GEAR TECHNOLOGY

MAY/JUNE 2004
The Journal of Gear Manufacturing
www.geartechnology.com

GEAR DESIGN
- The Pumping Action Between Gear Teeth
- Rating Trends in ISO & AGMA

GRINDING & ABRASIVES
- 11-Page Special Section

Anniversary Issue

- 20 Years of *Gear Technology*
- Flashback to 1984: Single-Flank Testing of Gears

ALSO IN THIS ISSUE • Globalization and Gear Standards • Bending Strength of Carburized Gears • Gear Horoscopes

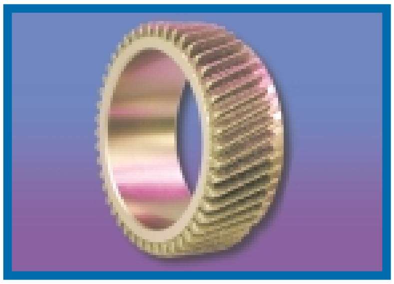
THE GEAR INDUSTRY'S INFORMATION SOURCE

THE NEW 245TWG HIGH SPEED THREADED WHEEL GRINDER...

NOTHING FINISHES FASTER

Economical grinding is now a reality!

Fully integrated load/unload automation



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Imagine getting hard finish grinding quality at "green" shaving prices. The new Gleason® 245TWG uses infinitely variable direct-drive spindles to deliver 60M/sec. grinding speeds — and fully integrates wheel dressing and load/ unload automation to cut floor-to-floor times to just seconds.

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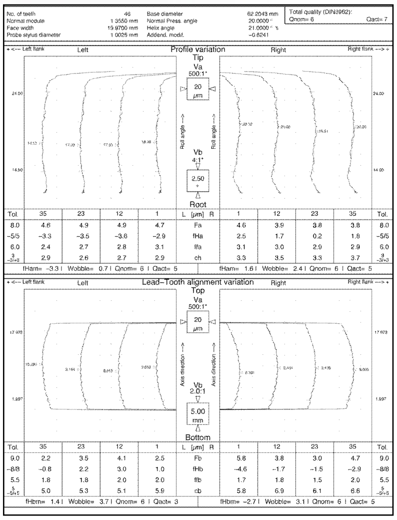

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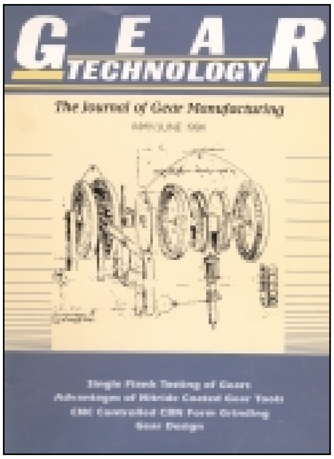

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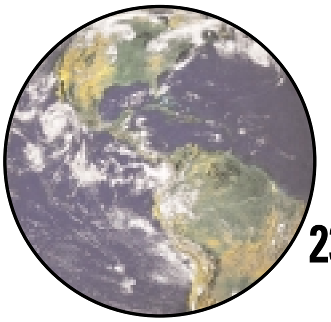

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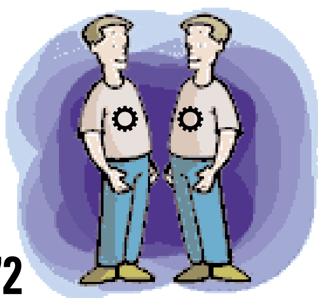

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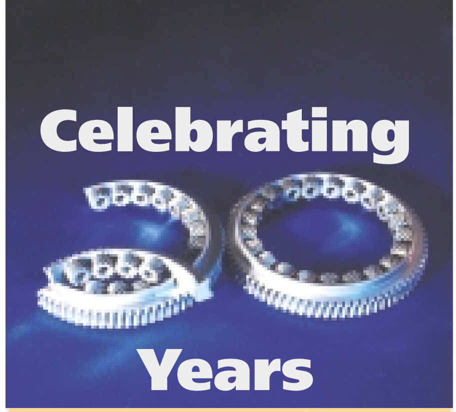
Gear sculpture by Jay Lensink, *www.metalclocks.com.* Photo by Jennifer Flam.

20th ANNIVERSARY ISSUE



GEAR TECHNOLOGY

The Journal of Gear Manufacturing

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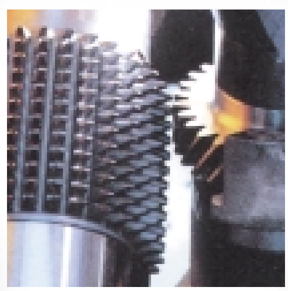

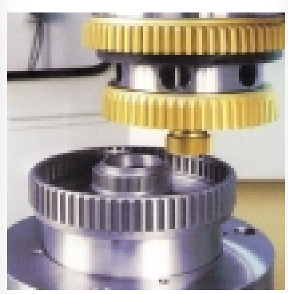

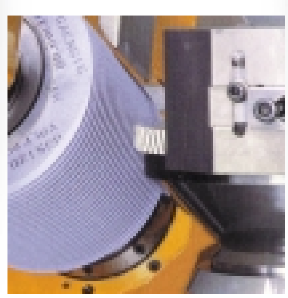

Shaanxi Qinchuan Machinery Development Co.,Ltd.

Shaanxi Qinchuan Machinery Development Co. Ltd. (formerly Qinchuan Machine Tool Works) is one of the key enterprises in the machinery industry of China. It was established in 1965. We are the only ones in China to manufacture precision gear grinding machines. We can produce seven series of gear grinders, more than 30 models. Our precision grinding has reached the advanced international level.

We can manufacture other machines. They include machinery for plastic products, machining centers, cylindrical grinders, and tool & die grinders.

Our main products enjoy 80% market share in China. They have been exported to more than 20 countries, such as the United States, Japan, South Korea, Germany and others.

Our company has the "three precision advantages": precision machining, precision assembling and precision measurement. Our machines produce professional-quality metal boxes, shaft sleeves and gears, and 40 percent of our machines are CNC. Our company is at the leading edge in the Chinese machine tool industry.

The company is certified in the ISO 9001 quality system.
In this new century, our goals are to create an enterprise that is internationally competitive and is friendly to the manufacturing industry, to make our company into a research and development base for manufacturing precision machine tools and plastics machinery, to create eight industrial groups featuring precision machine tools, plastics and food packaging machinery, automobile parts, gear transmissions, electronic information, environmental protection and material, and modern agriculture facilities. Our goals also are to become a world-class manufacturing center, the technology research center for the Pacific Ocean area and the running and management center at home.

ABOUT US

- Gear Grinder Series
- Machining Center Series
- Plastics Machinery Series
- Cylindrical Grinder Series
- Tool & Die Grinder Series
- Machinery Parts
- Water Saving Irrigation Products
- Instrument Series

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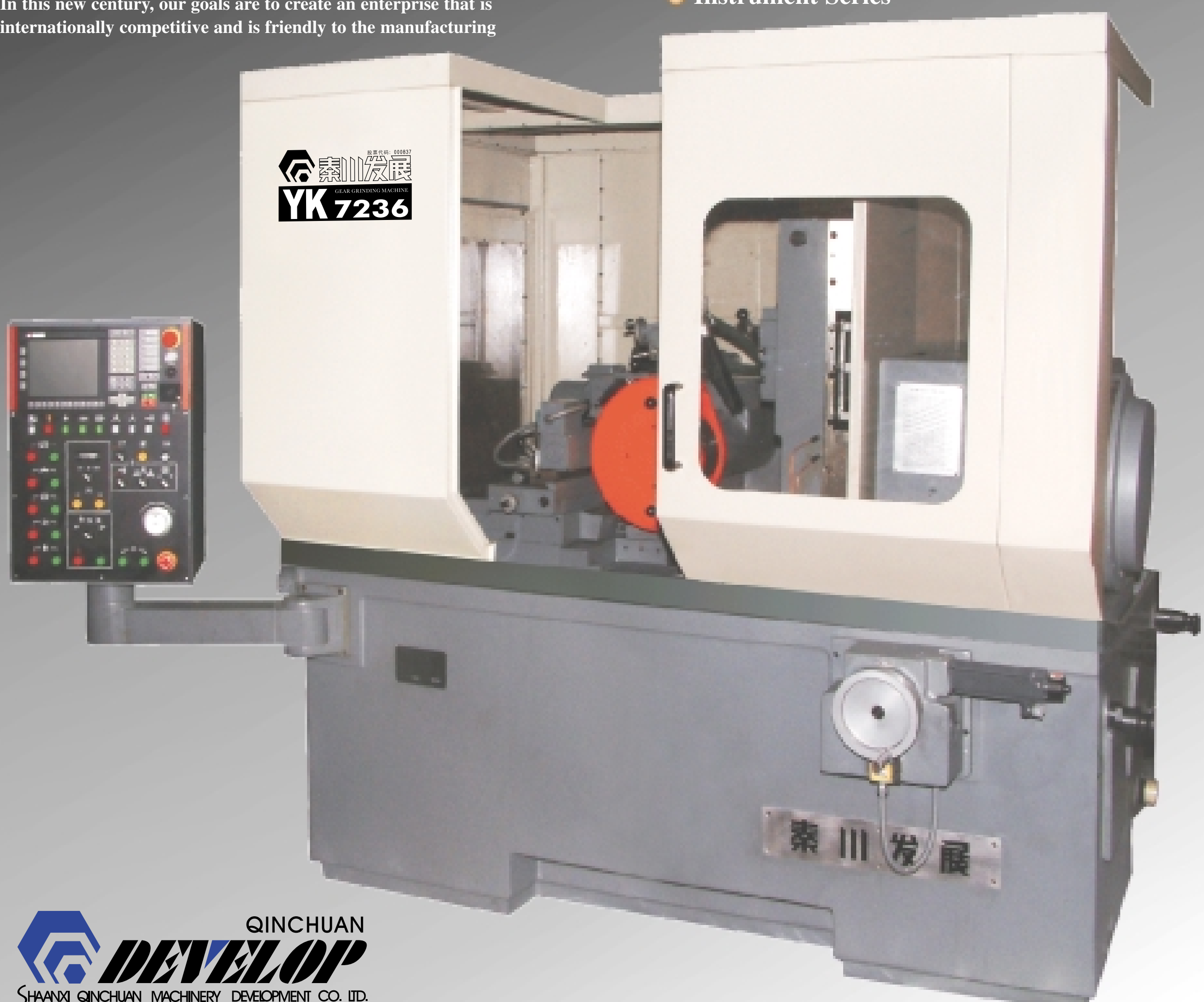

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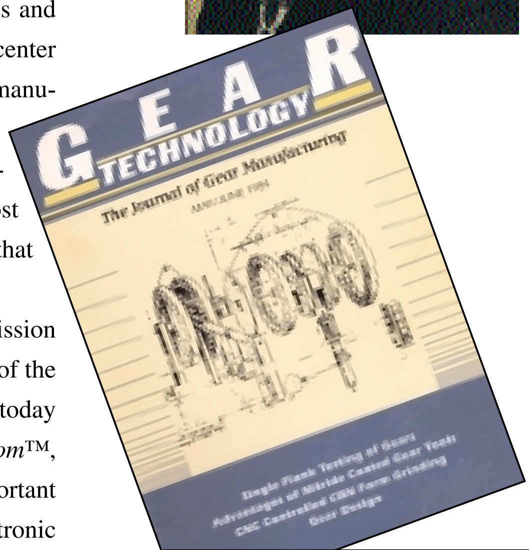
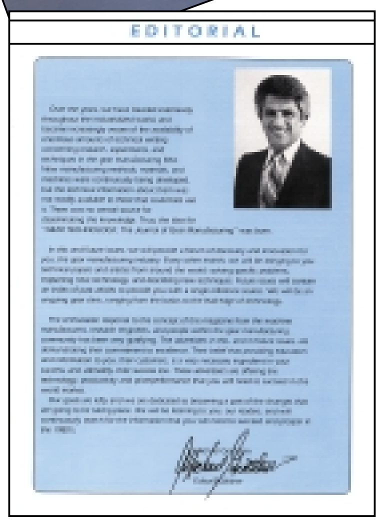
Reflections

When a man looks into a mirror, the image reflects who he is today. But it also reveals who he used to be. Although appearances change, many of the underlying characteristics remain the same. The same is true with *Gear Technology,* as we celebrate our 20th anniversary and reflect on who we are. The ideas we started with—our focus on quality, our dedication to helping our readers be better at their craft, our commitment to being the gear industry's information source—are still clear in the reflection. But at the same time, many of those characteristics have grown and matured.

In my first editorial back in 1984, I made several promises to our readers. First and foremost, *Gear Technology* would be a technical resource for the gear manufacturing industry. It would include technical papers and articles from around the world. These would show how to solve specific problems, explain complicated technologies and describe cutting-edge techniques. *Gear Technology* was intended to serve as a center of information concerning research, ideas, experiments and processes in gear manufacturing and to serve as a conduit for productivity-enhancing technology between suppliers and users. We aimed to provide the very highest quality product, using the highest quality paper, printing and content, and to establish the most accurate mailing list of gear industry professionals throughout the world. All of that is still in the reflection.



But over the years, much has changed as well. For example, our original mission of being the industry's information source expanded dramatically with the rise of the Internet. In 1996, we launched *The Gear Industry Home Page*™, which today receives 30,000 visitors a month. In 1997, we launched *powertransmission.com*™, which today receives 40,000 visitors a month. Both of these websites are important information sources for the gear industry. In 2003, we launched *E-GT*, the electronic version of *Gear Technology*. Now with more than 3,500 subscribers in more than 60 countries, *E-GT* has expanded our reach even farther around the world.


EDITORIAL

Our commitment to quality has also matured. In 1996, we became the only publication serving the gear industry with a mailing list audited by an outside source. When advertisers see the logo of BPA International, our independent circulation auditor, they know that we have gone through a lot of extra steps and expense to qualify our mailing list. Those extra steps help ensure that we mail the magazine to people in the gear industry and—most importantly—that the recipients want to receive it. Our qualified subscribers have all requested the magazine, most of them within the past year.

Over the years, we've also added technical editors and instituted a formal review process for articles that appear in our pages. Much of what you read here is reviewed and approved by several sets of expert eyes before you see it. For each issue, we rely

Reflections

When a man looks into a mirror, the image reflects who he is today. But it also reflects who he used to be. Although appearances change, many of the underlying characteristics remain the same. The same is true with Gear Technology.

on the expert advice and experience of Bob Errichello, Don McVittie, Bob Smith and Dan Thurman—four of the most knowledgeable people in the gear industry. We do everything possible to ensure that what you read is technically sound, balanced and applicable to your jobs as designers, manufacturers, engineers, testers and buyers of gears and geared products.

Over the last 20 years, we've seen tremendous change in those jobs. Since 1984, virtually every aspect of gear manufacturing has changed, with much of that change coming through the incorporation of computer technology.

Twenty years ago, most gear manufacturers were still using manual machines. Even the early versions of CNC gear machines only incorporated one, two or three axes of control. Now 6- and 7-axis machines are standard. Today, software runs everything, from our engineering and production to our accounting and sales.

But there have been plenty of changes in the physical aspects of gear manufacturing as well. I'm talking about processes like dry cutting, hard honing, hard cutting, electronically-controlled guideless shapers and other things made possible by advances in tool coatings, carbide materials, rigid machine tools, faster spindles, more powerful controls and the like. Machine tools and cutting tools have changed to allow greater and greater productivity.

For example, I recently read in the annual report of American Axle & Manufacturing Inc. that its Detroit facility used to employ 300 wet-cut manual gear cutting machines for manufacturing ring gears and pinions. Those machines have been replaced by just 50 dry-cutting CNC machines, freeing up 30,000 square feet of factory floor space and reducing the distance each gear travels in the plant by 1,700 feet.

Also, many of the gears that were cut in 1984 are now manufactured using other materials and methods, including plastic injection molding and powdered metal manufacturing.

Aside from those changes, the landscape of our industry has changed dramatically, mostly through increased globalization. Many companies have focused on their core competencies and are competing in more narrow niches. Others have used globalization as an opportunity to adapt and change, forming partnerships and establishing locations around the world to expand product offerings and increase their geographical coverage.

Indeed, much has changed in the gear industry, and it will continue to do so. And so will *Gear Technology*. Our mission of being the gear industry's information source remains the same, but we're not done evolving yet. You're going to see some exciting changes in our magazine in the near future.

I am both happy and proud that we have kept our focus as the gear industry's information source and have to thank a dedicated staff, more than 12,000 appreciative readers—many of whom have read and saved every issue—and our extremely supportive advertisers. I look forward to spending the next 20 years with you to see what changes the coming years will bring.

Michael Goldstein, Publisher & Editor-in-Chief

Frenco—Inspecting All Flanks in Minutes

GIVE US TWO MINUTES,
AND WE'LL GIVE YOU 370 CONTACT POINTS PER *FLANK.*

The above sentence might be the best way for Frenco GmbH to describe what its RollScan gear inspection machine can do.

In less than two minutes, the RollScan machine can inspect all of a helical gear's flanks and provide complete topographical information on them. It can inspect a small helical gear in about one minute.

Rapid is the reason for the RollScan's invention.

"Rapid by the measuring time," Andreas Pommer says. "Rapid by its availability because it's designed to be used directly on the shop floor."

A senior design engineer with Frenco, Pommer oversees research and development of the machine.

The RollScan, though, is best suited for inspecting large numbers of identical helical gears, like automotive gears.

That's not surprising given its corporate inventors: Ford AG and Ford Global Technologies. Although patented by them, the machine has been licensed since '01 to Frenco, which is responsible for developing, designing and producing the machine.

The RollScan can inspect helix/lead, profile, runout and pitch deviations. It can provide theoretical calculations for several types of composite deviations, such as total single-flank, tooth-to-tooth tangential and total tangential, including the short-period and long-period components of total tangential. It can calculate theoretical double-flank contact results, too.

A helical gear is ready to have its involute profiles inspected by two "hedgehog master gears" on a RollScan machine. Licensed to Frenco GmbH, the RollScan can also use conventional master gears with whole teeth. The RollScan can inspect all of a helical gear's flanks and provide complete topographical information on them in less than two minutes.

Welcome to* Revolutions, *the column that brings you the latest, most up-to-date and easy-to-read information about the people and technology of the gear industry.* Revolutions *welcomes your submissions. Please send them to* Gear Technology, *P.O. Box 1426, Elk Grove Village, IL 60009, fax (847) 437-6618 or send an e-mail message to* hazelton@geartechnology.com*.

The RollScan also can measure tooth thickness and, based on the thickness, can calculate span size and size over balls.

The machine takes these measurements using a method like single-flank gear rolling inspection.

A gear to be inspected is clamped on the RollScan's arbor, between the machine's two master gears.

Each master gear has measuring tracks placed on certain flanks. Each measuring flank has either a lead track or a profile track. Each master gear can have up to eight lead tracks, covering major diameter to form diameter, and typically can have up to three profile tracks to check involute profile.

The result: a grid of about 370 points for each measuring flank.

For inspection, the gear rolls simultaneously with the master gears, one master gear inspecting all the gear's left flanks, the other all the right flanks. The three gears are kept in direct contact at all times by brakes.

To inspect all of a gear's flanks, the RollScan operator figures the number of rotations needed for the tracks to mesh with all the gear's flanks.

RollScan's method, though, was created to check deviations that couldn't be checked with normal single-flank roll testing. Such testing measures deviations as angular errors between the axes of the driving and driven gears. Also, in such testing, helical gears can have contact ratios of up to three.

As Pommer explains, such contact ratios prevent precise locating of detected deviations.

RollScan avoids this ratio problem with its lead and profile tracks, which reduce the contact ratio. It also avoids the interference problem because the tracks are separated by a number of intervening teeth.

The separation reduces each tooth's contact line to more of a contact point. But the point's exact position can be calculated because its track location is known. Consequently, all detected deviations can be located, so a scan of the gear flank can be obtained.

The machine's basic model costs €120,000, about $144,000. The cost includes two master gears for inspecting a gear with specific measurements and one clamping tool.

Pommer, though, recommends a possible customer first rent a model and buy two master gears to test the system. Also, the customer can have Frenco position the tracks to collect more or less data depending on which tooth aspects the customer most wants to know about.

The customer can then use the system in his factory to gain practical experience collecting data, choosing which inspection reports he wants, deciding if he's satisfied with the gear aspects being inspected.

"It helps that the customer has more practical experience," Pommer says.

After testing, the customer can have Frenco redesign the master gears, moving their tracks again.

A pair of master gears has an estimated lifetime of 200,000 measurements. Due to wear, the pair will need regrinding after that many measurements. The pair can be reground twice.

Frenco also has a second type of master gear in the final stages of development. This second type was designed to have two advantages over the first: 1.) be less expensive to produce and 2.) have a longer life.

Frenco expects this new type of master gear to be fully ready and available for commercial purchase in the second half of '04.

This new type is called a "hedgehog master gear." Instead of whole teeth, a hedgehog master gear consists of tooth segments.

These segments reminded Frenco employees of a hedgehog. A European animal, the hedgehog has pointed spines on its back. The resemblance between segments and spines was sufficient; the new type of master gear had its name.

Each segment is a profile track, so it scans a part of every tooth on a gear being inspected. The partial scans of each tooth are then combined to create a full scan. A hedgehog can have many profile tracks, depending on its size. Pommer estimates that a realistic limit on the number of tracks would be 15.

Frenco added a ceramic coating on the hedgehog to extend its lifetime.

Frenco, though, is still testing the hedgehog to determine its lifetime. The company is also field testing two pairs of hedgehogs with two potential customers.

The RollScan offers several report options. An operator can see all profile graphs or all lead graphs, so he can find the most important flanks as fast as possible. He can also see lead and involute graphs. Moreover, these reports are in the format of normal CMM inspection reports.

He can see single-flank test results, too. The RollScan can perform single-flank inspection if the operator reverses the machine's spindle rotation.

To manage all this data, the operator can use statistical methods to obtain distributions, so he can concentrate on mean and maximum values.

He can also see theoretical double-flank contact results, calculated by RollScan, and see graphs of them.

Then there's the topography report, which shows all inspection data. On a computer screen, this report appears as a 3-D grid of the flank. Topographical measurement of all teeth requires use of statistical methods for evaluating deviations.

"The main objective was to bring more information to the user," Pommer says. ☼

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Celebrating

Years

Some Things Change, Some Things . . .

"We will be an ongoing gear clinic, ranging from the basics to the lead-edge of technology."

Publisher Michael Goldstein made that promise in *Gear Technology's* first issue: May/June 1984. Twenty years later, we continue to keep our word by publishing top-notch technical articles, as well as our industry's latest news. Every issue, we present the best of what's available from the industry's leading authorities to help you be more productive, be more efficient and better understand the technology used to manufacture gears and gear drives.

Randall Publishing's purpose has stayed the same, even as we expanded the ways we achieve that purpose.

In 1984, we launched *Gear Technology* to educate the gear manufacturing industry. The magazine's pages featured articles, news and advertisements. All the parts educated; they told readers about new and established processes and technologies for manufacturing gears, about people and events in the industry and about the many types of gears available from gear manufacturers.

By the mid-'90s, Randall Publishing had a new means for serving the industry as its ongoing gear clinic. That means was the Internet.

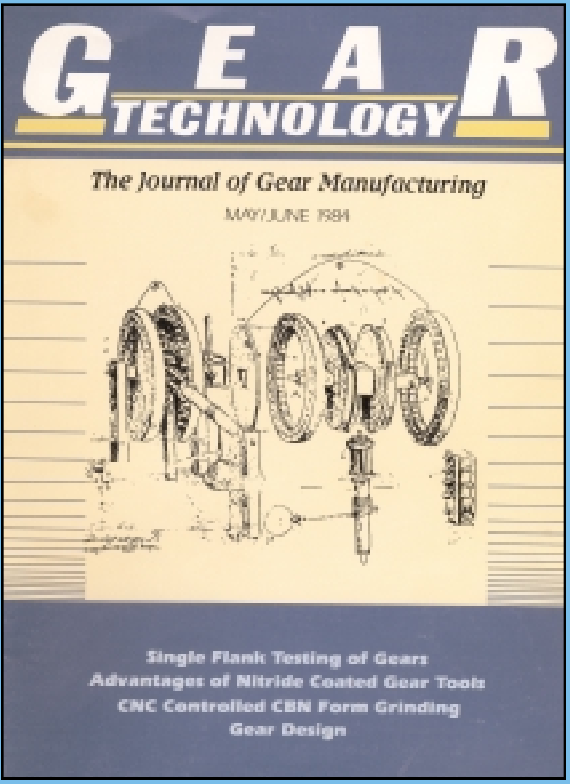
In 1996, we launched a website, *The Gear Industry Home Page*, at *www.geartechnology.com* to serve two groups among our readers: those who provided the machines, tools and other equipment and services for manufacturing gears and those who needed them.

In 1997, we launched *The Power Transmission Home Page* at *www.powertransmission.com* to serve *Gear Technology* readers who buy, sell and use gears, bearings, motors and other power transmission products and services.

Six years later, information technology allowed us to offer an online version, an exact duplicate of the entire magazine: departments, features, ads—everything.

In 2003, *E-GT* became available for free anywhere in the world, making it easier for *Gear Technology* to reach all the people in our increasingly global industry.

The next 20 years could bring even more startling transformations. But, while some things change, some things stay the same. And a promise made 20 years ago is worth repeating today: "We will be an ongoing gear clinic, ranging from the basics to the lead-edge of technology."

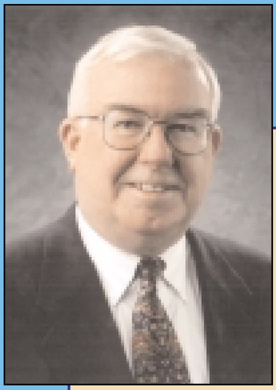


The cover of *Gear Technology's* first issue, the May/June 1984 issue.

Some things change, some things stay the same. For *Gear Technology's* 20th anniversary issue, we asked people and organizations involved in our first issue about how things have changed.

Some Things Change,

1. How has gear technology changed since mid-'84?



James S. Gleason, chairman, Gleason Corp.
"Productivity increases brought about by the huge increase in the application (almost universal) and sophistication (six axes of essentially simultaneous control) of numerical control technology."

"New tooling, carbide and coatings, coupled with higher cutting speeds result in huge gains in productivity."

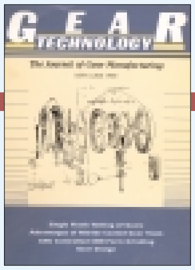
Anthony M. Spinks, vice president, Parker Industries Inc.
"Improved steels have led to higher gear cutting speeds and reduced cost per unit. The same is true of coatings, which have seen greatly extended use along with new coatings offering ever-improving performance and more specific applications."

Robert E. Smith, gear consultant, R.E. Smith & Co.
"The development of CNC-type gear manufacturing machines and inspection instruments. The CNC gear manufacturing machines have used several improved technologies to increase production rates and product accuracy."

"Today's CNC gear inspection instruments are user-friendly, fast, very accurate, and can do a more thorough computer-aided analysis of data."

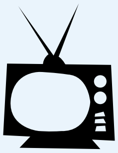
Peter Kozma, president, Liebherr Gear Technology Co.
"The emergence of dry hobbing machines, made possible by the development of PM-HSS. Dry hobbing has positive environmental impacts and provides a cleaner work area. Manufacturers using dry hobbing technology know that it also has significant financial benefits. Obviously, it eliminated the cost of the oil. In addition, by avoiding the need to clean each part before the next step in production or quality measurement, dry hobbing further reduces production cost."

May/June 1984 First Issue of Gear Technology



1985
"Dynasty," starring John Forsythe and Linda Evans, finishes as the most popular show of the '84–'85 TV season.

1986
Nintendo video games are introduced in the United States.



1987
Fox Broadcasting Co. airs the first episode of the TV show "Married With Children."

1988
Compact discs, CDs, outsell vinyl records for the first time.

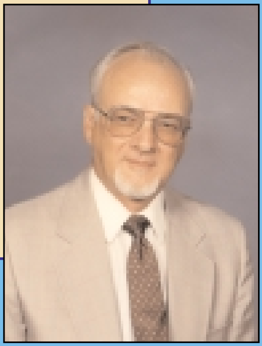
But How?

2. How else has the gear industry changed since mid-'84?

Anthony M. Spinks, vice president, Parker Industries Inc.
"The closing down of some gear plants, the migration of some operations from northern to southern U.S. states, and the outsourcing of gear production to other countries."

"A change in distribution channels with the development of integrated suppliers and their operations inside customer plants."

Robert E. Smith, gear consultant, R.E. Smith & Co.
"Downsizing. Many users of gearing have typically eliminated positions of gear engineering and expertise and have relied on outsourcing. This has caused a host of problems. Many times, their specifications are not up to date, correct or complete. They rely upon the company they contract with to provide good product. This company may then pass the job along to other suppliers. When product finally comes back, they don't have a clue as to the incoming quality. Then product problems result."



Peter Kozma, president, Liebherr Gear Technology Co.
"The gear industry's market has certainly expanded over the past twenty years. The main contributors to this expansion were changes in the automotive industry, such as the growing variation of models and an increased number of transmission speeds. Additionally, gears began to be used for new automotive applications such as timing gears, balance gears, camshaft adjustment gears, and for power-steering."

Diether Klingelnberg, recently retired chairman, Klingelnberg Group*
"The gear industry experienced a consolidation. Companies who were not ready to invest in the latest technology disappeared. Also the number of equipment and material suppliers was reduced. The companies with good management and financial strength have a bright future."

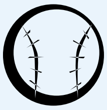
*Diether Klingelnberg retired March 24 as chairman of Klingelnberg Group.

1989
"Batman," starring Michael Keaton, is the year's top grossing film.

1990
Musical duo Milli Vanilli, winner of the 1989 Grammy award for best new artist, is stripped of its Grammy after the public learns the men were lip-syncing to other people's singing.

1991
Nolan Ryan, 44, pitched his record 7th no-hitter, striking out 16 Blue Jays batters.

1992
Andy Van Slyke, a Pittsburgh Pirate, became the first outfielder in almost 18 years to record an unassisted double play.

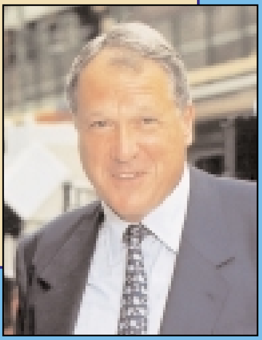


1993
Body piercing became more popular after actress Alicia Silverstone appeared in 1993 music video with a navel ring and tattoo.

3. How will gear technology change in the next 20 years?

Diether Klingelnberg, recently retired chairman, Klingelnberg Group
"The tendency in technology is going to continue: more accuracy, more efficiency, more software driven, better process control, better tooling, in-line checking."

"Business will remain in the highly industrialized areas as long as the companies are ready to invest heavily in new methods and equipment."



Peter Kozma, president, Liebherr Gear Technology Co.
"We are expecting further advances in cutting tool lifetimes and increased operating speeds. This will be accomplished by improvements in the cutter's substrate and coatings. Cutting tool coatings will likely change from titanium to more advanced varieties such zircon or gallium."

Anthony M. Spinks, vice president, Parker Industries Inc.
"There will be a move towards combining more operations, including hobbing or shaping, on one piece of equipment."

4. What else will change in the next 20 years?

Peter Kozma, president, Liebherr Gear Technology Co.
"There is also a recent technological movement towards eliminating gears in many products . . . The auto industry predicts passenger cars will be without gears within the next 10–15 years. This, however, is not to say that the gear industry is in for an eventual demise, since future technologies will certainly also create new markets for our industry. One example of this is the developing demand for transmissions in wind turbines."

"Globalization not only creates challenges for our industry but also creates new opportunities. Foreign developing economies will surely also increase the demand for gears."

David J. Burns, CEO, Gleason Corp.
"Globalization. On the equipment supply side, that globalization is well underway. It is also clear, from our perspective, that the notion of globalization is coming to the gear-manufacturing arena at an astounding rate."

"Information technology is a huge enabler for this trend. People in really diverse geographic regions can now access information in real time, and then interface with each other in an almost virtual mode. All of that means that the companies that can quickly leverage their strategic advantages (price, quality, throughput) will gain increasing global market share."

1994
Lion King animals and Power Rangers were the most popular Christmas toys.

1995
"Braveheart," produced, directed and starring Mel Gibson, won the Oscar for best picture.

1996
Launch of The Gear Industry Home Page

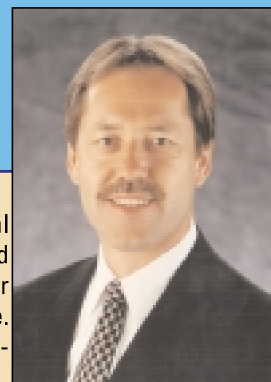
1997
Launch of The Power Transmission Home Page

1998
Led by Michael Jordan and Scottie Pippen, the Chicago Bulls win their sixth NBA championship in eight years.

5. What effects has *Gear Technology* had in the gear industry during its 20 years?

Marty Woodhouse, vice president–sales, Star Cutter Co.
"*Gear Technology* has brought to the industry a tool for education."

David J. Burns, CEO, Gleason Corp.
"There had been no worldwide voice for technological exchange within the gear industry. *Gear Technology* provided the first real periodical forum that gathered input from all over the world and made it readily available to anyone, anywhere. This was done in an impartial way, relative to region or company affiliation."



Joe T. Franklin Jr., president, AGMA
"The single most valuable service *Gear Technology* has provided has been in the area of dissemination of technical knowledge. The technical papers and articles are prized as guides to worldwide technological advancements. By opening the magazine to papers from international conferences, you have helped readers keep up with information largely beyond the reach of most."

Peter Kozma, president, Liebherr Gear Technology Co.
"By providing the industry a reliable source for current information, *Gear Technology* has made an invaluable contribution to all facets of our industry."

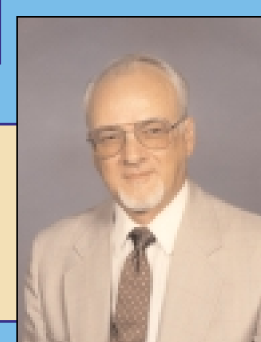
6. How has the Internet affected *Gear Technology*'s role as a source of technical information, news and advertisements about the gear industry?

Joe T. Franklin Jr., president, AGMA
"*Gear Technology* embraced it as a way to get information to more readers and to cut the time—especially for the international readers—necessary for the delivery of the information. The Internet is just another way to help the market function efficiently and to disseminate the technical information that has become a hallmark of *Gear Technology.*"

David J. Burns, CEO, Gleason Corp.
"Hopefully, the Internet and *Gear Technology* [will] work in complementary ways to support the worldwide dissemination of technological information of the gear industry."

Peter Kozma, president, Liebherr Gear Technology Co.
"Through the use of the Internet, *Gear Technology* is able to reach a global audience."

Robert E. Smith, gear consultant. R.E. Smith & Co.
"The magazine has been made available electronically, which is especially valuable to people in the overseas gear industry."



1999
Singer Ricky Martin's "Livin' La Vida Loca" finishes as one of the year's most popular hits.

2000
People celebrate the year 2000, which is widely viewed at the start of the new Millennium.

2001
The new Millennium really starts.

2002
Halle Berry and Denzel Washington make movie history as the first black actors to win both lead-role Oscars.

2003
E-GT launched with the January/February issue

2004

Single-Flank Testing of Gears

Robert E. Smith

Management Summary

This article was originally published 20 years ago, in *Gear Technology*'s first issue. It describes a method of evaluating the smoothness, or lack of smoothness, of gear motion. This lack of smoothness of motion, known as "transmission error," is responsible for excitation of gear noise and problems of gear accuracy and sometimes has a relationship to gear failure.

This method of evaluation was not in very common usage 20 years ago and, unfortunately, even now is very much underused.

The article is still timely today. This method has now been included in some gear accuracy standards, such as AGMA and ISO. Also, it is a technique that is used often by the author in the solution of gear noise problems.

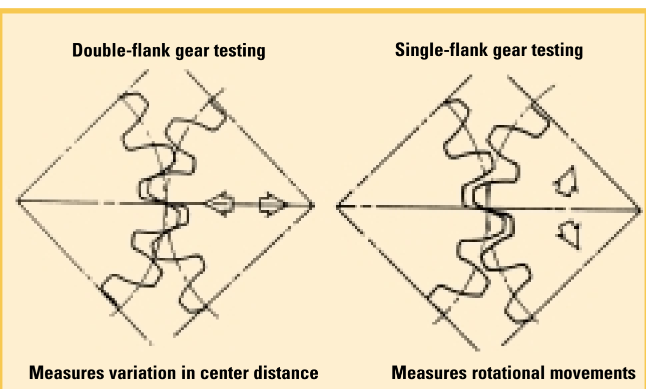


Figure 1—Composite gear testing.

Figure 2—Gleason Corp.'s 600HTT Turbo Tester® is an example of a machine able to perform single-flank testing.

Presumably, everyone who would be interested in this subject is already somewhat familiar with testing of gears by traditional means. Three types of gear inspection are in common use: 1.) measurement of gear elements and relationships, 2.) tooth contact pattern checks and 3.) rolling composite checks. Single-flank testing falls into this last category, as does the more familiar double-flank test (see Fig. 1).

As an introduction to the basic understanding of the subject, most of this article relates to the simple case of inspecting spur gears. The interpretation of data, relative to helical gears, is a little more complex, but the general principles apply.

With single-flank testing, mating gears roll together at their proper center distance with backlash and with only one flank in contact. Testing gears in this manner more closely simulates operation of the gears in their application than any other means of evaluation. Gears can be tested by pairs, or with master gears.

The single-flank test is run using optical encoders, which measure rotational motion (angular displacement error). Encoders may be attached to the input and output shafts of a special machine for testing pairs of gears. The encoders may also be used portably by attaching them directly to the input and output shafts of an actual gear box so as to inspect the quality of a complete train of gears.

Data from the encoders is processed in an instrument that shows the accuracy or smoothness of rotational motion resulting from the meshing of the gears (transmission errors). This data can be directly related to portions of involute or profile errors, pitch variation, runout and accumulated pitch variation. Probably the most important aspect of single-flank testing is that it permits measurement of profile conjugacy, which is the parameter that most closely relates to typical gear noise.

Single-flank testing is not a panacea. Lead or tooth alignment variation of spur and helical gears cannot be measured directly by this method. Lead errors do, however, influence motion transmission errors. These result from profile variations, due to the influence of overlap or increased contact ratio. Likewise, in the case of bevel or hypoid gears, tooth contact pattern checks are important to the development of tooth shape to allow for deflection characteristics under load. Lead or spiral is best measured by elemental checks or by tooth contact pattern checks.

Figure 2 shows a typical single-flank measuring machine. Figure 3 shows its principle of operation. The two motions which are to be compared are monitored by circular optical gratings. Each grating produces a train of pulses having a frequency which is a measure of the angular movement of each corresponding shaft and hence of each gear mounted thereon.

Pulse frequencies from each grating are usually different because the gear ratio is not normally 1:1. It is, therefore, necessary to modify the frequency from shaft Z_1 based upon the frequency from shaft Z_2, which is hereby established as the reference frequency. The signal from shaft 2 has a frequency of f_2, which is equal to:

$$f_2 = f_1 \text{ x } \frac{Z_1}{Z_2}$$

where: Z_1 = the number of teeth in the gear on shaft 1 and
Z_2 = the number of teeth in the gear on shaft 2.

However, f_2 has superimposed on it a frequency modulation due to transmission errors of the gears under test. Therefore, the pulse train coming from the grating on shaft 2 will have small differences in phase from the pulse train for shaft 1. This phase difference between the two represents the amount of error in the gears being tested.

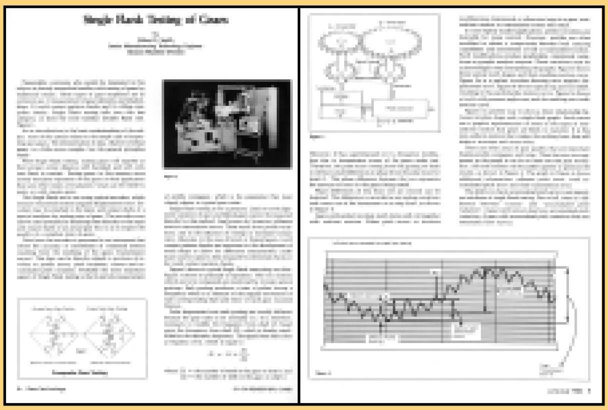
Phase differences of less than one arc-second can be detected. This difference is recorded as an analog waveform and comes out of the instrument on a strip chart, as shown in Figure 4.

Gears with perfect involute tooth forms will roll together with uniform motion. When pitch errors or involute modifications (intentional or otherwise) exist in a gear, nonuniform motion or transmission errors will result.

In some lightly loaded applications, perfect involutes are desirable for noise control. However, profiles are often modified to obtain a compromise between load carrying capabilities and smoothness of roll or transmitted motion. Such modifications produce predictable, intentional variations on graphic analysis outputs. These variations must be acknowledged when interpreting the graphs. Figure 5 shows three typical tooth shapes and their resulting motion curves. Figure 5a is a perfect involute

FLASHBACK TO 1984

In 1984, the Macintosh computer was introduced during Super Bowl XVIII. The movie "Amadeus" won the Academy Award for best picture. The musical group Van Halen was at the top of the music charts and this article by Robert E. Smith first appeared in *Gear Technology.*



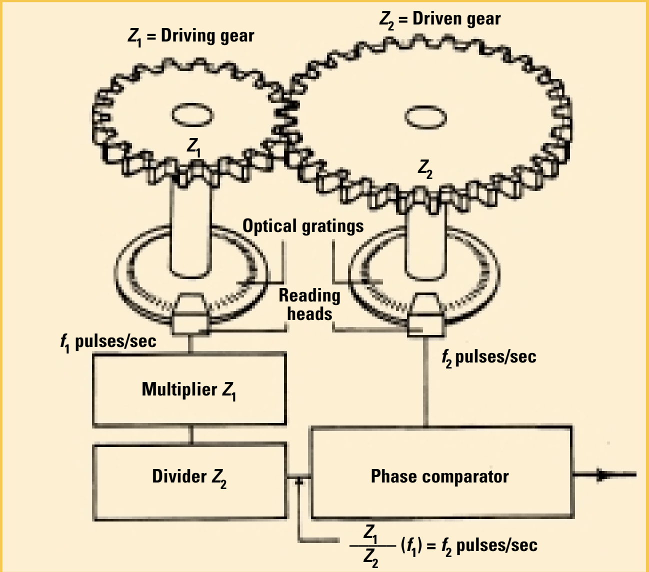


Figure 3—The principle of a single-flank measuring machine.

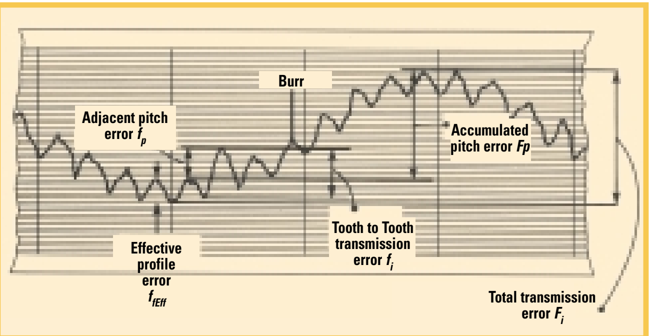


Figure 4—Individual errors revealed by single-flank testing.

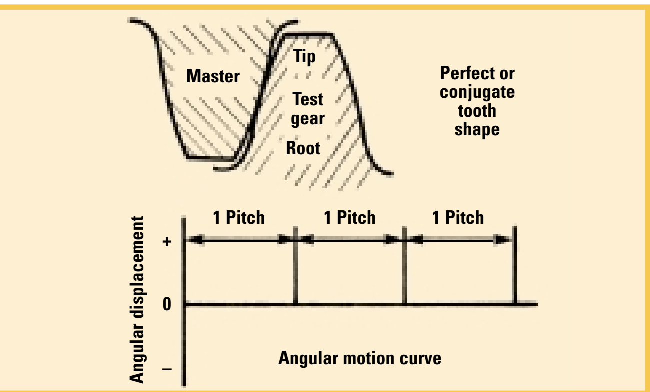


Figure 5a—A perfect involute tooth showing zero angular displacement error.

Robert E. Smith

is president of R.E. Smith & Co. Inc., a gear consultancy in Rochester, New York, U.S.A. A mechanical engineer, he's worked extensively with single-flank testing equipment and on gear noise evaluation since the late 1950s. He's also written several AGMA technical papers on transmission error and gear noise. Twenty years ago, Smith was a technical author in Gear Technology*'s first issue. Since 1991, he's been one of our technical editors.*

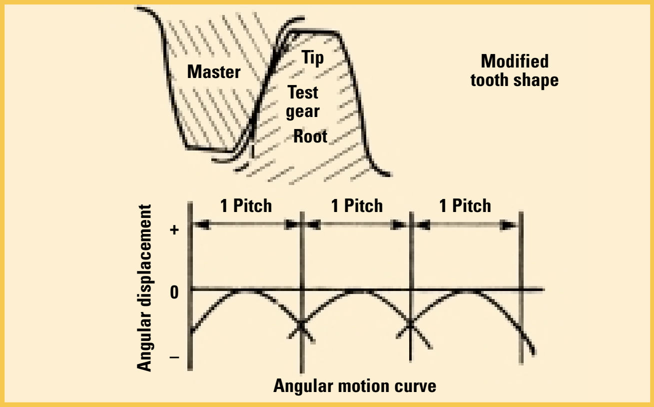


Figure 5b—An involute tooth with tip and root relief that result in parabola-like motion curves.

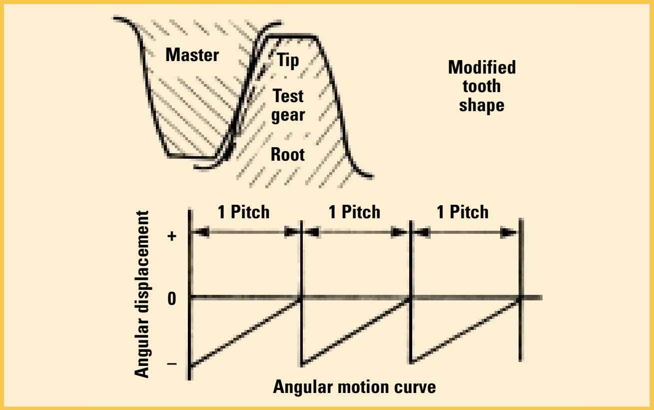


Figure 5c—An involute tooth with pressure angle error that results in saw tooth motion curves.

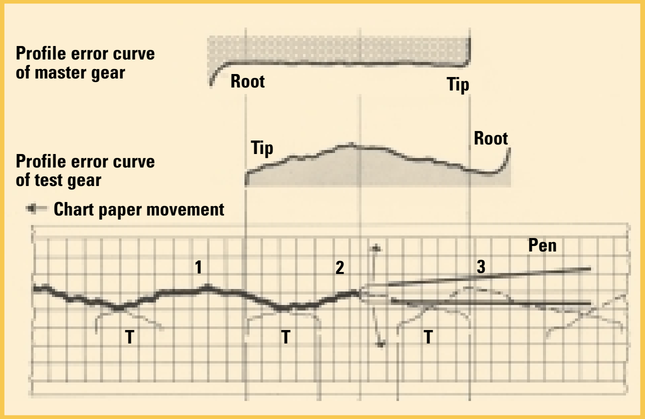


Figure 6—Direct relationship between an involute tooth and a single-flank graph.

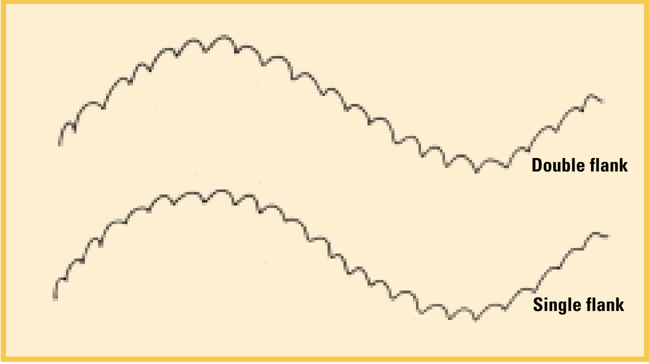


Figure 7—Typical recording of gear with runout.

showing zero angular displacement error. Figure 5b shows gradual tip and root relief, typical of shaving operations, that result in the parabola-like motion curve. Figure 5c shows a tooth with pressure angle error and the resulting saw tooth motion curve.

Figure 6 is another way to show a direct relationship between involute shape and a single-flank graph. Such curves are graphic representations of some of the types of nonuniform motion that gears are likely to transmit. It is this nonuniform motion that creates the exciting force that will shake a structure and cause noise.

There are other areas of gear quality that are important besides profile conjugacy and noise. These become more apparent as the graph is run for at least one test gear revolution. All tooth meshes will be added together to generate the results, as shown in Figure 4. The graph in Figure 4 shows additional information: adjacent pitch error, total accumulated pitch error and total transmission error.

The ability to check accumulated pitch error is an important attribute of single-flank testing. First of all, there is a difference between "runout" and "accumulated pitch variation." A gear with runout has accumulated pitch variation. A gear with accumulated pitch variation does not necessarily have runout.

Runout occurs in a gear with a bore or locating surface that is eccentric from the pitch circle of the teeth. Runout is shown as a variation in depth of a ball type probe as it engages each successive tooth slot. Or, it can be a large total composite error if observed on a double-flank tester.

A gear can be produced, by various means, that will have no runout, as described above, and will show little or no reading by the ball check. It could, however, have large accumulative pitch errors. This can happen when a gear is hobbed with runout and then shaved or ground on a machine that does not have a rigid drive coupling the tool to the workpiece.

When the gear is hobbed with an eccentric pitch circle, the slots are at different radii and angular positions. When the gear is shaved, it is run with a tool that maintains a constant, rigid center distance, but is not connected to the workpiece by a drive train. Therefore, all slots are now machined to the same radius, from the center of rotation, and are displaced from true angular position by varying small amounts. The resulting gear has very small amounts of individual pitch errors, but has a large accumulated pitch error, which the single-flank tester responds to.

These accumulative pitch errors have all the undesirable effects of a gear with traditional runout. It would check "good" by either a ball check or a double-flank composite test. Accumulative pitch errors can only be found or properly evaluated by a precision index/single probe spacing checker, or by a single-flank composite test.

Figures 7 and 8 are intended to help illustrate the advantages of single-flank vs. double-flank composite tests.

Figure 9 is an extreme example, whereby the wrong number of teeth is cut in the part. Double-flank composite testing will indicate that the part is acceptable, but single-flank testing will reject it.

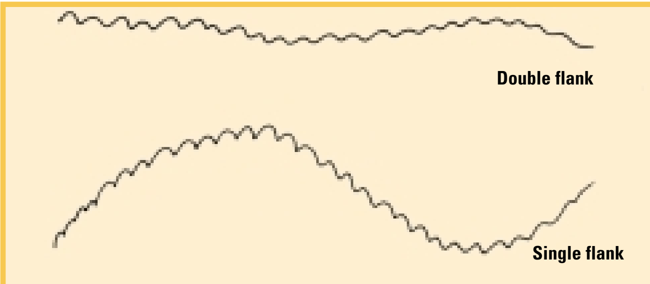


Figure 8—Typical recording of gear with accumulated pitch variation, as can be produced by abrasive hobbing or hobbing/shaving process.

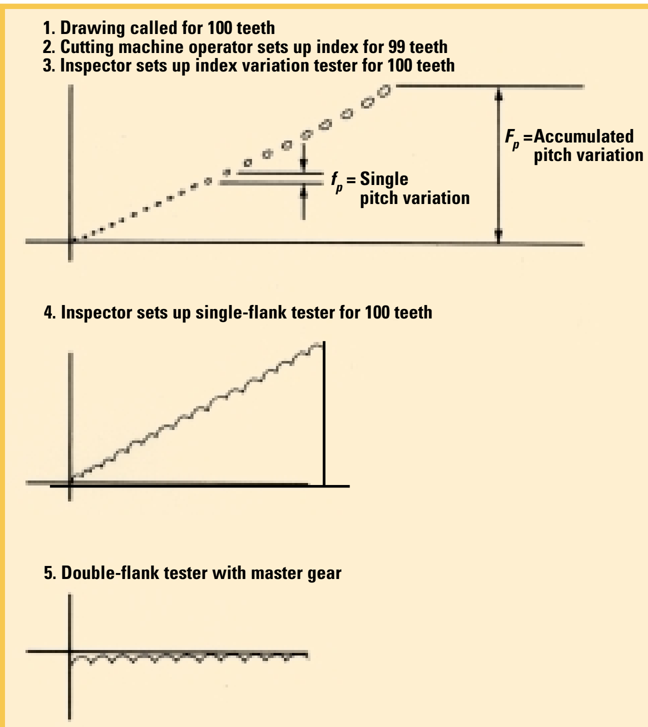


Figure 9—An extreme example to show the advantages of single-flank vs. double-flank composite tests.

Conclusions

Single-flank testing can check all elements of gear quality, except possibly lead/helix or spiral angle error, much faster and more thoroughly than individual elemental tests or double-flank composite tests. This method:

1. Explores, essentially, all areas of all teeth.
2. Finds all kinds of runout, including accumulated pitch variation (hidden runout).
3. Measures the combined profile errors on bevel gear teeth that cannot be measured adequately by tooth contact patterns or by elemental gear measurements. ⚙

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Globalization Brings AGMA, ISO Standards Closer

"The gear marketplace is a global marketplace."

Bill Bradley says it easily, with no special emphasis. The vice president of AGMA's technical division sees the statement as an obvious fact.

And he's acted on that idea, spending more than 15 years helping AGMA develop ISO standards for the global marketplace.

Today, U.S. gear manufacturers sell their gears to customers around the world, sending the gears across borders and oceans to customers in Brazil, Germany and South Korea now much like they could across state lines to customers in Michigan and Ohio in past decades.

In those years, U.S. gear manufacturers could expect customers in Michigan, Ohio and other states to specify gears according to AGMA standards.

Now, though, global customers may specify gears using any of a number of standards used around the world, including AGMA, BSI, DIN, ISO, JIS.

"We will manufacture in the same way for all standards and measure to what the customer requires," says Roger Bailey, vice president of supply chain management for Textron Fluid & Power Systems.

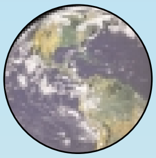
Located in Huddersfield, England, U.K., this Textron Power Transmission division uses AGMA, British and DIN standards.

"We will continue to do what our customers want," says John Windl, production supervisor in the gear department of Ontario Drive & Gear Ltd., located in New Hamburg, Ontario, Canada. "We will still study the other standards so we can change as our customers' demands change."

Like those British and Canadian companies, U.S. gear manufacturers have to be familiar with as many widely-used standards as possible to have as many global customers as possible.

But familiarity with three, four, five or more sets of standards—that's no small feat.

AGMA and ISO standards are becoming more and more alike, but which is changing more?



"It's not a quick and easy answer." —Bill Bradley, Vice President of Technical Division, AGMA

Making Standards More Alike?

Another approach, though, would have those standards become more alike, making it easier for gear manufacturers to move from one set of standards to another, like from AGMA to DIN.

This converging of standards would be welcomed by Chuck Awot, engineering supervisor for Andrews Products Inc. The U.S. company, located in Mount Prospect, Illinois, uses AGMA, DIN, ISO and JIS standards in manufacturing gears.

"The more standardization that occurs, the easier it is for us. Historically, AGMA, DIN and ISO quality classifications could not convert directly," Awot says. "It created a lot of additional work for us to clearly define the requirements for our people on the shop floor in order to conform to the customer's specifications. A single standard would eliminate all of that work and confusion."

AGMA can't bring about the convergence of most widely-used standards, though. Germany, Japan, the United Kingdom and other countries will adopt what standards they want.

AGMA can, though, make its standards converge with ISO standards and has been making them more alike for years.

"This trend would be convenient and would bring the AGMA standards more in line with the international ones," says Tony J. Bannan, engineering director for Holroyd, located in Milnrow, England, U.K.

AGMA INFLUENCE ON ISO STANDARDS, VICE VERSA

AGMA and ISO standards are becoming more and more alike, but which is changing more?

"It's not a quick and easy answer. The ISO standards are influencing the AGMA standards and vice versa," says Bill Bradley, vice president of AGMA's technical division. "But to say which is changing more is hard."

Gear accuracy and calibration standards serve as an example of how AGMA and ISO influence each other's standards.

Bradley describes AGMA and ISO inspection standards as becoming "very close to each other." This increasing similarity is because AGMA is replacing its gear accuracy standard, 2000-A88, with a new standard based largely on ISO 1328-1:1995.

Bradley says the new AGMA standard and the ISO standard approach similar topics in similar ways, so they give similar results.

But, if the standards provide similar results, then their underlying calibration methods would have to be similar.

"The methods are just about identical," Bradley says.

The process that made them similar, though, was the reverse of the one for the accuracy standards.

In this case, AGMA offered its calibration methods to ISO. The association has had a calibration standard for more than 10 years. ISO had no calibration standard—until December.

That month, ISO published its first standard for calibrating a gear measuring instrument for inspecting spur and helical gears.

According to Bradley, the standard includes most of the calibration methods from three AGMA standards on spur and helical gears. The three standards cover calibrating and measuring 1.) involute 2.) pitch and runout, and 3.) lead/helix.

This type of situation has occurred previously because AGMA has more gear standards than ISO and the association targets those topics it covers that ISO doesn't.

According to Bradley, AGMA looks at topics covered in its standards but not in ISO standards, then takes specific standards and suggests ISO consider them while developing its standards on those topics.

Bradley cites the ISO temper etch inspection standard as an example.

In the early 1990s, ISO had no standard for inspecting gear teeth for grinding temper. AGMA offered its 2007-B92 standard as an ISO standard. The resulting ISO standard, 14104:1995, was based on the AGMA standard. Bradley says that the two standards were nearly identical.

Five years later, AGMA adopted the ISO standard.

The process hasn't been so neat and clean with the two organizations' gear rating standards. AGMA has adopted some ISO rating principles for spur and helical gears, but the actual rating methods are still different. So AGMA and ISO ratings can be compared, but not directly (see the article in this issue on pages 56–63).

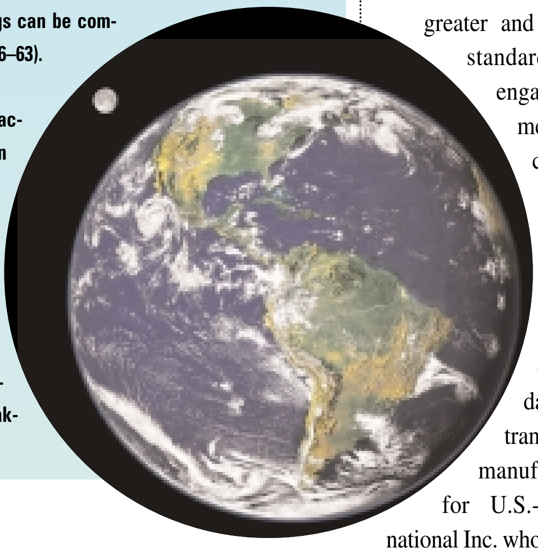
"The differences aren't consistent," Bradley says.

In one case, a gear may receive a higher load carrying capacity using the AGMA system than it does using the ISO system. In another case, a second gear may receive a higher capacity using the ISO system than it does using the AGMA system.

This inconsistency extends to gear drive sizes and calculated lifetimes.

So, for comparison, a person needs either a comprehensive knowledge of both rating systems or the right software.

In Bradley's opinion, AGMA and ISO standards are probably changing at the same rate: "I wouldn't say that either is making substantially more changes than the other."



"We would welcome this in our business," Bannon says of the trend.

At this time, ISO standards don't appear to be as widely used as other standards, such as DIN. But, in time, they may be.

"ISO standards are still gaining acceptance," Bradley says.

And this acceptance is being noticed by some gear manufacturing companies, such as Holroyd. The U.K. company uses AGMA, DIN and ISO standards. In his work, Bannan says use of DIN and ISO are increasing, while use of AGMA is decreasing.

Munish Nalwa is noticing greater ISO acceptance at his company, Ingersoll-Rand Wadco Tools, located in Sahibabad, India.

"We see a shift towards ISO because of global sourcing," says IRWT's deputy manager of engineering. "However, it will take some time to reach a significant number of users."

With ISO standards more widely accepted, U.S. gear manufacturers would more and more need the ability to use ISO standards. Making achievement of this ability as easy as possible is AGMA's considerable activity in developing ISO standards.

The association sees the increased similarity between AGMA and ISO standards as an opportunity for U.S. gear manufacturers to increase their number of potential global customers.

Those manufacturers using the latest AGMA standards would find them in greater and greater accord with ISO standards, making it easier to engage in international commerce, says Edward Lawson, chairman of the AGMA Technical Division Executive Committee.

"Standardizing gear measurements and controls will make the process of moving from one [standard] to the other an easy transition," says Doug Webb, a manufacturing/process engineer for U.S.-based Honeywell International Inc. who works in Phoenix, Arizona.

AGMA in ISO

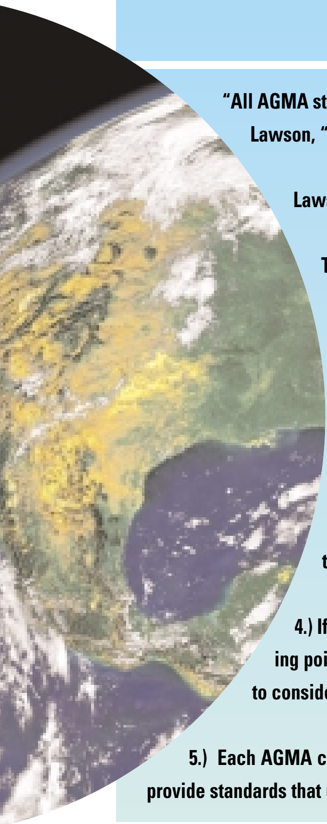
The decision that AGMA should become more active in ISO started with the association's executive members: the board of directors and its executive committee. In the 1980s, the members realized the gear marketplace was becoming an international marketplace. If ISO standards became widely accepted, U.S. gear manufacturers would have an easier time using them if they were based on principles and procedures familiar to the manufacturers, like those contained in the manufacturers' own national standards.

Before the executive members' decision, AGMA participation in ISO amounted to one observer, who attended meetings of the ISO group responsible for gear rating standards.

"There wasn't any active participation," Bradley says.

Today, AGMA participation is considerable. The association has 10 committees with ISO delegates. The 10 delegates represent U.S. positions to ISO Technical Committee 60, which is responsible for

AGMA INFLUENCE ON ISO STANDARDS



"All AGMA standards committee work is expected to proceed with an objective of leading standards development in ISO working groups," says Edward Lawson, "as well as producing AGMA standards that are in harmony with ISO documents."

Lawson is chairman of the AGMA Technical Division Executive Committee. TDEC sets policy for AGMA standards committees.

To achieve this objective, TDEC uses five guidelines for overseeing AGMA standards committees. Lawson explains these guidelines:

1.) Each AGMA standards committee is expected to develop the U.S. positions on its standards topic—for example, gear accuracy. The committee's positions are then presented by its ISO delegate to the ISO working group responsible for the same topic.

2.) When creating or revising an AGMA standard, each committee is expected to consider whether an existing ISO document would be acceptable as the AGMA standard.

3.) If no ISO document exists, then the committee is encouraged to create or revise its AGMA standard with an eye to later presenting it to the corresponding ISO working group to use as a starting point for creating the ISO standard.

4.) If an ISO document exists and would be acceptable with minor changes, then the committee is encouraged to use the document as its starting point. Even then, the committee is expected to develop its standard with an eye to later presenting it to the corresponding ISO working group to consider as a possible update to the existing ISO document.

5.) Each AGMA committee is expected to develop standards that use the metric system, as ISO standards do. Each committee, however, is allowed to also provide standards that use inches and feet.

ISO gear-related standards. Each delegate belongs to a TC 60 subcommittee, called a working group. These groups cover acceptance testing, accuracy, bevel gears, cutting tools, gear rating, high speed units, lubricant testing, metallurgy, nomenclature, and worm gears. AGMA also has an 11th ISO delegate, who presents U.S. positions to TC 14, which covers couplings, keys, shafts and splines.

AGMA participation also extends beyond its committees' work.

AGMA is the secretariat for TC 60, meaning the association does the administrative work for all ISO gear-related standards. This secretariat consists of Bradley and technical division manager Charles Fischer.

Also, the association is in charge of two TC 60 subcommittees, Working Groups 2 and 9. WG 2 develops ISO standards for measuring gears, WG 9 for acceptance testing of gears, including sound and vibration testing. WG 2 is led by Lawson, WG 9 by Bradley.

"The ultimate goal is to have ISO standards that are acceptable in the U.S."
—Bill Bradley, AGMA

Given all this participation, it may not surprise anyone that AGMA and ISO standards are becoming more alike. This increased similarity will make it easier for U.S. gear manufacturers to use both AGMA and ISO standards in the global gear marketplace.

But AGMA is aiming for more than ease of use for U.S. gear manufacturers. It's aiming for acceptance from them.

"The ultimate goal," Bradley says, "is to have ISO standards that are acceptable in the U.S." ✪

To help develop AGMA and ISO standards, contact the American Gear Manufacturers Association at:

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Evaluation of Bending Strength of Carburized Gears

Tomoya Masuyama, Katsumi Inoue, Masashi Yamanaka, Kenichi Kitamura and Tomoyuki Saito

Management Summary

The aim of our research is to clearly show the influence of defects on the bending fatigue strength of gear teeth. Carburized gears have many types of defects, such as non-martensitic layers, inclusions, tool marks, etc. It is well known that high strength gear teeth break from defects in their materials, so it's important to know which defect limits the strength of a gear.

In this article, we propose a method of inferential identification of principal defects and an evaluation of strength based on defect size. Furthermore, the results of this research should show how to reduce the defects.

Table 1—Dimensions of test gears used for the derivation of a formula.

Code	C1	C2	EP1	EP2
Module [mm]	5			
Number of teeth	18			
Face width [mm]	8			
Material	SCM415			
Heat treatment	Carburized			
Removal stock [µm]	0	0	10	20
Surface residual stress [MPa]	–230	–130	–160	–190
Fatigue strength [MPa]	842	890	901	906

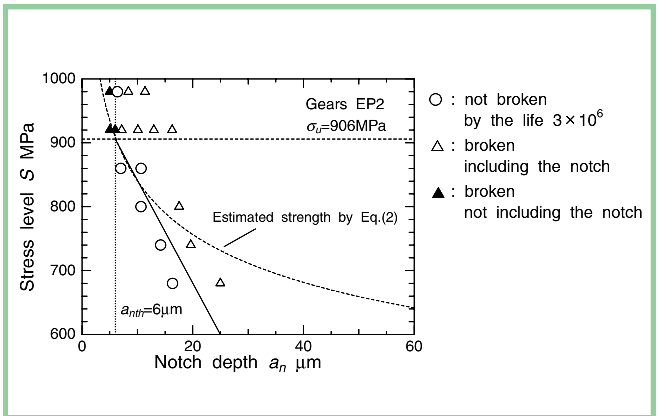

Figure 1—Strength of electropolished gear with a micronotch.

Abstract

The high load capacity of carburized gears mainly originates from the hardened layer and induced residual stress. On the other hand, the decarburization at the surface, which causes a nonmartensitic layer, and the inclusions such as oxides and segregation act as a latent defect, and the defect considerably reduces the fatigue strength. In this connection, the authors have proposed a formula of strength evaluation by separately quantifying the influence of the defect. However, the principal defect that limits the strength of gears that have several kinds of defects remains unclarified. This paper presents a method of inferential identification of the principal defect based on the test results of carburized gears made of SCM420 clean steel, gears with both an artificial notch and nonmartensitic layer at the tooth fillet and so forth. It makes clear the practical use of the presented method, and the strength of carburized gears can be evaluated based on the principal defect size.

Introduction

The high load capacity of carburized gears mainly originates from the hardened layer and induced residual stress. This is the reason that carburization is frequently used as a normal heat treatment for heavy duty gears. One of the authors has clarified the effects of hardness and residual stress on the enhancement of bending fatigue strength and proposed an experimental formula for the estimation of strength (Refs. 1 and 2). The formula was expressed as a function of hardness and residual stress. The effectiveness of the formula has been verified by comparison with many fatigue test results (Ref. 3).

Contrary to the positive effect of carburization mentioned above, the decarburized nonmartensitic layer appears at the tooth surface through the treatment, and this decreases the strength. The authors have observed many microcracks in the nonmartensitic layer and presented a model of fatigue crack propagation. Some cracks are combined when the tooth is loaded and the most critical crack propagates into the deeper region (Ref. 4). Therefore, the nonmartensitic layer should be considered as a defect, which reduces the strength. Besides the nonmartensitic layer, many inclusions such as oxide or sulphur, exist in the hardened layer. Their influence has to be included in the strength evaluation.

Murakami (Ref. 5) proposed a formula to estimate the fatigue strength of a high-strength material from its hardness, stress ratio and the projected area of a defect. It may be used for

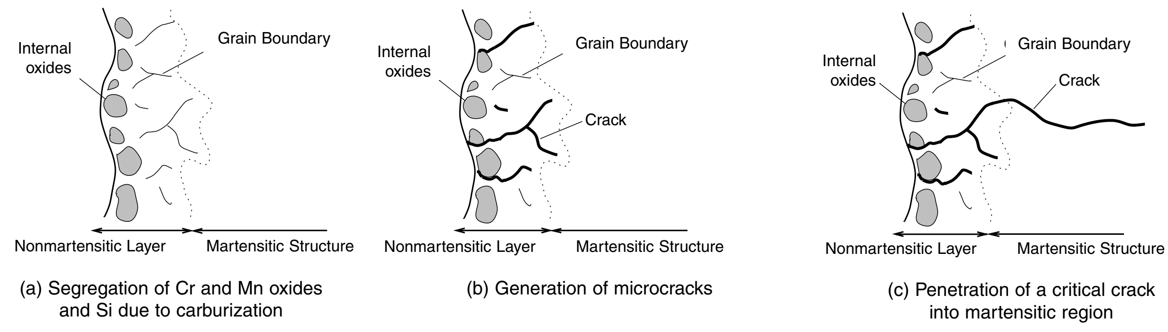

Figure 2—A model of crack initiation mechanism.

the investigation of why the empirical proportionality relationship between fatigue strength and hardness deviates from the relationship in the region of higher hardness (Ref. 6). The formula is also useful for the strength evaluation of carburized gears with latent defects. Quantification of the defects is the key to the derivation of a formula for gears. Therefore, the authors performed a fatigue test using gears with an artificial notch at the fillet, which was processed by focused ion beam, to quantify the influence of the defect in the tooth by this equivalent notch depth (Ref. 7). Another test was also performed to quantify the influence of a nonmartensitic layer, and a formula for the strength of gears with or without nonmartensitic layers was derived using these defect sizes (Ref. 8).

In this paper, the derivation of the formula is briefly reviewed first, and the formula is applied to the fatigue test result of carburized gears made of SCM420 clean steel to demonstrate its wide application. Then, the principal defect, which is substituted for the defect size in the formula to estimate the strength, is inferentially identified so as to evaluate the strength of gears with several kinds of defects, such as inclusions, surface defect and a nonmartensitic layer. This enables use of the formula in a practical gear design and enhancement of the strength. Lastly, the validity of the formerly proposed formula is examined in comparison with the estimation focusing on the defect size.

Derivation of a Formula for Bending Strength Considering the Influence of Defect Size

In order to derive a formula for the evaluation of bending strength of carburized gears, the test gears C1, C2, EP1 and EP2, as shown in Table 1, are used. The material, module and the number of teeth used in the study are low alloy steel SCM415, 5 and 18, respectively. The chemical composition of the alloy is standardized as shown in Table 2.

Carburized gears without nonmartensitic layer. A micronotch is created at the fillet of EP2 gears using a focused ion beam, and the fatigue test is carried out to experimentally determine the threshold notch depth, which is the limit that doesn't reduce the strength of the carburized gear. The notch is at the position where cracks are most frequently initiated in the fatigue test (Ref. 9). The ion beam etching area is rectangular, 500 µm (along face width) x 10 µm, at the center of the face

Table 2—Standard of chemical compositions of material SCM415 (wt%).

C	Si	Mn	P	S	Cr	Mo
0.13–0.18	0.15–0.30	0.60–0.80	<0.03	<0.03	0.90–1.20	0.15–0.30

width. The desired notch depth is obtained by controlling the time of ion beam irradiation. Figure 1 shows the result of the fatigue test. In this figure, open circles indicate that the tooth is not broken. The open triangle and the closed triangle indicate tooth breaks with and without a notch in the fracture structure, respectively. Teeth with notches of 6 µm or smaller break without the notch in the fracture surface while the teeth with the larger notches break with the notches. Therefore, the threshold notch depth a_{nth} is found to be 6 µm and this quantifies the influence of the defect in the teeth.

The nonmartensitic layer is completely removed in the EP2-type gears. So, the authors assume that the initiation and propagation of cracks of the gears are similar to those of ordinary high strength materials, and fatigue strength can be evaluated by the modification of the following experimental formula (Ref. 5).

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Table 3—Chemical compositions of material SCM420 (wt%, O:ppm).								
Material	C	Si	Mn	P	S	Cr	Mo	O
Range (JIS G4105)	0.17–0.23	0.15–0.25	0.55–0.90	<0.030	<0.030	0.85–1.25	0.15–0.35	–
Ordinary steel	0.22	0.31	0.84	0.019	0.013	1.21	0.15	8
Clean steel	0.21	0.25	0.85	0.012	0.003	1.18	0.15	5

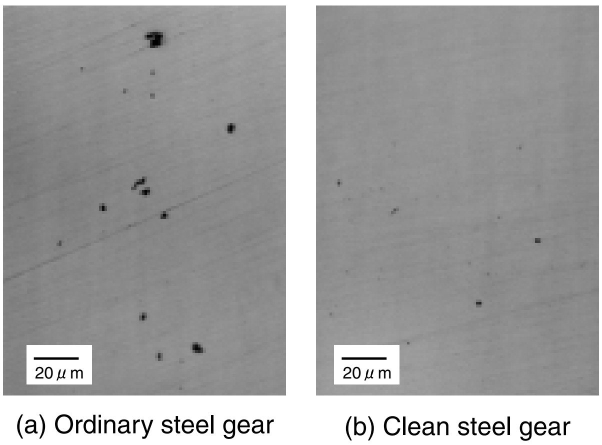


Figure 3—Microstructure of the ordinary steel and clean steel by optical microscope.

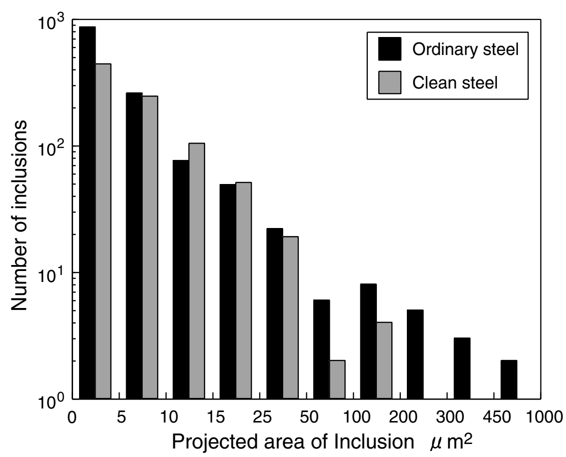


Figure 4—Distribution of inclusions in observed area.

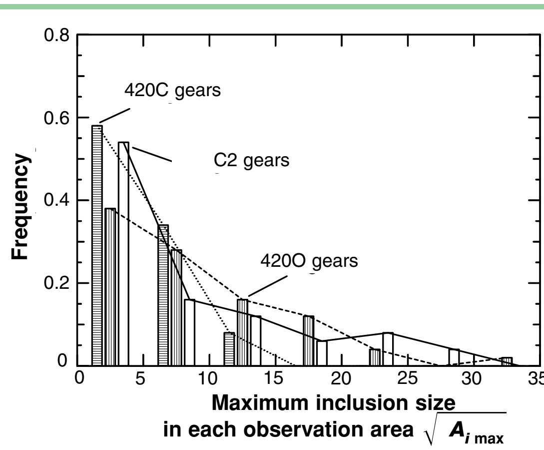


Figure 5—Distribution of the maximum inclusion size in each observed area.

$$\sigma_w = \beta \frac{(H + 120)}{(\sqrt{A}\,)^{1/6}} \left[\frac{(1 - R)}{2} \right]^{\alpha} \qquad (1)$$

$$\alpha = 0.226 + H \bullet 10^{-4}$$

Here, σ_w, H and R are fatigue stress amplitude [MPa], Vickers hardness [Hv] and stress ratio, respectively. A represents the projected area of a defect in the direction of the principal stress [μm²]. The coefficient β is given as β = 1.43 and may be modified, since the experiment which was the basis of the formula includes few specimens of hard material and few tests subjected to the mean stress.

The formula is applied first to the experimental result of the EP2-type gear. The value of A is assumed to be $\sqrt{A} = \sqrt{10}\, a_{nth}$ since the notch is wide enough to be two-dimensional (Ref. 5) and the stress ratio R is defined assuming that the measured residual stress at the surface, –190 MPa, acts as the mean stress. The strength is estimated at 1,300 MPa and this value is approximately 1.4 times the experimental value of 926 MPa. The estimation error is considerably large, even though the above formula is expected to include approximately ±15% of error (Ref. 5). The coefficient β is therefore modified so that the estimated value agrees well with the strength obtained by the experiment, and the following formula

$$\sigma_w = 0.98 \frac{(H + 120)}{(\sqrt{A_i}\,)^{1/6}} \left[\frac{(1 - R)}{2} \right]^{\alpha} \qquad (2)$$

is obtained. The dashed line in Figure 1 shows the strength calculated according to the formula.

It is used for the evaluation of the strength of carburized gears without the nonmartensitic layer. In general, since the threshold notch depth is unknown, we have to find the size of inclusion A_i in the surface layer to substitute it for A in the formula.

For highly reliable design of safety, the worst condition of defect in the gear tooth has to be estimated and substituted for A. The extreme value analysis can be used to estimate the maximum inclusion size in the material (Ref. 5). The authors have applied this analysis to the gear of clean steel and estimated the inclusion size (Ref. 10). However, in this report, we discuss the mean value of gear strength.

Therefore, since the mean size of the defect that determines strength is specified, the average value of the maximum inclusion size contained in each microscope view was substituted into the formula.

Carburized gears with a nonmartensitic layer. The fatigue-loaded C1-type gear is prepared until a crack is detected. The gears were observed using a scanning electron microscope (SEM) and an electron probe microanalyzer (EPMA) to clarify the characteristics of the crack initiation mechanism in the nonmartensitic layer. The test tooth is cut at the center of the face to the normal direction using a cutting wheel. After cutting, the newly produced surface is polished with emery paper and then buff-polished. The obtained surface is etched with 3% nitrate ethanol, then observed by the SEM. In the deeper region, a needle-like martensitic structure is observed. However, at the surface area, there is a layer in which the martensitic structure is not observed. Many microcracks are observed in the nonmartensitic layer, in addition to the cracks which penetrated from the nonmartensitic layer into the deeper region.

The process of crack initiation in a carburized gear tooth with a nonmartensitic layer is considered to be as follows, and the schematic illustrations are shown in Figure 2. In the tooth's nonmartensitic layer before loading, there are Cr and Mn oxides and grain boundaries where Si is segregated (Fig 2a). When subjected to loading, the grain boundaries or oxides act as stress-concentration areas and many microcracks are generated. Some of them combine to form larger cracks (Fig. 2b). The most critical crack is the one that penetrates into the deeper regions while most of the cracks remain in the nonmartensitic layer (Fig. 2c).

As mentioned above, a number of oxides and segregations are distributed in the nonmartensitic layer, and they act as microcracks. Therefore, the nonmartensitic layer should be considered as a defect, which reduces the strength. Here, we assume the thickness of nonmartensitic layer δ is used as the defect size by modifying $\sqrt{A} = \sqrt{10}\,\delta$ and it is substituted for $\sqrt{A}$ in Equation 1. In the case of $\beta = 1.17$, the calculated strengths agree with the experimental results of the three types (C1, C2, EP1) of gears with nonmartensitic layers. Consequently, the following formula is derived.

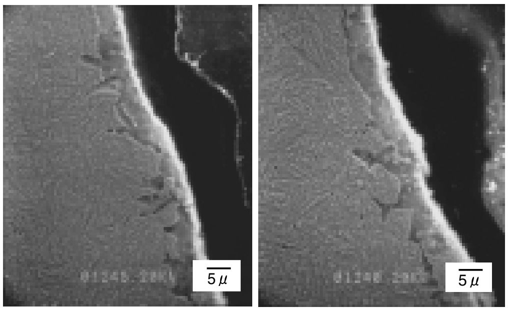
$$\sigma_w = 1.17\,\frac{(H+120)}{(\sqrt{10}\,\delta\ )^{1/6}}\left[\frac{(1-R)}{2}\right]^{\alpha} \qquad (3)$$

Strength evaluation formula represented by the integrated form. As shown in the above section, we presented two fatigue strength evaluation formulas, Equation 2 and 3, of which coefficients β differ depending on whether the nonmartensitic layer exists or not. In this section, we propose the defect size parameter A', then modify the formula as Equation 4.

$$\sigma_w = \frac{(H+120)}{(\sqrt{A'})^{1/6}}\left[\frac{(1-R)}{2}\right]^{\alpha} \qquad (4)$$

Here, the A' is represented as a belong equation.

When the formula is applied to gears without nonmartensitic layers



(a) Ordinary steel gear (b) Clean steel gear

Figure 6—Microstructure of the specimen observed by the SEM.

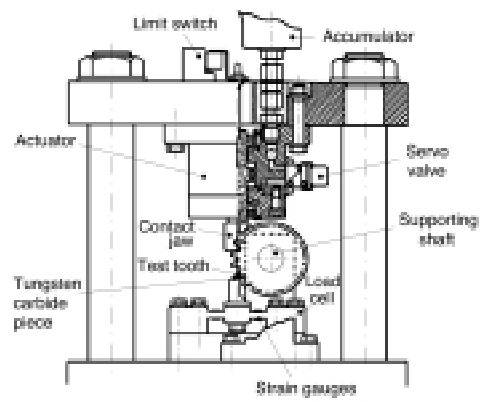


Figure 7—Pulsating fatigue test rig.

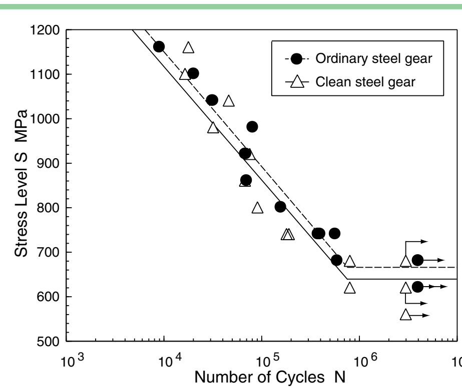


Figure 8—S-N curves in 420O gears and 420C gears.

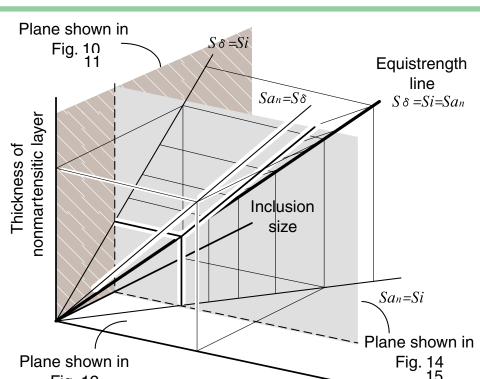


Figure 9—Schematic illustration to infer the principal defect about a carburized gear tooth with an artificial notch.

$$\sqrt{A'} = \frac{\sqrt{A_i}}{0.98^6} \qquad (5)$$

$$= 1.13\sqrt{A_i}$$

When the formula is applied to gears with nonmartensitic layers

$$\sqrt{A'} = \frac{\sqrt{10}\,\delta}{1.17^6} \qquad (6)$$

$$= 1.23\delta$$

Fatigue Test of Carburized Gears With Defects of Different Sizes

In order to investigate the influence of defects, two types of gears made of SCM420 ordinary steel and SCM420 clean steel were prepared. They were labeled as 420O and 420C respectively. The chemical compositions of these steels are shown in Table 3. The content of oxygen in the clean steel is as low as 5 ppm, and the sulphuric content is also reduced.

Figure 3 shows the optical micrographs at a cross section of both types of gear teeth. Evidently, the clean steel has a few smaller inclusions. It is clearly shown in Figure 4. Though there is no difference in the distribution of inclusion size under 50 μm^2, in the clean steel gears there are few inclusions greater than 50 μm^2. In particular, no inclusions greater than 200 μm^2 were observed. The maximum inclusion size contained in each microscope view was distributed as shown in Figure 5.

The effective case depths of 420O and 420C are 0.92 mm and 0.82 mm, respectively. There was no distinct difference in the hardness distribution. The residual stress σ_R at the root of a tooth was measured by X-ray diffraction method. The residual stress of the clean steel gears is approximately equal to the stress of ordinary steel gears. They are also listed in Table 4. Figure 6 shows SEM micrographs at the fillet of the clean steel gear and the ordinary steel gear. Both of the gears have a similar nonmartensitic layer. In the strength evaluation described later, 15 μm was substituted for thickness of the nonmartensitic layer δ, although the boundary of the nonmartensitic layer is not parallel to the tooth profile.

The fatigue test of the gear is performed using an electro-hydraulic fatigue test rig, as shown in Figure 7. The pulsating load is well controlled and the fluctuation of the peak load is less than 2%. The load is applied at a position of 0.5 mm below the tip with the speed of about 40 Hz. To avoid impact loading to the tooth, the stress ratio is set to 0.01. The load is represented by the maximum stress applied at the fillet (Ref. 11).

The S-N curves of the 420O and 420C gears are shown in Figure 8. The test was stopped at $N = 3 \times 10^6$ in each gear and the tooth which was not broken by this lifetime was considered a non-failure. The mean fatigue strengths are obtained as 685 MPa and 650 MPa, respectively, by a staircase method (Ref. 12). The step of stress was 62 MPa.

Since the thickness of the nonmartensitic layer of the two gears is almost identical and the fatigue strength is limited by the nonmartensitic layer, the inclusions did not affect the fatigue strength. After the removal of the nonmartensitic layer, the fatigue strength increases to 1,070 MPa for clean steel gears and 837 MPa for ordinary steel gears. The fatigue strength enhancement is about 22% and 65%, respectively.

Inferential Identification of Principal Defect Limiting the Strength

From the viewpoint of defects, the carburized gears for practical use are damaged in the process of steel manufacturing, hobbing and heat treatment. The damage consists of inclusions, tool marks and nonmartensitic layers. In this section, supposing the artificial notch approximates the tool mark, the influences of these defects are discussed to inferentially identify the principal defect which limits the strength.

The proposed formula is used in reverse to evaluate the defect size from the given strength. The relationship among the defects which causes the equal strength is shown in Figure 9, where the top notch depth, inclusion size and nonmartensitic layer thickness are taken as coordinates. Three defects at a point on the line in the space give the equal bending strength. When the hardness and residual stress are constant, A' is equal on the equistrength line.

Inclusion size and thickness of nonmartensitic layers. In the first place, the influences of the inclusion size and the thickness of the nonmartensitic layer are examined. They are illustrated in Figure 9. The line in the figure is the projection of the equistrength line in Figure 10 to the plane of notch depth = 0. Therefore, the nonmartensitic layer acts as the principal defect in the region above the line. The defects of several test gears are plotted in the figure. This shows how the nonmartensitic layer evidently acts as the principal defect in the gears as carburized, and the inclusion becomes tangible after complete removal of nonmartensitic layer. In the case of test gear EP1 electropolished halfway, the remaining nonmartensitic layer seems to be the principal defect, as shown in the figure.

The strengths are estimated based on the defect size mentioned above and compared with the experimental results in Figure 11. The error is about 15% and the inferential identification of principal defect is approximately verified. The fatigue test results of the gears made from spheroidal graphite cast iron FCD700 and FCD950, of which hardness, residual stress and graphite size are H = 330, 280, σ_R = –153 MPa, –92 MPa and A_i = 41.6 µm, 42.2 µm are also shown in this figure. The graphite is considered to be the principal defect in this case, though the error of strength estimation is a bit large, namely 30%.

Figure 10 also suggests a way to enhance the strength. In the case of 420O, for example, the strength increases as the nonmartensitic layer decreases until the thickness is about 4 µm on the curve. The strength is expected to be 970 MPa. Since the clean steel 420C has a small inclusion size, the strength after removing the nonmartensitic layer is expected to be 1,070 MPa. However, more of the nonmartensitic layer should be removed.

Principal defect of gears with an artificial notch on nonmartensitic layer. In the second place, the influences of the notch depth and the inclusion size on the strength of gears

Table 4—Dimensions of test gears.

Code		420O	420O(EP)	420C	420C(EP)
Material		SCM420 (Ordinary)		SCM420 (Clean)	
Module	[mm]	5			
Number of teeth		18			
Face width	[mm]	8			
Heat treatment		Carburized			
Removal stock	[µm]	0	30–40	0	30-40
Hardness	[Hv]	628	700	605	702
Residual stress	[MPa]	–109	–284	–101	–283
Fatigue strength	[MPa]	685	837	650	1,070

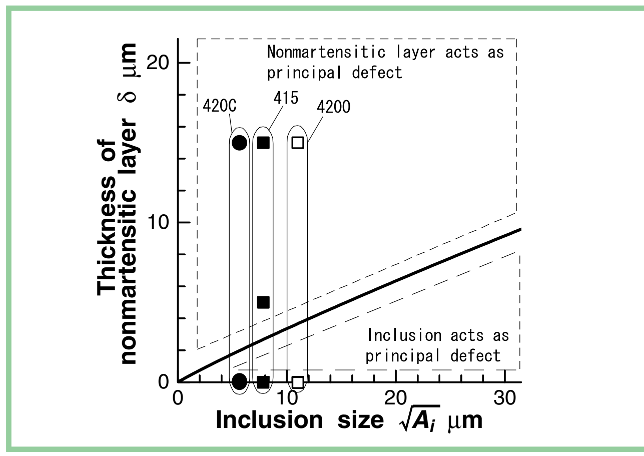


Figure 10—Comparison of the influence of the inclusion size and the thickness of nonmartensitic layer.

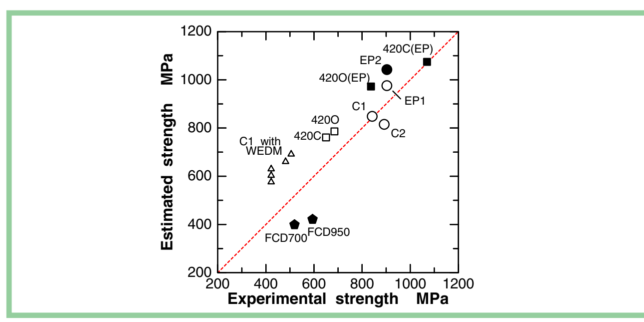


Figure 11—Estimation of strength of gears based on the defect size.

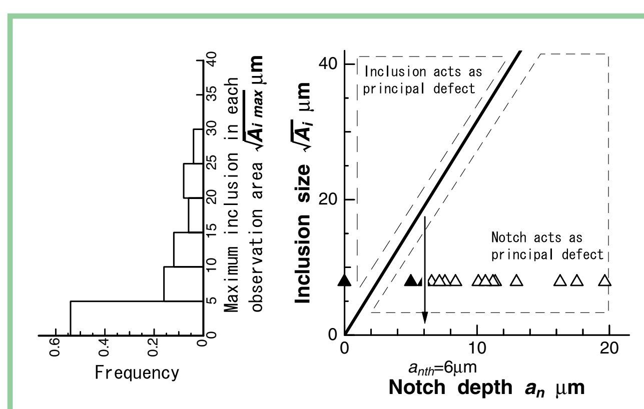


Figure 12—Comparison of the influence of the notch depth and the inclusion size.

without nonmartensitic layers are shown in Figure 12. The equistrength line in Figure 9 is projected on this plane, and the inclusion acts as the principal defect in the region above the line. The test results of broken EP2 gears shown in Figure 1 are plotted in the figure. As mentioned before, the closed triangle indicates the notch was not included in the fractured surface. Therefore, an inclusion would act as the principal defect and the plot should be in the region above the equistrength line. Contrary to expectation, there is a plot in the region below the line, and it remains unsolved. As mentioned above, the value of the vertical axis in this evaluation is the average value of the maximum inclusion size in each observed area. The size of inclusion obtained by the microscopic observation is, however, scattered in a rather wide range as illustrated in the figure. So, the actual size of the inclusion which caused the tooth breakage is not clarified, and this may be the above mentioned result. This figure quantitatively shows the effectiveness of tooth surface finishing in enhancing the strength.

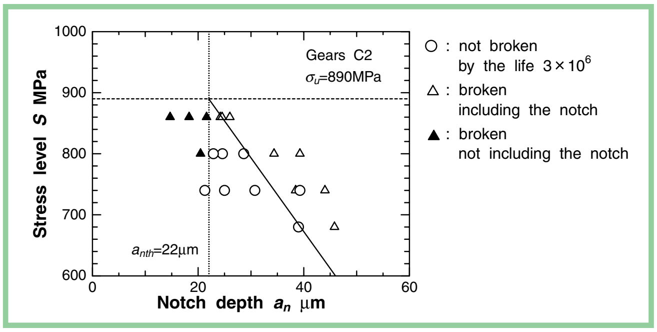


Figure 13—Strength of carburized gear with a micronotch.

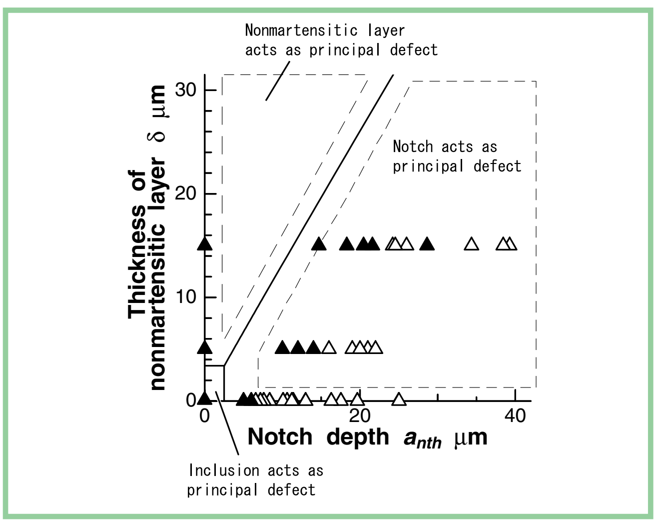


Figure 14—Comparison of the influence of the notch depth and the thickness of the nonmartensitic layer when the inclusion exists.

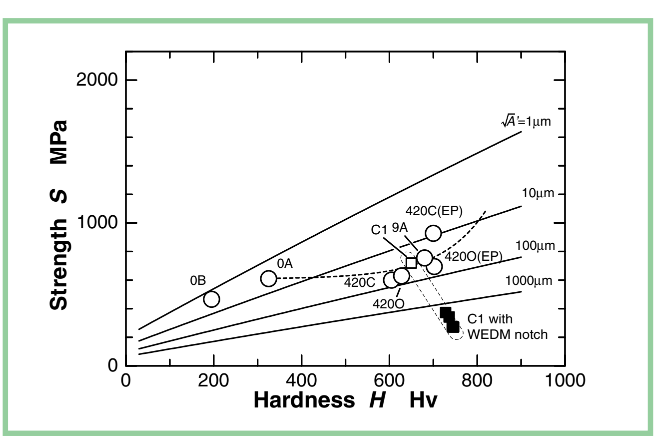


Figure 15—Estimation of strength of gears.

Figure 13 indicates the fatigue test result of C2 gears with an artificial micronotch as well as a nonmartensitic layer. The meaning of marks in the figure is the same as Figure 1. Since the inclusion is comprised in the material, the influences of three kinds of defects are examined in the plane of inclusion size of A_i = 8.7 µm in Figure 9. It is illustrated in Figure 14. The region where the inclusion acts as the principal defect is presented by the small area close to the origin and the equistrength line is drawn in the region except for the area shown in the figure. This suggests the inclusion acts as the principal defect, and only in the case of good surface finishing is it experienced. Though numerous tooth breakages, which were not caused by the notch, are plotted in the region below the equistrength line, it remains unsolved.

Verification of the Effectiveness of Proposed Formula

The authors have clarified the effects of hardness and residual stress on the enhancement of bending fatigue strength and proposed an experimental formula for the estimation of strength (Refs. 1 and 2). The formula is expressed as

$$\begin{aligned}\sigma_u &= \sigma_{uc} + \sigma_{usc} + \sigma_{uR} \\ &= f(Hc) + g(Hs - Hc) + h(\sigma_R) \\ &= (257 + 1.17Hc) + 3.1\exp[0.0097(Hs - Hc)] \\ &= -0.5\sigma_R\end{aligned} \quad (7)$$

Here, Hc[Hv] is core hardness, Hs[Hv] is surface hardness, σ_R [MPa] is residual stress. Additionally, $\sigma_{uc} = f(Hc)$, $\sigma_{usc} = g(Hs - Hc)$, and $\sigma_{uR} = h(\sigma_R)$ express fatigue strength of the material without heat treatment, increased fatigue strength due to case hardening and fatigue strength due to residual stress, respectively. In the formula, the influence of defects on the strength is not considered.

The strength obtained in Equation 7 is compared with the strength evaluated in Equation 4 in Figure 15, taking the defect size as a parameter. The estimation by Equation 7 is close to the strength of the gears with 30–40 µm defects and has a considerable error in case of the clean steel 420C(EP). It is confirmed from the figure that the formula in Equation 7 can be used for practical gear design except when the gears have such a small defect. In Figure 15, the gears 0A, 0B and 9A were used for the derivation of Equation 7.

The square plots shown in Figure 15 are the strength of C1 gears with a notch processed by wire electric discharge machining. The strength evaluation method proposed in this report is applicable to the gears with an extremely large defect.

Conclusion

In order to establish a strength evaluation method that takes defects into consideration, the authors had proposed a formula of strength evaluation. In this research, the formula was modified to more general form and the influences of inclusion size, notch depth and nonmartensitic layer thickness were quantitatively clarified based on the fatigue test results of carburized gears made of SCM420 ordinary steel and SCM420 clean steel. The conclusions may be summarized as follows.

The strength evaluation formulas derived from the test of the carburized gear with the artificial micronotch as well as the nonmartensitic layer were unified using the equivalent defect size $\sqrt{A'}$. Its effectiveness was confirmed by the fatigue test result of carburized gears made of SCM420 ordinary steel and SCM420 clean steel.

The principal defect, which limited the strength, was inferentially identified so as to evaluate the strength of gears with several kinds of defects such as inclusions, tool marks and nonmartensitic layers.

After removing the surface nonmartensitic layer, the fatigue strength of clean steel gears was 28% greater than that of ordinary steel gears. However, there was no difference in strength in the case when the nonmartensitic layer existed in the surface. These results were explained from the viewpoint of principal defect.

The strength estimated from hardness and residual stress was close to the strength of gears with 30–40 µm defects. ⚙

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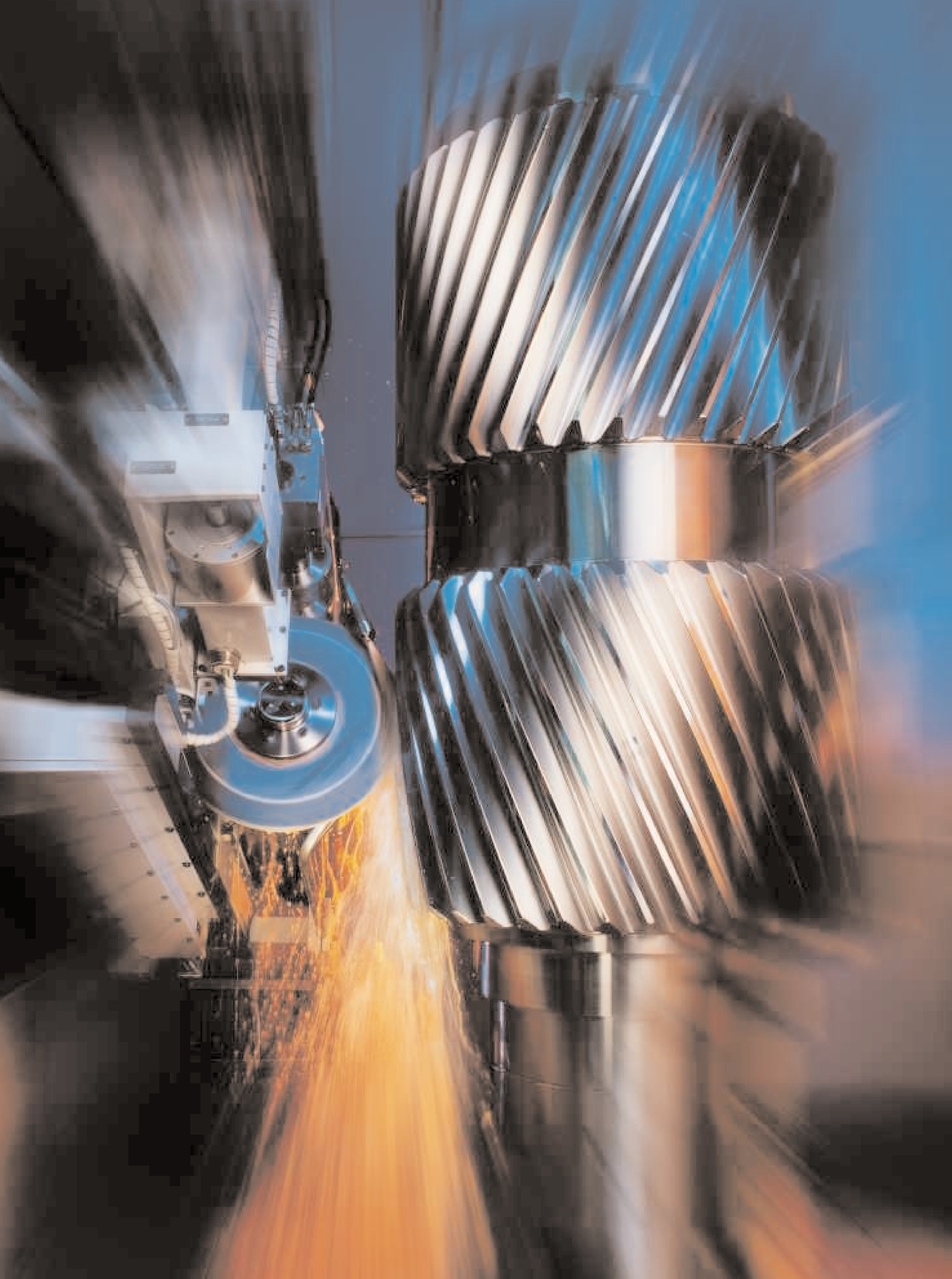

Grinding and Abrasives

Flexibility and productivity are the keywords in today's grinding operations. Machines are becoming more flexible as manufacturers look for ways to produce more parts at a lower cost. What used to take two machines or more now takes just one.

Flexibility is seen in many of the newest model gear grinding machines. Several machine tool manufacturers (Kapp, Liebherr & Samputensili) now offer dedicated gear grinding machines that are capable of either generating grinding or form grinding on the same machine, and the machines can use either dressable wheels or electroplated CBN wheels. On-machine dressing and inspection have become the norm.

Automation is another buzzword in grinding and abrasives this year. Gear manufacturers are reducing their costs per piece by adding automation and robotics to their grinding and deburring operations.

Productivity is being further enhanced by the latest grinding wheels and abrasive technology. Tools are lasting longer and removing more stock due to improvements in engineering and material technology.

All of this adds up to a variety of possible solutions for the modern gear manufacturer. If your manufacturing operation includes grinding, honing, deburring, tool sharpening or any number of other abrasive machining operations, today's technology offers the promise of increased productivity, lower costs and greater quality than ever before.

By William R. Stott

Photo courtesy of Gleason Corp.

ROTARY TRANSFER GRINDER FROM ITM

International Tool Machines of Florida, Inc. (ITM), located in Palm Coast, FL, has introduced a new multi-station grinder, the RTG Rotary Transfer Grinder, a compact grinding cell made up of as many as five precision grinding heads attached by a high-speed rotary transfer mechanism.

The RTG can produce complete gears, worms, cams, splines, shafts, and other ground parts. The machine's concept is to produce a complete workpiece by spreading the grinding operations over up to five different grinding stations on the same machine. The cycle time to produce a ground part is equal to the longest single operation plus transfer time.

For example, the RTG can grind OD, ID, face, threads, gear teeth, lobes, etc., in sequence, without having to remove the part from the machine. According to Kenneth H. Larson, Jr., VP of sales and marketing, cycle time reductions of over 80% are possible when compared with conventional setup and movement between machines.

The multi-station design also allows for improved part quality and longer wheel life because finer wheels and lower feed rates can be used for the shorter grinding operations without affecting the overall cycle time to produce a complete part, Larson says.

The machine can be equipped with a variety of loading options, including cassette, hopper, vibratory, and robotic loading. Options such as in-process gaging, finished part inspection, oversize blank inspection, wheel balancing, wheel dressing, and machine networking are also available. Motor spindles up to 50 hp are available.

To further enhance productivity, Larson says, up to 10 multi-station grinders can be run by a single operator.

ITM manufactures a wide range of grinding machines, including a variety of tool and cutter grinders, as well as their Series 2005 Universal Gear Grinder, which is designed for the high production grinding of gears up to 20" in diameter.

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Today's Flexible Gear Grinders

Form grinding and generating grinding used to be separate processes, requiring separate machines from separate manufacturers. Either you had a form grinding machine or you had a continuous generating grinding machine. Or, if you had applications that required both processes, you needed two or more very expensive, dedicated machines. However, over the past year, Kapp, Liebherr and Samputensili have introduced machines that incorporate both form grinding and generating grinding processes on one machine. In addition, these machines are capable of using either electroplated or dressable grinding wheels.

KAPP KX300P Introduced in 2004, the KX300P features spindle-integrated balancing of the grinding tool, and it comes with on-board gear inspection. The machine can be equipped with a custom-designed automatic loading system.

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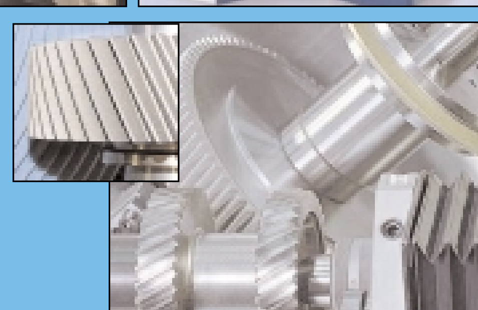
2870 Wilderness Place, Boulder, CO 80301
Phone: (303) 447-1130 • Fax: (303) 447-1131
E-mail: *info@kapp-usa.com* • Internet: *www.kapp-usa.com*

LIEBHERR LCS SERIES With the LCS series, CBN profile grinding can be used for grinding internal gears, either spur or helical. The LCS 300 was introduced at EMO 2003 in Milan.

Liebherr Gear Technology Co.
1465 Woodland Drive, Saline, MI 48176-1259
Phone: (734) 429-7225 • Fax: (734) 429-2294
E-mail: *info@lgt.liebherr.com* • Internet: *www.liebherr.com*

SAMPUTENSILI S CLASS The S class gear grinding machines from Samputensili can grind external gears, shafts, worms or rotors. Besides profile and continuous generating grinding, the machines can also shave grind. The S 250 G was introduced in October at EMO 2003 in Milan. The S class grinders can be equipped with on-board inspection, an external balancing unit and various automation systems for workpiece exchange and storage.



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Staying Competitive Through Automation

Sam Haines, president of Gear Motions Inc., is building what he believes to be the only fully automated gear grinding job shop in the country at the Nixon Gear division in Syracuse, NY. In January, Nixon installed a new Reishauer RZ-400 gear grinder. After a runoff and shakedown period, the machine will soon be equipped with a robot, parts movers and software.

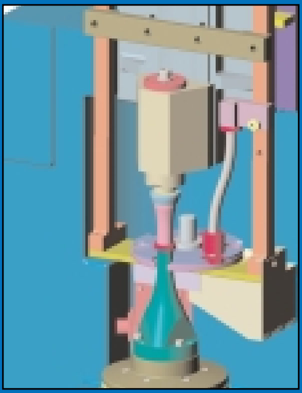
"When we finish this project," says Haines, "we believe we'll be the first job shop in the country with automated gear grinding of this magnitude."

Haines says this latest investment is part of a natural progression for the company, which built its first manufacturing cell more than 10 years ago and which has been working on ways to improve throughput and manufacturing processes ever since.

"In order to compete worldwide, we have to employ more technology," Haines says.

Last year, Nixon Gear spent nearly $750,000 to fully automate the pre-heat treat part cell, which produces gears for the BMW Mini Cooper automobile. That cell includes a fully automated bar-fed turning center and robotically loaded CNC gear hobbing machine, enabling the company to take parts from raw material to pre-heat treating with minimal human intervention, Haines says.

That manufacturing cell allows Gear Motions to produce as many as 2,000 gear sets (4,000 parts) per week, Haines adds.



In addition to buying the latest-model equipment, which Haines says is proving to be about twice as productive as the previous technology, Gear Motions has also been investing time and money into developing robotics systems to make existing machines more productive. Nixon Gear recently completed design and development of a small, inside-the-machine robot system, for its Gleason TAG400 gear grinder. The hard finishing operation for the very small Mini Cooper parts is expected to double production simply by reducing changeover time, Haines says.

Developing automated manufacturing has enabled Gear Motions to develop significant process capability, Haines says. "One of the things we've learned as we employ more technology is that it's not only productive from a time standpoint, but it's improving process capability as well."

Over the past three years, Gear Motions companies have invested more than $3 million in technology. The large gear division, Oliver Gear, in Buffalo, NY, recently installed the new Höfler Helix 700 gear grinder with on-board inspection. On-board inspection helps significantly reduce the time spent moving large, heavy parts to the company's quality lab. Automation on that machine has led to faster setups and greater part yields, according to Oliver's vice president, Mike Barron.

"The investment seems to be paying off for the Gear Motions companies," Haines says. "We were able to emerge from the recent recession with a bottom line *and* move the ball forward for our customers." He says the company has been able to reduce the lead time for its biggest customer down to one week.

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NEW GLEASON-HURTH ZH 200 GEAR HONING MACHINE

Gleason has introduced the ZH 200 gear honing machine, a completely re-designed and re-engineered version of the company's ZH 250 gear honing machine.

The ZH 200 incorporates a direct-drive honing head and headstock to deliver higher accuracies and speeds on workpieces up to 200 mm (7.87"), with maximum tooth widths of 50 mm (1.97"), and module range of 0.5 to 4.5. The ZH 200 can combine its high cutting speeds with an optional, fast, fully integrated gantry loader system, thus offering the potential for significant improvements in overall cycle times.

The ZH 200 has been designed for ease of use, reliability and maintainability in even the harshest environments.

Like the ZH 250, the ZH 200 uses Gleason's patented Spheric® Honing process. This process ensures that every workpiece/tool contact point is precisely controlled, thus significantly improving tooth geometry, run-out and pitch errors, thereby producing a high-quality flank surface with low-noise tooth contact characteristics.

The Gleason-Hurth Spheric® Honing software is fully integrated with the Siemens CNC controller, enabling the operator to create the optimum machining cycle simply by entering the tool and workpiece information. The machine software automatically creates the machining cycle.

Gleason-Hurth also provides the tooling: in this case both the internal gear abrasive honing ring for machining and the diamond dressing tools used to dress the abrasive tooling.

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All On-Board!
Integrated Inspection and Dressing Increase Productivity

Grinding gear teeth used to be a very time-consuming process involving multiple setups and transfer of parts between a gear grinding machine and a gear inspection machine.

Typically, an operator would set up a part to be ground, then grind one flank or tooth space. The part would then be taken off the grinding machine—leaving that machine idle—and taken to a dedicated gear checker or inspection machine for a thorough inspection. If the part passed this inspection, it would be returned to the gear grinder and set up again. When corrections were necessary, additional test spaces would be ground and rechecked before the rest of the cycle would be allowed to run, meaning even more idle time for the grinding machine.

At Overton Gear & Tool of Addison, IL, removing the gear, transfering it and checking it on a gear checker took anywhere from one to three hours, depending on the size of the gear, every time they had to do it, says executive vice president Kevin Walsh. He adds that it was common at Overton to remove the gear three times before the full cycle was allowed to run.

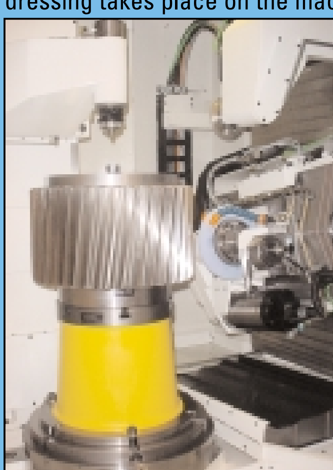
But recently, Overton invested in a NILES ZE800S profile grinding machine sold by KAPP Technologies of Boulder, CO. That machine came equipped with on-board inspection and on-board dressing, two options that are becoming increasingly common on today's gear grinders.

According to Walsh, an operator can use the machine to grind two opposite tooth spaces, inspect them, immediately make corrections, regrind them and retest them.

"It saves hours," Walsh says. "With this machine, we save a significant amount of time in the setup procedure and don't waste nearly as much material in the beginning because of the on-board inspection."

The first gear that is ground still has to be removed from the machine and sent to the lab for inspection, but the company no longer suffers idle time waiting for the results. Operators have enough confidence in the on-board inspection process to grind the next part without having to wait for the inspection, Walsh says. Instead of being idle one to three hours, "The machine continues to run."

Similarly, on-board dressing of grinding tools is a significant advantage. Instead of a separate device and more setups, dressing takes place on the machine. This helps save idle time and improves quality, Walsh says.



The NILES ZE800S.

Overton Gear specializes in short runs and quick delivery of high-quality cut and ground gears for locomotives, off-highway vehicles, wind power turbines, industrial extruders and other heavy machinery. The company can cut either internal or external spur or helical gears from 12 mm (1/2") up to 2 m (80") in diameter, and it can grind internal gears up to 1.2 m (47") and external gears up to 1.5 m (60"). Overton Gear also has its own in-house heat treating facility.

Because of Overton's niche in short runs and its need for quick deliveries, the ability to incorporate on-board inspection is a significant advantage, Walsh says. "We can grind 10 one-piece orders in a three-day time frame. Before it took us three times as long."

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DRAKE GRINDER COMBINES ROUGH/FINISH OPERATIONS

Drake Manufacturing of Warren, OH, has introduced a new 5-axis CNC grinding machine, the GS:G^2, which allows the rough and finish grinding of hardened, pre-cut gears in one operation.

The GS:G^2 employs two grinding wheels, so there's no time lost between rough and finish grinding operations, according to the company's press release.

The machine is equipped with a menu-driven control system that includes Drake's Gear Smart™ programming, which allows part changeovers in 15 minutes or less. The control system can be adapted with additional menu entries for customer-specific applications.

Other features of the machine include CNC contour diamond roll dressing, constant surface speed as the wheel wears, infinitely variable wheel and work speeds selectable for roughing and finishing, and CNC-controlled helix and work rotation.

The GS:G^2 can grind from 0.5 to 8 module (50 to 3 DP), from 25–250 mm (1.0 to 10") pitch diameter, and it can grind gears to AGMA 12 specifications.

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NEW TOOL GRINDER FROM SCHÜTTE LLC

The new WU305 CNC Universal Tool and Cutter Grinder from Schütte LLC of Jackson, MI, allows for the grinding of gear cutting tools and other cutting tools on the same machine. The WU305 features menu-driven software for the grinding of bevel gear stick blades, gear shaper cutters and hobs, according to David Brigham, vice president.

Automated Deburring

A manufacturer of hydraulic pumps in Italy used to spend a lot of time manually deburring gears. Not only did the manufacturer seek a more efficient way to deburr, but the company wanted to improve the surface finish on the shafts and walls of the gears.

The solution was a completely automated deburring cell, designed and manufactured by Dan di De-Antoni s.r.l., also known as Dan Technology, of Coccaglio, Italy.

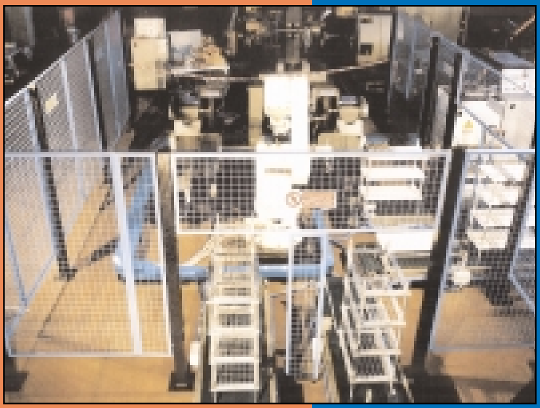
The system deburrs the gears, provides a slight chamfer (edge break) along the tooth edges and superfinishes the walls of the gears (Ra = 0.2 mm) and the shafts (Ra = 0.15 mm).

What used to be done manually is now completely automated for Dan Technology's customer, says Carlos Trujillo, director of sales, marketing and application engineering for the Americas. The system was designed to operate 24 hours a day, seven days a week.

In fact, the deburring cell has a magazine capacity of 8–10 hours, meaning it can run unattended for a full shift. "You may work without labor costs—even on Saturday or Sunday," Trujillo says.

The center of the deburring cell is a deburring machine tool that incorporates a patented system for maintaining constant pressure and speed of rotation of the abrasive wheel on the workpiece, Trujillo says. "Our systems have a lot of accuracy not because of the robots, but because of the technology in the patented Dan units."

The cell includes a robot that manages the magazine of baskets, receiving them, creating stacks and moving stacks with automatic conveyor belts. After the deburring/chamfering operation, the parts move automatically to a parts washing station.



The system can be programmed for different types of gears and different sizes. Systems can also be set up to use brushes for deburring instead of abrasive wheels.

A system similar to the one set up for this pump manufacturer costs in the range of $190,000–$300,000.

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Switching the gear-related tooling to standard cutting tools involves changing the 50-taper tool holding and calling up the software, Brigham says.

Since the WU305 is a standard machine from Schütte, no special machine components or modifications are required to grind gear tools. As an example, the menu-driven software for the regrind or manufacture of stick blades allows the machine operator the flexibility to modify any ratio on the blades being produced.

"This makes the machine an affordable alternative to having to send your gear-related cutting tools back to the manufacturer," Brigham says.

Full factory support for the North American market is located at the Schütte facility in Jackson, MI.

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SUNNEN ANNOUNCES SINGLE-STROKE HONING TOOLS

Sunnen Products Co. of St. Louis, MO, has introduced a new generation of helix plated diamond tools designed for fast stock removal and consistent bore geometry at competitive prices. The Single Stroke Honing® tools can be designed to optimize customer applications.

With Single Stroke Honing, the tools go through the bore only once, removing a predetermined amount of stock, progressively enlarging the bore. According to the company's press release, thousands of bores can be sized with the same tool.

The Single Stroke Honing tools can be used on Sunnen's VSS Single Stroke Honing system or machines manufactured by others. They can be used with either water- or oil-based coolants.

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Internet: *www.sunnen.com*

LONGER LASTING DEBURRING WHEELS FROM CRATEX

Cratex MX abrasive wheels are commonly used in gear deburring operations, says John Rossi, VP sales & marketing for Cratex Manufacturing Co. Inc. of Encinitas, CA. But recently, the company has developed a new generation of the abrasive wheels that provide a number of benefits.

The company's focus has been on developing a completely non-loading, cool working abrasive wheel without sacrificing wheel life, Rossi says. Cratex's research and development effort has produced a new, stronger cotton fiber backing material without the side effects of increased rigidity.

In some cases, the new wheels allow the deburring machine operator to turn off his automatic wheel dresser or his manual timer, Rossi says. "The enhancements achieved are free cutting, non-loading, long lasting abrasive wheels."

Rossi adds that further experiments with single-wheel grain percentages have been successful in developing a process for polishing and deburring in one step.

Cratex MX abrasive wheels are suitable for use on most gear deburring equipment, including Redin, Chamfermatic and others, Rossi says.

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DR. KAISER, RAPPOLD WINTERTHUR ANNOUNCE COOPERATION

Dr. Kaiser dressing tools are now being sold in Austria and Slovenia by agents of Rappold Winterthur Technologie GmbH of Villach, Austria, according to a Rappold Winterthur press release.

Technicians of Rappold Winterthur are being specially trained by Dr. Kaiser as application engineers for Dr. Kaiser's product range.

Rappold Winterthur Technologie GmbH is part of the Rappold Winterthur Group, based in Winterthur, Switzerland.

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SERVICE NETWORK INC. APPOINTS NEW REP.

Service Network Inc. has appointed Kansas-Oklahoma Machine Tools (KOMT) as its exclusive representative for the states of Kansas, Oklahoma, and Missouri. KOMT has offices located in Wichita, KS; Kansas City, KS; Oklahoma City, OK; Tulsa, OK; and St. Louis, MO.

SNI recently introduced two new lines of production grinders, including the SN400-I Internal and the SN200-E External. SNI also offers service, upgrade and remanufacturing of Heald grinders.

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58 Mountain Road
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Internet: *www.sni-grinders.com*

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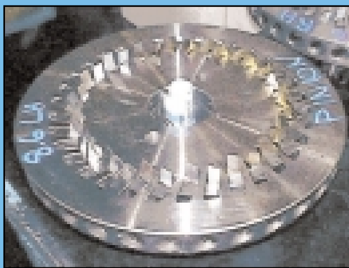
Internet: *www.komt.com*

ANCA DEVELOPS DEDICATED STICK BLADE GRINDER

ANCA, located in Melbourne, Australia, has developed a complete system for manufacturing and reconditioning of bevel gear stick blades. The system includes the ANCA SBG (stick blade grinder) CNC machine, loader, fixtures and dedicated software.



According to the company's press release, the system also includes post-process measurement and compensation, which increases efficiency in setup and grinding of batches with different cross sections and geometries.

The SBG was designed to achieve high accuracy and fast cycle times in order to serve the needs of the manufacturers of hypoid gears for automotive differentials.

The machine is equipped with linear scales, and it comes with a rigid pick-and-place-style loader that is capable of tool change in seven seconds. The system can be equipped with a robotic loader as an alternative automation solution.

The machine uses a 250 mm (10") diameter grinding wheel. Precision is achieved through the use of a Renishaw tool probe, both before and after the grinding session. ANCA guarantees ground parts to within 5 micron (+/- 0.002") profile accuracy.

According to the company's press release, the SBG has been successfully installed at the manufacturing operations of a number of leading automotive suppliers.

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SUNNEN INTRODUCES ML-2000 HONING MACHINE

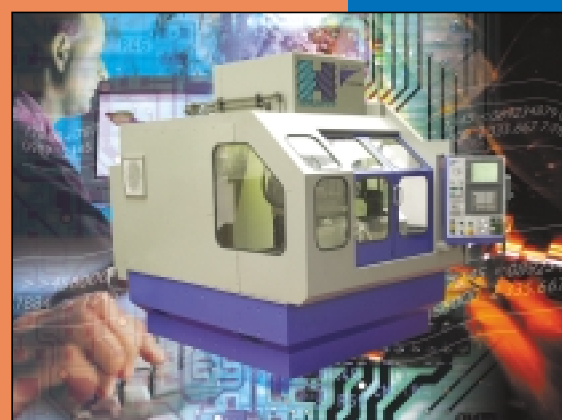
Sunnen Products Co. of St. Louis, MO, announced the introduction of the ML-2000, a new model of the company's power-stroked honing machines. The new

Holroyd Introduces New Turnkey Superabrasive Facility

Holroyd Machine Tools of Milnrow, England, has set up a project team to provide turnkey manufacturing systems to customers for Edgetek superabrasive grinding machines.

"Providing turnkey solutions is what we are good at," says Paul Hannah, director for Edgetek machine sales at Holroyd. "It is something we have routinely undertaken for customers for our range of thread grinding machines."

Edgetek machines use high efficiency deep grinding (HEDG), a process that aims to remove a lot of stock quickly, thus increasing productivity. According to Holroyd, the specific removal rates range from 50–2,000 mm^3/mm/second, much higher than the 0.1–10 mm^3/mm/second associated with creep feed grinding. Also, the process is intended to be used on hardened parts and has been successfully implemented on difficult-to-machine materials, such as nickel-based steels common in aerospace applications and powdered metals used for timing gears and sprockets in car engines.



"We've seen at least a 40–50 percent increase in throughput on every job we've done, and in many cases, it is much, much more," Hannah says. "In one recent U.K. application, a single 5-axis Edgetek suprabrasive machine replaced seven conventional milling and grinding machines, providing a reduction in the throughput time for a complex finished part from 8 hours to just 12 minutes."

HEDG uses CBN abrasives, which offer high thermal conductivity to remove heat from the grinding process, and the machine tools are designed for rigidity and high spindle speeds. The machines are built on a granite polymer base and column. The base typically weighs 3 tons and has no resonant frequency, according to Holroyd.

"With our new service, we undertake to engineer our customer's complete process on an Edgetek machine, typically integrating automatic loading facilities, measuring machines for SPC, washing machines for parts cleaning, coolers and filters, design fixtures, work benches—in fact, anything that the customer requires," Hannah says.

Holroyd Machine Tools
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Phone: + (44) (1706) 526590
Fax: + (44) (1706) 353350
E-mail: *phannah@holroyd.renold.com*
Internet: *www.holroyd.com*

machine is designed specifically to meet the needs of job shops and mid-volume production applications.

According to the company's press release, the ML-2000 has twice the power and more speed than older Sunnen MBC-style honing machiens. All setup is accomplished through computer control. There are no belts or pulleys to change.

The machine can be equipped with an optional automatic size control feature, which allows better control of bore size, finish and geometry. With this feature, the honing cycle automatically stops when the bore is to size.

The ML-2000 provides an alternative to I.D. grinding and other finishing processes. Because of its stock removal rates, preliminary reaming, boring or grinding can be eliminated on many operations, according to the release.

Sunnen Products Co.
7910 Manchester Ave.
St. Louis, MO 63143
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Internet: *www.sunnen.com*

KAPP EXPANDS SALES CHANNELS

KAPP Technologies of Boulder, CO, is now offering CBN-plated wheels to be used with or without a KAPP form grinding machine.

"We are excited to be able to supply CBN-plated grinding wheels to the entire gear and form grinding industry," says Tom Lang, vice president and general manager of KAPP Technologies. "This opens up new markets to us and gives us the opportunity to work with customers who before now couldn't use our wheels because they didn't use KAPP machines.

KAPP manufactures high-precision, galvanically plated CBN and diamond tools. In the past, KAPP sold its tools with its machines to provide a complete customer-focused, turnkey machining process. KAPP's products include CBN-plated form grinding wheels for discontinuous profile grinding of involute gears, rotors and other special profiles. KAPP form grinding wheels can produce both internal and external profiles.

KAPP also manufactures CBN-plated cylindrical worms and diamond-plated Coroning™ tools. The worms are used for continuous generating grinding of involute gears. The Coroning rings are used for continuous honing of involute gears.

"Now all gear manufacturers, regardless of machine type, can take advantage of our quality and delivery," said Lang. "Others advertise delivery of CBN wheels within weeks; our standard is 10 days."

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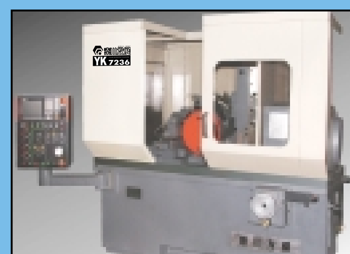

NEW CNC GRINDERS FROM CHINA

Shaanxi Qinchuan Machinery Development Co. Ltd. of Shaanxi, China, has announced two new models of CNC gear grinding machines.

The 8-axis (5-axis simultaneous) YK7250 CNC uses worm wheels for continuous-generating grinding of gear teeth. According to the company's press release, the machine is suitable for either single workpiece or batch production.

The YK7250 comes with CNC-controlled worm wheel dressing, electrostatic oil mist collection, temperature control system and dynamic balancing of the grinding wheel. It is designed for grinding gears from 100–500 mm diameter, from 2–8 module and face width up to 200 mm.

The company has also developed a new model of gear grinding machine specifically designed for internal gears. The 4-axis YK7550 CNC gear grinding machine is designed to meet the needs of manufacturers of planetary gear reducers, internal combustion engines, gas turbines and other equipment that requires internal gears.

Shaanxi Qinchuan Machinery Development Co. Ltd.
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E-mail: *qinchuan@qinchuan.com*
Internet: *www.qinchuan.com*

PRECISION DEEP GRINDING OF GEARS

Companies in the Czech Republic and Russia have developed a new method for grinding gears, according to the Eureka project, a Belgium-based research & development network that strives to foster international coopration in a variety of technology-based fields.

The new technology uses precision deep grinding using form-grinding wheels made by fusing abrasive grains of alumina corundum and silicon carbide to the surface of the tool with strong ceramic bonds.

"We developed various formulae for new high-porosity tools and conducted industrial tests in 14 Russian factories," says professor Viktor Starkov, director of the Research Centre at the Moscow State Technological University "Stankin."

The new tools and process produce higher quality gears and increase productivity, says Josef Frumar, production manager at Carborundum Electrite, a partner in the project and manufacturer of grinding wheels from the Czech Republic. Carborundum Electrite carried out most of the trial testing of the new technology.

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Tovarni 1
294-71 Benatky Nad Jizerou
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NEW WORM GEAR GRINDING MACHINE FROM DOIMAK

The RER-W Series grinding machine from Doimak is designed for machining worm gears of any type of profile (ZK, ZN, ZE, ZA) and multiple starts. In addition, it can machine worm gears of variable lead and constant diameter as well as those of variable diameter and constant lead. Features include CNC-controlled wheel-head tilting up to +/- 30° and automatic calculation of the wheel profile and dressing path.

Great Lakes Gear Technologies
8755 Ronda Dr.
Canton, MI 48187
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Winds of Change in Profile Grinding

by Michael T. Hayes

Recent breakthroughs in profile grinding software are helping Anderson Precision Gears and others meet wind power's insatiable appetite for faster production of large, high-quality gears.

Stand out in the open on the Scottish Highlands or on a golf course or beach along the North Sea for any length of time, and you'll understand why Scotland is considered one of the world's fastest growing and most promising renewable energy markets. The British government has estimated that construction of a new £1 million wind turbine must be completed every day for the next seven years to meet the country's ambitious renewable energy target—all part of the European Union's 2010 objective of producing 22% of its electricity using renewables.

Companies like Anderson Precision Gears (APG) of Motherwell, United Kingdom, are gearing up to get a piece of this business, knowing full well that hundreds of wind turbine gearboxes multiplied by thousands of gears equals, well, you do the math. APG managing director Willie Wales and APG sales and marketing director Ian Kinstrie evidently have, because they've just made a significant investment in a Gleason-Pfauter P 2000 G.

"With gearboxes accounting for fully 20% of the total cost of a wind turbine, gearbox manufacturers are keen to take cost out of the gear production process," says Wales. "But complicating matters is the size of these gears and the need for very high quality, since reliability is an enormous concern. These wind turbines are often installed in the most remote locations and operate under adverse and extreme temperature and wind conditions."

The Gleason-Pfauter P 2000 G

New frontiers, revolutionary software. Gleason has unveiled new profile grinding software, driven by the latest Siemens 840D CNC, for its new-generation Gleason-Pfauter profile grinders. According to Gleason product manager Richard Scoda, the new software reduces non-productive time—a disproportionately large and costly part of overall part processing that has defied big improvements. The approach taken by Gleason Pfauter reduces the "dead time" in the cycle through adaptive control. The machine knows where the grinding wheel is and moves quickly when there is air between the wheel and gears.

"New grinding wheel compounds and grades, combined with improvements in machine kinematics, have optimized the grinding cycle to the point where only incremental improvements can be made," says Scoda. "We're now machining about as fast as we can with current wheel technology. That leaves nonproductive time—setup, cutting air, inspection—as the areas still left where we can make a big impact on cost per piece and quality. The new software is a big part of that process."

Setup measured in minutes vs. hours. Among the benefits to end-users like APG is Gleason's new patent-pending software, which automatically compensates for clamping misalignments and eliminates the possibility of both radial eccentricity and axial runout after the setup.

Traditionally, manual setup can take four, even five times as long as the actual machining cycle, as the operator, using a dial indicator and rubber hammer, painstakingly bangs a part into a centered position relative to the table and machine axes.

The software, combined with a special measuring device and the calculating power of the CNC unit, initially determines the position of the part after clamping and then compensates for actual eccentric or oblique positioning using the machine's five axes during machining.

Willie Wales, managing director, and Ian Kinstrie, marketing director, of Anderson Precision Gears.

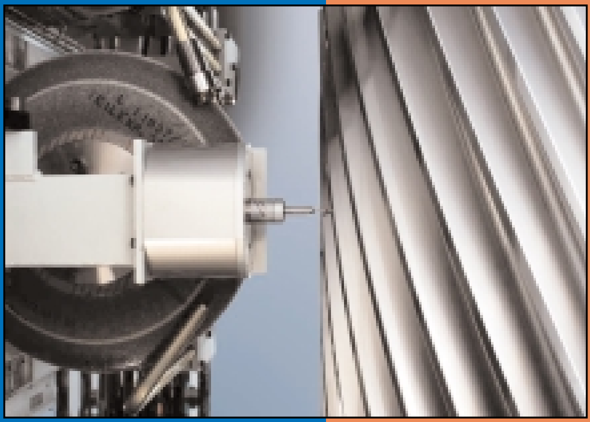
"An investment in the latest technology, while sizable, is the only way we know of to achieve our future growth potential in the world of big gear production.'"
—Ian Kinstrie, Marketing Director, Anderson Precision Gears

Cutting cycle times, not air. Using Gleason's new Adaptive Process Control software, APG will also be able to squeeze out additional savings in its actual cycle times, by greatly reducing the cutting of air.

"Typically, the grinding cycle is programmed based on the pre-determined size of a 'perfect gear,' but the distortion caused by heat treat makes this difficult to accurately determine," says Scoda. "As a result, the grinding wheel might not be actually in contact with the tooth flank as much as we think, so that the cycle might take longer than it needs to, and dressing intervals might be more frequent than required, given how much material is actually removed."

Gleason's Adaptive Process Control system can actually detect when there is no contact between the grinding wheel and the workpiece flank during axial infeed, and then a higher axial feed rate kicks in. The normal feed rate is used only when the grinding wheel is engaged. This dynamic adaptation of the axial feed rate to actual part size after distortion ultimately can save many minutes of cycle time on a large part.

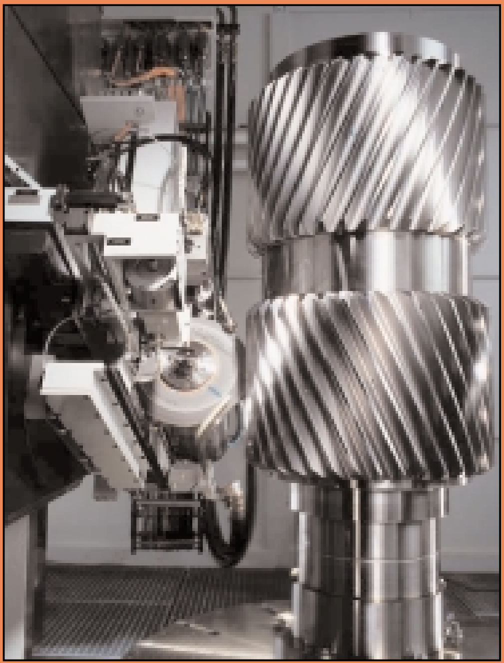
Dual-flank speed, single-flank flexibility. The P 2000 G software also will give the machine the ability to perform dressable grinding of both tooth flanks simultaneously—a normal procedure on basic, identical involute profiles—but with the flexibility to grind special profiles on one of the flanks at the same time. According to Scoda, this is particularly vital in the hard finishing of gears for wind turbine gearboxes. "Creating a special tooth twist for optimum contact conditions is critical in wind power in order to compensate for the enormous loads placed on these gears and make them more reliable," Scoda says. "Now you can do what normally could only be done with single-flank grinding, but at dual-flank production rates."



Other features of the P 2000 G include an integrated Windows®-based user interface, fully automatic stock division, on-machine dressing with automatic compensation for wheel wear, the ability to use either vitrified or plated CBN wheels, a built-in grinding technology database, K-chart inspection and the ability to grind both external and internal gears.

The ability to finish internal ring gears is a key capability, according to Kinstrie, since planetary gear systems are the most common found in wind turbine gearboxes.

Kinstrie is optimistic about his company's chances at expanding its wind power business throughout the U.K. and Europe, while further improving its product offering to traditional markets like mining, earthmoving, aerospace and rail. "This new Gleason-Pfauter technology meets the need for faster production and better quality, the watchwords in all of these industries today," he says. "An investment in the latest technology, while sizable, is the only way we know of to achieve our future growth potential in the world of big gear production."



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TECHNICAL CALENDAR

May 11–13—ABAR-U. Ipsen International Inc., Rockford, IL. Attendees learn the fundamentals of heat treating, pumping systems and pumps and step-by-step procedures for operating vacuum furnace equipment. For more information, contact Ipsen International by telephone at (815) 332-4941 or by e-mail at *DLN@abaripsen.com*.

May 11–13—Grinding Principles & Practice. TechSolve facility, Cincinnati, OH. Topics include principles and types of grinding, control and predictability of grinding operations, grinding wheels, grinding relationships and engineering, part cooling, surface vibration and more. $895. For more information, contact TechSolve on the Internet at *www.TechSolve.org*.

June 7–9—AGMA Gear Manufacturing Technology Course. Star-SU facility, Hoffman Estates, IL. Aimed at all levels of gear manufacturing personnel from operators to engineers, this class is focused on troubleshooting the manufacturing process from basic principles. Later this year, this course will also be held in California and North Carolina. $750. For more information, contact Gear Consulting Group by telephone at (269) 623-4993 or by e-mail at *gearconsulting@aol.com*.

June 8–9—Theory of Geometry and Strength Calculations for Gears: Gear Design Determination and Optimization. KISSsoft facility, Zurich, Switzerland. This seminar explains the basis for strength calculations according to ISO 6336 and gives participants the opportunity to implement the knowledge on PCs. Topics covered include geometry of gears, manufacturing tolerances, non-involute tooth forms, strength calculation for gears and for non-involute forms. Seminars will be held in English and in conjunction with an overview of *KISSsoft* and shaft/bearing calculation software on June 7 and *KISSsys: Modeling of a System of Machine Elements* on June 10. €400. For more information, contact KISSsoft by e-mail at *info@kisssoft.ch*.

June 8–10—Centerless Grinding Principles. TechSolve facility, Cincinnati, OH. A companion course to the company's Grinding Principles & Practice, this seminar covers roundness generation, chatter and vibration, thermal considerations and process design. $895. For more information, contact TechSolve on the Internet at *www.TechSolve.org*.

June 21–25—Basic Gear Fundamentals Course. Gleason Corp., Loves Park, IL. This program is designed for individuals seeking a basic understanding of gear nomenclature, geometry, manufacturing and inspection. $895 includes handbook, materials, a group dinner and lunches. For more information, contact Gleason Corp. on the Internet at *www.gleason.com.*

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A Model of the Pumping Action Between the Teeth of High-Speed Spur and Helical Gears

C. Milian, J.P. Distretti, P. Leoni, and P. Velex

Summary

With the evolution of the high-speed gearbox market for high-power turbo units, mesh velocity is increasing year after year.

For a high-speed gearbox, an important part of power losses is due to the mesh. A global estimation is not possible and an analytical approach is necessary with evaluations of three different origins of power losses: friction in mesh contact, gear windage and pumping effect between teeth.

This article thoroughly explains the last subject. The theoretical model, which is developed, is a useful tool for analyzing the physical effect of pumping in mesh. It can be used to optimize the choice of the gear parameters that influence heat generation and predict temperature distribution along the teeth for the design of thermal lead corrections.

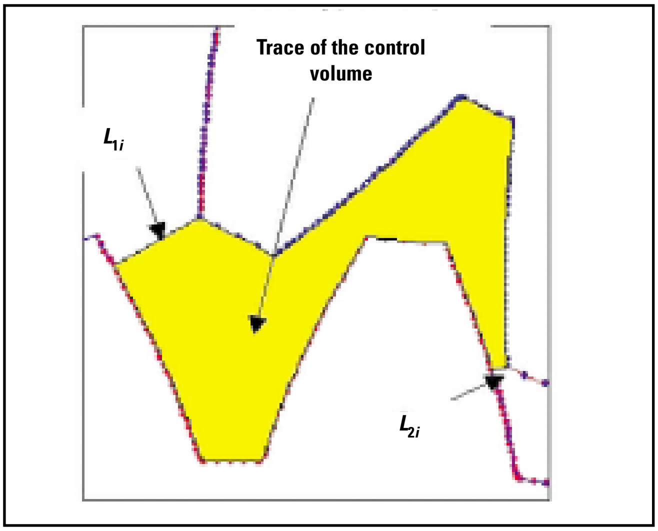

Figure 1—Definition of the control volume and exit flow areas.

Abstract

An approximate one-dimensional hydrodynamic analysis of the air-lubricant pumping between gear teeth is presented. Assuming an isentropic compression and considering the air-lubricant mixture as a perfect gas, the continuity equation is applied to the control volume limited by the surfaces of the teeth. Once critical conditions are reached, the exit flows are bounded and the gas in the control volume is compressed and heated. The temperature variations along the tooth face delivered by the model compare favorably with those measured on two industrial turbo-gear sets. It is therefore concluded that the proposed approach can provide useful indications at the design stage on the air-lubricant compression between the teeth and on related heating problems.

Introduction

The gear temperature and temperature distribution are important parameters for the evaluation of scoring and scuffing risks as well as tooth load distributions across face widths. However, the mechanism of heat generation and cooling by the lubricant in wide-faced, high-speed geared transmissions remains one of the lesser understood phenomena related to gear design. During the time period in which a tooth first crosses the addendum cylinder and proceeds to fill up most of the volume between the teeth, a fraction of the air and the lubricant in the tooth space is expelled from the gear.

The time duration of a mesh period in turbo-machinery is extremely short, and the air-lubricant mixture can be significantly compressed and heated. Rosen (Ref. 1) computed the velocity of the air flow in spur gears using an incompressible flow theory and found that the air velocity approaches sonic conditions for a particular gear set, and this corresponded to an experimentally observed rise in noise. Smith (Ref. 2) notes that noise can be generated when oil is trapped in the roots of wide-faced gears, and the acoustic measurements of Houjoh and Umezawa (Ref. 1) led to the conclusion that the pulsating flow from the gear pumping action can be a significant noise source.

The thermal issues associated with fluid being expelled between the teeth are discussed in the classic handbooks of Buckingham (Ref. 4) and Dudley (Ref. 5). Pechersky and Wittbrodt (Ref. 6) have presented incompressible and compressible fluid flow analyses between meshing spur gear teeth, and they found substantial pressure and temperature rises. Butsch (Ref. 7) developed a compressible flow model for spur gears and showed that sonic conditions can lead to compression and heat generation in the air-lubricant mist. In a series of papers, Matsumoto et al. (Ref. 8–9) have analyzed thermal behavior of high-speed helical gears and obtained uneven temperature distributions along tooth faces in accordance with their experimental findings.

The objective of this article is to present a simplified hydrodynamic analysis of the pumping action resulting from the meshing of wide-faced helical gears. Compressible flows are considered, and the fluid velocity, pressure and temperature along the face width are estimated. The calculations require a detailed analysis of involute and helical geometries in order to determine the proper mesh region volumes and exit flow areas. The agreement between the measured temperatures on two different gear sets and the predicted figures is reasonable and proves the interest of the proposed method at the design stage.

Hydrodynamic Model

The equations for the fluid velocity, pressure and temperature are derived by applying the continuity equation for a perfect gas to a time-varying control volume. Considering an isentropic transformation, one gets:

$$\frac{dp}{p} = \gamma \frac{d\rho}{\rho} \qquad (1)$$

where p is the pressure, ρ the fluid density and γ the isentropic coefficient ($\cong 1.4$).

The control volume V, i.e., the inter-tooth volume, varies during rotation. It is bounded by the flanks of two adjacent pinion teeth, their bottomland and the surface of the meshing gear tooth (Figure 1). One-dimensional flow is assumed (Ref. 6) and the integral form of the continuity equation applied to the control volume V reads:

$$\frac{\partial}{\partial t}\int_{(V)} \rho dV + \int_{(S)} \rho v.ndS = 0 \qquad (2)$$

with v as fluid velocity with respect to the exit surface S and n as unit vector to S.

Assimilating a helical gear to a series of staggered spur gears, the hydrodynamic model for the pumping effect between the teeth is made of a succession of discrete fluid pockets, each with constant state variables (Figure 2). If one elemental spur gear (or one pocket) is isolated, the air-lubricant mixture is ejected through the time-varying inter-tooth clearances L_{1i}, L_{2i} and across the axial discharge front and rear surfaces perpendicular to the apparent plane. Three different cases have to be distinguished: i) the first pocket in the direction of the meshing progress (pocket 1) which is connected to the ambient at one side and to pocket 2 at the other side, ii) any generic pocket i linked to pockets i–1 and i+1, and iii) the extreme one (pocket N) in connection with pocket N–1 and the ambient.

For any pocket i, Equation (2) is discretized as:

$$\rho_i \frac{dV_i}{dt} + V_i \frac{d\rho_i}{dt} + \alpha\rho_{i-1} S_{Ai-1} U_{Ai-1} + \delta\rho_{i+1} S_{Ai+1} U_{Ai+1} + (S_{Ri1} + S_{Ri2})U_{Ri} = 0 \qquad (3)$$

which, after multiplying by $\frac{1}{\rho_i V_i}$ and introducing (1) is finally rewritten as:

$$\frac{1}{V_i}\frac{dV_i}{dt} + \frac{1}{\gamma P_i}\frac{dP_i}{dt} + \frac{1}{V_i}\left(\frac{P_e}{P_i}\right)$$

$$[\alpha\rho_{i-1} S_{Ai-1} U_{Ai-1} + \delta\rho_{i+1} S_{Ai+1} U_{Ai+1} + (S_{Ri1} + S_{Ri2})U_{Ri}] = 0 \qquad (4)$$

with:

P_i :	pressure in pocket i
P_e :	ambient pressure
S_{Ai-1}, S_{Ai+1} :	axial discharge areas
S_{Ri} :	radial discharge area
U_{Ai-1} , U_{Ai+1} :	axial speeds
U_{Ri} :	radial speed
V_i :	instantaneous volume of pocket i

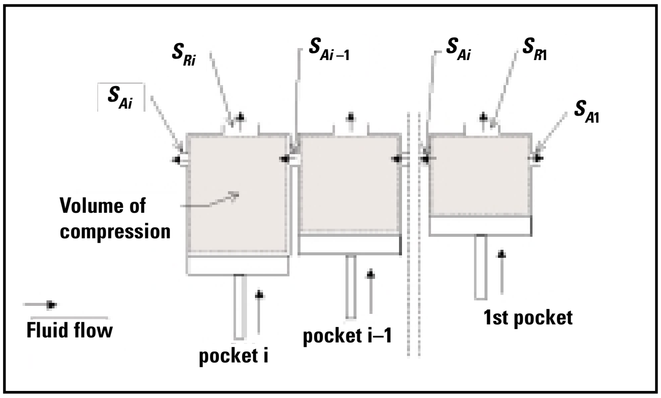

Figure 2—Discrete hydrodynamic model for helical gears.

Table 1—Gear data (Example for the calculation of radial clearance and axial exit area).		
Tooth number	47	103
Module (mm)	6.8	
Pressure angle (°)	22.5	
Helix angle (°)	0	
Profile shift coefficient	0.291	0.322
Addendum coefficient	1	1
Dedendum coefficient	1.475	1.474

P. Leoni *is the managing director of the high-speed gearbox division of Flender Group in Illkirch-Graffenstaden, France.*

Phillipe Distretti *is an engineer and the R&D manager of Flender-Graffenstaden.*

Phillipe Velex *is a professor at the engineering school INSA, in Lyon, France. He's working in LaMCoS, a research laboratory in Lyon, and specializing in tribology and gears.*

Cedric Milian, *a mechanical engineer, is working in R&D at Flender-Graffenstaden.*

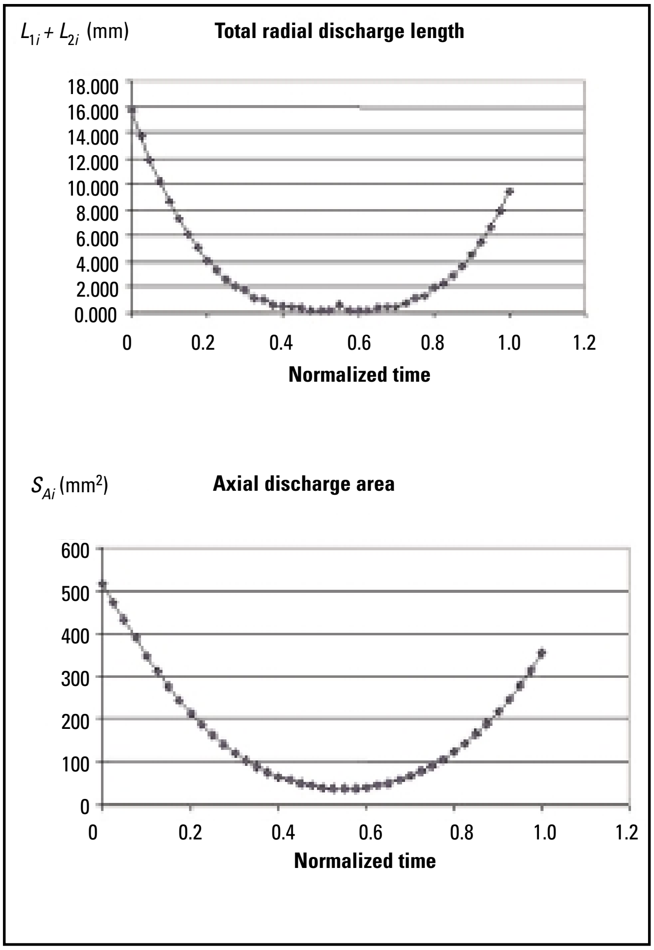

Figure 3—Evolution of radial clearances and axial exit area.

Figure 4—High speed test rig.

Table 2—Gear Data (Case 1).		
Tooth number	47	117
Module (mm)	7	
Pressure angle (°)	20	
Helix angle (°)	12.75	
Profile shift coefficient	0.16	0.05
Addendum coefficient	0.9919	0.9925
Dedendum coefficient	1.47921	1.47885

$$\alpha = 0 \text{ if } i = 1,\ \alpha = -\left(\frac{P_e}{P_i}\right)^{\frac{-1}{\gamma}} \text{ if } i \neq 1$$

$$\delta = 1 + \left(\frac{P_e}{P_i}\right)^{\frac{-1}{\gamma}} \text{ if } i = 1,\ \delta = \left(\frac{P_e}{P_i}\right)^{\frac{-1}{\gamma}} \text{ if } i \neq 1 \text{ and } N,$$

$$\delta = 1 \text{ if } i = N$$

Connections between the different volumes are ensured by writing the conservation of mass flow at all interfaces between any pair of pockets. Equation (4) is a non-linear differential equation of major unknown P_i, pressure in pocket i. $\frac{1}{V_i}\frac{dV_i}{dt}$ as well as the exit surfaces S_{Ai-1}, S_{Ai+1}, S_{Ri} depend on the relative position of the meshing gears and pinion teeth and have to be evaluated step-by-step in time. The involute profiles of the teeth of the pinion and the gear at one arbitrary initial position are discretized. The axial discharge area S_{Ai} is obtained by numerical integration, and clearances L_{1i}, L_{2i} are set to be the minimum distance between the tip corners of gear teeth and the pinion profiles (Figure 1). The volume V_i and the flow areas associated with an elemental spur gear (or pocket) of width b are deduced by:

$$V_i = S_{Ai} b \tag{5-1}$$

$$S_{Ri1} = L_{1i} b \quad S_{Ri2} = L_{2i} b \tag{5-2}$$

The profile coordinates are recalculated after rotating the pinion of an angle $\Delta\theta_p = \Omega_1 \Delta t$ and the gear of the corresponding angle $\Delta\theta_g = \Omega_2 \Delta t$. The volume, the exit areas and the volume time-variation for all pockets are then determined by using (5-1), (5-2) and $\frac{dV_i}{dt}$ and $\frac{V_i(t+\Delta t) - V_i(t)}{\Delta t}$. For one elemental spur gear, Figure 3 represents the evolution of the total inter-tooth clearance $L_{1i} + L_{2i}$ along with the volume V_i over one complete pumping stroke (the gear data are in Table 1).

Temperature, fluid density and mass flows are derived from the following equations for perfect gases:

$$T(t) = T(t-\Delta t)\left[\frac{P(t-\Delta t)}{P(t)}\right]^{\frac{1-\gamma}{\gamma}} \tag{6-1}$$

$$\rho(t) = \rho(t-\Delta t)\left[\frac{P(t-\Delta t)}{P(t)}\right]^{\frac{1}{\gamma}} \tag{6-2}$$

$$Q(t) = \rho(t)U(t)S(t) \tag{6-3}$$

The mass flow $Q(t)$ through any surface $S(t)$ has to be compared with the maximum value, which can be expelled, i.e., the mass flow for sonic (critical) conditions (Ref. 7).

$$Q_{\max}(t) = \frac{1}{r}\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \sqrt{\frac{2\gamma r}{\gamma+1}}\ \frac{P(t)}{\sqrt{T(t)}}\ S(t) \tag{7}$$

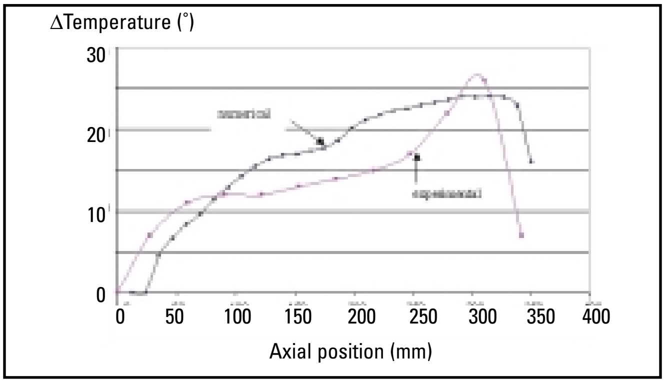

Figure 5—Temperature variations versus axial position—Case 1.

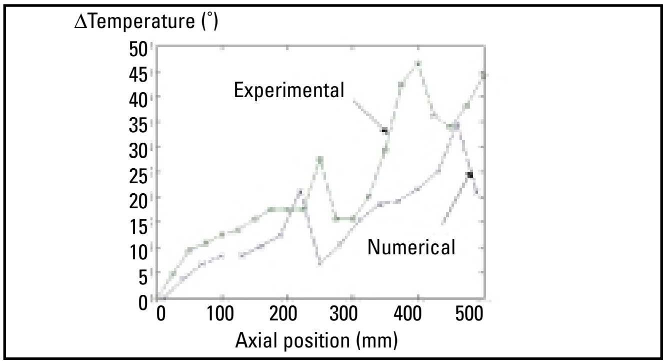

Figure 6—Temperature variations versus axial position—Case 2.

with $r = R/M$ as fluid constant, R as molar constant (8.3144 J.mole^{-1} K^{-1}) and M as molar mass.

If the calculated output flow exceeds the critical value Q_{max} (t), the fluid between the teeth is compressed and its state variables are re-evaluated iteratively by using a Newton-Raphson technique until the continuity equation and the critical mass flow condition are simultaneously satisfied.

Experiments on High-Speed Gear Sets

The test-rig is an open-loop, single-stage reduction system (Figure 4). The gears are lubricated by jets, and shafts are mounted on hydrodynamic bearings. Power is supplied by a 1500 kW electric motor, which operates the test stand through a speed multiplier from 0 rpm to a maximum speed of 26,000 rpm on the input shaft. In what follows, all tests were conducted in no-load conditions. Two gear sets were tested (data is given in Tables 2 and 3) at high-speed, respectively 9,267 rpm (Case 1) and 8,962 rpm (Case 2) on the pinion shaft.

It can be shown that, for high-speeds, the temperature distribution in the gear teeth does not depend on the angular coordinate. Since longitudinal tooth modifications are the major concern of the present work, only axial temperature distributions have been measured. Temperatures were sensed by several thermocouples along the face width as shown in Figure 4. The thermocouple heads were located at a distance of approximately 1 mm from the tooth topland. In such conditions, the absolute temperatures within the air-lubricant mixture or at the tooth surface cannot be obtained, but it is believed that realistic relative variations can be derived. Figures 5 and 6 show the experimental temperatures versus axial positions and the corresponding numerical results. The pumping of the fluid between the teeth leads to over-

Table 3—Gear Data (Case 2).		
Tooth number	52	79
Module (mm)	6.8	
Pressure angle (°)	22.5	
Helix angle (°)	10	
Profile shift coefficient	0.198	0.21
Addendum coefficient	0.9891	0.9894
Dedendum coefficient	1.47469	1.47507

heating of the gear side close to the trailing edge, which, in Case 2, probably distorts mating teeth and imposes longitudinal shape modifications. It is also shown that a groove at mid-face width interrupts the compression process and reduces heat generation along the face width. For the two examples, a reasonable agreement is observed on the relative temperature distributions, and it is proven that the proposed simplified approach brings useful qualitative indications in terms of the system sensitivity to the compression-heating mechanism.

Conclusion

A one-dimensional approximation of the air-lubricant flow caused by the meshing of high-speed, wide-faced helical gears is presented. The results show that fluid velocity can reach high rates and, in certain cases, sonic conditions can be obtained. The air-lubricant flow is therefore compressed and heated along the axial direction. The theoretical predictions have been compared with the experimental evidence from two turbo-gear sets. It is found that the simulated relative temperature variations across tooth faces agree reasonably well with the measured data. In the context of tooth lead modifications, the proposed model can bring useful indications on modification design and on the influence of changing geometrical gear parameters. However, the model discussed in this paper is based on several important approximations, the most important being the assumption of one-dimensional flow through discrete elements. Further research is under way in order to relax these approximations and consider continuous flows between moving boundaries.

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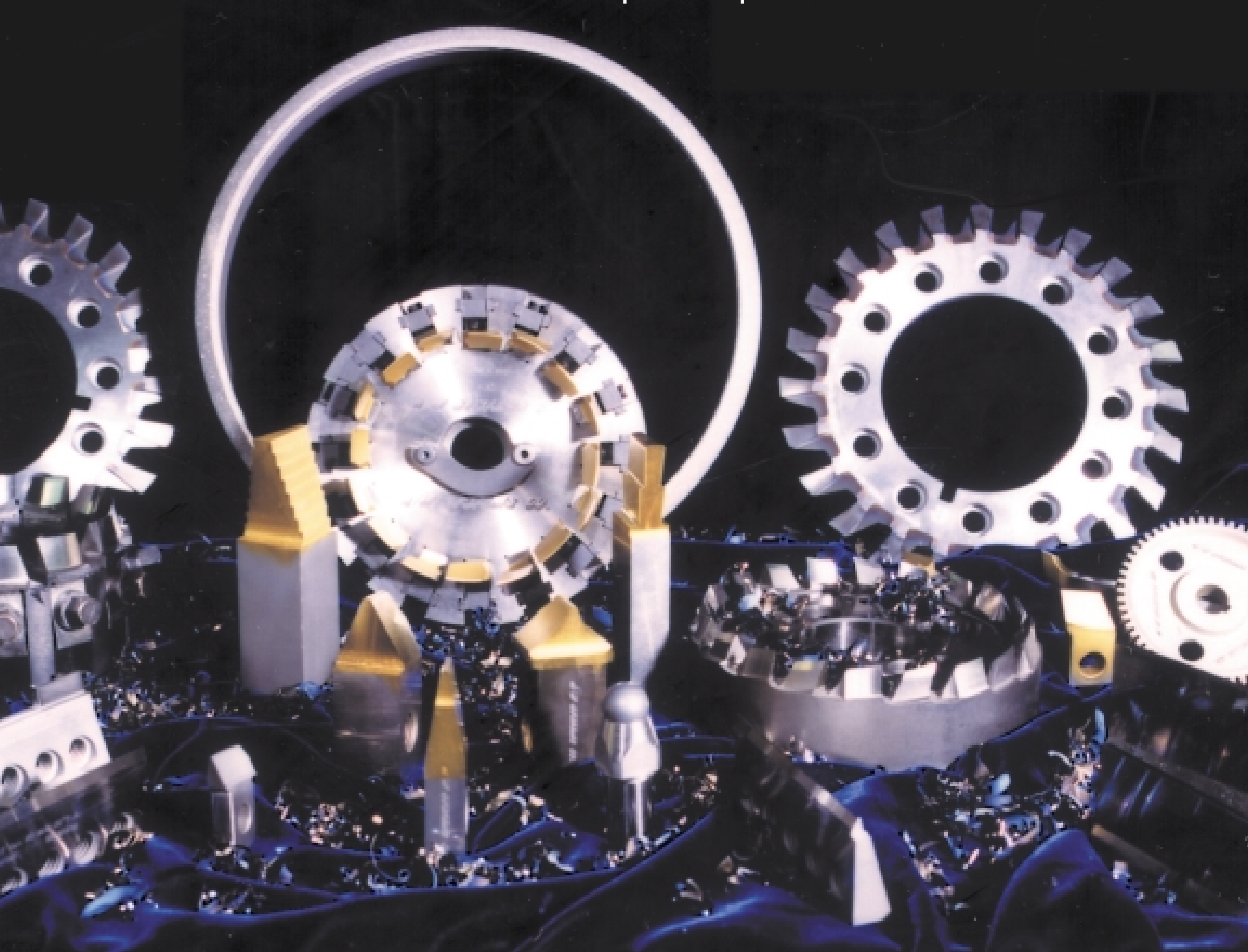

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Comparison of Rating Trends in AGMA Versus ISO

Octave A. LaBath and Dennis Richter

Summary

As the international business community grows closer together, the need for understanding differences between national and international gear rating standards becomes increasingly important for U.S. gear manufacturers competing in the world market.

In the international gear business, the ISO 6336 rating standard is gaining more acceptance across many industries and markets. This is important to U.S. gear manufacturers as it can affect not only the ratings on existing designs that form the basis for a company's standard line of units, but can also dictate the basic design philosophy of sizing a new gear design.

Using an AGMA-developed software package to compare the ratings for gears by the ISO and AGMA methods shows how the AGMA and ISO standards differ as various parameters are changed.

The gear parameters studied include profile shift/addendum modification coefficient changes, helix angle changes and pressure angle changes. Since this comparison is for rating trends instead of actual ratings, they were normalized for each rating method. The article indicates how each rating standard could alter the design for the same gearbox.

This article is condensed from AGMA Paper 02FTM10, which was presented at the AGMA Fall Technical Meeting in St. Louis on October 22, 2002. Copies of the original paper are available from the American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, VA 22314. Visit *www.agma.org*.

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currently the sole proprietor at Gear Consulting Services, has more than 40 years of experience in the gear industry. He was vice president of engineering at Cincinnati Gear Co. until 2001. He received an AGMA Technical Division award in 1982 and is now chairman of AGMA's epicyclic enclosed drives committee.

Many people have made comparisons of the differences in ratings between AGMA rating methods and ISO rating methods.

In 1977, G. Castellani (Ref. 1) was the first to point out that there was a difference in the rating trend on spur gears when you change from standard gears to those with a profile shift.

In an ASME paper (Ref. 2) presented in 1980 by Imwalle, LaBath, and Hutchenson, the comparisons of AGMA and ISO ratings for 54 different gear sets were studied. In some cases, large differences were calculated.

In an AGMA paper (Ref. 3) presented in 1981, LaBath compared the change in calculated stresses for three sample gear sets as a function of the profile shift and one sample as a function of the helix angle.

The above study on the difference in trends for corrected gears and different helix angles was included in another AGMA paper (Ref. 4) also presented in 1981, by Imwalle and LaBath along with a study on 156 gear sets.

In the latter two papers, Imwalle and LaBath showed that, with a positive profile shift, the strength rating increases in AGMA and ISO, but with different magnitudes. With a negative profile shift, the AGMA strength rating decreases and, depending on the gear geometry, the ISO strength rating can go down or sometimes remain almost constant. The durability ratings also had different trends for AGMA and ISO.

The comparisons in the three papers by Imwalle, LaBath, and Hutchenson were based on computer programs written at The Cincinnati Gear Co. for the then-current AGMA rating standards and the draft ISO standards. They were based on the interpretation of the various standards by the engineers at Cincinnati Gear.

In a 1989 AGMA paper (Ref. 5), Dr. Hosel also reported that the rating trends were different for AGMA and DIN (ISO) with respect to the effect of profile shift on the ratings.

In a 2002 paper prepared for NREL (Ref. 6), Robert Errichello compared the different rating trends for AGMA and ISO. The durability rating trend for AGMA and ISO with respect to profile shift was almost the same for a spur gear sample. The strength rating trend was significantly different for the spur gear example. Errichello showed that the trends for both the strength rating and the durability rating were different for a helical gear example. He also showed that there was a difference in trends from AGMA and ISO for variations in the pressure angle.

The comparisons made by Errichello were based on calculations made for AGMA by his Geartech AGMA 218 program package and for ISO by the ISO 6336 Gear Rating Program copyrighted by AGMA in 1997.

Calculation Method

The comparisons made in this paper will be based on calculations formulated from the AGMA copyrighted ISO 6336 program and the newly developed AGMA program for calculations per ANSI/AGMA 2001. These two programs are being released as "Gear Rating Suite by AGMA." Using these two programs to do the rating comparisons, the results are independent of any one individual's opinion or interpretation of either standard.

By using these programs, the input data for the gear geometry is the same for both the AGMA and the ISO ratings. This allows for a consistent trend analysis by only changing one gear geometry parameter while holding all of the other items constant within the program.

The focus of this paper is to show the trends of the two rating systems by varying specific geometry parameters one at a time. This paper is not trying to establish a "rating constant" between the two rating standards and should not be used as such.

Examples similar to the three from the 1981 AGMA papers will be re-examined to determine the rating trends with respect to changes in the profile shift. An example similar to Reference 4 will also be re-examined to determine the rating trends with respect to changes in the helix angle. Two examples will be added to investigate the differences in rating trends with respect to pressure angle for a spur gear set and a helical gear set.

We will rate the gears as carburized and hardened gearing ground to AGMA Class Q11. This is approximately ISO Class 6. We will use the upper life factor curves and rate the gearing for a life of 10,000 hours. The pinion speed will be set at 1,750 rpm. An input power of 250 hp (186.3 kW) is being used and the programs can calculate the factors of safety.

In each example, the first calculated factor of safety becomes the reference factor of safety. The other calculated factors of safety are then divided by the reference factor of safety to get the factor of safety trend value. In the tables, we are calling the factor of safety trend "FST." This is repeated for each rating item: pinion bending, gear bending, pinion durability, and gear durability. FST is calculated independently for AGMA and ISO. The factor of safety trend value is then plotted versus the factor being varied for each example.

Running the Rating Program

The tooling was specified as not having protuberance. The tooling tip was specified to be a full root radius or as large as the geometry would allow. No grind stock was specified. The surface finish was specified as 32 RMS for both the flank and the root fillet.

The leads were specified as having an ideal crown/correction with favorable tooth alignment. The gears were specified as commercial. The gear was specified as being a solid blank design. The

Figure 1-1 Example #1 Pinion Bending

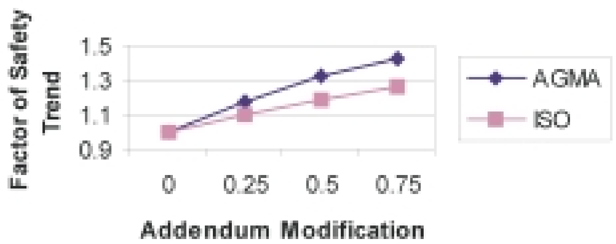


Figure 1-2 Example #1 Gear Bending

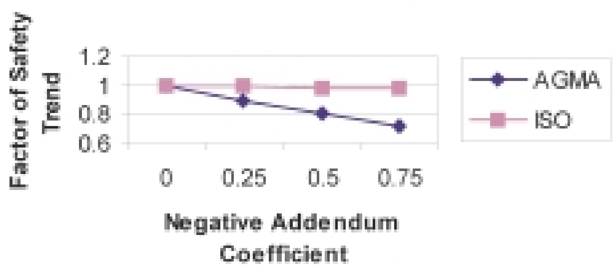
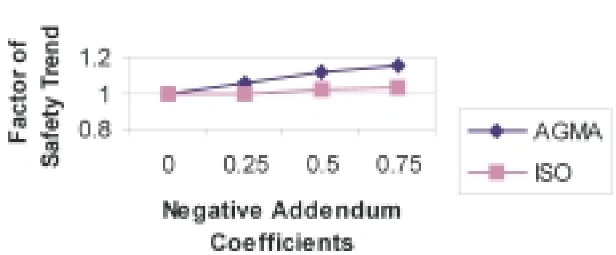


Figure 1-3 Example #1 Pinion Durability

Figure 1-4 Example #1 Gear Durability



bearing span was specified as being twice the face width. The gearing was centered in the bearing span. The ISO load distribution factor, KHbe, was calculated per method C1.

The AGMA gear quality was specified as 11. The ISO quality was specified as Class 8 for the pinion and Class 7 for the gear. The ISO dynamic factor was specified per method B. The reliability was specified as 99%. The stresses were for industrial application, the upper curve. A 1.0 application factor was used.

In AGMA, the strength ratings were calculated for the load applied at the HPSTC for the spur gear meshes.

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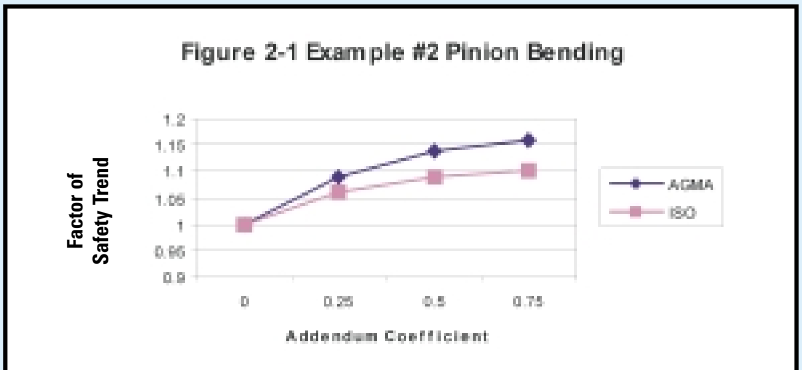
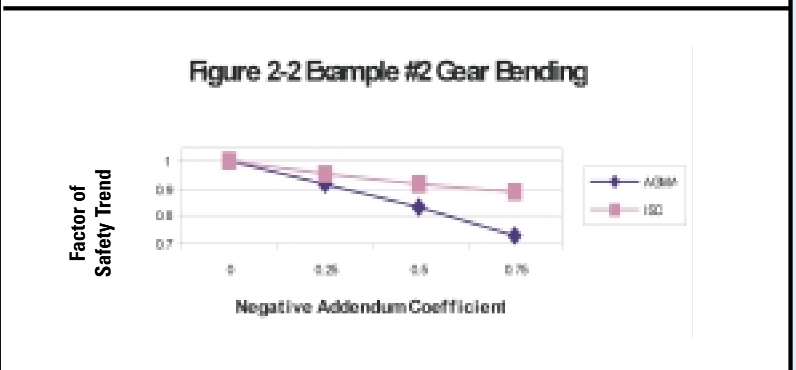
For ISO, a viscosity of 220 was specified.

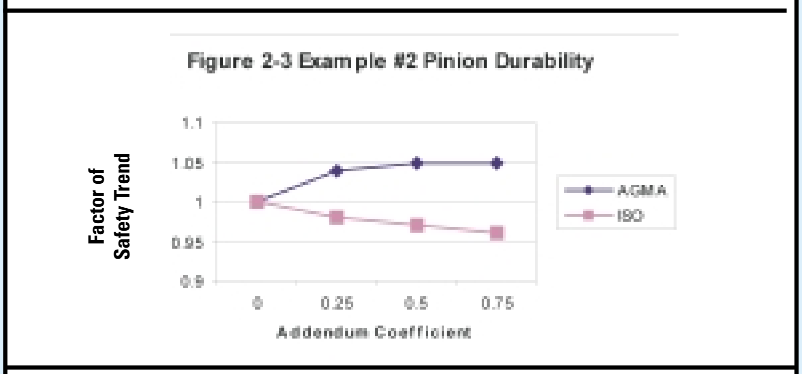
Again, the absolute ratings are not relevant to this study. The ratings calculated are consistent within the examples used, and the trend differences are real.

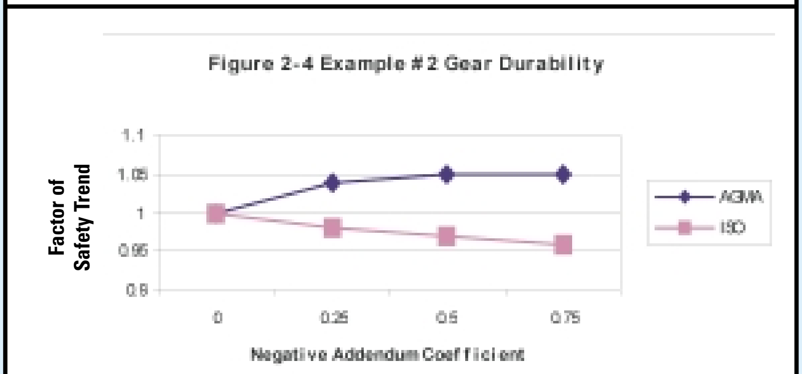
Example #1—Spur Gearing With Varying Profile Shift Coefficients

This example is a spur gear set operating on the standard center distance. The gear geometry is as follows:









21 teeth on the pinion
84 teeth on the gear
5 module (5.08 normal diametral pitch)
20° pressure angle
100 mm (3.939") face width
Standard hob proportions are being used
Center Distance = 262.5 mm (10.3346")

For this example, we will rate the gear set as a standard gear set and then rate it for increasing profile shifts or addendum modification coefficients on the pinion. The profile shift coefficient is as it is defined in the MAAG Handbook (Ref. 7).

Since the center distance is being maintained at the standard center distance, the rack shift coefficient for the gear has the same value as the rack shift coefficient for the pinion, but is positive on the pinion and negative on the gear.

The factors of safety have been normalized around the factors of safety for standard gearing and are plotted in Figures 1-1, 1-2, 1-3 and 1-4. As you can see, for this spur gear, both AGMA and ISO give an increased factor of safety for bending stress on the pinion when the addendum modification coefficient is increased. This is what would be expected since the tooth thickness increases as the addendum coefficient is increased. As the value of the positive addendum modification is increased, AGMA gives more of an increase in the factor of safety than does ISO.

In Figure 1–2, the addendum modification coefficient is negative. On this spur gear, AGMA gives a reduction in the factor of safety for bending when there is a negative addendum modification coefficient. As the value of the negative addendum modification coefficient is increased, AGMA gives a corresponding higher reduction in the factors of safety. This is what would be expected since the tooth thickness is reduced as the amount of the negative addendum modification is increased.

In ISO, for this spur gear, the factors of safety for bending are almost independent of the increasing negative addendum modification coefficient and the decreasing tooth thickness.

It is the goal of this paper to present the differences in the trends, not to explain the differences.

When there is a positive addendum modification coefficient, both AGMA and ISO calculate a higher factor of safety for durability on this spur pinion. As the value of the positive addendum coefficient is increased, the calculated factor of safety increases for both AGMA and ISO. With an almost extreme value of positive addendum modification coefficient, x = 0.75, AGMA gives a slightly higher increase than ISO.

Even though there is a negative addendum modification on the gear, both AGMA and ISO give an increase in the factors of safety for durability on this spur gear. The factor of safety is increasing with the growing value of negative addendum modification coefficient. The increases in the factors of safety are higher in AGMA than they are in ISO.

Example #2—Helical Gearing with Varying Rack Shift Coefficients

This example is a helical gear set operating on the standard center distance. The gear geometry is the same as that used in Example #1. The only difference is the helix angle. Due to the helix angle, the standard center distance is a little larger than that used with the spur gearing in Example #1. Center Distance = 271.76 mm (10.6992").

Again, we will rate the gear set as a standard model and then for increasing profile shift coefficients on the pinion and decreasing negative profile shifts on the gear.

The factors of safety have been normalized around the factors of safety for standard gearing and are plotted in Figures 2-1, 2-2, 2-3 and 2-4.

For this helical pinion, both AGMA and ISO give an increased factor of safety for bending stress on the pinion when the addendum modification coefficient is increased. Similar to the spur pinion example, as the value of the positive addendum modification is increased, AGMA gives more of an increase in the factor of safety than ISO.

On the gear, the addendum modification coefficient is negative. On this helical gear, both AGMA and ISO give a reduction in the factor of safety for bending when there is a negative addendum modification coefficient. As the value of the negative addendum modification coefficient is increased, both AGMA and ISO give a corresponding higher reduction in the factors of safety. The reduction in the factors of safety for bending by ISO is less than that from AGMA.

When there is a positive addendum modification coefficient on the pinion, AGMA calculates a higher factor of safety for durability on this helical pinion. As the value of the positive addendum coefficient is increased, the factor of safety calculated increases for AGMA. Here, ISO is calculating a reduction in the factor of safety for durability on this helical pinion. As the addendum modification coefficient is increased, the ISO calculated factor of safety actually reduces. Even for $x = 0.75$, the differences in the factors of safety are less than 5% for both rating systems compared to a standard pinion.

Figure 3-1 Example #3 Pinion Bending

Figure 3-2 Example #3 Gear Bending

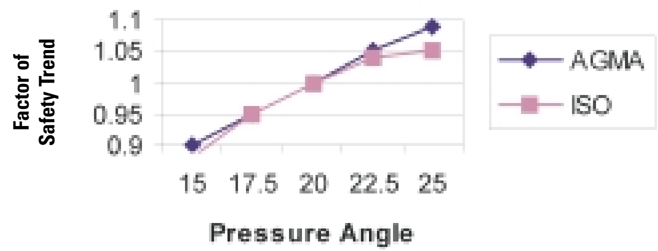


Figure 3-3 Example #3 Pinion Durability

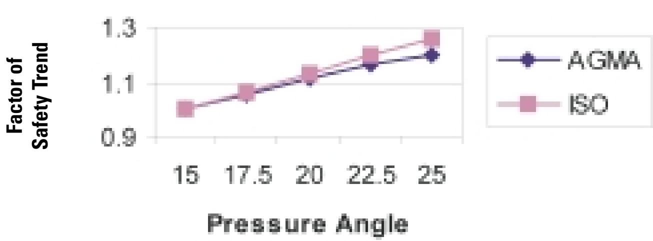
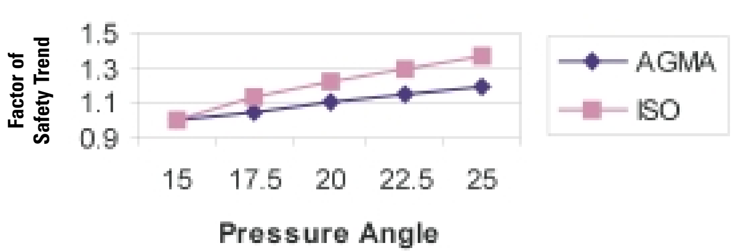


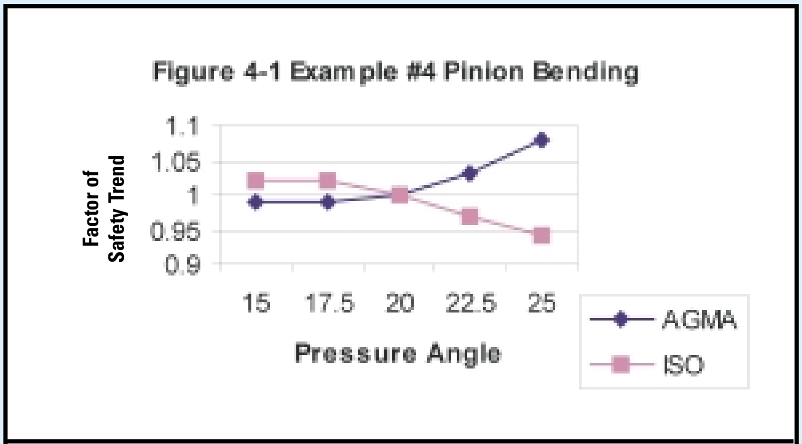
Figure 3-4 Example #3 Gear Durability

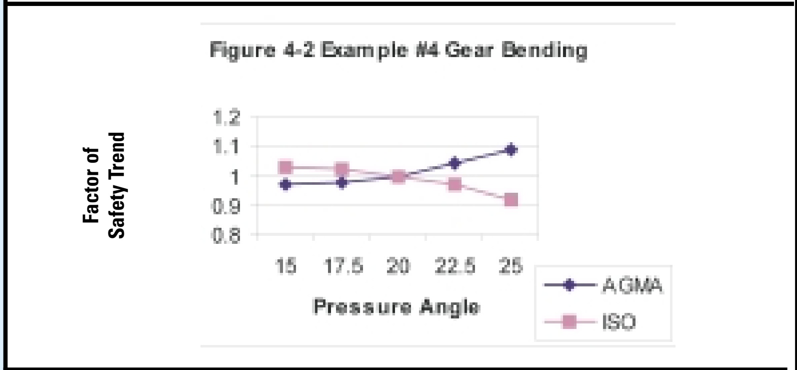


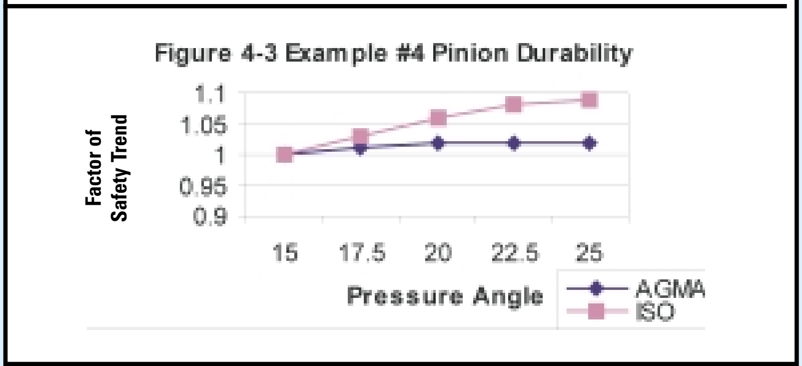
Similar to the spur gear example, even though there is a negative addendum modification on the gear, AGMA gives an increase in the factors of safety for durability on this helical gear. The factor of safety is increasing as is the increasing value of the negative addendum modification coefficient. In ISO, there is a decrease in the factor of safety for this helical gear when there is a negative addendum modification coefficient. As the value of the negative addendum coefficient is increased, there is a corresponding decrease in the factor of safety. Again, the differences are less than 5% compared to a standard gear.

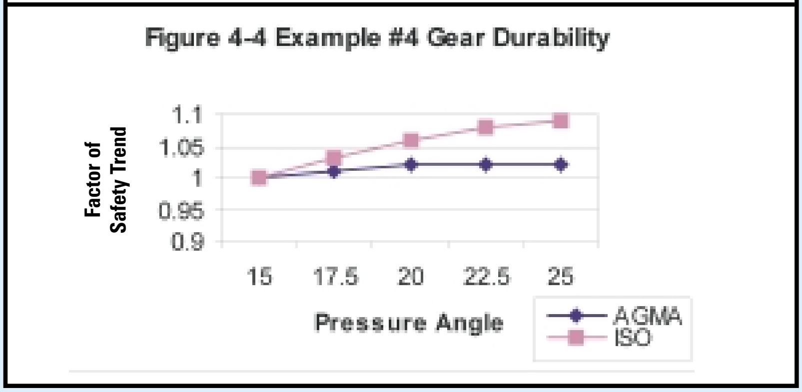
Example #3—Spur Gearing With Varying Pressure Angle

This example is a spur gear set. The gear set is a standard gear set. With the exception of the pressure angle, everything else is the same as in Example #1 when the profile shift coefficient was 0.









Here, we will rate the gear set using pressure angles that vary from 15–25°. All other gear geometry is being kept constant.

It is interesting to note that we were able to run both rating programs for the 15° and 17.5° pressure angles even though a simple calculation indicates that the 21-tooth pinion will have undercut for these two conditions. The AGMA rating program does print out a warning that the pinion may have undercut for both of these pressure angles. The bending ratings below 20° pressure angles are probably not correct. For this reason, we are making the 20° pressure angle rating the reference rating in bending.

For durability, the 15° pressure angle rating is the reference rating.

The factors of safety have been normalized and are plotted in Figures 3-1, 3-2, 3-3 and 3-4.

The trends of the factors of safety in bending with respect to pressure angle are very close to being the same for AGMA and ISO on this spur pinion and the spur gear. AGMA does give a slightly higher factor of safety than ISO as the pressure angle is increased above 20°.

The trends of the factors of safety in durability with respect to pressure angle are the same for AGMA and ISO on this spur pinion. The increase in factor of safety is slightly higher in ISO than in AGMA.

The trends of the factors of safety in durability with respect to pressure angle are in the same direction for AGMA and ISO on this spur gear. The increase in factor of safety is significantly more in ISO than in AGMA.

Example #4—Helical Gearing With Varying Pressure Angle

This example is a helical gear set. The gear set is a standard gear set. With the exception of the pressure angle, everything else is the same as that in Example #2 when the profile shift coefficient was 0.

Again, we will rate the gear set using pressures angles that vary from 15–25°. All other gear geometry is being kept constant.

As in the spur gear example, we were able to run both rating programs for the 15° and 17.5° pressure angles, even though a simple calculation indicates that the 21-tooth pinion will have undercut for these two conditions. The AGMA rating program did print out a warning that the pinion may have undercut for 15°. Again, the bending ratings below 20° pressure angles are probably not correct. Here, we are again making the 20° pressure angle rating the reference rating for bending.

For durability, the 15° pressure angle rating is the reference rating.

The factors of safety have been normalized and are plotted in Figures 4-1, 4-2, 4-3, and 4-4.

With an increase in the pressure angle, AGMA gives an increase in the factors of safety for bending on this helical pinion while ISO gives a decrease in the factors of safety for bending on this helical pinion.

In addition, with an increase in the pressure angle, AGMA gives an increase in the factors of safety for bending on this helical gear while ISO actually gives a reduction in the factors of safety.

For both the pinion and the gear in this helical gear set, as the pressure angle is increased, both AGMA and ISO give an increase in the factors of safety for durability. The increase in ISO is greater than the increase in AGMA.

Example #5—Helical Gearing With Varying Helix Angles

This example is a helical gear set. The numbers of teeth, module/pitch, pressure angle, and face width are the same as in Example #2. The only difference is that the helix angle will be varied from a spur gear (0° helix angle) to a helix angle of 30°. Due to the helix angle variation, the standard center distance for each gear set will be different.

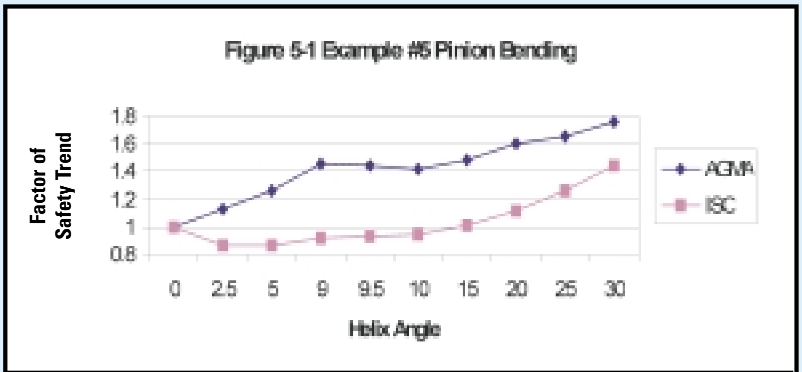
We will rate the gearing for each of the different helix angles and the corresponding standard center distance. All other gear geometry is kept constant.

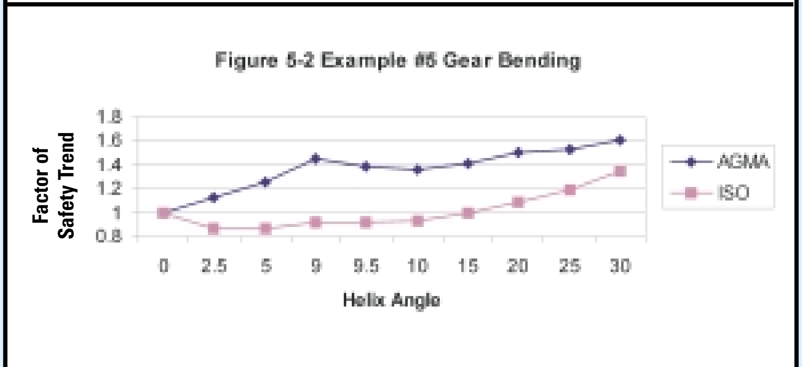
Below 9.0°, the helical gear sets have a helical overlap or face contact ratio less than 1.0. At 9.5° or higher the face contact ratio is greater than 1.05.

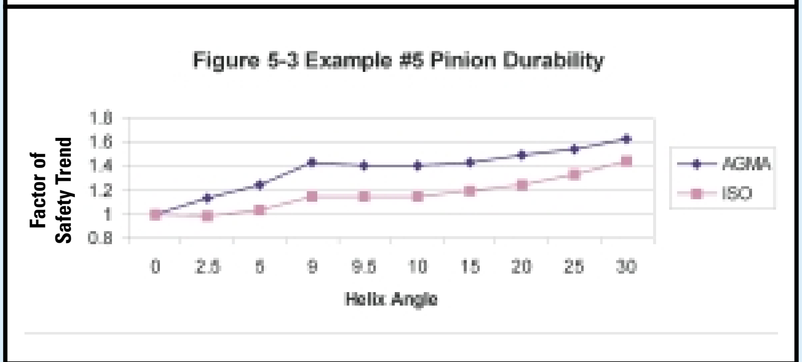
Note that as the helix angle increases, the standard center distance increases. At the higher helix angles, the center distance increases become more significant. From 0–5°, the center distance changes only 0.28%. From 25–30°, the center distance changes 4.65%.

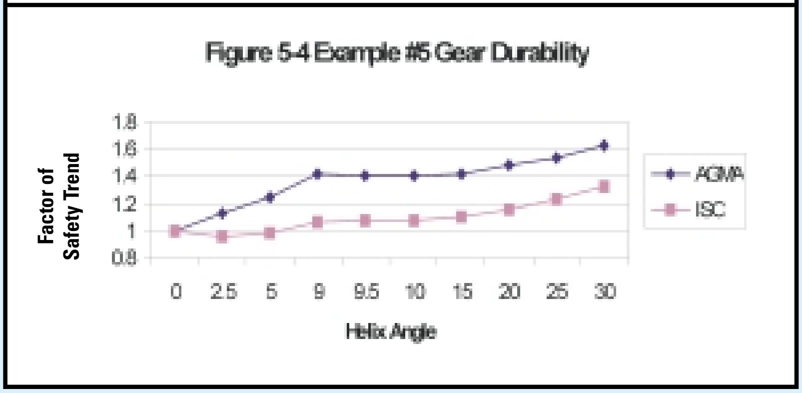
The factors of safety have been normalized and have been plotted in Figures 5-1, 5-2, 5-3, and 5-4.

AGMA has two curves for the factor of safety with respect to the helix angle. Below the value where the helix angle is large enough to have a helical overlap or face contact ratio greater than 1.0, AGMA calculates a progressively higher factor of safety for bending as the helix angle is increased on both the pinion and the gear in this helical gear set. ISO also has two curves, but the distinction is very small. In ISO, the factors of









safety for both the pinion and the gear are lower for a helical gear than for a spur gear until the helix angle reaches 15° on this sample gear set. In AGMA, the factors of safety for bending on both the pinion and the gear in this gear set are lower between the value for the helix angle that has a helical overlap greater than 1.0 and a helix angle of 15°.

Similar to the bending study, AGMA has two curves for the factor of safety with respect to the helix angle for durability. Below the value where the helix angle is large enough to have a helical overlap or face contact ratio greater than 1.0, AGMA calculates a progressively higher factor of safety for durability as the helix angle is increased on both the pinion and the gear in this helical gear set. ISO also has two curves, but the distinction is very small. In ISO, the factor of safety for both the pinion and the gear is again lower for a helical gear than for a spur gear until the helix angle reaches about 5°, which is about half of the value where the helical overlap ratio is greater than 1.0. In AGMA, the factor of safety for durability on both the pinion and the gear in this set is lower between the value for the helix angle that has a helical overlap greater than 1.0 and a helix angle of 15°.

Because the center distance increases when the helix angle increases, the rating differences are influenced by both the helix angle changes and the increases in sizes for the gearing. For this reason, a new example was developed where the center distance was held constant when the helix angle was changed. This required that the transverse pitch/module be kept constant. This requires that the normal pitch/module be changed when the pressure angle changes.

Figure 6-1 Example #6 Pinion Bending

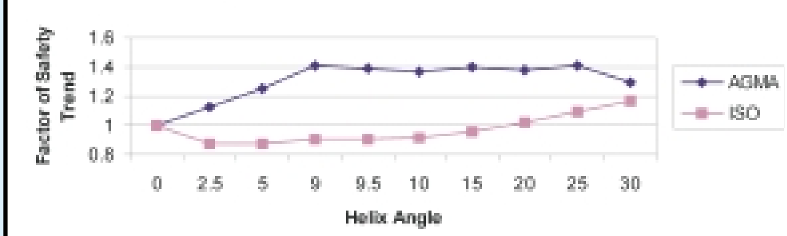


Figure 6-2 Example #6 Gear Bending

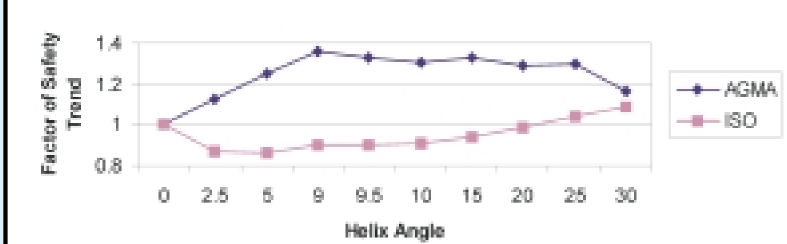


Figure 6-3 Example #6 Pinion Durability

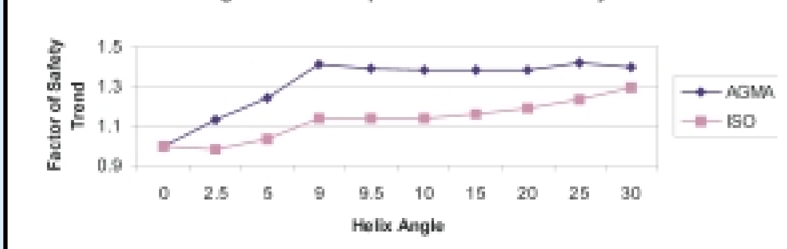
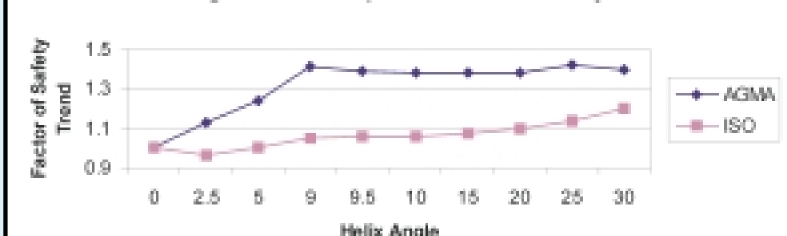


Figure 6-4 Example #6 Gear Durability



Example #6—Helical Gearing With Varying Helix Angles

This example is also a helical gear set. The numbers of teeth, transverse module/pitch, pressure angle, center distance, and face width are the same as in Example #2. The only difference is that the helix angle will be varied from a spur gear (0° helix angle) to a helix angle of 30°. To maintain the same transverse pitch/module and center distance, the normal pitch/module will be changed as required.

We will rate the gearing for each of the different helix angles and the corresponding normal pitch/module. All other gear geometry is being kept constant.

Again, below 9°, the helical gear sets have a helical overlap or face contact ratio less than 1.0. At 9.5° or higher, the face contact ratio is greater than 1.05.

The factors of safety have been normalized around the rating for a spur gear and have been plotted in Figures 6-1, 6-2, 6-3 and 6-4.

In AGMA, for bending on this helical pinion, as the helix angle varies from 0° to the helix angle that has a helical overlap greater than 1.0, the factor of safety increased significantly. From the helix angle where the helical overlap is greater than 1.0 to a helix angle of 25°, the AGMA factor of safety is almost independent of the helix angle. Above 25°, the factor of safety goes down with an increase in the helix angle. In ISO, the factor of safety for a helical gear is less than that of a spur gear until the helix angle is greater than 15°. In ISO, the factor of safety increases with an increasing helix angle if you do not consider the spur gear case.

For bending on this helical gear, as the helix angle varies from 0° to the helix angle that has a helical overlap greater than 1.0, the factor of safety increased significantly. From the helix angle where the helical overlap is greater than 1.0 to a helix angle of 25°, the AGMA factor of safety tends to be reduced with an increase in the helix angle. Above 25°, the factor of safety goes down at a steeper slope with an increase in the helix angle. In ISO, the factor of safety for a helical gear is less than that of a spur gear until the helix angle is greater than 20°. In ISO, the factor of safety increases with an increasing helix angle if you do not consider the spur gear case. Above a 15° helix angle, the ISO factor of safety increases as the helix angle is increased and at a steeper slope.

In AGMA, for durability on this helical pinion, as the helix angle increases from 0° to the helix angle that has a helical overlap greater than 1.0, the factor of safety increased significantly. Above the helix angle where the helical overlap is greater than 1.0 to a helix angle of 25°, the AGMA factor of safety is almost independent of the helix angle. Above 25°, the factor of safety goes down with an increase in the helix angle. In ISO, the factor of safety for a helical gear is less than that of a spur gear at a low helix angle. The ISO factor of safety increases with an increase in the helix angle. The increase is greater until the helix angle reaches the value where the helical overlap ratio is greater than 1.0. The ISO factor of safety continues to increase but at a lower slope above the point where the helical overlap is greater than 1.0. Both AGMA and ISO have two distinct curves, one below where the value of the helix angle is such that the helical overlap is greater than 1.0 and another curve above that helix angle value.

For durability on this helical gear, as the helix angle increases from 0° to the helix angle that has a helical overlap greater than 1.0, the AGMA factor of safety increased significantly. Above the helix angle where the helical overlap is greater than 1.0 to a helix angle of 25°, the AGMA factor of safety is almost independent of the helix angle. Above 25°, the AGMA factor of safety goes down with an increase in the helix angle. In ISO, the factor of safety for a helical gear is less than that of a spur gear at a low helix angle. The ISO factor of safety increases with an increase in the helix angle with a greater increase until the helix angle reaches the value where the helical overlap ratio is greater than 1.0. From the point where the helical overlap ratio is greater then 1.0 until 15°, the ISO factor of safety for durability on the gear is almost independent of the helix angle. Above 20°, the increase in factor of safety is at a steeper slope.

Both AGMA and ISO have two distinct curves, one below where the value of the helix angle is such that the helical overlap is greater than 1.0 and another curve above that helix angle value.

Conclusions

The purpose of this paper is to show the differences in the rating trends between the ISO and AGMA rating standards by independently varying specific gear parameters. The parameters chosen are those that have the most significant effects on ratings that consequently are quite often adjusted by gear designers to achieve optimized designs. It is beyond the scope and was not the intent of this article to point out the specific reasons for the differences between each of these trends. However, it is quite evident that the two standards differ for many of the examples shown. These trends show that there is a discrepancy between how the two rating systems handle changes in profile shift (tooth thickness), pressure angle, and helix angle.

Although this information should be of little surprise to many who have worked often with these two rating systems, hopefully this paper reveals these differences to those who may only be familiar with one of the two standards. It highlights the need for further investigation into why these differences exist and to eventually resolve them.

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EXCITING NEWS FROM THE INDUSTRY

NEW MANAGER AT PHILADELPHIA GEAR

Richard Chrzanowski was named as general manager of Philadelphia Gear's eastern regional service center to oversee service from Maine to North Carolina.

According to the company's press release, Chrzanowski started with Philadelphia Gear in 1996 and was promoted to director of customer and field service, where he was responsible for leading an internal effort to increase customer response times in relation to quote development, contracts and pricing and on-time delivery.

Prior to joining Philadelphia Gear, Chrzanowski worked in various engineering positions at Crane Co.

NEW FACILITY FOR ROYAL PURPLE

Royal Purple has completed construction of a new production facility in Porter, TX.

According to the company's press release, the 125,000 square-foot plant will allow Royal Purple to quadruple its production capacity.

New production hardware and software will allow the plant to produce more than two million gallons of finished products each month while operating only one shift.

Royal Purple is a manufacturer of lubricants.

BOEING ORDERS ELDEC SYSTEM

The Boeing Co. ordered eldec Schwenk Induction GmbH's SDF gear hardening system.

According to the company press release, the simultaneous dual frequency system is comprised of an MS SDF induction generator and a 5-axis CNC-controlled universal hardening machine for precise part handling/processing.

Additionally, it is equipped with an automatic laser inductor alignment system as well as a process control/quality monitoring system.

T.M. COOK AWARDED SALES CONTRACT FOR OHIO BROACH

Ohio Broach & Machine Co. appointed T.M. Cook Co. as its sales representative for upstate New York and the surrounding areas.

Based in East Syracuse, T.M. Cook provides metal cutting tools and machinery to manufacturing companies.

Ohio Broach designs and manufactures broaching tools and machines.

NEW PRESIDENT AT PRECISION GEAR

M. Briggs Forelli was named president of Precision Gear Inc.

He has worked in various positions within the company's operations, marketing and finance departments over the course of the past 16 years.

The previous president, Matthew S. Forelli, will continue to serve as chairman of the board.

WALL COLMONOY RECEIVES NADCAP AND ISO ACCREDITATION

Wall Colmonoy Corp. announced the re-accreditation of its materials testing lab to NADCAP and its recently awarded accreditation to ISO/IEC 17025.

The scope of the accreditation includes testing of the atomic emission spectroscopy.

Wall Colmonoy Corp. of Madison Heights, MI, manufactures nickel-base hard surfacing alloys and brazing filler metals.

NEW MANAGER AT RADYNE

Brian Locktiski

Brian Locktiski was hired as district sales manager for the Inductotherm Group, which represents Radyne Corp.'s induction systems for forging, heat treating, and brazing in Michigan, Ohio and Pennsylvania.

According to Radyne's press release, Locktiski's induction heating experience extends more than 10 years.

CST BUYS ASSETS OF CINCINNATI GEAR

CST-Cincinnati purchased 100% of the technical and select machinery assets of Cincinnati Gear Co., which was recently liquidated.

CST-Cincinnati manufactures lightweight, high-power-density marine transmissions for primary and boost turbines.

According to the company's press release, they can accommodate custom to high volume gearing from 1–150".

NEW MACHINE TOOL REPRESENTATION FROM BOHLE: BURKHARDT+WEBER

Bohle Machine Tools was named the sole North American representative for Burkhardt+Weber's (b+w) machines.

Headquartered in Plymouth, MI, b+w builds high precision machining centers and flexible manufacturing systems. Designed for flexible or complete production applications, these systems are applicable for aerospace applications, injection molds, automotive components and pumps and compressors.

NEW VICE PRESIDENT AT FAIRFIELD MANUFACTURING

Dan Phebus was appointed vice president of quality and process improvement at Fairfield Manufacturing Co. of Lafayette, IN.

Phebus comes to Fairfield from Carraro North America, where he was vice president of sales. According to Fairfield's press release, he has worked in the power transmission and specialized components industries for the past 20 years.

Fairfield Manufacturing designs and manufactures custom gears and gear sets, power transmission assemblies and planetary drives.

HUDAPACK ACQUIRES MIDLAND METAL TREATING

Hudapack Metal Treating has expanded its Wisconsin capacity by acquiring the assets of Midland Metal Treating Inc. of Franklin, WI. The new facility will be called Hudapack Franklin, and it adds substantial aluminum heat treating capability, along with scanning induction hardening and atmosphere processing.

The additional capacity includes 40 heat treating units in a 40,000 square-foot facility.

NEW MANAGER AT GENERAL MOTORS BALTIMORE TRANSMISSION PLANT

William A. Kulhanek has been named plant manager for the General Motors Baltimore transmission manufacturing operations.

Kulhanek replaces Rick McKinnon, who retired in February. Kulhanek was previously assistant plant manager at GM's Parma, OH, metal fabricating plant.

He began working for GM in 1981 and has held a number of supervisory and leadership positions.

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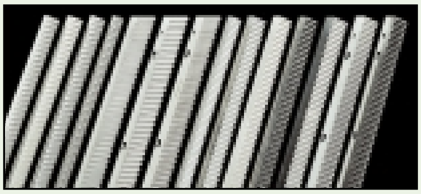

RACK AND PINION DRIVE SYSTEM FROM ANDANTEX

The preloaded rack and pinion system from Andantex is engineered for axis drive applications requiring high accuracy positioning.

According to the company's press release, the systems can eliminate backlash between the rack and pinion by using two pinions. One drives the axis while the other preloads the axis to eliminate backlash.

The company offers two types of preloaded rack and pinion drive systems. One version is mechanically preloaded, and the other is electrically produced.

For more information, contact Andantex of Wanamassa, NJ, by telephone at (800) 713-6170 or by e-mail at *info@andantex.com*.

NEW HOB CUTTER FROM STAR-SU

Star-SU developed a new hob design tool (patent pending) for hobbing precise, uniform chamfers on the end faces of gear teeth.

According to the company's press release, this cutter can place a precise, uniform edge chamfer from the outside diameter, down the flank of the gear tooth into the root radius and up the adjacent tooth flank.

Incorporated into the normal tooth hobbing operation, the cutter takes less than a minute. The chamfering hob is mounted on the same spindle as the tooth-cutting hob and shifts into the chamfering position when the tooth cutting is completed.

Available only from Star-SU, the hob is not sold but licensed on a renewable annual basis.

For more information, contact Star-SU of Hoffman Estates, IL, by telephone at (847) 649-1450 or on the Internet at *www.star-su.com*.

NEW COMPARATOR FROM BROWN & SHARPE

The Tesascope optical comparator is designed to measure gears as well as other complex round parts.

According to the company's press release, the system includes horizontal or vertical fiber optic surface illumination, profile illumination with green filters, a hard anodized and stabilized stage with high resolution linear glass scales, quick change bayonet lenses and automatic lamp shutoff.

Measurement routines with 0.001" resolution, independent zero reset (X/Y), absolute and incremental measurement, X/Y linear compensation, illumination control, RS232 output, radius calculations using three to 10 entered points, distance calculation from last datum radius or diameter and auto entry function are included.

For more information, contact Brown & Sharpe of North Kingstown, RI, by telephone at (800) 766-4673 or on the Internet at *brownandsharpe.com.*

NEW CARBIDE TAPS FROM LMT-FETTE

The HPF carbide insertable forming taps from LMT-Fette feature a replaceable carbide insert on a steel body.

According to the company's press release, the insert allows for cutting speeds two to three times faster than that of an HSS form tap.

Featuring a hardened steel shank designed with four drive tangs that handle the torque in a tapping operation, each shank is made to DIN specifications for added reach capability.

For more information, contact LMT-Fette of Cleveland, OH, by telephone at (800) 225-0852 or on the Internet at *www.lmtfette.com.*

NEW SOFTWARE FROM UTS

TK Solver 5.0 from UTS Inc. is a rule-based system that sets up and solves problems on a simple syntax.

According to the company's press release, the system operates on a programmable interface and combines an object-based structure, simple syntax, unit management and handling of lists and tables.

The enhanced feature set includes a solution optimizer, solution tracer, Instant MathLook for viewing formulas, plot annotation and report tools.

For more information, contact UTS Inc. of Rockford, IL, by telephone at (800) 435-7887 or on the Internet at *www.uts.com.*

NEW VERTICAL SPLINE ROLLER FROM ANDERSON COOK

The Maran 340V from Anderson Cook can roll splines, threads, oil grooves, snap ring grooves, burnishing, speedometer grooves and high helical parts.

Designed for the cold forming industry, the product is an alternative to horizontal rolling. According to the company's press release, the electric servometer does not require any hydraulics.

Additional features include four symmetric pre-loaded tie bars, independent axis movement, a menu-driven control system, electronic rack synchronization and metric based design.

For more information, contact Anderson-Cook Inc. of Fraser, MI, by telephone at (586) 293-0800 or on the Internet at *www.andersoncook.com.*

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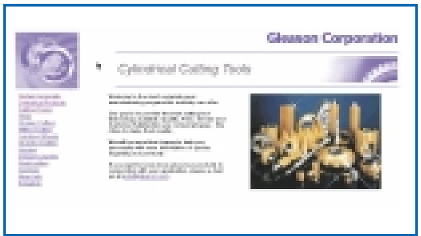

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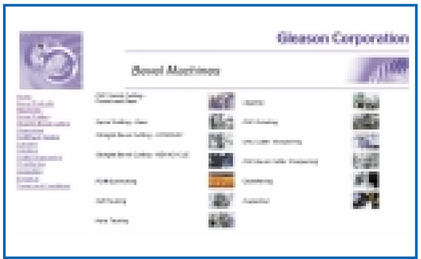

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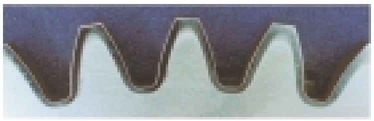

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GEAR MANUFACTURING

SOFTWARE

How often have you put your elbow on the water cooler, sipped from your paper cup and wondered: How's my work in this gear shop affected by my astrological traits?

Like the Addendum team, we're sure you've asked yourself this question on many occasions. But you may not have had the time to investigate your zodiac sign to find the answers.

However, we've taken the time to do that for you, as part of *Gear Technology*'s ongoing mission to benefit the gear industry.

The Addendum team conducted extensive research, we looked on a Website, to learn the traits of people born under each sign and how those traits help or hinder their work.

During our research, we even learned that people may be well or ill suited for certain shop positions based on their astrological traits.

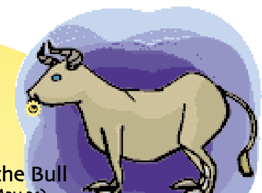
When you read about your sign, if you find you're not in your right job, we recommend you ask your boss for an immediate transfer. He'll understand; it's for the good of the company.

Our research results follow, starting with March 21, often the spring equinox, which is the beginning of the zodiacal year.

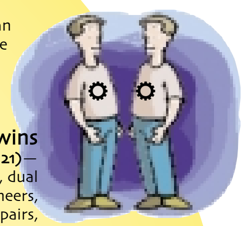
The Signs

According to Gear Heads

Aries the Ram
(March 21–April 20)—People born under the sign of the ram are enthusiastic and full of energy; they make good impressions as young job applicants. But they can be impatient and impulsive, so they may be bad choices for long projects, like carburizing operations—as one Aries we know proved with an unfortunate furnace incident. Thankfully, hair grows back.



Taurus the Bull
(April 21–May 21)—Taureans are industrious and reliable. Good craftsmen, they enjoy art and may see gear manufacturing as an art. This attitude explains why one of our Taurean friends operates his gear generator while wearing all black: pants, turtleneck sweater, beret.



Gemini the Twins
(May 22–June 21)—Geminis often have complex, dual natured personalities. As gear engineers, they tend to believe in matched pairs, so they think bevel gear lapping is the greatest process of them all. But their desire for perfect agreement between mates can annoy their spouses.

Cancer the Crab (June 22–July 22)—Purposeful and shrewd, but moody and uncompromising, sometimes describe Cancerians. Also, they often have a talent for mimicry—which should be used carefully at work. A friend used his talent before he saw his boss on the other side of his gear cutting machine. Anybody need a good machine operator?

Leo the Lion (July 23–August 21)—Self-confident and powerfully intelligent are among the best traits of people born under the sign of the lion. But they can be very stubborn about upholding out-of-date practices. We know a Leo who insists to us: "There's still a *huge* market for wooden gears."

Virgo the Virgin (August 22–September 23)—Virgos tend to be intellectual. They're logical, methodical, studious and teachable. They're also practical with their hands and good technicians. So they often can learn to expertly operate every machine in a gear shop: think utility infielder.

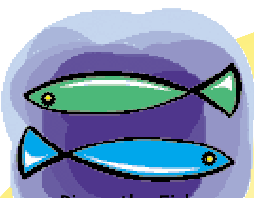
Libra the Balance
(September 24–October 23)—Sociable and idealistic are typical traits of Libras. Another possible trait is a dislike of coarse, dirty work. On the shop floor, they may be most comfortable in the gear inspection department—like one of our friends. As a Libra, he's also indecisive and changeable, though he says he's just "recalibrating my opinions."

Scorpio the Scorpion
(October 24–November 22)—Scorpios are sometimes critically perceptive with analytical capacities, making them good at investigating gear failures. They also tend to be intense and passionate, but not well-spoken. That's why we smile at a failure analyst we know, when he says: "I love failures."

Sagittarius the Archer
(November 23–December 22)—Sagittarians may sometimes be superficial, but they're also honest, philosophical and optimistic. This last trait can be a problem, as they can be too optimistic and therefore prone to statements like: "It's not an economic slowdown; it's just a very long coffee break."

Capricorn the Goat
(December 23–January 20)—Bosses like Capricorns; they tend to be calm and disciplined, with great respect for authority. Surprisingly, they also tend to have an interest in the occult. This trait surprised us when we saw a Capricorn co-worker rubbing chicken bones on bar stock. But he explained: "So the gears come out good."

Aquarius the Water Bearer (January 21–February 19)—Aquarians commonly are friendly and inventive. Born under the water bearer sign, they often are best at buying their gear shop's lubricants and cutting fluids. But they tend to view dry hobbing with great suspicion.



Pisces the Fishes
(February 20–March 20)—A hallmark of the Piscean personality is kindness. They're often best at dealing with a gear shop's fluids because they were born under the sign of the fish. So a Pisces may work well in a shop's nital etch department. Submerging gears in a fluid—even a mild acid—may seem right to them.

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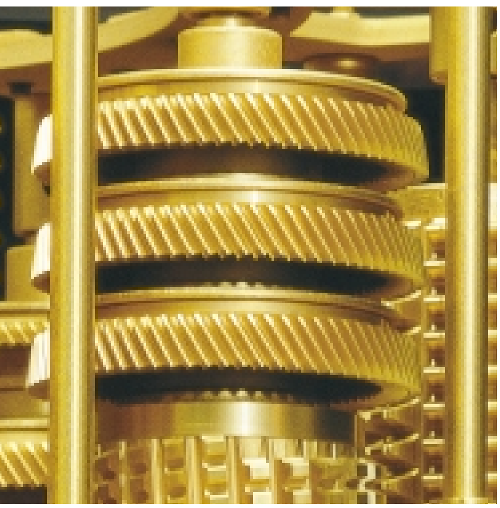

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