GEAR TECHNOLOGY

SEPTEMBER/OCTOBER 2002

The Journal of Gear Manufacturing

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IMTS SHOW ISSUE
- Booth Listings
- Show Information

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- Direct Gear Design
- Carburizing Large Gears
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GEAR TECHNOLOGY

SEPTEMBER/OCTOBER 2002

The Journal of Gear Manufacturing

IMTS SHOW ISSUE

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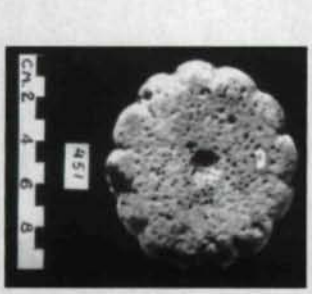

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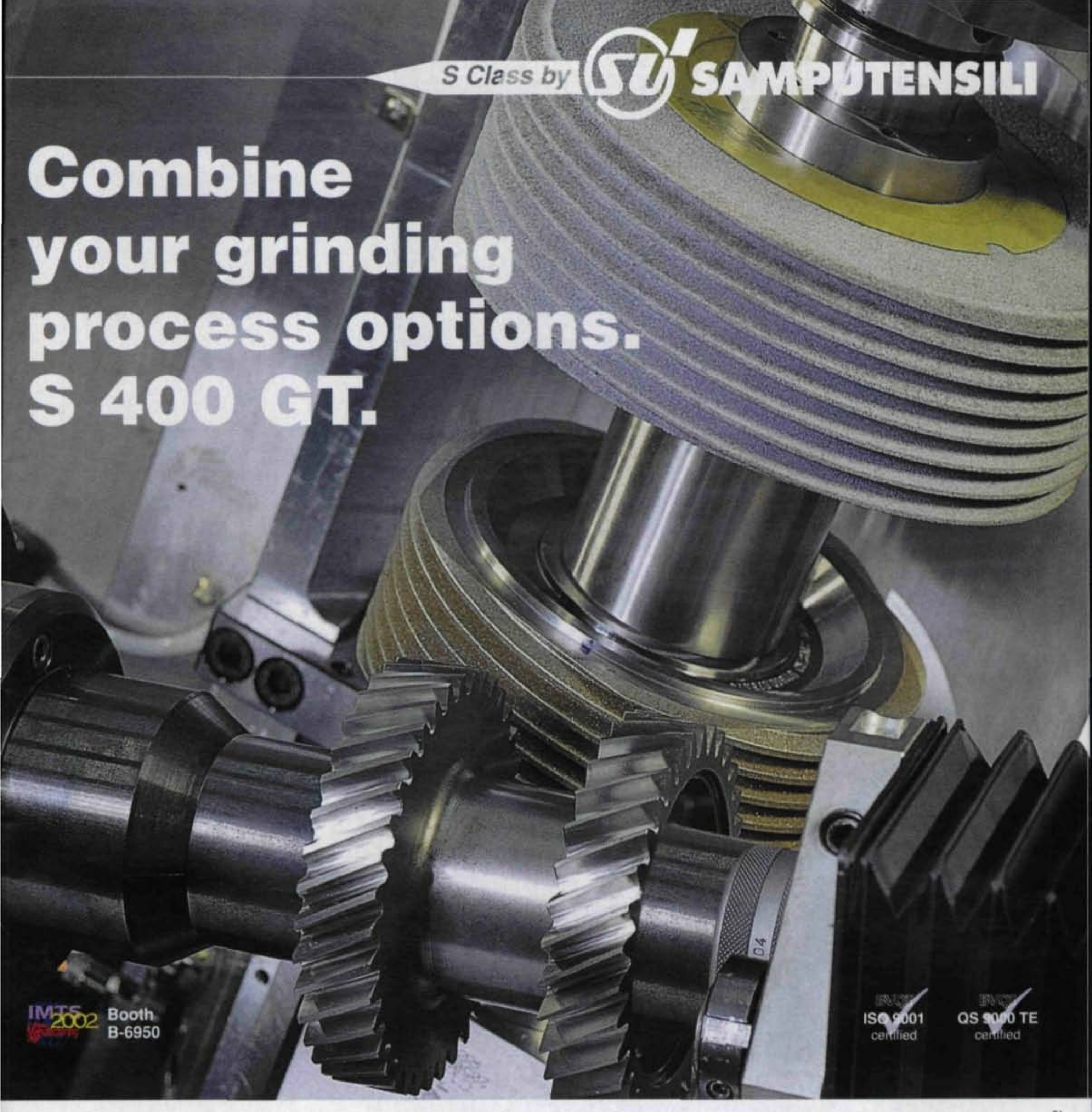
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GEAR TECHNOLOGY

The Journal of Gear Manufacturing

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RELIEF VALVE

Some of the pressure on American manufacturers seems to be letting up. This is welcome relief, considering the squeeze they have been under for the past few years.

Not only have American manufacturers been crushed by a slowdown in the economy, but the recent high value of the U.S. dollar has made matters even worse. While the slow economy has reduced the demand for all types of goods, including those containing gears, the strong dollar has made American exported goods more expensive overseas and made imported goods less expensive. The fierce pricing pressure that resulted has led many to believe Americans could not be competitive.

But now, the economy seems to be picking up—including the manufacturing sector. Many gear manufacturers are extremely busy, some as busy as they have ever been. Just last week I spoke with a manufacturer of automotive driveline components who said his factory is running seven days a week. I also spoke with the president of a Midwest gear manufacturer specializing in aerospace parts who told me that he's just finished the two best shipping months in his company's 50+ years.

These may be isolated examples, but I'm increasingly hearing that business is improving, and there are other encouraging signs. According to U.S. Federal Reserve Board statistics, industrial production has grown in each month so far in 2002. The anecdotes and the statistics say the same thing: Manufacturing appears to be on the upswing.

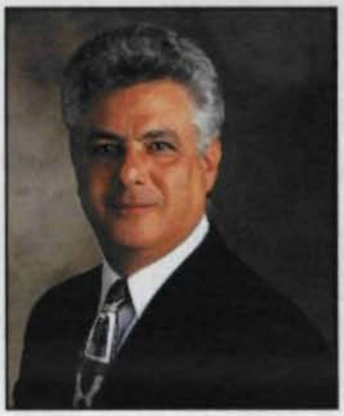
In addition, the U.S. dollar has been weakening. In fact, this summer it dipped below parity with the Euro for the first time since the Euro was launched in 1999. While a weak dollar sounds like a bad thing, it is actually beneficial to both American exporters and those that compete against imported goods. Those who try exporting will find their prices are more attractive to potential buyers overseas, and conversely, those whose markets are domestic may find that foreign import prices are less attractive to their potential customers. Either way, American gear manufacturers seem to be in a better position today than they were even several months ago, because of increased industrial activity and more favorable exchange rates. As it turns out, America is more competive than was thought.

With all of these encouraging indicators, it appears that IMTS is coming at the right moment (the show begins September 4 in Chicago). As always, the show provides an excellent opportunity to find out more about the technologies available to increase productivity or quality in your manufacturing operation. Even if you don't consider yourself in the market for machine tools right now, there are several factors you should think about that might help you decide to go to IMTS.

If demand for gears is on the rise, which it seems to be, then demand for machine tools to produce them is likely to follow. The cash prices of machine tools today are as low as they have been in a long time. With increased demand, you can expect that those prices will be firming up sometime soon.

Also, the decrease in the value of the dollar probably affects machine tool manufacturers the opposite way it affects American gear manufacturers. Many of the machine tools purchased for use in the United States are manufactured in other countries. Even American equipment manufacturers, such as Gleason Corp., manufacture some machines overseas. In the case of those companies, the weakening of the dollar will serve to increase pricing pressure because the cost of their goods is suddenly more expensive.

Of course, this doesn't necessarily mean that machine tool prices are going to go up immediately. Many machine tool manufacturers will probably be forced by competitive pressures to absorb the increased costs or find some way to protect themselves against the exchange rate risk. But if there is a window of opportunity to take advantage of the market, it is likely to occur over the next year. Your best opportunity to strike a good deal may be at IMTS.



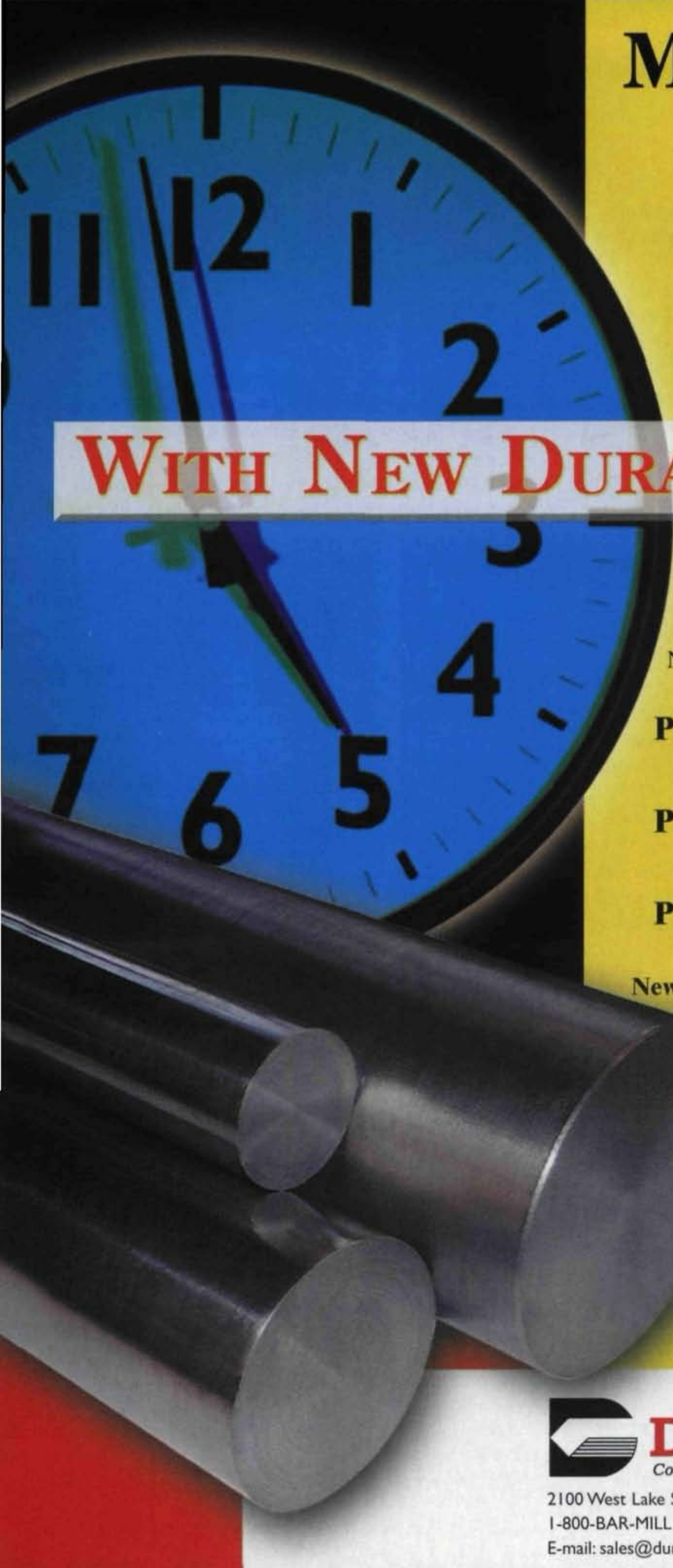
Also, Uncle Sam has provided another reason why now may be a good time to consider a machine tool purchase. As some of you are probably aware, the U.S. government recently enacted the Job Creation and Worker Assistance Act of 2002. This tax relief act provides for an additional 30% first-year depreciation allowance on property acquired after September 10, 2001 and before September 11, 2004. Your machine tool purchases may qualify for this allowance.

All things considered, IMTS provides the best opportunity for gear manufacturers to do what they have not done in a long time: Go shopping.

Michael Goldstein

Michael Goldstein, Publisher & Editor-in-Chief

P.S.—Thank you to the more than 500 of you who have signed up for FREE subscriptions to *E-GT*, the electronic version of *Gear Technology*, announced last issue. *E-GT* will be an exact duplicate of *Gear Technology*, prepared in PDF format and available worldwide FREE through our website, beginning with the January/February 2003 issue. If you haven't signed up yet, you can do so by visiting *www.geartechnology.com* and following the subscription link for *E-GT*. Signing up will not affect your subscription to the printed version of *Gear Technology*.



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 e-mail* **people@geartechnology.com**. *If you'd like more information about any of the articles that appear, please use Rapid Reader Response at* **www.geartechnology.com/rrr.htm**.

Dragonslayer Gears

According to legend, a samurai's sword was so strong and sharp that it could slice an opponent's blade in two. In medieval Japan, the forging of steel reached a high art among expert blade-masters. A professional warrior, the samurai depended heavily on his blade's quality. The steel had to be extremely hard on the outside, to hold a sharp edge and withstand the forces of battle. But, it couldn't be brittle. It had to be tough on the inside, so it wouldn't shatter during combat.

Those properties are very like the ones required of modern gears.

At least, that's what Charlie Kuehmann, president of QuesTek Innovations LLC of Evanston, IL, says. His company develops materials, including steels for gears and swords. "We developed a steel for high performance helicopters that we figured out would also do pretty nicely for swords and knives," Kuehmann says.

Medieval bladesmiths learned forging by apprenticeship, trial-and-error and luck. QuesTek uses sophisticated computer modeling and a systems engineering approach to develop what the company calls Materials by Design®.

For example, QuesTek has software that models how different processing variables affect a material's strength. The models predict how materials will act under various processing variables, like carburizing and quench temperatures and cycle times, Kuehmann says.

QuesTek's GearMet® C61 and Ferrium® C69 alloys have been designed with gears in mind, Kuehmann says. These alloys can be carburized to a case hardness of Rockwell C61 and Rockwell C69, respectively, which is quite a bit harder than most gear steels.

In the annealed state, these steels are a little bit harder than gear steels such as AISI 9310 or 8620, Kuehmann says. Although this might lead to shorter cutting tool life, Kuehmann says: "We haven't had anybody have any problems with machining."

Because they can be made harder than gears made from other steels, QuesTek expects that gears made from its steels will last longer. Alternatively, the steels can be used to make smaller, lighter gears that perform the same job as gears made from other materials, Kuehmann says.

QuesTek has performed some initial rolling contact fatigue and wear tests on prototype gears made from Ferrium® C69 steels. According to QuesTek literature, these tests have indicated a longer life for the gears made of C69 steels when compared with gears made of some other commercially available steels. The GearMet® C61 steel has undergone only bending fatigue tests, not tests of actual gears made of the material. "One thing that's been a big hurdle for us has been getting good data," Kuehmann says. But the company has arranged to have gears made of its steels tested at a major gear research facility later this year.

So far, the primary applications for QuesTek gear steels are in racing and aerospace, Kuehmann says—where minimizing transmission weight is critical. But he adds that other types of companies are testing the materials for their own gear applications.

QuesTek also continues to develop materials for other applications. One of the company's showcase projects is to make a sword even better than the legendary samurai sword. That project is called "The Dragonslayer," a sword that—theoretically—could slice a samurai sword in two.

"We're pretty close to being there," Kuehmann says. QuesTek tested a blade made from its Ferrium® C69 alloy against a Japanese-manufactured hunting knife. C69 is the alloy that QuesTek sees as ideal for gears. The Japanese knife was the closest thing available to an actual samurai sword (without damaging a valuable antique).

The result: The C69 blade was virtually untouched, and the Japanese knife had a notch about 1/2" deep, according to Kuehmann.

He believes he can make the Dragonslayer a reality by optimizing the nitriding process.

QuesTek hopes they'll be able to sell Dragonslayer swords to collectors. Just as important, they believe that one day soon they'll be selling Dragonslayer gears for your applications.

UTS, AGMA Offer New Gear Rating Software

Universal Technical Systems Inc. and the American Gear Manufacturers Association want to make work easier and more efficient for engineers who have to rate gears according to AGMA 2001 C-95 and ISO 6336.

To do that, UTS and AGMA each have new software for analyzing and calculating capacities of spur and parallel-axis helical gears according to both standards.

Based in Rockford, IL, UTS released its new rating software in August. The software consists of two programs, or modules: one for the AGMA standard, one for the ISO standard.

Those two modules were part of a larger release of 70 updated UTS modules. That software includes modules for designing, analyzing, rating and manufacturing gears and gear systems. The modules cover external spur and helical gears, internal gears, worm gears, face gears, planetary gear drives and involute splines.

Located in Alexandria, VA, the AGMA is scheduled to release its new program, the Gear Rating Suite, in October.

George Lian, a developer of AGMA's software, sees the program as useful to gear manufacturers and users, especially to their design and application engineers. Lian is senior project engineer at Amarillo Gear Co. of Amarillo, TX, and a member of AGMA's Computer Programming Committee, which created the software.

The committee's vice chairman, John Rinaldo, expects engineers to save time and aspirin entering gear data because of the program's "very flexible" input routine. Rinaldo is senior development engineer for Atlas Copco Comptec Inc., located in Voorheesville, NY.

The software's "flexible" input routine lets engineers enter their data in whatever way they want. For example, they can enter tooth thicknesses as x factors (profile shift coefficients) or as any of the six common measuring methods. Also, they can switch between those methods, entering a span measurement, then asking for display of the equivalent measurement over balls or of any other method.

More than that, they can enter their data in inches, metric units or a combination of both units, switching between the two "on the fly."

Engineers with a gear drawing that has a mix of both units don't have to convert them to one system before entering them. They can enter a face width of 20", convert the screen to metric units, enter an outside diameter of 1,000 mm, switch the screen back, and continue to enter the rest of the drawing's data.

The UTS modules likewise use inches and metric units and can switch back and forth between them.

Also, UTS designed its modules so people wouldn't have to re-enter data as they moved from one module to another while working on a gear.

Similarly, AGMA's software lets engineers enter a set of common gear geometry, then add just those factors needed to rate a gear with ISO 6336 or with AGMA 2001—without having to re-enter the whole set of geometry data for each standard.

The AGMA software also has a gear geometry checker. Providing a gear's geometry data and hob information, an engineer can obtain a geometry review to make certain the gear's numbers are internally consistent. Rinaldo says the checker also helps people select the proper tooling.

Similarly, the UTS modules will warn people if a gear parameter, like center distance or outside diameter, goes beyond what would be considered good practice. They can override the warnings; but if they stray too far from good practice, the module alerts them that their gear is flawed.

Lian adds that the AGMA program was created to "faithfully" rate according to either standard—that is, to rate without injecting personal design rules or limitations from the program's authors.

"Whatever the standard allows," Lian says, "this program will allow."

The program's users also can enter their own design limits, and the program will warn users if those limits are exceeded.

The two UTS rating modules cost $1,200 a piece. Gear manufacturers can buy UTS's 70 updated—and integrated—modules separately, customizing their software sets to their particular needs.

The AGMA program will cost $1,195 for AGMA members and $1,495 for nonmembers.

AGMA's Windows-based software consists of screens created using Visual Basic and calculating routines that use Fortran.

"Any standard PC would be able to run (the software) without problems," says Frank Uherek of Flender Corp. of Elgin, IL. A developer of the software, Uherek designs gearboxes for power transmission applications and manages Flender's quality assurance program.

The UTS modules also were designed to operate with Windows. They consist of Visual Basic interfaces and TK Solver mathematical modeling engines.

Rinaldo sees the AGMA software as helping American gear manufacturers who are trying to sell gears overseas and need to rate them with the ISO standard.

"The international community is trying to move to one gear rating standard and that is ISO," Uherek says. "Through this software, people who are not familiar with the ISO standard but are comfortable with the AGMA method can compare their design."

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NEW TECHNOLOGY AT IMTS

The following products were selected because they hold the most interest for gear industry professionals. Contact the company or visit its display at IMTS for more information.

A/W Systems Co.
Booth: B-7130
612 E. Harrison
Royal Oak, MI 48067
Phone: (248) 544-3852
Fax: (248) 544-3922

A/W Systems will display a selection of cutter bodies and blades, including straight bevel cutters, spiral bevel cutters, HSS and carbide stick blades. Additionally, the company will offer bore and height gages, hobs, an assortment of diamond tools for hard turning and dressing, keyseat cutters and dove tails as well as other hardware.

Bourn & Koch Machine Tool Co.
Booth: B-7048
2500 Kishwaukee St.
Rockford, IL 61104
Phone: (815) 965-4013
Fax: (815) 965-0019

Bourn & Koch will demonstrate dry hobbing with a 400H Series II gear hobber. In addition, the company will exhibit the newly redesigned Roto-Check 30" gear inspection system, Roto-Grind rotary tables and examples from the Fellows product line, which was recently purchased by Bourn & Koch.

Broach Masters Inc./Universal Gear Co.
Booth: B-7129
1605 Industrial Drive
Auburn, CA 95603
Phone: (530) 885-1939
Fax: (530) 885-8157

The Broach Masters Inc./Universal Gear Co. manufactures gear cutting tools, including gear and spline broaches, special form broaches, and shank- and disk-type cutters. It also manufactures spline gages, spline arbors and master gears and provides production broaching services, including blind hole broaching.

Broaching Machine Specialties
Booth: B-7251
25180 Seeley Rd.
Novi, MI 48375-2044
Phone: (248) 471-4500
Fax: (248) 471-0745

Broaching Machine Specialties will introduce the Electro-Mate, the next generation of its Cell-Mate internal, table-up broaching machine. This machine eliminates the need for operator stands and pits, and hydraulic units. The single-piece construction is designed to make for simple cell reconfiguration. Available with linear bearings as opposed to traditional box-way design, the Electro-Mate can meet the tightest part dimensional tolerances and surface finish requirements, according to the company. Completely electromechanically operated in every axis, the Electro-Mate is powered by force tube and servo motor technology and requires no hydraulics. The table-up machine design can be tooled to broach multiple parts simultaneously and is available with up to 10-ton capacities and 72" strokes.

Darex Corp.
Booth: B-7234
P.O. Box 277
Ashland, OR 97520
Phone: (541) 488-2224
Fax: (541) 488-2229

Darex Corp. will display chamfering tools; counterbores/countersinks; deburring machines; deburring tools; drilling and reaming tools; end mills; grinding machines; tool, cutter and drill point; grinding wheels and abrasive belts; plant maintenance and repair equipment; and woodworking equipment.

DATES AND LOCATION
September 4–11, 2002
McCormick Place
2301 S. Lake Shore Drive
Chicago, IL 60616

IMTS REGISTRATION FEES
$50 after August 4

EXHIBIT HOURS
Lakeside Center (East) and North Building, Hall C: 9:00 a.m.–5:00 p.m.
South Building & North Building, Hall B: 10:00 a.m.–6:00 p.m.
Sunday, September 8 Only–All Buildings: 10:00 a.m.–4:00 p.m

FOR MORE INFORMATION
Contact The Association for Manufacturing Technology by telephone at (703) 893-4206 or visit *www.imtsnet.org* on the Internet.

D.C. Morrison Co.
Booth: B-6781
201 Johnson St.
Covington, KY 41011
Phone: (859) 581-7511
Fax: (859) 581-9642

D.C. Morrison will display two versions of keyseaters—the 1/4" and 3" models, which both have a variable speed. Additionally, Schauer speed polishing/deburring lathes will be showcased.

Dura-Bar
Booth: E-2284
2100 W. Lake Shore Dr.
Woodstock, IL 60098
Phone: (815) 338-7800

Fax: (815) 338-1549
Dura-Bar will feature tooling materials, blanks and premachined stock and workpiece materials.

Flair Industry Accessory Co.
Booth: B-7140
No. 36 San Feng Rd.
Houli, Taichung Hsieu, Taiwan
Phone: (886) 4-255-793-80
Fax: (886) 4-259-769-90
Flair will feature bearings, pulleys, clutches, gears and v-belts, handwheels, knobs, cranks, pumps and coolant.

Forst GmbH & Co. KG
Booth: B-7126
Schutzenstrasse 160
D-42719
Solingen, Germany
Phone: (49) 212-409-130
Fax: (49) 212-409-111
Forst produces horizontal, internal and vertical broaching machines, as well as broach sharpening machines and broaching tools.

Gear Technology Center, Division of Mitsubishi International Corp.
Booth: A-8701
46992 Liberty Dr.
Wixom, MI 48393
Phone: (248) 669-6136
Fax: (248) 669-0614
Mitsubishi manufactures boring machines; gear grinding machines; gear honing machines; gear shaping machines; gear shaving machines; cylindrical OD grinding machines; machining centers; four- and five-axis horizontal and vertical machining spindles; universal machining centers; and bed-, planer-, gantry- and bridge-type milling machines.

IMTS OFFERS TECHNICAL CONFERENCE

In addition to walking the exhibit floor, IMTS attendees have the option of taking part in the 60+ conference sessions that focus on various manufacturing practices.

The categories offered for the IMTS 2002 Manufacturing Conference are:

Machining—includes emerging trends and high-speed machining,
Grinding & Abrasives—a focus on the latest technologies,
Toolings—sessions on design engineering and rapid tooling,
Quality—strategies and six sigma applications in manufacturing,
Job Shops—concentrating on the unique needs of contract and small manufacturing operators, and
Manufacturing Strategies—provides sessions on lean manufacturing practices, advances in manufacturing automation as well as supply chain and resource management and tools.

All of the sessions focus on issues like increasing productivity, strategies for reducing lead time, tools for assuring quality and the latest technical developments. SME organizers have scheduled speeches by executives at companies such as Motorola Inc., Visteon Corp. and Lean Works Inc.

In addition to hearing the speeches, attendees have the opportunity to network with other industry professionals during the technical conference. The intended audience consists of people with management, engineering, design, supervision, quality control, human resources, sales and marketing, purchasing, production operations and maintenance functions.

For those holding memberships in SME, the conference is free on September 9. For other cost information, visit the SME website at *www.sme.org/imts.*

For more information on the conference schedules for the six categories, visit the IMTS homepage at *www.imts.org* or e-mail the IMTS 2002 Manufacturing Conference team at *mfgconf@sme.org.*

Gleason Corp./Gleason Cutting Tools Corp.
Booth: B-6931
1000 University Ave.
P.O. Box 22970
Rochester, NY 14692-2970
Phone: (585) 473-1000
Fax: (585) 461-4348
Gleason will introduce a threaded wheel grinder, a bevel gear cutting machine, a gear inspection machine and its most complete line of gear shaper cutters.

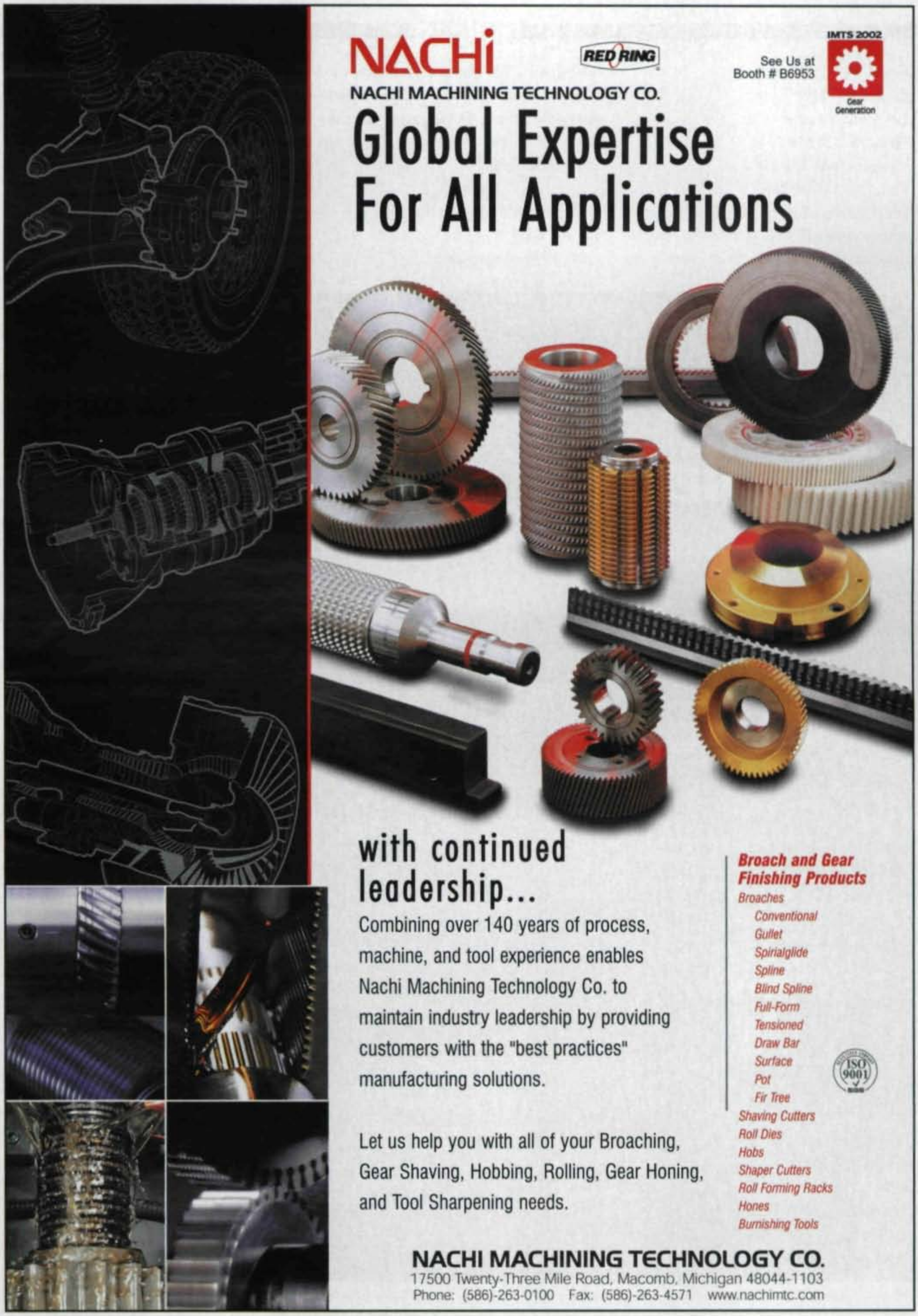
The 245 TWG threaded wheel grinder is designed for finish grinding of automotive final drive ring gears, speed gears, planet pinions and gears up to 245 mm in diameter and modules of 3.25. With this product, grinding surface speeds of up to 60 meters/second are possible. According to Gleason, other features include the integration of on-machine dressing, a load/unload mechanism that enables the machine to cut floor-to-floor time on a typical final ring gear to approximately one minute and a planet pinion to 20 seconds or less.

The Phoenix ® II 275 HC bevel gear cutting machine is designed to run dry or wet as required.

The Gleason Mahr 275 gear inspection machine is designed from the ground up in a joint development effort between Gleason and Mahr for the elemental inspection of all gear types.

The Gleason shaper cutter line is available in size ranges from 1.2 to 64 DP with no limit on the number of teeth ground to Class 5 tolerances. This CNC grinding technology is created to fulfill requirements for small shanks and special forms with higher levels of accuracy than typical manual machine processes.

Gold Star Coatings (Star Cutter Co.)
Booth: E-2701
2234 S. Dam Rd.
West Branch, MI 48661
Phone: (800) 426-2538
Fax: (989) 345-3020
See listing for Star Cutter Co. This division of Star Cutter Co. will feature its line of wear resistant thin-film coatings for cutting tools and wear parts.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RED RING
See Us at Booth # B6953
IMTS 2002
Gear Generation
NACHI MACHINING TECHNOLOGY CO.
Global Expertise For All Applications
with continued leadership...
Combining over 140 years of process, machine, and tool experience enables Nachi Machining Technology Co. to maintain industry leadership by providing customers with the "best practices" manufacturing solutions.
Let us help you with all of your Broaching, Gear Shaving, Hobbing, Rolling, Gear Honing, and Tool Sharpening needs.
Broach and Gear Finishing Products
Broaches
Conventional
Gullet
Spirialglide
Spline
Blind Spline
Full-Form
Tensioned
Draw Bar
Surface
Pot
Fir Tree
Shaving Cutters
Roll Dies
Hobs
Shaper Cutters
Roll Forming Racks
Hones
Burnishing Tools
ISO 9001
NACHI MACHINING TECHNOLOGY CO.
17500 Twenty-Three Mile Road, Macomb, Michigan 48044-1103
Phone: (586)-263-0100 Fax: (586)-263-4571 www.nachimtc.com

Great Taiwan Gear Ltd.
Booth: B-7139
108 Collier Lane
Greer, SC 29650
Phone: (864) 322-1266
Fax: (864) 609-5268

Great Taiwan Gear will display a gearbox with a motor for wheelchairs, a gearbox for scooters, a zero backlash gearbox for NEMA 17/23/34 motors, pump gears and a worm gear set. Gear reducers, transmissions, cutting tools, gears, and gearboxes from fine to coarse pitches are available as well.

Haug Verzahnungen GmbH
Booth: B-6938
Kirchheimer Strasse 27
D-73271 Holzmaden
Germany
Phone: (49) 70-23-9526-0
Fax: (49) 70-23-9526-10

See listing for Koepfer America L.L.C.

H.B. Carbide Co. (Star Cutter Co.)
Booth: E-2701
2234 S. Dam Rd.
West Branch, MI 48661
Phone: (800) 426-2538
Fax: (989) 345-3020

This division of Star Cutter Co. will feature its line of carbon preforms, including fluted preforms, special rod blanks, special extruded shapes, cold heading dies and bushings, round rods, flat blanks, gundrill blanks and special tooling. See listing for Star Cutter Co.

Ingersoll Cutting Tools Co.
Booth: A-8039
707 Fulton Ave.
Rockford, IL 61103
Phone: (815) 987-6000
Fax: (815) 987-6725

Ingersoll Cutting Tools will feature its automated fiber placement machine, the RigiDyne hydrodynamic spindle system and the MultiTec machining system.

The automated machine can place material over the end of a part rotating on the centerline of the head and tailstock, making it possible to create composite fuel tanks and other barrel-shaped objects complete with integral domes.

The RigiDyne is a 40,000 rpm hydrodynamic spindle system for high velocity machining. Featuring seven main parts, the system includes a motor drive that is separate from the spindle. At 34 lbs., the spindle can be switched out in less than five minutes.

The MultiTec machining system will make its first large scale debut at IMTS and is a modular machining system combining milling, grinding, turning, turn milling and five-axis milling in a single machine. Five basic types are offered in horizontal, vertical and gantry style configurations. A variety of gear cutting tools will be on display as well.

J. Schneeberger Corp.
Booth: B-7053
1525 Holmes Rd.
Elgin, IL 60173
Phone: (847) 888-3498
Fax: (847) 888-3665

Visitors will find CNC tool and cutter grinders, hob sharpening equipment and broach and profile grinders.

Kapp Group
Booth: B-6962
2870 Wilderness Place
Boulder, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131

The Kapp Group will feature two new machines. Niles will be introducing the ZE 800, which was designed as a machine for manufacturing low noise transmission gears for the turbo-machinery and windpower industries. Kapp GmbH offers its newest manufacturing solution to hard-gear finishing in the CX/KX machine family. Designated CX for Coroning and KX for grinding, these machines were created to meet the needs of the U.S. automotive market by offering Coroning, profile grinding and generating grinding processes. Both machines have modular structures, Siemens Sinumerik 840D controls and integrated inspection systems.

Klingelnberg GmbH
Booth: B-7040
Peterstrasse 45
D-42498 Hückeswagen, Germany
Phone: (49) 2192-81-0
Fax: (49) 2192-81-200

See listing for Sigma Pool.

Koepfer America L.L.C.
Booth: B-6938
635 Schneider Dr.
South Elgin, IL 60177
Phone: (847) 931-4121
Fax: (847) 931-4192

Koepfer will introduce its new triple part loading system on the CNC Model 200 hobbing machine. The KFS100 CNC hob sharpening machine with spiral gash capability is suitable for steel and carbide hobs. The fine pitch MZ120 CNC hobbing machine offers spur, helical and high helix worm cutting on one machine. Also, the Monnier + Zahner Model M647 CNC burr grinding machine for the dental industry will be displayed. Cutting tools manufactured from premium high speed steel, powder metals and carbide, as well as Haug honing wheels, gears and dressing tools designed for all honing machines will be featured.

The combined gear hobbing/worm milling machine Koepfer MZ 120 is designed for small-module spur gears, worm gears, worm wheels and worm threads. By pivoting the milling spindle from horizontal to vertical position and choosing the corresponding operating mode in the CNC control, the worm milling machine turns into a gear hobbing machine.

The grinding machine M 647 produces dental burrs and rotary cutters.

Both tungsten carbide and hardened steel can be processed on this machine. Six-shaft path control with industrial PC and a touch screen, an automatic loading and unloading system with funnel magazine for 1,000 parts (rod sizes), a grinding wheel attachment for three wheels, and software for all shapes (radii and straight lines) are included.

Leistritz Corp.
Booth: C-5315
165 Chestnut St.
Allendale, NJ 07401
Phone: (201) 934-8262
Fax: (201) 934-8266
Leistritz will demonstrate hard whirling of ball screws, full machining to finish quality ball threads in a single pass.

Liebherr Gear Technology Co.
Booth: B-7040
1465 Woodland Dr.
Saline, MI 48176
Phone: (734) 429-7225
Fax: (734) 429-2294
Libeherr Gear Technology Co. is the North American distributor of Sigma Pool's gear manufacturing technologies and processes. See listing for Sigma Pool.

LMT-Fette
Booth: E-2889
18013 Cleveland Pkwy., Suite 180
Cleveland, OH 44135
Phone: (800) 225-0852
Fax: (216) 377-0787
LMT-Fette, Bilz and Onsrund, members of the Leitz Metalworking Technology Group, will display Fette® and Lorenz® gear cutting tools, carbide milling tools and inserts; mold and die tools; axial, radial, and tangential thread rolling systems; crankshaft mills; bar peeling heads; taps, turning holders and inserts; smaller diameter end mills; and the Bilz ISG 3000, 3100, 2000 and 4000. Hourly demonstrations of the Twincut Vario and Magic Tap will occur.

M&M Precision Systems Corp.
Booth: B-7132
300 Progress Rd.
Dayton, OH 45449
Phone: (937) 859-8273
Fax: (937) 847-6364
M&M Precision Systems will feature two new CNC gear inspection systems, the Sigma Series and the Microtop. The new Sigma 3 and 7 systems combine four-axis generative motion with 3-D probe technology and high-speed linear motor direct drive. The Microtop provides full four-axis, Windows-based, generative measuring capacity. This shop hardened system is suitable for today's manufacturing cells and offers the same analysis capacity for parallel axis gears, worms and worm shafts as is available on M&M's larger Sigma Series machines.


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Mahr Federal Inc.
Booth: D-4321
1144 Eddy St.
P.O. Box 9400
Providence, RI 02940
Phone: (401) 784-3100
Fax: (401) 784-3457

Mahr's gear inspection equipment is represented by Gleason Corp. See listing for Gleason Corp. Mahr Federal will display calibration equipment; optical and other comparators; coordinate measuring machines; flatness measuring equipment; gages and gaging equipment, including statistical processing; control data collectors; laser measurement systems; electromechanical probes; roundness measuring equipment; surface finish measuring equipment; surface plates and vision systems.

Micromatic Textron
Booth: B-6979
345 E. 48th St.
Holland, MI 49423
Phone: (616) 494-3200
Fax: (616) 392-1710

Micromatic Textron will feature gear products, such as rolling machines and shear speed gear shapers, honing products, special machinery, micro-precision rotary actuators, and tooling and abrasives.

Mitts & Merrill L.P.
Booth: B-7144
P.O. Box 691
Harvard, IL 60033
Phone: (815) 943-3303
Fax: (815) 943-3366

Mitts & Merrill will introduce a new generation of keyseaters that uses electromechanical drives and ball screws for the stroke and infeed movements. The stiffness of the drives is designed to improve workpiece surface finish and promote longer tool life. According to the company, because there is no thermal expansion as is common on hydraulic machines, greater positioning accuracy, depth control and part-to-part repeatability is possible. Additionally, all keyway data can be entered directly from the part drawing.

Cutting and return speeds as well as stroke length are preselected on the panel. The electrical cabinet and panel are mounted on the machine frame to minimize the floor space required. Machine capacity is keyway width 1" and keyway length 12". A manual indexing table is available as well.

Molemab Abrasives USA Inc.
Booth: B-7148
2616 Arizona Ave.
Plattsburgh, NY 12903
Phone: (800) 962-2226
Fax: (888) 203-3876

Molemab Abrasives will display vitrified, resinoid and rubber bonded wheels, mounted points, and diamond and CBN products. Abrasive wheels for many applications are available, with diameters from 1/32" to 47".

Monnier + Zahner
Booth: B-6938
Hauptstrasse 115
CH-2553 Safnern
Switzerland
Phone: (41) 32-356-0370
Fax: (41) 32-355-2654
See listing for Koepfer America L.L.C.

Nachi Machining Technology Co.
Booth: B-6953
17500 23 Mile Rd.
Macomb, MI 48044-1103
Phone: (586) 226-5133
Fax: (586) 263-4571
Nachi's exhibit will include a display of current production parts, tools and processes. The company's latest semidry forming technology will be available for inspection at the show.

Niles Werkzeugmaschinen GmbH
Booth: B-6962
2870 Wilderness Place
Boulder, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131
See listing for Kapp Group.

Parker Majestic, Division of Penn United Technology
Booth: B-7258
330 E. Cunningham St.
Butler, PA 16001
Phone: (724) 431-2482
Fax: (724) 431-2487
Parker Majestic will introduce its Liberty and CNC Series Grinders. These Siemens PC-based machines are automated for productivity. The Freedom CNC surface grinder with optical CNC over-the-wheel form dresser is suitable for gear and broach grinders.

Reishauer Corp.
Booth: B-7033
1525 Holmes Rd.
Elgin, IL 60123
Phone: (847) 888-3828
Fax: (847) 888-0343
Reishauer will showcase the RZ 400 precision gear grinding machine that incor-

porates gearless planetary drives, acoustic sensing for alignment of dressing diamonds and low noise shifting, which produces a random surface structure on the teeth to prevent excitation.

The machine working area was designed to facilitate fast changeovers. Other features are convenient location for the setup of the dressing unit and an ergonomic ease of wheel change. According to Reishauer, the wide range of the gear location on the shaft or arbor allows the product maximum machine uptime. The main column that carries the grinding spindle and slide rotates 90° to facilitate wheel change and another 90° to perform the wheel dressing operation. Also, the company will display diamond and CBN dressing and grinding tools.

Sigma Pool
Booth: B-7040
1465 Woodland Dr.
Saline, MI 48176
Phone: (734) 429-7225
Fax: (734) 429-7225

Liebherr Gear Technology Co. will have the Liebherr LC 382 gear hobbing machine, the Liebherr LCS 282 gear grinding machine, the Klingelnberg P 26 gear inspection machine, the Oerlikon CS 200 gear cutter setting device, the Oerlikon T 60 bevel gear tester, the Oerlikon C 20 spiral bevel gear cutting machine and the CM digital double-flank gear tester/analyzer.

Star Cutter Co.
Booth: E-2700
23461 Industrial Park Dr.
Farmington Hills, MI 48335
Phone: (248) 474-8200
Fax: (248) 474-9518

Visitors will see CNC sharpening and tool grinding machines; hobs; form relief milling cutters; pressure coolant drills and reamers; non-pressure coolant drills and reamers; PCD tooling; Gold Star thin-film, wear-resistant coatings; carbide preforms; shaper cutters; shaving cutters; solid carbide tools and single- and two-flute gun drills.

Star-SU Inc.
Booth: B-6844 and B-6950
5200 Prairie Stone Pkwy., Suite 100
Hoffman Estates, IL 60192
Phone: (847) 649-1450
Fax: (847) 649-0112

Star-SU will show hobs, milling cutters, rack and saw cutters, shaper cutters, shave cutters, grinding wheels and worms, chamfering/deburring tools as well as tool systems for bevel gear manufacturing needs.

SU America Inc.
Booth: B-6844
5200 Prairie Stone Pkwy., Suite 100
Hoffman Estates, IL 60192
Phone: (847) 649-1450
Fax: (847) 649-0112

SU America is showing the latest machine designs of the S350 hobbing machine for dry cutting and the S400 GT flexible grinding machine, which is capable of profile grinding, continuous generating grinding and honing, as well as combinations of these processes.

Ty-Miles Inc.
Booth: B-7241
9855 Derby Ln.
Westchester, IL 60154
Phone: (708) 344-5480
Fax: (708) 344-0437

Ty-Miles will exhibit its high speed broaching systems, which can be integrated into an automated manufacturing cell or used as stand-alone machines. Miles broaching systems, vertical, horizontal and table-up, provide from 2- to 30-ton forces and from 12" to 72" strokes. Table-up models require no pits or platforms and part loading/unloading is done conveniently at operator waist height. Standard/interchangeable broach tooling includes fixtures, holders and broach cutting tools.

Welduction Corp.
Booth: B-7245
22750 Heslip Dr.
Novi, MI 48375
Phone: (248) 735-2800
Fax: (248) 735-2821

Welduction will display its induction heat treating systems and commercial processing devices, such as standard scanners for various heat treating applications, including heat treating of gears. With the ability to single shot or scan harden, Welduction induction centers can handle different sizes of gears for hardening, tempering and annealing applications. Standard machine attributes include compact design, precise vertical slide, part rotation and quenching, quench containment and filtration, built-in power supply diagnostics and operator safety features.

A complete list of booths is available at *www.imts.com*.

More IMTS Stuff

Robin Wright

STUDENT SUMMIT INTRODUCES NEXT GENERATION TO MANUFACTURING

The IMTS 2002 Show offers an opportunity for students, ranging from grade school to college, to take part in the exhibition.

This opportunity started at the 1998 show and attendance rose 11% by the time of IMTS 2000, according to the IMTS website.

Whether these students are college seniors ready to enter the engineering field or in elementary school, they will have the opportunity to visit the inside of the booths and speak to company representatives to better understand the technology. In the past, older students took advantage of this opportunity in greater number but all ages are invited, according to the IMTS website.

A goal of the student summit is to introduce the students to career opportunities and explain the future of the manufacturing technology industry.

Teachers and parents are also permitted to participate in the student summit. Show itineraries and assignments are available to teachers.

In 2000, a total of 3,923 students were chaperoned through the IMTS show by 605 teachers and parents. The students and their chaperones represented 35 states and 13 foreign countries.

Registration is free for the student summit and students may attend on any day of IMTS.

Interested students and industries can obtain forms on the IMTS website at *www.imtsnet.org*. For more information, call Myrta Mason at (703) 827-5219 or e-mail her at *mamason@amtonline.org*.

NEW BUSWAY SHORTENS COMMUTE FROM HOTELS TO MCCORMICK PLACE

During the eight days of the IMTS show, shuttle buses will be able to bypass traffic by traveling on a two-lane, 2.5-mile roadway.

By avoiding the congestion of the Randolph Street to McCormick Place route, IMTS attendees should be able to make the trip in about eight minutes.

According to the official IMTS website, the busway should cut shuttle bus costs for show organizers by one-third.

Funding for the busway, which totaled about $43 million, was provided by the Metropolitan Pier and Exposition Authority. Part of the money will be used for the second phase of the project, which will add a connection that will cross the Metra tracks and provide access to the North Building and Lakeside Center of McCormick Place.

For those who opt not to use the shuttle buses, the Metra line transports attendees directly to McCormick Place's grand concourse, to level 2.5. Service from the Randolph station on Wacker Drive to the convention center begins at 5:15 a.m. and runs on the hour until 12:50 a.m. During the rush hour commute, more frequent pickups are offered.

For more information on the Metra schedule, contact the Chicago Transit Authority at *www.transitchicago.com* or at (312) 836-7000.

HOTEL ACCOMMODATIONS FOR IMTS ATTENDEES

Travel Technology Group (TTG), the official housing coordinator for the 2002 IMTS Show, has blocked off rooms in more than 55 hotels for IMTS attendees. Accommodations run the gamut from the economical to the more exclusive hotels.

Among the hotels offered are some of the city's finest, including landmarks like The Drake, The Inter-Continental, and The Swisshotel.

For visitors seeking simpler lodgings, TTG presents options that provide a resting place as well as an economical advantage to attending the show. For example, the Essex Inn and the Congress Plaza Hotel are both centrally located and available for about $130 a night.

Room rates vary from about $120 to nearly $800, depending on factors like room or suite size, hotel amenities and proximity to the city's financial and entertainment districts.

IMTS PAVILIONS

Abrasive Machining/Sawing/Finishing—North Building, Hall B

This pavilion will feature cylindrical grinders; internal grinders; angular wheelside grinders; creep feed grinders; thrufeed grinders; centerless grinders; surface grinders; abrasive belt grinders; jig grinders; CNC tool and cutter grinders; universal grinders; cam grinders; bench, crankshaft and abrasive cutoff machines; band saws; circular saws; lapping machines; balancing machines; honing machines and polishing machines.

Controls and CAD-CAM—East Building, Hall D

This pavilion focuses on CIM/CAD/CAM systems, CNC controls, automation management systems, communications systems and LANs, software development systems and services, computers and software, instruments-controls and systems integration services.

EDM—East Building, Hall D

One of the largest gatherings of EDM manufacturers ever assembled, the pavilion features CNC wire EDM, EDM filtration system and supplies, ram-type EDM, metal disintegrators and die sinking machines.

Gear Generation—North Building, Hall B

Gear hobbers, gear shapers, gear cutters, gear shavers, broaching equipment, gear grinding equipment and gear measuring equipment are showcased in this pavilion.

Machine Components/Cleaning/Environmental—East Building, Hall D

Air purification equipment and services, safety guards, mats and equipment, filtration equipment, water and oil purification, air filtration, oil separation, sump cleaners, noise control equipment, dust removers, electrical equipment, way covers/tracks, storage systems, parts cleaners, parts washers, materials handling/storage systems, ball screws, bearings, spindles, conveyors, coatings, servo motors, pumps, degreasers, robotics, plant maintenance equipment, assembly/test equipment, motion control equipment and environmental management software are featured.

Metal Cutting—South Building, Hall A and North Building, Hall C

The Metal Cutting Pavilion includes machining centers, turning centers, assembly automation, milling machines and centers, boring machines, drilling machines, transfer machines, screw machines, broaching machines, burnishing machines, gun drilling machines, planer/mills, boring mills, multiple spindle drills and automatics, drill/mill/bore heads and slides, thread rolling, jig boring/milling machines and knurling machines, vertical turret lathes, bar feeds, automation systems, assembly machines, end finishers, machining cells, chuckers and CNC lathes.

Metal Forming & Fabricating/Laser—North Building, Hall B

All types of presses and the latest in laser production and technology are displayed here.

Quality Assurance—East Building, Hall D

Precision, laser and coordinate measuring machines; automated, precision and in-process gaging machines; tool condition monitoring equipment; measurement software; quality, control, testing and measuring equipment; comparators; metrology and vision systems will be on display.

Tooling & Workholding Systems—East Building, Hall E

This pavilion has special tooling, including boring bars, coolants, oils, ceramics, and composite cutting tools, gun drilling systems, jigs, reaming tools, and vises.

Business Services—North Building, Concourse Lobby

Here you will find industry-related publications, government organizations and other non-manufacturing organizations.

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TECHNICAL CALENDAR

September 4–11—International Manufacturing Technology Show 2002. McCormick Place, Chicago, IL. See page 15 for complete IMTS 2002 coverage.

September 11–13—Fundamentals of Gear Design. University Center for Continuing Education, University of Wisconsin–Milwaukee, Milwaukee, WI. This course will provide attendees with a beginning knowledge of modern gear system design and analysis. A knowledge of geometry, trigonometry, and elementary algebra is required. $1,095. For more information, contact the University Center for Continuing Education at (414) 227-3100 or visit the center's web pages via *www.uwm.edu*.

September 23–24—11th Annual Gear Failure Analysis Seminar. Big Sky Resort, Big Sky, MT. Attendees will learn the causes of and prevention methods for gear failure. Types of gear failure such as macropitting and micropitting, scuffing, tooth wear and breakage will be discussed. $625 for AGMA members, $795 for non-members. For more information, contact the AGMA at (703) 684-0211 or by e-mail at *tech@agma.org*.

October 21–25—AGMA School for Gear Manufacturing. Richard J. Daley College, Chicago, IL. Attendees will receive training in gearing and nomenclature, principles of inspection, gear manufacturing methods, and hobbing and shaping. $650 for AGMA members, $775 for non-members. For more information, contact the AGMA at (703) 684-0211 or by e-mail at *fentress@agma.org*.

November 13–14—Advanced Gear Processing and Manufacturing with Tabletop Exhibits. Hilton Northbrook, Northbrook, IL. Sponsored by the Society of Manufacturing Engineers, this program analyzes the issues in processing and manufacturing high quality gears. $795 for SME members, $895 for non-members. For more information, contact the SME by telephone at (800) 733-4763 or on the Internet at *www.sme.org*.

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Direct Gear Design for Spur and Helical Involute Gears

Alexander L. Kapelevich and Roderick E. Kleiss

This paper presents an alternative method of analysis and design of spur and helical involute gears.

Nomenclature

b_w	face width in the mesh
d_a	outside circle diameter, mm (in.)
d_b	base circle diameter, mm (in.)
d_Δ	tip circle diameter, mm (in.)
m_a	proportional top land tooth thickness
m_b	proportional base tooth thickness
p_b	base pitch, mm (in.)
S_a	top land tooth thickness, mm (in.)
S_b	base tooth thickness, mm (in.)
u	gear ratio
z	number of teeth
α_a	outside circle profile angle, degrees
α_p	profile angle in the bottom contact point, degrees
α_w	operating pressure angle, degrees
β_b	base circle helix angle, degrees
ε_α	contact ratio
ε_β	axial contact ratio
ν	tip circle profile angle, degrees

Subscript

1	pinion
2	gear

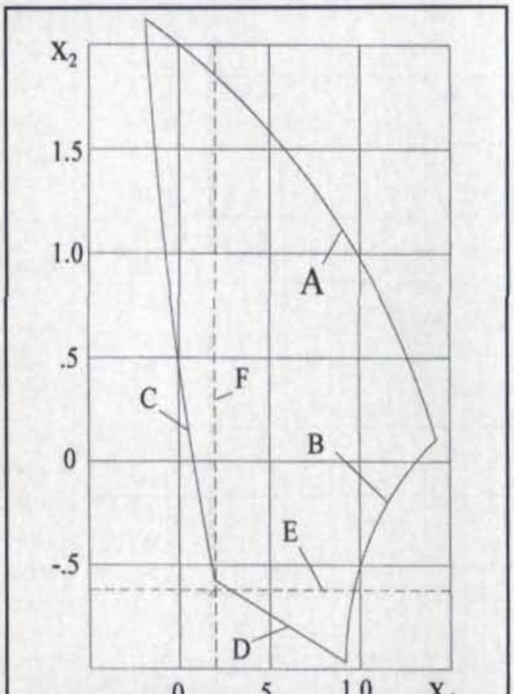


Figure 1—The zone allowed by the standard 20° rack for a gear pair $z_1 = 14$, $z_2 = 28$.

Introduction

Modern gear design is generally based on standard tools. This makes gear design quite simple (almost like selecting fasteners), economical, and available for everyone, reducing tooling expenses and inventory. At the same time, it is well known that universal standard tools provide gears with less than optimum performance and—in some cases—do not allow for finding acceptable gear solutions. Application specifics, including low noise and vibration, high density of power transmission (lighter weight, smaller size) and others, require gears with nonstandard parameters. That's why, for example, aviation gear transmissions use tool profiles with custom proportions, such as pressure angle, addendum, and whole depth. The following considerations make application of nonstandard gears suitable and cost-efficient:

- CNC cutting machines and CMM gear inspection equipment make production of nonstandard gears as easy as production of standard ones.
- Cost of the custom cutting tool is not much higher than that of the cutting tool for standard gears and can be amortized if production quantity is large enough.
- The custom gear performance advantage makes a product more competitive and justifies larger tooling inventory, especially in mass production.
- Gear grinding is adaptable to custom tooth shapes.
- Metal and plastic gear molding cost largely does not depend on tooth shape.

This article presents the direct gear design method, which separates gear geometry definition from tool selection, to achieve the best possible performance for a particular product and application.

The direct design approach that is commonly used for most parts of mechanisms and machines (for example, cams, linkages, compressor or turbine blades, etc.) determines their profiles according to the operating conditions and desired performance. Ancient engineers used the same

Dr. Alexander L. Kapelevich

is an owner of the consulting firm AKGears of Shoreview, MN, and principal engineer for Kleiss Gears Inc. of Centerville, MN. He has more than 20 years of experience in development of aviation and commercial gear transmissions in Russia and the United States.

Roderick E. Kleiss,

professional engineer, is owner and president of Kleiss Gears Inc. His company engineers and manufactures high precision, plastic molded gears using the direct gear design approach.

approach for gear design, developing the tooth shape first and then figuring out a way to get it. During the technological revolution in the 19th century, the highly productive gear generating process was developed. New machine tools required complicated and expensive tools, hobs or gear shapers. Common parameters of the cutting tool (generating rack) were standardized. This has made modern involute gear design indirect because the gear tooth profiles depend on a preselected, usually standard set for parameters of the generating rack (diametral pitch or module, pressure angle, addendum and dedendum proportions, tip radii, etc.) and its location (addendum modification or x-shift), relative to a standard pitch diameter of the gear.

Table 1		
Drawing Specification	Generating Process Parameter	Gear Parameter
Number of Teeth		X
Standard Normal Pitch	X	
Normal Pressure Angle	X	
Standard Pitch Diameter	X	
Helix Angle	X	
Hand of Helix		X
Helix Lead		X
Base Diameter		X
Form Diameter	X	
Root Diameter		X
Outside Diameter		X
Tooth Thickness on Standard Pitch Diameter	X	
Addendum	X	
Whole Depth	X	

Table 2			
Parameter	Symbol	Equation	Value
Number of teeth (given)	z_1		14
	z_2		28
Proportional top land thicknesses (given)	m_{a1}		0.075
	m_{a2}		0.075
Center distance, in. (given)	a_w		3.000
Proportional base tooth thicknesses	m_{b1}		0.755
(chosen from area of existence)	m_{b2}		0.645
Profile angle in the involute intersection point, deg.	ν_1	(4a)	42.14
	ν_2		32.85
Profile angles on outside diameters, deg.	α_{a1}	(5a)	41.23
	α_{a2}		31.83
Operating pressure angle, deg.	α_w	(10)	24.98
Transverse contact ratio	ε_a	(12)	1.60
Profile angles in the bottom contact points, deg.	α_{p1}	(13)	8.87
	α_{p2}	(14)	14.61
Base diameters, in.	d_{b1}	(11a)	1.813
	d_{b2}	$d_{b2} = d_{b1} \cdot u$	3.626
Base pitch, in.	p_b	(3)	0.407
Operating pitch, in.	p_w	(7)	0.449
Operating pitch diameters, in.	d_{w1}	(8)	2.000
	d_{w2}		4.000
Operating tooth thicknesses, in.	S_{w1}	(9)	0.279
	S_{w2}		0.170
Outside diameters, in.	d_{a1}	(2a)	2.410
	d_{a2}		4.267
Outside diameter tooth thicknesses, in.	S_{a1}	(5b)	0.030
	S_{a2}		0.030

Table 1 shows a typical helical gear specification, where gear parameters and the generating process (rack and its location) parameters are separated. The gear as a part does not have a pressure angle, pitch diameter, diametral pitch or module, helix angle, addendum or addendum modification. All these parameters are related to the tool and generating process. The involute gear has a number of teeth, base diameter, outside diameter, helical lead, and base tooth thickness.

The generating rack method of gear design does not guarantee sufficient gear design. The minimum number of pinion teeth is limited to avoid undercut. The addendum modification or x-shift of the generating rack is introduced to balance bending fatigue stresses and specific sliding for pinion and gear, and to reduce undercut for pinions with small numbers of teeth.

Why must tooth profiles be modified or corrected at the very earliest stages of the gear design? The modification must occur so early because the traditional approach is limited by its own arbitrary selection of generating rack parameters. The zone depicted (Ref. 1) in x-shift coefficient coordinates x_1 and x_2, for a pair of spur gears $z_1 = 14$, $z_2 = 28$ formed by a standard generating rack with 20° pressure angle is shown in Figure 1. The zone shown contains all gear combinations that can be produced using this particular generating rack. Its area is limited by the minimum contact ratio for spur gears $\varepsilon_\alpha = 1.0$ (isogram A), the sharp tip of the pinion (isogram B), and the tip-fillet interference (isograms C and D). The undercut isograms E and F put additional limitations on the zone area. Other available gear combinations exist outside the zone borders, but in order to realize them, the generating rack parameters would have to be changed. In other words, a range of possible gear combinations is limited by the cutting tool (generating rack) parameters and the machine tool setup (x-shift).

Direct gear design is the way to obtain all possible gear combinations by analyzing their properties without using any of the generating process parameters. Those parameters can be defined after the gear design is completely finished.

There were attempts to use the base circle as a foundation for the involute gear theory, separating the gear analysis from the gear generating process. Professor E.B. Vulgakov developed the so-called theory of generalized parameters for involute gears (Ref. 2). J.R. Colbourne (Ref. 3) described an alternative definition of the involute without using the generating rack. The self-generating method "gear forms gear" was proposed for plastic molded gears (Refs. 4 and 5). According to this method, the top land of the tooth of one of the gears forms the fillet of the mating gear and vice versa. At a glance, it looks similar to a gear shaping or gear rolling process, but the fact that both gears are described without the generating rack parameters makes a difference in their geometry and characteristics.

Involute Tooth Parameters

An involute tooth is formed by two involutes unwound from the base circle d_b, outside circle diameter d_a and fillet (Ref. 2) (see Fig. 2). Unless otherwise stated, the following equations are correct for spur gears and for helical gears in the transverse section (the section perpendicular to the axis of the gear). Equation numbers with alphabetic modifiers are given for use in the numeric examples listed in Tables 2, 3 and 4.

The profile angle in the intersection point of the two involutes (tip angle) is

$$\nu = \operatorname{acos}(d_b/d_\Delta) \quad (1)$$

where d_Δ is the sharp tip circle diameter.

The profile angle on the outside diameter d_a is

$$\alpha_a = \operatorname{acos}(d_b/d_a) \quad (2)$$

$$d_a = d_b/\cos(\alpha_a) \quad (2a)$$

The base pitch is

$$p_b = \pi \bullet d_b/z \quad (3)$$

where z is the number of teeth.

The proportional base tooth thickness is

$$m_b = S_b/p_b = z \bullet \operatorname{inv}(\nu)/\pi \quad (4)$$

$$\operatorname{inv}(\nu) = \pi \bullet m_b/z \quad (4a)$$

where S_b is the base thickness.

The proportional top land thickness is

$$m_a = S_a/p_b = z \bullet (\operatorname{inv}(\nu) - \operatorname{inv}(\alpha_a))/(\pi \bullet \cos(\alpha_a)) \quad (5)$$

$$\cos(\alpha_a) + z\operatorname{inv}(\alpha_a)/(\pi \bullet m_a) = m_b/m_a \quad (5a)$$

$$S_a = p_b \bullet m_a \quad (5b)$$

$$\operatorname{inv}(\nu) = (\pi \bullet m_a\cos(\alpha_a) + z\operatorname{inv}(\alpha_a))/z \quad (5c)$$

where S_a is the top land thickness. The recommended value of m_a should be between 0.06 and 0.12 to avoid a sharp tooth tip and provide sufficient contact ratio in the mesh.

Involute Gear Mesh Parameters

Figure 3 shows the zone of tooth action of the pinion and the gear in close mesh (backlash is zero). The close mesh condition is

$$p_w = S_{w1} + S_{w2} \quad (6)$$

where

$$p_w = \pi \bullet d_{w1}/z_1 = \pi \bullet d_{w2}/z_2 \quad (7)$$

is operating circular pitch,

$$d_{w1} = d_{b1}/\cos(\alpha_w),\ d_{w2} = d_{b2}/\cos(\alpha_w) \quad (8)$$

are the pinion and the gear operating pitch diameters, and

$$S_{w1} = (\operatorname{inv}(\nu_1) - \operatorname{inv}(\alpha_w)) \bullet d_{b1}/\cos(\alpha_w), \quad (9)$$

$$S_{w2} = (\operatorname{inv}(\nu_2) - \operatorname{inv}(\alpha_w)) \bullet (d_{b2}/\cos(\alpha_w)$$

are the pinion and the gear operating tooth thicknesses.

The operating pressure angle can be found by substitution of Equation 6 with 7, 8, and 9:

$$\operatorname{inv}(\alpha_w) = (\operatorname{inv}(\nu_1) + u \bullet \operatorname{inv}(\nu_2) - \pi/z_1)/(1 + u) \quad (10)$$

where u is the gear ratio $u = z_2/z_1$.

The operating pressure angle is a gear mesh parameter and it cannot be defined for one separate gear.

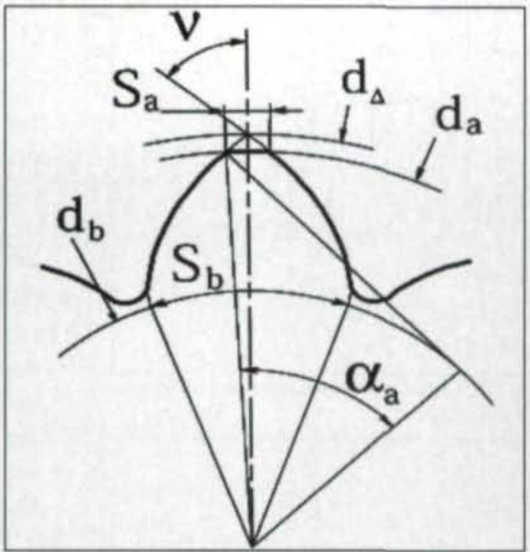
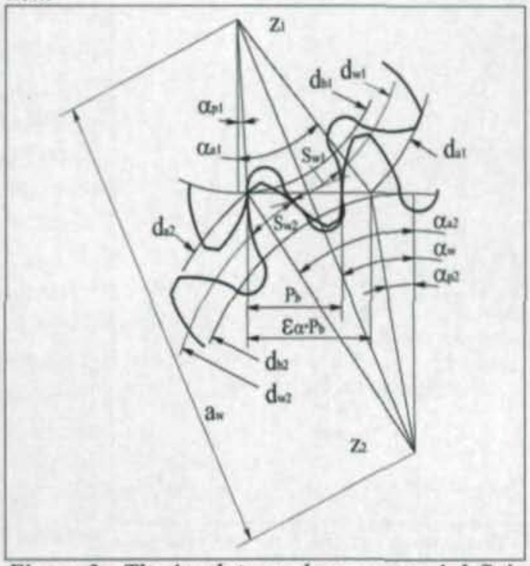


Figure 2—The involute tooth parameters' definition.



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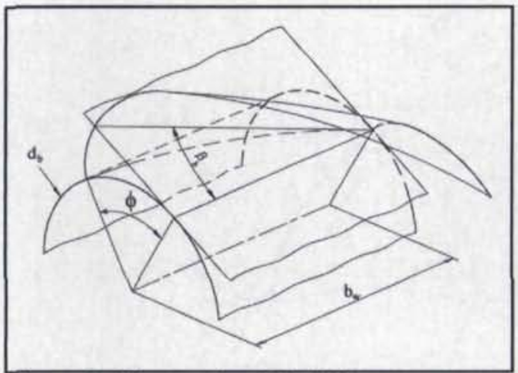


Figure 4—The angular shift of the transverse sections for a helical gear.

Figure 5—The area of existence for the gear pair $z_1 = 14$, $z_2 = 28$.

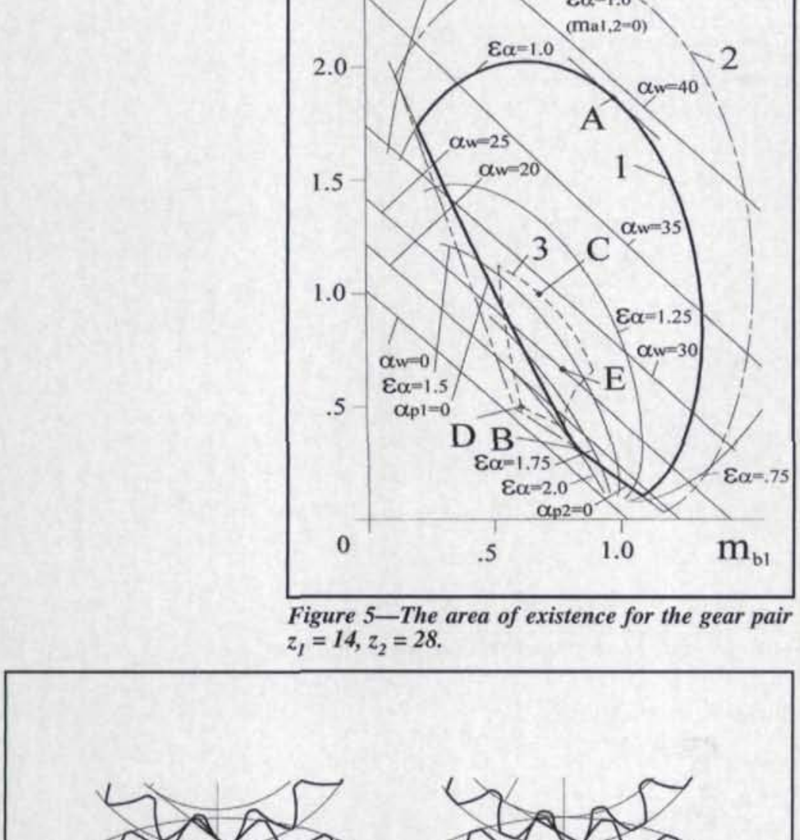


Figure 6—Involute gear meshes: 6a, at point A of Figure 5 ($\alpha_{wmax} = 39.5°$, $\varepsilon_\alpha = 1.0$); 6b, at point B of Figure 5 ($\alpha_w = 16.7°$, $\varepsilon_{\alpha max} = 2.01$); 6c, at point C of Figure 5 ($\alpha_{wmax} = 29.6°$, $\varepsilon_\alpha = 1.0$); 6d, at point D of Figure 5 ($\alpha_w = 15.9°$, $\varepsilon_{\alpha max} = 1.64$).

The center distance is

$$a_w = d_{b1} \cdot (1 + u)/(2 \cdot \cos(\alpha_w)) \qquad (11)$$

$$d_{b1} = a_w \cdot (2 \cdot \cos(\alpha_w))/(1 + u) \qquad (11a)$$

The contact ratio (for spur gears and for helical gears in the transverse section) is

$$\varepsilon_\alpha = z_1 \cdot (\tan(\alpha_{a1}) + u \cdot \tan(\alpha_{a2}) - (1 + u) \cdot \tan(\alpha_w))/(2 \cdot \pi). \qquad (12)$$

The profile angle in the bottom contact point must be larger than or equal to zero to avoid involute undercut:

for the pinion

$$\alpha_{p1} = \mathrm{atan}((1 + u) \cdot \tan(\alpha_w) - u \cdot \tan(\alpha_{a2})) \geq 0, \qquad (13)$$

for the gear

$$\alpha_{p2} = \mathrm{atan}((1 + u) \cdot \tan(\alpha_w)/u - \tan(\alpha_{a1})/u) \geq 0. \qquad (14)$$

The axial contact ratio for helical gears is

$$\varepsilon_\beta = z_1 \cdot \phi_1/(2 \cdot \pi) \qquad (15)$$

where ϕ (in radians) is the angular shift between the opposite transverse sections in the helical mesh (see Fig. 4), and

$$\phi = (2 \cdot b_w) \cdot \tan(\beta_b)/d_b, \qquad (16)$$

where b_w is the width of the helical mesh and β_b is the helix angle on the base circle.

The fillet profile must provide a gear mesh with sufficient radial clearance to avoid tip-fillet interference. The fillet also must provide necessary tooth bending fatigue resistance and mesh stiffness. The direct gear design approach allows selection of any fillet profile (parabola, ellipsis, cubic spline, etc.) that would best satisfy those conditions. This profile is not necessarily the trochoid formed by the rack or shaper generating process.

Tool geometry definition is the next step in direct gear design. This will depend on the actual manufacturing method. For plastic and metal gear molding, gear extrusion, and powder metal gear processing, the entire gear geometry—including correction for shrinkage—will be directly applied to the tool cavity. For cutting tools (hobs, shaper cutters), the reverse generating approach "gear forms tool" can be applied. In this case, the tooling pitch and profile (pressure) angle are selected to provide the best cutting conditions.

Area of Existence of Involute Gears

Figure 5 shows an area of existence for a pinion and gear with certain numbers of teeth z_1, z_2, and proportional top land thicknesses m_{a1}, m_{a2} (Ref. 2). Unlike the zone shown in Figure 1, the area of existence in Figure 5 contains all possible gear combinations and is not limited to restrictions imposed by a generating rack. This area can be shown in proportional base tooth thicknesses $m_{b1} - m_{b2}$ coordinates or other parameters describing the angular distance between two involute flanks of the pinion and gear teeth, like $\alpha_{a1} - \alpha_{a2}$ or $\nu_1 - \nu_2$. A sample of the area of existence for a pair of gears $z_1 = 14$, $z_2 = 28$, $m_{a1} = m_{a2} = 0.075$ is shown in Figure 5. The area of existence includes a number of isograms reflecting constant values of different gear parameters, such as operating pressure angles α_w, contact ratios ε_α, etc. The area of existence of spur gears (thick line 1) is limited by isogram $\varepsilon_\alpha = 1.0$, and undercut isograms $\alpha_{p1} = 0°$, $\alpha_{p2} = 0°$. Helical gears can have a transverse contact ratio less than 1.0 because the axial contact ratio can provide proper mesh. The area of existence of helical gears is therefore much greater. Each point on the area of existence reflects a pair of gears with dimensionless properties that can fit a particular application. These properties are pressure angles, contact ratios, pitting resistance geometry factor I, specific sliding ratio, etc.

The absolute area of existence includes spur gear combinations with any values of proportional top land thicknesses between $m_{a1} = m_{a2} = 0$ to $m_{a1} = m_{b1}$ and $m_{a2} = m_{b2}$ (phantom line 2). This area is substantially larger than the area with given values of proportional top land thicknesses. The zone for a standard generating rack with 20° pressure angle (as shown in Fig. 1) is only a fractional part of the available area of existence as shown by hidden line 3 in Figure 5. An application of a traditional gear generating approach for gear pairs outside the zone outlined by hidden line 3 requires selection of a generating rack with different parameters. The generation of some gear combinations (top left and bottom right corners of the area of existence shown in Fig. 5) will require different generating racks for the pinion and for the gear.

Analysis of the area of existence shows how many gear solutions could be left out of consideration if a traditional approach based on a predetermined set of rack dimensions is applied. For example, spur gears with a high operating pressure angle (point A on the Figure 5, where the operating pressure angle $\alpha_w = 39.5°$, contact ratio $\varepsilon_\alpha = 1.0$), or with a high contact ratio (point B on the Figure 5, where contact ratio $\varepsilon_\alpha = 2.01$, operating pressure angle $\alpha_w = 16.7°$) could not be produced with standard rack dimensions. Figures 6a and 6b show these gears. Figures 6c and 6d are the gears that are achievable using a standard generating rack that are presented by points C ($\alpha_w = 29.6°$, $\varepsilon_\alpha = 1.0$) and D ($\alpha_w = 15.9°$, $\varepsilon_\alpha = 1.64$) in Figure 5. Even gears with the same operating pressure angle (point E in Fig. 5) look quite different (Fig. 7). The standard designed gear pair (Fig. 7b) has almost sharp-pointed pinion teeth and short and stubby gear teeth with excessive top land tooth thickness. The direct designed gear pair shown in Figure 7a has a contact ratio $\varepsilon_\alpha = 1.47$. The standard designed gear pair has a contact ratio of only $\varepsilon_\alpha = 1.16$ in close mesh. In an actual application with real manufacturing tolerances and operating conditions, the contact ratio of a standard designed gear pair could be reduced to an unacceptable level $\varepsilon_\alpha < 1.0$.

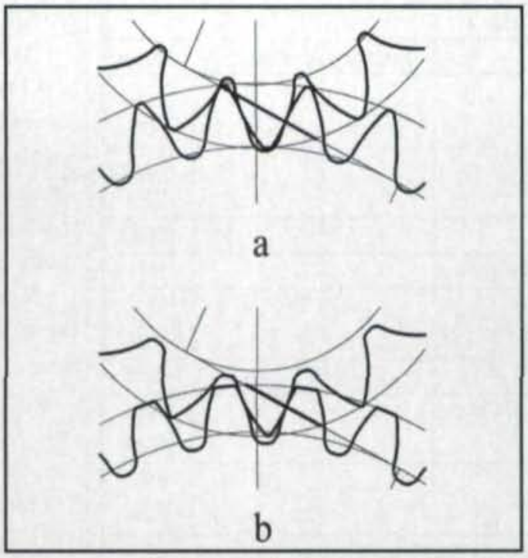


Figure 7—Involute meshes for the gear pair $z_1 = 14$, $z_2 = 28$ (at point E of the area of existence shown in Figure 5, $\alpha_w = 25°$) 7a, direct designed gears ($\varepsilon_\alpha = 1.47$); 7b, standard designed gears ($\varepsilon_\alpha = 1.16$).

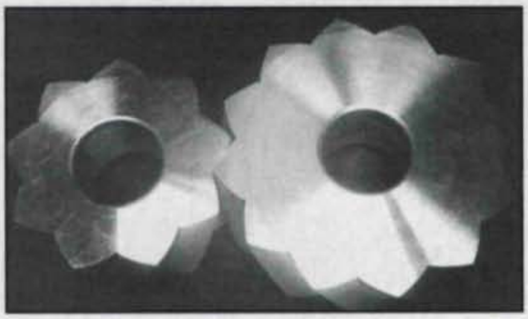


Figure 8—A helical gear pair with high operating pressure angle: $z_1 = 9$, $z_2 = 12$, $\alpha_w = 68.8°$, $\varepsilon_\alpha = 0.504$, $\beta = 30°$, $\varepsilon_\beta = 0.55$.

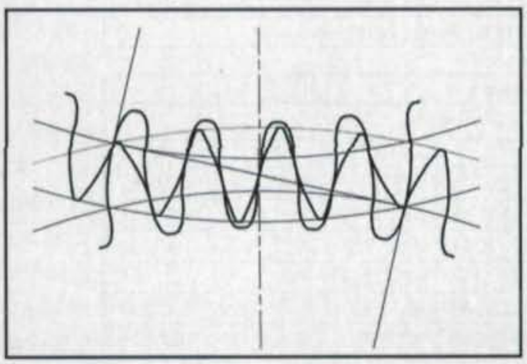


Figure 9—A spur gear with a high contact ratio: $z_1 = 55$, $z_2 = 55$, $\alpha_w = 12.9°$, $\varepsilon_\alpha = 4.0$, $m_{a1} = m_{a2} = 0.075$.

Synthesis of Gearing: Numerical Examples

There are several ways to define gear parameters using the direct gear design approach. This

Table 3			
Parameter	Symbol	Equation	Value
Number of Teeth (given)	z_1		14
	z_2		28
Proportional top land thicknesses (given)	m_{a1}		0.075
	m_{a2}		0.075
Center distance, in. (given)	a_w		3.000
Operating pressure angle, deg. (chosen)	α_w		33
Profile angles on outside diameters, deg	α_{a1}	(10) & (17)	40.02
	α_{a2}		38.84
Transverse contact ratio (maximum)	$\varepsilon_{\alpha\,max}$	(12)	1.246
Profile angle in the involute intersection point, deg.	ν_1	(5c)	41.03
	ν_2		40.36
Proportional base tooth thicknesses	m_{b1}	(4)	0.687
	m_{b2}		1.296
Use Table 2 to identify remaining equations.			

Table 4			
Parameter	Symbol	Equation	Value
Number of teeth (given)	z_1		14
	z_2		28
Proportional top land thicknesses (given)	m_{a1}		0.075
	m_{a2}		0.075
Center distance, in. (given)	a_w		3.000
Transverse contact ratio (chosen)	ε_α		1.05
Profile angles on outside diameters, deg.	α_{a1}	(10), (12)	43.29
	α_{a2}	& (17)	43.12
Operating pressure angle, deg. (maximum)	$\alpha_{w\,max}$	(10), (12) & (17)	37.97
Profile angle in the involute intersection point, deg.	ν_1	(5c)	44.06
	ν_2		43.52
Proportional base tooth thicknesses	m_{b1}	(4)	0.886
	m_{b2}		1.693
Use Table 2 to identify remaining equations			

Table 5							
$\alpha_w^A/\varepsilon_\alpha^B$		Pinion z_1					
		5	10	20	30	40	50
Gear z_2	5	31.5°/1.0	35.0°/1.14	37.8°/1.21	39°/1.23	39.6°/1.24	40°/1.24
	10	35.0°/1.14	36.8°/1.43	38.5°/1.66	39.4°/1.72	39.9°/1.75	40.8°/1.76
	20	37.8°/1.21	38.5°/1.66	39.4°/2.14	39.9°/2.37	40.2°/2.48	40.4°/2.54
	30	39°/1.23	39.4°/1.72	39.9°/2.37	40.2°/2.74	40.4°/2.97	40.6°/3.1
	40	39.6°/1.24	39.9°/1.75	40.2°/2.48	40.4°/2.97	40.6°/3.28	40.7°/3.49
	50	40°/1.24	40.8°/1.76	40.4°/2.54	40.6°/3.1	40.7°/3.49	40.8°/3.78

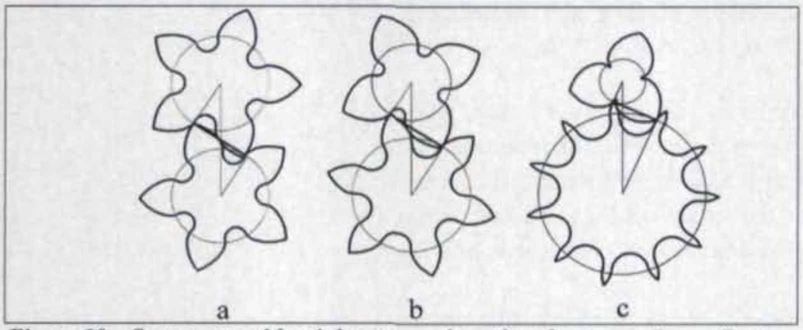


***Figure 10—Spur gears with minimum number of teeth:** a) $z_1 = 5, z_2 = 5, \alpha_w = 33.1°, \varepsilon_\alpha = 1.04$; b) $z_1 = 4, z_2 = 6, \alpha_w = 32.6°, \varepsilon_\alpha = 1.02$; c) $z_1 = 3, z_2 = 11, \alpha_w = 24.3°, \varepsilon_\alpha = 1.01$.*

article considers some of them.

Area of existence is known. The initial data for the synthesis of a pair of gears (z_1, z_2, m_{a1}, m_{a2}) could be taken from the area of existence at some particular point. The coordinates of this point and center distance a_w describe all operating gear parameters. This calculation procedure and numerical example are presented in the Table 2.

Area of existence is not known. Typical problems could be finding the maximum pressure angle if the transverse contact ratio is chosen or finding the maximum transverse contact ratio if the pressure angle is chosen. Both of these cases require finding the point of area of existence where isograms α_w and ε_α have the same tangent. This condition is described (Ref. 2) as:

$$\cos(\alpha_{a1})^2 \cdot (1 + \pi \cdot m_{a1} \cdot \sin(\alpha_{a1})/z_1) = \cos(\alpha_{a2})^2 \cdot (1 + \pi \cdot m_{a2} \cdot \sin(\alpha_{a2})/z_2) \qquad (17)$$

and allows solution of these problems without knowing the area of existence. The calculation procedures and numerical examples are presented in Tables 3 and 4.

The fillet between teeth is not involved in gear mesh operation, but its shape greatly affects gear performance and durability. In traditional gear design, the fillet profile is a function of the cutter shape and the machine tool setup. It typically has excessive radial clearance resulting in high bending stresses. Direct gear design does not limit fillet shape definition. One possibility is to describe the fillet profile as a trace of the top part of the mating gear tooth (with corresponding minimum radial clearance) (Refs. 4 and 5). Application of finite element analysis allows for forming the fillet profiles to balance and minimize bending stresses.

Extreme Parameters of Involute Gears

Point A (tangent point of isograms $\varepsilon_\alpha = 1.0$ and $\alpha_w = \max$) of the area of existence describes gears with the maximum achievable operating pressure angle. There is no such limit for helical gears because a lack of the transverse contact ratio ($\varepsilon_\alpha < 1.0$) is compensated by the axial contact ratio ε_β. A sample of a helical gear with high operating pressure angle (Ref. 6) is shown in Figure 8. In Figure 5, the point B (intersection point of interference isograms $\alpha_{p1} = 0°$ and $\alpha_{p2} = 0°$) of the area of existence describes the gears with the maximum achievable transverse contact ratio. Table 5 presents maximum values for operating pressure angle α_w^A (Point A of the area of existence) and transverse contact ratio ε_α^B (Point B of the area of existence) for gear pairs with different numbers of teeth and the proportional top land thicknesses $m_{a1} = m_{a2} = 0.075$. An example of a spur gear mesh with a high contact ratio is shown in Figure 9.

Spur gears (contact ratio $\varepsilon_\alpha \geq 1.0$) with a minimum possible number of teeth (Ref. 2) are shown in Figure 10. The minimum possible number of teeth for helical gears is not limited by transverse contact ratio and could be as few as one (Ref. 6). An example of a helical gear with the number of teeth $z_1 = z_2 = 1$ is shown in Figure 11.

Involute Gears with Asymmetric Tooth Profile

Opposite flanks (profiles) of the gear tooth are functionally different for most gears. The workload on one profile is significantly higher and/or is applied for longer periods of time than on the opposite one. The asymmetric tooth shape accommodates this functional difference.

The design intent of asymmetric teeth is to improve performance of main contacting profiles by degrading opposite profiles. These opposite profiles are unloaded or lightly loaded, and usually work for a relatively short period. The improved performance could mean increasing load capacity or reducing weight, noise, vibration, etc.

Degree of asymmetry and drive profile selection for these gears depends on the application. Asymmetric profiles make it possible to manage tooth stiffness and load sharing while keeping a desirable pressure angle and contact ratio on the drive profiles.

Direct design of gears with asymmetric teeth is considered in detail in other articles (Refs. 7 and 8), covering topics such as analysis and synthesis of asymmetric gearing, area of existence, and applications. Examples of gears with asymmetric tooth profiles are shown in Figure 12. Gears with asymmetric teeth should be considered for gear systems that require extreme performance, like aerospace drives. They are also applicable for mass production transmissions where the share of the tooling cost per one gear is relatively insignificant. The most promising application for asymmetric profiles is with molded gears and powder metal gears. Molded gear tooling usually requires a custom shape, so the asymmetric profile does not significantly affect cost.

Summary

Direct gear design is an alternative approach to traditional gear design. It allows analysis of a wide range of parameters for all possible gear combinations in order to find the most suitable solution for a particular application. This optimum gear solution can exceed the limits of traditional rack generating methods of gear design.

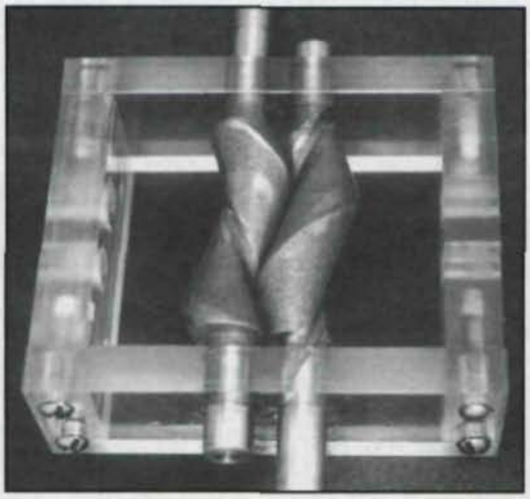
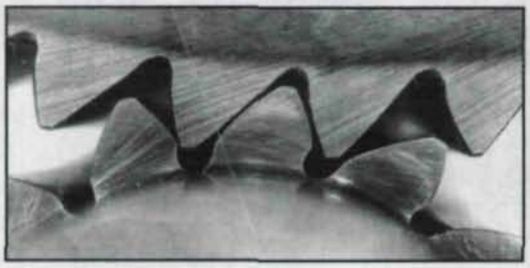


Figure 11—Helical gears with one tooth: $z_1 = 1$, $z_2 = 1$, $\alpha_w = 68.8°$, $\varepsilon_\alpha = 0.56$, $b = 34.9°$, $\varepsilon_\beta = 0.92$.



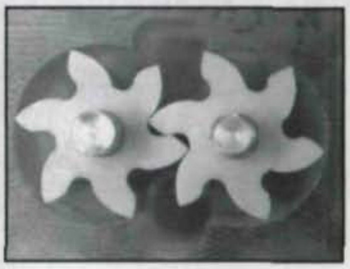


Figure 12—Spur gears with asymmetric teeth: 12a) a generator gear drive with $\alpha_w = 41°$, $\varepsilon_\alpha = 1.2$ for drive flanks and $\alpha_w = 18°$, $\varepsilon_\alpha = 1.64$ for coast flanks; 12b) a plastic gear pump with $\alpha_w = 45.7°$, $\varepsilon_\alpha = 1.01$ for drive flanks and $\alpha_w = 10.3°$, $\varepsilon_\alpha = 1.09$ for coast flanks.

Direct gear design for asymmetric tooth profiles opens additional reserves for improvement of gear drives with unidirectional load cycles that are typical for many mechanical transmissions.

Acknowledgments

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Carburizing of Big Module and Large Diameter Gears

L.J. Cheng, K.H. Wu, S.H. Yue and T.C. Kuo

This paper was presented at the JSME International Conference on Motion and Power Transmissions, MPT2001, in Fukuoka, Japan, in November 2001.

Carburized gears have higher strengths and longer lives compared with induction-hardened or quench-tempered gears. But in big module gears, carburizing heat-treatment becomes time-consuming and expensive and sometimes cannot achieve good hardness due to the big mass-effect. Also, it is not easy to reduce distortion of gears during heat treatment.

Figure 1—Conventional gas-carburizing furnaces. Maximum measurements of a gear can be 1.3 m in diameter, 2 m in height and 5,000 kg in weight. Carrier gas is endogas, enriching gas is propane.

Figure 2—New gas-carburizing furnaces. Maximum measurements of a gear can be 2.5 m in diameter, 2.5 m in height, and 15,000 kg in weight. Carrier gas is a mixture of methanol and nitrogen, enriching gas is propane.

Figure 3—Induction hardening of tooth flank only. The gear has 92 teeth, each one 405 mm long, a module of 36.4, an outside diameter of 3,115 mm and is made of SCNCrM2A, a JIS material specification.

In order to achieve good surface hardness of the carburized layer, it is necessary to precisely control the carbon content distribution. The carburizing time is much longer for big module gears due to deeper case-depth requirements. So, after carburizing, it is necessary to have intermediate cooling to less than 650°C to get finer grain size and better mechanical properties. By using a carburizing furnace equipped with a fast cooling function, workpieces can proceed through intermediate cooling and heat up again to quench temperature inside the same furnace. This can remarkably reduce the total heat-treatment time, as well as costs.

The distortion that comes from heat treatment is unavoidable. But, by improving the arrangement of a load of parts, we can reduce distortion and thereby reduce manufacturing costs.

Introduction

Surface hardening technology is very important to increasing the durability and strength of big module gears, thereby reducing the size and weight of those gears and their gear reducers and, furthermore, reducing the weight of their whole machines. But, in past years, most of the big module gears or large diameter gears were designed as either casted or welded and were heat-treated by either normalizing or through-hardening. After years of running, pitting or wear becomes serious and finally vibration and tooth breakage can happen and stop a production line.

Until recently, we at Formosa Heavy Industries Corp. of Taiwan used either carburizing or induction hardening, but the company was limited to carburizing gears with diameters of at most 1.3 m. To reduce manufacturing costs and increase the carburizing capability for big module, large diameter gears, we recently installed a new set of furnaces that can carburize gears with diameters of up to 2.5 m.

The new set of furnaces is equipped with a new carburizing process and technology in order to produce higher quality carburized gears. The computer simulation program can control the carbon content profile in order to achieve good hardness, and the fast cooling function within a nitrogen atmosphere can shorten the total heat-treatment time.

Induction Hardening

Gears with diameters bigger than a carburizing furnace should be induction-hardened. Because of the big diameters, teeth are hardened one by one. There are two ways to harden the teeth: "tooth flank hardening only" and "tooth root hardening." Figure 3 shows the treatment of tooth flank hardening, and Figure 5 shows the treatment of tooth root hardening.

Figures 4 and 6 show the macrostructure and hardness distribution curve of the hardened layers from tooth flank hardening and tooth root hardening, respectively. Figure 7 shows the tooth profile after induction hardening of the gear shown on Figure 5. That gear has been tooth root induction hardened. The result shows that the tooth pressure angle decreased slightly. Because only one tooth has been heated while the gear's other teeth remain cold during induction hardening, the geometrical accuracy and tooth lead are almost unchanged during tooth-by-tooth induction hardening.

Carburizing

Carburizing via small furnace with traditional process and carrier gas generator. Figure 8 shows the typical carburizing process of a 1.3 m furnace for about a 3 mm case depth. During carburizing, Formosa Heavy Industries uses carrier gas produced by an endogas generator. Also, the carbon potential is enriched by propane gas and controlled by an oxygen sensor. After carburizing, the workpieces must be taken out of the carburizing furnace and put into a tempering furnace for intermediate cooling, then air cooled to room temperature. After cooling, the workpieces will be painted with anti-carburizing paste, then put into the carburizing furnace again to heat up to quenching temperature. Figure 9 shows the load being taken out of the carburizing furnace, ready for quenching.

Carburizing of large diameter gears with new process furnace. Figure 10 shows the typical carburizing process for about a 5 mm case depth. The carrier gas comes from a mixture of liquid methanol and pure nitrogen. The carbon potential is measured by oxygen sensor and controlled via propane as an enriching gas and air as a diluting gas. In this case, we don't need any gas generator for our carrier gas. The carburizing, intermediate cooling and quenching procedures are continuous and don't involve taking the load out of the furnace. Figure 11 shows the load being taken out of the carburizing furnace, ready for quenching.

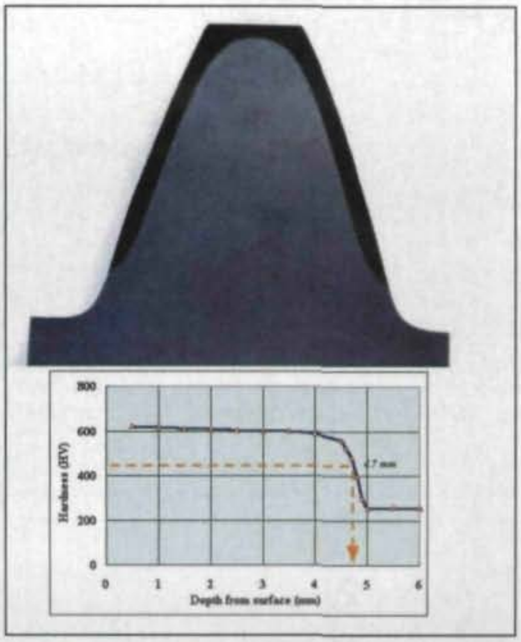

Figure 4—Test piece showing profile of tooth-flank hardened gear in Figure 3. Hardness of material before hardening: HB 250~265. Hardness of surface after hardening: HRC 52~55. Thickness of hardened layer: about 4.7 mm.

Figure 5—Induction hardening of tooth flank and root. The gear has 108 teeth, each one 182 mm long, a module of 25, an outside diameter of 2,776 mm and is made of SCM440, a JIS material specification.

Results of carburizing. Figures 12 and 13 show the macrostructure and hardness distribution of a true-sized test piece from the load shown in Figure 9 that was carburized via a 1.3 m furnace. The measured case depth is about 3.5 mm. The hardness within 0.2 mm of the surface is lower; this decarburizing effect comes from taking workpieces out of the furnace when doing intermediate cooling. Figure 14 shows the microstructure of the hardened layer; the microstructure is fully martensitic.

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T.C. Kuo

is assistant plant manager of Formosa Heavy Industries' gear plant.

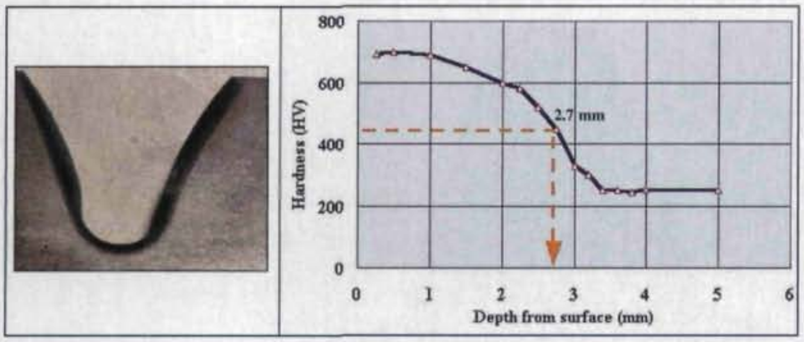


Figure 6—Test piece showing profile of tooth-root hardened gear shown in Figure 5. Hardness of material before hardening: HB 250~265. Hardness of surface after hardening: HRC 52~55. Thickness of hardened layer: about 2.7 mm.

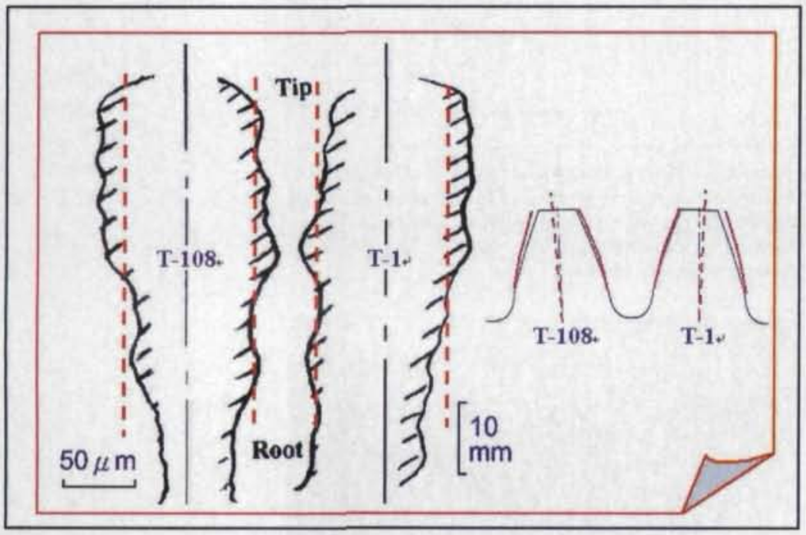


Figure 7—Tooth profile after induction hardening of tooth flank and root of gear shown in Figure 5.

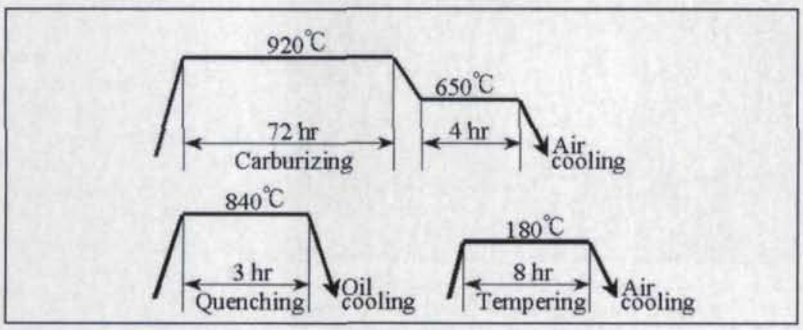


Figure 8—Carburizing process of conventional furnace, with maximum gear diameter of 1.3 m.

Figures 15 and 16 show the macrostructure and hardness distribution of a true-sized test piece from the load shown on Figure 11, which was carburized with a new 2.5 m furnace. Since the intermediate cooling occurs inside the carburizing furnace and there is nitrogen gas protection at less than 750°C, the surface of workpieces will not oxidize or decarburize; so the near-surface hardness is better than it would be if carburized via a 1.3 m furnace. Figure 17 shows the microstructure of this test piece; it is fully martensitic.

The distortion of carburized gears is a problem of great concern. According to our experience, the lower side of the gear, which touches the oil first, will shrink and that side's diameter will be smaller than the upper side's and, therefore, the gear will be a little bit conical. Consequently, the lead will change drastically. Figures 18 and 19 show the profile and lead of the gear shown in Figure 11 before and after heat treatment.

Figure 20 shows one example of load arrangement; there are 20 gears in one load. After heat treatment, we measured the geometric accuracy and hardness of every gear. In order to decrease the distortion of gears, the arrangement of workpieces during heat treatment is very important. We put plates under and above the gears to decrease their distortion. For small or ring-type gears, we overlap gears, as Figure 20 shows. For bigger gears, we have to separate them by a charging jig, as Figure 11 shows. The jig between gears will reduce the conical distortion from quenching. Figures 21 and 22 are the results of two loads arranged as shown in Figure 20 with the same heat treatment conditions. Figure 21 shows the results of normal quenching, and Figure 22 shows the results of turning the load when quenching in the oil. The latter has better geometric accuracy and more homogeneous hardness.

Performance of Carburized Gears

The performance of carburized or induction hardened gears used in a sugar plant is shown in

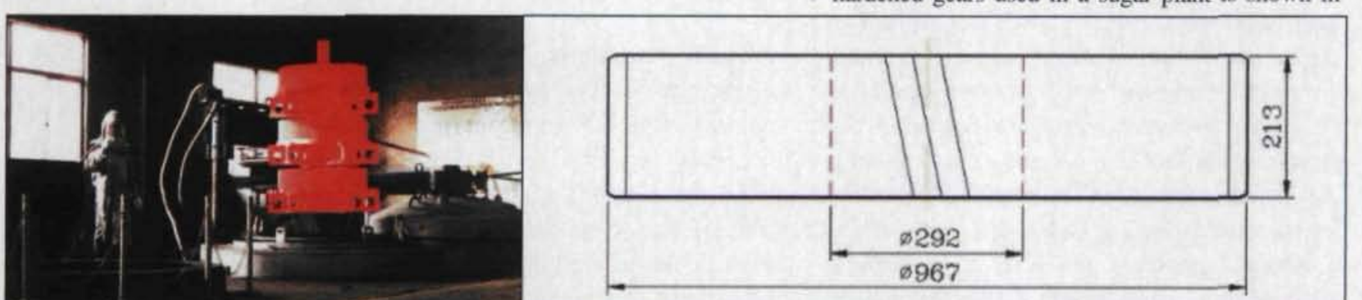


Figure 9—Just carburized gears are removed from conventional furnace before quenching. Each gear has 73 teeth, each one 213 mm long, a module of 12, an outside diameter of 967 mm and is made of SCM420H, a JIS material specification. Hardness of carburized teeth is HRC 58~59, case depth is 3.5 mm.

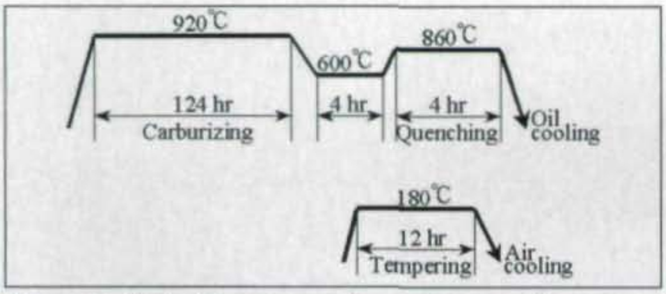


Figure 10—Carburizing process of a new furnace, with maximum gear diameter of 2.5 m.

Figure 11—Just carburized gears are removed from a new furnace before quenching. Each gear has 78 teeth, each one 407 mm long, a module of 20, an outside diameter of 1,638 mm and is made of SCM420H, a JIS material specification. Hardness of carburized teeth is HRC 58~60, case depth is 5.5 mm.

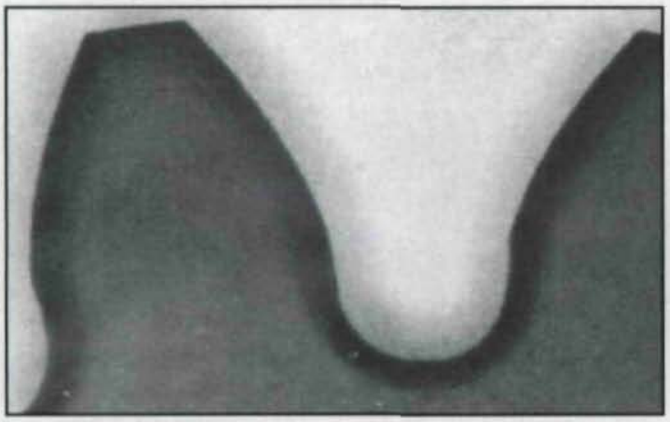


Figure 12—Macrostructure of gear test piece carburized with the gears shown in Figure 9. The test piece has five teeth, a module of 12 and is made of SCM420H, a JIS material specification.

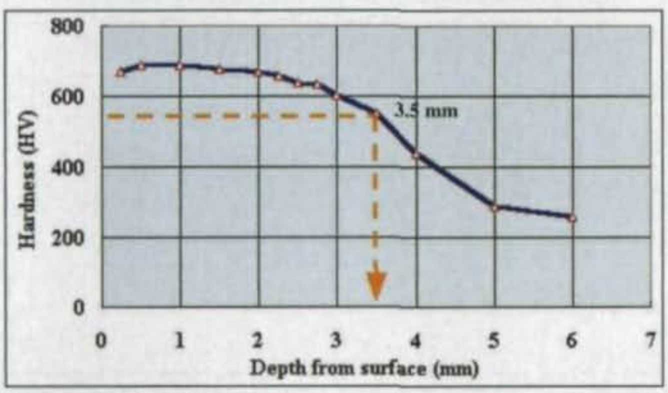


Figure 13—Hardness profile curve of gear test piece shown in Figure 12. Case depth of test piece is 3.5 mm.

Figure 14—Microstructure of carburized layer of gear test piece shown in Figure 12.

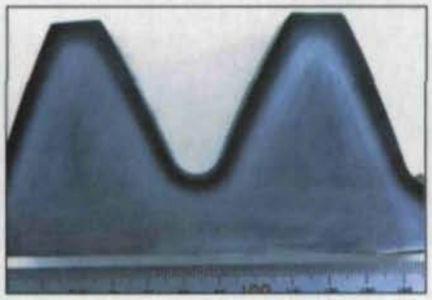


Figure 15—Macrostructure of gear test piece carburized with the gears shown in Figure 11. The test piece has 5 teeth, a module of 20 and is made of SCM420H, a JIS material specification.

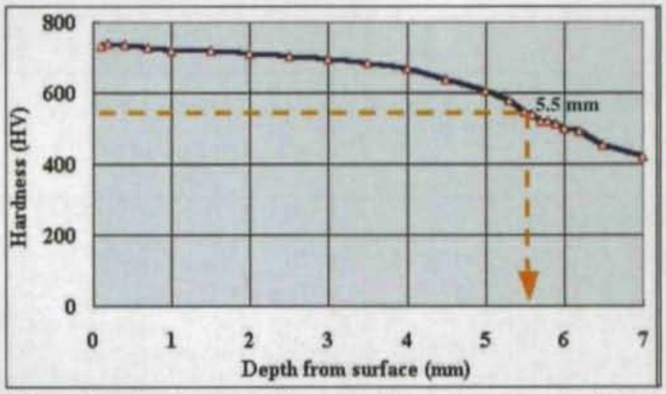


Figure 16—Hardness profile curve of test piece shown in Figure 15. Case depth of test piece is 5.5 mm.

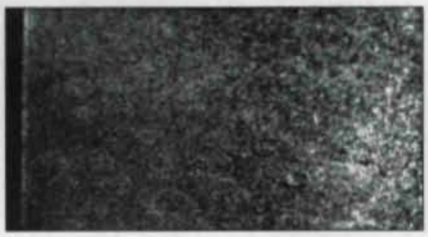


Figure 17—Microstructure of carburized layer of gear test piece shown in Figure 15.

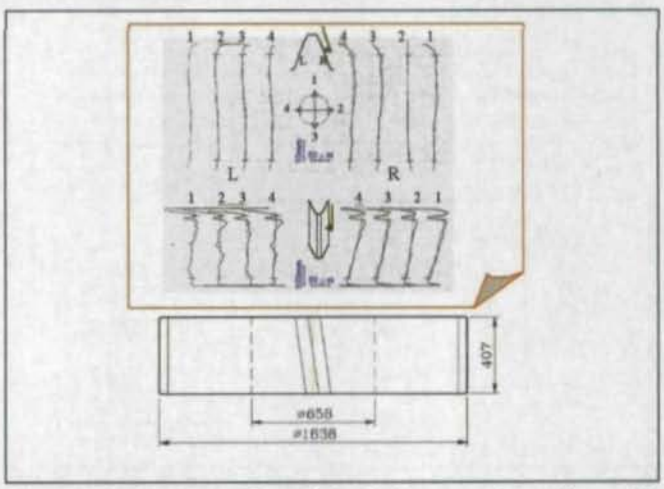


Figure 18—Tooth profile and lead of a gear from Figure 11 before carburizing.

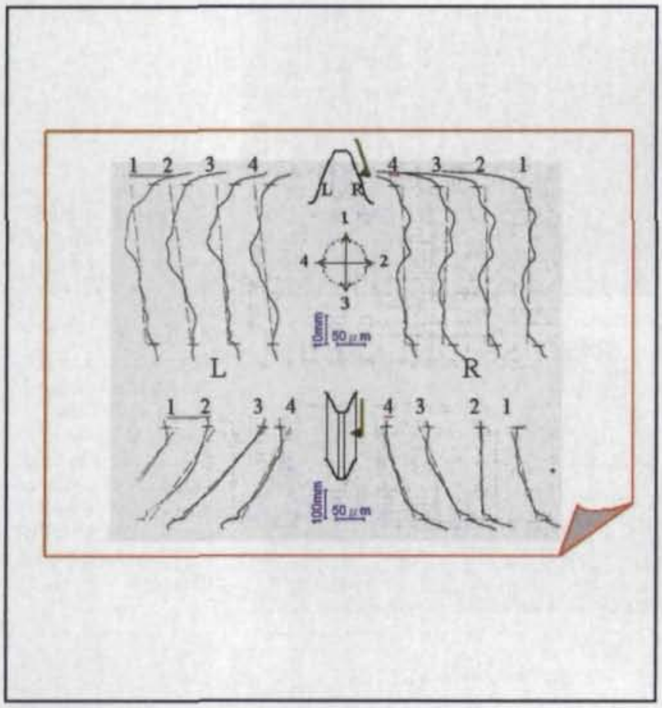


Figure 19—Tooth profile and lead of the same gear from Figure 18 after carburizing in a new process furnace.

Figure 20—Arrangement of gears before carburizing in a new process furnace. Each load consists of 20 gears. Each gear has 107 teeth, each one 160 mm long, a module of 9, an outside diameter of 980 mm and is made of 17CrNiMo6, a DIN material specification. Case depth of gears is 2.8 mm.

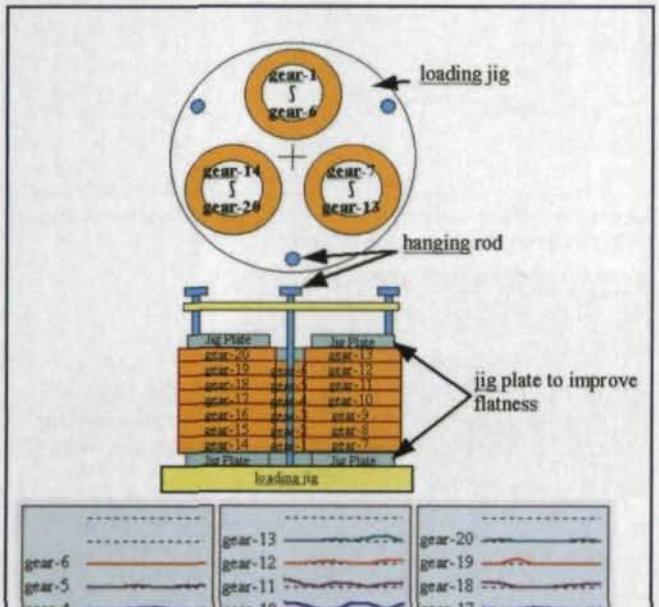


Figure 21—Comparison of gear flatness and hardness of one load of gears arranged as shown in Figure 20 and quenched normally.

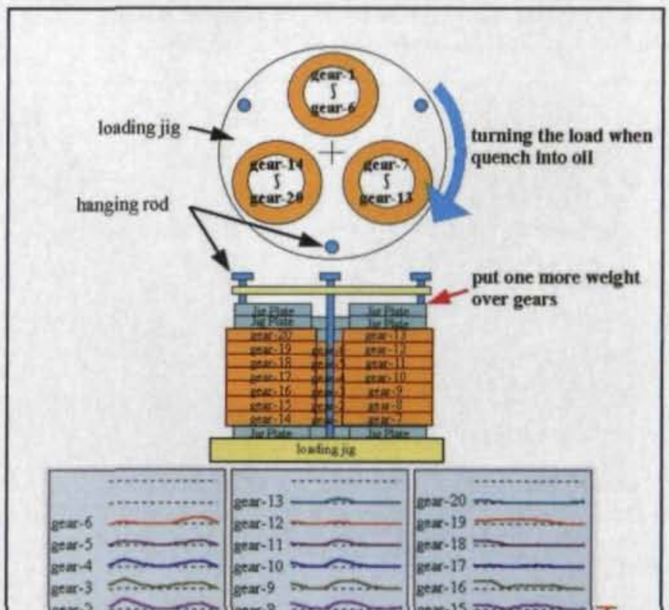


Figure 22—Comparison of gear flatness and hardness of another load of gears arranged as shown in Figure 20 and turned while quenching in oil.

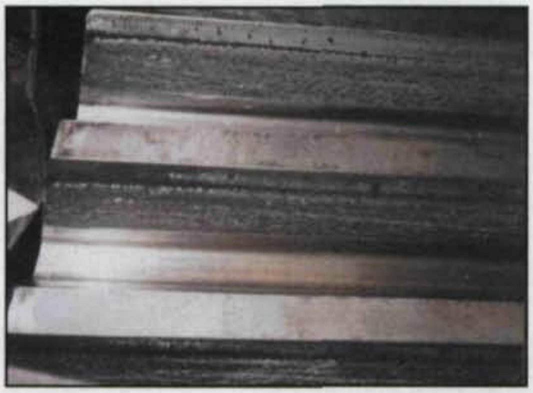
Figures 23 and 24. Figure 23 shows an open gear with normalization and a pinion with quenching and tempering. They have operated for three milling seasons, and the gear tooth surface is already pitting because the surface hardness is too low. Figure 24 shows an open gear with induction hardening and a pinion with carburizing. They also were operated for three milling seasons. Since the hardness was raised for both gear and pinion, the surface is in very good condition and the gear and pinion's lives can be longer.

Conclusion

Induction-hardened gears have less lead and profile distortion compared with carburized ones, but they have less contact and bending strength. The induction hardening of big gears requires special induction coils and more operators. Of the two types of induction hardening, tooth root hardening results in more bending strength than tooth flank hardening, but the former requires more advanced technology.

Carburized gears have higher tooth surface hardness than induction-hardened gears. Also, the hardness distribution and microstructure of carburized gears are more homogeneous than they are in induction-hardened ones. Therefore, carburized gears have higher contact strength and bending strength compared with induction-hardened gears.

The distortion of carburized gears is bigger than that of induction-hardened gears. When the diameter of a gear becomes bigger, it is necessary to increase the gear's case depth to compensate for the bigger distortion. This will increase the heat-treatment time, as well as the grinding time after heat treatment. We have reduced the distortion of gears by better arranging workpieces in a load and turning the workpieces during quenching. We will continue to reduce distortion through further testing and data collection.



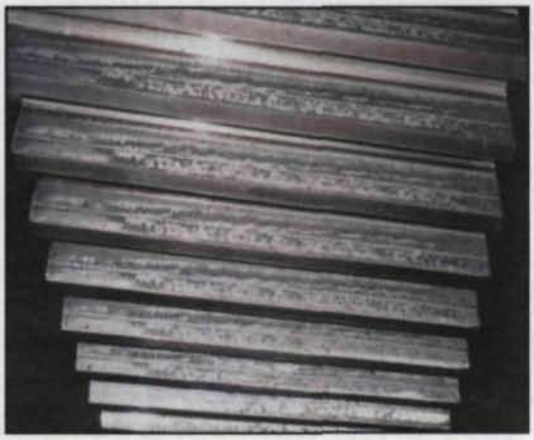


Figure 23—Open gear and pinion used in a sugar plant and made by another gear manufacturer, after three milling seasons in operation. The pinion (upper) has 22 teeth, each one 710 mm long, a module of 40, an outside diameter of 982 mm and is made of quenched and tempered SCM440, a JIS material specification. The gear (lower) has 95 teeth, each one 700 mm long, a module of 40, an outside diameter of 3,858 mm and is made of an unknown normalized material.

Figure 24—Open gear and pinion with the same dimensions as in Figure 23, used in the same sugar plant and made by Formosa Heavy Industries, after three milling seasons in operation. The pinion (upper) is made of SCM420H, a JIS material specification, carburized to HRC 57~59, with case depth of 4.5 mm. The gear (lower) is made of SCM440, a JIS material specification, tooth flank and root induction hardened to HRC 52~55.

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Measuring Profile and Base Pitch Errors with a Micrometer

Richard L. Thoen

In this article, equations for finding profile and base pitch errors with a micrometer are derived. Limitations of micrometers with disc anvils are described. The design of a micrometer with suitable anvils is outlined.

Introduction

The span method is not widely used in the fine-pitch field, mainly because "it would be necessary to make micrometers with special anvils" (Ref. 1). Consequently, the pin method is still in widespread use, despite its requiring several micrometers instead of one or two, a large set of pins instead of no set at all, a computer instead of a pocket calculator for computations, and a change factor (Ref. 2) that is variable instead of constant. The pin method has, in George Grant's words (on the cycloid versus involute controversy, Ref. 3),

> . . . the recommendation of many well-meaning teachers, and holds its position by means of "human inertia," or the natural reluctance of the average human mind to adopt a change, particularly a change for the better.

For a relatively sharp edge between the tip land and involute, a condition typical of fine-pitch generated gearing (hobbed, shaped, ground), the tooth thickness can be measured with an ordinary micrometer, as shown in Figure 1. But for a relatively large tip round between the tip land and involute, a condition typical of formed gearing (molded plastic, die cast, powder metal, stamped, cold-drawn), the tooth thickness generally cannot be measured with an ordinary micrometer, since contact is near the tooth tips.

Conventional wisdom has it—dating back to Wildhaber, the originator of the span method (Ref. 5)—that contact should be near the mid-point of the active profile, away from any tip and/or root relief. Yet, it is essential to understand that tooth thickness is not measured directly but is calculated from an equation based on perfect teeth. As a result, there are unknown errors in measured tooth thickness (Refs. 6 & 7) that can nullify the apparent benefit of contact near the mid-point of the active profile, particularly in the fine-pitch field wherein profile modification is not prevalent.

As Louis Martin, chairman of the AGMA Fine-Pitch Committee from its inception in 1941 until 1953, stated (Ref. 4):

> The glaring mistake that has been made by the gear industry is to try to relate fine-pitch requirements with experience gathered from the coarse-pitch field.

Micrometer Design

A micrometer with suitable anvils can measure not only the profile and base pitch errors on fine-pitch gearing, but also the tooth thickness on

Nomenclature

d	Diameter of reference circle
d_b	Diameter of base circle
M	Span dimension or measurement
M_b	Basic span dimension
N	Number of teeth on gear
n	Number of spanned teeth
P	Diametral pitch
p	Circular pitch on reference circle
$p/2$	Basic tooth thickness on reference circle
p_b	Base pitch
r	Radius of reference circle
r_b	Radius of base circle
r_c	Radius to point of contact
r_{if}	Inside form radius
r_{of}	Outside form radius
Δt	Deviation from $p/2$
t_b	Tooth thickness on base circle
Δt_b	Deviation from t_b
τ_b	Angle subtended by $t_b/2$
Φ	Profile angle

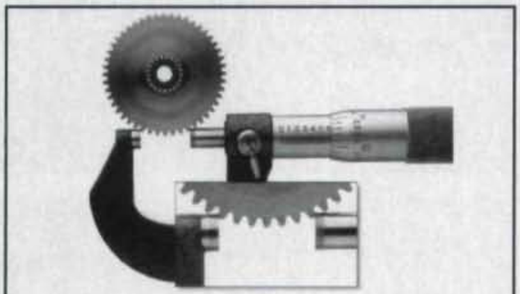

Figure 1—Span measurement with an ordinary micrometer.

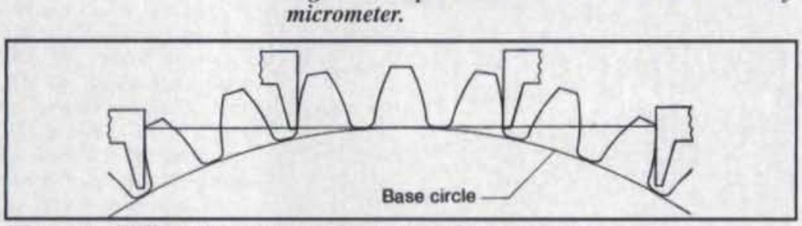

Figure 2—Different span measurements on the same gear.

formed gearing. Specifically, it is seen from Figure 2 that the tooth thickness can be calculated from any one of several different span measurements. Thus, the calculated tooth thickness for a perfect gear is the same for different span measurements. Conversely, the calculated tooth thickness for an imperfect gear is not the same for different span measurements—a symptom of errors in profile and/or pitch.

Also, from Figure 2 it is seen that the base pitch can be measured by starting with the maximum span measurement and then, while retaining the point of contact on either outermost tooth, reducing the span dimension in steps equal to the base pitch.

When measuring the minimum span dimension, contact is near the tips of the anvils, as seen in Figure 2. So, for a micrometer with conventional disc anvils, there is little more than point contact on the teeth, not line contact. Moreover, the full face width of a pinion on a cluster gear generally cannot be spanned with disc anvils.

Consequently, the anvils should be square, not round. And since a square anvil cannot rotate, the micrometer spindle must be non-rotating, as on conventional blade micrometers. A micrometer with these features, made for spanning gears of 20–80 diametral pitch, is shown in Figure 3.

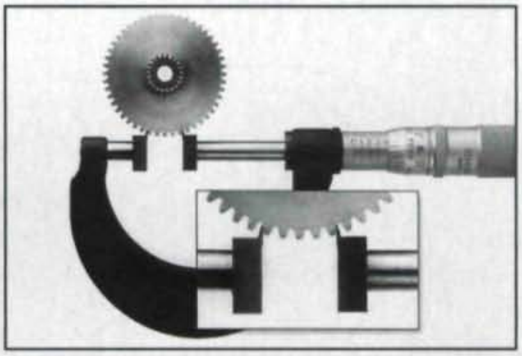

Figure 3—A micrometer with special anvils. Courtesy of S-T Industries Inc., St. James, MN.

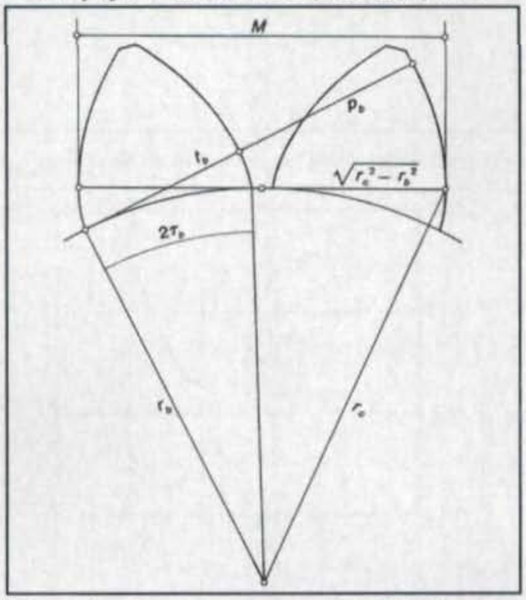

Figure 4—Span measurement of tooth thickness.

Averaging

On generated gearing, the profile error tends to be uniform around the gear, whereas the index error tends to be sinusoidal (Refs. 8 & 9). As a result, the error in span measurement tends to be sinusoidal around the gear. Thus, to minimize the detrimental effect of index error, the calculated tooth thickness should be based on the average of two or more span measurements.

In particular, for even tooth numbers, the calculated tooth thickness is based on the average of two diametrically opposite span measurements. Odd tooth numbers 23 and greater can be treated as an even tooth number without incurring a significant error. For $N = 21$, 15 and 9, the calculated tooth thickness is based on the average of three span measurements 120° apart.

It is important to remember that if the averages for various sets of teeth around the gear are significantly different (a condition typical of formed gearing), then averaging is not applicable (Refs. 10 & 11).

For $N = 19$, 17, 13 and 11, the calculated tooth thickness is based on the average of the maximum and minimum span measurements, provided that they are within 180°/N of being diametrically opposite. For $N = 7$ and 5, the calculated tooth thickness is based on the average of all seven and five span measurements, respectively, provided that the variation around the gear is sinusoidal.

It is pertinent to note that the pin method is not applicable to profile measurements on formed gearing, since the profile error can be quite different on diametrically opposite teeth.

Basic Geometry

From Figure 4, it is seen that the span dimension across n teeth is $M = (n - 1)p_b + t_b$,

where

$$p_b = \frac{\pi d_b}{N}$$

and

$$\frac{t_b}{r_b} = 2\tau_b,$$

so that

$$M = d_b[(n-1)\frac{\pi}{N} + \tau_b].$$

From Figure 5, it is seen that the

$$\tau_b = inv\Phi + \frac{\frac{p}{2} + \Delta t}{2r}.$$

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is a consultant specializing in medium- and fine-pitch gearing. He is the author of several articles and papers on measurement, involute mathematics, statistical tolerancing and other gearing subjects.

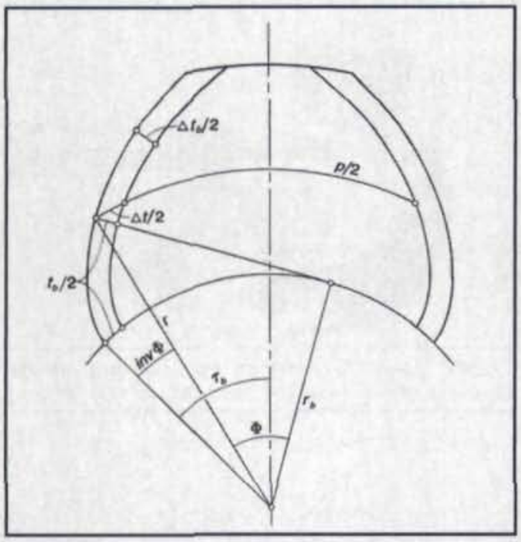

Figure 5—Deviation from basic tooth thickness.

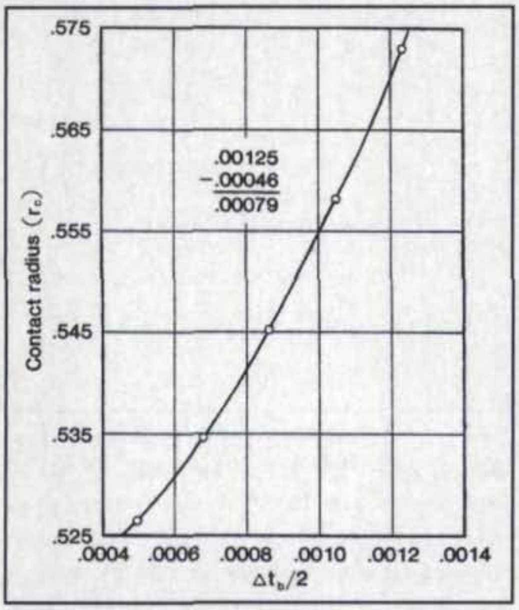

Figure 6—Profile error obtained from span measurements.

Table I					
	40.2*P*		40*P*		
	M	r_c	M_b	r_c	$\Delta t_b/2$
n	Eq. 1	Eq. 3	Eq. 1	Eq. 3	Eq. 4
7	0.49266	0.5702	0.49513	0.5731	−0.00123
6	0.41923	0.5553	0.42132	0.5581	−0.00105
5	0.34579	0.5425	0.34752	0.5453	−0.00086
4	0.27236	0.5320	0.27372	0.5346	−0.00068
3	0.19892	0.5238	0.19991	0.5264	−0.00050

where $\frac{p}{2}$ is the basic tooth thickness, namely, $\frac{p}{2} = \frac{\pi d}{2N}$, and Δt is the deviation from $\frac{p}{2}$, so that

$$\tau_b = inv\Phi + \frac{\pi}{2N} + \frac{\Delta t}{d},$$

where $d = d_b/cos\Phi$.

Then, substituting for τ_b, the span dimension becomes

$$M = d_b \left[\left(n - \frac{1}{2}\right)\frac{\pi}{N} + inv\Phi\right] + \Delta t\, cos\Phi. \quad (1)$$

An examination of Figure 4 shows that

$$M = 2\sqrt{r_c^2 - r_b^2}\,.$$

Equating this equation to Equation 1 and solving for n, the number of teeth to span is

$$n = \frac{N}{\pi}\left[\sqrt{\left(\frac{r_c}{r_b}\right)^2 - 1} - inv\Phi - \frac{\Delta t}{d}\right] + \frac{1}{2}. \quad (2)$$

To find the range of n, Equation 2 is solved for $r_c = r_{of}$ and $r_c = r_{if}$, where r_{of} is the outside form radius (minimum outside radius less chamfer or tip round), and r_{if} is the inside form radius (lowest point at which the mating gear can make contact).

In Equation 2, the n for $r_c = r_{of}$ is rounded down, and the n for $r_c = r_{if}$ is rounded up, both to the nearest integer.

The radius to the point of contact is, as seen in Figure 4,

$$r_c = \frac{\sqrt{d_b^2 + M^2}}{2}. \quad (3)$$

As mentioned earlier, the calculated tooth thickness for an imperfect gear is not the same for all span measurements. Specifically, given a span measurement (M), the Δt is calculated from Equation 1. However, as seen in Figure 5, the $\Delta t/2$ is a circular arc on the reference circle, not a normal to the involute at radius r_c (Eq. 3). Even so, in Equation 1 the $\Delta t cos\Phi = \Delta t_b$, where $\Delta t_b/2$ is normal to all points on the involute; that is, in Figure 5 the arcs $\Delta t/2$ and $\Delta t_b/2$ subtend equal angles, namely,

$$\frac{\Delta t/2}{r} = \frac{\Delta t_b/2}{r_b}, \text{ or } \Delta t\frac{r_b}{r} = \Delta t_b,$$

where from Figure 5 the $rcos\Phi = r_b$, so that $\Delta t cos\Phi = \Delta t_b$. Thus, the equation for $\Delta t_b/2$ is simply

$$\frac{\Delta t_b}{2} = \frac{M - M_b}{2}, \quad (4)$$

where M is the span measurement and M_b is the basic span dimension, namely, that for $\Delta t = 0$ in Equation 1.

It is important to remember that the profile error is the variation in $\Delta t_b/2$ from r_{of} to r_{if}, not a particular value from Equation 4.

For example, given that $N = 44$, $\Phi = 20°$, $\Delta t = 0$, $r_{of} = 0.575$, $r_{if} = 0.525$, and a diametral pitch that is mistakenly 40.2*P* instead of 40*P*. Find the profile error relative to the $40P$. From Equation 2, for $40P$ the $n = 7.1$ and 2.8 for r_{of} and r_{if}, respectively. See Table I for $\Delta t_b/2$.

The r_c for $40P$ is plotted against $\Delta t_b/2$ in Figure 6, which shows a profile error of 0.00079 between r_{of} and r_{if}. The exact profile error, as determined from enlarged layouts (Ref. 12), is 0.00076. Thus, for this idealized example, the error in the span method is 0.00003, or only 4%. The reason for the discrepancy is that in practice the r_c is known for the perfect gear ($40P$), not for the imperfect gear ($40.2P$). ❍

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Gear Industry News

Longtime President of Star Cutter Dies

Norman Ballard Lawton, president of Star Cutter Co. for more than 50 years, died June 29. He was 88 years old.

First located in Detroit, Star Cutter was started in 1927 by his father, Howard Lawton, and Frank Burgess and had 10 employees. Norman Lawton became president of the cutting tool company in 1945.

While he was president, Star Cutter grew to a company with more than 900 employees working in plants in several states. Also, the company introduced many practices and innovations to cutting tool manufacturing and patented advances for producing metal cutting tools.

Mr. Lawton was born June 25, 1914 in Athol, MA. While he was a child, his family moved to Detroit. He later studied engineering for three years at the University of Michigan, located in Ann Arbor, MI. With the outbreak of World War II, Mr. Lawton returned to Detroit to work in his father's business.

His surviving son, Bradley L. Lawton, succeeded him as president of Star Cutter Co. in 1995.

Founder of Barit International Dies

Alexander Polevoy, founder of gear cutting tool company Barit International Corp., died June 22 of lung cancer. He was 57 years old.

Mr. Polevoy started his career in the gear industry after graduating in 1969 from Minsk Polytechnic Institute, located in Minsk, Belarus. He graduated with a master's degree in mechanical engineering.

Born August 10, 1944 in Moscow, Russia, he immigrated in 1978 to the United States. Once in America, he worked at Overton Gear & Tool Corp. of Addison, IL, rising to the position of chief process engineer.

In 1989, Mr. Polevoy left Overton and founded Barit International Corp. Based in Northbrook, IL, Barit provides gear cutting tools.

Mr. Polevoy served as president of Barit until he died. His son Vladimir succeeded him as president of Barit.

Bourn & Koch, Star-SU Divide Assets of Fellows Corp.

Bourn & Koch Machine Tool Co. and Star-SU Inc. bought the gear shaper machine tool and cutting tool manufacturing assets of Fellows Corp.

According to Star-SU's press release, the assets related to the manufacture of Fellows gear shaping machines, involute/lead masters and related products, part inventory and work-in-process were bought by Bourn & Koch of Rockford, IL. Bourn & Koch will continue to manufacture Fellows machines and parts from its Rockford facility.

Through Bourn & Koch, Star-SU of Hoffman Estates, IL, acquired all assets relating to the manufacture of Fellows gear shaper cutting tools, including inventory and work-in-process. Star-SU will continue to manufacture Fellows disk-type, shank-type, fine pitch, special and cam shaper cutters using the Fellows/Star-SU name.

Both companies entered into a general marketing agreement. Star-SU will promote, represent and sell Bourn & Koch-built Fellows gear shapers through Star-SU and Bourn & Koch distribution channels.

Fellows Corp., previously owned by Goldman Industrial Group, ceased operations on Feb. 13 and filed for Chapter 11 bankruptcy protection.

Philadelphia Gear Appoints New General Manager

Philadelphia Gear Corp. of Norristown, PA, hired John Maskaluk as general manager of its western region, headquartered in Lynwood, CA.

According to the company's press release, Maskaluk will manage the company's manufacturing and service center, overseeing its transition toward a more customer-centered business model.

New Director of Metrology for Process Equipment Co.

Mark Cowan was named director of metrology of Process Equipment Co., which manufactures gear measurement systems in Tipp City, OH.

Among his new responsibilities will be managing the software development for the Windows-based Next Dimension gear measurement system.

Cowan has held technical positions in the gear industry for 19 years.

Chicago Gear Acquires Franke Gear Works

Chicago Gear, a subsidiary of D.O. James Corp., acquired Franke Gear Works of Chicago, IL.

Franke will continue to specialize in manufacturing precision ground racks and double enveloping worm sets.

In its press release, Chicago Gear said this acquisition adds gear grinding capacity to its recently purchased Niles Kopf grinder.

Chicago Gear manufactures gears and gearboxes and is located in Chicago, IL.

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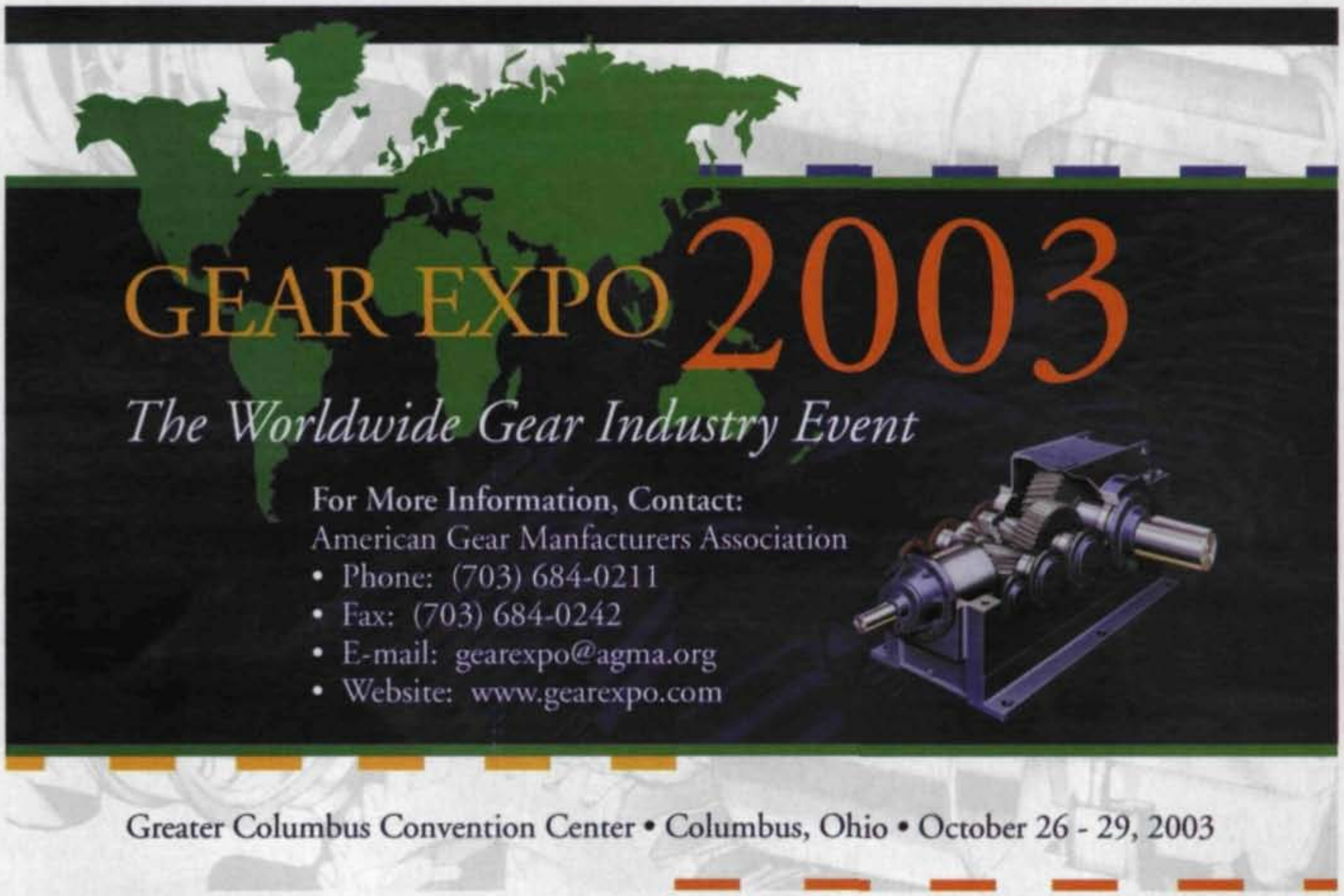
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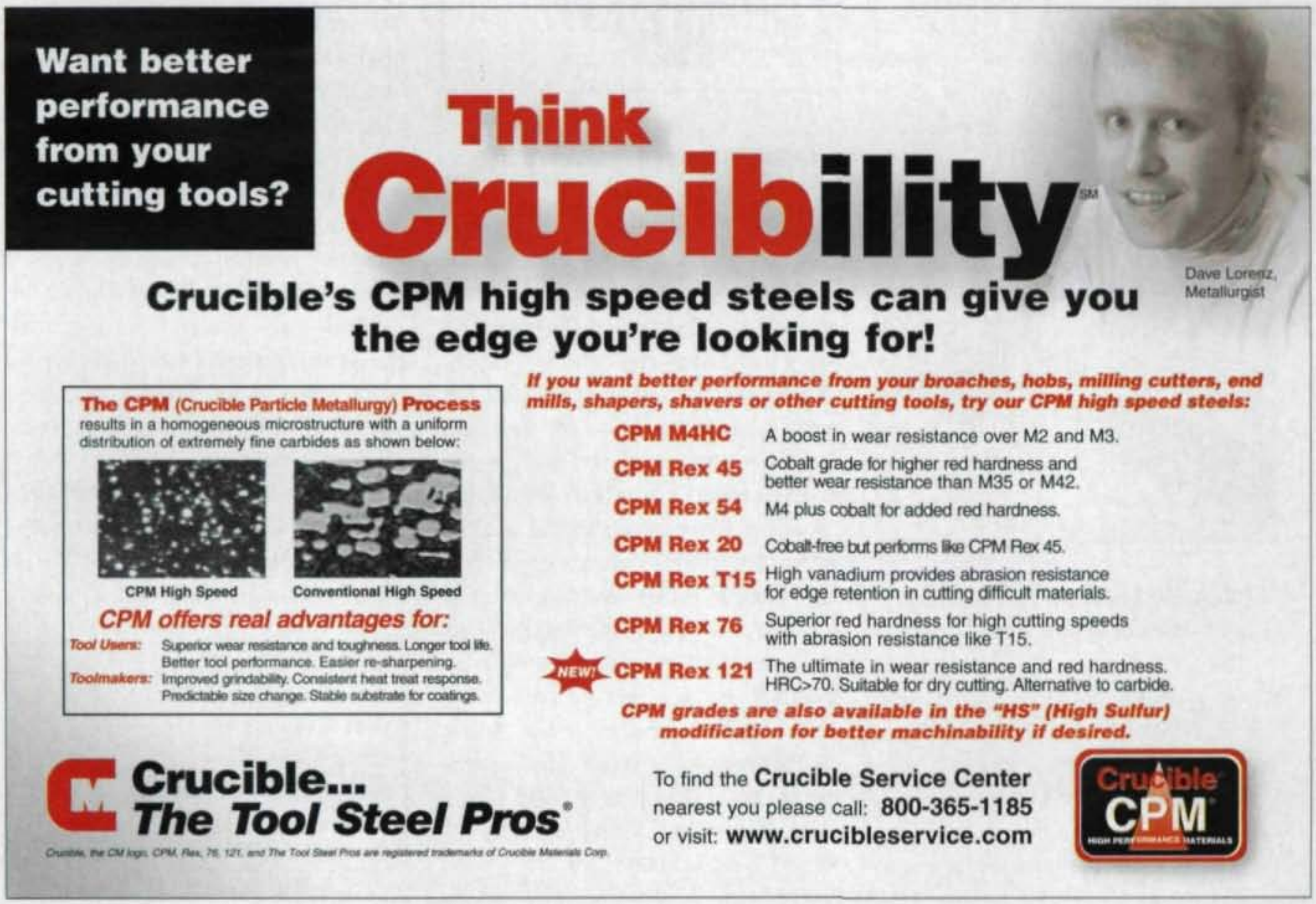
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Products for the Gear Industry

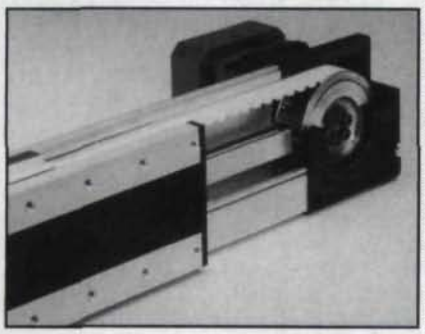
Induction Hardening Tool for Gears from Quantik

Quantik Corp. introduced an induction hardening machine tool for gears that is programmable from a CNC controller and pendant.

Tolerances of 0.01″ are programmed and held during production. The computer memory can store as many programs as there are gear sizes to run. The computerized controller allows various combinations of teeth/roots to be processed in both internal and external modes. After gear faces and roots are hardened, the unit automatically goes into position to scan harden a ball raceway if programmed into the cycle.

The induction cycle can be executed in a submerged or spray quench condition with recirculating controlled temperature fluid for distortion control.

For more information, contact Quantik Corp. by telephone at (503) 654-4264 or on the Internet at *www.quantik.com.*



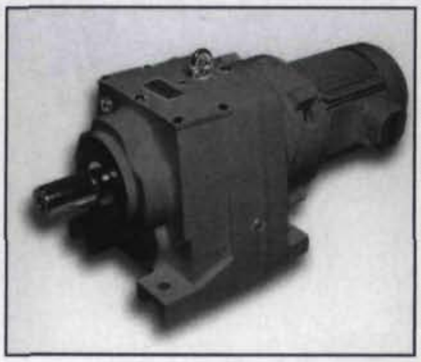
Integrated Geared Pulley Drive System from Alpha Gear Drives

The LPB Integrated Geared Pulley Drive System from Alpha Gear Drives was designed to be integrated with linear motion applications.

The gearbox has a flange output, which allows it to be nested inside the pulley and eliminates the need for a right angle gearbox, couplings and additional bearings. The product is available in sizes 70–120 mm with ratios of 1:1, 3:1, 5:1 and 10:1.

According to a company press release, its design reduces package size and installation space requirements.

For more information, contact Alpha Gear Drives Inc. of Elk Grove Village, IL, by telephone at (847) 439-0700 or on the Internet at *www.alphagear.com.*



Gearmotors and Reducers from Cone Drive

The Series M range of helical inline gearmotors and reducers has been redesigned to provide a compact drive solution for OEM and handling and conveyor manufacturers, as well as a variety of industries including energy, pulp and paper, water treatment, oil and gas.

A key element in the units is the motor connection, which offers the option of fitting any standard electric motor. The patented motor adapter system means the range accepts all sizes of standard NEMA and IEC flange-mounted electric motors without the need for modifications or interface connectors, according to the company's press release.

These motors can meet most requirements up to 120 hp or 90 kW with a maximum output torque capacity of 97,350 lb.-in. (11,000 N-m).

For more information, contact Cone Drive at (231) 929-8355 or on the Internet at *www.textronpt.com.*

New Gear Inspection Systems from M&M Precision

M&M Precision Systems Corp. of Dayton, OH, introduced two new gear inspection systems: the Microtop CNC and the Sigma Series.

The Microtop provides full four-axis, Windows®-based generative measuring capacity. The shop hardened system is designed for modern manufacturing cells and offers the same analysis capability for parallel axis gears, worms and worm shafts as the larger Sigma Series Machines.

The Sigma 3 and 7 Systems combine four-axis generative motion with 3-D probe technology and high speed linear motor direct drives. According to M&M Precision's press release, these machines come standard with Windows®-based inspection software. In addition to complete analysis capability for parallel axis gears, application-specific software modules are available for cross-axis gears, including bevel, spiral bevel and hypoid gears, as well as worms and worm shafts, gear cutting tools and other rotating components.

For more information, contact M&M Precision Systems by telephone at (937) 859-8273 extension 8969 or 8967 or on the Internet at *www.mmprecision.com.*

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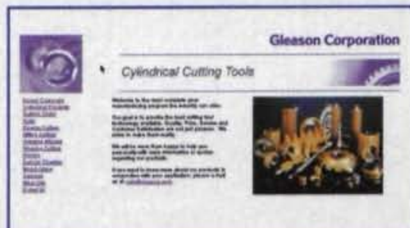

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Gears of
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Nobody's sure what went on in Bolsa Chica, CA, when gear-shaped stones were used there 8,700 years ago, but a popular belief is that at least some activity revolved around manufacturing.

"A few (stones) were found with human remains," says Patricia Martz, an archaeologist at California State University who researched the findings at Bolsa Chica because of her interest in preservation. "A few were found buried and some of these displayed various stages of manufacture. Therefore, it is thought that the site was a manufacturing and distribution center for cogged stones, because of the unfinished ones and because so many more have been found at this site than elsewhere in the region."

Thousands of such stones have been found at The Bolsa Chica Mesa, which overlooks the Bolsa Chica wetlands and the Pacific Ocean at Huntington Beach, CA. Some of them were shaped like gears and others were shaped like stars and donuts. Officially named CA-ORA-83, the mesa also contains arrowheads, beads, fish and animal bones, shellfish, fishing equipment, crystal, and plummet and charm stones that were collected by early archaeological investigators. Cogged stones were found along the Pacific coast and the Santa Ana River. Similarly contoured stones were found on a site called Quebrada Los Conchas in Chile. The stones at both sites dated back approximately 8,700 years.

The stones were unearthed as far back as the 1920s when archaeologists first began combing the Bolsa Chica territory. Approximately 20 years ago, even more were discovered when the Hearthside Homes real estate development company hired archaeologists to prepare the land for groundbreaking.

More than 1,000 cogged stones were discovered at Bolsa Chica during the excavation project.

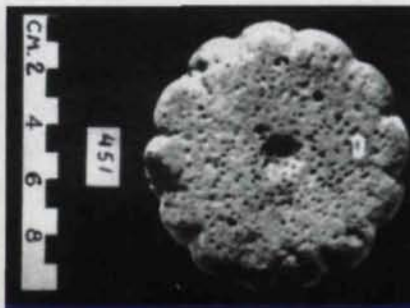
Because there were no markings or signs of wear on them, archaeologists conjectured that they might have some kind of tribal religious significance. Most of the stones were found on the surface of the burial site. According to speculation, they were placed above the cemetery for symbolic purposes, says Martz.

Another facet of the mystery is that they were found in stacks two to three stones high, says Chris Moser, curator of anthropology at Riverside Municipal Museum in Riverside, CA.

"It could mean a lot of different things," he says. "They could have been used as ritual objects or as weights on a fishing net. We'll never be able to know for sure."

In the 1920s, Samuel Evans, then mayor of Riverside, took it upon himself to solve the mystery of the cogged stones. He placed ads in newspapers soliciting geology experts and contacted local collectors and Native Americans for their help. He never reached any conclusion and died in 1932.

Not all the cogged stones are in museums, but they have all been removed from Bolsa Chica through the development process, according to Martz. After the archaeological team analyzed the stones, they turned them over to an archaeologist with a private rock collection. An album of slides and photos of the cogged stones exists at the department of anthropology curation facility at California State University in Long Beach, CA.



"They could have been used as ritual objects or as weights on a fishing net. We'll never be able to know for sure," says Chris Moser, an anthropology curator, about some ancient gear-shaped stones.

The land, devoid of its cogged stones, soon will be split between the wetlands and an Orange County subdivision. Though the 1,200-acre wetland area has protected historical status, a real estate development group plans to build 388 tract homes on the upper part of the Bolsa Chica.

The cogged stones may not be around for rock enthusiasts to dig up anymore, but at least some of the stones are being preserved for gear aficionados everywhere.

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