only place where the end-user (buyer) and builder (seller) meet on neutral ground. There is no question that IMTS and EMO are the two most important shows for the manufacturing world. Of the two, EMO is the more complete show. IMTS tends to be a metalcutting show, which has resulted in spin-off shows such as Gear Expo, METALFORM, PMTS, FABTECH, etc. These shows serve niche markets and might well be consolidated into IMTS—and be better off for doing so. On the other hand, the single-product, off-year shows are more personal, less crowded and serve specific segments of manufacturing.

However, I do question if it is practical or cost-effective to run a show for an attendance of some 2,000 actual visitors.

FABTECH 2005, a combined show with SME & AWS, had an attendance of 24,000—the largest number of visitors since 1999. In contrast, METALFORM had 75 press exhibitors in 1999, 41 in 2005 and 23 in 2006, in part due to the outsourcing of stampings, a declining market, and less interest in the U.S. market on the part of foreign press manufacturers. Gear Expo is faced with some of the same economic factors.

Regardless of the size of the show, the value an exhibitor gets out of it is in direct relation to the effort put forth in preparing for it. There is nothing more disconcerting to the president of an exhibiting company than seeing an empty booth with four of his top salespeople talking to each other. And the value attendees get out of a show is in direct proportion to the amount of new technology on the show floor and the quality of the technical sessions.

Looking back at the interval of the NMTBA, five-year shows were too long. But the two-year cycle of IMTS and the frequency of some of the single-product and regional shows make them more difficult to justify—both in terms of the cost to exhibit and the cost to attend.

The long-term effect of trade shows is difficult to evaluate. I recall receiving a large machine tool order from a young OEM manufacturing engineer. He asked if I had remembered him. I replied no. He said, "You were the only one who took time to talk to me at IMTS when I was a student many years ago." So when we speak about the quality of the visitors, it's not just those with a P.O. in their pocket.

Finally, from the exhibitor's viewpoint, the objective is to get your name out in front of prospective customers, end-users and buyers—and to get qualified inquiries regarding your product. Industrial shows are only one of a number of means of doing so. And as the cost of exhibiting increases, industrial shows become less cost-effective. Sales is a numbers game, and if the attendance numbers continue to drop, the exhibitors will decline in direct proportion, and the show will lose its importance to the segment of the industry it is intended for.

Albert B. Albrecht, Owner
Albrecht Associates

Michael:

Quite frankly, my impression and experience at the show are in contrast to the rather negative one that you described. As an actual attendee, I certainly found much value in being there. My vice president of engineering and I spent a day and a half walking the show, meeting with a long list of current and potential suppliers, learning of and viewing the latest technology, and taking advantage of being able to speak with various company representatives and executives who we may not normally get a chance to talk with. With everything "under one roof" at the Expo, we were able to do this in a very focused and concentrated setting. It makes for a very efficient use of our time.

I can also say that, almost without exception, the exhibitors that I talked to were feeling very good about the Expo, the attendance and most importantly, the level of business or potential business that was being generated. Were there fewer attendees? Were they the real decision makers? If you take Milwaukee Gear as being representative, then the answer would be yes to both questions. We send fewer people today than in prior years because of the tremendous demand on everyone's time. But between myself and Terry, you had the chief technologist and decision maker. I don't think the exhibitors are disappointed in that.

Rick Fullington, President
Milwaukee Gear Co.
(Editor's Note: Rick Fullington became vice chairman of the AGMA executive board in March.)

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Michael,

I am a gearing consultant and supplier of software. I did attend the show this year, but only because I was a presenter at the AGMA Fall Technical Meeting as well. I did not rent booth space for the simple reason that those who attend the show are not my target audience. The target audience should be those people who manufacture the consumer product that uses the gear (for example, a windshield wiper motor manufacturer, or a garage door opener manufacturer).

If the advertising for the show could reach those types of people, then exhibitors would set up their displays to solve problems for their clients in specific products as opposed to just selling hobs to other gear manufacturers. The mailing list would be much larger if you included all consumer product suppliers.

The show is a "Gear Expo," not a "Hob Expo," so the gear manufacturers should be showing off what they can do to help the people who buy gears. Anyone who is in the gear business already knows who to contact for hobs and machinery.

Ernie Reiter, President
Web Gear Services Ltd.

Mr. Goldstein,

I read your editorial about attendance at Gear Expo with some interest. I attended the show, and was also a speaker at an associated technical seminar. I was accompanied by two other company employees as well, so we were about a quarter of a percent of the total non-exhibiting attendees.

We attended as a supplier to the industry. Our main purpose in attending the show is to keep an eye on whatever is going on in the industry. A market-wide expo like this showcases many different sides of the business and helps us get a good impression of the overall status or health of the industry, as well as anything new that may affect our direct business. Also, we do have a number of customers exhibiting, and it gives us a view into how our products are ultimately represented to the market.

In my observation, over the past several years of attending various manufacturing trade shows of this type, the general trend has been for disappointingly low attendance almost across the board, even well after the business levels of several years ago picked up again. I am concerned about a couple of permanent changes in the business infrastructure that could negatively impact the future of trade shows.

First, during the recent business downturn, many companies downsized. Even where the design or engineering functions were not directly affected, the demands on the time of remaining current employees is greater, and fewer people seem to feel they have the luxury of leaving their work for a few days to attend such a function.

Second, among the coming generation of designers and engineers, there may be an expectation that all useful information can be obtained from the Internet, and there is no need to physically visit suppliers, customers, or industry functions to gain information. Traditional networking is not seen as a useful or efficient way to do business.

Finally, because of the economic crunch faced by manufacturing businesses in the United States today, the businesses seem driven far more strongly by a need to reduce up-front costs and product pricing, rather than by a need to improve their products. Their customers, the end users of their products, perhaps influenced strongly by the auto market, are constantly demanding lower pricing, not higher performance or a better mousetrap. Products are less frequently evaluated based on their contribution to operating and production costs, or overall cost effectiveness, but more commonly solely on their initial price, and under competitive bidding at that. This may be a by-product of the survival mode that many manufacturing companies have found themselves in for the past five years or so, but it does little to encourage companies to spend time and money on new developments.

Many of the traditional benefits of attending a trade show—sharing information with peers, making contacts, learning new things, expanding the horizons, and so forth—are difficult to reconcile with the current short-term needs of manufacturing organizations. Perhaps trade show organizers could regain some of their traditional attendance by focusing on presenting trade shows as venues for cost reductions or improved competitiveness.

Ed Tarney, Chief Product Metallurgist
Crucible Service Center

The following letter was written in response to the Addendum column, "Wicked Gears," which appeared in the January/February 2006 issue.

Dear Ladies and Gentlemen:

I am really not a big fan of musicals, so it is rather unlikely that I will visit a performance—and probably it has not been shown yet in Switzerland or other parts of Europe.

I myself prefer more complex symphonic concerts or operas.

Have you seen the last Salzburg Festival production of Turandot conducted by Gergiev (it is available on DVD and was shown on TV as well in several countries)?

Really a lot of gears on stage! But practically no circle involute form. So does this mean that in Turandot's times they had another gear geometry, or did the stage designer simply have no idea how to construct the curves?

And maybe it should symbolize something in connection with the composer, Berio, who wrote a new version for the finale of this opera, left unfinished by Puccini—"If the gears would be human beings."

With kind regards,
Dr. Uwe Schulz, gear mathematician
Wendt Diawal
Neukirch-Egnach, Switzerland

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Shorter Cycle Times for Carburizing: Dana Develops Atmosphere, Microwave-Based Process

Dana Corp. is developing a process that carburized a straight bevel gear to a carbon content of 0.8% in 60 fewer minutes than atmosphere carburizing did with an identical straight bevel.

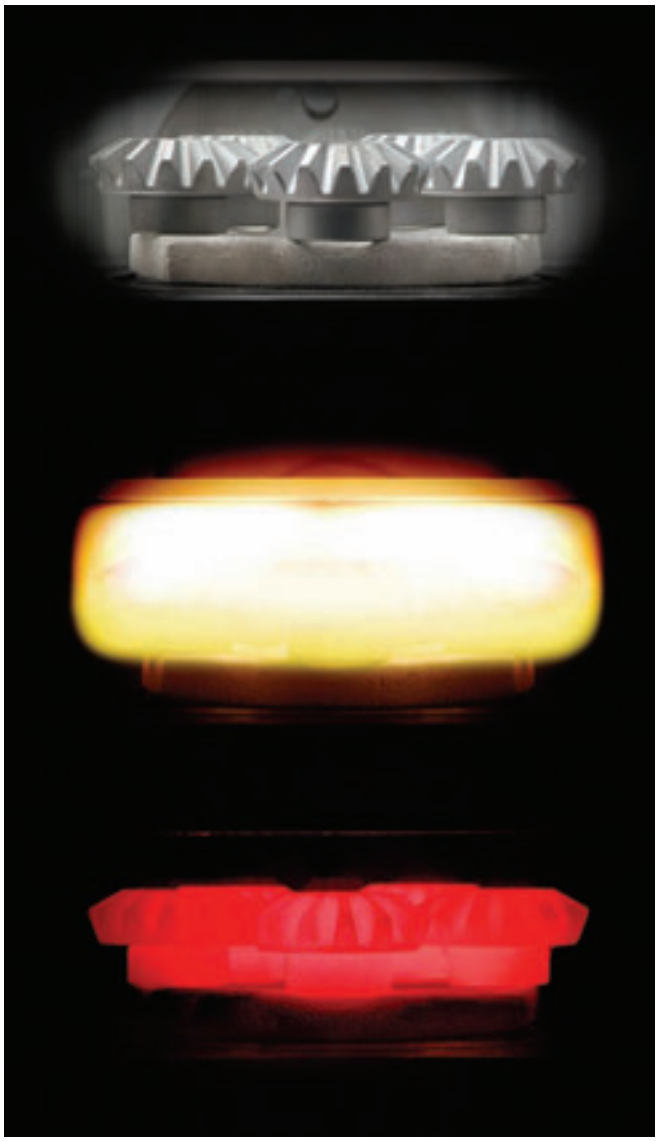
The Dana process, called AtmoPlas, uses plasma and microwaves to carburize workpieces at atmospheric pressure. Moreover, in the above test, the atmosphere carburized gear achieved a case depth of 0.035", the AtmoPlas processed gear: 0.045".

The test was one of many AtmoPlas trials being run by Dana with its lab research system to benchmark the carburizing of various single workpieces.

In trials, the microwave technology results in shorter cycle times than atmosphere carburizing, with time saved in the heat-up and carburizing parts of the cycle. "This would translate to overall lower gas consumption and lower power cost," says Kuruvilla Cherian, a Dana senior materials scientist and one of the developers of the AtmoPlas process.

In the above benchmark test, the straight bevels were differential side gears with outer diameters of 70 mm (about 2.76"). They were made of 8620 steel and had starting carbon contents of 0.2%. The AtmoPlas lab system was programmed to carburize its gear at 930°C. The other identical gear was atmosphere carburized at the same temperature.

Cherian provides the results for both treatments. The total time for the atmosphere carburizing was 272 minutes, and for the AtmoPlas processing: 212 minutes. The atmosphere carburizing time consisted of 142 minutes for the boost phase, 110 for the diffusion and 20 for the temperature-drop. The AtmoPlas time was 112 minutes for the boost phase, 80 for the diffusion, and 20 for the temperature-drop. Afterward, both gears were oil quenched.



Microwave-Based Carburizing—Dana Corp. has developed a process, AtmoPlas, that uses microwaves and plasma at atmospheric pressure to carburize gears. Differential side gears are shown (from top) before carburizing; during heat-up, while plasma absorbs microwave energy; and right after the microwaves are discontinued.

Cherian and application engineer John Hudson, another AtmoPlas developer, were also using the test to achieve a target effective case depth: 0.035". The atmosphere carburized gears achieved that depth after 272 minutes. In 212 minutes, the AtmoPlas processed gears had 0.010" of additional case depth.

Having surpassed the target, Cherian and Hudson have to run further tests to find the right time and temperature combination to get the 0.035" depth. The combination will likely be even less than 212 minutes.

The heat treatments were designed to harden the gears to greater than 57 HRc. Cherian says the atmosphere carburized and AtmoPlas processed gears reached the target hardness and were comparable to each other.

Also, Cherian points out that AtmoPlas results in smaller grains. In trials with coupons, he and Hudson were able to compare AtmoPlas processing to atmosphere and vacuum carburizing. In the cases, grains were 15.9–22.5 microns for the vacuum carburized coupon, 11.2–22.5 microns for the atmosphere carburized, and 5.6–11.2 for the AtmoPlas processed. Smaller grains mean: "Higher strength properties in the gears," Hudson says.

However, Cherian says microwaves' effects on crystal growth aren't fully

known at present, so AtmoPlas' effects on grain size would require more research.

AtmoPlas heat treats workpieces at atmospheric pressure using plasma heated by microwave energy. The system consists of two chambers, an outer one and an inner one. Workpieces are placed inside the inner chamber. A mixture of three gases—argon, hydrogen and nitrogen—is injected into the chamber, which is insulated with ceramic walls.

In the outer chamber, magnetrons are activated to generate microwaves. The microwaves pass through the inner chamber's walls, which are transparent to them. The microwaves convert the gases into plasma. The plasma absorbs the microwave energy, heating rapidly. Acetylene is introduced as the enriching gas, the carbon source. The heat and carbon are then absorbed by the workpieces. The plasma uses about 95% of the microwave energy for its carburizing.

Acetylene makes up a small amount of the total volume of gases—"The acetylene is typically less than 5%," Cherian says. Still, it is one of the more expensive gases, so Cherian and Hudson are looking into using methane as the enriching gas for the next round of benchmark tests with single workpieces.

The inner chamber's atmosphere doesn't include oxygen, so the system doesn't create intergranular oxidation in its workpieces. By avoiding IGO, the AtmoPlas processed gears would avoid the possibility of their ultimate strength being reduced.

According to Hudson, AtmoPlas' power consumption is comparable to an atmosphere carburizing furnace—when both are heat treating parts. Between jobs, AtmoPlas can be turned off. Unlike atmosphere carburizing, there's no need to keep the AtmoPlas system running between gear jobs, to keep it at temperature and maintain its atmosphere.

"We can establish our atmosphere very quickly with a minimal amount of gas," Hudson says. "We have no reason to keep the module running when empty."

"It's basically a switch-on, switch-off system," Cherian says.

Besides differential side gears, AtmoPlas has carburized crown gears with 8" diameters, as well as 7" long spiral bevel pinions. The system's gear trials have mostly consisted of gears made of 8620 alloys, but AtmoPlas has also been used to carburize gears made of manganese-chromium alloys. Cherian and Hudson plan additional trials of the Mn-Cr gears in conjunction with high pressure gas quenching.

Next Step: A Production-Scale Machine—Development of the AtmoPlas process has progressed to trials using the above lab pilot system, the MD-800. Dana's next step is to create a pilot production-scale machine for further trials.

AtmoPlas needs the trials in part to catch up with atmosphere and vacuum carburizing. Those processes have known time-temperature profiles. Heat treaters with gears of a certain type and size and with a certain target case depth and hardness, know or can easily figure the needed time-temperature profile for existing commercial processes. AtmoPlas, still in development, doesn't have established profiles yet.

"We're in the stage of developing the time-temperature profiles for AtmoPlas," Hudson says. He adds that AtmoPlas' carburizing profile can be changed like vacuum carburizing's profiles, so the microwave technology can achieve desired case depth and percent carbon.

Also, the process hasn't been tested in a production-scale system yet. Hudson says the pilot production system is scheduled for installation this year, in the fourth quarter, in a production, vacuum carburizing line with a gas quenching system. The pilot system would be built with a work area 24" wide, 36" deep and 24 or 30" high, with a rated gross load of 500 kilograms. Once installed, the system would undergo three to six months of testing via production work. Then Cherian and Hudson would be able to compare its power consumption with those of production-scale atmosphere and vacuum carburizing.

Also, after the testing, Dana would be able to decide when AtmoPlas will become commercially available. The technology would be licensed to equipment manufacturing companies. In fact, Dana has already announced joint development agreements with ALD Vacuum Technologies GmbH of Hanau, Germany, and Rübig GmbH & Co. KG of Wels, Austria.

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Gleason's New Hobbing Machine Can Cut Cycle Time Down to a Second

The Genesis 130H CNC vertical hobbing machine from Gleason features a new design that optimizes dry machining, reduces floor space requirements and improves cycle times.

This machine is the first in the new Genesis family of gear production equipment. Genesis machines all include a single-piece frame cast from an advanced polymer composite material that ensures a small, compact machine footprint and enables the user to install and relocate the machine with no special lifting equipment or foundations.

Jim Gnadt, manager of product development for Gleason, says, "One unique feature is that the base unit is not cast iron. We're able to offer much more thermal stability and vibration absorption by using a polymer-graphite combination."

The hobber can accommodate wet cutting processes but is better suited for dry machining. The work area is completely isolated from the machine frame to minimize thermal expansion from contact with hot chips, and a stainless steel cutting chamber with steep inclination ensures that chips fall clear of the work area.

Another feature is the hobber's new mechanical, cam-driven, double gripper loader that is fully integrated into the machine. This cuts non-productive time down to a minimum and significantly reduces part load/unload times.

"It's a cam-operated, high-speed device, and it's now possible to achieve cycle times as low as one second. One of our most popular machine applications is the 125GH, and it usually takes 4–5 seconds for loading and unloading. Now we've got it down to 2 or 2.5 seconds tops," says Gnadt.

The D-Drive system enables the spindle to transmit more torque with less runout and also accommodate the use of larger diameter hobs for greater performance and longer tool life. Also, direct-drive spindle motors reduce setup and machining times by eliminating the need for mechanical adjustments and change gears. Higher acceleration/deceleration rates and increased torque, combined with faster axis motions, reduce non-cutting time between cycles.

Other features include an easy-access service module that consolidates hydraulics, lubrication and pneumatics into one location, optional on-board chamfering and deburring, availability of the latest Siemens or Fanuc controls and Gleason software running in a Windows environment, and a chip conveyor that can be located from either side or the rear of he machine to meet any cell/system arrangement.

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Mahr's Air Gage Uses Single- or Dual Master Air Tooling

The Universal Dimensionair line of air gages from Mahr Federal combines the performance of a single-master air gage system with the ability to use two-master air gage tooling.

In single-master systems, the gage is calibrated to zero or a reference measurement, and users rely on the gage system accuracy to determine tolerance limits. Dual-master systems use two masters to calibrate maximum and minimum. For go/no-go applications, the air gage is usually calibrated with both masters or

setting gages set for both tolerances.

Built-in magnification and zeroing controls allow the product to act as a dual-master air gage comparator. By selecting the appropriate dial configuration, users can adjust the gage for dual-master air tooling or span master tooling, according to the company's press release.

The user sets system sensitivity (scale factor) by adjusting the air comparator span to correspond to the difference between minimum and maximum setting masters, thus setting the sensitivity of all the components of the gaging system. A zeroing control brings the span to a balanced position on the dial.

The Universal Dimensionair is available with a range of interchangeable dials for selecting magnifications from 1,250:1 to 10,000:1 in inch or metric scales. Dials are quickly exchanged by a snap-off bezel that allows for changing while protecting the gage against contamination from the shop environment. An analog dial provides fast visual representation of size and degree of good/bad or approaching readings.

Lastly, tooling can be mounted directly on the front of the unit. This lets the Universal Dimensionair act as a bench gage where the parts are brought to the air tooling. When the parts are too large for a bench-mounted gage, a hose and handle assembly provide portable measurement on the part.

For more information:
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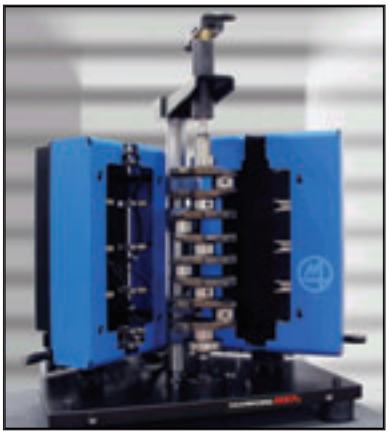
Phone: (401) 784-3100
Internet: *www.mahrfederal.com*

Marposs' Vertical Solution Provides a Smaller Footprint

The M57V bench from Marposs provides a smaller footprint that occupies less surface space than the company's horizontal solution, according to its press release.

Vertical loading of the workpiece eliminates part and structural deformation as well as bending in the reference centers and helps part dragging in dynamic applications. The bench is engineered for



crankshafts weighing more than 6 kg, can also check camshafts, gear shafts, rotors and axle shafts and can be configured as a single or double gage station.

The bench gage is dedicated to the interoperational inspection of a single part type (or when no retooling is required) after end face milling, turning, pin bearing milling and grinding.

The workpiece is loaded manually or by a manual gantry between centers in the vertical position. Centers are fixed (static measurement) or motorized (dynamic measurement) and the measuring stations are brought onto the part by manual pivoting arms.

For more information:
Marposs Corp.
3300 Cross Creek Pkwy.
Auburn Hills, MI 48326
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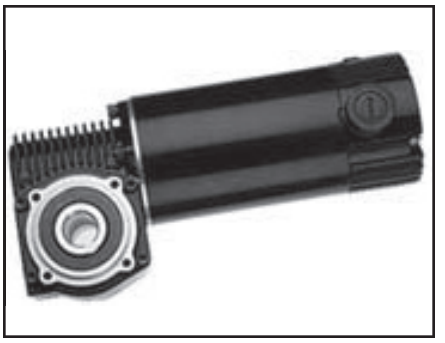
Internet: *www.marposs.com*

Bison Gear's Hollow Shaft Gearmotor Doubles Continuous Torque Ratings

Bison Gear's new 562 series hollow shaft gearmotor offers increased low speed center distance coupled with greater clearance for wider faced gears.

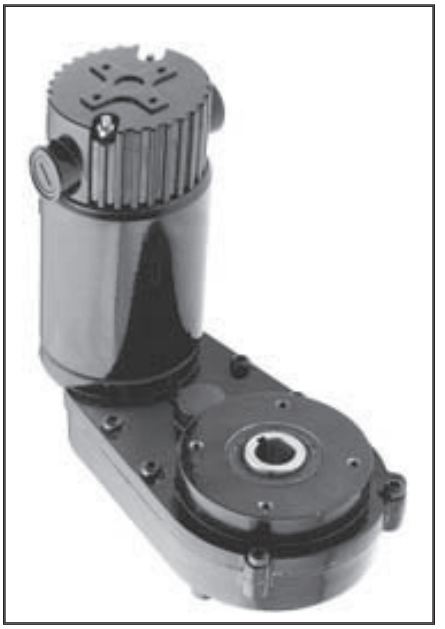
According to the company's press release, the gearmotor allows for up to 1,100 in.-lbs. continuous torque—twice



traditional continuous torque ratings. An optional fourth stage of gear reduction is possible as well, providing ratios up to 2,200:1 in the same envelope, allowing for a smaller input motor without sacrificing output torque.

Additional features include hollow shaft options with multiple configurations and various AC and DC input motors, including three-phase and inverter duty. A hollow bore diameter of 3/4" allows for interchangeable shaft designs.

Bison Gear also introduced low voltage additions to its 750 series right-angle gearmotor design. New additions consist of two input motor options rated at 1/8 hp, 12 VDC, and 1/8 hp, 24 VDC. Gear ratios will be 5, 10, 13, 20, 30, 45 and 60 to 1 and available from stock with a 3/4" diameter hollow shaft with face mount or a 5/8" diameter solid shaft insert with steel footplate. These options allow uses of battery power and other low voltage applications.



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Marposs' Inspection Software Cuts Production Time

The new 3-D Shape Inspector software from Marposs performs on-machine measurement. When used with Mida touch probes, the software enables high precision measurement to be accomplished on the same machine used for cutting parts.

According to Marposs, the software checks the part shape and dimensions. Furthermore, the program generates geometric dimensioning & tolerancing (GD&T) reports and allows for immediate reworking of out-of-tolerance measurements without time lost by sending the part for measuring on a CMM and then refixturing and setting up the part after inspection. The program can be used as a direct TCP/IP or DMC interface on a CNC-integrated PC or offline by creating probing programs on an external PC.

Michael Sterioff, a product manager, says this product will be displayed in the Marposs booth at Westec, but won't be officially introduced to the manufacturing community until IMTS in September.

Currently, the shape inspector software is used on Fanuc and Fanuc-compatible controlled machines, typically horizontal or vertical machine tools. Marposs will demonstrate the software capabilities on a Haas machine at Westec. Sterioff says that the software will be compatible with Siemens, Heidenhain and Selca controls by early May. When it's officially released in September, the software will also be compatible with Okuma controls. Looking to the future, Marposs would like to expand its uses into lathe applications.

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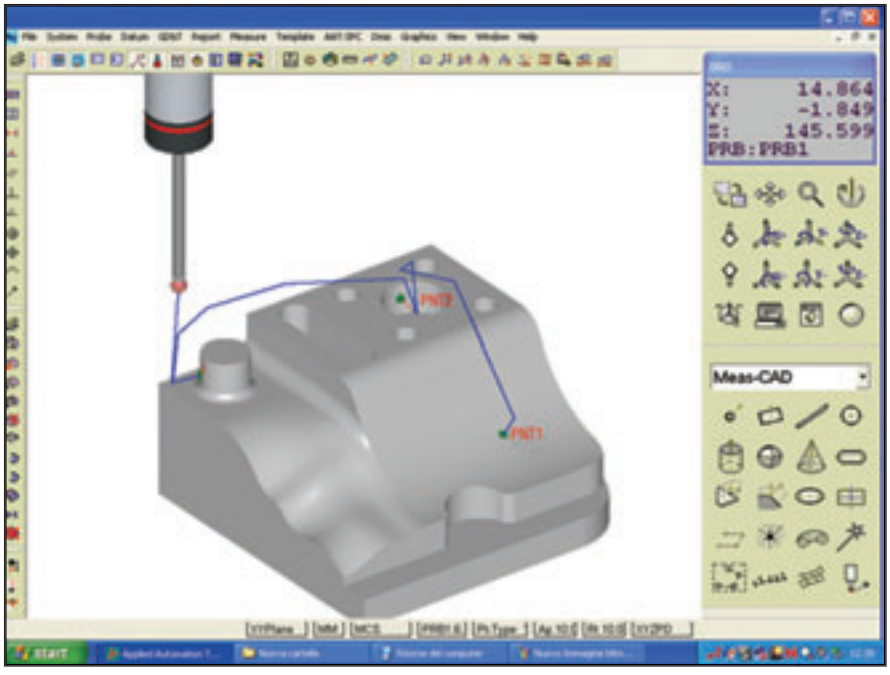

Sterling Instruments' Anti-Backlash Gears Eliminate Marred Shafts

A new series of 1158 anti-backlash gears manufactured by Sterling Instruments features the Fairloc integral hub fastening system, which eliminates marred shafts.

According to the company's press release, the fastening system helps adjustment, timing and frequent removal problems with full component support along the entire hub system. In addition, the self-contained gears offer a small gear hub envelope.

Each gear comprises a set of two gear halves that give the appearance of a split gear. Built-in springs, mounted around the hub, force the two gear halves to turn in opposing directions relative to one another until the tooth space between the inner and outer mating gear is filled. This technique is applied to gears with diameters down to 0.642" to eliminate backlash in gear trains.

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Growing Markets for Gear Manufacturers

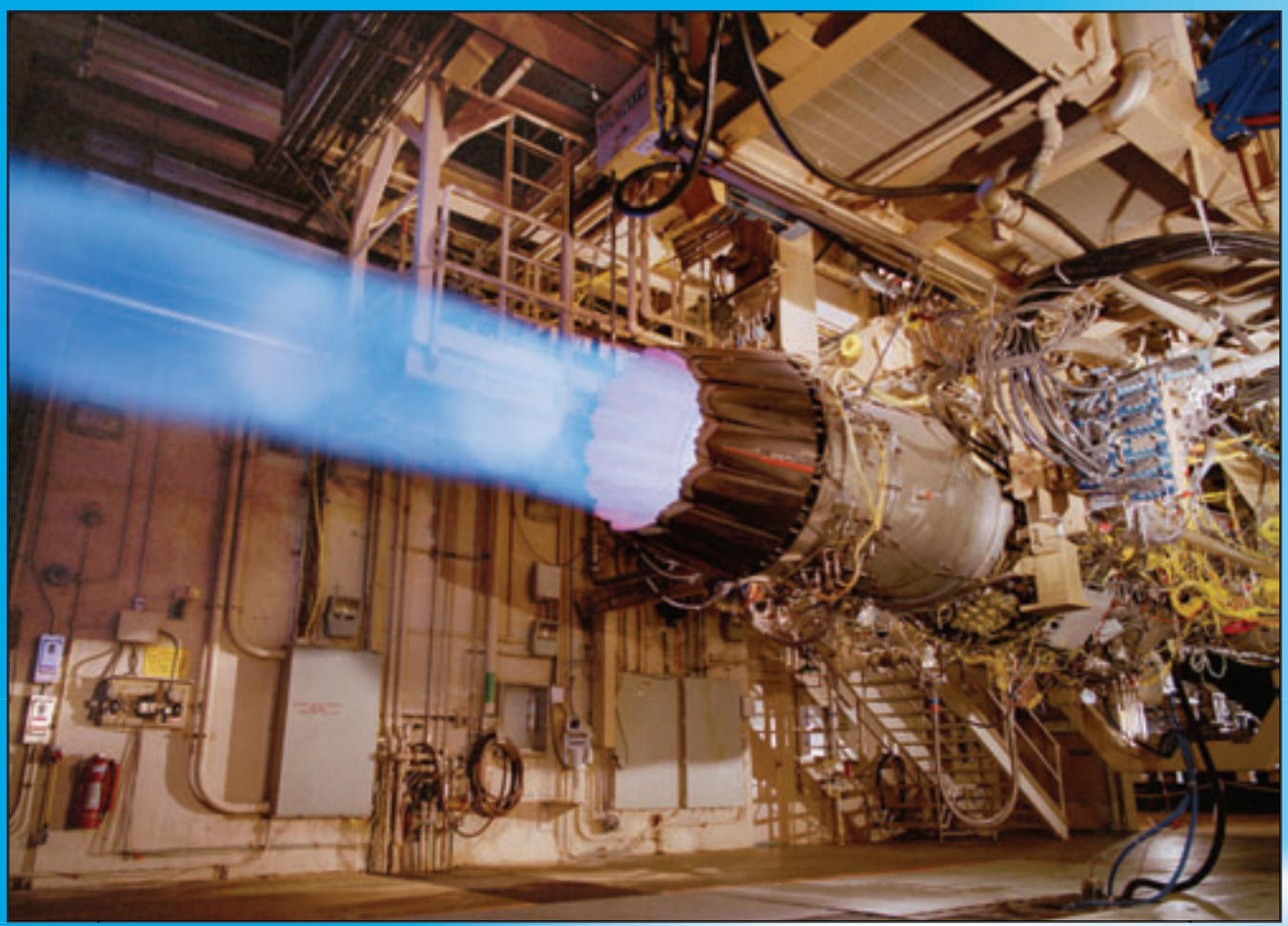
In this issue, our editors have focused on three market segments that promise to keep gear manufacturers busy over the coming years. Whether you're already involved in manufacturing in one of these segments or you're interested in getting started, these articles should provide an overview, some insight, and ideas about where to look for additional information.

We're interested in your feedback. If you're involved in one of these industries and you'd like to put your two cents in or if you're involved in other industries you think have great potential for gear manufacturers, we'd like you to let us know. Send a letter to us at *publisher@geartechnology.com*.

Blue Skies for Aerospace Parts Manufacturing

William R. Stott, Managing Editor

Development of next-generation aircraft like the Joint Strike Fighter is driving demand for aerospace gears. Photo by Lockheed-Martin, Courtesy of the U.S. Marine Corps.



A full-power test of the F135 engine for the Joint Strike Fighter program. Photo courtesy of Pratt & Whitney.

Aerospace manufacturing has seen quite a turnaround in the past few years. The world's manufacturers of airplanes, helicopters, missiles, space vehicles and satellites are all extremely busy right now—and that's keeping quite a few gear manufacturers busy as well.

There's no question that the events of 9/11 had a profound effect on aerospace manufacturers. To say that the industry struggled after the 9/11 terrorist attacks would be considered a huge understatement.

"9/11 knocked the bejeezus out of us," says Joe Arvin, president of Arrow Gear Co. in Downers Grove, IL. Arrow supplies spur and bevel gears and complete gearboxes to aircraft manufacturers.

After 2001, orders from aerospace manufacturers slowed so much that the company had to downsize to nearly half its former number of employees. The company's sales to one customer alone dropped by $6 million almost overnight, Arvin says.

But with air passenger traffic returning to healthy levels, worldwide economic growth and expanded military programs, all that has changed.

"The industry is booming," Arvin says.

According to the Aerospace Industries Association, based in Arlington, VA, the U.S. aerospace industry generated a record $170 billion in sales during 2005, up 9.2 percent from 2004's $156 billion. Moreover, those sales increased in all product categories (civil aircraft, military aircraft, missiles and space sales).

The association is predicting those strong sales to continue. "We're looking forward to a year in '06, in which we grow by another $14 billion," said John Douglass, AIA's president and CEO, at the association's annual year-end review and forecast luncheon, held in December.

The reason for the industry's optimism has a lot to do with the recovery and projected growth of the commercial airline business. Part of that is shown by the large number of backlogged airplaine orders waiting to be manufactured and delivered. According to AIA documents, the current industry backlog is around $241 million, which is about a year-and-a-half's worth of airplane sales.

Those backlogs have been trickling down to the producers of parts and component systems, such as Arrow Gear.

"I have the largest backlog in the history of the company," Arvin says.

Two years ago, Arrow Gear's order backlog was around $26 million. Today, it's up to around $40 million, Arvin says.

Airbus and Boeing, the two largest airplane manufacturers, are both projecting steady demand for their products over the next 20–30 years.

According to Airbus' *Global Market Forecast*, published in December 2004, Airbus expects world passenger air traffic to increase by about 5.3% per year from 2004 through 2023. To meet that demand, Airbus expects the number of aircraft in service to double.

Similarly, Boeing's *Current Market Outlook*, published in 2005, predicts passenger air traffic will increase about 4.8% per year from 2005–2024, and that the worldwide fleet will more than double by adding more than 35,000 passenger and cargo jets over that period.

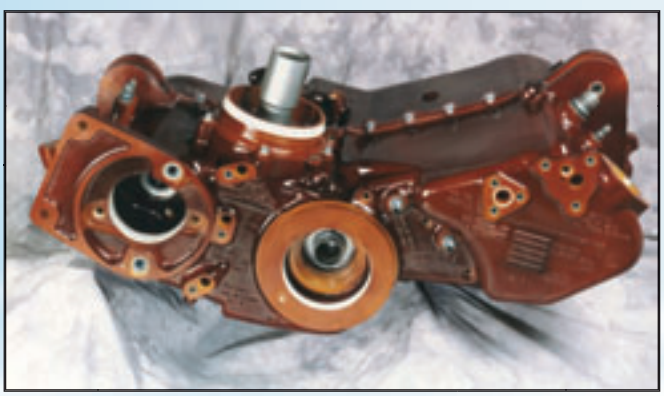
"The long-term outlook for air travel is positive," Boeing's report says. "The fundamentals of economic development, globalization, and the need for people to travel will be strong in the coming decades."

The growth of the commercial airline market and the need for airlines to replace aging fleets is what's driving the demand for newer and larger aircraft that can fly farther, such as the Airbus A380. New airplanes mean new engines and new parts for companies like Arrow Gear, which manufactures spiral bevel gears for the Airbus A380.

In addition to the recovery of the commercial airplane manufacturing business, the demand for military aircraft is very strong. One of the things driving that demand is the United States' war on terrorism.

Purdy Corp. of Manchester, CT, manufactures spiral bevel gears, curvic couplings and splined shafts for helicopter drive systems and aircraft engines. According to Barry R. Noonan, Jr., VP sales, the U.S. military operations in the Middle East have driven demand for Purdy's products.

Installation of a Rolls-Royce Lift Fan System on a Joint Strike Fighter prototype. Courtesy of Rolls-Royce p/c.



A gearbox from Arrow Gear Co. for the Joint Strike Fighter program.

"Given the war effort with gears and gearboxes coming out of the theater with less life...this has placed a never-seen-before demand for new parts, and if available, repairables," Noonan says.

In addition to the war effort, there are a number of high-profile military aircraft development projects underway, including the Joint Strike Fighter program, the V-22 Osprey tilt-rotor program and other projects, all of which require precision gears.

Both Arrow Gear and Purdy manufacture parts for the Joint Strike Fighter program. The F-35 Joint Strike Fighter is a supersonic, multirole stealth fighter designed to replace a number of aging

fighter and strike aircraft. Assembly of the first F-35 was completed in February, and its first flight will take place later this year.

The F-35 is designed to be fitted with either of two propulsion systems: the F135 engine from Pratt & Whitney or the F136 engine from GE/Rolls-Royce. Gears from Arrow and Purdy are used in those engines.

Besides the Joint Strike Fighter, the U.S. military is also rebuilding its helicopter fleet, with light utility helicopters, armed reconnaissance helicopters and the new CH-53K being developed by Sikorsky Aircraft.

With all of that in mind, the helicopter market is definitely a growth market, says Noonan.

Another aspect of the industry adding to demand for aerospace gears is the fact that most OEMs are now outsourcing work that used to be done in-house.

"The OEMs have a tremendous amount of work on their plate," Noonan says. "This has now forced them to go out with this type of work; previously this core work remained inside their facilities."

In fact, the more services and value a gear manufacturer can provide, the better he may be able to serve this market, both Arvin and Noonan say.

"How can one stay relevant, add value and remain a necessary entity for the OEMs?" adds Noonan. "If you are able to answer that, remain focused on that and create your own niche, you should be able to survive."

In addition to manufacturing the gears, Arrow offers its design services to many of its OEM customers—customers who used to do all of the design work for themselves.

"All major OEMs are divesting themselves of bevel and spur gear designs," Arvin says, adding that Arrow Gear has done the design, development and manufacturing of gears and gearboxes for the Airbus A380, the F-35 Joint Strike Fighter and other projects.

The recent increased demand for aerospace gears has had a profound effect on the operations of both Arrow and Purdy.

"We are continuing to hire," says Noonan, who adds that the company expects steady employment growth and new equipment acquisition to keep pace with part demands the next few years.

Hiring can be difficult, though. "The qualified labor pool...is nonexistent, which has made this a very difficult, arduous task," Noonan says. "Bottom line: you can have all the equipment in the world, but unless you can find and retain qualified, competent people to run it, you will be out of business very soon."

Installing the engine in the F-35. Courtesy of Lockheed-Martin.

Over the past six months or so, Arrow Gear has hired about 85 employees, and Arvin expects to hire another 10 as soon as possible. After that, the company will be at about 220 employees, almost to the level it was at before 9/11.

Arrow has also invested heavily in equipment. Within the last year, the company has spent about $3 million on a new carburizing furnace, a new superfinishing system, a new bevel gear cutting machine, a new CNC gear inspection system, a new 5-axis milling machine and four new lathes.

"We have to continually invest in new technology to take care of our customers and future customers," Arvin says.

Both he and Noonan expect that the good times will continue in aerospace manufacturing, at least for the short term. Arvin sees the demand leveling off around the middle to end of 2007, while Noonan expects to see the same level of growth and part demand over the next 5–8 years, possibly longer if the war on terrorism continues.

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Airbus Global Market Forecast
Internet: *www.airbus.com/en/myairbus/global_market_forcast.html*

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Aerospace gears from Arrow Gear Co.

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Medical Device Manufacturing Keeps Gear Industry Healthy

Invacare Corp.'s power wheelchairs and rehab products rely on gears.

High quality gears transport wheelchair-bound patients with minimal sound.

Background photo courtesy of GE Healthcare.

When Forest City Gear started manufacturing gears for medical components in the 1980s, it was a minuscule part of the company's business. Today, the medical device industry represents 18–20% of Forest City Gear's customer base, and those numbers seem to be rising.

Everett Hawkins, project manager/sales for Forest City Gear, says many of the spur and worm gears they manufacture perform in different medical devices in optometry, doctor's equipment on the hospital floor or in physical therapy devices.

Gears likely will continue spinning in these devices in the coming years, due to growing medical needs of the aging Baby Boomer population. According to a report issued by the Census Department in 2001, the 51–55 year old age group increased by 55% from the time of the last census. The second fastest growing age group, at 45%, was the segment aged 45–49.

Given these numbers, it's easy to understand why medical devices—and by extension, their suppliers—are in such high demand.

Gear Shops Expand to Accommodate Medical Manufacturing

Precipart Corp. manufactures gears, ranging from planetary systems to backlash assemblies, worms, spurs and helicals for all types of medical equipment, including various surgical and neurological pumps. Scott Alexander, director of sales and marketing for the company, is aware of the increased activity from medical component manufacturers in the last decade.

"When you think about it, medical technology seems to be the fastest-growing economic proof. That industry always is impacted very little by economic factors," he says.

Precipart's sales to medical component companies has provided the impetus for the company to add new employees, equipment and processes to its business structure.

"We're constantly growing. Also, we're looking at potential acquisitions and expanding into value-added assembly areas. This entails taking the components and moving to the next level of assembly. We've found that if you can partner with the customers to allow them to increase their own capacity, that's something they're always receptive to," says Alexander.

Gears are Shrinking and Getting Quieter

End-use aside, one trend in the medical component industry is a move toward smaller sizes. Forest City Gear sells gears to the device market as small as 3/8".

In 2004, Ikona Gear licensed a gear drive design to a cast manufacturer and remarked on the same trend toward smaller gears. Vladimir Scekic, vice president for business development at Ikona, sums it up.

"People want the gear to work, yet they don't want to know it's there. So, size is always an issue."

One notable exception to this trend is the growing number of scanning-type devices that involve rotating machinery and require larger gears. Philips Medical Systems recently launched the Genesis GXL combination open PET/CT System with a 28" gear that encircles the patient to provide a spinning radiation source.

The machine combines high sensitivity required for faster imaging exams with 3-D reconstruction to provide a more accurate representation and location of events. An open gantry design allows the machine to function as one integrated PET/CT system or two

independent imaging scanners.

Gears play a pivotal role in all of Phillips' diagnostic imaging technology, says Bruce Lutheran, principal mechanical engineer. The scanner rotates at a precision speed to capture the image, and the gears facilitate rotation and ensure that the timing is exact.

Other branches of medical devices rely on gears as well. Aircast licensed the Ikona Gear design two years ago for the commercial launch of its elbow brace. In this case, the Ikona design works with the hinging mechanism, which enables the product to provide static and adjustable stretch with the option of complete range of motion. This is mostly utilized by patients after elbow surgery or who are experiencing elbow trauma.

Ikona anticipates future work with the medical components industry. The Ikona Gear is a non-involute internal gear set manufactured with a one-tooth difference, making for high-ratio actuators, plastic application and the robotic applications that are prevalent in medical devices, says Ray Polman, Ikona's CFO.

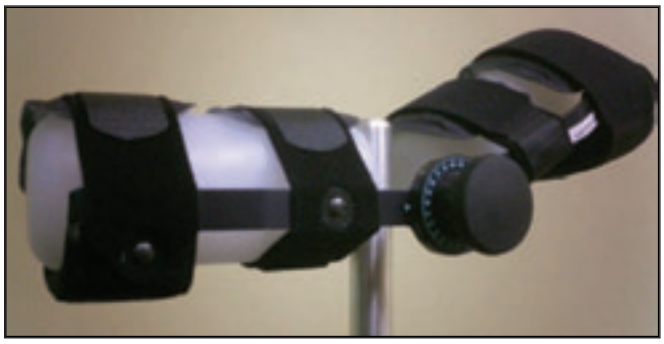
Regardless of the application, gear manufacturers report that working with medical component manufacturers requires more attention to detail to meet the often stringent quality requirements. Most of the gears that Precipart Corp. makes for the medical industry fall in the AGMA quality levels between 6–12. A variety of stainless steel alloys are used including 17–4 PH, 440C, 316, 303 and 304. Brass is common as well. Precipart estimates that about 75% of the parts it designs or manufactures have complex configurations, which creates challenges when working with any of the above alloys.

Alexander says, "To meet the performance requirement for the medical companies is an entirely different experience than for industrial manufacturing. In terms of quality and precision, the medical industry really gravitates toward higher-end components. In that aspect, it's most like aerospace manufacturing."

Invacare Corp. makes wheelchairs, mostly utilizing permanent magnet motor drives and right-angle worm gears to drive the wheels. Virtually all of the company's power wheelchairs use gears. The gears that Invacare buys are mostly AGMA's new Class 8, says Tom Neroda, principal engineer for Invacare. (*Editor's Note: AGMA's new class 8 corresponds roughly to about AGMA Q9 according to the older standard with which most readers are probably familiar.*) One of their biggest concerns is noise.

"As you can imagine, a wheelchair-bound person does not want to be noticed when they're moving around or call attention to themselves when they enter a room. Durability is also an issue, but that's

This powered hinge allows Aircast brace patients to stretch their arms.



Aircast uses the Ikona Gear to provide elbow surgery sufferers with a full range of motion.

not typically a problem. When the customer is out and about, we certainly want the chair to be at its best," he says.

Outsourcing to Overseas Gear Manufacturers

Invacare is headquartered in Elyria, OH, and the company calls itself the leader of the $6 billion market for home medical products. Reports estimate that sales of the company's wheelchairs, mobility aids, patient transport equipment, sleep therapy products, oxygen systems and other products have skyrocketed over the past 15 years.

Though the market in general is yielding unprecedented high sales, revenue in the last couple of years has tapered off slightly due to additional government regulations on the medical device marketplace. Invacare's most recent challenge is a government initative to match the individual more accurately with the type of wheelchair being prescribed. The aim is to ultimately reduce the cost of Medicare by not over-prescribing.

One way that Invacare has offset the financial effect of the new regulations is by outsourcing some of its gear manufacturing business to Asia. Nedora says that the gearmotors they buy from suppliers are split almost evenly between domestic suppliers and the more economic off-shore suppliers.

Competing with the allure of cheaper overseas gear manufacturing is just one of the challenges that more traditional gear companies must surmount to succeed in this niche of the medical industry. Additional quality requirements present another, but with the medical device market surpassing the $100 billion mark in 2004, these hurdles seem like small ones to playing a part in this market of the future.

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Wind Energy: An Established Industry with Emerging Opportunities

Joseph L. Hazelton, Associate Editor

Photo courtesy of Hansen Transmissions

"An industrial business with a very important growth potential for the next decade." That's the wind energy industry as described by Ivan Brems of gear manufacturer Hansen Transmissions International nv.

Brems, vice president–corporate marketing and business development, should know. Hansen Transmissions is much involved in the business of turning wind power into electricity. Headquartered in Antwerp, Belgium, the company has a new factory that only manufactures gearboxes for utility-scale wind turbines.

Such turbines generate 1–3 megawatts of electricity. Each with a combination of planetary and helical gears, they can be found around the world in wind farms—collections of massive towers whose rotating blades generate electricity.

Though decades old, the wind energy industry still has growth potential in its main markets: Europe, North America and Asia.

Europe: Established, But Still Growing

Europe is the most developed wind energy market and has the highest demand, according to figures from the Global Wind Energy Council (GWEC). Europe had 40,900 megawatts of installed capacity at the end of '05. The next largest market, North America, had 9,800. Also, the European market installed no less than 5,000 megawatts of wind power each year in '03, '04 and '05.

Portugal, Italy, the United Kingdom and France were among the 10 fastest growing countries in '05, with each installing at least 350 megawatts of new capacity.

North America: Vast Potential

For U.S. gear manufacturers, the fastest growing market for wind turbine gears is their own. America installed more megawatts than any other country during '05: 2,400. The next largest amount of new capacity was 1,800, installed by Germany.

However, the North American market has been volatile, based on GWEC numbers. In terms of new capacity, Canada and the U.S. installed 1,700 megawatts in '03, about 500 in '04, then more than 2,500 in '05.

Brems says the U.S. will remain one of the largest wind energy markets during the next 10 years, possibly installing as much as 40,000 megawatts of wind turbine capacity.

Also, Canada appears to be an emerging market, installing 120 and 230 megawatts of new capacity in '04 and '05, respectively.

"The Canadian market is really breaking out now," Brems says.

"Over the next 10 years, I believe they'll have a growth potential of generating 6,000–10,000 megawatts of wind power generation."

Asia: Vast Potential Too

"I would consider Asia to be the largest emerging market," says David Neidig, vice president of ITAMCO, a manufacturer of wind turbine gears.

According to GWEC figures, India and China are fast growing. India installed 1,430 megawatts during '05, the fourth largest amount that year. China installed 490. Brems predicts each of the two Asian countries will install 15,000–20,000 megawatts in the next 10 years.

Brems gives several reasons for wind energy's continuing growth: cost, public support for a clean environment, the growing need for energy around the world, and the ongoing emergence of new markets. Another of his reasons is political commitment.

Demand for wind turbines—and consequently, their gears—partly results from government action.

Main Markets: Nature of Demand

Wind energy's main markets include countries committed to the Kyoto Protocol, an international agreement for reducing emissions of greenhouse gases. A main way of reducing emissions is to generate more electricity from wind power. Countries committed to the protocol include Denmark, France, Germany, Italy, Portugal, Spain, the United Kingdom, Canada, India and China.

The U.S. doesn't operate under the Kyoto Protocol, but federal and state governments promote the development of wind energy.

More than 15 state governments promote it by mandating that specific amounts of their electricity must come from renewable energy sources, one of which is wind energy, reports the Union of Concerned Scientists, an environmental group consisting of citizens and scientists.

But government support can be withdrawn or can lapse.

U.S. Market: Tax Support

The U.S. has been an up-and-down market and depends considerably on a federal tax credit.

The credit is the wind energy production tax credit. The PTC is 1.9 cents for each kilowatt-hour of electricity generated by wind turbines during the first 10 years of a wind farm's operation. The credit has been described as a way to help level the playing field between companies generating electricity from wind power and those generating it from other sources, like gas, coal, oil and nuclear.

The PTC has existed since 1992, but it's not permanent, so the federal government must decide from time to time whether to extend the expiration date. On several occasions, it has allowed the PTC to lapse.

Without the credit, demand in the U.S. market drops. The drops aren't immediate—planning and installing a utility-scale wind farm takes time—but they are noticeable.

For example, the PTC expired June 30, '99, but was reinstated late that year. The lapse was followed by a drop. In '99, the U.S. installed 661 megawatts of new capacity. In 2000, it installed 53.

The credit, though, had been reinstated with a new expiration date, Dec. 31, '01. The U.S. installed 1,696 megawatts of new capacity in '01. The credit expired at the end of the year and wasn't reinstated till March '02. Lapse led to drop. The 1,696 new megawatts in '01 was followed by 410 in '02.

The U.S. market may be more stable through '07. The federal

government extended the PTC in mid-'05, months before it was due to expire and established a new expiration date: Dec. 31, '07. It was the first time the U.S. government avoided a lapse in the PTC.

After the credit was extended, the American Wind Energy Association said in a press release it "anticipates that strong growth momentum will continue in 2006 and 2007."

However, the government may not avoid lapses in the future. "If the government lets the PTC expire again, then that can have a negative impact on the market," Neidig says.

Serving the Markets

Gear manufacturers can serve the wind energy industry by making any of a range of parts and assemblies, from loose gearing to whole gearboxes.

In Plymouth, IN, ITAMCO supplies wind energy with gears and housings for utility-scale wind turbines. The company can manufacture a variety of wind turbine gears, but it tends to specialize in the internal ring gears. "We have a lot of a capability in that area," Neidig says. "We have a lot of shaping and grinding capacity."

ITAMCO wants to increase its business in the wind energy industry. "We're in the process of getting into assembling complete drives for the wind turbines," Neidig says. To this end, ITAMCO purchased a former automotive plant in Argos, IN, and plans to employ 40 people in the 385,000-square-foot facility.

Hansen Transmissions manufactures complete wind turbine gearboxes and built a new factory dedicated to making them. According to Brems, the factory performs all the processes for manufacturing wind turbine gearboxes, including heat treatment of all the gears, except for one—the large internal ring gear: "The nitriding of the ring gears is the only process we outsource."

The factory also includes two 4.5–megawatt test stands for running the gearboxes under full load. Brems says Hansen is adding another 4.5–megawatt test stand and is building a 13–megawatt test stand, for both production testing and for research & development.

"We have spent $125 million dollars to build such a factory," Brems says. "On the one end, we bring in raw material, and on the other end, we ship out completely manufactured and tested wind turbine gearboxes."

Today's Wind Turbine Gears

Generally, utility-scale wind turbines generate 1–3 megawatts of electricity. They're industrial applications, so they require large, coarse-pitch gears. A good example of what large means is the internal ring gear. "Wind turbines are using planetary systems with ring gears that are 60 inches in diameter and bigger," Neidig says.

However, wind turbine gears also have to be high quality. "Basically, all the gears get ground," Neidig adds. So gear quality is commonly Q12 or better under AGMA 2000-A88.

A utility-scale wind turbine commonly has 10 or more gears, most of them in the drive system. Generally, a turbine has either a.) one planetary stage, with spur or helical gears, and two sets of helical gears, or b.) two planetary stages with one helical gear set. Each planetary stage consists of a sun gear, three or more planet gears and an internal ring gear. Each set of helicals has two gears.

Size and quality aren't the only concerns. "We have to meet very long design lifetimes, 20 years," Brems says. "You need very high reliability."

Also, gears will likely become even larger as the wind energy industry shifts to increasingly powerful wind turbines.

Tomorrow's Wind Turbine Gears

The industry has already developed 5-megawatt turbines. "It's logical to assume these prototypes will be developed over the next years into serial production," Brems says, adding that turbines in the 6–8 megawatt range could be developed in the next five years.

Larger turbine gearboxes present problems in terms of size, weight and quality. Gearbox manufacturers may be able to reduce size and weight by having turbines parts, such as the rotor bearing, integrated into the gearbox itself, Brems says. He predicts quality levels for today's wind turbine gears should be sufficient for tomorrow's, but he cautions: "Achieving those quality levels as gearboxes grow bigger will be a challenge."

Still, Neidig says: "This wind turbine business has probably been one of the best things for the gear industry in a long time."

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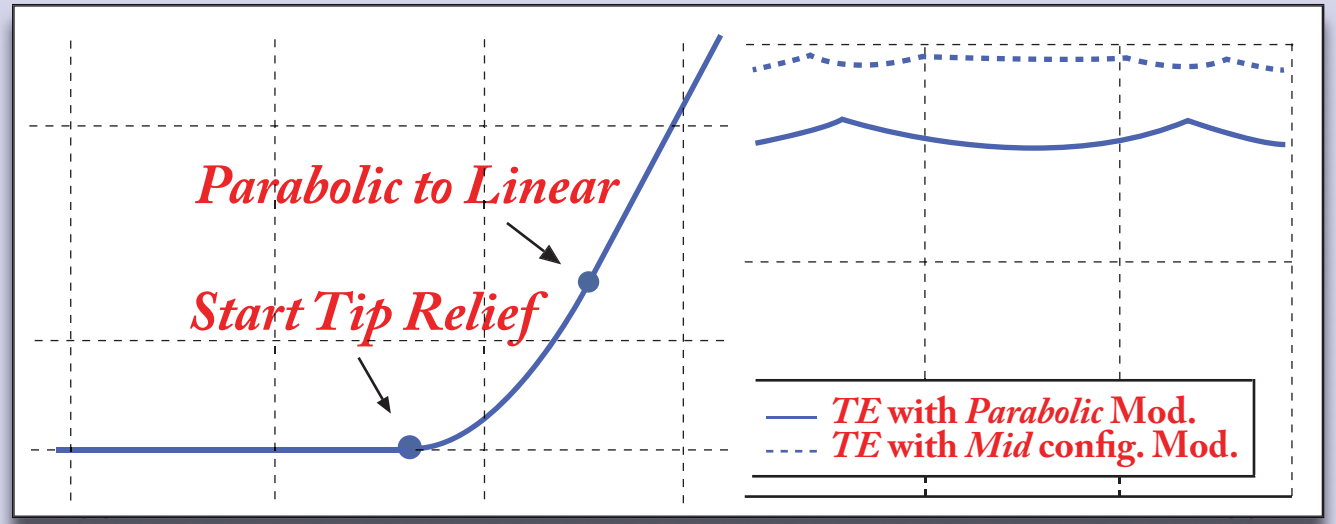
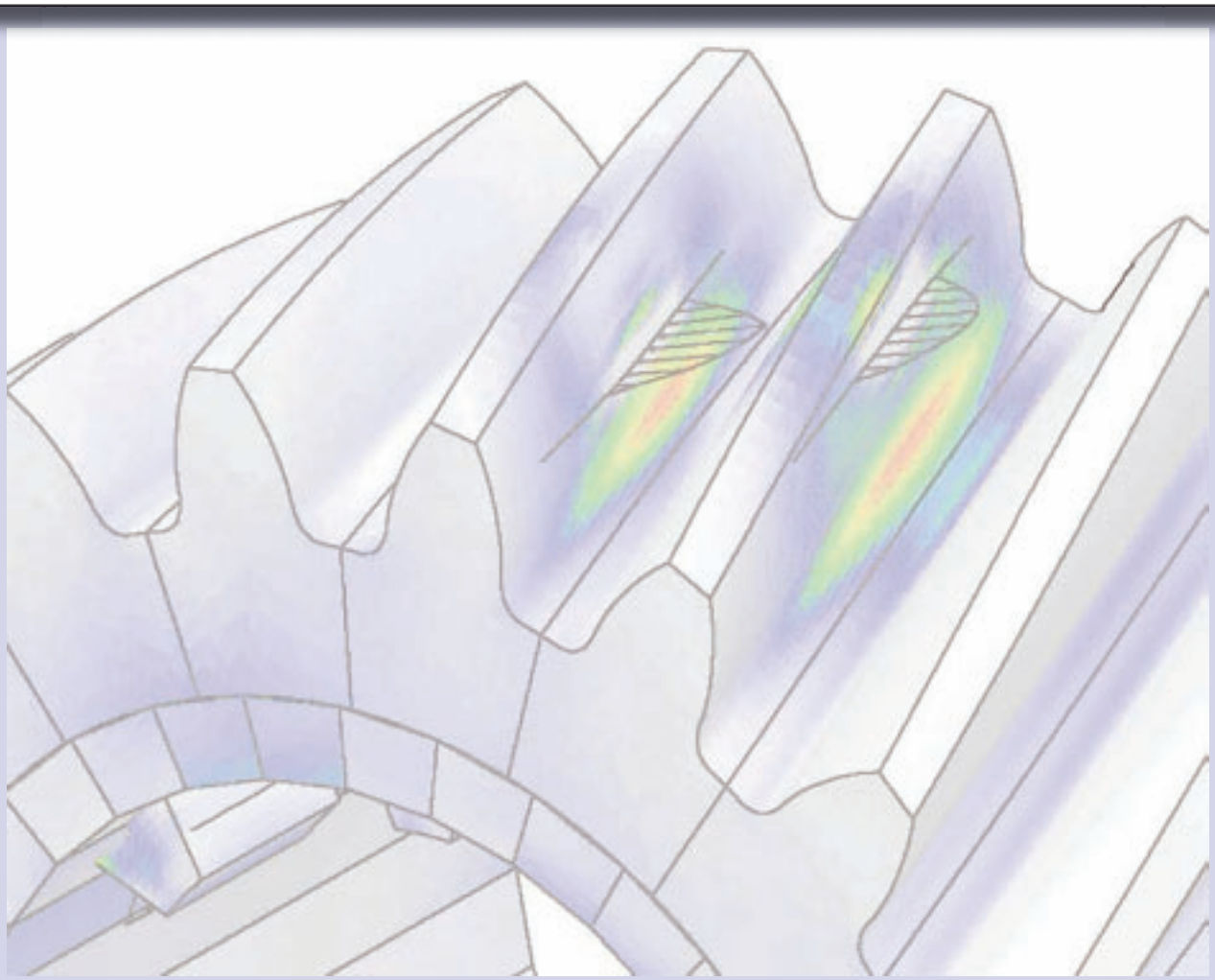
Proposal for Tip Relief Modification to Reduce Noise and Sensitivity to Meshing Conditions in Spur Gears

Ciro Santus, Fabio Presicce, Marco Beghini





Ciro Santus *is assistant professor in the department of mechanics at the University of Pisa in Pisa, Italy. Currently, he is researching various aspects of machine design. Santus has worked extensively in FEM simulation in gears and contact mechanics. He has an advanced degree in mechanical engineering and a Ph.D. in metal fatigue related to oil drilling technology.*

Fabio Presicce *is an engineer for Selex Corp., a Finmeccanica company. His main responsibilities include developing hardware engineering requirements in avionics technology and human-machine interface systems. Presicce has also worked extensively in aerospace gear transmission applications in flight controls and human-machine interface systems.*

Marco Beghini *is a professor in the mechanical department at the University of Pisa. He has twenty years' experience in material and mechanical component analysis and design as well as several years' collaboration with Avio SpA in testing, analysis and design of gear transmissions for aeronautical applications.*

Management Summary

In this article, a new tip relief profile modification for spur gears is presented. The topography proposed here is a classical linear profile modification with a parabolic fillet (linear-parabolic modification). The parabolic fillet extension is treated as a parameter and its effect investigated.

The proposed topography combines advantages from both linear and parabolic tip relief. The evolution from linear to parabolic is discussed in terms of peak-to-peak transmission error. Anomalous contact conditions due to particular tip relief modifications are reported, and maps are obtained in order to find optimum tip relief by taking into account contact condition boundaries.

Introduction

In a gear set, transmission error (TE) is defined as the difference between the effective and the ideal position of the output shaft with reference to the input shaft. The ideal position represents a condition of perfect meshing, without geometrical errors or distortions. TE can be expressed either by an angular displacement or, more conveniently, as a linear displacement measured along the line of action tangent to the base circle. TE is considered to be the primary cause of whining noise (Ref. 1). Indeed, whining noise is produced by changes of tooth load:

- Amplitude,
- Position along the profile,
- Direction.

These changes are consequences of tooth deflection, local contact deformation and body deformation, which are the origin of TE.

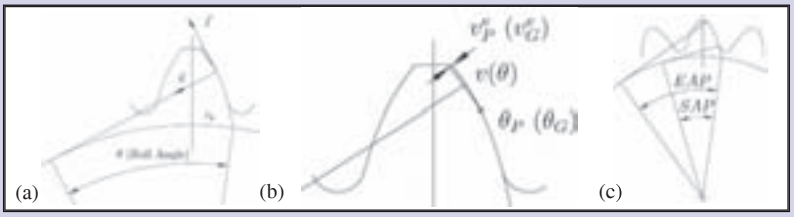


Figure 1(a)—Definition of the roll angle θ. Figure 1(b)—Definitions of: profile modification $v = v(\theta)$ as function of the roll angle, the total thickness at the end of the flank either for pinion v^e_P or gear v^e_G and the start roll angle for either pinion θ_P or gear θ_G. (c) Definition of start of active profile (SAP), end of active profile (EAP) angles.

Several authors (Refs. 2–6) studied the correlation between TE and tip relief profile modification since it is a strong tool to modify TE by looking at fixed gear parameters. Niemann proposed long and short modifications (Ref. 4). The difference in denomination is based on the starting point of tip relief along the profile. According to experimental results, gears with long modifications show reduced TE excursion, indicated as peak-to-peak transmission error (PPTE), and therefore little noise level at the design torque.

At lower torque, this optimum condition was not verified, and an intermediate or short modification is suggested.

In tooth modification design, tip relief is defined as the thickness v of the material removed along the tooth flank with reference to the nominal involute profile. Profile modification is usually defined versus the roll angle coordinate (θ), shown in Figure 1 (a, b), and measured in the direction of the inner normal, shown in Figure 1 (c).

The type of function $v = v(\theta)$ is usually indicated as profile modification topography. Meshing sensitivity to topography is explored throughout this article.

A different shape for the tip relief profile modification is proposed with the aim of reducing noise since TE can be significantly reduced if an optimized profile modification is produced (Refs. 1, 5, 3). Litvin (Ref. 7) agrees with this approach even though tooth contact analysis is considered only, instead of loaded tooth contact analysis (LTCA). This article shows how the new profile tip relief modification proposed here can influence TE meshing response, according to LTCA hypothesis.

Linear and parabolic topographies are the only shapes that have been deeply studied (Refs. 8–11). Considering recent grinding developments, it is possible to consider more complex

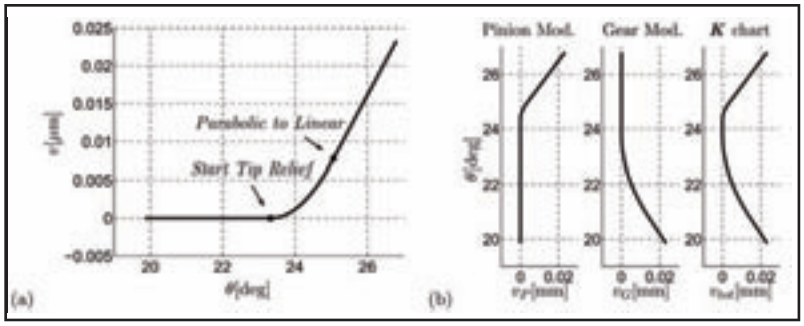


Figure 2(a)—Tip relief profile modification definition. Figure 2(b)—Example of pinion-gear tip relief modification and K-chart combination.

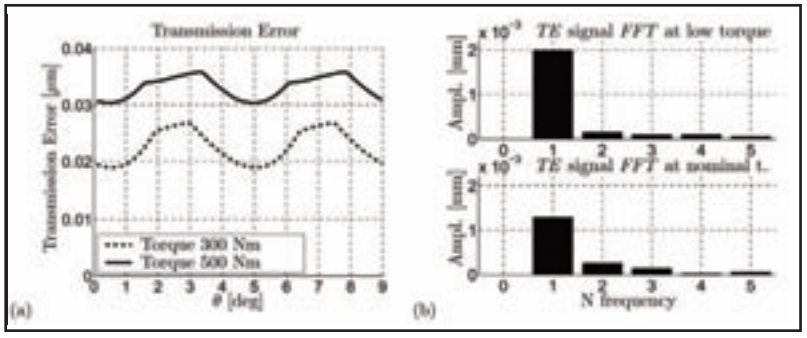


Figure 3(a)—TE at low torque and nominal torque applied. Figure 3(b)—Fast Fourier Transform (FFT) of the TE signal, both cases.

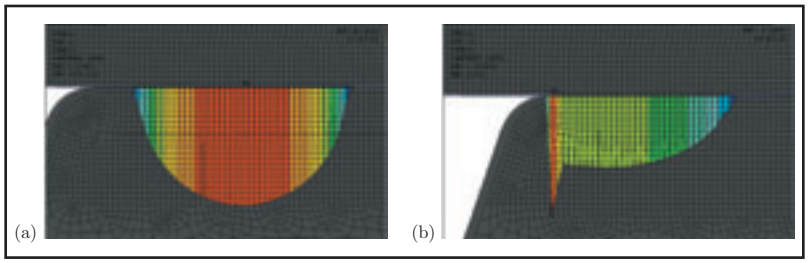


Figure 4(a)—No corner contact detected. Figure 4(b)—Corner contact detected.

shapes, in particular for spur gears in which profile modification is strategic (Ref. 12).

Linear tip relief modification produces minimal transmission error in spur gears if properly designed at a given load (Refs. 4, 11).

Parabolic profile modification satisfies tangent continuity condition even though sharp curvature changes is produced. Linear profile modification produces an edge instead. At the modification start point, discontinuity arises. Indeed, according to solid elastic contact mechanics, a sharp edge generates singular pressure when an angular point falls inside the contact region. Therefore this modification topography is considered to be more dangerous for contact pressure, which is the primary reason of micropitting activation (Refs. 13, 14).

The new topography proposed here is able to exploit both linear and parabolic topography properties since it is a linear relief with a parabolic fillet, as shown in Figure 2.

The topography shown here has never been found by the authors in the technical literature.

Transmission error produced by the modification pattern of Figure 2 is shown in Figure 3, along with a fast fourier transform analysis of TE. In Figure 3(b), the mean value of the TE signal is eliminated, first frequency component is predominant, and it is remarkable that with higher load, PPTE and first frequency amplitude can be smaller than with lower load.

As discussed, PPTE can be effectively considered as the main parameter of TE roughness (Ref. 8).

The tool exploited to find the optimum tip relief configuration is a map plotting PPTE as a function of start relief roll angles θ_P and θ_G for fixed profile modification magnitudes at the top v^e_P and v^e_G.

Methodology

The methodology proposed by the authors (Ref. 8) is applied here.

Simulations of meshing gears have been carried out by means of a hybrid method, combining the finite element technique with a semi-analytical solution (Refs. 15, 16).

The main assumptions for the analysis are the following:

• **Plain strain conditions suggested by the spur gear geometry (high ratio b/h)**. Two-dimensional plane strain analysis is adequate for this kind of tooth. Moreover, the two-dimensional version of the software requires little time both for model generation and simulations, with very precise results.

• **Static analysis**. Static TE was determined while neglecting rotational speed and inertia forces. This is the main assumption; undertaking dynamic analysis is too time consuming.

• **Friction neglected**. It is assumed that it has little effect on TE output.

• **Space error and pitch error not considered**. No statistical consideration was included in the analysis.

The quantities v^e_P (v^e_G) and θ_P (θ_G) are defined in Figure 1(b). The ranges for both of these two variables are the start of active profile roll angle (SAP) and the end of active profile roll angle (EAP) for each gear, as shown in Figure 1(c).

Research Boundaries

Corner contact boundary. Corner contact is produced when the contact region includes zones of the fillet of the tooth tip (Ref. 17). As a consequence of tooth deflection, the effective contact

ratio is greater than that found according to rigid geometry. Hypothesis: The contact pressure rises locally at the tip fillet, as shown in Figure 4.

This definition of corner contact can be exploited if an FEM analysis is performed. When the corner contact is detected, the calculated pressure peak was not considered reliable since the maximum is strongly affected by the radius of the fillet, which is a very unpredictable quantity.

High curvature boundary. There is also the possibility of getting an anomalous contact condition if the tip relief is too high along the tooth profile. In this condition, high curvature occurs and then contact pressure is expected to be much higher than the Hertz model according to the nominal involute curvature.

In Figure 5, three contact pressure histories are shown in which only linear-parabolic profile modification parameters are modified.

For each case, two load conditions (nominal and low load) are shown in comparison. It is worth noting that corner contact is related to torque versus tip relief, so configuration can show corner contact if the load is high enough. This is obviously detectable only if loaded tooth contact analysis (LTCA) is considered.

PPTE Maps

This paper's main result is to obtain PPTE maps in order to find the minimum inside an acceptance domain defined according to contact pressure. Maps hereafter presented plot PPTE as a function of tip relief start roll angles (θ_P, θ_G), which are strongly PPTE-dependent parameters, for a given quantity of material removed at the top (v^e_P, v^e_G). Initial values of v^e_P and v^e_G have to be related to the nominal torque of the gear set even though they are also strongly PPTE-dependent (Refs. 8–11) .

To define completely the linear-parabolic modification (θ_P, θ_G) and (v^e_P, v^e_G) is not enough; the transition from parabolic to linear point roll angles needs to be defined (θ_{pP}, θ_{pG}) (see Figure 2(a)).

It is clear that:

$$\theta_P < \theta_{pP} < EAP_P$$
$$\theta_G < \theta_{pG} < EAP_G \qquad (1)$$

To let the transition from linear to parabolic be described in natural fashion, configurations at fixed ratios are considered in singular maps.

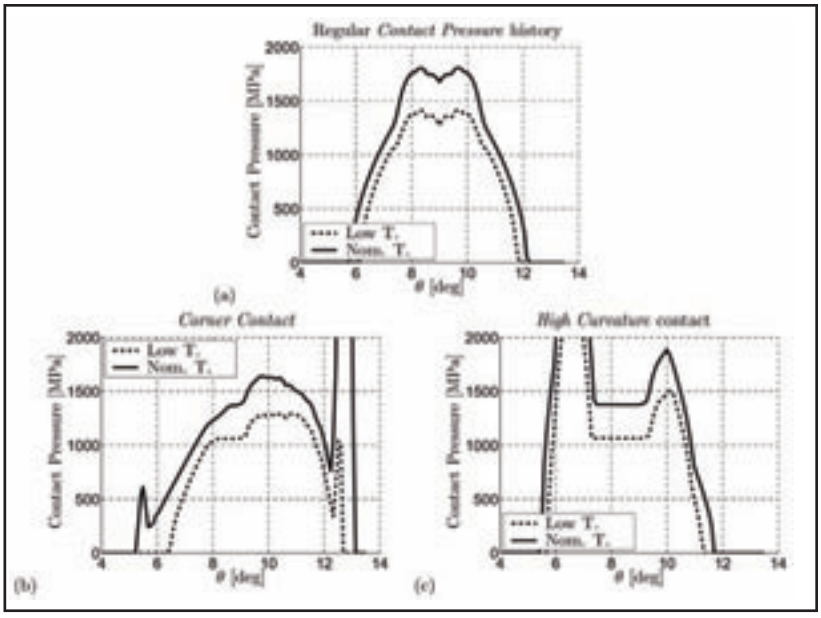


Figure 5(a)—Regular contact pressure history configuration. Figure 5(b)—Corner contact configuration. Figure 5(c)—High curvature configuration.

Table 1—LCR gear set design parameters.

Modulus	**1.75 mm**	**Pressure angle**	**22.5°**
Pinion N. teeth	**80**	**Gear N. teeth**	**80**
Pinion external diameter	**143.2 mm**	**Gear external diameter**	**143.2 mm**
Pinion root diameter	**135.3 mm**	**Gear root diameter**	**135.3 mm**
Pinion face width	**11.0 mm**	**Gear face width**	**11.0 mm**
Pinion v^e_P	**23.3**	**Gear v^e_G**	**23.3**

$$\lambda_P = (\theta_{pP} - \theta_P)/(EAP_P - \theta_P)$$
$$\lambda_G = (\theta_{pG} - \theta_G)/(EAP_G - \theta_G) \qquad (2)$$

Limit configurations are $\lambda_{P(G)} = 0$ (linear modification) and $\lambda_{P(G)} = 1$ (parabolic modification). Maps with λ ranging from 0 up to 1 are reported hereafter.

Computational Performances

To perform parameter sensitivity analysis, a common PC platform was used with the following characteristics:

- CPU 2.6 GHz
- RAM 1 GB

Plane strain analysis was performed by ExtPair2D™ (Refs. 18, 19). Analyses were automatically performed in about 4.5 CPU hours, simulating 50 time steps for each meshing, for 225 different tip relief (θ_P, θ_G) configurations.

Results

The aforementioned methodology was applied to a low contact ratio (LCR) gear set. The main parameters of the set are reported in Table 1.

For the equal number of the set, several sym-

Table 2—Profile modification ratios and analysis of configurations.					
$\lambda_{P(G)}$	0	1/4	2/4	3/4	1
0	(Lin)				
1/4		(1-1)	(1-2)	(1-3)	
2/4		(2-1)	(2-2)	(2-3)	
3/4		(3-1)	(3-2)	(3-3)	
1					(Par)

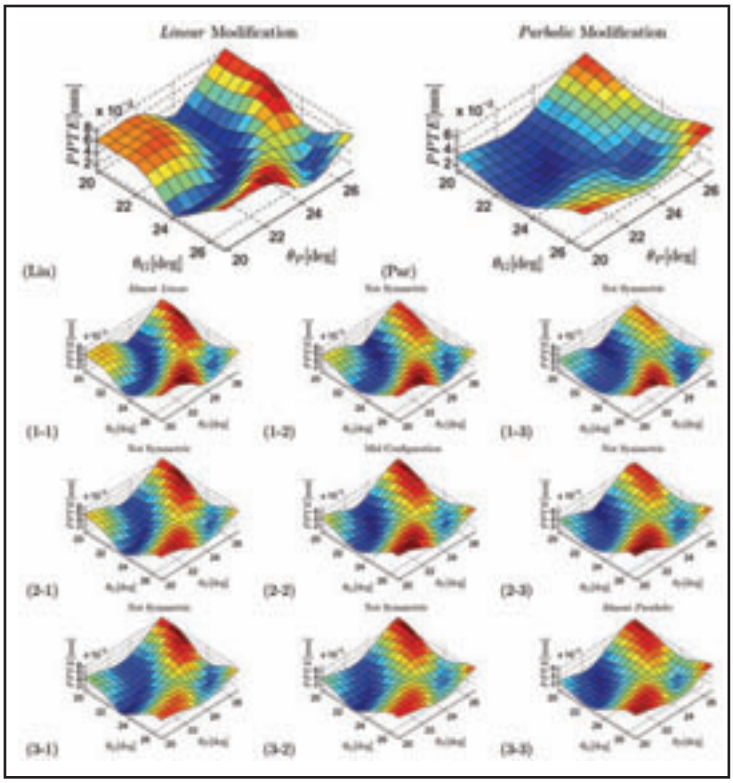


Figure 6—Nominal load (Lin) PPTE obtained with linear modification topography. (Par) PPTE obtained with parabolic modification topography. Intermediate configuration meshing conditions shown in (1-2), (1-3), (2-1), (2-3), (3-1) and (3-2).

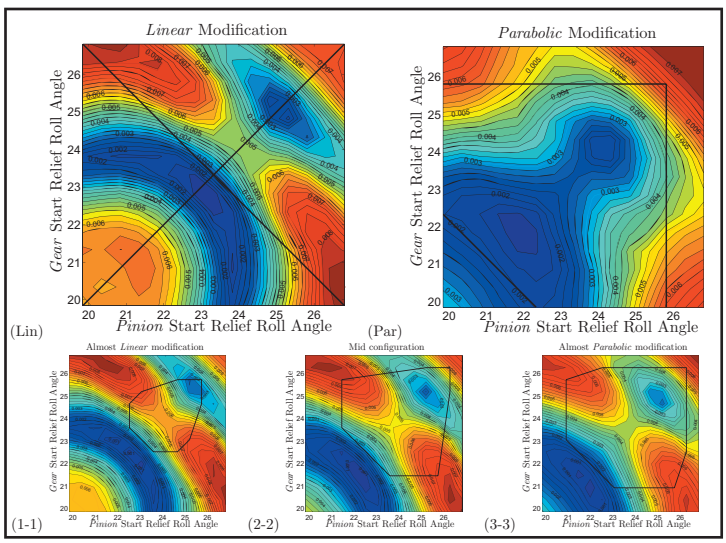


Figure 7—Nominal load (Lin) linear modification. No boundary can consistently be applied. (Par) parabolic modification, boundaries are wider. Intermediate configurations shown in (1-1), (2-2) and (3-3).

metry properties are expected. Configurations analyzed are reported in Table 2.

Two load conditions applied to the gear set were considered in this article:

- 300 Nm—considered a low load for the gear set,
- 500 Nm—nominal load for the gear set.

Nominal load

For nominal torque, the effect on PPTE of the migration from linear to parabolic topography is depicted in Figure 6.

Furthermore, boundaries were applied. Results are reported only for symmetric configurations in Figure 7.

When searching the minimum inside boundary, it is clear that parabolic modification is the one that offers a wider acceptance domain. Therefore, larger areas in which PPTE produces an absolute minimum can be considered.

Minimum values for configurations shown in Figure 7 are reported in Table 3, not considering boundaries.

Among minimum values reported in Table 3, only the one referring to parabolic modification is acceptable. Though others are lower, they fall outside the boundary. Taking boundary into account, parabolic modification leads to the best result.

In Figure 8, a transmission error trace is reported both for parabolic optimum (continuous line) and for mid-configuration minimum PPTE configuration. PPTE is lower for mid-configuration, but edge contact is evident. Indeed, this configuration falls outside the acceptance boundary as shown in Figure 7.

Low Load

For low torque, the migration from linear to parabolic topography is depicted in Figure 9. For this load level, no boundary related to contact pressure was applied since load is not expected to be dangerous at this level. Even though there are also necessary conditions of anomalous contact (edge contact or high curvature) at lower load, it is possible to assume that they are confined to useless configurations. Minimum values found at the different configurations are reported in Table 4.

It is worth noting that neither linear nor parabolic topography generates minimum PPTE at both loads.

Table 3—Minimum PPTE values at the nominal load.		
(LIN) 1.14 µm		
(1-1) 0.63 µm	(2-2) 0.76 µm	(3-3) 0.57 µm
(Par) 1.39 µm		

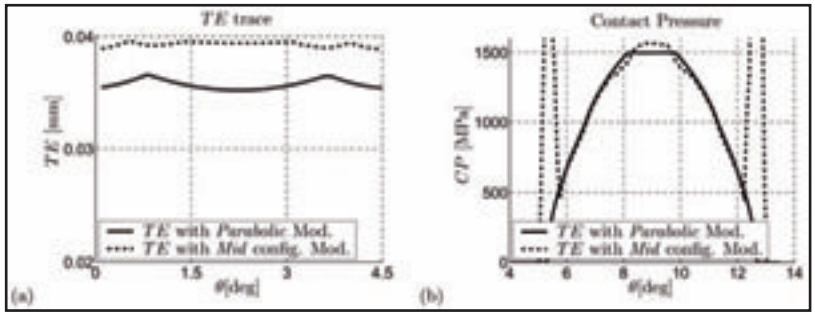


Figure 8(a)—Parabolic optimum TE trace. Figure 8(b)—Mid-configuration linear with parabolic fillet optimum TE trace.

In the configuration proposed here, minimum PPTE output is generated by a linear with parabolic fillet configuration. However, the optimum is dependent on the load. Therefore, the aim of this article is not to propose this result as a "golden" rule, but to show that the parabolic fillet can be an effective parameter for obtaining an optimum solution.

Sensitivity to Center Distance

In order to avoid a huge amount of graphical output, sensitivity to center distance offset is considered for linear modification at nominal load. Results are shown in Figure 10.

The entities of offset are around ±0.2 mm. In comparison with modulus, it is clear that perturbations induced by the meshing condition have an influence on the PPTE map.

Conclusions

In this article, a new tip relief profile modification is proposed along with loaded tooth contact analysis methodology. Static peak-to-peak transmission error is considered as the main meshing output since it can be related to noise level. Extensive parametric numerical analysis results are presented. PPTE maps are reported as a function of pinion and gear start of tip relief roll angles. Migration from linear to parabolic modification is effectively described.

Contact pressure anomalies are presented and applied as limits of acceptance on PPTE maps.

Modifications that are close to parabolic can show a wider acceptance domain, since edge contact and strong curvature issues are less dangerous.

The optimum configuration is found here for a gear set at a given load. The new topography introduces a degree of freedom that can be useful in designing optimum profile modifications for any gear set.

Simulations are performed with the aim of gear contact dedicated tools produced by Advanced Numerical Solutions (ANSol)

The authors are grateful to Dr. Sandeep M. Vijayakar, head of ANSol, for his large support to the development of the work.

Table 4—Minimum PPTE values at the low load.		
(Lin) 0.87 µm		
(1-1) 0.39 µm	(2-2) 0.53 µm	(3-3) 0.52 µm
(Par) 0.95 µm		

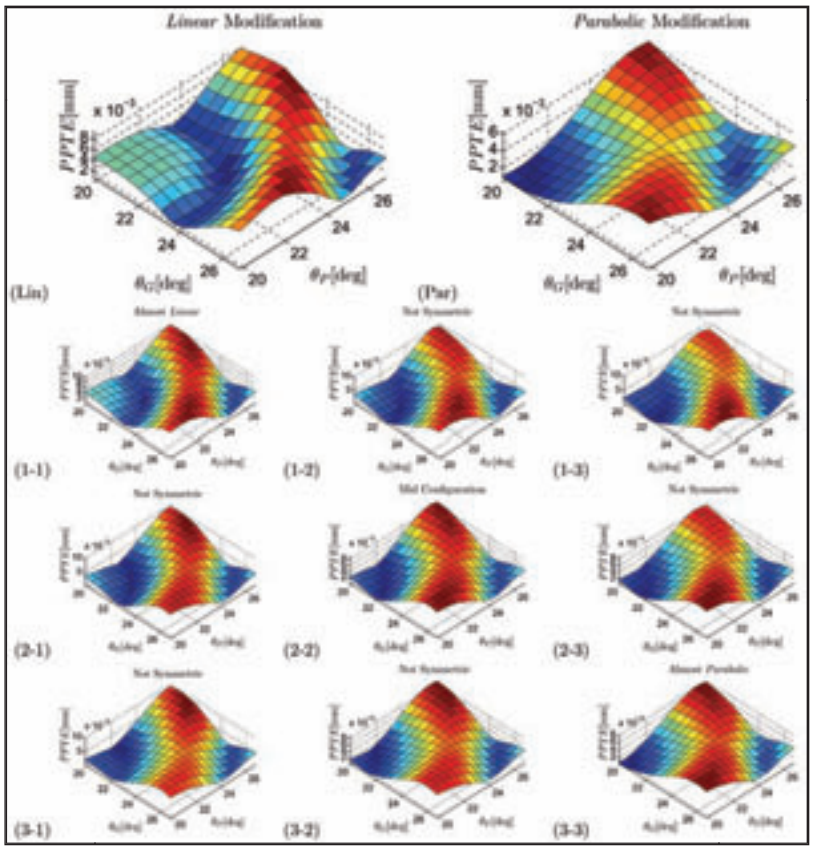


Figure 9—Low load: (Lin) PPTE obtained with linear modification topography. (Par) PPTE obtained with parabolic modification topography. Intermediate configuration meshing conditions shown in (1-2), (1-3), (2-1), (2-3), (3-1) and (3-2).

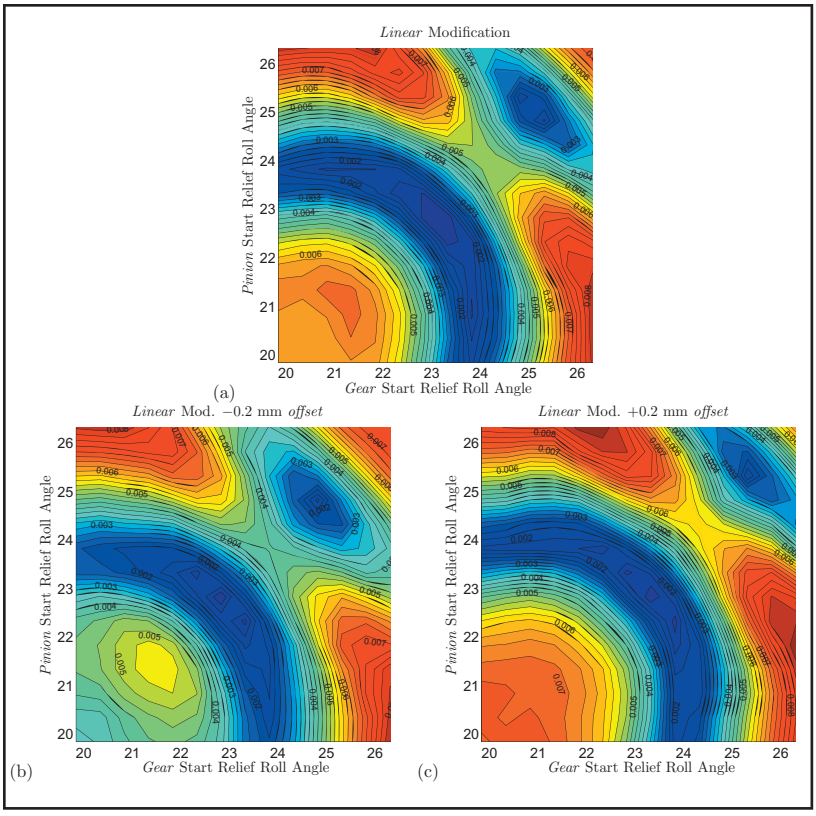


Figure 10(a)—Linear modification. Figure 10(b)—Linear modification with offset –0.2 mm. Figure 10(c)—Linear modification with offset +0.2 mm.

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Detailed Computer Model of Gearbox Reduces Design Time

Francois Gerard

Business Development Manager, LMS Engineering Services

LMS International, an automotive consultancy, helped Elasis S.C.p.A., a Fiat subsidiary, develop a new, dynamic vibroacoustic prediction method to reduce design time and engineering costs through accurate prediction of gear noise in the design phase. The method, based on a pure computer aided engineering (CAE) model, demonstrated the potential for reducing time and costs when LMS and Elasis were working on a new transmission project.

Currently, large amounts of time and money are spent during the prototype phase of powertrain development identifying and solving noise problems occurring under various operating conditions. Elasis and LMS worked together to simulate gearbox noise using a detailed CAE model that simulates noise generation mechanisms at the source. Experimental testing was used at every phase of the modeling in order to validate the CAE modeling. This approach provides more information on the root cause of noise problems than even prototype testing and makes it possible to develop solutions earlier, faster and at a lower cost.

LMS International and Elasis S.C.p.A. used a test rig like in the above photos, a virtual engine simulator inside a semi-anechoic chamber, to perform an in-depth study of gear rattle noise on a new transmission. The simulator results were compared with measurements from a CAE model of the gearbox to validate the accuracy of the modeling method's vibroacoustic predictions.

As automobile manufacturers continue to substantially reduce engine and road noise, the transmission is becoming of much greater importance as its noise is less and less masked by other sources. Transmission designers must address noise problems occurring in many different conditions, such as clutch clunk noise, gear whine, gear rattle, driveline boom, etc. Two major classes of gearbox noise encountered in practice are gear whine and gear rattle.

Major Noise Generation Mechanisms

Gear whine is a tonal noise that occurs at orders of engine rpm which correspond with the number of teeth in the different gear pairs. Gear whine can result from several causes, a main one being errors in manufactured tooth geometry or shape,

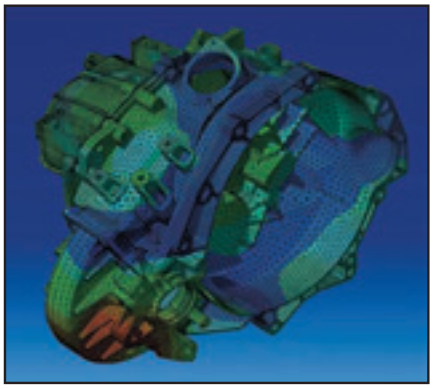
another one being excessive intentional modifications to tooth shape (like tip and root relief) that affect conjugacy in mating pairs of gears. However, gear whine is also caused by variation in the rotational stiffness of contact between two gear pairs. This stiffness varies as a function of time for two different reasons. The number of teeth in contact can vary through each revolution, with two teeth being in contact at one point in time and three at another, for example. Also, the point of contact on a given gear pair continually moves along the face of the teeth. One can view each tooth as a beam that is clamped at its root. The bending stiffness of these beams changes as the contact point moves along the beam. For one given tooth, the stiffness rises as the contact point moves towards the root diameter and falls as the contact point moves towards the outer diameter. This phenomenon accounts for additional stiffness variation as a function of time.

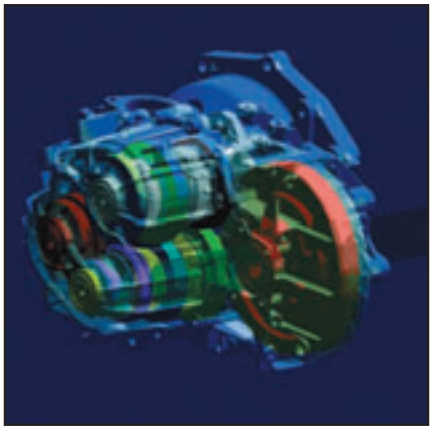
Gear rattle results from the fact that non-power transmitting gears are free to move within boundary limits defined by the tangential clearance between the teeth of different gears and the radial and axial clearance between gear and shaft. These gears impinge upon other gears and shafts, resulting in metal-to-metal impacts. These impact forces generate a wideband vibration frequency content. The impacts are driven by engine speed fluctuations due to combustion forces. Gear whine and rattle sources are transferred to the shaft bearings, which finally excite the transmission housing. The housing vibrates and acts as a noise radiator.

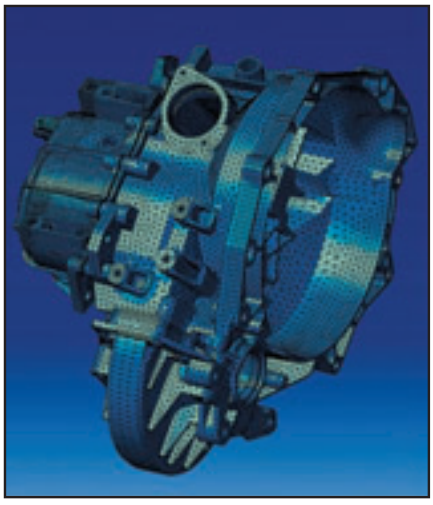
Move from Build and Test to CAE

Today, transmission manufacturers typically address these problems by spending considerable time and energy during the prototype testing phase evaluating transmission noises occurring when gears are being shifted, as the engine is accelerated in various gears, while idling, etc. The problem with this approach is that it's very expensive and time-consuming to build prototypes, perform physical testing and then modify the prototypes in an effort to solve the problem. Another problem is that the amount of information provided by physical testing is limited by the number and accuracy of sensors that can be used to instrument the transmission. Many important areas, such as the gear teeth, are difficult or impossible to instrument.

The challenge was modeling the full complexity of the internal operation of the transmission to the level of detail required to accurately predict internal dynamic forces in the wide frequency range associated with gear rattle.







For these reasons, Elasis has in the last several years begun working to develop CAE methods to evaluate and understand gearbox noise in the design stage when prototypes are not available. The aim is to be able to optimize the design while reducing or eliminating the need for troubleshooting during the prototype phase. One approach that has been used successfully by LMS is to focus on the analysis of the transmission housing, analyzing how the transmission housing vibrates and radiates noise under known forces at the bearings and how this noise is transmitted to the vehicle interior. The transmission housing can be modeled using finite element (FE) and boundary element models, and the forces at the bearing can be identified by means of experimental methods, such as transfer path analysis. This combined test-CAE simulation can be used to identify weaknesses in the housing and make corrections such as adding ribbing, changing wall thickness, etc.

This method can be used based on forces identified on the current design of the gearbox, if the box is already available for testing, or with realistic forces defined from experience with similar types of gearboxes. This approach is appropriate when the noise problem lies in resonances of the gearbox housing, which amplifies the internal forces generated at the bearings. However, when the problem is mainly due to high excitation forces, the solution cannot always be found in structural housing modifications, and another approach must be used.

Eliminating Noise at its Source

Elasis is a Fiat-owned engineering company that works mainly for Fiat Auto and on the Fiat-GM Powertrain joint venture (FGP), carrying out research and development on vehicles and powertrains. In the current project, LMS and Elasis set out to go beyond the above method by analyzing in detail the sources of the noise in a new transmission. The challenge was modeling the full complexity of the internal operation of the transmission to the level of detail required to accurately predict internal dynamic forces in the wide frequency range associated with gear rattle.

LMS engineering specialists developed an approach that combines multibody simulation and boundary element analysis to capture the root causes of noise generation within the transmission. The first step was using LMS DADS software to create

a dynamic model of the internal transmission mechanism that incorporates gear stiffness, gear backlash, bearing characteristics, and hub and sleeve connection properties. The flexibility of components, such as the shaft and housing, was represented by using modal parameters obtained from FE models. In the project, a constant stiffness at the contact of each pair of teeth was considered because the focus was mainly on gear rattle. Stiffness fluctuations due to the moving contact between teeth were neglected.

However, when focusing on gear whine, it is possible to extend the procedure. A person can, for instance, use an analytical relationship that provides the stiffness of the tooth contact as a function of the parameters related to the contact location. This relationship can be incorporated into the model as a user-defined subroutine.

The next step was building a boundary element model of the housing using LMS Sysnoise software in order to predict the noise radiated under the simulated conditions.

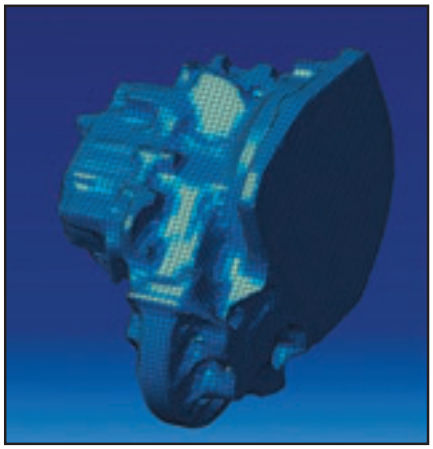
Validating the Accuracy of the Model

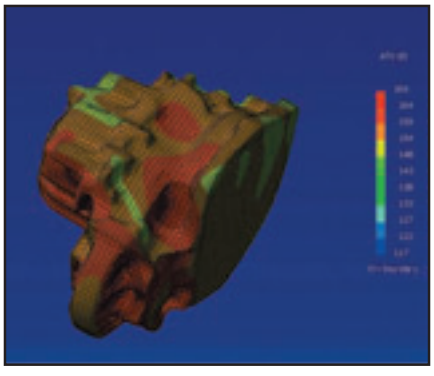
The NVH department at Elasis has built a state-of-the-art test rig to evaluate manual gearboxes. Within the scope of this project, this test rig was used to identify the main source of gear rattle and to provide the necessary information and physical insights to the numerical modeling and analysis.

This test rig is a virtual engine simulator (VES), which has the ability to reproduce speed and torque fluctuations, up to 500 Hz, similar to those generated by a physical internal combustion engine. This simulator eliminates the need to have a real engine. Moreover, it ensures that the gearbox is the sole source of the recorded noise. This capability allows for an in-depth study of gear rattle noise and eliminates the mask effects of engine noise. Furthermore, the VES allows the "core" parameters to be changed to perform a parametric sensitivity study.

One important insight gained during the project is that velocity fluctuations at the engine shaft primarily increase gear rattle at low rotational speeds.

The input to the multibody simulation was 1.) the combustion pulsations represented by the engine speed fluctuations and 2.) the resistance torque as seen by the transmission, which represented the vehicle load. The multibody simulation was carried out in fifth gear, by inputting the rotational speed on the flywheel while applying a resistance torque at the output shaft. The gearbox housing acted as the noise radiator. Because the gearbox was simulated as a flexible component characterized by the modes of an FE model, the modal participation factors as a function of time were computed during the multibody simulation. They were transferred to the frequency domain and applied to the vibroacoustic model of the gearbox, which yielded the noise radiation prediction. The simulated results were compared to the measurements to validate the modeling approach.





This advanced modeling procedure can be used for optimization purposes, and a big advantage is that both the source parameters (gear clearance, contact stiffness) and the transfer path parameters (component inertia and flexibility, housing dynamics) can be investigated and modified with a view to improving the noise and vibration performance.

This method will enable Elasis to make better design decisions in the early phases of the development when prototype results are not available. It will also become possible to obtain far more detailed information on the performance of proposed designs and evaluate alternate decisions at much less time and expense compared to the build-and-test method. As was already mentioned, the modeling procedure can be extended easily to also simulate gear whine. As the new simulation methods are further refined and used more widely within Elasis, they should substantially improve the transmission design process.

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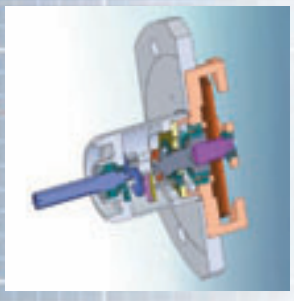

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Photos of Oldsmobile 442 and 442 engine courtesy of *ClassicMuscleCars.com*.

What's The Right Tolerance?

Charles D. Schultz, PE

Charles D. Schultz, PE *is chief engineer at Brad Foote Gear Works Inc., located in Cicero, IL. In the gear industry since 1971, he currently designs custom gearboxes and modifies standard ones, both for industrial applications. He's also overseen the repair and refurbishing of several hundred gearboxes from different manufacturers. Schultz is author of* An Introduction to Gear Design *and of "Gearbox Field Performance from a Rebuilder's Perspective," which was presented at the AGMA 1999 Fall Technical Meeting.*

In the late '60s, the "gearhead" lunch table at my high school spent several months discussing a classmate's effort to "blueprint" the motor in his already powerful Oldsmobile 442. My childhood service as "bolt bucket boy" while my dad attempted to rebuild the family station wagon left me questioning the wisdom of taking apart a functioning muscle car to obtain a few more horsepower, but I was in the minority at the lunch table.

Articles in the various hot rod magazines we memorized spoke of optimizing cylinder wall clearances and improving surface finishes as if the benefits of such work were common knowledge. Many of us were taking drafting classes at the time, but the entire concept of "tolerancing" dimensions had yet to be introduced. I don't remember it ever coming up in engineering school either.

Two things brought this memory to mind recently. First there was the photo of an Olds 442 on a muscle car calendar popular in our shop. Then there was the study in the Oct. 5 edition of *Design News* showing a certain Asian car with 127,000 miles to be "more reliable" than a brand new European luxury model. As it was generally acknowledged that the individual part quality of the European car was the best in the world, the study had lots of explaining to do. Almost as much explaining as the average quality engineer does when proposing a sizeable investment in non-chip-making assets at a gear company. This got me thinking about how engineers establish an appropriate tolerance for a specific feature on a part. How do we know what is "good enough" and what is "scrap"?

Aside from the obvious cost and schedule implications of declaring a part "scrap," an engineer's tolerancing decision has a big impact on how a part is made and how much it costs. We've learned a lot about process capability in recent years, and modern machine tools are certainly more capable than those of old.

There are, however, limits to how consistently a diameter can be turned, and when a part requires more accuracy than those limits, an additional operation is required. Every additional operation results in extra production time, extra cost, and extra capital investment. As we can see from the luxury car mentioned above, tight tolerances do not, in and

of themselves, ensure good operational performance.

Some organizations do a better job of determining what "works" and what doesn't. Certain part features (such as bearing fits, seal diameters, and keyways) are covered by supplier or trade association standards. The engineer still has some work to do in determining which conditions apply to a particular part or assembly so that the proper tolerances can be extracted from the often-voluminous reference books. This is much easier than starting from a clean sheet of paper and subjecting yourself to the second-guessing of your manufacturing associates.

Unfortunately, not all part tolerances have been so thoroughly and scientifically studied. This puts the engineer in the position of balancing his perception of what the application "needs" against what the manufacturing people think they can "hold." A typical part drawing might have 10 or 15 such dimensions to argue about. My classmate's big V-8 engine probably had several hundred "features" to be optimized with no way to know if the right decisions had been made until he crossed the finish line.

Consider something as simple as the outside diameter of a helical gear. The gear designer has a number in mind when he completes his calculations. The shop would like as much tolerance as they can get, including an allowance for "mismatch" should they decide to turn halfway across in one operation and finish in a second operation. Then the process engineer calculates the expected size change in heat treat.

All of this has to be considered before someone puts a size on the part drawing. A poor decision results in extra manufacturing cost; a terrible decision results in part recalls for interference with the mating part's root diameter. A good decision goes unnoticed. Also unnoticed is the effect of tolerance decisions made on related parts. Would the root interference have occurred if the center distance tolerance had been tighter? If the whole depth of the pinion had been deeper? The possibilities for finger pointing are endless.

So what is an engineer to do? As we can see from the luxury car manufacturer, just applying tighter than normal tolerances to everything isn't the answer. Becoming comfortable with third party tolerance standards is certainly part of the solution, as is understanding the process capability of your particular shop and being informed of the potential of newly available equipment.

Most important of all, in my opinion, is maintaining a questioning attitude towards each and every tolerance on each and every part. Just because you've always put a 125 AA finish on a gear outside diameter is not an acceptable reason for continuing to do so. Just because you've always used 0.125 divided by the normal diametral pitch as a maximum backlash doesn't mean 0.130 won't work.

During my first assignment as a detailer, the design engineer, who was an old-school curmudgeon of legendary temper, insisted that I have a reason for every single tolerance on a part. He didn't appreciate answering the same question twice either, so I started keeping notes and retaining photocopies of reference pages he directed me to. Thirty years on, my "book of knowledge" has grown to a three-inch-thick ring binder that is still expanding.

The binder used to have a listing of tolerances for various features that seemed to work well, but the advent of spreadsheet programs has made it easier to look at the effects of loosening or tightening tolerances on the overall "stack-up" within a machine. This approach, according to the automotive study, is a key to getting better quality while helping to reduce part cost.

By studying tolerances on a system rather than on individual parts, the engineer can identify key interactions and actually take fewer measurements. It also helps you eliminate parts; when I saw how much money we were spending on shaft spacers and how much they contributed to length variation in shaft assemblies, it didn't take long to find ways to eliminate them entirely. Without spacers to interact with, gear blank widths no longer needed to be held closely; more cost savings resulted. The automotive equivalent was to make bodies from fewer but bigger panels. Fewer panels meant fewer welds and less rattles after years of service.

Some shops take a more formal approach to building a "standard practice" database and incorporate it into their quality engineering systems. The important thing is to regularly re-visit your assumptions in light of changing technology and field experience. As an industry, we've spent far too much time checking chamfer sizes when we should have been looking at the big picture. No amount of quality control effort will make up for poor design or checking the wrong features.

Put your money where your problems are and never settle for "that's the way we've always done it." That's how the high mileage car got to be more reliable than the brand new luxury model, and that's how my classmate collected a mantle full of trophies at the drag strip.

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Ikona Gear Launches Oil and Gas Division, Signs Licensing Agreements

Ikona Gear launched Ikona Industries Corp. to focus on developing, manufacturing and shipping novel gearing applications for the oil and gas industries.

According to the company's press release, the new division has already secured its first customer with the lead project boosting revenue in excess of $250,000. Vladimir Scekic, Ikona's new vice president for business development, is spearheading this project.

The new division will develop gearing solutions for speed increasers, speed reducers and draw works applications.

"The oil and gas market is the hottest it's ever been," says Scekic. "It's characterized by an older generation of inefficient technologies, and with today's equipment utilization rates well over 90% across the market, new technology is necessary to meet burgeoning demands. Not only does the oil and gas industry provide the perfect arena for our technology, but the applications we've developed are portable across other alternative energy markets, including wind power generation."

Ikona has also entered into two licensing agreements. The company signed a multi-million dollar technology licensing agreement with Magna Powertrain AG & Co. as well as a separate agreement with a global robotics company.

The Magna Powertrain agreement stipulates that Magna will license the Ikona Gear platform for incorporation into automotive applications in passenger cars and light trucks, SUVs, pick-up trucks, minivans, cross-utility and similar vehicles throughout North America and Europe. Ikona Gear will receive royalties on a per-application, per-unit basis for exclusive and non-exclusive Magna automotive applications.

Finally, Ikona has also signed an agreement for the design and development of a gearbox for a robotic application. Ikona will receive an initial prototype development fee and, once commercialized, a sliding scale royalty stream of 4–9% based on sales volume. A non-disclosure agreement was signed by both companies.

Mid-Europa Partners Acquires Wheelabrator Group

Mid-Europa Partners (MEP), through its Emerging Europe Convergence Fund II LP, has completed the acquisition of all outstanding Wheelabrator Group equity from an investment group led by Bard & Co.

According to Wheelabrator's press release, this new development will not affect its current strategy. The group will continue to pursue the action plan it developed over the last three years following its spinoff from Veolia Environment. Wheelabrator's corporate functions, currently located in Golden, CO, will be moved to Altrincham, England, over the coming year.

"This is a major milestone in our development," says Robert E. Joyce Jr., chief executive officer of Wheelabrator. "Central Europe has a key role in our growth strategy, and MEP brings to the group investment and geographical expertise in the market segment we have targeted in the region. In line with this strategy, we are significantly increasing our main manufacturing activities in Poland to further strengthen our position in these markets. Central Europe is also at the very heart of MEP's investment philosophy, making them the perfect partner for us to achieve our next level of growth."

Rotork Acquires Italian Valve Gearbox Manufacturer

Rotork Controls Ltd. acquired the business and assets of Omag Snc, a gearbox manufacturer based in Milan, Italy.

According to Rotork's press release, this acquisition provides its gears division with a manufacturing and sales base in the Italian valve market in addition to its current manufacturing sites in the United Kingdom, United States and the Netherlands.

Omag specializes in sub-sea valve gearbox design. The Omag name has been changed to Rotork Gears Srl. Roberto Boldorini, current owner of Omag, has accepted the position of general manager.

Wall Colmonoy Promotes John Sturch

The board of directors at Wall Colmonoy Corp. elected John Sturch to the position of vice president. Sturch has worked at Wall Colmonoy for the past 30 years, most recently as general manager of the business unit in Oklahoma City.

Sturch will be responsible for business development and growth of the Wall Colmonoy licensed repair stations in Oklahoma City and San Antonio.

Wall Colmonoy

TSA America Relocates, Appoints New Sales Manager

Janice Thomas was appointed sales manager for the gear cutting tools product line of TSA America.

According to the company's press release, she has worked in the global gear tool industry for the past 25 years. Most recently, she was sales manager for Greg Allen Co. Before that she worked as U.S. sales manager for David Brown Gear Tools.

Thomas is responsible for managing and directing a nationwide network of sales and customer service representatives.

TSA America has also recently relocated. The new address is:

TSA America LLC
30311 Clemens Rd., Ste. #2
Westlake, OH 44145
Phone: (440) 614-0170
Fax: (440) 614-0173

Kleiss Gears Accredited to ISO 9001

Kleiss Gears announced its recent accreditation to ISO 9001.

According to Rod Kleiss, company president, the certification was necessary for several of the company's customers.

"We already had many of the requirements in place that ISO wants," he says. "We document requirements, keep inspection records, maintain machinery on a scheduled basis, etc. ISO did force us to look at each individual task and put down in writing what we intend to do and how we intend to do it. There were some areas that needed attention, and I'm not sure we would have discovered them so quickly without this process."

Koepfer Offers Training in Parallel Axis Gear Manufacture

A gear manufacturer's dilemma: training versus production. Teaching new, entry-level employees versus interrupting work on the factory floor. A solution: intensive, off-site training that includes lecture on fundamentals and demonstrations of gear-manufacturing machinery.

One company offering this solution for parallel axis gears is Koepfer America LLC via its three-day seminar, "Fundamentals of Parallel Axis Gear Manufacturing."

"It is an accelerated class, so at the end of the three days, there is a lot of knowledge transferred," says Dennis Gimpert, Koepfer America's president and the course's main instructor. "It's a manufacturing, industrial engineering-type course."

This seminar will next be held May 23–25 at Pheasant Run Inn and Resort, in St. Charles, IL. The course is designed for entry-level personnel—"By that, we assume they don't know what a gear is," Gimpert says. Still, many past students have had considerable gear manufacturing experience. Attendees have included manufacturing managers, industrial engineers, supervisors, set-up people, operators and quality control personnel.

The seminar will cover gear nomenclature, basic gear mathematics, hobbing, shaping, finishing—including skiving—gear inspection using AGMA and DIN standards, and troubleshooting. The course will also cover fixturing, blanks, use and support of cutting tools, and multi-thread hobs. Other topics include automation systems and estimating production times for making gears using the above processes.

The course also provides demonstrations of gear manufacturing equipment, including hobbing, gear shaping, gear grinding—both form and generating—and gear inspection machines. "Just about everything we talk about," Gimpert says.

The demonstrations take place during tours, which occur every day. The tours are of four gear-related companies: 1.) Forest City Gear, which has a variety of current equipment, 2.) a manufacturer of large gears, 3.) a motor and gearbox manufacturer, and 4.) Koepfer America, which can demonstrate machines such as hob sharpeners. Transportation to and from the tours is provided.

In-class lectures consist of PowerPoint presentations; videos of hobbing, gear shaping, grinding and inspection; example problems, so students can practice gear mathematics; and question-and-answer sessions.

Gimpert, the main instructor, has been in the gear industry for more than 30 years, starting as an application engineer, first with Barber-Colman Co., then with American Pfauter Corp. He moved into sales while with American Pfauter. He became Koepfer America's president when the U.S. operation opened. His experience was "always on the machine side, but it included grinding, shaping and inspection, and it continues to this day."

Each student receives a workbook, scientific calculator and other materials for the course. After the seminar, attendees can keep the materials, including the scientific calculators.

"The handbook becomes a great resource," Gimpert says. He describes it as a guide for troubleshooting gear problems, a guide he himself uses. The workbook, 250+ pages, includes copies of the class presentations, equations, example problems, their solutions, and a picture dictionary, which provides words, their abbreviations and drawings to illustrate the terms.

"In the beginning, that's very useful," Gimpert says of the dictionary.

Also, attendees are taught to read inspection charts, using them to detect gear problems, which may result from a machine's set up, cutting tool or blank. They learn a logical approach to solving problems, too.

Class size is limited to 30 people to promote interaction, with students being invited to contribute to answering other students' questions. "Too big a group restricts interaction," Gimpert says. Also, each attendee can submit a problem from work in advance of the seminar. If appropriate, the problem would be covered in class.

The course costs $795 per person and includes meals: continental breakfasts, buffet lunches and dinners. The price doesn't include hotel accommodation.

To reserve hotel rooms, attendees should phone Pheasant Run Resort at (630) 584-6300. They can obtain discounted rates by mentioning they're with the Koepfer group. Also, the resort offers shuttle service, so attendees can arrange transportation to and from the airport.

For more information:
Jennifer Schmitz
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Internet: *www.koepferamerica.com*

UK Manufacturing Expos Join Forces

MACH 2006, a British manufacturing technology show, will take place May 15–19 at the National Exhibition Center (NEC) in Birmingham, England. Primarily a machine tool show, MACH 2006 will be co-located with the Drives & Controls component show, as well as several other related industrial shows.

The MACH 2006 expo features machine tools, cutting tools, CAD/CAM, metrology and other technology for manufacturing.

FANUC Robotics will have a gear assembly cell at its booth to demonstrate a new range of integrated sensor systems. Developed by FANUC for use on its Intelligent Robot range, the sensors are designed to bring system integration into the world of plug-and-play.

Visitors to the FANUC exhibit will have the opportunity to randomly load components into the gear assembly system, which uses force sensing and a 3-D vision system. A FANUC Robotics M16iB Intelligent Robot fitted with a V-500iA/3DL laser vision sensor will locate the gears and pick them up.

The robot will then assemble the gears by feeling the fit, with a FANUC FS-30 force sensor fitted to its wrist.

The demonstration illustrates the savings that can be made on reduced tooling requirements for applications including machine loading, depalletizing and assembly.

The Drives & Controls show takes place at the NEC May 16–18. Exhibitors at Drives & Controls include suppliers of drives, motors, power transmission, automation and motion control applications, such as Danfoss, Güdel, Mini Gears (Stockport) Ltd., Rexnord, Rossi Gearmotors and SEW-Eurodrive.

In addition, the following shows will be co-located with MACH 2006:

- **Electrex**
- **Air-Tech**
- **Product Development 2006**
- **Subcon**
- **Environmental Technology**

A number of gear manufacturers will have displays at the Subcon show, including Depe Gear, Gibbs Gears, HPC Gears, and J&D Gears.

The organizers expect the combined shows to draw more than 40,000 attendees.

For more information:
MACH 2006
The Manufacturing Technologies Assoc.
62 Bayswater Road
London W2 3PS
Phone: +(44) 20-7298-6400
Fax: +(44) 20-7298-6430
E-mail: *gshearsmith@mta.org.uk*
Internet: *www.mta.org.uk*

April 25–28— Plastic Gear Design & Manufacturing. Universal Technical Systems, Rockford, IL. Focuses on robust design methods, application of non-standard proportions, material properties, operations variation, predicting tooth deflection, contact ratio and tip relief. A tour of Forest City Gear is offered, as well as one-on-one time with an instructor to discuss design problems. Knowledge of TK Solver is a pre-requisite. $1,250. For more information, contact UTS by telephone at (815) 963-2220 or by e-mail at *sales@uts.com*.

May 2–3—Designing Products for Assembly. Madison Concourse Hotel, Madison, WI. An intensive course sponsored by the University of Wisconsin at Madison focusing on assembly methods, component tolerances, number of adjustments, type of fabrication tooling and the Design for Assembly process. $1,195. For more information, contact the school's engineering department by telephone at (800) 462-0876 or on the Internet at *epd.engr.wisc.edu/webH524*.

May 3–7—Taipei International Manufacturing Technology Show. Taipei, Taiwan. A general, integrated manufacturing technology and equipment trade fair showcasing Taiwan's capabilities in machinery, equipment and technical services essential for product design, components' purchasing subcontracting, facilities acquisition and plant construction. Registration is free. For more information, visit the website at *www.TaipeiTradeShows.com.tw.*

June 5–7—AGMA Regional Gear School. Star SU, Hoffman Estates, IL. Concentrates on the relationships between basic geometry of parallel axis gears and the inspection and manufacturing process with additional details regarding logical troubleshooting. $750. Additional courses are planned for the Southeast and West Coast in 2006. For more information, contact the Gear Consulting Group by telephone at (231) 829-3760 or via email at *gearconsulting@aol.com.*

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What's On Your iPod?

We, the Addendum team, like to think of ourselves as hip, cutting-edge, culturally conscious and cool. And because we're curiously (some would say pathetically) devoted to gears, we thought we'd share with you our MP3 playlist, which, of course, consists only of songs with the word "gears" in the lyrics.

Our playlist includes a wide variety of musical genres, from the Beach Boys to 50 Cent. We've got blues, country, pop, heavy metal and rap. We like to think of ourselves as having eclectic tastes. Most people just think we're weird.

The Addendum Team MP3 Playlist:

ARTIST/GROUP	SONG TITLE
50 Cent	"Da Repercussions"
Aerosmith	"Head First"
Air Supply	"It's Automatic"
Anthrax	"Metal Thrashing Mad"
Bad Religioin	"Sanity"
The Beach Boys	"Little Deuce Coupe"
The Beastie Boys	"Sure Shot"
Garth Brooks	"Ain't Going Down ('Til the Sun Comes Up)"
Garth Brooks	"Papa Loved Mama"
Jimmy Buffett	"Vampires, Mummies and the Holy Ghost"
Johnny Cash	"One Piece at a Time"
Elvis Costello	"5ive Gears in Reverse"
Bob Dylan	"Minstrel Boy"
Don Henley	"Man with a Mission"
Alan Jackson	"Where I Come From"
Kid Rock	"Son of Detroit"
B.B. King	"Shake it Up and Go"
Elvis Presley	"Spinout"
REO Speedwagon	"One Too Many Girlfriends"
Rush	"Double Agent"
ZZ Top	"I Wanna Drive You Home"

We're always looking for new "gear" songs to download. If you have any you'd like to suggest, drop us a line at *publisher@geartechnology.com*.

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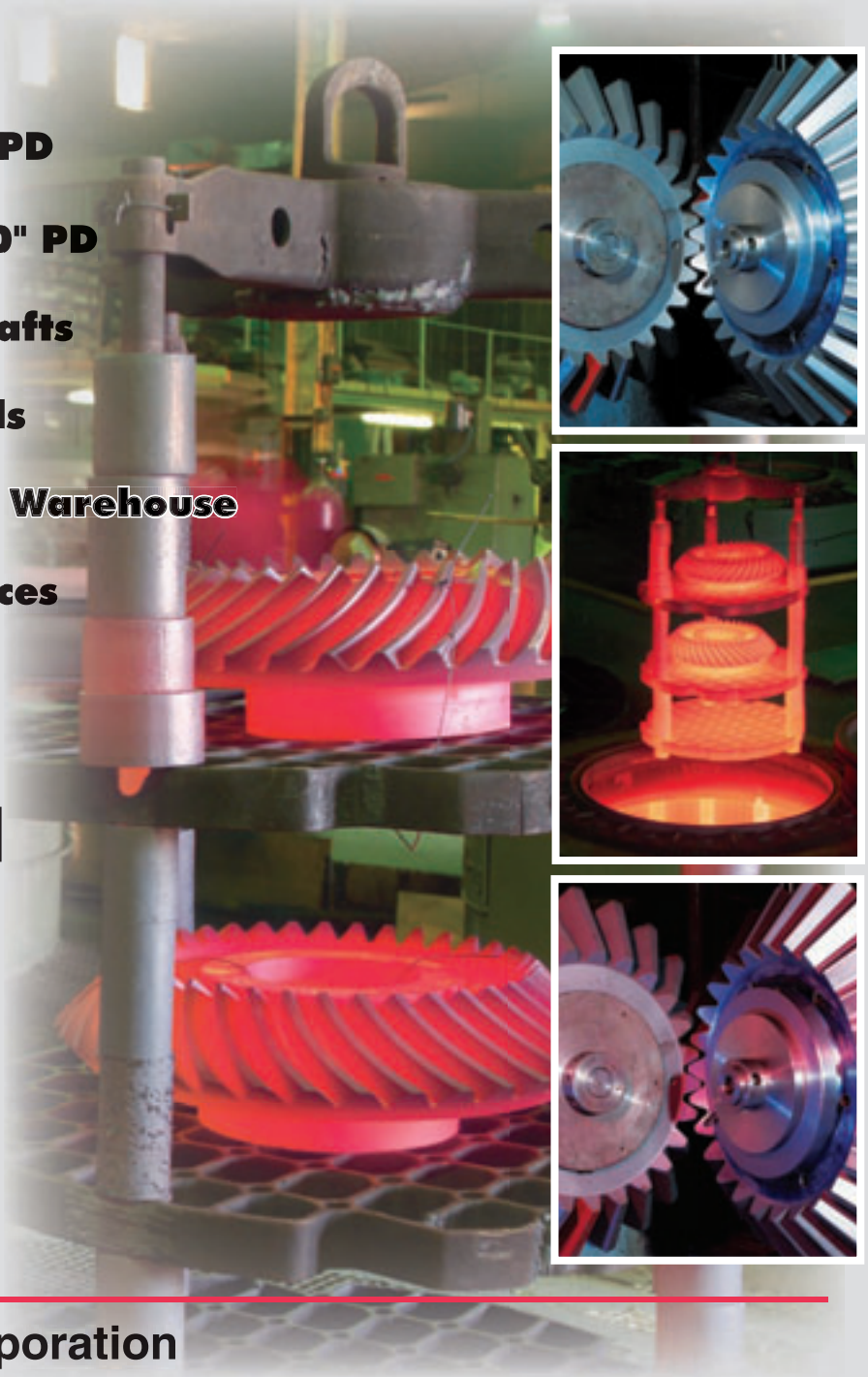

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