GEAR TECHNOLOGY

SEPTEMBER/OCTOBER 2006
The Journal of Gear Manufacturing
www.geartechnology.com

IMTS 2006

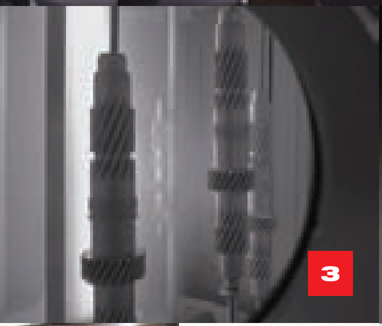
- Booth Previews

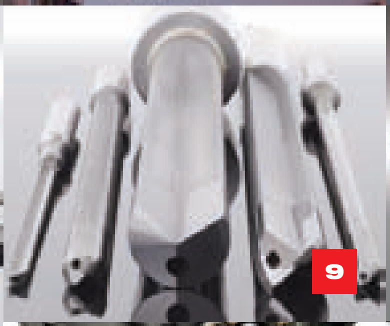
TECHNICAL ARTICLES

- The Effects of Pre-Rough Machine Processing
- Optimization of Gear Shaving
- Determining the Shaper Cut Helical Gear Fillet Profile

THE GEAR INDUSTRY'S INFORMATION SOURCE

by helping you get through yours.





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3 Star SU – Balzers Applied Coating Technology enhances your cutting processes and reduces your overall tool cost-per-part.
4 Star PTG 1 CNC 5 Axis Hob & Shaper Cutter Tool Resharpening Machine – gives you the additional capability to sharpen form relief cutters, end mills, drills and step drills. Includes NUMROTO software and quick change tooling.
5 Bourn & Koch's 100H CNC Horizontal Hobbing Machine - ideal for hobbing multiple splines and gears on shafts with tandam mounted hobs and milling cutters.
6 PTG 4 5 Axis Tool and Cutter Grinding Machine - gives you the capability to grind or sharpen tools and cutters as well as grinding orthopedic surgical tools. NUMROTOplus software running on Windows. Many optional features.
7 Bourn & Koch's Fellows MS450-125 CNC Gearless Gear Shaper with CNC controlled guide
8 H.B carbides for fluted preforms, flat blanks, cold-head dies and bushings, round rod, gundrill blanks, special extruded shapes, wear parts and punches
9 Star SU Gundrills & Reamers
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12 Star SU Bevel Stick Blades
13 Star SU PCD Rotary Cutting Tools
14 Samputensili S250CDA-CF CNC Chamfer Deburr Machine

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SEPTEMBER/OCTOBER 2006 *The Journal of Gear Manufacturing*

IMTS

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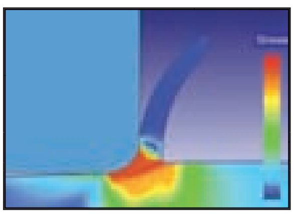
TECHNICAL ARTICLES



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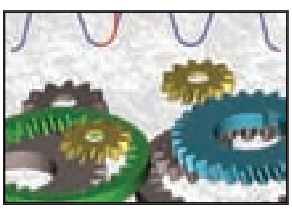

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GEAR TECHNOLOGY

The Journal of Gear Manufacturing

EDITORIAL

Publisher & Editor-in-Chief
Michael Goldstein

Managing Editor William R. Stott

Associate Editor Joseph L. Hazelton

Assistant Editor Robin Wright

Editorial Consultant Paul R. Goldstein

Technical Editors
Robert Errichello, Don McVittie,
Robert E. Smith, Dan Thurman

ART

Graphic Designer Kathleen O'Hara

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Web Developer Dan MacKenzie

***Gear Industry Home Page*™ Sales**
Ryan King

***powertransmission.com*™ Sales**
Jim King

RANDALL PUBLISHING STAFF

President Michael Goldstein
Vice President Richard Goldstein
Accounting Luann Harrold

Phone: 847-437-6604
E-mail: ***wrs@geartechnology.com***
Web: ***www.geartechnology.com***
www.powertransmission.com

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Come to Chicago

Once again, IMTS is upon us. It's being held September 6–13 at Chicago's McCormick Place Exposition Center. If you're like most of the gear manufacturers I talk to lately, you're extremely busy. You don't have enough people, machines, experience, or time to get the work done—and maybe most importantly, you're not getting enough sleep.

I know what you're thinking: You don't have time for IMTS. You can't afford to take a day off—let alone two or three. You've got orders to fill, and you're short-staffed, and you're behind schedule. To top it off, there's that crabby customer who always complains if his order is a day late, and you've got to figure out how to get him his gears, even though all your machines are booked, and "Old Bessie"—that vintage hobber you keep in the back of the shop—has finally broken down for good. If any of that sounds familiar, you're probably not alone.

Despite all these demands on your time and energy, sometimes you just need to get away. Force yourself to get out of the office or the shop—not for a vacation, which you probably *do* need—but to find the technology and solutions that will get you ahead of your production schedule instead of behind it. Take a break from today's problems and details to focus on tomorrow's productivity and growth.

So come to Chicago and IMTS, even for just a day or two. What you'll find is the best manufacturing technology and expertise available in the world—not just gear manufacturing technology, but technology for your entire shop. These technologies will provide your company ways to increase productivity in turning, grinding, inspection, the tool room and more.

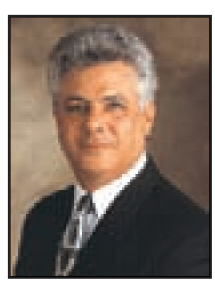
Of course, gear industry suppliers will be there as well, mostly in and around the gear pavilion. We have previews of some of the premier suppliers beginning on page 19. Maybe it's a good thing Old Bessie broke down. She may have served you well, but she's probably not the answer anymore. New, efficient, automated and productive gear machine tools might be able to double or triple your productivity while taking up less floor space (sorry, Bessie).

And that's the answer, really. Increase your productivity. Today, you're competing against gear manufacturers from all around the world. Some of them may be in countries where labor is a fraction of the cost of what you pay. You can minimize the effect of that benefit by squeezing the labor content out of your product. Instead of 20% of the cost of your products being attributable to labor, work to get it to 10%.

The way to reduce the labor content is to invest in better, faster, more productive equipment and tooling, to understand alternative processes, methods and techniques. As you reduce the labor content of your products, you minimize the impact of your competitors' lower costs. And there's no better way to see the options than by visiting IMTS.

Don't let the fact that you're busy today stop you from taking the time to make important investments that will benefit you tomorrow. As we all know, the economy runs in cycles, and—as good as it may be now—eventually, there's a downturn coming. I hope we have a couple more good years. But if you don't invest in the latest productivity now, you might miss the cycle completely—and who knows when your next chance might be. Can you afford to wait seven to eight more years to upgrade your shop? If you don't keep up with developments today, will your shop be around in seven to eight more years?

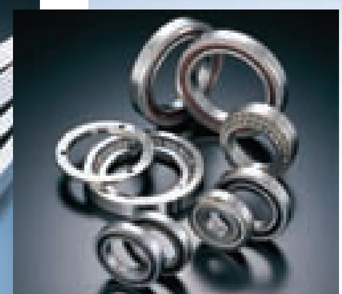
Come to beautiful Chicago to seek your company's next investment. Maybe the technology you find there will help you increase productivity enough that you'll be able to breathe a little easier by this time next year. Who knows? Maybe that extra productivity will allow you to take that vacation you deserve.



Michael Goldstein,
Publisher & Editor-in-Chief

P.S.—Stop by and see us when you come to the show. We'll be in the gear pavilion at booth B-7113.

Nachi Establishes Tool Regrinding/Recoating Facility in North Carolina



Nachi Fujikoshi has expanded its manufacturing services in the United States by establishing Nachi Precision North Carolina Inc. (NPNC), a company specialized in regrinding/recoating precision tools. The new facility is open and operating as of May 2006. The North Carolina location was selected because of its close proximity to several automobile manufacturers and their parts/components suppliers.

As a recent trend, manufacturers have been actively regrinding/recoating worn cutting tools to extend existing tool life.

Many automobile manufacturers and their parts/components suppliers have constructed factories in Southern U.S. states and are expanding production of transmissions and other components that request advanced engineering technologies. Accordingly, demand for accurate precision tools is increasing rapidly.

To achieve precision, accuracy, efficiency, stable cutting conditions and tool replacement intervals, reground/recoated tools must provide a level of quality and performance comparable to newly manufactured tools. As a result, companies performing these services must provide a comprehensive quality assurance system encompassing wide-ranging areas of technology such as cutting tool design, machine design, surface treatments and other special technologies and factors affecting accuracy and life.

Backed by over 75 years of experience and well-diversified technical capabilities covering cutting and machine tools, materials, heat treatment, bearings, hydraulic equipment and robotics, Nachi Fujikoshi has built a firm foundation in the automobile and industrial machinery industries by conducting a diverse range of interlinked businesses. Specifically, Nachi Fujikoshi provides all key processes involved in cutting tools — including the production of specialty materials, heat treatment systems, coating systems and the associated manufacturing machines. This approach has elevated Nachi Fujikoshi's accumulated wealth of original technologies and know-how not available to other companies.

Utilizing NPNC and NMTC, servicing the Midwest area, also utilizing the resources of other US bases such as NAI and NRS, the Nachi Fujikoshi Group will provide wide-ranging engineering and manufacturing services to meet all machining needs.

NACHI North America Group Overview – Location in North America

Expanding Business of the Nachi Fujikoshi Group in the U.S. History

- Established Nachi America Inc. (NAI, headquartered in Michigan) in 1962 as the Group's headquarters in the Americas, and began selling a wide range of products including cutting tools, machine tools, robots, bearings, hydraulic equipment and materials.
- Established Nachi Technology Inc. (NTI, headquartered in Indiana) in 1974 and began local bearing production.
- Established Nachi Robotic Systems Inc. (NRS, headquartered in Michigan) In 1989 and began offering industrial robots and engineering services.
- Established Nachi Machining Technology Co. (NMTC, headquartered in Michigan), a precision tool production company, in 1991. NMTC provides high-quality broaching and gear-cutting/forming tools for automobile manufacturers and their parts/components suppliers in the Midwest.

- **NACHI Canada Inc.** St. Laurent, Quebec Canada
- **NACHI Canada Inc.** Vaughn, Ontario Canada
- **NACHI Robotic Systems Inc.** Vaughn, Ontario Canada
- **NACHI America Inc. Headquarters** Macomb, Michigan USA
- **NACHI Machining Technology Co.** Macomb, Michigan USA
- **NACHI Robotic Systems Inc. Headquarters** Novi, Michigan USA
- **NACHI Robotic Training Center** Wixom, Michigan USA
- **NACHI Precision North Carolina Inc..** Charlotte, North Carolina USA
- **NACHI Robotic Service Center** Greenville, South Carolina USA
- **NACHI Robotic Service Center** Frankfort, Kentucky USA
- **NACHI America Inc.** Cerritos, California USA
- **NACHI Robotic Service Center** Saltillo, Mexico
- **NACHI Mexicana, S.A. DE C.V.** Mexico City D.F., Mexico
- **NACHI Robotic Systems Inc.** Mexico City D.F., Mexico
- **NACHI Robotic Service Center** St. Louis, Missouri USA
- **NACHI America Inc.** Miami, Florida USA
- **NACHI America Inc.** Greenwood, Indiana USA
- **NACHI Technical Center** Greenwood, Indiana USA
- **NACHI Technology Inc.** Greenwood, Indiana USA

NACHI
NACHI AMERICA INC.
17500 Twenty-Three Mile Rd.
Macomb, MI 48044
Phone: (586) 226-5151
Fax: (586) 263-0445
general@nachi-in.com
www.nachiamerica.com

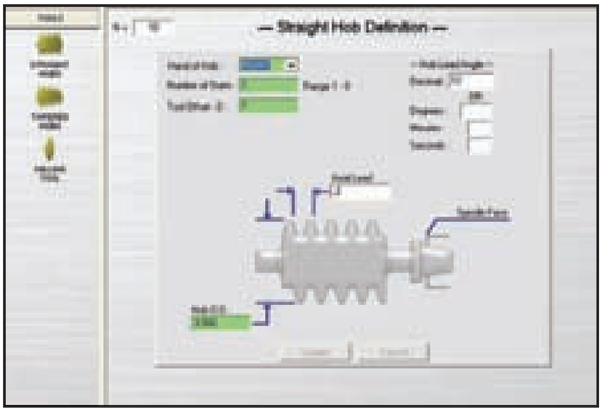
NUM's Graphical and Conversational Software Compatible with Gear Manufacturing

NUM's control systems will be displayed at IMTS and are suitable for use in gear manufacturing. The embedded machining cycles for gear hobbing, shaping or grinding and automatic gear/tool alignment are governed by a graphical and conversational human/machine interface (HMI).

According to the company's press release, the PC- or CNC-based HMI allows operators to program the machine without knowledge of ISO code. Operators are guided by pictorial information, and entry screens provide a graphical approach that depicts the hob or grinding wheel, the gear and associated setup data. Users fill in the data in fields, and the program automatically generates and stores the information. It is also possible to combine conversational/graphical programming with ISO programming or use one or the other individually.

Two system packages are available. The simple electronic gearbox package includes a CNC program that synchronizes cutter rotation and axial tool motion (Z-axis) with the rotation of the workpiece (C-axis). This configuration is designed for simple machines with three axes (X, Z and C) and a spindle. A high-speed control links from tool or axial input to the drive worktable.

With the full electronic gearbox, the CNC adds tangential tool movement to the synchronization of the Z and C axes. This configuration is designed for applications with up to six axes (X, Y, Z, A, C and W) and a spindle and allows for manufacturing of bevel and helical gears with straight and conical cutting tools. A high-speed control links from tool, axial or tangential input to the drive worktable.

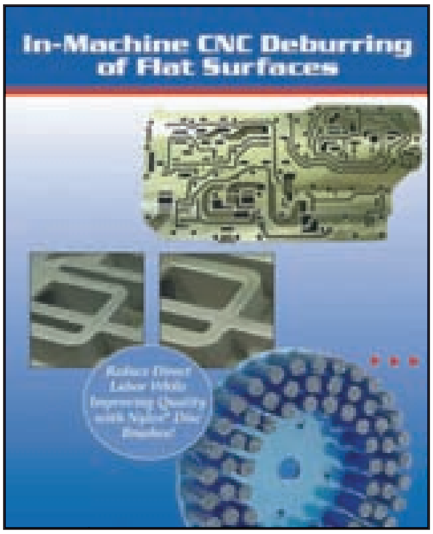


Additional features of all packages include operator-prompted teach routines to find the first gear; a high-speed interface to tooth edge sensor for storing gear images; automatic hob shift management; helical, spur or worm gears; hobbing cluster gears via a number of sequential machining cycles; vertical or horizontal machine configuration; tooth modifications (crown or taper); tooth alignment to another gear on the same shaft; radial hobbing cycle (standard or single index); radial axial hobbing cycle (up to four cuts); tangential or diagonal hobbing cycle; integrated context-sensitive help file; manual or automatic part loading and clamping; and tailstock and coolant.

The gear alignment option provides cutting tool and gear re-synchronization via a non-contact sensor, allowing for automatic tool-workpiece timing pickup when re-introducing a pre-cut or hardened gear into the machine.

For more information:
NUM Corp.
603 E. Diehl Rd., Ste. 115
Naperville, IL 60563
Phone: (630) 505-7722
E-mail: ***brian.kordzinski@num.com***
Internet: ***www.num.com***

Weiler's New Brochure Details In-Machine CNC Deburring on Flat Surfaces



Weiler Corp.'s newest brochure details its in-machine CNC deburring of flat surfaces and highlights the company's Nylox disc brushes, which allow users to deburr flat parts in a CNC machine.

According to the company's press release, the brushes are adaptable to automated equipment and suitable for deburring complicated parts on which burs lie in a single plane. Brushes can remove burrs and finish surfaces without altering part dimensions. In addition, the brushes can deburr and finish in one setup.

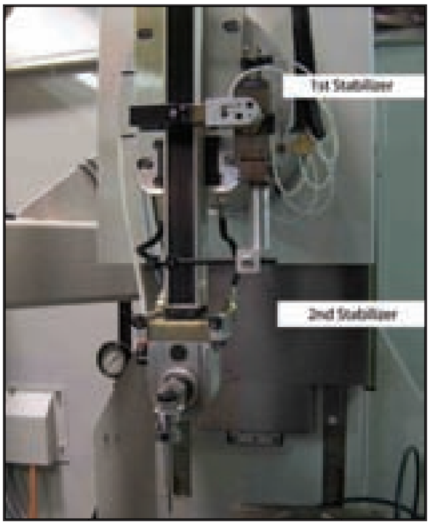
The brushes' filaments operate as a collection of flexible files which remove burrs and sharp edges as the rotating disc is fed across part features, such as milled faces.

For more information:
Weiler Corp.
1 Wildwood Dr.
Cresco, PA 18326-0149
Phone: (570) 595-7495
E-mail: ***info@weilercorp.com***
Internet: ***www.weilercorp.com***

Beaumont Machine Introduces Two-Step Diffuser Process

Beaumont Machine plans to exhibit its two-step diffuser process at this year's IMTS.

Diffuser shapes have become a challenge for aircraft engine OEMs and their suppliers. In most production environments, diffuser shapes are generated on an EDM sinker after a "fast hole" EDM drill creates a through or meter hole. This process requires two separate machines with two distinct EDM processes. According to Beaumont's press release, this multi-machine process often creates several manufacturing bottlenecks and quality issues, including diffuser shape to meter-hole alignment, part reloading or fixture/part shuttling, multiple operator interventions and multiple QC inspection checks.



Beaumont's diffuser process improves this process by generating both features, meter hole and diffuser, on the same machine, according to the company. First, the meter hole is drilled. Then, the dressed diffuser shape is locked to the required angular location, and the shape is sunk over the meter hole.

For more information:
Beaumont Machine Inc.
5161 Wolfpen-Pleasant Hill Rd.
Milford, OH 45150
Phone: (513) 248-3650
E-mail: ***sales@beaumontmachine.com***
Internet: ***www.beaumontmachine.com***

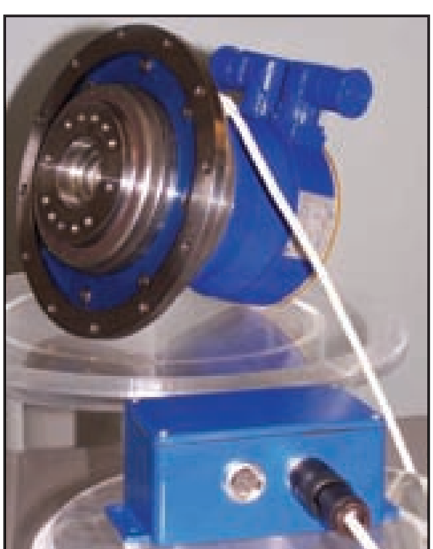
alpha Introduces New Advanced Integrated Sensor Technology

alpha gear drives Inc. developed a method of integrating torque and force sensors into the housings of a range of motion control solutions from precision gear reducers to TPM-integrated gear and motor products.

Sensor technology allows for accurate torque measurement, axial loading and radial loading. Real-time measurement of the performance criteria allows for more accurate process control by eliminating the method of using motor current and a measured scaling factor to determine torque output. According to the company's press release, the direct method also eliminates friction or splash losses otherwise associated with gearing.

Measurement of loading on an axis can help determine changes to the process being performed. A change in material thickness results in less or more force in a roll-feed application. Changes in material density require a change in torque in bending or forming applications.

Advanced sensor technology in prototype machines helps designers eliminate unknowns from the system by providing real-time feedback. Sensor technology can also be used to close the torque loop of a control system at the output stage. Machine life can be measured by determining the loads and forces at the drive mechanism.



For more information:
alpha gear drives Inc.
1249 Humbracht Circle
Bartlett, IL 60103
Phone: (630) 540-5341
E-mail: *mbilstein@alphagear.com*
Internet: *www.alphagear.com*

Team Technik Introduces Modular Gearbox Test Rig

The new modular gearbox test rig from Team Technik is divided into three parts—a standardized input drive module, an output drive module and a product-specific central body that takes over the matching of the test bench to different transmission types and automation levels.

According to the company's press release, instrumentation, control technology and test bench software were also standardized or modularly programmed, so the new test benches are more flexible with respect to model variations and automation levels.

The company says production systems can be upgraded within weeks to match a new transmission model or provide a new level of automation for increasing production quantities. Due to an adapter change that can be put into effect in minutes as well as an automatic adjustment of the shaft separation, a single test bench can be used to test 10 different transmission versions. New automatic transmission gearboxes are tested on the same modular test rig as conventional manual gearboxes without needing conversion or a new system.

The delivery program for the modular test rigs extends from the manually loaded rig through to the fully automatic test line with improved levels of automation.

For more information:
Team Technik USA
3741 Venture Dr., Ste. 320
Duluth, GA 30096
Phone: (678) 957-0334
E-mail: *application.usa@teamtechnik.com*
Internet: *www.teamtechnik.com*

Zimmerman Presents New Milling Machine with Linear Drive

The new FZ 38 from Zimmerman is a CNC portal milling machine driven by linear motors.

According to the company's press release, the machine can achieve time/chip volumes up to 4,500 cm^3/min. Feed rates on linear axes of up to 60 m/min. and spindle speeds of up to 35,000 rpm make genuine HSC processing possible. Torque motors on rotational axes with feed rates of up to 150° per second are possible as well. With these feed rates, ancillary times for repositioning, tool orientation or tool change can be reduced.

The FZ 38 allows different work areas, milling spindles and control systems to be combined. The machine has permanent lateral walls, a clamping table connected to the foundation and an upper portal that moves in the x-direction and is driven on both sides. The workpiece is not moved.

The machine bed is constructed from gray cast steel, while the lateral walls, portal and z-slides are welded steel constructions. The lateral walls are filled with a special compound material for damping vibration and stabilizing temperature.

For more information:
Zimmerman Inc.
24371 Catherine Industrial Dr., Ste. 233
Novi, MI 48375-2455
Phone: (248) 305-9707
E-mail: ***Matthias@zimmermann-inc.com***
Internet: ***www.zimmerman-inc.com***

Tornos Technologies Debuts New Swiss-Type Multi-Axis Machine

The new DECO 8sp single-spindle Swiss-type multi-axis, multi-function machine will be making its debut at IMTS.

The machine accommodates parts up to 8 mm. According to the company's press release, the precision machine has accuracies of +/– 1μ.

The machine was developed for new markets in the electronics sector, particularly for mini disk parts for mobile IT units, but is also applied for other types of short parts requiring high precision in the watch, medical and automotive industries.

Key specifications include spindle rpm of up to 15,000, powered by a 3.7 kW motor. Four tools serve the main spindle, up to six for the sub-spindle with up to seven live tools—five for the main and two for the sub-spindle. Programming can be accomplished with traditional ISO G-code or via Tornos' dedicated TB-DECO ADV program, which utilizes DECO's kinematics designed for faster processing.

For more information:
Tornos Technologies U.S. Corp.
70 Pocono Rd.
Brookfield, CT 06804
Phone: (203) 775-4310
E-mail: ***contact@tornousa.com***
Internet: ***www.tornos.com***

New Six-Jaw Power Chuck from Schunk

The new ROTA NCR six-jaw power chuck from Schunk was designed for machining thin-walled and easily deformed workpieces. With six-point contact on the workpiece, even pre-machined parts can be clamped without deformation, according to Schunk.

The ROTA NCR consists of a central chuck piston that has master jaws oscillating in pairs for concentric clamping. A pendulum is connected to each set of two case jaws. The result is that the workpiece is centered between six points of contact in which the members of each pair lie opposite one another. The clamping forces align towards the center of the chuck, thus permitting maximum roundness of workpieces with conventional jaw clamping.

For certain applications, such as finish machining or clamping pre-machined surfaces, the pendulums of the chucks can be clamped in their center position. With this configuration, all six clamping jaws move simultaneously and concentrically. Clamping is achieved by inserting the attachment bolt in the piston.

The ROTA NCR is available in sizes 165, 210, 250 and 315 mm.

For more information:
Schunk Inc.
211 Kitty Hawk Dr.
Morrisville, NC 27560
Phone: (919) 572-2705
E-mail: *info@us.schunk.com*
Internet: *www.schunk.com*

China Pneumatic Unveils Precision Planetary Gear Reducers

China Pneumatic Corp. is introducing a new line of precision planetary gear reducers for air motors, servo motors and stepping motors for a wide range of applications in aerospace, semi-conductor equipment, robotics, medical, telecommunications, pharmaceutical, packaging, printing, assembly, material handling, coordinate measuring, automotive, textile, special machinery and machine tools.

According to the company's press release, its goal is to collaborate with gearhead, servo and stepping motor and relevant motion control components manufacturers to have the gearheads included as a complementary add-on.

For more information:
China Pneumatic Corp.
Gison Machinery Co. Ltd.
No. 2, Alley 105
Lane 68, Sec. 2
Sinan Rd.
Wurih, Taichung 414
Taiwan
Phone: (886) 4-233-532-02
Internet: *www.airtools.tw*

Command Tooling Systems Expands Toolholder Line

Command Tooling Systems announced the addition of more than 1,200 metric toolholders.

The metric expansion crosses into product lines including Micro Precision and XT Precision Collet Chucks; ThermoLock ShrinkFit toolholders; end mills and shell mill holders; and select tap and specialty holders. Shank styles include BT, DIN and HSK, with lengths up to 200 mm.

For more information:
Command Tooling Systems
13931 Sunfish Lake Blvd.
Ramsey, MN 55303
Phone: (763) 576-6910
E-mail: *askauge@commandtool.com*

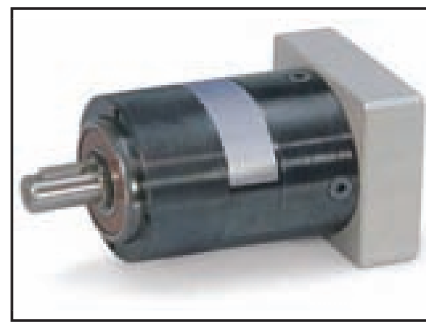
SIPCO Mechanical Linkage Solutions Fine Tune Technogear Line

The newest addition to the Technogear product line from SIPCO Mechanical Linkage Solutions is a low-backlash, economical gearbox designed for automation and precision power transmission applications.

The Technogear LC series precision planetary gearbox is available in four sizes: 50, 70, 90 and 120 with varying ratios from 3:1 to 100:1. Its torque ranges from 10–360 N-m. It reports efficiency ratings of 97% on single-stage units, 94% on double-stage units as well as numerous input configurations.

According to the company's press release, the precision planetary gearbox is built with rigid bearings rated for a service life of 20,000 hours and designed with a lubricated-for-life construction.

For more information:
SIPCO Mechanical Linkage Solutions
12610 Galveston Rd.
Webster, TX 77598
Phone: (281) 480-8711
E-mail: *info@sipco.cc*
Internet: *www.sipco-tech.com*



SMW Autoblok Introduces New Line of Live Tooling

SMW Autoblok introduces a complete line of live tools to provide increased machine utilization of turning centers, resulting in more parts per hour. Standard tooling models feature straight, angle or dual heads and are in stock to fit most OEM turning centers with motorized turrets.

According to the company's press release, the live tooling features precision gears and bearings for accurate and repeatable machining. Tools are sealed against contaminants and coolant intrusion.

For more information:
SMW Autoblok Corp.
285 Egidi Dr.
Wheeling, IL 60090
Phone: (847) 215-0591
E-mail: *autoblok@smwautoblok.com*
Internet: *www.smwautoblok.com*

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Just the Facts

September 6–13, 2006

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- Abrasive Machining/Sawing/Finishing
- Controls & CAD/CAM
- EDMs
- Fluid Power
- Gear Generation
- Machine Components/Cleaning/Environmental
- Metal Cutting
- Metal Forming & Fabricating/Lasers
- Quality Assurance
- Tooling and Workholding Systems

Hours:

Lakeside Center: 9:00 a.m.–5:00 p.m.

North & South Buildings: 10:00 a.m.–6:00 p.m.

Sunday, September 10, hours for all buildings will be 10:00 a.m.–4:00 p.m.

Nachi to Feature Gear Machines, Tooling, Robots and Materials

Booth B-7021

Nachi Fujikoshi Co. will display a number of gear machine tools at its booth at IMTS 2006, including machines from its Japanese partner companies—Kashifuji, Kanzaki and OSK. Nachi represents all three companies in North America, and in Japan, Nachi, Kashifuji and Kanzaki form the Gear Production Alliance.

Visitors will be able to see the Kashifuji KN151 hard hobbing machine, which is designed for hobbing gears both before and after heat treating. The machine is especially suitable for the production of gears that are difficult to grind, says Toru Inoue, VP of Nachi America

Inc. Example parts include pinion gears for electric power steering.

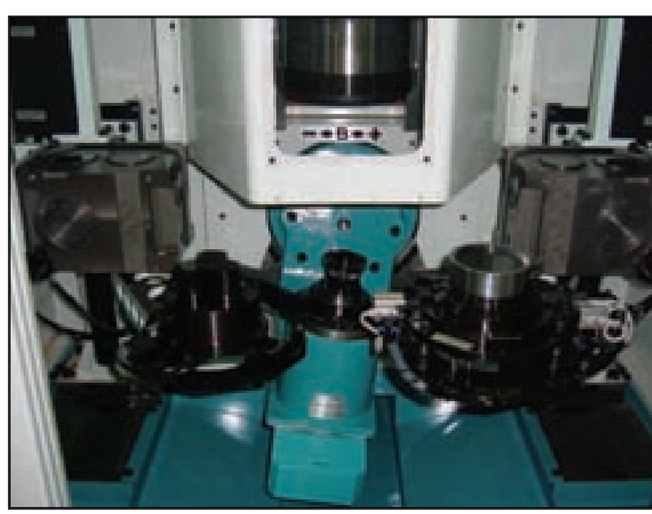
The KN151 was first introduced in 2002, but it has been updated with an index table for hard hobbing, Inoue says.

Also on display will be the Kanzaki GSU-180-NC3 internal shaving machine. Unveiled for the first time in North America, the machine uses a shaving cutter with an axial cutting angle to process spur and helical gears with internal teeth. The machine offers advantages over broaching processes, Inoue says, because it is capable of producing tooth surface corrections, such as crowning and taper. These corrections are important to many manufacturers, he adds, because they help reduce noise.

"We think internal shaving is good for hybrid transmissions," Inoue says.

The company will also display the CLP35 inspection machine from OSK. The CLP35 was introduced in 2005, but it will be on display at IMTS for the first time.

Nachi will feature three of its machines, including the NBM-50087 semi-dry broaching machine, the PFM-610E semi-dry roll forming machine, and the Hi-5010 hard



broaching machine. The Hi-5010 has been on the market for several years, but it will be displayed at IMTS for the first time this year, Inoue says. The Hi-5010 is capable of broaching hardened parts up to 60 HRC using broaches made out of carbide materials and coated with heat- and wear-resistant coatings. The Hi-5010 is capable of cutting speeds up to 80 m/min with a maximum stroke of 1,000 mm and maximum pulling force of 50 kN.

All of Nachi's machines are capable of using a high-speed, minimum-quantity-lubricant system.

Nachi will also display its line of cutting tools, including hobs and broaches for cutting gears in both green and hardened states. In addition, visitors will be able to watch Nachi robots in action as well as see displays of Nachi's capabilities in bearings, hydraulics and materials for applications such as hot forging dies.

For more information:
Nachi America Inc.
17500 Twenty-Three Mile Road
Macomb, MI 48044
Phone: (586) 263-0100
Fax: (586) 263-4571
Internet: *www.nachimtc.com*

Reishauer To Display New Hard Gear Finishing Technology at IMTS

Booth B-7005

Reishauer will display the RZ 400 precision gear grinding machine at its IMTS booth.

According to the company's press release, the RZ 400 incorporates a gearless planetary drive, acoustic sensing for alignment of dressing diamonds and LNS low noise shifting, which produces a random surface structure on the teeth to prevent excitation. All of the features have been recently patented.

The machine working area was designed to facilitate fast changeovers. Additional features include a convenient location for the setup of the dressing unit, ergonomic ease of wheel change and almost unlimited restriction of the gear location on the shaft or arbor, allowing the machine to achieve maximum uptime. The main column that carries the grinding spindle and slide rotates 90° to perform the wheel dressing operation.

Gear profile modifications can be realized with a few keystrokes and do not require special diamond discs due to the new line dressing feature. Using the machine axis, the wheel is moved during the dressing cycle to produce root, flank and tip modifications that will be imparted to the gear during grinding.

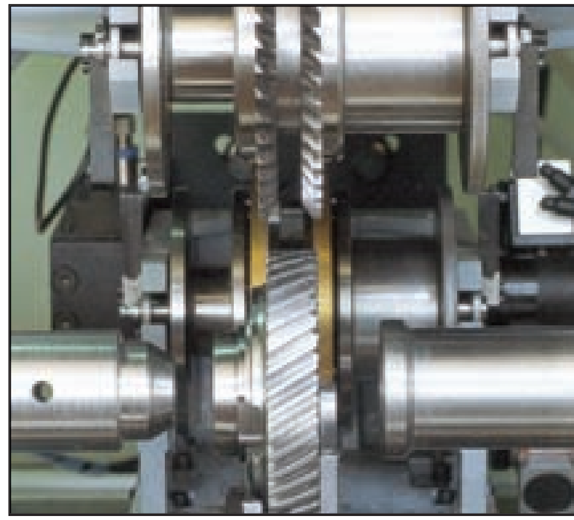
A key component of the machine that will be on display is the Felsomat Compact Cell FZ 250 machine tool loader. The cell is designed for loading precision parts into high production machine tools. Parts are organized in stacks of steel or plastic baskets and processed using horizontal and vertical NC axes.

The compact cell de-couples individual processes. Each machine and cell has an optimum buffer of parts which provides significant machine autonomy with minimal operator attendance. In addition, the cell facilitates system designs that are inherently scalable and easily optimized.

For more information:
Reishauer Corp.
1525 Holmes Rd.
Elgin, IL 60123
Phone: (847) 888-3828
Fax: (847) 888-0343
E-mail: ***sales@reishauer.com***
Internet: ***www.reishauer.com***

Star SU Brings Mass Production Machines to North American Market

Booth B-6912



Star SU plans to introduce the S 250 CDA stand-alone chamfering and deburring machine at its booth at IMTS. The machine, intended for use in mass production, uses an automatic loading system with an integrated gantry loader. It was introduced to the European community earlier this year and is now ready for the North American market.

The machine will be exhibited with a creative automation conveyor feeding the machine-integrated pick-and-place device, and it will be set up with SU chamfer/deburr tools. The company says chamfering and deburring an automotive pinion has a floor-to-floor cycle time of 14 seconds with this type of setup.

According to company literature, the product's workpiece outside diameter ranges from 20–250 mm. The workpiece's maximum width is 150 mm, and its maximum module is 8 mm. The two tool-headed machine has a PLC control.

The S 250 CDA is part of Star SU's new S-CD series of machines. The company already introduced the S 250 CD, a series of stand-alone machines for flexible production of small to medium lots with manual loading capabilities.

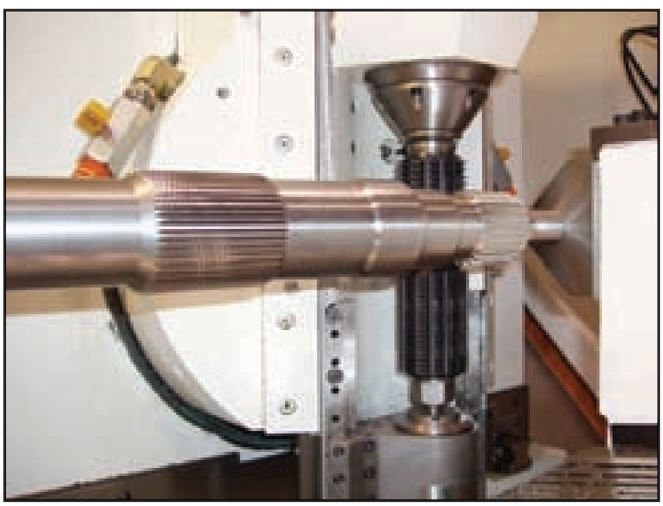
The S 250 CDX is a module that can be integrated onto a hobbing machine for mass producing gears of 200–300 mm. The S 250 CDX includes simultaneous or consecutive chamfering/deburring of shafts with a maximum of five different gears or a family of different ring gears and pinions with the same clamping system.

The S 250 CDP, currently under development, includes the same features as the S 250 CDA, but with a pass-through loader.

Additional features of the entire machine family include a new electro-welded bed with chip gathering under the work area; process flexibility and security with dry or wet machining; modularity between models to offer a range from simple, basic machines to extensive, complete solutions; and modular standard automation, allowing for easier setup and connection to existing or new machine tools.

The company also plans to include the Star PTG-1 and PTG-4 hob sharpening and reconditioning machines. The PTG-1 sharpens both straight and spiral gash hobs. Additionally, the PTG-1 sharpens disk and helical shaper cutters and various round tools.

A customer-owned Bourn & Koch Fellows MS450-125 will be at the Star SU booth as well. The CNC guide machine



is designed for shaping spur and helical internal and external gears and shafts of up to 450 mm in diameter.

Also on display will be the Bourn & Koch Blanchard 11AD-20 rotary surface grinder, previously from the old DeVleig Bullard company, and the Bourn & Koch 100H horizontal CNC hobbing machine, a six-axis machine featuring NUM 105OH six-axis CNC control, full machine enclosure for wet or dry hobbing, pneumatic live center, automatic single- or double-cut hobbing on multiple gears or splines, automatic shift hobbing, speed and feed change between cuts, crown hobbing, taper hobbing, radial or tangential feed worm gear cycles, and CNC hob swivel. Bourn & Koch will demonstrate multiple spline hobbing on a shaft with two splines having different numbers of teeth, with two hobs with different numbers of starts, dry cutting in a single clamping, as well as single-axis milling.

For more information:
Star SU
5200 Prairie Stone Pkwy., Ste. 100
Hoffman Estates, IL 60192
Phone: (847) 649-1450
Fax: (847) 649-0112
E-mail: ***sales@star-su.com***
Internet: ***www.star-su.com***

Kapp and Niles to Highlight Gear Grinders' On-Board Measuring and Ring Loader Automation

Booth B-7030

The Kapp Group will feature at IMTS a technology transfer involving a popular Kapp gear grinder and Niles' ZE 400S (extended stroke) gear grinder.

The ZE 400S will simulate profile grinding of internal gears. However, the machine's on-board measuring and inspection will be demonstrated for real, with contact between workpiece gears and probe.

"The machine will actually demonstrate gear measuring," says Bill Miller, newly appointed vice president of sales for Kapp Technologies, the North American operation of the Kapp Group.

The ZE 400 can measure lead, involute, and index on internal and external gears in accord with AGMA standards, DIN standards or customer specifications, such as via K charts. The measuring is done with a Renishaw touch probe, which isn't sensitive to temperature, Miller says, so it doesn't require frequent recalibration due to temperature variations.

Also, the ZE 400 can perform on-board dressing of its grinding wheels. The on-board measuring and dressing are transferred Kapp features, and together, they allow the correction of the tooth form in a semi-automated process that Kapp calls GMG (grind-measure-grind) technology.

"It doesn't require the typical trip to the gear lab with the component," Miller says of the on-board measuring and correcting. "The most important feature is the higher productivity for larger gears."

Kapp will display its KX 300 P, too. The popular profile and generating grinder features on-board measuring and inspection and on-board dressing of its grinding wheels and worms. Also, the machine will be set up for simulated grinding cycles and for demonstration of a working, integrated ring loader system.

"It's coming as a turnkey solution from Kapp," Miller says. "It's designed to be very easy to set up, so it can be used for smaller lot sizes."

However, Miller says automation, like the ring loader system, is usually for large production, such as in the automotive industry. He adds that the ring loader system is Kapp's first to be integrated within the machine enclosure.

"It's designed as a CNC axis," Miller says of the system. "The CNC axis enables the loading to be faster, more precise and easier to set up, so it can be efficient for batch lot production also."

Kapp and Niles personnel will be available to discuss the new ZX series, too. A gear grinder in that series is the ZX 1000, which was introduced in June in Düsseldorf at the German show METAV (Manufacturing Technology and

Automation). Miller describes the ZX series as an extension of KX 300 P: "The ZX is an extension of that line to a larger platform."

As of early August, Kapp had delivered its first ZX 1000 to a company in the printing press industry.

Kapp and Niles will also display scale models of other machines and processes, such as the VUS 55 P and the CX 250. Miller says these models enable more efficient explanation of various processes available from Kapp and Niles.

The VUS 55 P form grinds external and internal spur and helical gears and uses either CBN or dressable grinding wheels. The CX 250 finishes external spur and helical gear flanks via Kapp's Coroning® process.

The VUS 55 P also performs on-board gear measuring, facilitating automatic documentation of the amount of stock removed from each gear tooth flank.

"Several of our customers have an interest in controlling the case depth of every single tooth," Miller says. He adds this interest exists when the gears will be heavily loaded in high-duty applications, such as in a city bus. He also cites aerospace as another application in which gears may be high duty and heavily loaded.

In such instances, inspection of each flank can be necessary, Miller says, because: "The case depth is so critical to the design integrity."

Also, on-board inspection allows gear inspectors to avoid problems that can result when matching a gear's in-lab orientation with its on-machine orientation.

Miller says the Kapp and Niles products coming to IMTS signify a continued sharing and integration of key technologies, yielding benefits for Kapp's customers.

For more information:
Kapp Technologies
2870 Wilderness Place
Boulder, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131
E-mail: *sales@kapp-usa.com*
Internet: *www.kapp-usa.com*

Gleason Unveils New Threaded Wheel Grinder

Booth B-6902

The new Genesis 130TWG High Speed Threaded Wheel Grinder from Gleason Corp. features a design that improves cycle times for the grinding of hardened spur and helical gears. The machine is designed to accommodate gears with diameters as large as 130 mm.

The 130 TWG was manufactured at Gleason-Hurth in Munich, Germany, and uses dressable grinding wheels, which can be dressed using either diamond-plated master dressing gears or standard dressing tools. According to Gleason, utilizing the master dressing gear method results in faster dressing, which is independent of the number of starts of the grinding wheel, particularly in high production applications. A fully automatic dressing unit with conventional dressing technology is used when greater flexibility is needed.

A new mechanical double gripper loader is fully integrated into the machine. According to the company's press release, this reduces part load/unload times. A rapid automatic stock dividing system automatically positions the workpiece in relation to the grinding wheel. No manual adjustment is necessary.

Direct-drive spindle motors are utilized as well. Higher acceleration/deceleration rates and increased torque combine with faster axis motions to reduce non-grinding time.

Additional features include a service module that consolidates hydraulics, lubrication and pneumatics into one location. Siemens controls combine with proprietary software for setup and operation control in a Windows environment. In addition, the machine frame is designed such that the coolant pump can be set up on either side or on the rear of the machine for connection to the coolant system. Gleason says this satisfies any cell/system arrangement.

For more information:
Gleason Corp.
1000 University Ave.
Rochester, NY 14692-2970
Phone: (585) 473-1000
E-mail: ***sales@gleason.com***
Internet: ***www.gleason.com***

Sigma Pool to Feature In-Process Gaging, Speed in New Hobber, and Gear Measuring

Booth B-7016

A Sigma Pool partner, the Liebherr Group will introduce at IMTS its new LC 60 CNC gear hobbing machine, a smaller hobber that features maximum hob and table speeds of 7,500 rpm and 1,400 rpm, respectively, as well as simplified automatic counterbearings for faster tool changeover.

Moreover, the LC 60's spindle and table speeds are high enough to permit full use of twist-free hobs, which were developed by Liebherr and LMT-Fette. The finishing hobs can remove twist (also called profile bias) from crowned helical gears. According to Peter Kozma, president of the U.S-based operation Liebherr Gear Technology Inc., the spindle and table speeds also permit use of hobs with high-starts for reducing cutting time.

Kozma adds that with the simplified automatic counterbearings for cutting tools: "You can do a significantly faster cutting tool change."

The LC 60 occupies about 20% less floor space than the LC 80 and can hob gears with maximum outside diameters of 60 mm (2.4 in.) and maximum modules of 2.25 mm. The new hobber was designed to be highly reliable, with minimum maintenance requirements, and to be suitable for job shops, dedicated gear shops, and plants that mass produce automatic transmission gears.

"They all want to make the gears as quickly and accurately as possible," Kozma says.

He adds that workpiece exchange time, from the end of cutting one gear to the start of cutting another, can be as little as 3 seconds. The LC 60 has a fully covered work area for optimal chip flow during dry cutting, too.

Also, Liebherr will demonstrate a pick-and-place loading system that features a gripper with an integrated gage for in-process measuring of part diameters. Specifically, the gage

measures the diameters of the crankshaft main bearing and pin bearing surfaces to make certain they're machined to their correct dimensions. Kozma says that the gripper/gage system can also be attached to gantry loading systems.

He adds that the gripper/gage system would also be suitable for placement in a gear manufacturing cell, between a turning center and a hobber, so workpieces could be measured while moving between the machines, to ensure the parts were turned properly: "The measurement is taken during the transfer to the next machine station."

Kozma adds that the gage is accurate to 0.001 mm, and its purpose is to reduce the number of scrap gears in an automated manufacturing system.

"We automatically check every part," he says, mentioning engine parts and transmission parts as examples. "Gear and shaft manufacturers can benefit from the integrated gage in the part handling."

Kozma says that with the gripper/gage system, manufacturers could avoid having a separate station for measuring turned parts and could move their parts faster through their manufacturing processes: "You can really reduce cost by gaging in the gripping."

About the pick-and-place loading system, Kozma says it can be used in either job shops or dedicated shops. "Our customers are looking for highly reliable automation systems."

Sigma Pool partner Klingelnberg GmbH will display its P 26 gear measuring center.

The CNC machine can measure cylindrical gears with external and internal teeth, worms and worm gears, spiral bevel gears, rotors, camshafts and other cylindrical workpieces. The P 26 measures gears with outside diameters of up to 260 mm.

Also, measuring programs are available for the most important gear cutting tools, such as hobs and shaper and shaving cutters.

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

Koepfer to Display Hobbers and Gear Inspection Machines

Booth B-6907

Koepfer America LLC will display four machines at IMTS: 1.) its Model 300 CNC hobber, 2.) Wenzel GearTec's Smart Gear inspection and CMM machine, 3.) Wenzel's WGT350 gear inspection machine, and 4.) Monnier + Zahner's Model MZ130 CNC fine-pitch hobber.

Koepfer's Model 300 is a nine-axis, heavy-duty machine able to hob gears with maximum modules of 4 mm.

The CNC hobber can also skive gears and perform diagonal hobbing. Moreover, it has a timing-to-part feature. Gimpert says this feature allows the Model 300 to easily perform difficult operations, such as aligning a gear tooth to a hole or slot in a helical steering pinion.

The Model 300 features direct-driven workpiece and cutter spindles. The workpiece spindle has a maximum speed of 800 rpm, while the cutter spindle's speed ranges from 200–2,000 rpm or alternatively from 400–4,000 rpm.

"It can fit in either a contract shop or a dedicated application," Gimpert says about the Model 300's flexibility.

Wenzel's Smart Gear machine, introduced in 2005, can perform four-axis measuring of internal and external spur gears, helical gears and splines, as well as worms and worm gears.

The machine can inspect gears with a minimum module of 0.4 mm, a maximum outside diameter of 270 mm and a maximum face width of 300 mm. It can also perform 3-D measurement and inspect tools such as hobs and shaping and shaving cutters and other special tools, like stick blades. Moreover, the machine can be equipped to perform CMM work.

Gimpert says the Smart Gear is "ideally suited for a job shop that needs a more economical gear inspection machine or a combination machine with gear and CMM capability."

The other Wenzel gear inspection machine on display will be the WGT350. This machine's four axes, including its rotary axis, have air bearings. Gimpert says the bearings allow for greater accuracy than mechanical bearings and: "The accuracy of the air bearing doesn't deteriorate over time."

The WGT350 uses Renishaw scanning probes to inspect gears with outside diameters of 5–400 mm and modules of 0.5–15 mm.

The WGT 350 can include software for measuring external and internal spur gears, helical gears and splines; worms and worm wheels; straight and spiral bevel gears; hobs; shaper cutters; shaver cutters; and cylindrical shafts. The machine can also use coordinate measuring software for 3-D measuring.

Koepfer will also exhibit Monnier + Zahner's Model MZ130 gear hobber and worm milling machine.

The MZ130 makes external spur and helical gears, worms and worm wheels, splines and threads. It can accommodate workpieces with outside diameters of 2–55 mm, can hob gears with modules up to 1.25 mm and mill worms with modules up to 2.0 mm.

The MZ130 was designed to be easy to reset from gear hobbing to worm milling and to be suitable for making small or large quantities.

Gimpert describes the MZ130's driven and synchronized tailstock as a unique feature, as providing a more rigid clamping of smaller gears as they can be driven by both the workpiece spindle and tailstock simultaneously.

For more information:
Koepfer America LLC
635 Schneider Drive
South Elgin, IL 60177
Phone: (847) 931-4121
Fax: (847) 931-4192
E-mail: ***sales@koepferamerica.com***
Internet: ***www.koepferamerica.com***

The Effects of Pre-Rough Machine Processing on Dimensional Distortion During Carburizing

Gregory Blake

Management Summary

A study was conducted to isolate the influence of pre-rough machine processing on final dimensional distortion. Methods are discussed to aid process development and minimize dimensional change during carburizing. The study examines the distortion during carburizing between five possible raw materials starting conditions. Coupons were used and manufactured from each population of material processing. All coupons were carburized and hardened at the same time. Dimensions were made before and after carburizing using a scanning coordinate measurement machine. The results show the dimensional distortion during carburizing increased with mechanical and thermal processing.

This article presents the methods and results of an empirical study that was conducted to aid process development of a carburized aerospace gear. The objective of the study was to determine the contribution of pre-machining material processing on dimensional distortion during carburizing. Five possible raw material starting conditions were evaluated. The five pre-rough machining conditions studied were: (i) normalized AMS6265 bar stock, (ii) hardened and tempered (core-treated) AMS6265 bar stock at 1,725°F, (iii) hardened and tempered (core-treated) AMS6265 bar stock at 1,550°F, (iv) normalized AMS6260 forging, and (v) hardened and tempered (core-treated) AMS6260 forging at 1,725°F.

Cost, time, and lurking variables were minimized by use of a standard distortion coupon in place of actual aerospace gears. The coupon design is shown in Figure 1. H. French used this type of coupon to study dimensional distortion during repeated quenching (Ref. 1). French's coupon was scaled as necessary for use in this study. The diametrical changes of the coupon indicate the volume changes during hardening. The width of the slot reflects the magnitude of internal stresses set up by the volumetric changes (Ref. 1). French showed that dimensional distortion increased as the number of quench cycles increased. The distortion coupon gap width increased with each quench cycle, thus indicating that residual stresses were increasing with each thermal cycle.

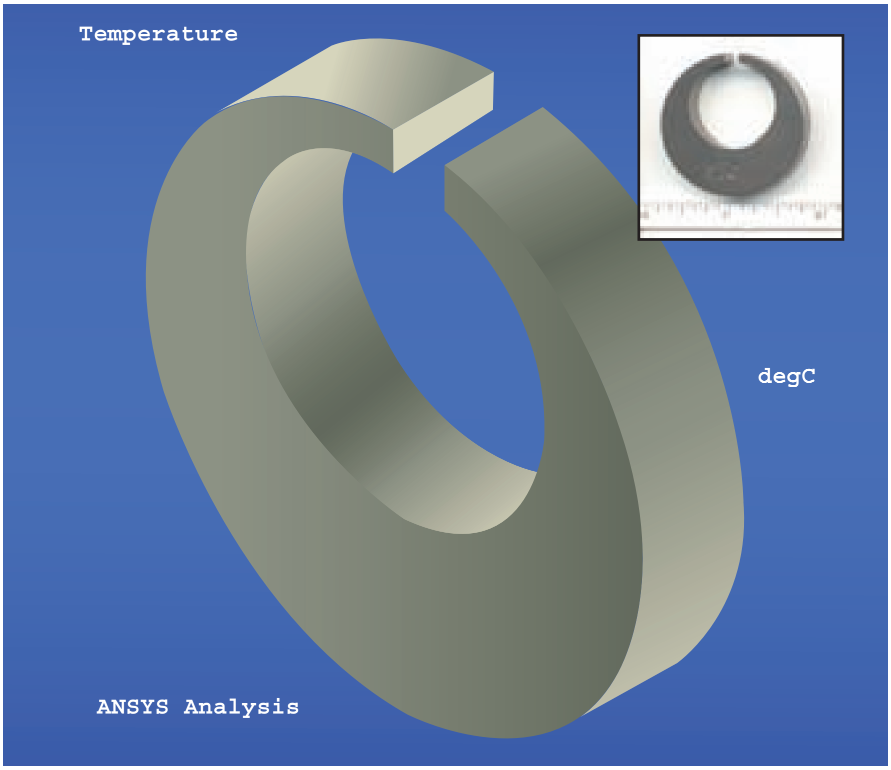


Figure 1—Distortion coupon, GR-0010.

The hypothesis is that dimensional distortion increases along with the thermal and mechanical processing of the raw material prior to machining. The implication is that dimensional distortion can be influenced before the raw material enters the machining process.

Precarburizing process variables and their influence on dimensional distortion were studied previously. The Instrumented Factory for Gears (INFAC) studied the effects of processing variables prior to carburizing. The INFAC study evaluated residual stresses induced by turning and hobbing and their contribution to dimensional distortion. Mechanical and thermal processing of the raw material, however, was not included in the study.

Background and Literature Review

A dedicated manufacturing cell to produce small aerospace gears was designed and implemented. The design of the manufacturing cell and process was to minimize lead time and cost. The shaping process was used to generate the spline and gear teeth. The resultant gear and spline surface integrity produced by the newly designed process was deemed unacceptable due to machining tears that would not clean up during gear grinding. An example of the post-shaped tooth surface is shown in Figure 2.

Surface integrity is the description and control of the many possible alterations produced in a surface layer during manufacturing. Surface integrity can be evaluated based on a minimum data set. The data set is composed of surface texture, macrostructure, microstructure, and microhardness alterations (Ref. 2). The data set for macrostructure will include surface imperfections such as pits, tears, and/or laps.

The raw material selected for use in the new manufacturing cell was normalized bar stock, which was within the engineering requirements of the finished gear. The soft normalized bar stock was viewed as a good choice for machinability. Many literature sources supported this conclusion. Mott defined machinability as being related to the ease with which a material can be machined with reasonable tool life (Ref. 5). Verzahntechnik Lorenz (Ref. 6) and Cluff (Ref. 7) indirectly used a similar definition stating that machinability (reasonable tool life) decreases as material hardness increases. The two key terms are "ease of material removal" and "reasonable tool life." An indication of expected surface integrity is not present using these definitions of machinability.

Material hardness can be used as a machinability indicator due to the close relationship between hardness and microstructure (Ref. 8). However, hardness is an accurate representation of machinability only for similar microstructures. Mullins states that a tempered martensite matrix will exhibit superior machinability to a pearlite matrix of similar hardness (Ref. 8). Woldman studied microstructure and machinability and noted that a microstructure selected for long tool life would not necessarily produce good surface integrity (Ref. 9).

Based on literature and experience, a tempered martensitic microstructure was desired to produce the required surface integrity. The addition of the hardening and tempering operation was viewed as a risk to changing the dimensional distortion during carburizing and hardening.

A great amount of manufacturing development had been done implementing the new cell. The dimensional distortion during carburizing and hardening had been established and had been determined acceptable and manageable. The addition of a hardening and tempering operation prior to rough machining was viewed as an addition to cost, lead time, and risk of increased dimensional distortion during carburizing. Increased dimensional distortion would then require more process development time and cost.

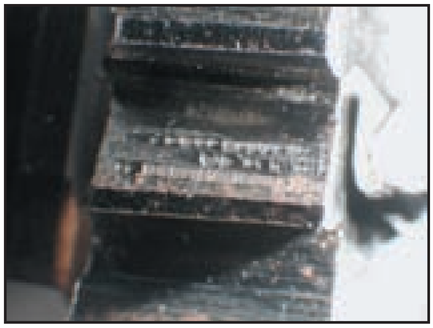


Figure 2—Gear tooth surface, post-shaping (Ref. 3).

Gregory Blake *is a senior specialist, mechanical engineer at Rolls Royce. He is responsible for technical support of gear system design and manufacturing, especially in the process development of gears.*

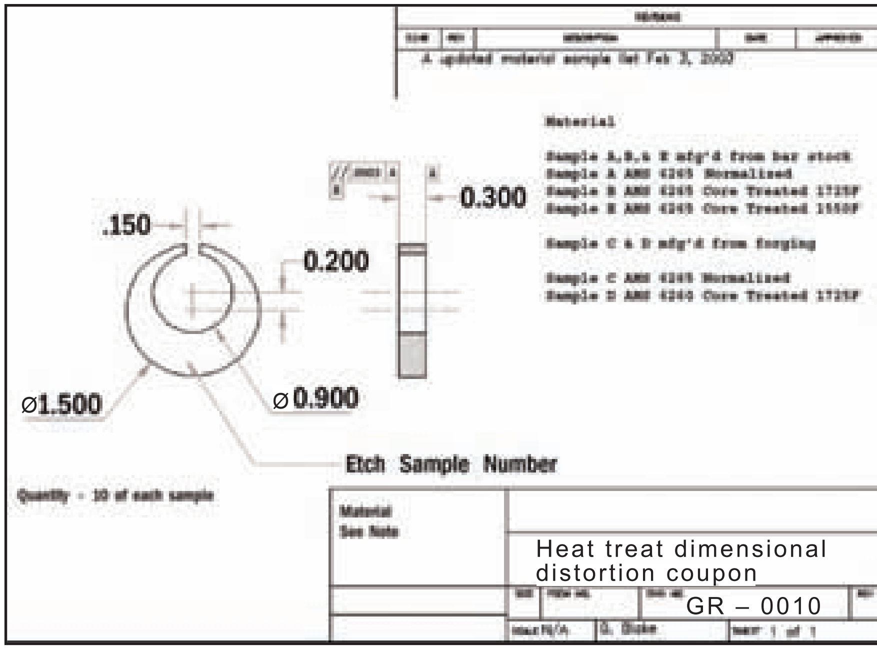


Figure 3—Detailed specimen drawing (units = inches).

Problem Statement

Common ground: Aerospace power transmission components must be manufactured to the highest quality standard while minimizing cost of nonquality.

Destabilizing condition: Gear tooth surfaces inconsistently have poor surface integrity ("tears") present after finish flank grinding. The surface defects are produced during the semi-finishing, pre-hardening operation and result in deviated, reworked, and/or scrapped parts.

Contributing factor: Aerospace gears are expensive and have long lead times. A study of many variables is not always practical using actual gears.

Problem: The shaping machine used in the manufacturing cell has limited cutting parameters. Literature suggests that hardening and tempering the material prior to any machining will improve the surface integrity during shaping. The material structure is then martensitic, and hardness ranges from Rc 25 to Rc 32. However, literature also suggests that this fix could negatively influence dimensional distortion during hardening.

Solution: Material samples made of different microstructure and hardness will be fabricated and tested. Paired data studies statistically analyzing dimensional distortion will be performed on coupons of similar size and process.

Assumptions

The material samples are assumed to fully represent their population. For example, a group of normalized material samples is assumed to represent all normalized material.

The change in coupon gap width is assumed to represent the relative dimensional distortion of an actual gear.

Methods and Procedures

This section contains the details of coupon manufacturing and processing. Standard distortion coupons were manufactured for each population as shown in Figure 1. The dimensions of the coupon were proportional to the gear being developed and are shown in Figure 3. Coupons from each population were machined,

Table 1—Specimen Populations.					
Material	Form	Pre-Machining Heat Treatment	Quantity	Expected Structure	Identification
AMS6265	Barstock	Normalized	10*	Pearlite in Ferrite Matrix	A
AMS6265	Barstock	Normalized + Harden at 1,725°F	10*	Pearlite in Ferrite Matrix	B
AMS6260	Forging	Normalized	10*	Pearlite in Ferrite Matrix	C
AMS6260	Forging	Normalized + Harden at 1,725°F	10*	Tempered Martensite	D
AMS6265	Barstock	Normalized + Harden at 1,550°F	10*	Tempered Martensite	E
*One additional specimen was manufactured for metallurgical evaluation.					

Table 2—Hardening and Tempering Process at 1,725°F.	
Operation	Operation Description
10	Load
20	Core Harden
	Temperature 1,725°F
	Time at temperature: 1 hour minimum
	Atmosphere: Endogas
	Quench in 110–190°F oil to 200°F max. part temperature
25	Wash
30	Load
40	Temper to BHN 258–301
	Temp. (ref.) 980°F
	Time at temperature: 2 hours minimum
50	Unload
60	Clean
69	Inspect

Table 3—Hardening and Tempering Process at 1,550°F.	
Operation	Operation Description
10	Load
20	Core Harden
	Temperature 1,550°F
	Time at temperature: 1 hour minimum
	Atmosphere: Endogas
	Quench in 110–190°F oil to 200°F max. part temperature
25	Wash
30	Load
40	Temper to BHN 258–301
	Temp. (ref.) 980°F
	Time at temperature: 2 hours minimum
50	Unload
60	Clean
69	Inspect

Table 4—Manufacturing Process of Coupons.	
Operation	
10	Heat treat as necessary
20	Rough turn outer diameter, leaving grind stock
30	Finish grind outer diameter
40	Rough cut over all length, leaving grind stock
50	Stamp ID
60	Finish grind face
70	Finish grind second face
80	EDM inner diameter and slot
90	Stress relieve 300°F minimum 1 hour
100	CMM inspection
110	Carburize (carburizing and hardening process in separate table)
120	CMM inspection
130	Harden and temper
140	CMM inspection

stress relieved, carburized, and hardened together. The coupons were randomly located in the carburization furnace and quench basket. A summary of the populations is shown in Table 1. A sample size of 10 was used with one additional sample used for metallurgical evaluation. The samples' letter designations will be used from this point on to identify the populations. The raw material requiring hardening and tempering was heat treated in-house as listed in Table 2 and Table 3 prior to any machining. The normalizing process was done per the AMS specification prior to receiving the material. The manufacturing and inspection stages of the coupons are listed in Table 4. The coupons were carburized and hardened using a cycle common to the actual gear (see Table 5).

Dimensional measurements. A Zeiss Prismo scanning coordinate measuring machine (brass tag #253685) was used to perform all measurements. The outside diameter, inside diameter, and the gap width of every coupon was measured before carburizing, after carburizing, and after hardening. Each time, the outside diameter and etched face were scanned and set as reference. The gap width was measured at a constant radius of 0.7000 inches from the reference center. All measurements were taken in a plane 0.1500 inches (half overall length) from the reference face using a 0.054" diameter probe. The coupons were soaked in mineral spirits, wiped dry and rinsed with alcohol before each measurement. The cleaned coupons were placed in the CMM room 24 hours before measurement to thermally soak and stabilize. The CMM room temperature is held at 69°F +/– 2°F. The actual measurements are contained in Appendices A–D. A sample inspection report is in Appendix D.

Findings

This section contains all of the data and findings collected during the study. Data collected includes characterization of the pre-carburization microstructure and dimensional measurements.

Pre-carburization microstructure. To document the pre-carburized material, an extra coupon was manufactured from each population for metallurgical evaluation. The evaluation was performed after finish machining and before carburizing. The chemistry of Sample E is not reported in Table 7. The sample was lost during the metallurgical evaluation process. The hardness (see Table 6), chemistry (see Table 7), and microstructure (see Figures

Table 5—Carburize and Hardening Process.

Operation	Operation Description
10	Carb:
	0.030" – 0.035" cycle
	1,700°F, 1.5 hrs.
	1,700°F, 1.15%C, 5 hrs.
	1,700°F, 0.85%C, 2 hrs.
	Furnace cool to 1,000°F
	Air cool to ambient
20	Harden: 1,500°F, 0.85%C, 2 hrs.
	Quench in 110–190°F oil for 10 minutes
30	Temper: 300°F, 3 hrs.
40	Stabilize: –100°F, 3 hrs.
50	Temper: 300°F, 3 hrs.

Table 6—Pre-Carburization Hardness (Refs. 10–11).

	Hardness BHN 3,000kg Load				
Face location	Sample A	Sample B	Sample C	Sample D	Sample E
Center	207	302	255	285	269
Near O.D.	207	285	248	302	269

Table 7—Pre-Carburization Chemistry in Weight % (Ref. 10).

	Location	C	Mn	Cr	Ni	Mo	P	S	Si	Al	Cu
A	Center	0.080	0.510	1.220	3.180	0.080	0.012	0.006	0.260	0.010	0.020
A	Near O.D.	0.080	0.510	1.230	3.170	0.080	0.013	0.006	0.280	0.010	0.020
B	Center	0.100	0.470	1.240	3.220	0.090	0.012	0.006	0.270	0.010	0.020
B	Near O.D.	0.090	0.620	1.250	3.200	0.080	0.012	0.006	0.270	0.010	0.020
C	Center	0.130	0.660	1.450	3.120	0.090	0.016	0.006	0.310	0.050	0.010
C	Near O.D.	0.130	0.640	1.430	3.120	0.080	0.014	0.006	0.270	0.040	<0.01
D	Center	0.080	0.630	1.300	3.050	0.110	0.014	0.018	0.230	0.010	0.150
D	Near O.D.	0.070	0.620	1.300	3.020	0.100	0.014	0.020	0.250	0.020	0.150
E	Center	Sample Lost									
E	Near O.D.										

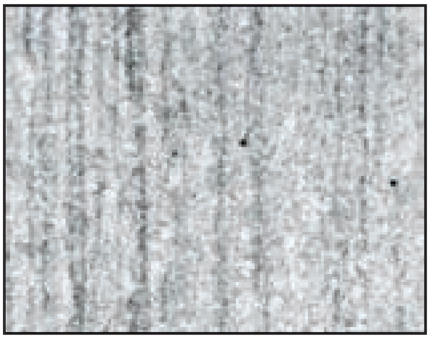


Figure 4—Sample A center microstructure 100X, 5% nital etch (Ref. 10).

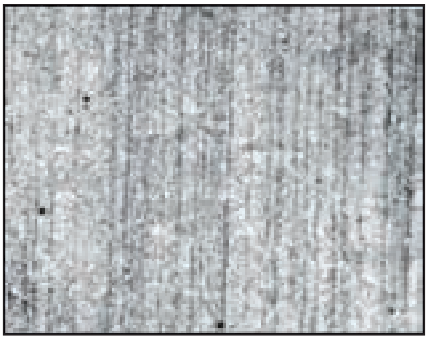


Figure 5—Sample A near OD microstructure 100X, 5% nital etch (Ref. 10).

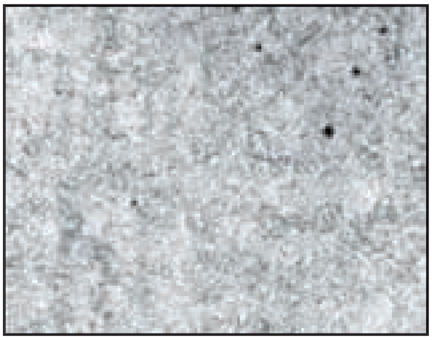


Figure 6—Sample B center microstructure 100X, 5% nital etch (Ref. 10).

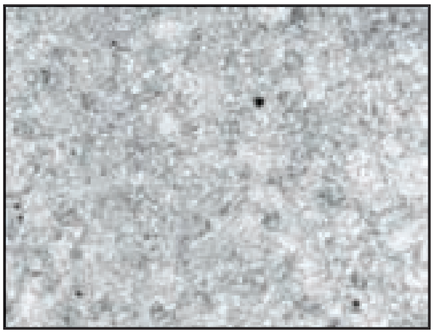


Figure 7—Sample B near OD microstructure 100X, 5% nital etch (Ref. 10).

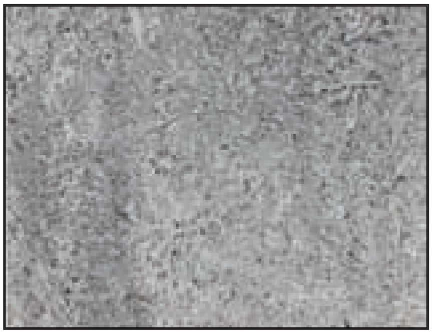


Figure 8—Sample C center microstructure 100X, 5% nital etch (Ref. 10).

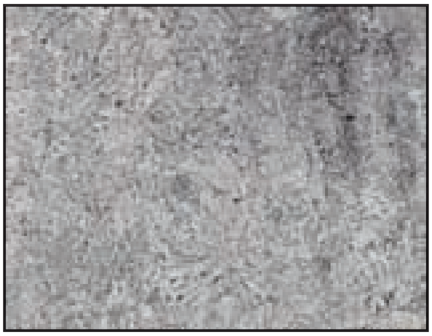


Figure 9—Sample C near OD microstructure 100X, 5% nital etch (Ref. 10).

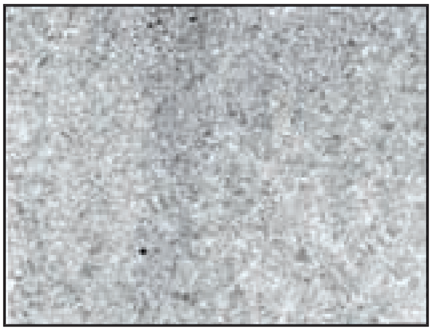


Figure 10—Sample D center microstructure 100X, 5% nital etch (Ref. 10).

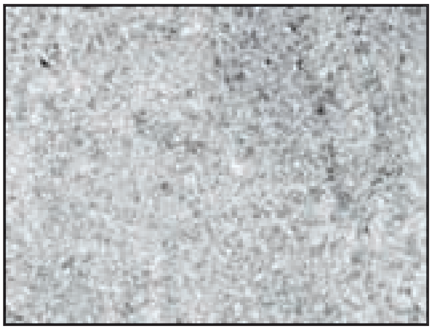


Figure 11—Sample D OD microstructure 100X, 5% nital etch (Ref. 10).

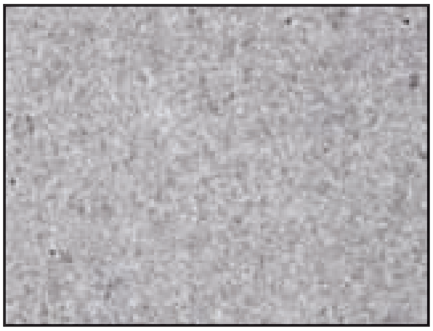


Figure 12—Sample E center microstructure 100X, 5% nital etch (Ref. 11).

Table 8—Descriptive Statistics of Pre-Carburization Gap Width Measurement.

	Pre-Carb Gap Width (inches)				
	A	B	C	D	E
Mean	0.1508	0.1525	0.1509	0.1520	0.1516
Standard Error	0.0001	0.0002	0.0001	0.0001	0.0001
Median	0.1509	0.1526	0.1508	0.1518	0.1517
Standard Deviation	0.0004	0.0005	0.0003	0.0004	0.0003
Sample Variance	1.32E–07	2.48E–07	8.00E–08	1.47E–07	9.90E–08
Range	0.0014	0.0017	0.0008	0.0012	0.0010
Minimum	0.1500	0.1513	0.1506	0.1513	0.1511
Maximum	0.1514	0.1531	0.1514	0.1525	0.1521
Sum	1.5081	1.5251	1.3579	1.5196	1.5161
Count	10	10	9	10	10
(95.0%) Conf.	0.0003	0.0004	0.0002	0.0003	0.0002

Table 9—Descriptive Statistics of Post-Carburization Gap Width Measurements.					
	Post-Carburization Gap Width (inches)				
	A	B	C	D	E
Mean	0.1496	0.1543	0.1504	0.1533	0.1504
Standard Error	0.0002	0.0002	0.0001	0.0003	0.0002
Median	0.1494	0.1543	0.1504	0.1537	0.1507
Standard Deviation	0.0005	0.0007	0.0004	0.0009	0.0008
Sample Variance	2.82E–07	4.54E–07	1.49E–07	9.02E–07	6.07E–07
Range	0.0015	0.0022	0.0012	0.0034	0.0025
Minimum	0.1491	0.1529	0.1500	0.1509	0.1488
Maximum	0.1506	0.1551	0.1512	0.1542	0.1513
Sum	1.4960	1.2344	1.3539	1.5328	1.5039
Count	10	8	9	10	10
(95.0%) Conf.	0.0004	0.0006	0.0003	0.0007	0.0006

Table 10—Descriptive Statistics of Post-Hardening Gap Width Measurements.					
	Post-Hardening Gap Width (inches)				
	A	B	C	D	E
Mean	0.1532	0.1581	0.1550	0.1587	0.1541
Standard Error	0.0006	0.0006	0.0003	0.0004	0.0005
Median	0.1537	0.1581	0.1553	0.1587	0.1540
Standard Deviation	0.0018	0.0017	0.0010	0.0012	0.0017
Sample Variance	3.33E–06	2.84E–06	1.07E–06	1.36E–06	2.81E–06
Range	0.0055	0.0047	0.0034	0.0040	0.0047
Minimum	0.1496	0.1555	0.1525	0.1567	0.1520
Maximum	0.1550	0.1603	0.1559	0.1607	0.1568
Sum	1.5316	1.2650	1.3946	1.5867	1.5405
Count	10	8	9	10	10
(95.0%) Conf.	0.0013	0.0014	0.0008	0.0008	0.0012

4–12) were evaluated on the etched face side of the coupon in two radial locations, center and near the outer diameter.

Dimensional measurements and descriptive statistics. Measurements were recorded before carburization, after carburization, and after hardening. Details of the measurement method are in the Methods and Procedures section. Serial numbers B5 and B6 were lost during carburization and serial number C10 was scrapped during manufacturing (see Appendix B). Descriptive statistics of the pre-carburization, post-carburization, and post-hardening measurements are listed in Tables 8–10. The actual measurements are shown in Figure 13. Descriptive statistics of the paired difference between

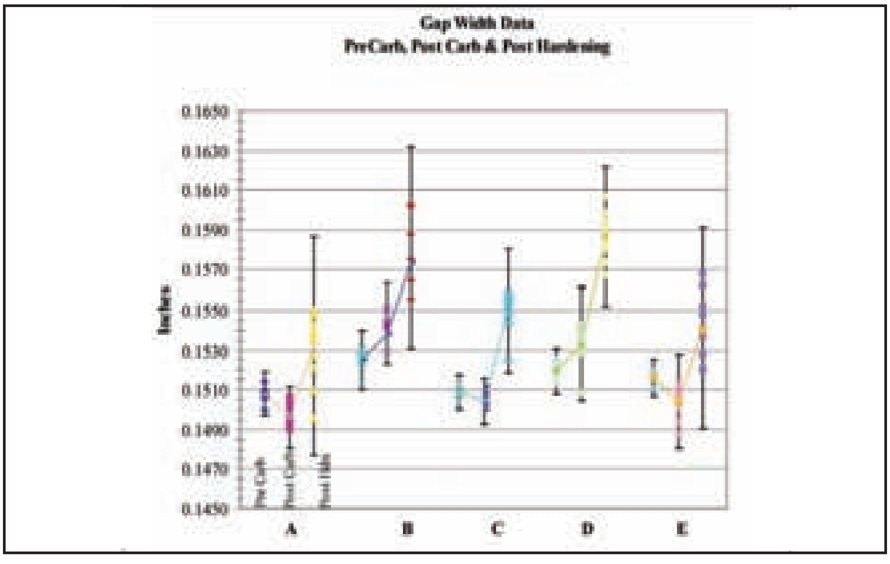


Figure 13—Gap width measurements after each processing step of carburizing and hardening.

Table 11—Descriptive Statistics of Paired Difference Gap Width Measurements.

	Paired Difference (Pre-Carburization/Post-Hardening) Gap Width (inches)				
	A	B	C	D	E
Mean	–0.0023	–0.0054	–0.0041	–0.0067	–0.0024
Standard Error	0.0006	0.0006	0.0003	0.0004	0.0005
Median	–0.0030	–0.0053	–0.0045	–0.0068	–0.0024
Standard Deviation	0.0019	0.0016	0.0010	0.0013	0.0017
Sample Variance	3.76E–06	2.47E–06	9.97E–07	1.76E–06	2.81E–06
Range	0.0056	0.0044	0.0030	0.0045	0.0051
Minimum	–0.0042	–0.0075	–0.0048	–0.0087	–0.0051
Maximum	0.0014	–0.0031	–0.0018	–0.0042	0.0000
Sum	–0.0235	–0.0434	–0.0367	–0.0671	–0.0245
Count	10	8	9	10	10
(95.0%) Conf.	0.0014	0.0013	0.0008	0.0009	0.0012

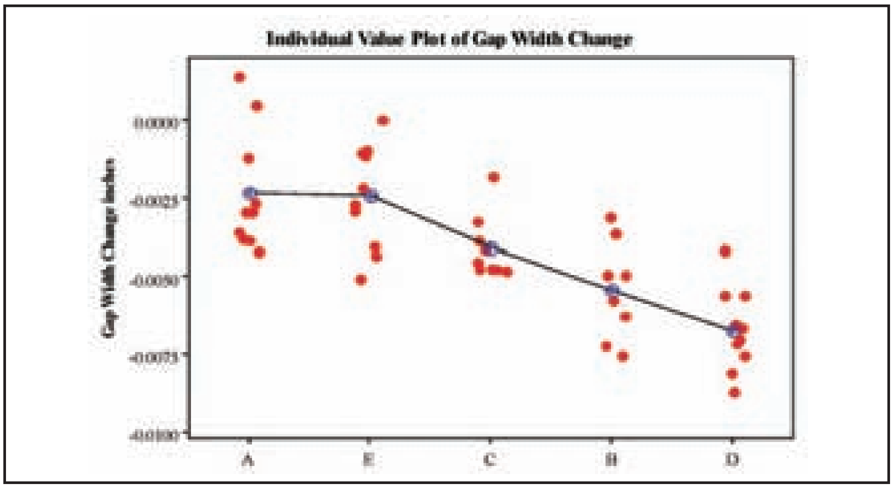


Figure 14—Data plot of gap width paired distance.

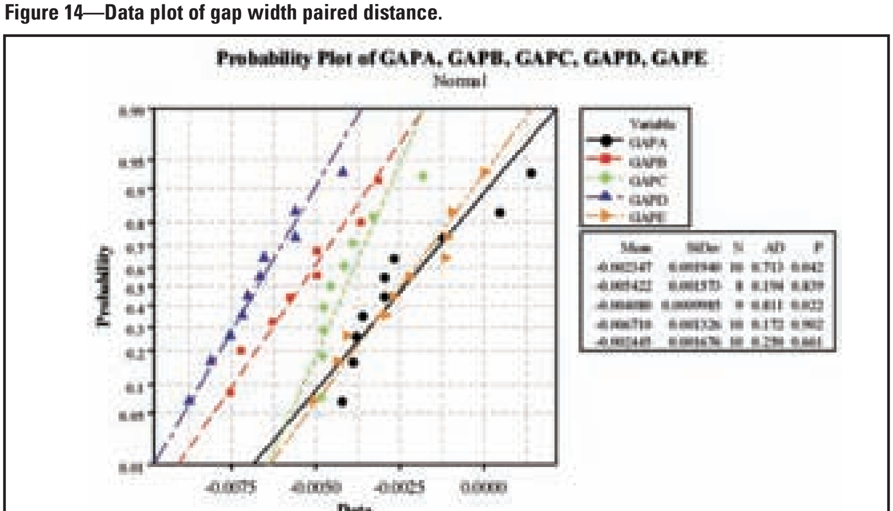


Figure 15—Probability plot of paired gap width distance.

Table 12—Gap Width Paired Difference Analysis of Variance (ANOVA).

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.000140	4	0.000035	14.674827	0.00000014	2.594263
Within Groups	0.000100	42	0.000002			
Total	0.000240	46				

pre-carburization and post-hardening are listed in Table 11. The mean paired difference values are shown in Figure 13.

Paired difference. The pre-carburization and post-hardening gap measurements were paired to enable a relative comparison. The gap width difference is reported as initial minus final. Thus, a change resulting in an increased gap width is reported as a negative value.

Graphical checks of the gap width change data were performed and shown in Figures 14 and 15. The checks include an individual data plot and a normal probability plot. Notice that the paired difference measurements were sorted based on each population's mean value and plotted.

An analysis of variance (ANOVA) was performed to compare the five population means (see Table 12). Formally, the data analysis is stated as:

H0: $\mu A = \mu B = \mu C = \mu D = \mu E$

H1: μA, μB, μC, μD and μE are not all equal

$\alpha = 0.05$

The F statistic is greater than the F critical value. Therefore, the null hypothesis is rejected, and the alternate accepted. The ANOVA identifies if difference is present between any of the mean values. A multiple comparison procedure is required to determine in what way they are not equal. A Fisher's Least Square Difference (LSD) test was performed at an individual $\alpha = 0.05$ to determine which of the population means were significantly different from each other. The results are listed in Table 13.

An upper value equal to or greater than zero indicates that the population is significantly less (greater distortion) than the population subtracted from. A summary of the LSD results is listed in Table 14.

Discussion

The gap width change was used to indicate differences in dimensional distortion during carburizing and hardening between five different raw material mechanical and thermal processes. Statistical analysis of the gap width change provides the following:

1.) Coupons manufactured from hardened and tempered barstock and forgings at 1,725°F had the greatest gap width change.

2.) Coupons manufactured from normalized barstock had the smallest gap width change. Coupons manufactured from normalized forgings had significantly more gap width change than those made from normalized barstock.

3.) Coupons manufactured from barstock hardened and tempered at 1,725°F had significantly more gap width change than those made from barstock hardened and tempered at 1,525°F.

4.) Coupons manufactured from barstock hardened and tempered at 1,550°F had no significant difference in gap width change than those made from normalized barstock.

The barstock used to manufacture coupons was from a common heat lot. Also, the forgings used were from a common heat lot. Additional heat lots could change the mean and/or scatter gap width change. It is recommended that future studies include multiple heat lots of materials. It is further recommended that future studies include residual stress measurements prior to carburization and hardening.

Based on the results of this study, hardened and tempered barstock at 1,550°F was selected. The surface integrity of the shaped gear and spline teeth improved greatly. Pre- and post-heat treat data collected from actual gears showed no change to the heat treat distortion.

See pages 42-44
for the Appendices
and References.

Table 13—Fisher's Least Square Difference Test (units = inches).

```
Fisher 95% Individual Confidence Intervals
All Pairwise Comparisons among Levels of Process
Simultaneous Confidence Level = 72.47%
Process = A substracted from:

Process    Lower       Center      Upper
E        –0.001493   –0.000098    0.001296
C        –0.003165   –0.001733   –0.000300
B        –0.004554   –0.003076   –0.001597
D        –0.005757   –0.004363   –0.002969

Process ---------+---------+---------+---------+
E                  (----*---)
C              (----*----)
B           (----*----)
D  (--- *----)
     ---------+---------+---------+----------+
            –0.0030     0.0000    0.0030      0.0060
Process = E subtracted from:

Process    Lower       Center      Upper
C        –0.003067   –0.001635   –0.000202
B        –0.004456   –0.002977   –0.001498
D        –0.005659   –0.004265   –0.002870
Process ---------+---------+---------+---------+
3               (----*---)
4            (----*----)
5    (----*---)
      ---------+---------+---------+---------+
             –0.0030    0.0000      0.0030      0.0060
Process = C subtracted from:

Process    Lower       Center      Upper
B        –0.002857   –0.001343    0.000172
D        –0.004062   –0.002630   –0.001197
Process ---------+---------+---------+---------+
B               (-----*----)
D            (----*----)
       ---------+---------+---------+---------+
              –0.0030    0.0000      0.0030      0.0060
Process = B subtracted from:

Process    Lower       Center      Upper
D        –0.002766   –0.001287    0.000191

Process ---------+---------+---------+---------+
D               (----*----)
      ---------+---------+---------+---------+
            –0.0030      0.0000     0.0030       0.0060
```

Table 14—Least Significant Difference Test Summary.

Identification	Material	Form	Pre-Machining Heat Treatment	Mean (inches)	LSD Results			
A	AMS6265	Barstock	Normalized	–0.0024	*			
E	AMS6265	Barstock	Normalized + Harden at 1,550°F	–0.0025	*	*		
C	AMS6265	Forging	Normalized	–0.0041	<	*	*	
B	AMS6265	Barstock	Normalized + Harden at 1,725°F	–0.0054	<	<	*	*
D	AMS6260	Forging	Normalized + Harden at 1,725°F	–0.0067	<	<	<	*

* No significant difference
< Significantly less (greater distortion)

Appendices

Appendix A—Pre-Carburization Measurements.

	OD	Gap Spacing	ID
A1	1.491777	0.150892	0.899649
A2	1.491833	0.151428	0.900125
A3	1.491889	0.150585	0.899613
A4	1.491864	0.150973	0.899684
A5	1.491463	0.150015	0.899672
A6	1.491518	0.150853	0.899942
A7	1.491897	0.150621	0.899719
A8	1.491825	0.150812	0.899795
A9	1.491830	0.150944	0.899858
A10	1.491699	0.150987	0.900030
B1	1.492130	0.152432	0.900146
B2	1.492317	0.153077	0.900630
B3	1.492522	0.152497	0.900089
B4	1.492463	0.152678	0.900317
B5	1.491625	0.151338	0.899684
B6	1.492083	0.152111	0.900149
B7	1.492541	0.152803	0.899924
B8	1.492419	0.152584	0.900315
B9	1.492507	0.152580	0.900418
B10	1.492581	0.153003	0.900233
C1	1.491860	0.150922	0.899908
C2	1.491729	0.150592	0.899712
C3	1.491832	0.151115	0.900064
C4	1.491791	0.150683	0.899635
C5	1.491955	0.150670	0.899736
C6	1.491934	0.151392	0.899899
C7	1.491609	0.150840	0.899937
C8	1.491915	0.151113	0.900109
C9	1.491870	0.150559	0.899998
C10	Lost	Lost	Lost
D1	1.492250	0.151756	0.900008
D2	1.491899	0.151808	0.900183
D3	1.492145	0.151759	0.899833
D4	1.492065	0.152528	0.900248
D5	1.492137	0.152459	0.900129
D6	1.492179	0.152392	0.900245
D7	1.492041	0.151956	0.899926
D8	1.491958	0.151321	0.899859
D9	1.492036	0.151865	0.899980
D10	1.492078	0.151759	0.900184
E1	1.492131	0.151698	0.900366
E2	1.491914	0.151144	0.900140
E3	1.492083	0.151885	0.900468
E4	1.492361	0.152086	0.900438
E5	1.492284	0.151717	0.900376
E7	1.492164	0.151831	0.900428
E8	1.492032	0.151081	0.900134
E9	1.492078	0.151536	0.900413
E10	1.492299	0.151610	0.900472

Appendix B—Post-Carburization Measurements.

	OD	Gap Spacing	ID
A1	1.491036	0.149513	0.897343
A2	1.491033	0.149186	0.897657
A3	1.491074	0.149532	0.897460
A4	1.490823	0.149060	0.897494
A5	1.490611	0.149263	0.897529
A6	1.490611	0.149263	0.897529
A7	1.491253	0.150098	0.897605
A8	1.490949	0.149235	0.897345
A9	1.491172	0.150590	0.897772
A10	1.491054	0.150287	0.898095
B1	1.491714	0.152937	0.898456
B10	1.492180	0.154464	0.898883
B2	1.492036	0.155081	0.899100
B3	1.492176	0.154322	0.898438
B4	1.492103	0.154088	0.898413
B7	1.492114	0.154273	0.898710
B8	1.492174	0.154173	0.898928
B9	1.492286	0.155087	0.899138
B5	LOST	LOST	LOST
B6*	LOST	LOST	LOST
C1	1.491083	0.150262	0.897598
C2	1.491028	0.150367	0.897641
C3	1.491203	0.151182	0.898020
C4	1.490913	0.150017	0.897155
C5	1.491221	0.150286	0.897484
C6	1.490911	0.150548	0.897335
C7	1.490769	0.149977	0.897728
C8	1.491139	0.150862	0.897897
C9	1.491030	0.150444	0.897760
C10	n/a	n/a	n/a
D1	1.491950	0.152889	0.898381
D2	1.492083	0.153695	0.899254
D3	1.492136	0.150858	0.898572
D4	1.491993	0.153699	0.898730
D5	1.491990	0.154248	0.899122
D6	1.491921	0.153672	0.898613
D7	1.491956	0.153817	0.898573
D8	1.492084	0.153777	0.898988
D9	1.492042	0.152932	0.898640
D10	1.491930	0.153221	0.898834
E1	1.491661	0.150680	0.898204
E2	1.491171	0.148791	0.897786
E3	1.491507	0.150825	0.898149
E4	1.491724	0.150663	0.898007
E5	1.491690	0.151033	0.898181
E6	1.491878	0.151272	0.898550
E7	1.491368	0.150030	0.898024
E8	1.491368	0.149373	0.897778
E9	1.491636	0.150844	0.898181
E10	1.491526	0.150382	0.898124

Appendix C—Post-Hardening Measurements.

	OD	Gap Spacing	ID
A1	1.490619	0.153859	0.896438
A2	1.490324	0.150953	0.896028
A3	1.490521	0.153558	0.896269
A4	1.490384	0.149559	0.895761
A5	1.490182	0.152694	0.896224
A6	1.490096	0.152069	0.895832
A7	1.490696	0.154222	0.896680
A8	1.491107	0.155014	0.897004
A9	1.491320	0.154763	0.897174
A10	1.490682	0.154885	0.896899
B1	1.491049	0.155546	0.897306
B2	1.491620	0.160287	0.898406
B7	1.491654	0.156456	0.897311
B8	1.491752	0.157525	0.897314
B3	1.491890	0.158768	0.897481
B9	1.492070	0.157517	0.897928
B10	1.492194	0.158739	0.898371
B4	1.492214	0.160193	0.898008
B5	LOST	LOST	LOST
B6*	LOST	LOST	LOST
C1	1.491160	0.155660	0.897044
C2	1.491215	0.155423	0.897330
C3	1.491222	0.154394	0.897220
C4	1.490598	0.152489	0.896345
C5	1.491542	0.155456	0.897286
C6	1.491036	0.155915	0.897238
C7	1.491051	0.154720	0.897478
C8	1.491340	0.155252	0.897652
C9	1.491132	0.155293	0.897370
C10	LOST	LOST	LOST
D1	1.491620	0.158277	0.897585
D2	1.491678	0.158458	0.898110
D3	1.491564	0.157367	0.897579
D4	1.491434	0.156716	0.897350
D5	1.491647	0.158048	0.898135
D6	1.491498	0.159406	0.897923
D7	1.491640	0.160681	0.897562
D8	1.491546	0.158859	0.898226
D9	1.492222	0.159044	0.898479
D10	1.492237	0.159842	0.898467
E1	1.491506	0.156774	0.897493
E2	1.491710	0.155209	0.897627
E3	1.491097	0.156209	0.897153
E4	1.491192	0.152073	0.896542
E5	1.491046	0.152790	0.896751
E6	1.491338	0.154177	0.897434
E7	1.491418	0.154764	0.897454
E8	1.490914	0.152042	0.896596
E9	1.491246	0.153723	0.896996
E10	1.491191	0.152753	0.897002

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Appendix D—Sample Zeiss CMM Report (continued on p.44).

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                    MEASURING RECORD ZEISS  UMESS

Greg Blake Rounds                                        CNC RUN
=================
DRAWING NUMBER      | ORDER NUMBER       | SUPPLIER/CUSTOMER | OPERATION
N/A                 |N/A                 |Rolls Royce        |true position-form

OPERATOR            DATE          PART NUMBER
ADMIN               06/20/03      a1

================================================================================
 ADR|REC | TASK    | IDF |SY| ACTUAL    | NOMINAL  | U.TOL | L.TOL | DEV    | EXC
--------------------------------------------------------------------------------
  13   12 *COORD. SYSTEM AS FOR  ADR.    12

##:OUTSIDE DIAMETER
  14  11! CIRCLEE       X    0.000000
                        Y   -0.000000
                        D    1.490619
                        S     .000050      FORM  .000241

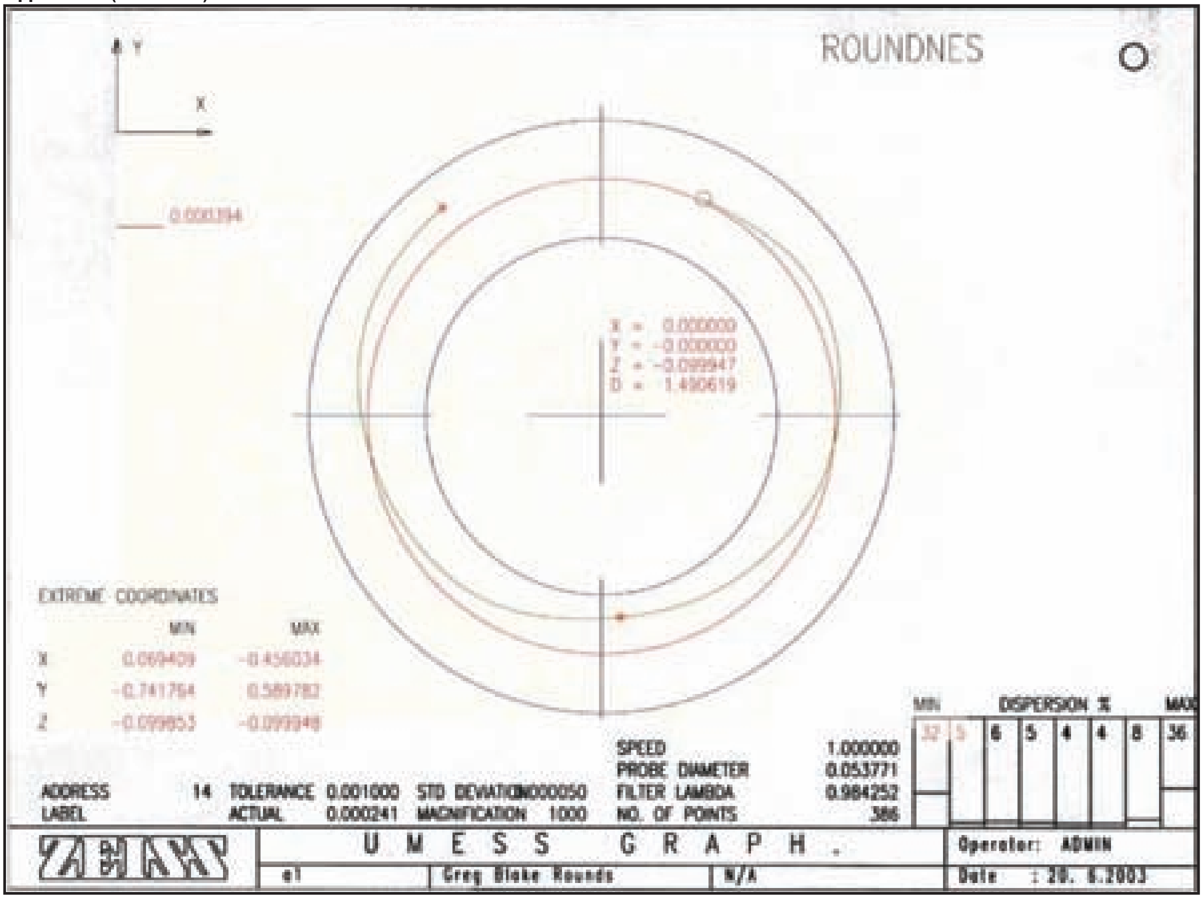
DISTANCE OF SLOT OPENING AT MID-DEPTH
  17   15 DIST 16       X    0.153859

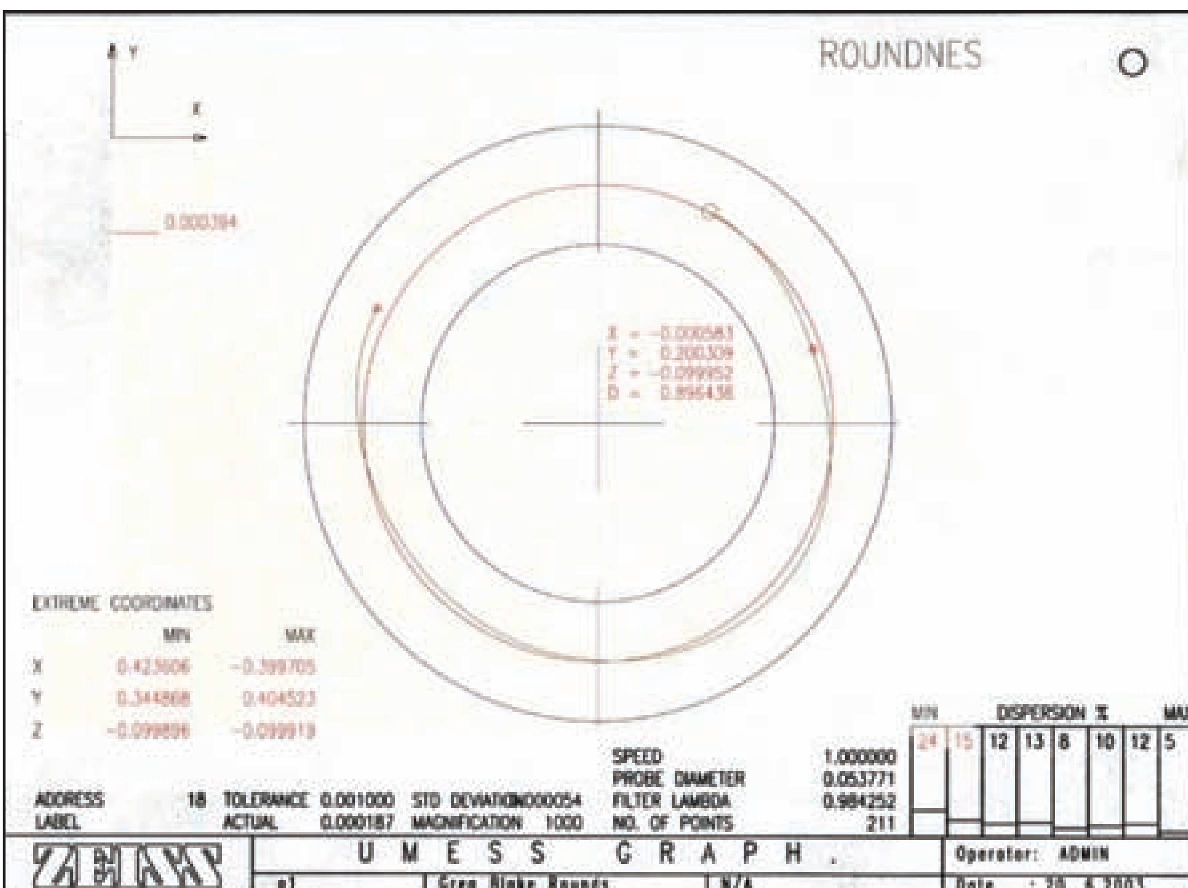
LOCATION AND SIZE OF CENTER BORE TO OD AND SLOT
##:INSIDE DIAMETER
Filter: DIN ISO EN 11562 (Gauss) Threshold wavelength =     25.00000
  18      CIRCLEI       X   -0.000583
                        Y    0.200309
                        D    0.896438
    211P S/MIN/MAX            .000054      (178)-.000074     (1;  000112


  4 hour 54 min 52.93sec

STATS STORED
================================================
                              CNC - END
                            ==============
```

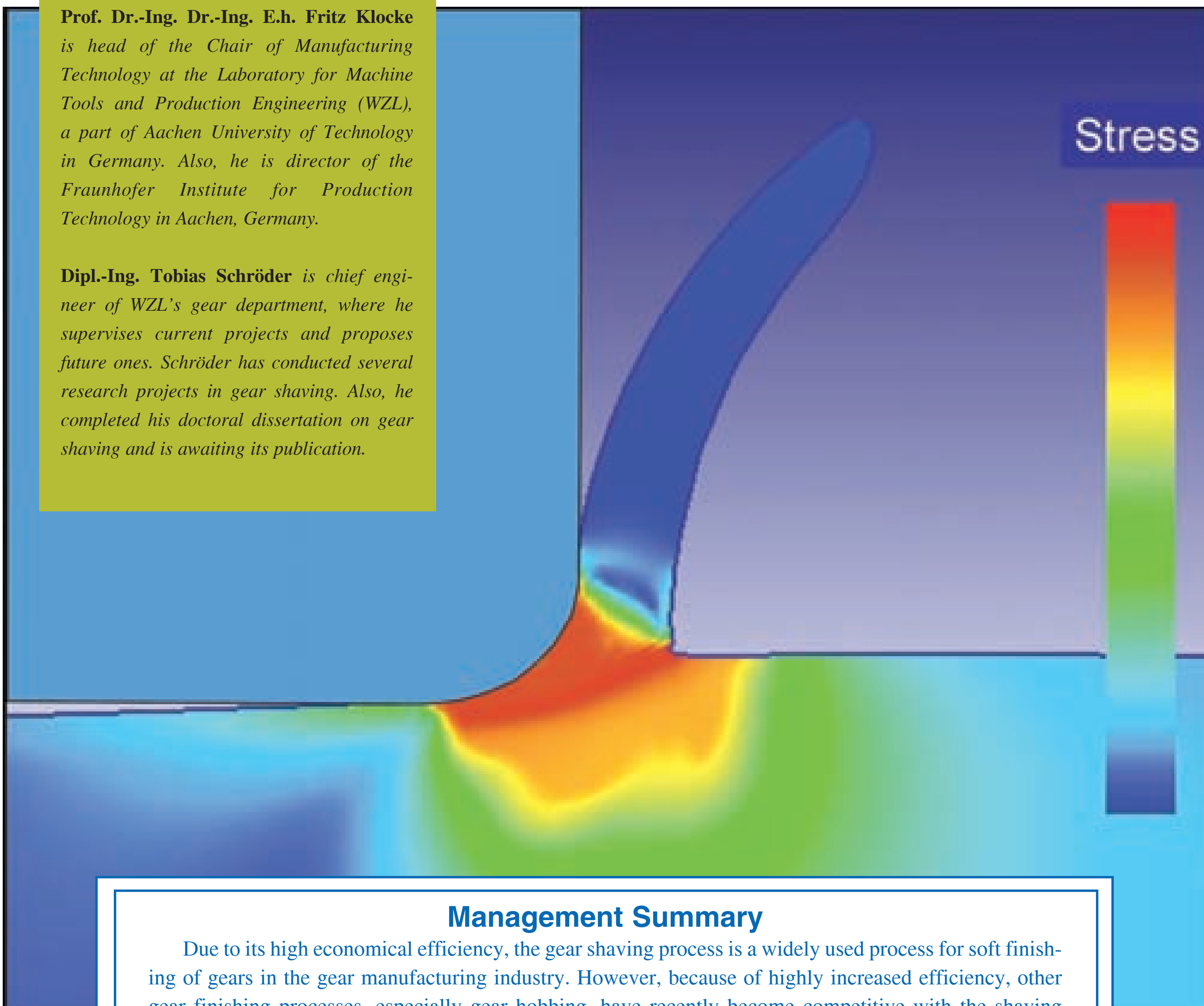
Appendix D (continued)





Gear Shaving—Process Simulation Helps to Comprehend an Incomprehensible Process

F. Klocke and T. Schröder



Prof. Dr.-Ing. Dr.-Ing. E.h. Fritz Klocke *is head of the Chair of Manufacturing Technology at the Laboratory for Machine Tools and Production Engineering (WZL), a part of Aachen University of Technology in Germany. Also, he is director of the Fraunhofer Institute for Production Technology in Aachen, Germany.*

Dipl.-Ing. Tobias Schröder *is chief engineer of WZL's gear department, where he supervises current projects and proposes future ones. Schröder has conducted several research projects in gear shaving. Also, he completed his doctoral dissertation on gear shaving and is awaiting its publication.*

Management Summary

Due to its high economical efficiency, the gear shaving process is a widely used process for soft finishing of gears in the gear manufacturing industry. However, because of highly increased efficiency, other gear finishing processes, especially gear hobbing, have recently become competitive with the shaving process for soft finishing of gears.

In contrast to other machining processes with geometrically defined cutting edges, the gear shaving process has been improved little during the past 30 years. So far, it is not known if the machining parameters in gear shaving represent an optimum as they are or if there is a potential for further optimization. Therefore, in this report, different approaches to increase the tool life and the productivity are discussed, using different simulation techniques.

At first, a geometrical simulation tool based on penetration calculation is used in order to analyze the geometrical and kinematical conditions of the gear shaving process. The information gained by this type of analysis is used to create another simulation model which is based on FEA. This two-dimensional model allows the determination of physical values like stresses, forces, temperatures and others. Also, with this type of simulation, it is possible to determine the effect of tool wear on the chip creation process.

The information gained with the two different simulation techniques is subsequently used to find different approaches to optimize the gear shaving process.

Introduction and Objective

With the gear shaving process, it is possible to create good gear quality with low machining costs and high process reliability. This has lead to a wide industrial application of this process for soft finishing of gears. However, this high economic efficiency has prevented further improvements in gear shaving during the recent decades. Due to the high reliability and economic efficiency, it was not considered necessary to improve the process.

In contrast to this, the productivity of other gear manufacturing processes has dramatically improved, especially during recent years. The reason for this can be seen in a high technological understanding of those processes. In gear hobbing, for example, productivity has been improved by about 800% during the last 30 years, making this process even competitive with gear shaving for soft finishing, despite fundamental theoretical disadvantages. At the same time, hard finishing processes like grinding or honing have also been improved so that, considering the higher achievable gear quality, these processes appear to be another viable alternative.

However, all other gear finishing processes—gear hobbing, grinding as well as honing—have to be driven at their technological limits, whereas in gear shaving, the process appears to be far from its possible limits. The applied cutting speeds are in the range of 20–60 m/min and the chip thicknesses are also very low.

Since gear shaving as a soft gear finishing process has various specific advantages against other gear finishing processes in many areas, there is a need for further improvement of the gear shaving process in terms of economic efficiency and quality. New machine concepts have been developed to fulfill this requirement, but in industrial practice, the increase of the process, in many cases, has not been achieved.

Therefore, this report will analyze by what means the costs of the gear shaving process can be decreased. This includes an analysis of the different types of costs in gear shaving and the creating of strategies to reduce the machining costs. For this, different types of simulation techniques will be used. The geometry of the cut and the process strategy can be analyzed using penetration calculation, while the effects on the chip creation and the process forces can be determined using an FEA-based process simulation model. The combination of both simulation techniques allows a detailed analysis of the gear shaving process, considering the technological peculiarities of the process, without costly and time-consuming machining trials.

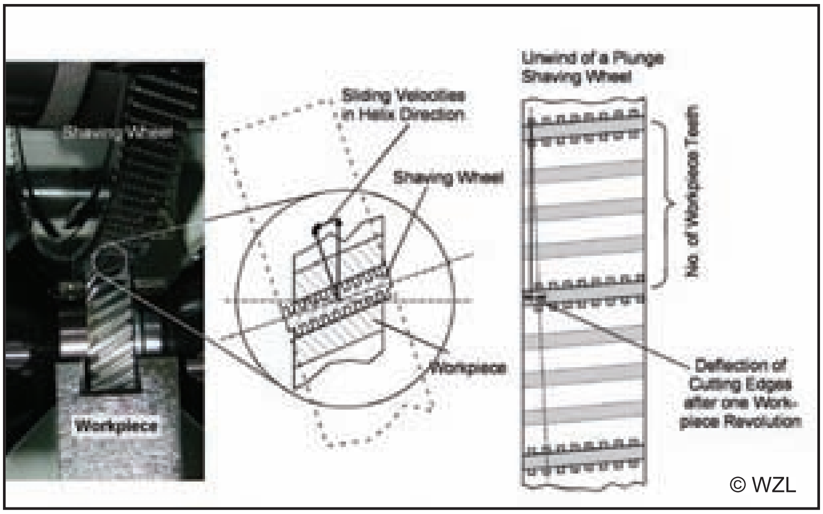


Figure 1—Principle of gear shaving.

State of the Art

Fundamentals of gear shaving. Gear shaving is a soft finishing process for gears using a geometrically defined cutting edge. The kinematics are identical to a non-parallel-axis gear drive. The tool is a gear with radial-interrupted flanks and with a different helix angle than the workpiece (see Fig. 1). The tool and the workpiece axis are therefore not parallel, which creates the so-called crossed-axis angle Σ. In industrial practice, the values for this crossed-axis angle range between 10–15°. In some exceptions, crossed-axis angles between 2–20° can be applied (Ref. 1).

The chip creation is accomplished by moving the workpiece and the gear radially together with high force while they are rolling up on each other. Usually, the tool is driven by the machine, while the workpiece is following freely. Due to the crossed-axis angle, an axial relative movement is created, and due to the penetration of the cutting edges and the gear flank, chips can be created (Ref. 2).

Since the flanks of the tool are radially interrupted in order to create the cutting edges, but there is no modification of the flanks, the constructive clearance angle is 0°. When the cutting edge is approaching the workpiece flank, even negative clearance angles are created, leading to a plastic deformation of the workpiece flank underneath the tool flank. This effect is desired in gear shaving since it leads to an elimination of the feed scallops of the machined surface, creating a good surface quality (Ref. 3). Due to this combination of machining and deforming, the gear shaving process is a machining process which shows various technological peculiarities compared with other machining processes with geometrically defined cutting edges. Therefore, research results accomplished in other manufac-

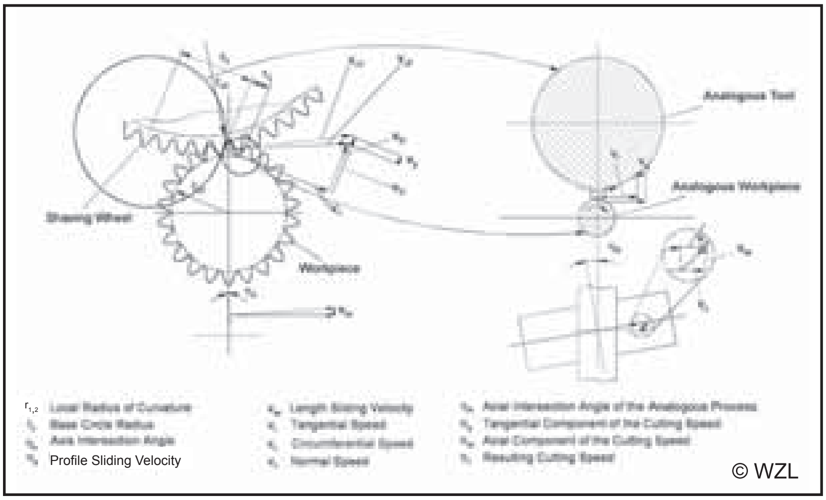


Figure 2—Analogous process for gear shaving.

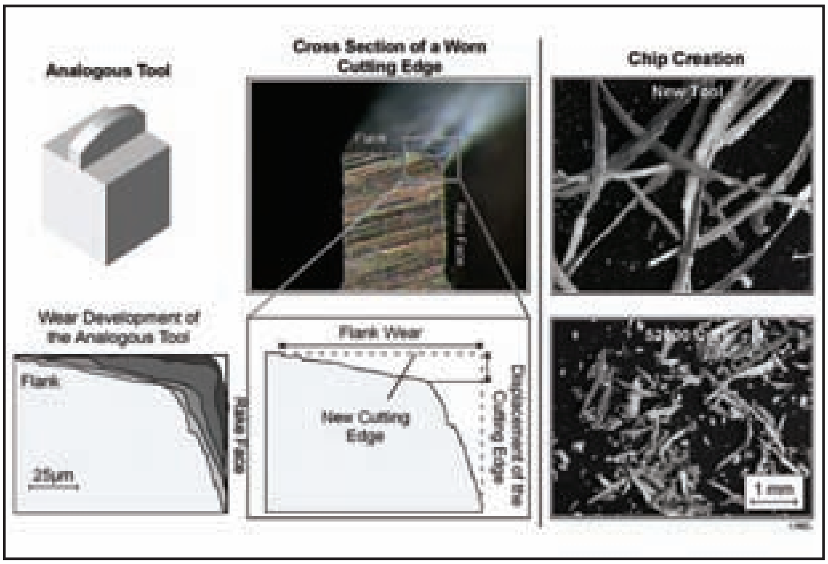


Figure 3—Tool wear and chip creation in the analogous process.

turing processes cannot be transferred to the gear shaving process.

Analogous process for gear shaving. One reason for stagnating development of the gear shaving process can be seen in the high expenditures necessary to perform systematic technological studies as well as in the very difficult analysis of tool wear on shaving wheels. A way to avoid these problems is via an analogous process for gear shaving, developed at WZL, which allows for a dramatic reduction of the expenditures for wear trials, while at the same time, much improving the accessibility of the cutting edge.

The aim of the analogous process is to reproduce the kinematic and geometrical contact conditions of the real gear shaving process as exactly as possible and thereby to create similar tool wear as in real gear shaving, considering the technological peculiarities of the process. Figure 2 shows the idea of this analogous process.

The left part of the figure shows a shaving wheel meshing with a gear. In the contact point, the two parts have different curvature radii, which can be calculated for each contact point. These radii are transferred to cylindrical parts in the analogous process. Like in the real gear shaving process, these two parts roll up on each other, and the two axes are crossed. By means of the crossed-axis angle, an axial cutting speed of the cutter on the workpiece surface is created.

This way, it is possible to simulate different points of contact in the analogous process. The slip in profile direction, which also occurs during the real shaving process, can be simulated by varying the individual turning speeds of the two axes. The analogous tool represents a section out of a cylindrical part which has approximately the thickness of one serration on a real shaving wheel. There is only one cutting edge on the analogous tool, and this edge has a key angle of 90°. In contrast to real shaving wheels, it is possible with this very compact tool to study the wear using conventional or even scanning electron microscope photographs. The geometrical and kinematic conditions of the gear shaving process and the effects of different parameters on tool wear in gear shaving can thereby be studied independent of each other.

Possible conclusions about the tool wear in the analogous process are shown in Figure 3. In the lower left part of the figure, the development of tool wear over the tool life is displayed in different cross sections of the tool. These cross sections have been created using a tactile measuring device. It can be seen that during the whole tool life, a relatively sharp cutting edge is present with a radius of about 5 µm. At the same time, however, a chamfer on each side of the cutting edge is created. During the life time of the tool, this chamfer is continuously increasing (Ref. 4).

In industrial practice, tool wear in gear shaving is not determined by monitoring the shape of the cutting edge but by determining the quality of the machined gear. Likewise, in the analogous process, a way must be found to study the effect of tool wear on the ability of the cutting edge to create chips. A standardized quality measurement like for real gears cannot be performed. In the analogous process, however, it is possible to observe the chips created during the life time of the tool. Therefore, in the right part of Figure 3, chips that are created with a sharp tool are compared with chips created via a worn tool. It can be seen that there is a clear relation between tool wear and chip creation in gear shaving.

The measuring plot, displayed in Figure 3, allows the determination of different characteristic values to quantify the wear, such as the displacement of the cutting edge $SV\gamma$ and the wear mark VB. These values can be considered to be relevant for the chip creation since they are responsible for the amount of material that must be plastically deformed underneath the flank of the tool.

Economic efficiency of gear shaving. The analogous process described above has been used in previous studies (Ref. 1) in order to perform systematic wear studies of gear shaving. It could be shown in combination with trials in the real gear shaving process that dramatic improvements in productivity are possible when proper adaptations to the process are applied. A high increase in productivity results especially from eliminating the speed reversal in the shaving process while increasing the process and cutting speed.

One example for an optimized gear shaving process is displayed in Figure 4. It can be seen that by optimizing the process, a reduction of the machining time (t_H) from 26 seconds to 12.5 seconds was achieved. That reduction is more than 50%. In the example, both the radial set-in per revolution and the axial feed were kept constant.

The machining costs are not only determined by the productivity of the process but also by the tool costs, which are nearly proportional to the tool wear. In order to study which of the two fields (productivity and tool costs) the highest costs are created, the machining costs for the processes described in Figure 4 are estimated in Figure 5.

The machine and labor costs are mainly determined by the cycle time, which consists of the machining time and the workpiece change time. The tool costs are determined by tool life, tool purchase costs and resharpening costs. The hourly costs for machine and worker have been estimated as accurately as possible, and the additional costs for maintenance, coolant, etc. were considered in separate hourly rates. The tool life has been estimated to about 1,500 parts per resharpening cycle for both machining processes, which is a realistic value according to the end-user. For the workpiece change, 15 seconds were estimated.

It can be seen in Figure 5 that for the state-of-the-art machining process, the machine and tool costs are on a similar level. Since the machine operator serves several machines at the same time, the labor costs are on a much lower level. By reducing the machining time by about 50%, the machining costs can only be reduced by about 15%. A further increase in productivity would cause an even lower reduction of machining costs. The reasons for this can be seen mainly in the constant workpiece change times, which cannot be improved by an increase in productivity, and in the constant tool costs. As a conclusion, it can be stated that in order to improve the economic efficiency of this process, the tool costs, and thereby the tool wear, must be reduced.

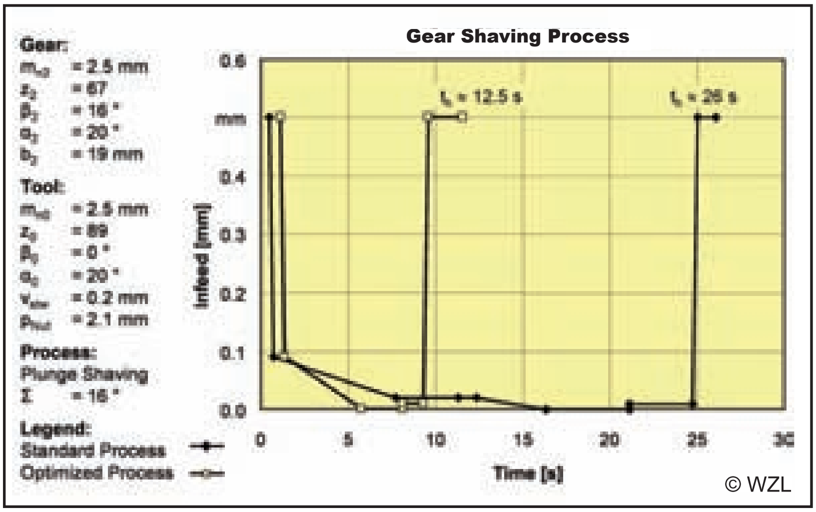


Figure 4—Comparison between optimized and state-of-the-art gear shaving process.

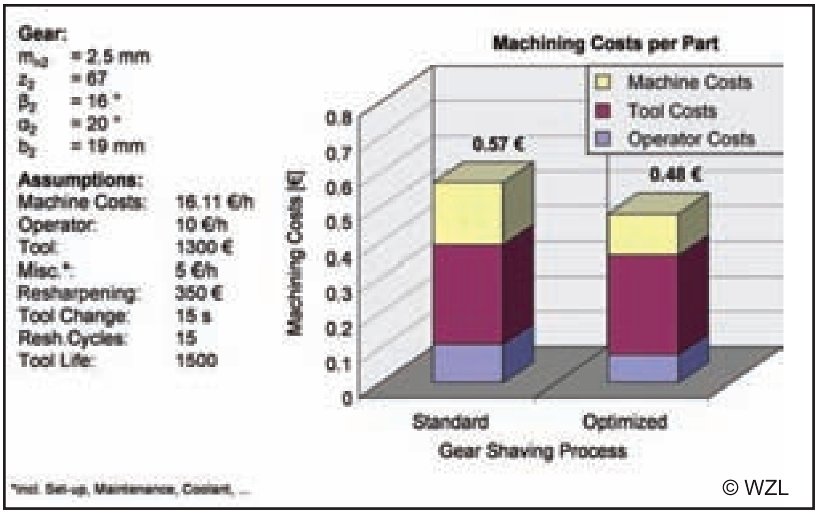


Figure 5—Estimated machining costs.

Geometrical Simulation of Gear Shaving by Penetration Calculation

As stated before, the gear shaving process is a very geometrically complex cutting process. In the past, it was not possible to determine the chip geometries in this process. By means of penetration calculation, however, a valuable tool is available to determine the geometries of the cuts and the chips (Ref. 4). The principle of this type of simulation is described in Figure 6.

In the left part of the figure, two teeth of a workpiece are displayed. Above them, the enveloping body of the cutting edge on its path through the gap can be seen. In the area in which the enveloping body and the gaps are penetrating, a chip is created. This area is better visible in the right part of the figure, in which not the whole teeth of the workpiece but only the flanks are displayed.

Since penetration calculation is a purely geometrical simulation, only an infinitesimally thin

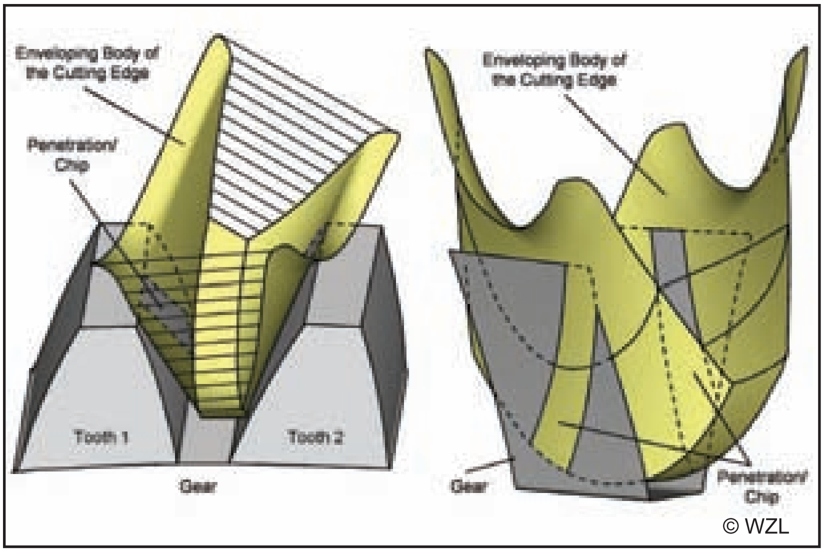


Figure 6—Penetration calculation, simulation model.

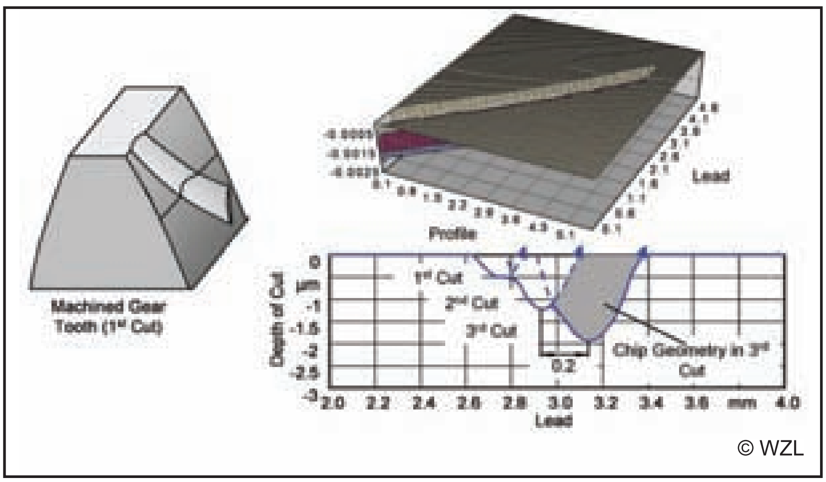


Figure 7—Example of simulation result.

cutting edge is used. In contrast to that, in the real gear shaving process, the flanks of shaving cutters have an extension of about 1 mm. Underneath these flanks, material is plastically deformed. This influence cannot be considered in penetration calculation.

In Figure 7, an example for a simulation result of the penetration calculation is given. The left part of the figure shows a workpiece tooth with a single cut. The upper right part of the figure represents a three-dimensional picture of the cut in relation to the ideal involute. With this illustration, however, it is difficult to determine the actual geometry of the cut.

In gear shaving, the cutting edges follow the gear profile and the cutting speed is perpendicular to this profile, so the cutting speed in gear shaving always points in the lead direction of the flank, despite the varying sliding velocities in the profile direction. Thus, the best analysis of the cutting edge track is possible in lead direction, displayed in the lower right part of Figure 7.

The diagram shows the flank in the lead direction after three cuts, which were performed according to a state-of-the-art plunge shaving process. Apart from the track of the cutting edge, the chip geometry (the hatched surface) can also be determined.

The simulation results can be used in order to create a model of the shaving process with realistic values for chip thickness and chip length, as shown in Figure 8. With this model, it is possible to estimate the actual loads on the cutting edge during the shaving process.

The figure shows the sequence of chips as created in a typical plunge shaving process. In this shaving strategy, the axis center distance is continuously reduced during the shaving operations. With this type of shaving process, the whole gear flank can be machined at once, so this is the most economical shaving process and therefore also the most popular one in industrial practice.

It can be seen in the figure that one cutting edge is exposed to a large number of different loads during the machining operation of one gear. While the cutting speed can be assumed to be almost constant during the whole machining operation, the chip thickness is changing significantly. At first, the chip thickness is constantly increasing as the axis center distance decreases until a constant level has been reached. In common plunge shaving processes, the value for the chip thickness is between 2–10 µm, depending on the feed rate and the gear data. When the final axis center distance is reached, the radial motion stops and the chip thickness decreases until the chip thickness falls below a critical value and no chips are created anymore. But not only the load on the cutting edge itself varies during one machining operation, the load on the tool flank (in other machining processes: clearance face) also varies strongly.

As a conclusion, it can be said that the shaving process differs in many ways from other machining processes with geometrically defined cutting edges. The main differences are (Ref. 1):

- negative clearance angles,
- very small chips (height: 50–150 µm; length: 100–400 µm),
- low thermal load on the cutting edge due to low cutting speeds and chip thicknesses, and
- strongly varying load on cutting edge and clearance face.

FE-Based Simulation of Gear Shaving

Starting in the recent past, FE-based machining process simulation has offered the opportunity to model machining processes and thereby to determine the loads on the tool depending on the previously mentioned boundary conditions of the gear shaving process. The penetration calculation model introduced above is used to determine the path of the tool through the workpiece surface and the workpiece geometry before the cut.

The FE-based simulation model used in the simulations described below is shown in Figure 9. Based on the previously determined path of the cutting edge, the path of the cutting edge in this simulation is approximated by a section of a circular curve, as shown in the upper middle part of Figure 9.

From the path of the cutting edge during the cut, the velocity function in the y-direction can be determined, as shown in the lower middle part of the figure. The geometry of the workpiece before the cut is implemented by interpolation points. The material data (16MnCr5) is implemented in a specific material database with respect to the temperature as well as the strain rate. By using this simulation model, various physical values can be determined, i.e. stresses, temperatures, strain and strain rates (Ref. 5).

Simulation of parallel shaving. In order to obtain valuable simulation results by using the simulation model introduced above, it is necessary to verify this model. With a regular gear shaving process, it is not possible to verify simulation results because during a gear shaving cycle, many teeth and even more cutting edges are in use at the same time. Also, a large variety of different chip geometries is being generated, and neither temperatures nor cutting forces can be determined for a single cut in the real gear shaving process.

However, the analogous process introduced above can be used in order to verify the simulation model. Since only one cutting edge is in use at the same time, it is possible to observe the chip creation depending on the shape of the cutting edge, as displayed in Figure 3. Therefore, in Figure 10, three different cutting edge shapes have been used within a simulation model that corresponds to the geometrical conditions in the analogous process and a conventional parallel shaving process.

In the upper part of the figure, the chip creation is displayed in the beginning of the cut (left) and close to the end of the cut (right) for a sharp tool with a cutting edge radius of about 5 μm. The stress within the workpiece surface is shaded dark. In the middle section of the figure, a worn cutting edge is simulated with a chamfer on each side of the cutting edge as shown in Figure 3. The bottom part of Figure 10 shows the chip creation when a cutting edge with a radius of about 20 μm is used without chamfers, as existent on coated

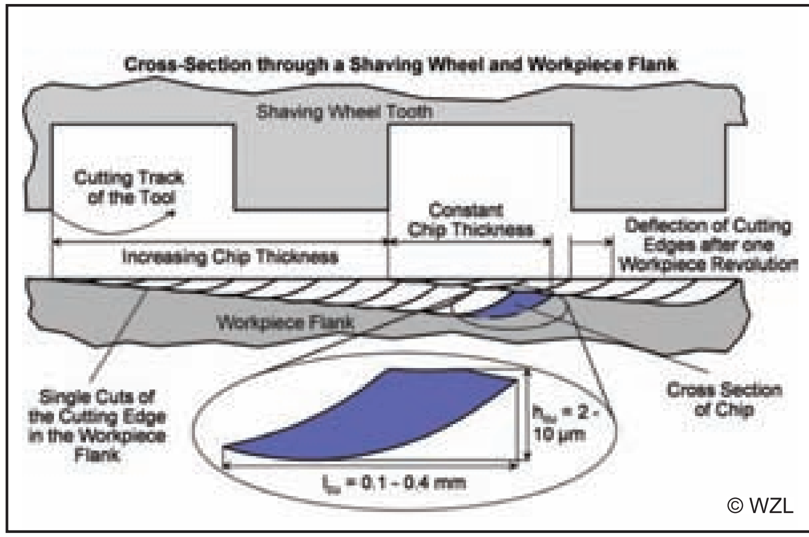


Figure 8—Chip geometries in gear shaving.

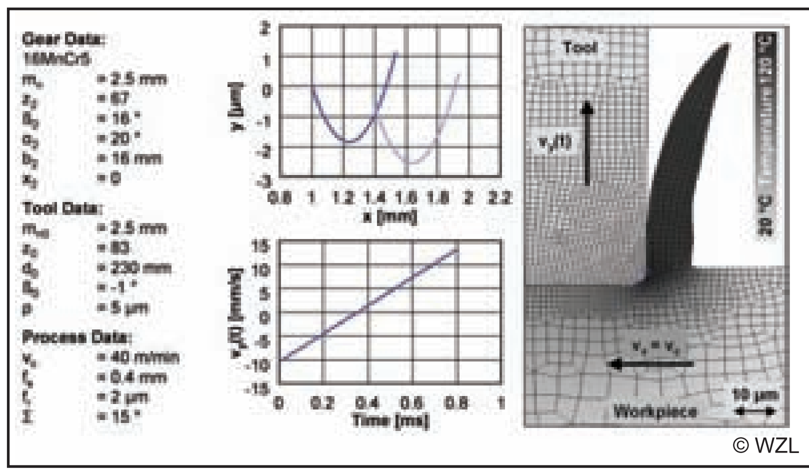


Figure 9—Model for FE-based simulation of plunge shaving.

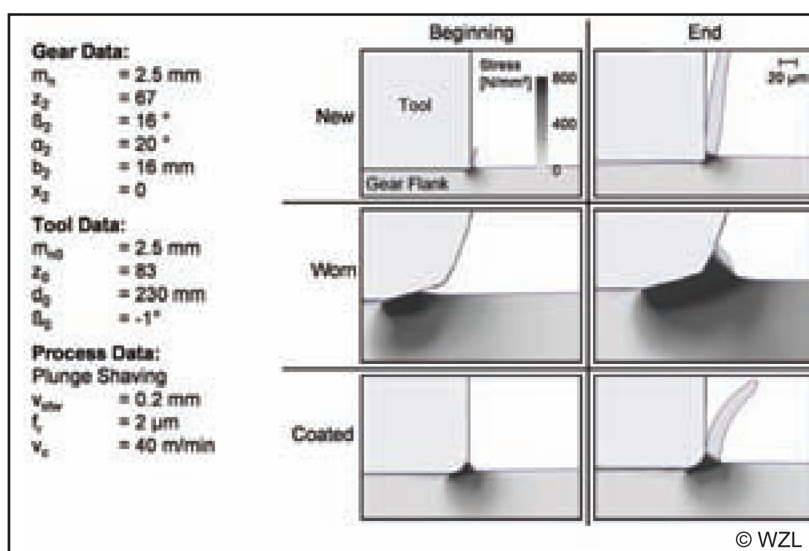


Figure 10—Simulation of chip creation in gear shaving.

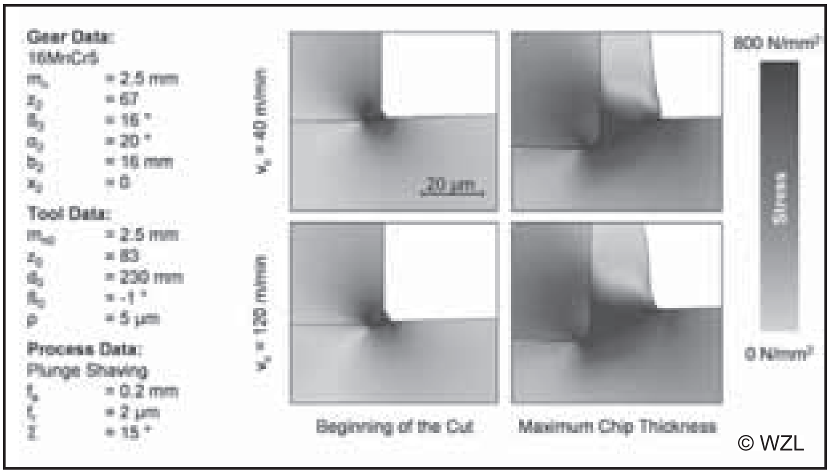


Figure 11—Chip creation with respect to the cutting speed.

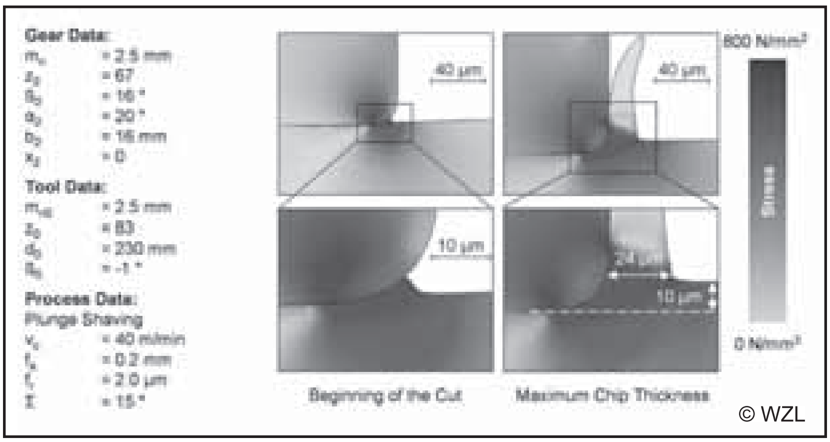


Figure 12—Chip creation in plunge shaving with respect to the cutting edge geometry.

cutting edges in gear shaving (Ref. 2).

It can be seen that there is a clear dependency of the chip geometry on the shape of the cutting edge. While, as in the analogous process, with a new cutting edge, thin and smooth chips can be created. With the worn and the coated cutting edges, the chips are much more deformed. With the worn cutting edge, nearly no chip creation is possible anymore. This could also be observed in Figure 3.

Simulation of plunge shaving. Due to its high economical efficiency, the plunge shaving process is by far the most commonly used gear shaving process in industrial practice (Ref. 3). With the analogous process, however, it is not possible to simulate the plunge shaving process, since only one cutting edge is used. On the other hand, the FE-based simulation model can also be used for this process in order to determine the loads on the tool with respect to different technological parameters, like the cutting speed, plunge feed rate, axial feed rate, crossed-axis angle and cutting edge roundness.

At first, the cutting speed is varied. In the upper part of Figure 11, the chip creation from a state-of-the-art plunge shaving process is shown at the beginning of the cut and at the point with the highest chip thickness. As in Figure 10, the stress within the workpiece flank is shaded dark, but in this case, the stress in the tool is also shown.

The lower part of the figure shows the chip creation at a cutting speed of v_c = 120 m/min in the same spots as in the upper part. Even though the cutting speed has been increased by three times, no remarkable change in the chip creation can be observed.

As a next step, the chip creation with respect to cutting edge geometry is shown in Figure 12. It can be seen that also in plunge shaving, there is a clear dependence of the chip creation on the shape of the cutting edge. Unlike the analogous process, the tool wear in real shaving processes is reflected in a higher cutting edge radius rather than as a chamfer on each side of the cutting edge (Ref. 4). Therefore, this cutting edge geometry has not been studied in this case.

The cutting edge used in this simulation had a radius of ρ = 20 µm. Again, the chip creation clearly depends on the cutting edge radius. Compared to the chip creation in Figure 11, where a cutting edge radius of ρ = 5 µm was simulated, the chip in this case is more deformed and more compact. In the lower right side of the figure, the deformation of the chip is quantified. The ratio of 24 µm to 10 µm from deformed chip thickness to undeformed chip thickness indicates a shortening of factor 2.4.

Also, in the lower left side of that picture, a fold can be seen. During the simulation, these folds occurred several times, which led to problems with the simulation. The mesh size had to be increased in order to allow the simulation to continue. This fold indicates a creation of lamella chips.

It is obvious that the cutting edge geometry also has an impact on the process forces. Thus, in Figure 13, the process forces for the two different cutting edge geometries are shown. In the upper part of the figure, the actual cutting force is displayed, while in the lower part, the passive forces—which are perpendicular to the cut—are shown. It can be seen that during the chip creating period of the cut, the cutting forces are increased by about 60% and the passive forces by more than 100% due to the higher cutting edge radius. This effect can be considered to be the main reason for the quality reduction that results when a gear is machined with this type of cutting edge geometry.

In the next step, the plunge (or radial) feed rate has been varied. The cutting forces of this study are displayed in Figure 14. Beginning with the state-of-the-art plunge shaving process, where the plunge feed rate is about 2 μm per workpiece revolution, the plunge feed rate has been increased to 3, 4.5 and 6 μm.

Again, it is obvious that the increase of the feed rate has a clear effect on the process forces. The maximum cutting force is increased by about 80% and the maximum passive force is increased by about 90%. Another important phenomenon that can be observed in Figure 14 is that one cut can be divided into two parts. Shortly after the first contact between tool and workpiece, both the cutting and passive forces reach their maximum values. The maximum is much higher for the passive forces than for the actual cutting forces, which indicates that the maximum forces are caused by the workpiece material, which has to be plastically deformed underneath the flank of the cutter due to negative clearance angles. After reaching their maximums, both forces drop quickly down to a minimum value when the path of the cutting edge has reached the deepest point in the workpiece flank. At that time, the actual chip creation begins, and the curve follows the chip thickness value along the cut. Thus, it can be stated that the first stage of the cut is the deforming stage, and the second stage is the cutting stage.

The maximum overall load during the cut for all plunge feed rates occurs during the deforming stage. Therefore, the load on the flank of the shaving cutter is higher than that on the rake face, since the flank is already in contact during the deforming stage, while the rake face is only in contact when a chip is formed.

In the last step, the axial feed rate has been varied. In real plunge shaving processes, varying the axial feed rate is only possible by modifying the tool. Therefore, it is very costly to perform trials in real shaving processes with different axial feed rates. In this paper, the axial feed rate has been varied, beginning with an industrial standard of 0.2 mm per workpiece revolution and increasing it to 0.4 mm per workpiece revolution. The process forces for this variation are displayed in Figure 15.

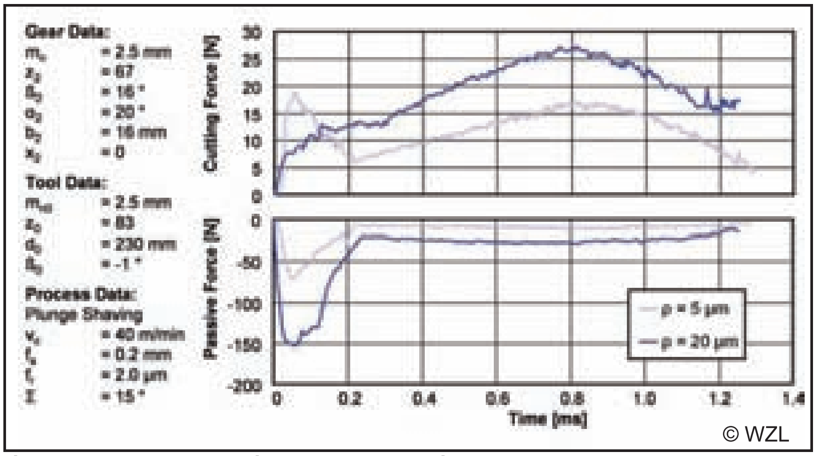


Figure 13—Process forces with respect to the cutting edge geometry.

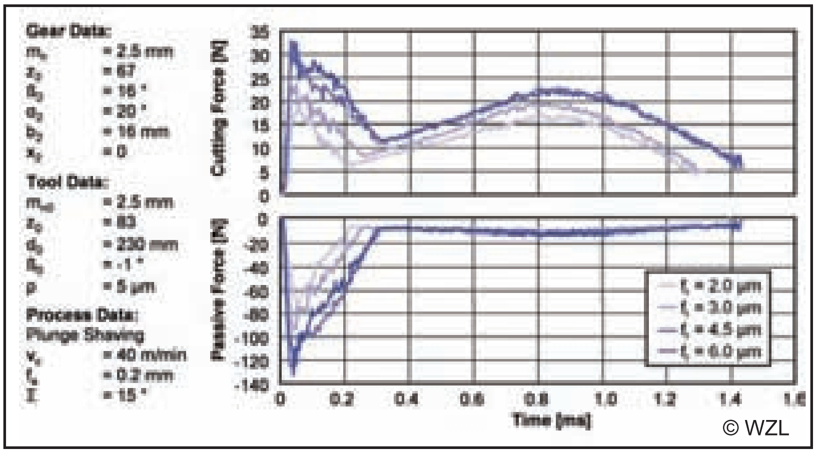


Figure 14—Process forces depending on the plunge feed rate.

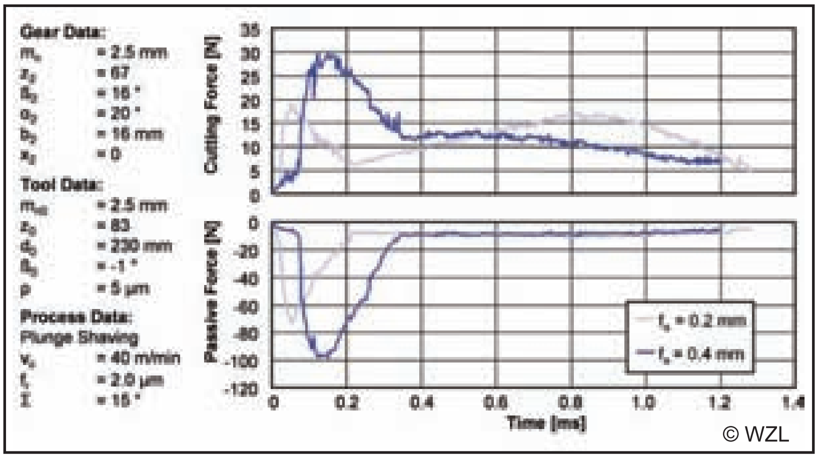


Figure 15—Process forces depending on the axial feed rate.

Again, the cuts can clearly be divided into two phases. The increase of the axial feed rate leads to a significant increase of the deforming phase. On the one hand, the share of the deforming phase along the cut is larger, and on the other hand, the forces during the deforming phase are higher due to the larger amount of material that has to be deformed underneath the clearance face.

During the variation of the feed rates, it was shown that an increase of both types of feed rates causes a strong increase of the passive forces during the deforming phase of the cuts. Therefore, it can be assumed that also the quality of the machined gears will be worse when either one of the two feed rates is increased. In contrast to that, the increase of the cutting speed has not shown significant influence on the cutting process.

Summary and Outlook

It was the aim of the work described in this report to show approaches for an optimization of gear shaving using different simulation techniques. At first, a detailed description of the gear shaving process and its technological peculiarities was given. After this, an analogous process was introduced that can be used for systematic technological wear studies in gear shaving. It was shown that, in the analogous process, similar chip geometries as in real shaving can be created.

In the next step, a simulation model was introduced that is based on penetration calculation. This model was used subsequently to determine the path of the cutting edges during the cutting operation. The results of this simulation were used as input data for another simulation type, based on FEA. This type of simulation allows for a detailed modeling of machining processes considering the process kinematics and geometric boundary conditions as well as the material data. As a result, measures like temperatures, stresses, forces and others can be determined on the surface or inside both the tool and the workpiece (Ref. 2).

Within the scope of this report, among the large number of possible outputs, mainly the process forces and the chip creation have been studied. At first, the simulation was verified using the analogous process introduced before. By simulating different cutting edge geometries, the effect on the chip creation was studied and compared to the results obtained in the analogous process.

In the next step, a commonly used plunge shaving process was simulated. Again, the effect of the cutting edge geometry on the forces and the chip creation was studied. For this, the radius of the cutting edge was increased to a value of $\rho = 20\ \mu m$. This increase corresponds to a radius that, in previous studies, was measured on a shaving wheel that was considered to be worn. Within the simulation, it could be shown that the cutting edge geometry has a strong effect on the chip creation process. The chips are significantly shorter and crushed during the cut. Also, both the cutting and passive forces are on a higher level than with a sharp tool.

The variation of the cutting speed does not show a significant effect on the chip creation but the results show that one cut in plunge shaving can generally be divided into two phases. In the beginning of the cut, there is a negative effective clearance angle leading to material deformation underneath the tool flank. This phenomenon can be seen in a high peak within the progression of the passive force. After this so-called deformation phase, the actual chip creation phase begins. After the deepest point on the track of the cutting edge has been passed, a positive clearance angle exists, and the passive forces decrease significantly.

In contrast to the cutting speed, the chip geometry, which can be modified by the plunge or the axial feed rate, has a strong effect on the process forces. In any case, the increase of each of the named values leads to an increase in the passive forces, while the cutting forces can only be slightly influenced.

As a conclusion it can be stated that the FE-based machining simulation, in combination with the simulation based on penetration calculation, represents a valuable tool in order to analyze and optimize the gear shaving process in detail. The simulation can be used to determine the loads on the cutting edge under the specific boundary conditions of the gear shaving process. In further studies, this simulation will be used to simulate the complete shaving wheel tooth in contact with the workpiece tooth in a three-dimensional simulation. Thereby, the deflection of the teeth under the load of the gear shaving process can be studied, and the reasons for the created gear quality can be found.

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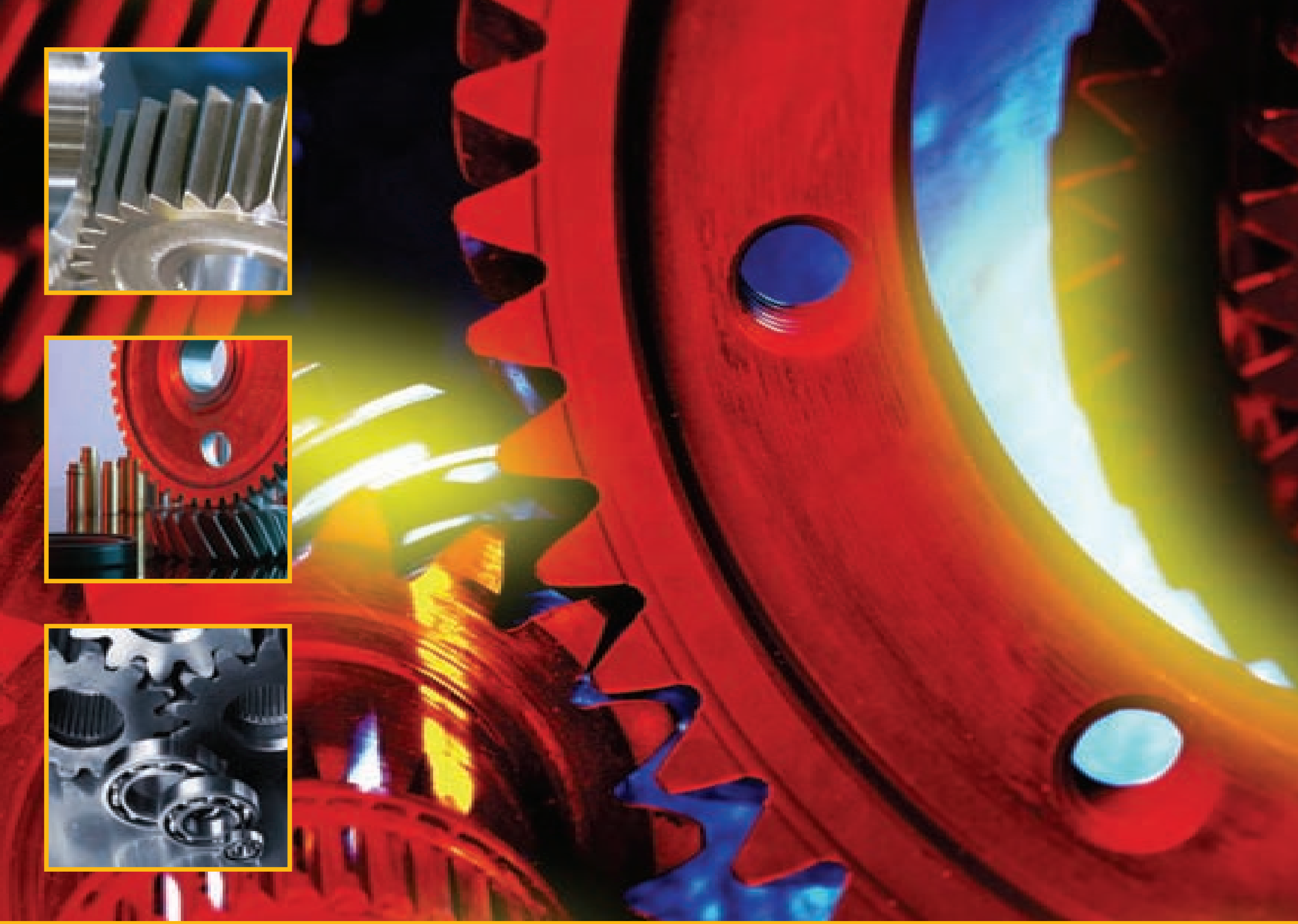

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Determining the Shaper Cut Helical Gear Fillet Profile

George Lian

Management Summary

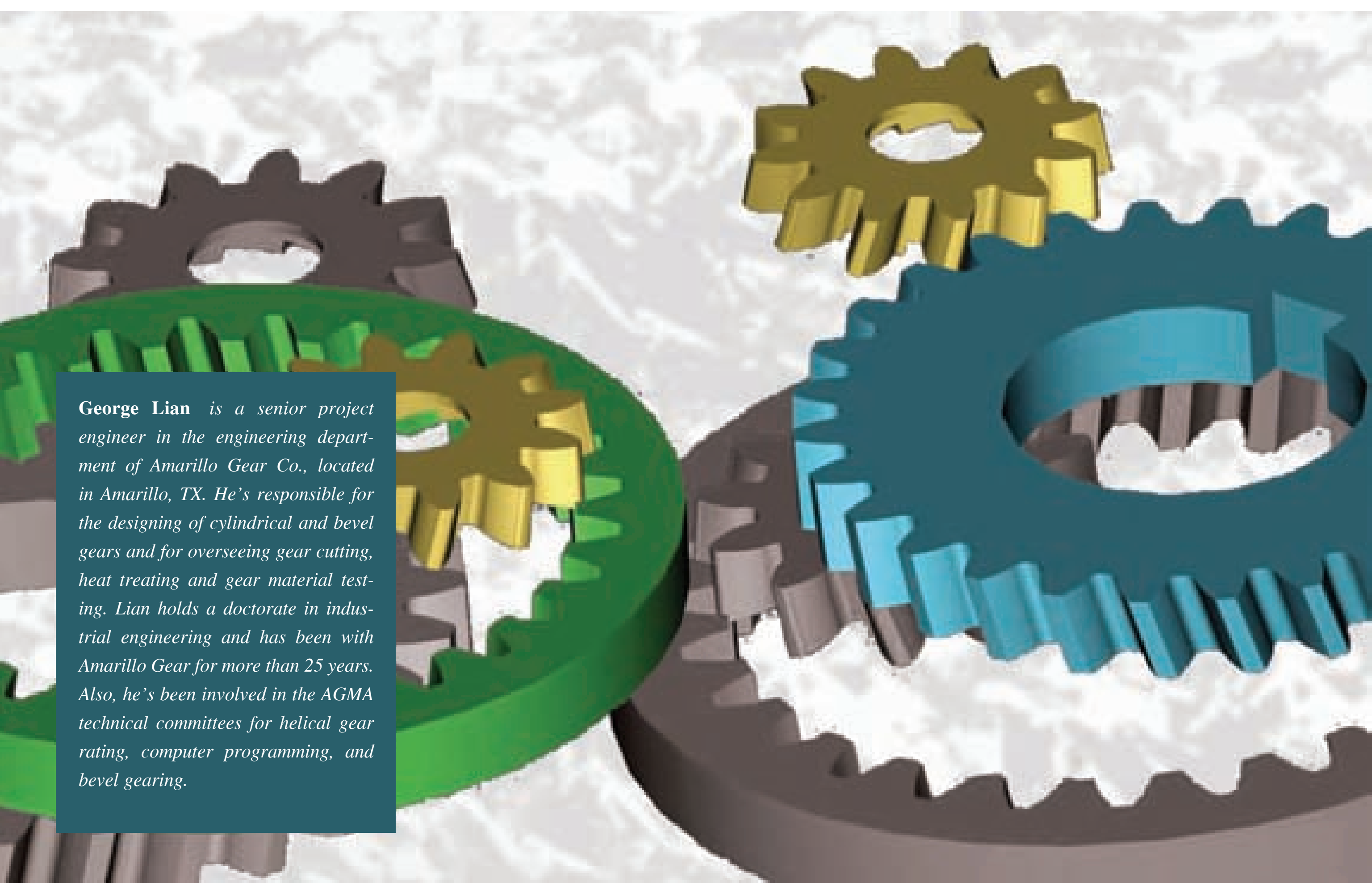
This article describes a root fillet form calculating method for a helical gear generated with a shaper cutter. The shaper cutter considered has an involute main profile and an elliptical cutter edge in the transverse plane. Since the fillet profile cannot be determined with closed-form equations, a Newton's approximation method was used in the calculation procedure. The article also explores the feasibility of using a shaper tool algorithm for approximating a hobbed fillet form. Finally, the article discusses some of the applications of fillet-form calculation procedures, such as form diameter (start of involute) calculation and finishing stock analysis.

Introduction

Analytical methods for determining the gear fillet profile (trochoid) have been well documented. Khiralla (Ref. 1) described methods for calculating the fillet profile of hobbed and shaped spur gears. Colbourne (Ref. 2) provided equations for calculating the trochoid of both involute and non-involute gears generated by rack or shaper tools. The MAAG Gear Handbook (Ref. 3) also provided equations for calculating trochoids generated with rack-type tools that have circular tool tips. Vijayakar, et al. (Ref. 4) presented a method of determining spur gear tooth profiles using an arbitrary rack. The above mentioned are only samples of many published works. However, the method for determining the trochoid of a helical gear generated with a shaper tool is not widely published. This article presents an intuitive algorithm where the fillet profile of a shaper-tool-generated external or internal helical gear can be calculated.

A shaper tool generating a gear can be visualized as a gear set meshing with zero backlash. The algorithm in this article is based on a shaper tool in tight mesh with a semi-finished helical gear. The semi-finished gear geometry was used for calculation because the shaper tool used as the semi-finishing tool is usually the one that generates the trochoid. However, if the shaper cutter *is* the finishing tool, the algorithm presented will also work by letting the finishing stock equal zero. The trochoid of a spur gear can also be calculated by letting the helix angle equal zero.

The shaper tool used in this algorithm may have a different reference normal pressure angle than that of the gear. A necessary condition for a shaper tool to generate the correct involute profile on a gear is that both the tool and the gear must have



George Lian *is a senior project engineer in the engineering department of Amarillo Gear Co., located in Amarillo, TX. He's responsible for the designing of cylindrical and bevel gears and for overseeing gear cutting, heat treating and gear material testing. Lian holds a doctorate in industrial engineering and has been with Amarillo Gear for more than 25 years. Also, he's been involved in the AGMA technical committees for helical gear rating, computer programming, and bevel gearing.*

equal normal base pitches. This article stipulates that the axis of the shaper tool and the gear are parallel, which is often true for gear shaping. Consequently, the shaper tool and the gear must also have equal base helix angles.

Although the algorithm is based on the shaper cutter as a generating tool, the presented method can also be used to calculate a trochoid generated with a hob or a rack-type tool if the number of the shaper teeth is large (e.g. 10,000).

Symbols and Conventions

The symbols are defined where first used. This article tries to adhere to the following rules in subscript usage:

- Symbols related to tool geometry have subscript "0".
- No subscript is used for symbols related to the gear.
- Subscript "n" is used for measurements in the normal plane.
- Subscript "r" is used for symbols related to the semi-finished gear.
- Subscript "g" is used for symbols related to the generating pitch circle.

When dual signs are used in an equation (e.g. ±), the upper sign is for external gears and the lower one for internal gears.

Non-italicized uppercase symbols are used to designate points on the shaper tool, the gear, or other points of interest. Points are also represented as the coordinates (*x*,*y*). The length of a vector (e.g. R) is represented as $\|R\|$.

Coordinate System

The reference position of a shaper tool generating a gear is depicted in Figure 1 for external gear shaping and Figure 2 for internal.

The following coordinate system and sign conventions are followed:

- A standard cartesian coordinate system is used. The center of the shaper tool O_0 is (0,0).
- The reference position of the shaper tool is with one of its teeth aligned with the y-axis. The end of the shaper tooth points in the –y direction.
- The center of the gear, O_G, is also on the y-axis with one of the tooth spaces aligned with the y-axis. The opening of the tooth space is in the +y direction.
- Angular measures, related to tool or gear rotation or location of a point, have signs. Counterclockwise rotation from the reference line is positive, and clockwise is negative.

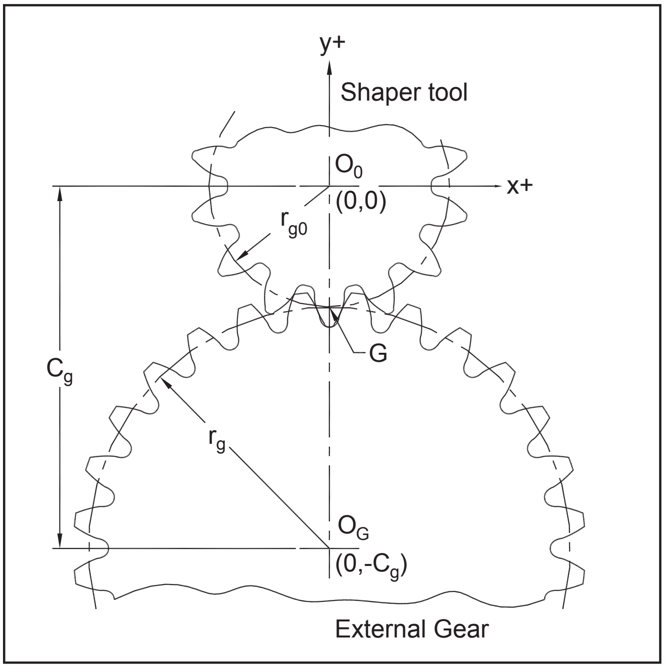


Figure 1—Shaping an external gear.

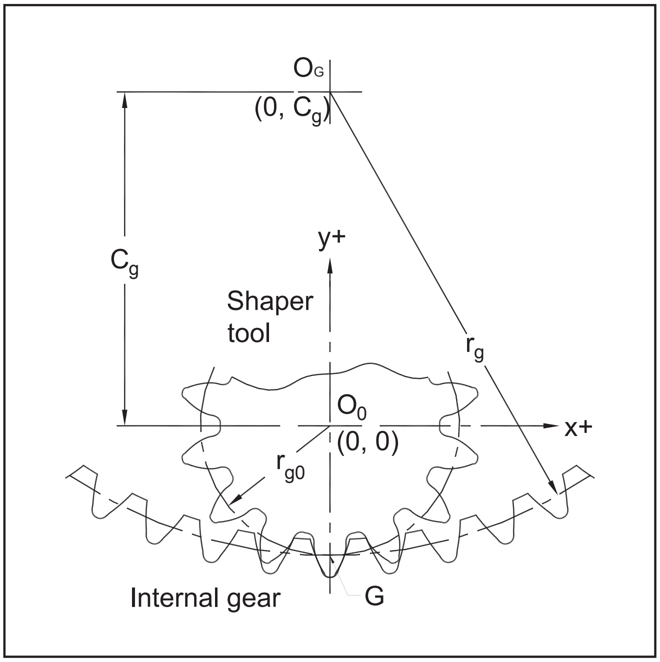


Figure 2—Shaping an internal gear.

Shaper Tool and Gear Geometry

The following are required tool and gear data for calculating the trochoid:

Shaper tool data:

P_{nd0} is the reference normal diametral pitch, tool (in.$^{-1}$)
n_0 is the number of teeth, tool
ϕ_{n0} is the reference normal pressure angle, tool
ψ_0 is the reference helix angle, tool
s_{n0} is the reference normal circular thickness, tool (in.)
d_{a0} is the outside diameter, tool (in.)
ρ_0 is the tool tip radius (in.)
δ_0 is the protuberance (in.)

Gear data:

P_{nd} is the reference normal diametral pitch, gear (in.$^{-1}$)
n is the number of teeth, gear
ϕ_n is the reference normal pressure angle, gear
ψ is the reference helix angle, gear
s_n is the reference normal circular thickness, gear (in.)
μ_s is the stock allowance per flank, gear (in.), defined on the reference pitch circle (not along the base tangent).

Basic Shaper Tool and Gear Geometry

The following equations calculate the basic tool and gear

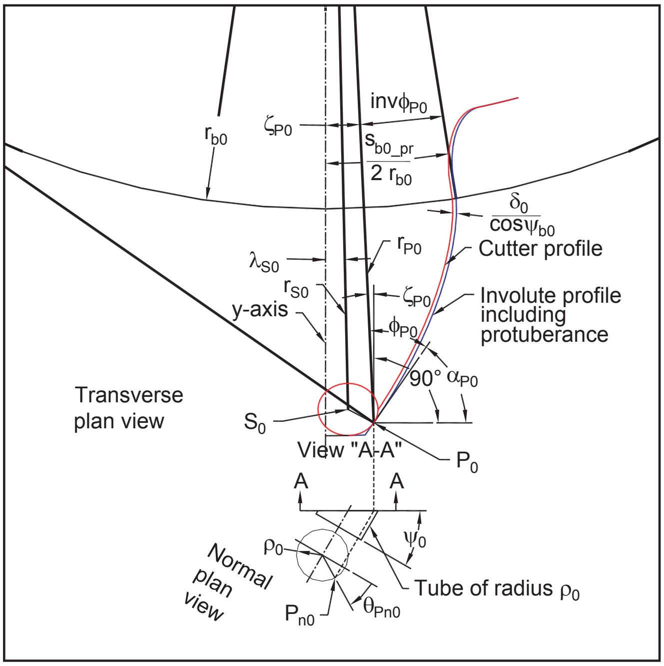


Figure 3—Tool tip of a shaper tool.

geometry:

Standard transverse pressure angle of tool, ϕ_0

$$\phi_0 = \arctan\left(\frac{\tan\phi_{n0}}{\cos\psi_0}\right) \tag{1}$$

Standard reference pitch radius of tool, r_0 (in.)

$$r_0 = \frac{n_0}{2P_{nd0}\cos\psi_0} \tag{2}$$

Base radius of tool, r_{b0} (in.)

$$r_{b0} = r_0\cos\phi_0 \tag{3}$$

Reference transverse circular thickness of tool, S_0 (in.)

$$s_0 = \frac{s_{n0}}{\cos\psi_0} \tag{4}$$

Transverse base pitch of tool, p_{b0} (in.)

$$p_{b0} = \frac{2\pi r_{b0}}{n_0} \tag{5}$$

Normal base pitch of tool, p_{nb0} (in.)

$$p_{nb0} = \frac{\pi\cos\phi_{n0}}{P_{nd0}} \tag{6}$$

Base helix angle of tool, ψ_{b0}

$$\psi_{b0} = \arccos\left(\frac{p_{nb0}}{p_{b0}}\right) \tag{7}$$

Base circular thickness of tool, s_{b0} (in.)

$$s_{b0} = 2r_{b0}\left(\frac{s_0}{2r_0} + \mathrm{inv}\phi_0\right) \tag{8}$$

where

inv is the involute function of an angle
inv $\alpha = \tan\alpha - \alpha$

Standard reference pitch radius of gear, r (in.)

$$r = \frac{n}{2P_{nd}\cos\psi} \tag{9}$$

Base radius of semi-finished gear, r_{br} (in.)

$$r_{br} = r_{b0}\frac{n}{n_0} \tag{10}$$

The helix angle at standard pitch radius of semi-finished gear, ψ_r

$$\psi_r = \arctan\left(\frac{r\tan\psi_{b0}}{r_{br}}\right) \tag{11}$$

Transverse pressure angle at reference pitch radius of semi-finished gear, ϕ_r

$$\phi_r = \arccos\left(\frac{r_{br}}{r}\right) \tag{12}$$

Transverse circular thickness of semi-finished gear, s_r (in.)

$$s_r = \frac{s_n + 2\mu_s}{\cos\psi_r} \tag{13}$$

Base circular thickness of semi-finished gear, s_{br} (in.)

$$s_{br} = 2r_{br}\left(\frac{s_r}{2r} \pm \mathrm{inv}\,\phi_r\right) \tag{14}$$

Center of Tool Tip on a Shaper Tool

A shaper tool for gear semi-finishing usually has protuberance. It generates undercut on a gear, so that the finishing tool only needs to machine the involute profile of the gear. To obtain the designed amount of protuberance on a shaper tool, the tool tip is made tangent to the involute profile that is temporarily formed by increasing the shaper tooth thickness to include the protuberance (see Fig. 3). The tangent point, common to the tool tip and the involute profile, will be referred to as the profile tangent point, P_0. When the temporarily formed involute profile is removed, the shaper tool will have the designed amount of protuberance.

The shaper tool tip is also made tangent to the outside diameter of the tool (see Fig. 4) so that the transition from the outside diameter to the tool tip will be smooth. The common tangent point on the shaper tool tip and the outside diameter of the tool will be referred to as the end tangent point, E_0.

The following are the required data for calculating the center of the shaper tool tip:

- d_{a0} is the outside diameter, tool (in.)
- s_{b0} is the base circular thickness, tool (in.)
- ρ_0 is the tool tip radius (in.)
- δ_0 is the protuberance (in.)
- ψ_{b0} is the base helix angle, tool
- ψ_0 is the reference helix angle, tool

The base circular thickness of the involute profile, formed by increasing the shaper tool tooth thickness to include the protuberance, s_{b0_pr}

$$s_{b0\_pr} = s_{b0} + \frac{2\delta_0}{\cos\psi_{b0}} \tag{15}$$

Coordinates of the center of the tool tip, S_0

$$S_0 = (r_{S0}\sin\lambda_{S0} , -r_{S0}\cos\lambda_{S0}) \tag{16}$$

where

r_{S0} is the tool radius to the center of the tool tip (in.)

λ_{S0} is the offset angle of the tool tip. For a shaper tool with full tip radius, λ_{S0} will equal zero.

Coordinates of the profile tangent point, P_0, are

$$P_0 = S_0 + (\rho_0 \frac{\cos\theta_{Pn0}}{\cos\psi_0}, \rho_0 \sin\theta_{Pn0}) \tag{17}$$

where

θ_{Pn0} is the auxiliary angle that locates P_0. The angle is measured in the normal plane, clockwise from the horizontal axis of the tool tip. θ_{Pn0} will usually have a negative value.

The tool radius to profile tangent point, r_{P0} (in.), is

$$r_{P0} = \| P_0 \| \tag{18}$$

The transverse pressure angle, ϕ_{P0}, at P_0 is

$$\phi_{P0} = \arccos(\frac{r_{b0}}{r_{P0}}) \tag{19}$$

The tangent angle, α_{P0}, at P_0 (the derivation of Equation 20 is given in Appendix A) is

$$\alpha_{P0} = \arctan (\frac{-\cos\psi_0}{\tan\theta_{Pn0}}) \tag{20}$$

The angle between the y-axis and the radius to the profile tangent point, ζ_{P0}, is

$$\zeta_{P0} = \frac{s_{b0\_pr}}{2r_{b0}} - \mathrm{inv}\phi_{P0} \tag{21}$$

The coordinates of the end tangent point, E_0, are

$$E_0 = S_0 + (\rho_0 \frac{\cos\theta_{En0}}{\cos\psi_0} , \rho_0\sin\theta_{En0}) \tag{22}$$

where

θ_{En0} is the auxiliary angle that locates E_0. The angle is measured in the normal plane, clockwise from the horizontal axis of the tool tip. θ_{En0} will usually have a negative value.

The angle of tangent, α_{E0}, at the end tangent point, E_0, is

$$\alpha_{E0} = \arctan (\frac{-\cos\psi_0}{\tan\theta_{En0}}) \tag{23}$$

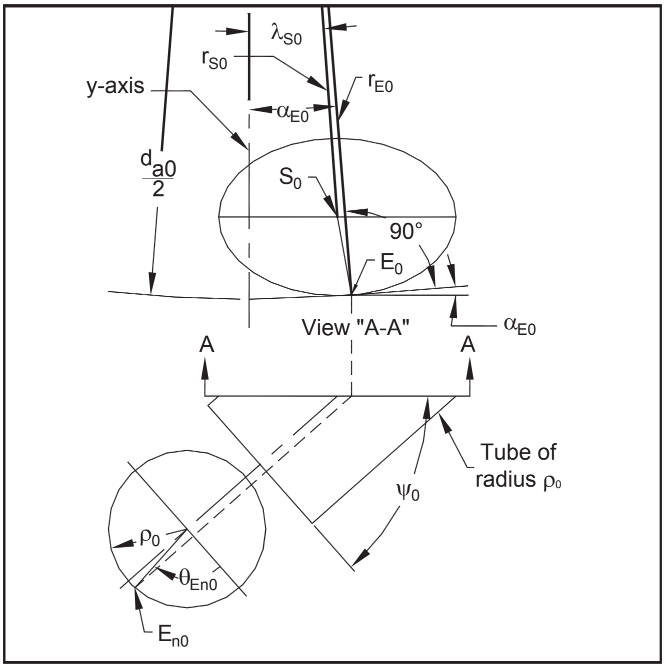


Figure 4—End of tool tip (with helix angle exaggerated).

The tool radius to end tangent point, r_{E0} (in.), is

$$r_{E0} = \| E_0 \| \tag{24}$$

The following are conditions for the tool tip to position properly on a shaper tool tooth:

1) The profile tangent point, P_0, on the tool tip must also be a point on the involute profile that includes the protuberance, thus

$$\alpha_{P0} + \phi_{P0} - \zeta_{P0} - \frac{\pi}{2} = 0 \tag{25}$$

2) The angle, ζ_{P0}, subtended by one half of the transverse circular thickness of the involute curve (include the tool protuberance) at P_0, must equal the angle formed by the y-axis and the line connecting the center of the tool to P_0.

$$\zeta_{P0} - \arcsin (\frac{x_{P0}}{r_{P0}}) = 0 \tag{26}$$

where

x_{P0} is the x-coordinate of profile tangent point, P_0 (in.)

3) The end tangent point must also be a point on the outside diameter of the shaper tool, thus

$$r_{E0} - \frac{d_{a0}}{2} = 0 \tag{27}$$

4) The tangent angle, α_{E0}, at the end tangent point, E_0, must equal the angle formed by the y-axis and the line connecting the center of the tool to E_0

$$\alpha_{E0} - \arcsin (\frac{x_{E0}}{r_{E0}}) = 0 \tag{28}$$

Equations 25–28 must all be satisfied for the tool tip to be correctly positioned on a shaper tool tooth. The variables to be determined are r_{S0}, λ_{S0}, θ_{Pn0} and θ_{En0}. Since the systems of the equations are transcendental and cannot be solved directly, the Newton's method is used to calculate the roots for Equations 25–28.

Solving the System of Non-linear Equations for Center of Tool Tip

For simplicity, rewrite Equations 25–28 as generic vector equations in the form

$$F(X) = 0 \tag{29}$$

where

$$F(X) = (f_1(X), f_2(X), f_3(X), f_4(X))^T = (\text{Eq. 25, Eq. 26, Eq. 27, Eq. 28})^T \tag{30}$$

$$0 = (0,0,0,0)^T \tag{31}$$

$$X = (x_1, x_2, x_3, x_4)^T = (r_{S0}, \lambda_{S0}, \theta_{Pn0}, \theta_{En0})^T \tag{32}$$

The Newton's iteration equation (Ref. 6) is written as

$$X1 = X + \delta X \tag{33}$$

where δX satisfies the following system of linear equations

$$J \bullet \delta X = -F(X) \tag{34}$$

where

X1 is the vector of the new roots for the next iteration
X is the vector of current roots
δX is the vector of Newton's steps for the next iteration
J is the Jacobian matrix

where

$$J = \begin{pmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \cdots & \frac{\partial f_1}{\partial x_4} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial f_4}{\partial x_1} & \cdots & \cdots & \frac{\partial f_4}{\partial x_4} \end{pmatrix} \tag{35}$$

$\frac{\partial f_i}{\partial x_j}$ is the partial derivative of the i[th] equation with respect to the j[th] variable

The partial derivatives in the Jacobian matrix can be approximated using the finite differences

$$\frac{\partial f_i}{\partial x_j} \approx \frac{f_i(X + \Delta X_j) - f_i(X)}{\delta x_j} \tag{36}$$

where

i is the i[th] row of the Jacobian matrix
j is the j[th] column of the Jacobian matrix
ΔX_j is a vector with its j[th] element equal to the j[th] element of the current Newton's step, δX, and all remaining elements equal 0

For each iteration, the sum of the absolute values of the functions (errors) is calculated.

$$ERR(X1) = \sum_{i=1}^{4} |f_i(X1)| \tag{37}$$

The Newton's iteration procedure is terminated when the error (see Eq. 37) becomes smaller than a predetermined tolerance, or when a predetermined number of iterations has been reached.

The Newton's iteration procedure is described below:

1) Select a set of initial guess values for the new root, X1. The following are the suggested values:

$$x_1(r_{S0}) = \frac{d_{a0}}{2} - \rho_0$$
$$x_2(\lambda_{S0}) = 0.0175$$
$$x_3(\theta_{Pn0}) = -\phi_{n0}$$
$$x_4(\theta_{En0}) = -1.4835$$

2) Select the initial Newton's steps, δX. The following values work satisfactorily:

$$\delta X = (0.01, 0.01, 0.01, 0.01)^T$$

3) Evaluate the system of non-linear equations (see Eq. 30) at the new root, F(X1).
4) Calculate the error ERR(X1) (see Eq. 37).
5) The iteration is terminated, if $ERR(X1) \leq 10^{-10}$ or if a predetermined number of iterations (30 should be sufficient) have been reached. Otherwise, continue with the next step.
6) Save the new roots as the current roots, so that a new set of roots can be calculated

$$X = X1 \tag{38}$$

7) Calculate the Jacobian matrix, column by column, starting with column one using Equation 36. Repeat the calculation procedure for the remaining columns until the Jacobian matrix is completed (see Eq. 35).
8) Solve the system of linear equations (see Eq. 34) for the next set of the Newton's steps, δX.
9) Calculate new roots, X1, using Equation 33.
10) Repeat steps 3–9 until step 5 is satisfied.

The system of linear equations in step 8 (see Eq. 34) can be solved by inverting the Jacobian matrix or by using one of many numerical root finding algorithms, such as Gaussian elimination method (Ref. 7).

Generating Pressure Angle and Center Distance

The generating pressure angle and the center distance are based on tight meshing of a shaper tool with a semi-finished gear. The involute function of the generating pressure angle, invϕ_g, is given by the following equation (the derivation of Equation 39 is given in Appendix A):

$$\text{inv}\phi_g = \frac{s_{b0} + s_{br} - p_{b0}}{2(r_{b0} \pm r_{br})} \quad (39)$$

where

s_{b0} is the base circular thickness of the tool (in.)
s_{br} is the base circular thickness of the semi-finished gear (in.)
p_{b0} is the transverse base pitch of the tool (in.)
r_{b0} is the base radius of the tool (in.)
r_{br} is the base radius of the semi-finished gear (in.)

The generating pressure angle, ϕ_g, can be calculated by taking the arc of the involute function (Ref. 5). The generating center distance, c_g (in.), is

$$c_g = \frac{r_{br} \pm r_{b0}}{\cos\phi_g} \quad (40)$$

The generating pitch radius of the shaper tool, r_{g0}, is

$$r_{g0} = \frac{r_{b0}}{\cos\phi_g} \quad (41)$$

The generating pitch radius of the gear, r_g, is

$$r_g = r_{g0}\frac{n}{n_0} \quad (42)$$

Determination of Shaper-Tool-Generated Fillet Profile

Conjugate point of an arbitrary point on a shaper tool tip. The fillet profile (trochoid) of a helical gear is generated by the tool tip of a shaper tool. This section describes the procedure for calculating a point on the trochoid that is conjugate to an arbitrary point on the shaper tool tip, X_0 (see Fig. 5).

The coordinates of an arbitrary point, X_0, on the tool tip are

$$X_0 = S_0 + (\rho_0 \frac{\cos\theta_{Xn0}}{\cos\psi_0}, \rho_0\sin\theta_{Xn0}) \quad (43)$$

where

S_0 are the coordinates of the center of tool tip (in., in.)
ρ_0 is the tool edge radius (in.)
θ_{Xn0} is the auxiliary angle that locates an arbitrary point on the tool tip. This angle is measured in the normal plane, clockwise from the horizontal axis of the tool tip. θ_{Xn0} will usually have a negative value.

The slope, m_{X0}, of the normal passing through X_0 is

$$m_{X0} = \frac{\tan\theta_{Xn0}}{\cos\psi_0} \quad (44)$$

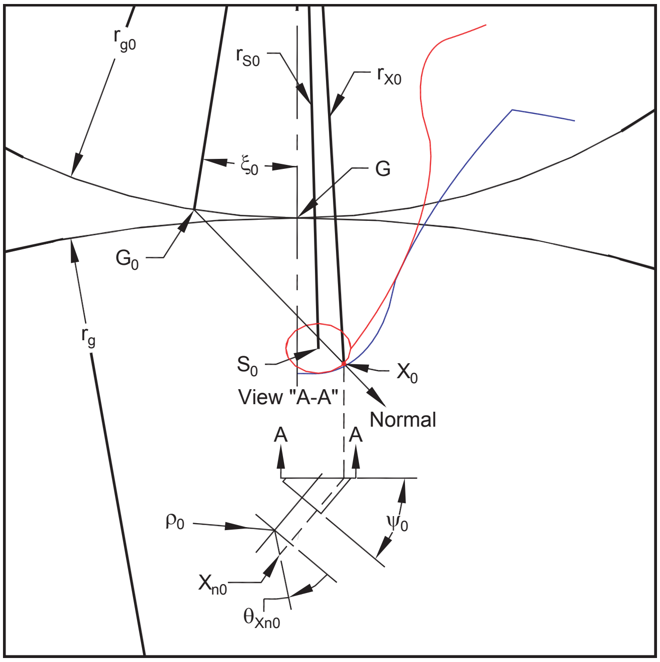


Figure 5—An arbitrary point X_0 and the normal on the tool tip.

The derivation of Equation 44 is given in Appendix A.

Note: For a shaper tool with non-elliptical tool tip, Equations 43 and 44 should be bypassed and the actual tool tip geometry, X_0 and m_{X0}, should be used for the subsequent calculations.

The normal at X_0 can be expressed as a linear equation:

$$y = m_{X0}(x - x_{X0}) + y_{X0} \quad (45)$$

where

x_{X0} is the x-coordinate of X_0
y_{X0} is the y-coordinate of X_0

When extended, the normal will intersect the generating pitch circle of the shaper tool at point G_0 (see Fig. 5). The x-coordinate of the intersection point can be calculated as:

$$x_{G0} = \frac{m_{X0}k_2 + \sqrt{r_{g0}^2 k_1 - k_2^2}}{k_1} \quad (46)$$

where

r_{g0} is the generating pitch radius, tool (in.)
k_1 is a temporary variable
k_2 is a temporary variable (in.)

$$k_1 = m_{X0}^2 + 1 \quad (47)$$

$$k_2 = m_{X0}x_{X0} - y_{X0} \quad (48)$$

The angle, ξ_0, formed between the y-axis and the tool radius at the intersection point, G_0, is

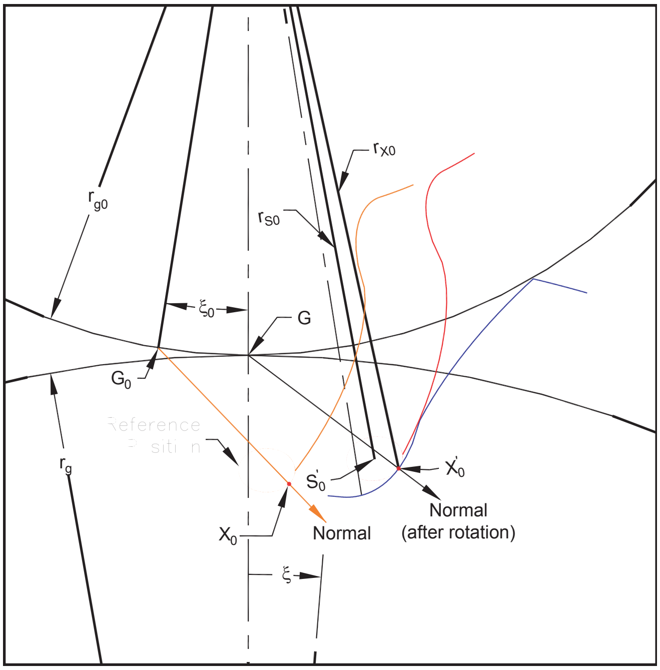


Figure 6—The arbitrary point X_0 and the normal after rotating the shaper tool for an angle $-\xi_0$.

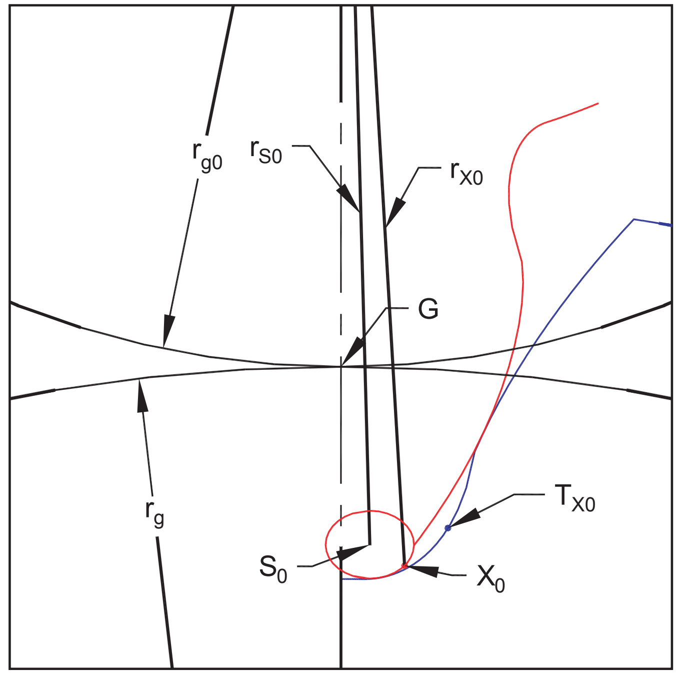


Figure 7—The arbitrary point X_0 on the tool tip and its conjugate point T_{X0} on the trochoid.

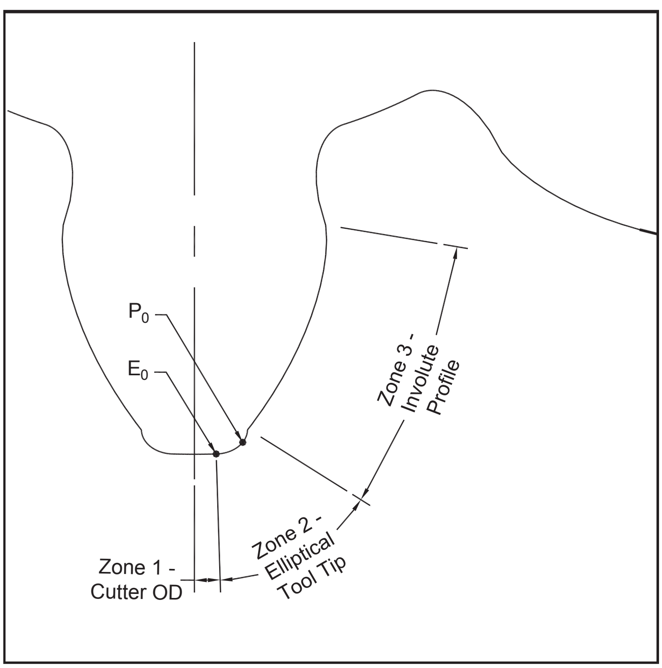


Figure 8—Zones of a shaper cutter.

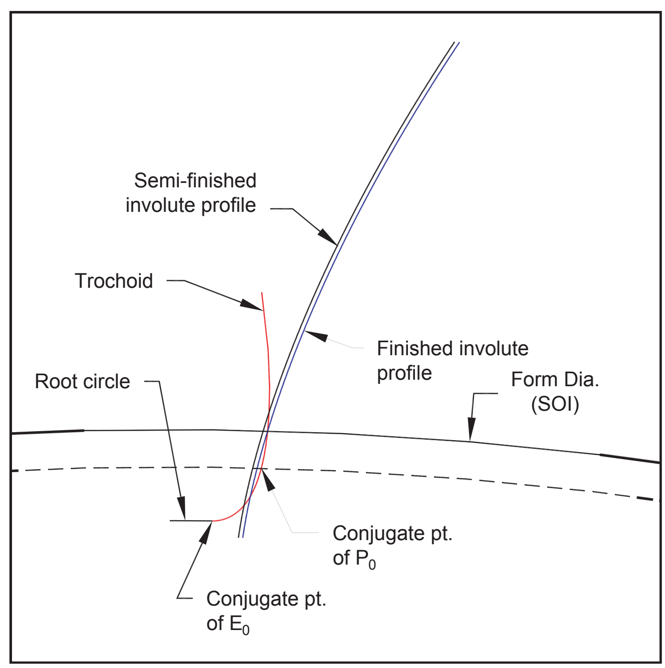


Figure 9—Shaper-tool-generated fillet profile (trochoid).

$$\xi_0 = \arcsin\left(\frac{x_{G0}}{r_{G0}}\right) \tag{49}$$

Note: The angle ξ_0 may be positive or negative. If G_0 is on the left side of the y-axis, x_{G0} (see Eq. 49) will be negative, and so will ξ_0. On the other hand, if G_0 is on the right side of the y-axis, ξ_0 will have a positive value.

To find the conjugate point of X_0, the shaper tool is rotated from its reference position (see Fig. 6) by an angle, $-\xi_0$. The arbitrary point X_0 will rotate to a new position, X_0'

$$X_0' = M(-\xi_0)X_0 \tag{50}$$

where

$$M(\varphi) = \begin{pmatrix} \cos\varphi & -\sin\varphi \\ \sin\varphi & \cos\varphi \end{pmatrix} \tag{51}$$

$M(\varphi)$ is a rotation matrix. When multiplied to a vector, the vector would be rotated an angle φ about the origin (0,0). If $\varphi > 0$, the rotation is counterclockwise. Otherwise, the rotation is clockwise.

After rotating the cutter (see Fig. 6), the normal at the arbitrary tool tip point (now X_0') will pass through the generating pitch point G, thus satisfying the *law of conjugate action* (Ref. 1):

To transmit uniform rotary motion from one shaft to another through the action between two geometric surfaces, the normal to the mating profiles, at the point of contact, must always pass through the same point on the common centerline.

It follows that X_0' is a common point on the tool tip and the trochoid of the gear.

Since the shaper tool and the gear rotate in a constant speed ratio, and the shaper tool has rotated an angle, $-\xi_0$, from its reference position, the gear rotation angle would have rotated an angle ξ, where

$$\xi = \pm\, \xi_0 \frac{n_0}{n} \qquad (52)$$

To return the gear to its reference position, it is rotated an angle $-\xi$ about the gear center O_G. After rotating the gear, the common point X_0' will move to T_{X0} (see Fig. 7), which is a point on the trochoid. T_{X0} can be calculated as:

$$T_{X0} = M(-\xi)(X_0' - O_G) \qquad (53)$$

Note: In Equation 53, the origin of T_{X0} (see Eq. 53) is the center of the gear O_G, not the center of the tool.

Determination of a Shaper-Tool-Generated Fillet Profile. The shaper tool discussed in this article can be divided into three zones (see Fig. 8):

1) Zone 1 is the portion of cutter profile that coincides with the outside diameter of the shaper tool. It starts from the outside diameter of the cutter on the y-axis, and ends at the end tangent point, E_0. The tool profile in this zone generates the root circle of the gear. If the shaper tool has a full tip radius, Zone 1 reduces to a single point on the outside diameter of the tool.
2) Zone 2 is the elliptical tool tip starting at E_0 and ends where the tool tip joins the main shaper tool profile (Zone 3).
3) Zone 3 is the main cutter profile that generates the involute profile on the semi-finished gear.

The shaper-tool-generated trochoid can be determined by calculating the conjugate points of the tool tip in Zone 2. Begin the calculation at E_0 (see Fig. 8), and continue in small increments towards P_0. The conjugate point of P_0 will usually penetrate deepest from the surface of the involute profile (see Fig. 9). Continue the calculation procedure until the trochoid intersects the involute tooth profile. Additional trochoid points can be calculated if desired.

Using Shaper Tool Algorithm to Calculate Fillet Profile of a Hobbed Gear

The tooth profile of a shaper tool with an infinite number of teeth will approach a rack. Naturally, if a shaper tool algorithm could handle an infinite number of tool teeth, a hobbed trochoid could be accurately approximated. Unfortunately, the shaper tool algorithm presented in this article does not allow for an infinite number of tool teeth. A shaper tool with a finite, but large number of teeth is permitted.

To investigate the feasibility of approximating a hobbed trochoid with the shaper algorithm using a shaper tool with a large number of teeth, a numerical example was calculated using Example 3.1.5 of AGMA 918-A93 (Ref. 8). The number

Table 1—Comparison of a Hobbed Pinion Fillet Profile (Ex. 3.1.5 - AGMA 918-A93) with Fillet Profiles Generated with 100-; 1,000-; and 10,000-Tooth Shaper Tools.

Description		Gear data	Tool data			
			Hobbed	100T-Shaper	1,000T-Shaper	10,000T-Shaper
Normal diametral pitch	in.$^{-1}$	12	12	12	12	12
Number of teeth		35	NA	100	1,000	10,000
Reference normal pressure angle	deg.	20	20	20	20	20
Reference helix angle	deg.	22.109	22.109	22.109	22.109	22.109
Outside diameter (or hob addendum)	in.	3.3686	0.1205	9.2357	90.1882	899.7129
Reference normal circular thickness	in.	0.1501	0.1309	0.1309	0.1309	0.1309
Stock allowance	in.	0.001	NA	NA	NA	NA
Tool tip radius	in.	NA	0.0100	0.0100	0.0100	0.0100
Protuberance	in.	NA	0.0025	0.0025	0.0025	0.0025
Comparison of the calculated fillet profile						
Maximum difference between hobbed & shaped profiles	in.	NA	NA	0.001901	0.000111	0.000011
Comparison of form diameter (SOI)						
Form diameter	in.	NA	3.040483	3.050692	3.041641	3.040600
Difference between hobbed & shaper-generated form diameters	in.	NA	NA	0.010209	0.001158	0.000117

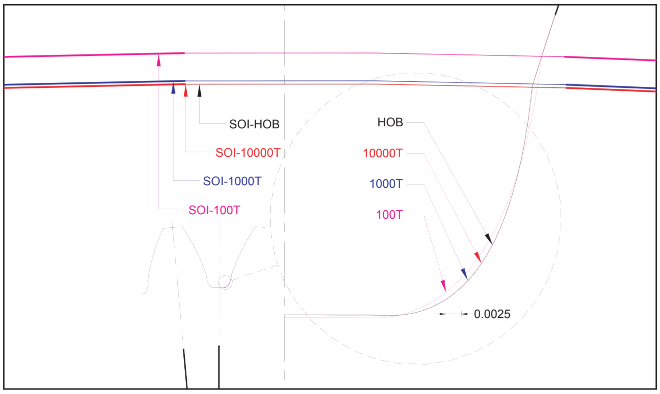


Figure 10—Pinion trochoid (Ex. 3.1.5-AGMA 918-A93) generated with a hob and shaper cutters.

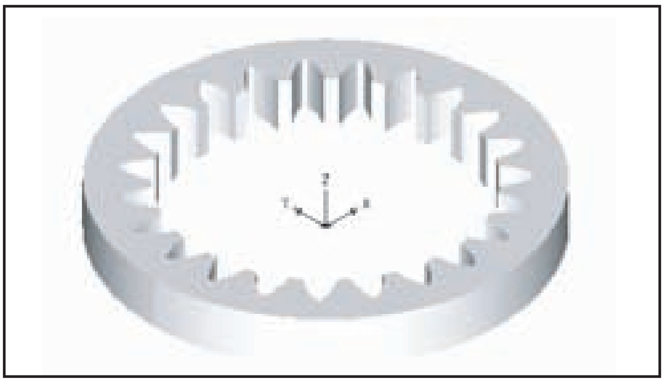


Figure 11—A 23-tooth internal spur gear model.

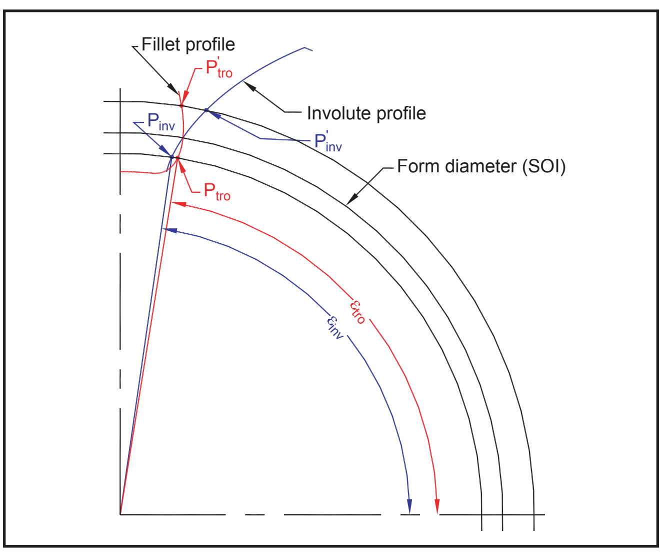


Figure 12—Polar angles of a trochoid point and an involute point.

of shaper tool teeth used were 100, 1,000 and 10,000. Table 1 compares the distances between the trochoid curves generated with the shaper cutters and the one generated with a hob. The form diameters or the start of involute (SOI) (to be discussed in the section "Calculating Form Diameter," below) based on the shaper tool were also compared to that generated with a hob. Figure 10 shows the trochoid curves superimposed on each other for a visual comparison.

Table 1 showed that the maximum distance between the trochoid curves generated with a 100-tooth shaper cutter and the hob to be 0.001901". For a 10,000-tooth shaper cutter, the difference decreased to merely 0.000011". The difference between the shaper-generated and the hobbed SOI's followed a similar trend. For the 100-tooth shaper cutter, the difference was 0.010209" and for 10,000-tooth shaper cutter, 0.000117".

The trochoid curves plotted in Figure 10 show the shaper-generated trochoid converging to that of the hobbed one when the number of teeth in the shaper tool is large (e.g. 10,000).

Applications for the Shaper Tool Algorithm

The shaper tool algorithm can be used in computer-aided gear design and gear tooth modeling as shown in Figure 11. The algorithm is also useful for calculating the trochoid geometry for finite element or boundary element analysis. The following sections describe applications of the shaper tool algorithm in form diameter calculation and gear finishing stock analysis.

Calculating Form Diameter

The form diameter or the start of involute (SOI) of a finished gear is the gear diameter where the trochoid joins or intersects the involute profile. When the two curves intersect, two intersection points may appear to exist. The intersection point that is closer to the tip diameter of the gear is the SOI. The other "intersection" point is an artificial one, as the involute curve has already been truncated at the SOI. When calculating the SOI of a gear by iteration, it is important to make sure that the algorithm converges to the SOI. Plotting the trochoid and the involute profile will provide a visual verification that the iteration process converges correctly (see Fig. 12).

The SOI can be calculated by comparing the polar angles of a trochoid point and an involute profile point, ε_{tro} and ε_{inv} respectively, on the same gear diameter (see Fig. 12) (Ref. 9). When the two polar angles become equal, the trochoid and involute points will coincide, and the gear diameter at the intersection point is the SOI. If the two polar angles are unequal, compare the polar angles for a new set of points at slightly larger or smaller gear diameter than the current one. Repeat the process until the two polar angles become equal.

Table 2 compares the calculated SOI's of the selected numerical examples in AGMA 918-A93 (Ref. 8) using the shaper tool algorithm presented in this article and those using other gear software. For hobbing examples, a 10,000-tooth shaper tool was used for the trochoid calculation. The calculated SOI's using the shaper tool algorithm compared well with those using other software.

Checking Gear Finishing Stock

For gears finished by grinding or shaving, the semi-finishing tool is usually designed with protuberance that would generate an undercut in the gear. The protuberance provides stock for finishing operations. The form diameter (SOI) of the finished gear must be smaller than the start of active profile (SAP) of the gear when the gear meshes with the mate. The algorithm presented in this article can verify if a semi-finishing tool would provide sufficient finishing stock on the gear while keeping the SOI smaller than the SAP.

Consider a helical gear set with the basic geometry given in Table 3. The initial pinion hob (A) design used the same standard reference pressure angle, 20°, as the part. Consequently, the calculated SOI (4.4873") was larger than the SAP (4.4788").

Table 2—Comparison of the Form Diameters Calculated Using the Proposed Algorithm and Other Software.							
Description		Example 3-1-1		Example 3-1-3		Example 3-1-9	
Gear data		Pinion	Gear	Pinion	Gear	Pinion	Gear
Gear type		Spur		Single helical		Internal helical	
Normal diametral pitch	in.$^{-1}$	5	5	6	6	9	9
Number of teeth		51	104	21	86	24	69
Ref. norm. press. angle	deg.	20.0000	20.0000	20.0000	20.0000	25.0000	25.0000
Standard helix angle	deg.	0.0000	0.0000	15.0000	15.0000	17.7276	17.7276
Normal circular thickness	in.	0.326267	0.293451	0.322622	0.257794	0.217257	0.192968
Stock allowance	in.	0.008000	0.008000	0.005300	0.005300	0.000000	0.000000
Tool data							
Tool type		Hob	Hob	Hob	Hob	Shaper	Shaper
Number of teeth		10,000	10,000	10,000	10,000	36	36
Addendum/Outside diameter	in.	0.291300	0.291300	0.246000	0.246000	4.295000	4.476600
Normal circular thickness	in.	0.314200	0.314200	0.261800	0.261800	0.102100	0.186000
Tool tip radius	in.	0.067300	0.067300	0.068200	0.068200	0.020000	0.012000
Protuberance	in.	0.009500	0.009500	0.008000	0.008000	0.000000	0.000000
Calculated form diameters							
SOI–based on this paper	in.	9.921823	20.204571	3.489356	14.525332	2.676943	8.225700
SOI–from other software	in.	9.921617	20.204577	3.489576	14.525135	2.676900	8.225700
Difference	in.	0.000206	–0.000006	–0.000220	0.000197	0.000043	0.000000

Table 3—Comparison of Form Diameters of a Pinion Generated with Normal Lead and Short Lead Hobs.					
Description	Unit	Oper. Cntr. Dist. 14.500 in.		Pinion Hob A (normal lead)	Pinion Hob B (short lead)
		Gear	Pinion		
Normal diametral pitch	in.$^{-1}$	4.0000		4.0000	4.1211
Number of teeth		93	18	10,000	10,000
Ref. norm. pressure angle (part or hob)	deg.	20		20	14.5
Reference helix angle	deg.	15.1560		15.1560	14.7003
Outside diameter (or hob addendum)	in.	24.5840	5.4160	0.3372	0.1373
Reference normal circular thickness	in.	0.3874	0.4812	0.3889	0.2419
Stock allowance per flank	in.	0.0050	0.0050	NA	NA
Tool tip radius	in.	NA		0.0900	0.0900
Protuberance	in.			0.0070	0.0070
Comparison of SOI and SAP					
Start of active profile (SAP)	in.			4.4788	4.4788
Form diameter (SOI)	in.			4.4873	4.4550
				SOI>SAP	SOI<SAP

Therefore, hob (A) does not provide the required grinding stock while keeping the SOI below the required SAP. In order to push the SOI closer to the root diameter, a short lead hob (B) was designed. The hob had a 14.5° reference normal pressure angle. The calculated SOI based on the short lead hob (B) was 4.4550", smaller than the SAP. Hob B provided the required finishing stock with satisfactory SOI (see Fig. 13).

Conclusions

A method for determining the shaper-tool-generated fillet profile (trochoid) was presented. The method is applicable to both external and internal helical gears. The algorithm is based on a class of shaper tool that has an involute main profile and elliptical tool tip in the transverse plane. However, the algorithm will also work for a shaper tool with other tool tip geometries, provided the coordinates and the normal of the tool tip profile are known.

The shaper tool algorithm can also approximate the trochoid generated with a rack-type tool if the number of shaper tool teeth is large. The numerical examples showed that a trochoid curve generated with a 10,000-tooth shaper tool can approximate that generated with a hob with small error.

The algorithm presented in this article does not require the

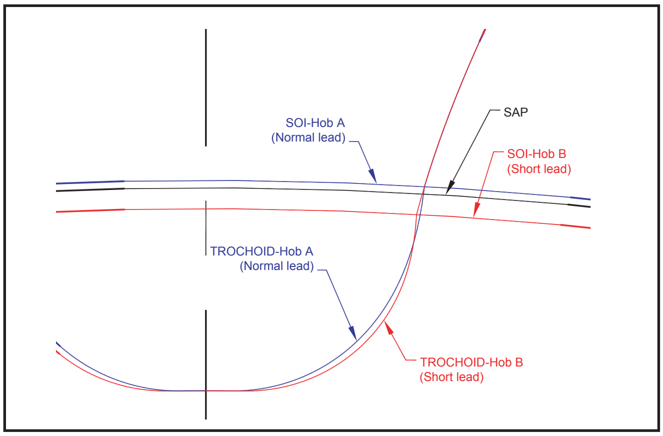


Figure 13—Trochoid curves generated with a normal lead and a short-lead hob.

tool and the gear to have equal reference normal pressure angle. Consequently, a trochoid generated with a non-standard cutter such as a short lead hob can also be calculated.

Examples for the form diameter (SOI) calculation and the finishing stock analysis were provided using the shaper tool algorithm presented.

A computer program was developed using the algorithm described in this article. The calculated form diameters (SOI's) for both external and internal gears compare well to those calculated with other gear software. An internal spur gear was used to verify the shaper tool algorithm.

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Finally, I would like to thank others, too many to mention individually, that have helped with this project or offered valuable comments that were, in one way or another, incorporated into this article.

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Appendix A—Derivation of Equations

The tangent and the normal of an arbitrary point on the shaper tool tip (Equations 20 and 44). The shaper tool tip considered in this article is circular in the normal plane and elliptical in the transverse plane, as shown in Figure A1. (Ref. A1). The coordinates of an arbitrary tool tip point X_0 (related to the center of the tool tip) in the transverse plane can be calculated as

$$x_{X0} = \rho_0 \frac{\cos\theta_{Xn0}}{\cos\psi_0} \tag{A.1}$$

$$y_{X0} = \rho_0 \sin\theta_{Xn0} \tag{A.2}$$

where

ρ_0 is the tool tip radius and
θ_{Xn0} is the auxiliary angle for point X_0 measured clockwise from the horizontal axis.

Differentiating Equation A.1 and Equation A.2 with respect to the auxiliary angle θ_{Xn0} we get

$$dx_{X0} = -\rho_0 \frac{\sin\theta_{Xn0}}{\cos\psi_0} d\theta_{Xn0} \tag{A.3}$$

$$dy_{X0} = \rho_0 \cos\theta_{Xn0}\, d\theta_{Xn0} \tag{A.4}$$

The slope of the tangent at point X_0 can be calculated as

$$\tan\alpha_{X0} = \frac{dy_{X0}}{dx_{X0}} = -\frac{\cos\psi_0}{\tan\theta_{Xn0}} \tag{A.5}$$

Similarly, the slope of the profile tangent point, P_0 (see the section "Center of tool tip on a shaper tool," above), can be calculated as

$$\tan\alpha_{P0} = -\frac{\cos\psi_0}{\tan\theta_{Pn0}} \quad (A.6)$$

Taking an arc tangent on both sides of Equation A.6 completes the derivation for Equation 20.

$$\alpha_{P0} = \arctan\left(\frac{-\cos\psi_0}{\tan\theta_{Pn0}}\right) \quad (A.7)$$

The normal at the given arbitrary point on a shaper tool tip is perpendicular to the tangent. Therefore, the slope of the normal, m_{X0} (see Eq. 44), is:

$$m_{X0} = \frac{-1.0}{\tan\alpha_{X0}} = \frac{\tan\theta_{Xn0}}{\cos\psi_0} \quad (A.8)$$

Generating pressure angle (Equation 39). The generating pressure angle is based on tight meshing of a shaper tool with a semi-finished gear. The derivation of the generating pressure angle equation is similar to the one given in 86 FTM 1 (Ref. A2).

The following tool and gear data are given:

s_{b0} is the transverse base circular thickness, tool (in.);
r_{b0} is the base radius, tool (in.);
s_{br} is the transverse base circular thickness, semi-finished gear (in.). If shaping is the finishing operation, the base circular thickness for the finished gear should be used; and
r_{br} is the base radius, semi-finished gear (in.).

The sum of the transverse circular thickness of the tool and the gear equals the circular pitch at the generating pitch circle.

$$p_{g0} = s_{g0} + s_{gr} \quad (A.9)$$

where
p_{g0} is the transverse circular pitch at the generating pitch circle;
s_{g0} is the transverse circular thickness at the generating pitch circle, tool (in.); and
s_{gr} is the transverse circular thickness at the generating pitch circle, gear (semi-finished) (in.).

The circular thicknesses of tool and semi-finished gear at the generating pitch circle can be calculated as

$$s_{g0} = 2r_{g0}\left(\frac{s_{b0}}{2r_{b0}} - \mathrm{inv}\phi_g\right) \quad (A.10)$$

$$s_{gr} = 2r_{gr}\left(\frac{s_{br}}{2r_{br}} \mp \mathrm{inv}\phi_g\right) \quad (A.11)$$

where
r_{g0} is the generating pitch radius of the shaper tool (in.);
r_{gr} is the generating pitch radius of the semi-finished gear (in.); and
$\mathrm{inv}\,\phi_g$ is the involute function of the generating pressure angle, ϕ_g.

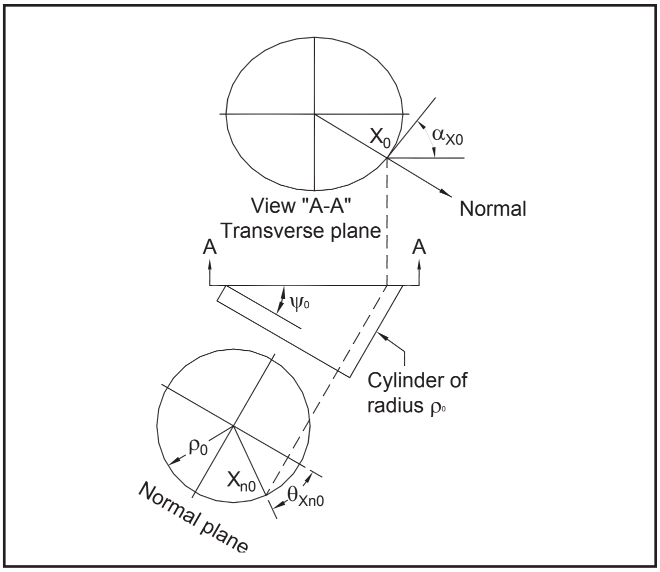


Figure A1—Shaper tool tip in normal and transverse planes.

Substituting Equation A.9 and Equation A.10 into Equation A.8 and dividing both sides of the new equation by $2r_{g0}$, we get

$$\frac{p_{g0}}{2r_{g0}} = \frac{s_{b0}}{2r_{b0}} - \mathrm{inv}\phi_g + \frac{r_{gr}}{r_{g0}}\frac{s_{br}}{2r_{br}} \mp \frac{r_{gr}}{r_{g0}}\mathrm{inv}\phi_g \quad (A.12)$$

using the following established relationships

$$\frac{p_{g0}}{2r_{g0}} = \frac{p_{b0}}{2r_{b0}} \quad (A.13)$$

$$\frac{r_{gr}}{r_{g0}} = \frac{r_{br}}{r_{b0}} \quad (A.14)$$

where

p_{b0} is the transverse base circular pitch, tool (in.).

Substituting Equation A.12 and Equation A.13 into Equation A.11, we get

$$\frac{p_{b0}}{2r_{b0}} = \frac{s_{b0}}{2r_{b0}} - \mathrm{inv}\phi_g + \frac{r_{br}}{r_{b0}}\frac{s_{br}}{2r_{br}} \mp \frac{r_{br}}{r_{b0}}\mathrm{inv}\phi_g \quad (A.15)$$

Multiply both sides of Equation A.14, by $2r_{b0}$ and solve for $\mathrm{inv}\,\phi_g$ (Eq. 39)

$$\mathrm{inv}\phi_g = \frac{s_{b0} + s_{br} - p_{b0}}{2(r_{b0} \pm r_{br})} \quad (A.16)$$

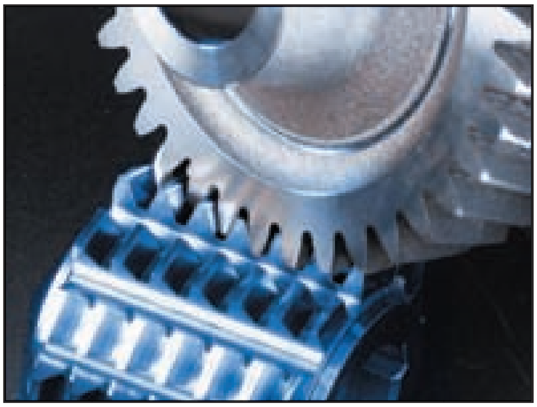
Bibliography

A1. American Gear Manufacturers Association. *Gear Rating Suite User's Manual*. American Gear Manufacturers Association, Alexandria, VA, 2003.
A2. McVittie, D.R. "Describing Nonstandard Gears–An Alternative to the Rack Shift Coefficient,."AGMA Technical Paper No. 86 FTM 1, 1986.

WZL Offers Seminar on Trends in Manufacturing Soft Gears

"Attendees learn about the developments outside their companies, for example, about new, alternative gear manufacturing processes," says Prof. Dr.-Ing. Dr.-Ing. E.h. Fritz Klocke, who heads the manufacturing technology division of WZL at Aachen University in Germany.

WZL, the German acronym for Laboratory for Machine Tools and Production Engineering, is a leading research center on processes used to manufacture gears. Also, on Nov. 29–30, WZL will be the site of a seminar, "Trends in Soft Gear Manufacturing." The conference is for managers and experts involved in R&D, design, process engineering, production management, and manufacture of gears.



Attendees will be informed of recent developments in gear manufacturing, in prevailing cutting processes and in alternative processes, such as the precision forging of gears and in creating gears via powder metallurgy.

"It's a good idea to be up-to-date on these processes and what are the capabilities of these processes," Klocke says.

The seminar will consist of about 16 up-to-date presentations from experts and scientists about the manufacture of pre-heat treated gears. The presentations will cover an industrial perspective on soft gear manufacture, technology and trends in the dry manufacture of soft gears, tool technology, the manufacture of large-module gears, as well as sintering and forming of gears.

Scheduled presenters include representatives from CemeCon, Ceratizit, Erasteel, ESKA Automotive, GKN, Gleason-Pfauter, O-Oka, Samputensili, SEW Eurodrive and WZL itself. Each presentation will be followed by a question-and-answer session. Also, the conference will feature simultaneous translation of presentations into English.

"WZL wants to offer a platform to exchange the latest developments and experiences for everybody's benefit," Klocke says. First held in 2002, the seminar takes place every two years.

The seminar will be held for the first time in WZL's new building, which was completed in July '05.

Besides hearing presentations, attendees will be able to tour the WZL laboratory Nov. 29. "We usually have some demonstrations of our gear manufacturing machines," Klocke says.

Klocke describes the seminar as an opportunity for attendees to learn about innovations in tools, machine tools and production processes, updating themselves about conventional and alternative processes, and as an opportunity for attendees to increase productivity and reduce costs in their own facilities. Also, the seminar is a chance to meet various experts in the international gear community. Sometimes, the conference even results in new ideas for research projects.

The seminar is limited to about 150 attendees, and the deadline to register is Nov. 22. Also, before the deadline, registrations may not be accepted once the seminar reaches its maximum number of participants.

Attendees have to reserve their own hotel rooms in Aachen. WZL, however, offers hotel recommendations to people registering for the seminar. The hotels are about 10 minutes by car from the seminar building.

The registration fee is 695€, about $880. Attendees receive 20% rebates if their companies are members of the WZL Gear Research Circle. The fee covers copies of the presentations, both printed copies in a proceedings book and electronic copies on a compact disc. The fee also covers a buffet dinner Nov. 29 in downtown Aachen and lunch on Nov. 29 and 30.

For more information:
Katrin Fausten
WZLforum gGmbH
Steinbachstraße 25
52074 Aachen
Germany
Phone: +(49) 241-80-20711
Fax: +(49) 241-80-22575
E-mail: ***k.fausten@wzl.rwth-aachen.de***
Internet: ***www.wzlforum.rwth-aachen.de***

September 11–15—AGMA Training School for Gear Manufacturing—Basic Course. Richard J. Daley College, Chicago, IL. Curriculum includes classroom and hands-on training on subjects such as hobbing, shaping and inspection. $750 for AGMA members, $850 for non-members. For more information, contact the AGMA by phone at (703) 684-0211 or by e-mail at *fentress@agma.org*.

September 13–15—Basic Gear Noise Short Course. Department of Mechanical Engineering, Ohio State University, Columbus, OH. Lectures on gear noise, gear design parameters and manufacturing errors are interspersed with demonstrations of the measurement and computer software capabilities of the Gear Dynamics and Gear Noise Research Lab. The concept of gear transmission error is presented along with methods of predicting transmission errors from design and manufacturing data. The second and third day's lectures discuss gear system dynamics and acoustics, gear rattle, signal processing and case histories. $1,450 for the basic course or $2,200 if taken with the advanced course. For more information, contact the GearLab by phone at (614) 688-3952 or on the Internet at *www.gearlab.org*.

September 18–19—Advanced Gear Noise Short Course. Department of Mechanical Engineering, Ohio State University, Columbus, OH. Dedicated to individuals who already attended the basic course. Possible topics include computer modeling, transmission error prediction, general system dynamics, bearing/casing dynamics, gear rattle models, experimental approaches, modal analysis of casings, acoustic radiation, advanced signal processing, sound quality analysis and transmission error measurement. $950 for the advanced course or $2,200 if taken with the basics course. For more information, contact the GearLab by telephone at (614) 688-3952 or on the Internet at *www.gearlab.org*.

September 19–22—Metal Gear Design & Manufacturing Course. Universal Technical Systems facility, Rockford, IL. Basic and advanced gear design theory. An hour of gear design consulting on the last day is included. $1,250. For more information, contact UTS by phone at (815) 963-2220 or on the Internet at *www.uts.com*.

September 25–28—Gear China. Shanghai International Exhibition Center, Shanghai, China. Featuring standard and special gears, gear production and testing equipment, cutting tools and machine accessories. Buyers are targeted in the aerospace, automotive/motorcycle, construction, electronics, food, general machinery, machine components, and related industries. For more information, contact Business and Industrial Trade Fairs Ltd. by phone at (852) 2865-2633 or by e-mail at *enquiry@bitf.com.hk*. e-mail at *enquiry@bitf.com.hk*.

October 10–12—Expo Metalmecanica. Expo Guadalajara, Guadalajara, Mexico. An exhibition of Mexico's metalworking industry and the tools, equipment, materials, supplies and services they utilize. Co-located with Mexico's Design and Manufacturing Technology Week. Registration is free. For more information, contact Roc Exhibitions by phone at (630) 271-8210 or on the Internet at *www.rocexhibitions.com*.

October 22–24—AGMA Fall Technical Meeting. Grosvener Resort, Orlando, FL. Preliminary lineup of presentations covers four categories: optimizing design, standards and micropitting, application analysis, and bevel gears. $545 for AGMA members, $845 for non-members. For more information, contact the AGMA by phone at (703) 684-0211 or on the Internet at *www.agma.org*.

October 24–26—Plastic Gear Fundamentals: Design and Manufacturing. Universal Technical Systems facility, Rockford, IL. Includes academic presentations by the GearLab at Ohio State University's Department of Mechanical Engineering, Ticona, UFE and UTS. Topics include robust design methods, application of non-standard proportions, generating coordinates for mold cavities, and inspection and quality control issues. One hour of one-on-one instructor consultation time is included. $1,250. For more information, contact UTS by phone at (815) 963-2220 or on the Internet at *www.uts.com*.

October 31–November 2—Shot Peening/Blast Cleaning Workshop. Indianapolis Marriott Downtown, Indianapolis, IN. Three days of instruction on the shot peening and blast cleaning industry. Product design engineers, machine operators, foremen, supervisors, maintenance and quality engineers all benefit from the workshop. Thirty-nine instructors will cover 49 industry topics. Before Sept. 8, the cost is $725 for one participant, $625 each for two to three people and $550 each for four or more. After Sept. 8, the cost is $850 for one person, $750 each for two to three and $650 each for four or more. For more information, contact Electronics Inc. by phone at (574) 256-5001 or on the Internet at *www.shotpeener.com*.

AGMA Welcomes Five New Members

The American Gear Manufacturers Association announced in its quarterly publication that five new companies recently joined the ranks as members.

The new members are:

- AK Gears,
- Metso Minerals,
- Drive-All Manufacturing Co.,
- ExxonMobil Research & Engineering Co., and
- L & H Industrial.

Fairfield Receives $9 Million Contract

Fairfield Manufacturing, a division of the Saurer AG Group, received a $9 million contract to provide jacking drive gearbox assemblies to GustoMSC. The contract stipulates that Fairfield provide ABS certified jacking drive planetary gearboxes lifting more than 300 tons each and rated for output torque of more than one million N-m.

"At five times the size of our largest planetary unit, this development helps Fairfield reach the next level of TorqueHub planetary drive solutions to meet market needs in marine/offshore market applications," says Paul Schlueter, vice president of sales for Fairfield.

Renold Discusses Sale of Machine Tool Business

The Board of Renold plc announced that the company is in advanced negotiations with Venture Private Equity regarding the acquisition by VPE of business and certain assets of Renold's Holroyd machine tool business.

The Board announced on June 6 that it is in separate discussions regarding the potential sale of the Group's automotive business. According to the company's press release, proceeds for both potential divestments will be used to reduce the group debt.

ANCA Pty. Invests $4 Million in Australia and Opens Thai Manufacturing Facility

ANCA Pty. will invest $4 million in Australia and officially opened its first overseas manufacturing facility, located in the Rayong province of Thailand.

According to the company's press release, these investments are part of a strategic plan to enable ANCA to continue its 30% year-on-year production growth rate.

The company is currently exporting more than 98% of production from its facilities located in the Melbourne suburb of Bayswater North. It has exported more than $500 million in the past six years.

The company plans to expand the more skilled technical operations in Australia while producing some of the less technical assemblies overseas.

"This will be a win-win for both Australia and Thailand and will allow ANCA to continue to increase production of finished machines in Australia to satisfy a growing global need," says group general manager Linsey Siede.

The facility in Thailand is currently manufacturing and exporting fully wired electrical cabinets and canopies to Australia for the high-tech grinding machines that ANCA builds in Melbourne. ANCA will manufacture in Thailand a number of sub-assemblies, which will then be exported to Australia for final assembly into the completed machines.

Northstar Aerospace Reports Increased Revenue

Northstar Aerospace reported revenue totaling $36.8 million for the three months ending June 30, 2006, an increase of $3.6 million when compared to the same time period for 2005. For the six months ending June 30, revenue increased to $73 million in 2006 from $68.9 million in 2005.

Mark Emery, president and CEO of Northstar Aerospace, says, "The second quarter demonstrated broad-based growth with established customers, such as The Boeing Co. and Honeywell, as well as on new programs, in particular the Rolls Royce Trent 1000 (aircraft engine)."

Toyota Raises Transmission Production Capacity in Poland

Toyota Motor Corp. announced that Toyota Motor Manufacturing Poland Sp.zo.o, a producer of transmissions and engines, will increase its annual production capacity of manual transmissions from the current 600,000 units to 720,000 units by mid-2009.

According to the company's press release, this increase is being implemented to further promote Toyota's localization in Europe. A new production line will be established within the plant site.

TMMP will invest approximately 19.7 billion yen (about $170 million) and hire 260 new employees to establish the new line and upgrade the current line.

Getrag to Sell Synchron Business Unit to Hoerbiger

The Getrag Group plans to sell Getrag Synchron Technik GmbH to Hoerbiger Drive Technology on Oct. 1.

After the contractual arrangements are completed, Hoerbiger will become a strategic partner for Getrag. According to a press release issued jointly by the companies, Hoerbiger will be able to supply Getrag locally at various sites worldwide.

The acquisition will accelerate Hoerbiger's international development. In May, Hoerbiger acquired Taizhou Orient Gear Co. Ltd. and integrated the company into the group under the name of Hoerbiger Orient Gear (Taizhou) Co. Ltd.

American Axle Announces Executive Appointments

American Axle announced several executive appointments.

John J. Bellanti was appointed vice president of manufacturing planning, capital planning and cost estimating. According to the company's press release, he has worked at four of AAM's manufacturing facilities. He has held numerous positions within the company, most recently vice president of engineering and chief technology officer.

Allan R. Monich was appointed vice president of quality assurance and customer satisfaction. He has worked in the automotive industry for the past 30 years. Prior to this appointment, Monich was vice president, program management and launch as well as vice president of program management and capital planning.

John S. Sofia was appointed vice president, engineering and product development. Sofia is being promoted from his position as AAM's vice president of quality assurance and customer satisfaction.

Philadelphia Gear Appoints New Turnkey Project Manager

Philadelphia Gear Corp. appointed Charles L. Zirkle as the on-site technical services project manager.

According to the company's press release, Zirkle has worked for Horsburgh & Scott Co. for the past 34 years. For the past five years, he served as field services manager.

In the new position, Zirkle will coordinate the on-site technical service product offering, working closely with the company's five regional service centers.

Ikona Receives Order from Schlumberger

Ikona Gear International received an order from Schlumberger Ltd. to provide two customized prototype gearboxes for use in an oil and gas well servicing application. Schlumberger requested that the exact nature of the application remain confidential.

The prototype systems are to be delivered in September and assessed by Schlumberger in both internal and field tests. A successful test program is expected to result in an initial order with a value of approximately $2.5 million.

According to Ikona's press release, Schlumberger is its first customer in the oil and gas market since it formed its new Ikona Industries division in January and launched six new products at the Global Petroleum Oil Show in June.

"We are pleased to be working with the world's leading oil field service company in the development of a new technology to increase oil production," says Ikona's CEO and president Laith Nosh. "In addition to our success in the automotive sector, the oil and gas industry holds tremendous promise for Ikona as analysts project the North American market for oil and gas field machinery to be approximately $11 billion per year."

Applied Process' Chinese Operation Sets an Opening Date

John Keough, CEO of Applied Process, announced that AP Suzhou, located in Suzhou, Jiangsu Province, China, will commence commercial austempering operations in November.

According to the company's press release, interim general manager Josh Keough will report to AP's COO John Wagner. AP Suzhou will be dedicated to growing the domestic market for austempered steels and irons in China.

The 4,250-square-meter plant is located in the Weiting Town District of the SIP Industrial Park, approximately 100 km west of Shanghai. AP Suzhou will offer a full line of austempering services, including austempered steel, carbo-austempered steel, austempered gray iron, austempered ductile iron and carbidic austempered ductile iron.

Fiat and Tata Announce Joint Venture in India

Italian carmaker Fiat Group and India's Tata Motors announced they've signed an agreement for a joint venture in India to make passenger vehicles, engines and transmissions for Indian and overseas markets. The companies also released a statement saying they've agreed to study the possibility of industrial and commercial cooperation in Latin America.

Service Network and Worcester Polytechnik Launch Grinding Consortium

Service Network is spearheading an effort with Worcester Polytechnic Institute to form a grinding research center located in Worcester, MA, to launch industry consortiums.

According to SNI's press release, the consortium is being introduced as a practical applications research consortium and will focus on improving member firms' grinding processes by studying key segments of the grinding process.

Among the features of the consortium would be an abrasive products lab and surface metrology lab. WPI's current surface metrology lab is best known for its work on the measurement and characterization of surface textures and topography in diverse applications and for discoveries of the correlation between roughness, adhesion and friction. The lab's current work is key to abrasive process research since abrasive processes use surface topographies of the abrasive to create surfaces on the workpiece while the workpiece abrades the abrasive. The capability to examine this interaction helps harness potential improvements in the grinding process.

Service Network contributes various levels of support including use of its OEM OD and ID precision grinding machines. Saint-Gobain joined WPI and Service Network as a co-sponsor.

New Rep Joins Clifford-Jacobs

Bob Jardine has established Jardine & Associates LLC, a manufacturer's representative sales agency, and will be representing Clifford-Jacobs Forging Co.

Jardine was formerly with Scot Forge.

His territory includes the eastern half of Pennsylvania, southern New Jersey, Delaware and Maryland.

Chick Workholding Implements Consumer Design Program

Chick Workholding Solutions invited the CNC marketplace to contribute to the design of its new CNC vise. The new vise does not fall into current workholding categories. It is not a traditional single station vise originally designed for use on a manual machine nor is it a double station workholding system for CNC production applications.

The company plans to roll out a conceptual prototype of the CNC vise for the public's viewing, use and comment at IMTS. Visitors to Chick's booth will be able to test the product in a real-world setting through the company's QwikChange Challenge. The challenge will put four participants at a time in a head-to-head race to see who can take the CNC vise through five different changeovers in the least amount of time.

According to the company's press release, Chick aspires to have the product ready in its final version, ensuring the CNC vise will not need to be redesigned later. By previewing the concept, Chick plans to field test the CNC vise.

The company launched an interactive website dedicated to the CNC vise at *www.BuildaCNCVise.com.*

Vail Resorts Buys Wind Power to Offset its Electric Power

Vail Resorts announced plans to buy enough wind power credits to offset the power needed for its resorts, retail stores and office buildings, making Vail the second largest corporate buyer of wind energy in the nation, according to the Environmental Protection Agency.

Vail officials said they plan to buy the equivalent amount of their energy needs in wind power credits from Renewable Choice Energy of Boulder, CO. Renewable Choice will then buy wind power from various producers and inject the amount of power Vail uses into the national electric grid.

The company would not estimate the program's costs but said that total energy use was about 152,000 megawatt hours a year. It also plans to create a promotional incentive plan to encourage employees and visitors to convert to wind power at home, with a free day ski pass to anyone who signs up.

Quayle Hodek, chief executive and founder of Renewable Choice Energy, says the idea of wind power credits is to displace fossil fuel generation nationally, if not quite locally. The day-to-day supply for Vail's chairlifts, lights and machinery will be generated by local suppliers, primarily by coal-fired generation.

Visitors to a Vail resort who sign up for wind power would not change utility providers but pay a $15 monthly family fee or $5 monthly individual fee to Renewable Choice to buy credits for the amount of wind used by their household, which would then be fed into the national grid. Buyers would pay the same electric bill as before.

Renault, Nissan and GM Explore Alliance Possibilities

General Motors, Renault and Nissan said that an exploratory discussion was held regarding the possibility of an industrial alliance among the three companies.

Carlos Ghosn, president and CEO of Renault, SAS and Nissan Motor Co., and Rick Wagoner, chairman and CEO of GM, agreed to cooperate in an expeditious, confidential review of an alliance between the three companies. It is expected that the review will take approximately 90 days.

Chimera Expands Mold Production Capacity

Chimera Co., a precision mold parts designer and manufacturer in Tokyo, Japan, plans to expand its finished mold product plants.

According to the company's press release, the output capacity for finished molds, most of which are used in the automobile and electrical equipment industries, will jump from 10–15 units a month to 20–25 units a month.

The expansion will take place at Chimera's No. 2 plant, which was acquired in 2000. Approximately 1,300 square meters of floor space will be revamped and outfitted with machine tools. The project will raise the production of molds used to make plastic products. Capital spending will total around 300 million yen ($2.6 million), including work to upgrade machine tools at the factory.

The firm aims to boost capacity to around 40 units a month and plans to open a sales site in Kawakki this fall. Chimera targets 2.4 billion yen in total sales for 2007, up 40% from 2005.

Kapp Hires Vice President of Sales

Kapp Technologies hired Bill Miller as vice president of sales for North American operations, effective September 1.

Miller has been in the gear industry since 1981, when he started in service, training, applications engineering and sales of Kapp products at American Pfauter. From 1995–1999, he was manager of North American sales for M&M Precision Systems. In 1999, he formed GearHelp LLC to service gear training needs and sell Konig, Dr. Kaiser, Dragon and GearOffice products.

GM, BMW and DaimlerChrysler Announce $1 Billion Hybrid Transmission Development Program

A research alliance consisting of GM, BMW and DaimlerChrysler plans to invest more than $1 billion to develop a new hybrid transmission to compete with a related system offered by Toyota.

For the past 18 months, approximately 500 engineers at the three companies have been jointly developing the next-generation hybrid engine technology, which combines a battery-powered electric motor with a conventional gasoline combustion engine.

The dual-mode hybrid technology includes an on-board fuel optimization computer that determines when and at what speeds the two motors will be used for power and how the on-board battery will be recharged.

Development of the transmission is expected to cost about $300 million. The rest of the investment will be devoted to integrating the new hybrid system with other vehicle components.

The hybrid engine will be available in two rear-wheel-drive configurations and a front-wheel-drive system.

ArvinMeritor Focuses on Automated Manual Gearboxes

ArvinMeritor announced a decision to place greater emphasis on the sales and marketing of the FreedomLine automated manual transmission by ZF Friedrichscafen in Germany. Conversely, the company plans to discontinue manufacturing the Meritor manual transmissions, effective January 2007.

The company will honor current manual transmission orders and all orders received prior to September 2006, provided that they are to be delivered no later than January 2007. All Meritor manual transmissions sold and in service will continue to be supported by the company's sales, service and aftermarket parts support teams.

"We are absolutely convinced that we have the most advanced and proven technology solution with the FreedomLine for our North American customers," said Tom Gosnell, president of the company's commercial vehicle systems business unit in an ArvinMeritor press release. "We pledge to expand the number of motor carriers and their drivers who are delighted with the performance and benefits of our FreedomLine."

Production of the FreedomLine will remain in ArvinMeritor's facility in Laurinburg, NC, and the workforce connected with the manual transmissions will be absorbed into other positions.

Bonfiglioli Plans New Headquarters

Bonfiglioli Riduttori is building a new headquarters in Hebron, KY, and plans to open in February 2007.

The new building will cover 83,000 square feet with 13,000 square feet dedicated to offices, balancing and warehousing. The assembly area will be divided into small and large planetary gearboxes, helical gearboxes and worm gearboxes.

According to the company's press release, Bonfiglioli is planning a distributor network with one reseller located in each state.

Suzlon Energy Plans Worldwide Expansions

Wind energy company Suzlon Energy plans to expand capacity by 4,200 MW and is scheduled to complete the project by June 2007.

Suzlon will also open an innovation center in Denmark, focusing on concepts such as materials technology, logistics cost, management areas and technology innovations for its turbines.

The company plans to extend the capacity of its gearbox manufacturing operation in Belgium (formerly Hansen Transmissions) from the 3,300 MW at present to 4,500 by the end of the fiscal year. Suzlon's two manufacturing facilities in the U.S. and China will be operational by September 2006.

The proposed 1,500 MW wind energy project at Udipi will be operational by June 2007 and expansions in India include establishment of a forging and machining facility at Baroda and a foundry at Coimbatore.

Paulo Products Purchases Bodycote Business

Paulo Products Co. purchased the metal treating and brazing business of Bodycote Thermal Processing of St. Louis, MO.

According to the company's press release, Paulo will transfer the processing of all work resulting from this acquisition as well as equipment to its existing facilities in St. Louis.

Paulo operates a heat treating facility offering continuous belt, batch, vacuum, induction heat treating, furnace brazing, cryogenics and black oxidizing.

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Schnyder S.A.	30	(630) 595-7333	hanikcorp@aol.com	www.hanikcorp.com
Setco	12	(800) 543-0470	sales@setcousa.com	www.setcousa.com
The *Shot Peener* magazine	31	(800) 832-5653, (574) 256-5001		www.shotpeener.com
Sigma Pool	5	(734) 429-7225	info.lgt@liebherr.com	www.sigma-pool.com
Star SU LLC	IFC–1	(847) 649-1450	sales@star-su.com	www.star-su.com
Stock Drive Products/Sterling Instrument	82	(516) 328-3300		www.sdp-si.com/e-store
Sunnen Products Co.	45	(800) 325-3670		www.sunnen.com
teamtechnik USA	70	(678) 957-0334	application.usa@teamtechnik.com	www.teamtechnik.com
Thermtech of Waukesha Inc.	31	(800) 752-6917	sales@thermtech.net	www.thermtech.net
Ticona	21	(800) 833-4882		www.ticona.com
The Timken Co.	76	(330) 438-3000	use.timken@timken.com	www.timken.com
United Tool Supply	22	(800) 755-0516	unitedtool1@aol.com	

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SERVICE

HEAT TREATING

Geezer World Party On!

It's unlikely that AARP will find itself in a revenue-generating crisis, but if it occurs, Fred Young of Forest City Gear in Roscoe, IL, is the man with the plan.

Young's rounding up his closest friends in the gear industry and considering applying for a synergistic membership (perhaps called GARP—Gear Association of Retired People). Even if his idea doesn't translate into cheaper movies for his friends, the "Gear Geezers," as they prefer to be known, are showing up everywhere.

Geezer headquarters, a.k.a. Wayne's World, is the lake house of Wayne Wellman, CEO of Chicago Gear–D.O. James Corp. This summer's Geezer-pollooza was a record-setter in terms of attendance and chock-full of activity. Several hours before the sun went down—and shortly after the early bird specials took effect—the geezers hit the streets. Gearettes cheered on their favorite geezer during an all-out game of shuffleboard.

As far as the next stage, anyone up for donating a warehouse for conversion into the first-ever Gear Geezer Retirement Home??

Fred Young (left) and Fred Schomaker (right) set sail.

Starting left: Wayne Wellman, Stan Blenke, Dennis Regan and Fred Young do lunch.

(Top left) Dennis Regan, Fred Young, Jack Nowlin and Wayne Wellman. (Bottom left) David Goodfellow, Bipin Doshi and Fred Schomaker take it easy.

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