July 2007

GEAR TECHNOLOGY

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The Journal of Gear Manufacturing

Quality

- How's Your Lead Time?
- Voices: Making Better Gears and Splines

Technical Articles

- Spiral Bevel and Hypoid Technology
- Large, High-Speed Load Gears

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CONTENTS

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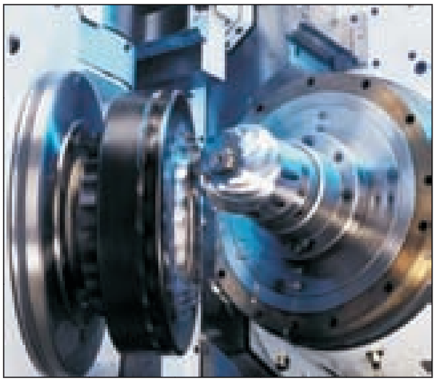
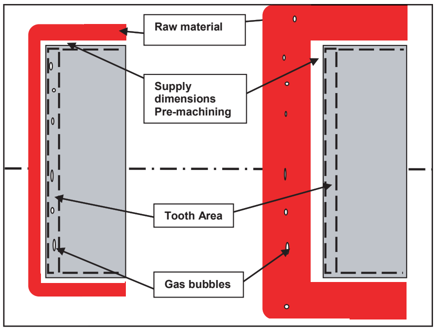
TECHNICAL ARTICLES





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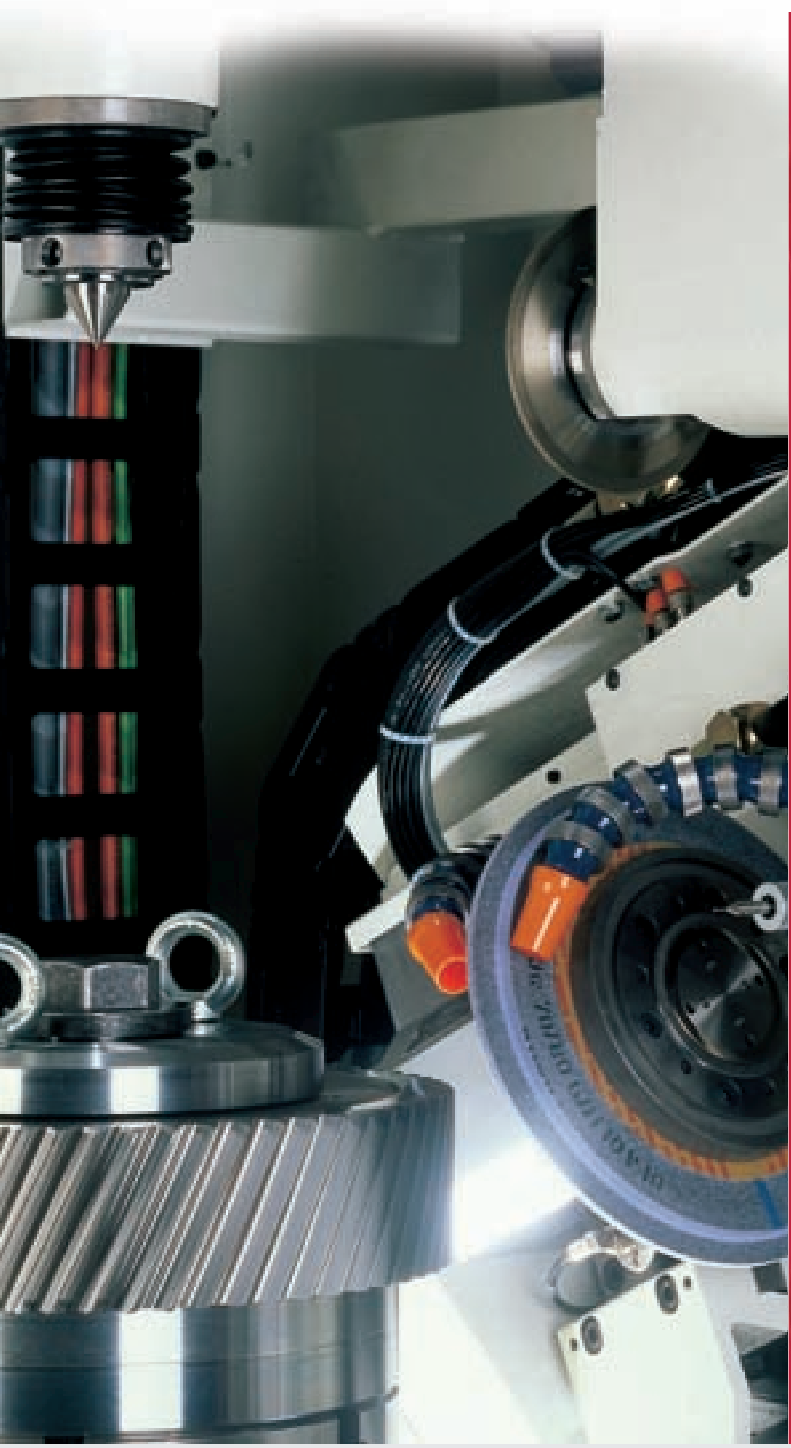
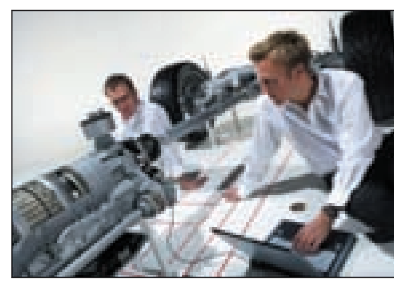


GEAR TECHNOLOGY

July 2007

CONTENTS

DEPARTMENTS



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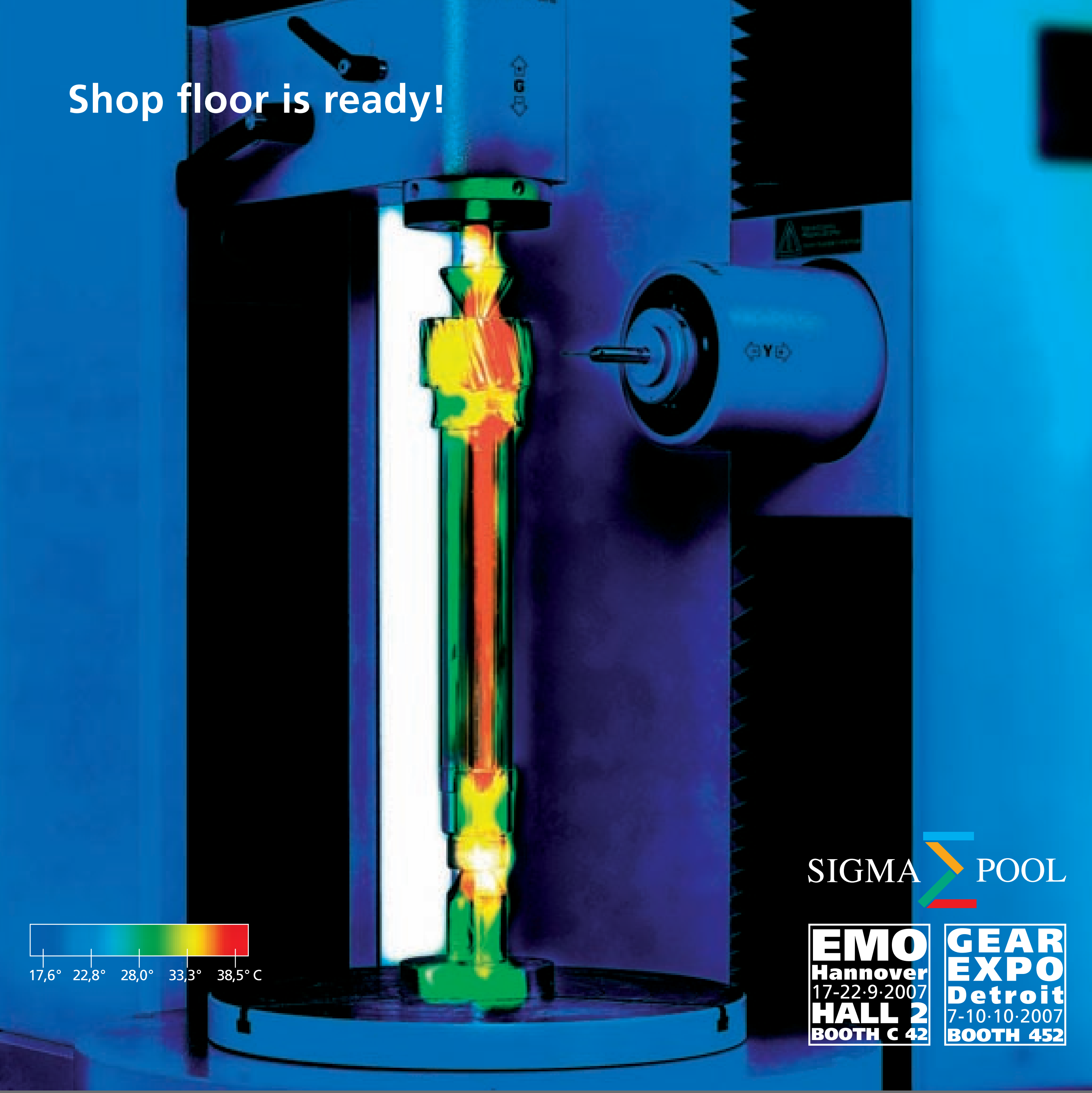
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GEAR TECHNOLOGY
VOL. 24, NO. 5

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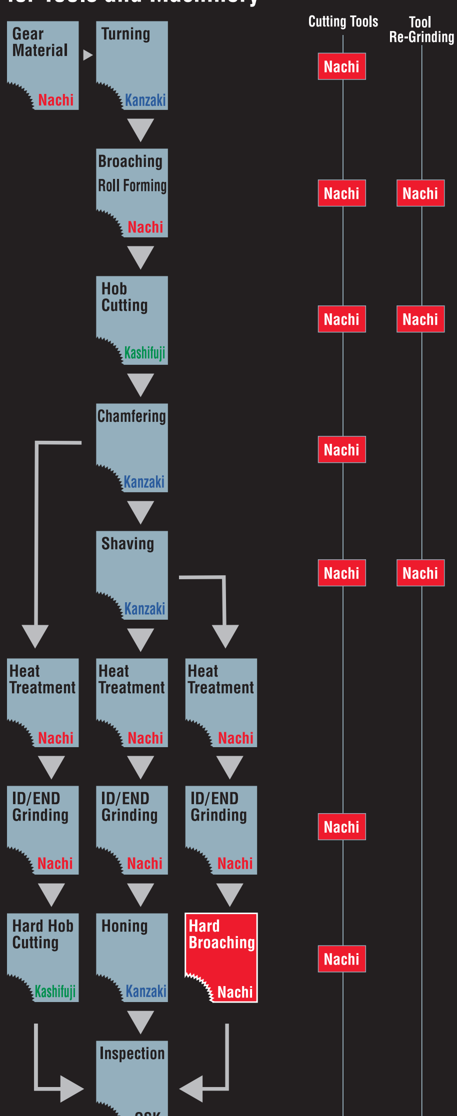
GPA provides total support for all your gear machining requirements. From package plans of tooling and equipment, to facility equipment planning and follow up service.

Gear Production Alliance GPA

Gear Cutting Process Task Assignments for Tools and Machinery



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Coming in Next Issue KANZAKI Display!

NACHI

What's All the Buzz About?

What's that you said? I'm sorry, could you repeat that? Would you speak up, please? I can't hear a thing you just said!

Sorry about that. It's just hard to hear around here lately with all the cicadas. Many of you have probably heard—or maybe you've been infested as well—but the Midwest is home to a very populous brood of 17-year cicadas, and 2007 was their year.

For 17 years, these cicadas live underground as nymphs, quietly sucking the sap from tree roots. Most of us don't even know they're down there all that time. But boy, do we know now. We're told that, in some areas, there are 1–1.5 million cicadas per acre (400,000–600,000 per hectare, or 250–370 cicadas per square meter).

Around the beginning of June, the nymphs began crawling out of the ground and making their way up tree trunks, where they attached themselves, shed their skins and transformed into winged adults. And then the chorus began.

In some areas, the noise is almost deafening. It seems more or less constant, but if you stand and listen, you can hear the cicadas react to each other en masse, their chirps rising in great waves of crescendos.

And then there are the dive-bombers. Cicadas aren't particularly good navigators, and they'll latch onto pretty much anything they run into, even—say—an editor out for an evening stroll.

By the time you read this, this batch of the 17-year cicadas will all be gone. They'll have mated, the females will have laid their eggs, and the adults will have died and their songs ended. Of course, the eggs will hatch and new nymphs will drop to the ground and burrow underground, where they'll stay for 17 more years.

Even though they are above ground for only about six weeks, the cicadas have given us plenty to talk about around Chicago. The whole town is abuzz with them, if you'll pardon my pun.

But for me, all the talk about cicadas reminds me of another cyclical event, one which is about to arrive in the gear industry. Of course, I'm talking about Gear Expo, which will take place October 7–10 in Detroit's Cobo Center.

Like the cicadas, Gear Expo comes on a regular cycle.

So I wonder: Will Gear Expo 2007 generate the same kind of buzz in the gear industry that the cicadas have generated in the Chicago area? Will gear industry professionals swarm to Gear Expo like the cicadas have swarmed some of our neighborhoods? Will we be talking about Gear Expo 2007 for months and years to come, or will we forget about it as soon as it's over?

It's hard to say. Mostly, the answers depend on you. AGMA has been running ads in every issue urging you to "Grab Your Gear and Go" to Gear Expo. (See page 55 for AGMA's show ad.) But how many of you have taken the time to log on and register? How many have penciled it in to your schedules? How many have booked reservations?

In theory, people attend trade shows when they have money to spend, when they need extra manufacturing capacity, when there are new technologies being introduced, or just to meet friends and develop relationships. I know that most of you are pretty busy. Hopefully, that means you're also making money. It probably means you're in need of extra capacity, but it also means you might not find the time to go to the show. But like the song of the cicadas, Gear Expo is a limited engagement. If you miss it, you'll have to wait another two years.

The onus is on you. If you value the show, if you value seeing new technology, if you value the opportunity to meet with the design, sales and service personnel of your suppliers, then support Gear Expo by going to Detroit.

Let's reverse the recent trend of dwindling attendance and make this a year to remember.

After all, a strong show demonstrates a strong industry. We'll be there, as always, making as much noise as we possibly can. We hope you'll join us. Let's give the gear industry something to buzz about.

Michael Goldstein,
Publisher & Editor-in-Chief

Better Gears & Splines with Metrology

Brian Slone,
Process Equipment Co.

What does it mean to make "better" gears? "Better" gears more closely resemble the intended design parameters for proper function in an application. To make better gears, information is needed to numerically quantify the current quality status of a component. One of the keys to sorting out the issues with a "problematic" gear component is determining if the error is due to the manufacturing process or due to the assembly or mounting orientation of the gear in question.

It may depend on your perspective when it comes to determining how to improve the "quality" of a gear. If you are a manufacturer, quality is influenced by the manufacturing variables with respect to the component's manufacturing datums. If you are troubleshooting a problem with a specific gear application, there could be an issue with the way the part was manufactured or there may be a problem with the part's assembly relationship to its functional datums. Depending on your perspective, determining how to make a "better" gear may be dependent on your approach to the measurement of the parts involved.

Manufacturing datums are the reference surfaces used during the manufacturing process. These could be centers, bores and faces. Functional datums are the surfaces that determine the gear's mounting and operational orientation. Functional datums are the reference surfaces about which the parts actually rotate. These could be bearing journals or splines, or they could be the same bores, shoulders and faces that served as manufacturing datums.

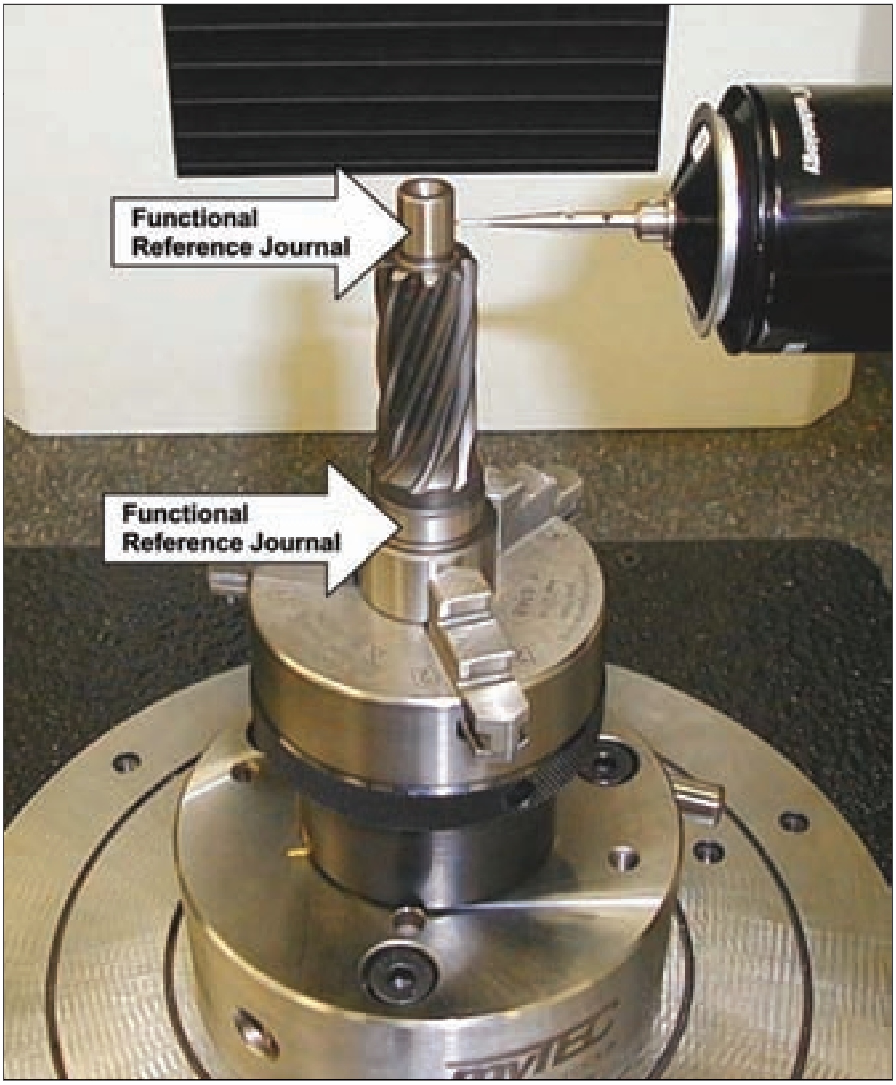

Figure 1.

Once it is determined that there is a problem with a gear set, measurements can be performed to (1) the manufacturing datums or (2) the functional datums of the part (Fig. 1).

A good place to start an investigation is to first determine if the manufacturing datums are the same as the functional datums by looking at the design print for the gear. Otherwise, a comparison of the design print to the observed operational orientation of the component is necessary to determine the true functional reference datums. If the manufacturing and functional

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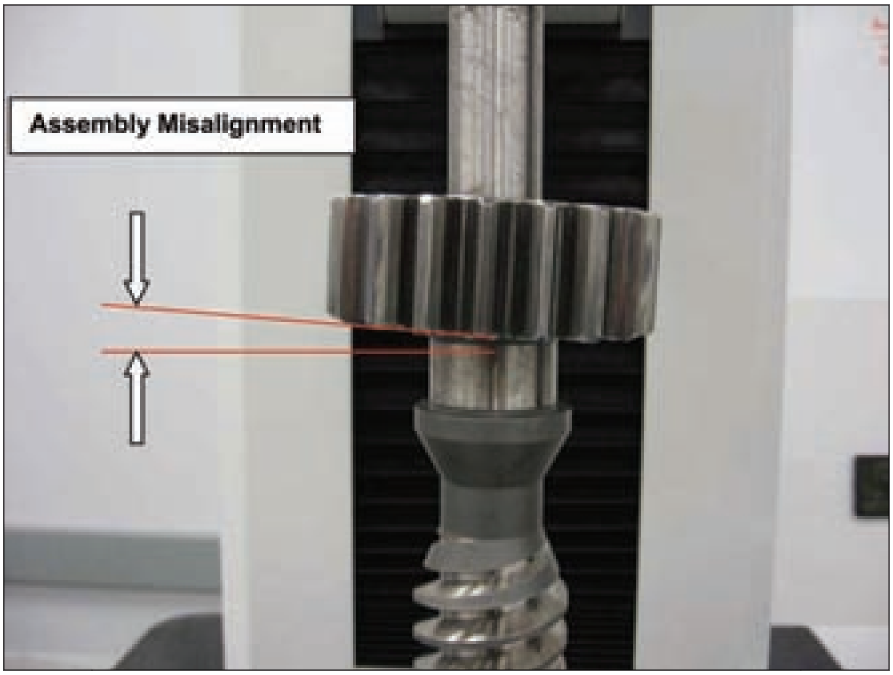

Figure 2.

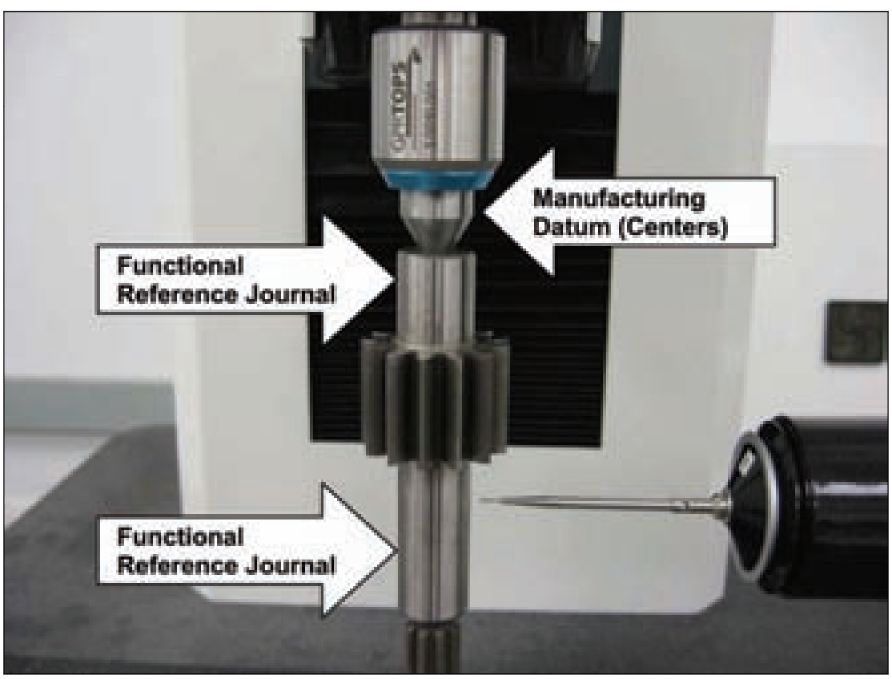

Figure 3.

datums turn out to be the same, an inspection of the gear component with respect to these datums will reveal both the "as made" and "as used" condition of the gear. If the manufacturing and functional datums are different, then measuring the component first to the manufacturing datums will confirm the manufacturing processes' role in affecting the gear's quality.

But with the enhanced capabilities of modern elemental CNC gear inspection equipment, functional datums can also be referenced to determine if the gear was properly mounted on a shaft or bolted to a mating component within the required alignment tolerances. Referencing the part to these functional datums will reveal the gear quality with respect to the gear's operation. There are times when the way a gear is mounted onto a shaft or against a shoulder affects the way the gear runs as an assembly. The gear manufacturer sometimes receives the blame for a "bad gear" when a faulty assembly procedure or an improper mounting design is the real culprit (Fig. 2).

An example would be a component manufactured to centers and then assembled with bearings pressed over the journals in application. The gear, when measured to centers, looks to be to the required tolerances, but when measured to the bearing journals, reveals a runout condition. This runout condition is from the operation that turned the journals, not the grinding operation which used the centers as a reference. In this case, the investigation needs to focus on the turning operation, not the gear manufacturing process (Fig. 3).

Much time can be saved in searching for the root cause of gear geometry problems with some preliminary investigation to determine the relationship between the manufacturing and functional datums. No matter how much care is taken in assembly, if a gear is not manufactured correctly, the function of the gear set will be affected. However, if the gear was manufactured correctly, but there are still problems, there is a chance that changing the assembly process or the mounting design can make for a "better" gear within an application.

Laser welding and high-speed pulse welding are two processes that join gears and splines to various shafts and sheet metal interfaces. If there are possible component issues and permanent assembly makes the original manufacturing datums unavailable, the individual components should be measured before welding or joining. Also, by measuring parts before joining, you save through-put capacity by not performing subsequent operations on otherwise "scrap" components from a faulty manufacturing process.

Dividing gear problems into both manufacturing and assembly categories helps to isolate the focus of investigation when trying to make better gears. Being able to measure elemental gear parameters with respect to how they are made and how they are used is the key to quickly determining where to make corrections in your operation. Making "better" gears is not solely dependent on the manufacturing process but sometimes has more to do with the final mounting condition with respect to the functional datums of the gear.

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Add your insight by e-mailing

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Haas

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A precise oil stream is injected at high speed directly at the spinning cutting tool. Oil coats the cutting tool and the immediate cutting area, providing sufficient lubrication to maintain optimum cutting conditions for the tool and material.

Our programmable, minimum-oil-machining (MOM) system dispenses oil directly to the cutting tool, leaving only a minute amount of oil on the workpiece and chips. The system can also be programmed to dispense a measured amount of oil onto a tap prior to tapping to prevent tool breakage.

This system is simple to program, easy on your shop maintenance, friendly to the environment and cost-effective. It works well for cutting most metals.

Drake's New Mini External Thread Grinder

TARGETS SMALL PARTS MAKERS

With a work envelope of 100 mm x 100 mm, Drake's GS: TEM mini three-axis thread grinder is aimed at higher volume, precision threaded parts manufacturers in the cutting tool, automotive, aerospace and medical equipment industries.

According to a company press release, the first mini was recently shipped to an Asian manufacturer of taps and other cutting tools. The machine was equipped with a fast cycling rocker-style magazine autoloader that was configured to grind taps M10 size or smaller.

The grinder comes equipped with a diamond roll contour dresser for dressing complex topping and non-topping wheel forms, including full radius and gothic arch, acme with chest and root radii or chamfers as well as 60 degrees, Whitworth, ISO, buttress and other thread forms.

Drake says the machine works best for grinding small taps, thread rolls, thread gages, worms, ballscrews, e-steering components, aerospace fasteners and surgical bone screws.

Additionally, the mini comes equipped with *PartSmart* menu-driven software with the customer's parts pre-programmed into the system. No programming knowledge is needed, as the operator simply follows the screen prompts and enters the value.

The Mini has a cell-friendly footprint and is 1.2 m wide x 1.8 m deep and weighs 3,000 kg.

For more information:

Drake Manufacturing Services Co. Inc.
4371 N. Leavitt Rd.
Warren, OH 44485
Phone: (330) 847-7291
E-mail: *info@drakemfg.com*
Internet: *www.drakemfg.com*

Kapp's Rotor Grinding Technology

IMPROVES EFFICIENCY BY 30%

The Kapp RX 59 allows the rotors used in air compressors to be manufactured using a high precision grinding process.

Rotors ground with Kapp CBN plated tools have a single layer of CBN abrasive held in a nickel bond to a steel bond. A grinding spindle is mounted on both sides and accommodates several grinding wheels, which are applied sequentially by moving the machine's shift axis. This enables the two-stage grinding process of roughing and finishing. Additionally, the rotor grinding machines integrate measuring equipment that allows controlled machining and size control in the micron range.

According to Kapp's press release, the machines produce faster cycle times, made possible by using high-powered, direct-drive spindle motors. The company says the RX 59 increased efficiency by 30% over the past three years.

For more information:
Kapp Technologies
2870 Wilderness Pl.
Boulder, CO 80301
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E-mail: *patteac@kapp-usa.com*
Internet: *www.kapp-usa.com*

Samputensili

UPDATES S 400GS

Samputensili has added a new NC-controlled axis on the workholding assembly to move shaving cutters axially in relation to their own bores on the S 400 GS shaving cutter machines.

A slide, equipped with high-precision, preloaded roller guides and a recirculating ball screw was incorporated on the traverse carriage (axis B) and enables workpiece axial movement by reciprocating orthogonally in relation to the traverse carriage itself. Linear motion is actuated by a 1 N-m torque brushless motor while a Heidenhain optical linear scale, with a micrometric resolution to the thousandth, guarantees correct axial positioning. The required axial position is maintained by a hydralic brake which is managed by the same hydraulic unit used to brake all machine axes. All machine axes are managed by a Siemens 840D numeric control unit.

According to the company's press release, additional features include a simplified control system, the elimination of rear mechanical spacers and grinding of workpiece with larger face widths.

For more information:

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Hoffman Estates, IL 60192
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Internet: *www.star-su.com*

ON LINE

Product News is updated constantly. For the latest product information, go to *www.geartechnology.com*

Heason's Gearmotors

BUILT FOR HIGH TORQUE APPLICATIONS

The AKM gearmotors set from Heason Technologies combines the torque density from the company's line of servomotors with its planetary gearheads.

The gearmotors are designed for demanding motion control requirements.

Additional features include a factory integrated and tested design to eliminate assembly errors; frame sizes from 60–142 mm; ratios of 3:1 to 25:1; true planetary gearing design; four arc-minutes of backlash; up to 8,282 lb.-in. of torque and a radial load capacity of up to 10,000 lbs.

For more information:
Heason Technologies
Unit 6, Lawson Hunt Industrial Park
Guildford Rd.
Broadbridge Heath
Horsham,West Sussex RH12 3JR
U.K.
Phone: +44 1403-755-800
Internet: *www.heason.com*

Koepfer's Hobbing Machine

OFFERS EXTENDED PART SIZE CAPABILITY

The heavy-duty Model 300 from Koepfer America provides bigger part diameter, coarser diametral pitch, and bigger hob capacity than traditional Koepfer hobbing machines.

According to Koepfer's press release, the Model 300 is equally suited to handle both the traditional Koepfer parts, as well as the new increased capacity workpieces.

The Model 300 has nine axes of CNC control with the gantry loading system, allowing for nearly all (parallel-axis or cylindrical) gear cutting applications, including the timing of one gear to another on the same workpiece and the timing of a gear tooth to an external or internal feature.

The Model 300 provides a maximum module of 4.0 mm (6.35 DP) with a maximum workpiece diameter of 195 mm (7.677"), and a maximum workpiece length of 500 mm (19.685") when manually loading (300 mm or 11.811" with automatic loading).

The design concept of symmetrical distribution of cutting forces ensures longer machine life with consistent part quality. The slant design of the hob head provides optimum chip flow for dry or wet cutting.

Some other features of this machine include a composite epoxy bed, ensuring the highest possible static, dynamic, and thermal stability; direct-drive digital work and cutter spindles, providing consistency and accuracy over the life of the machine; quick clamping work and cutter spindles for quick changeover; full color control panel with TFT touch screen; and optional CNC-controlled gantry automation system.

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635 Schneider Dr.
South Elgin, IL 60177
Phone: (847) 931-4121
E-mail: *sales@koepferamerica.com*
Internet: *www.koepferamerica.com*

BHS Getriebe's Turning Gears

SHOWCASED AT POWERGEN EUROPE

BHS Getriebe GmbH showcased its rotor turning gear capabilities in its booth at PowerGen Europe.

Units are used to prevent turbine rotors from warping as they cool to break away drive trains during plant start-up and to align shafts for maintenance and inspection. Breakout

continued

torques of 300–100,000 Nm and speeds of 0.2–400 1/min. are available.

According to the company's press release, BHS offers two designs of rotor turning gear. The simplest arrangement is to attach the rotor turning gear to a free shaft end. If this is not possible, the rotor turning gear may be integrated into the drive train by mounting it on a coupling guard or turbine pedestal and engaging with a flanged gear.

BHS Getriebe says more than 1,000 of these units are in operation worldwide, many in large power plants.

For more information:

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Germany
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E-mail: *info@bhs-getriebe.de*
Internet: *www.bhs-getriebe.de*

NUM's CNC

ADDRESSES NUMEROUS ASPECTS OF GEAR MANUFACTURING

The Axium Power CNC systems from NUM Corp. include embedded conversational/graphical operator interface and machining cycles for gear hobbing or grinding and automatic gear/tool alignment.

According to the company's press release, the PC or CNC based conversational/graphical interface (HMI) allows operators to program the machine without knowledge of ISO code. Operators are guided via pictorial information and questions presented on the screen. Entry screens provide the machine operator with a graphical interface that depicts the hob or grinding wheel, the gear and associated setup data. After the operator fills in the data fields, the program is automatically generated, stored and ready for execution. If desired, the operator can combine the conversational/graphical programming with the ISO language.

Two system packages are available. With the basic package, the CNC synchronizes cutter rotation and axial tool motion (Z-axis) with the rotation of the workpiece (C-axis). This configuration is primarily designed for the simplest machines with three axes (X, Z, and C) and a spindle.

The advanced package adds tangential tool movement (Y-axis) to the synchronization of the Z and C axes. This configuration is designed for applications with up to 6 axes (X, Y, Z, A, C and W) and a spindle, allowing for manufacturing of bevel and helical gears with straight or conical cutting tools.

The gear alignment option provides cutting tool and gear re-synchronization via a non-contact sensor and allows for automatic tool workpiece timing pickup when re-introducing a precut 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: *sales.us@num.com*
Internet: *www.num.com*

Hexagon Metrology

INTRODUCES SHOP FLOOR CMM AT EASTEC

Hexagon Metrology introduced a continuous contact analog scanning option for the Brown & Sharpe ONE Shop Floor CMM.

Two models, the ONE 7.7.5—with a 700x700x500 mm measuring range—and the 7.10.7 are offered. The 7.10.7 offers a measuring range of 700x1000 x700 mm. According to the company's

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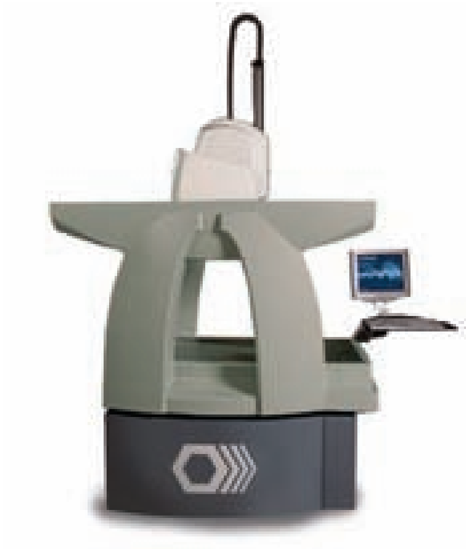

press release, both models are offered in a scan ready package that includes a TESA Swiss-made TESASTAR-m 2,952 position motorized probe head that can be mated to a variety of contact scanning prove options including the SP25M.

For more information:
Hexagon Metrology
250 Circuit Dr.
North Kingstown, RI 02852
Phone: (800) 343-7933
E-mail: *bwnshp@us.bnsmc.com*
Internet: *www.hexagonmetrology.com*

mG miniGears

INSTALLS FURNACE LOADING SYSTEM

mG miniGears installed a furnace loading system in its powder metal department to avoid defects, especially for gears where small damage of the toothing can compromise the functionality of a component.

According to the company's press release, miniGears applied lean manufacturing techniques to powder pressing with continuous flow to sintering furnaces. Two presses feed a palletized holding area at the entrance of a 24" belt furnace. Robots handle the compacted (green) parts in a fully automated production line, thereby avoiding any damage risk.

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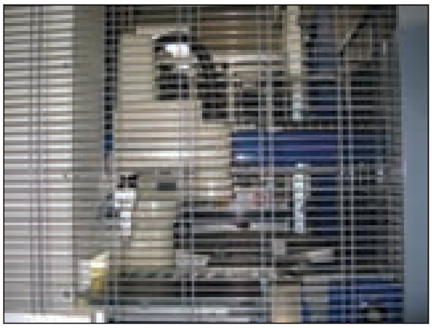
Phone: (757) 627-4554
E-mail: *mg_usa@minigears.com*
Internet: *www.minigears.com*



Absolute Machine Tools' Turning Center

DESIGNED FOR BIG PARTS, HEAVY DUTY TURNING

The Johnsford ST-80CH from Absolute Machine Tools is a heavy-duty high precision CNC turning center built for the oil field, energy and construction industries as well as others utilizing large lathes for big parts.

The 35,500 lb, 60° slant bed machine is available in bed lengths up to 200" and with spindle holes up to 12". The 60° slant bed is a torque tube design with a hole cast through the center of the bed for rigidity and heat dissipation.

According to the company's presss release, the Meehanite iron turning center utilizes its 50 HP high torque spindle motor and standard four speed gearbox to deliver high torque at a low RPM. An optional 60 HP spindle motor is available for high power cutting. The precision spindle structure is mounted using precision double row roller bearings in conjunction with angular contact ball bearings. The spindle quill inner and outer lining are precision ground for fit with the spindle.

Additionally, the machine features hand scraped, square box ways to provide rigidity for heavy duty turning. Turcite B applied to all mating sliding surfaces ensure high rapid traverse rates and accurate positioning. Headstock, tailstock and saddle are all mounted on the same plane at a 60° angle for thermal stability.

The coolant tank is separate from the machine base to prevent heat transfer to the machine casting. Ball screws are double nut type and pretensioned to eliminate thermal growth.

A 12-station bi-directional turret or optional VDI turret provides 0.5 second indexing as well as coolant through the tool holders. A full C axis with live tools is available for applications requiring milling operations.

Standard features include a hydraulic 20" chuck with soft jaws, a chip conveyor, Fanuc controls, and a hydraulic, programmable tailstock body and quill. Options include a C-axis with live tools which reports an accuracy of 0.001°. The live tooling used for the C-axis is back by a 15 HP spindle motor delivering up to 2000 rpm.

For more information:
Absolute Machine Tools
7420 Industrial Pkwy.
Lorain, OH 44053
Phone: (440) 960-6911
Internet: *www.absolutemachine.com*

Zeitlauf's Angular Gearing

OFFERS WORM GEAR DRIVE/BEVEL SPUR GEAR ALTERNATIVE

The EtaCrown concept from Zeitlauf offers an energy-efficient alternative to worm gear drives and bevel spur gears.

According to the company's press release, the EtaCrown gear offers 70% less loss of power or an efficiency improvement of a factor of 3.5. This allows reduction of the size of the drive motor, which allows the energy requirement in the application to be reduced.

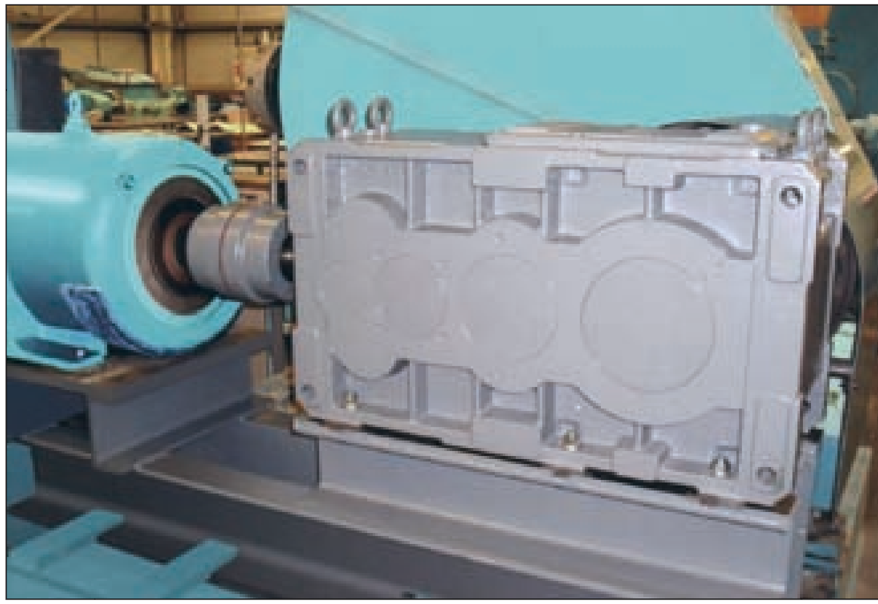
The company says a 30% space saving is possible as the result of the smaller drive units and symmetry of the angle gearhead, which allows mirrored installation. The EtaCrown's narrower profile allows component stocking requirements to be reduced as well. In door driving technology, for example, if two drives are installed opposite one another, the worm gear requires wider profiles and two different worm gear designs.

Also relative to the field of door technology, the EtaCrown does not self-lock.

For more information:
Zeitlauf GmbH
Antriebstechnik & Co. KF
Industriestr. 9
D-91207 Lauf
Germany
Phone: 49-9123-945-0
Internet: *www.zeitlauf.com*

Brevini's Gearbox

OPERATES QUIETLY FOR RUBBER SHEETING MANUFACTURER



When Primasil, a U.K.-based independent silicone compounder and manufacturer of non-silicone rubber sheeting, discovered its main drive gearbox on the central sheet rubber molding machine required replacement, it turned to Brevini Power Transmission UK.

For Primasil, once the raw ingredients are mixed in an application, the material is created by extrusion through a high pressure roller. The sheet forming process creates heat, and close control of the roller speed and torque—especially at low speeds—is crucial.

Dave Brown, sales manager of the PIV division of Brevini Power Transmission UK, said his first reaction was to initiate a repair. Since Primasil's 14" worm gear was producing 97dBA noise and leaking oil, its maintenance team first tried rebuilding the original box and building a basic acoustic isolation chamber around it.

Brevini's research indicated that repair was not possible and the company specified a Posired 2 bevel-helical unit offering triple-stage speed reduction, a 16,800 Nm torque capacity and quieter operation. According to Brevini's press release, the noise was immediately reduced to a 75dB(A) operating level, but the plant's busy schedule had to be overcome.

Within ten weeks, Brevini specified and supplied the gearbox, designed a replacement transmission line and mounting and installed the system. The installation required two days on-site, including installation of an input coupling and adapter frame, removal of existing equipment and installation of the updated drivetrain including re-machining the existing output coupling.

For more information:

Brevini Power Transmission UK
PIV Division
Exmoor Ave.
Skippingdale Industrial Estate
Scunthorpe DN15 8NJ
United Kingdom
E-mail: *dbrown@brevini.co.uk*
Internet: *www.brevini.co.uk*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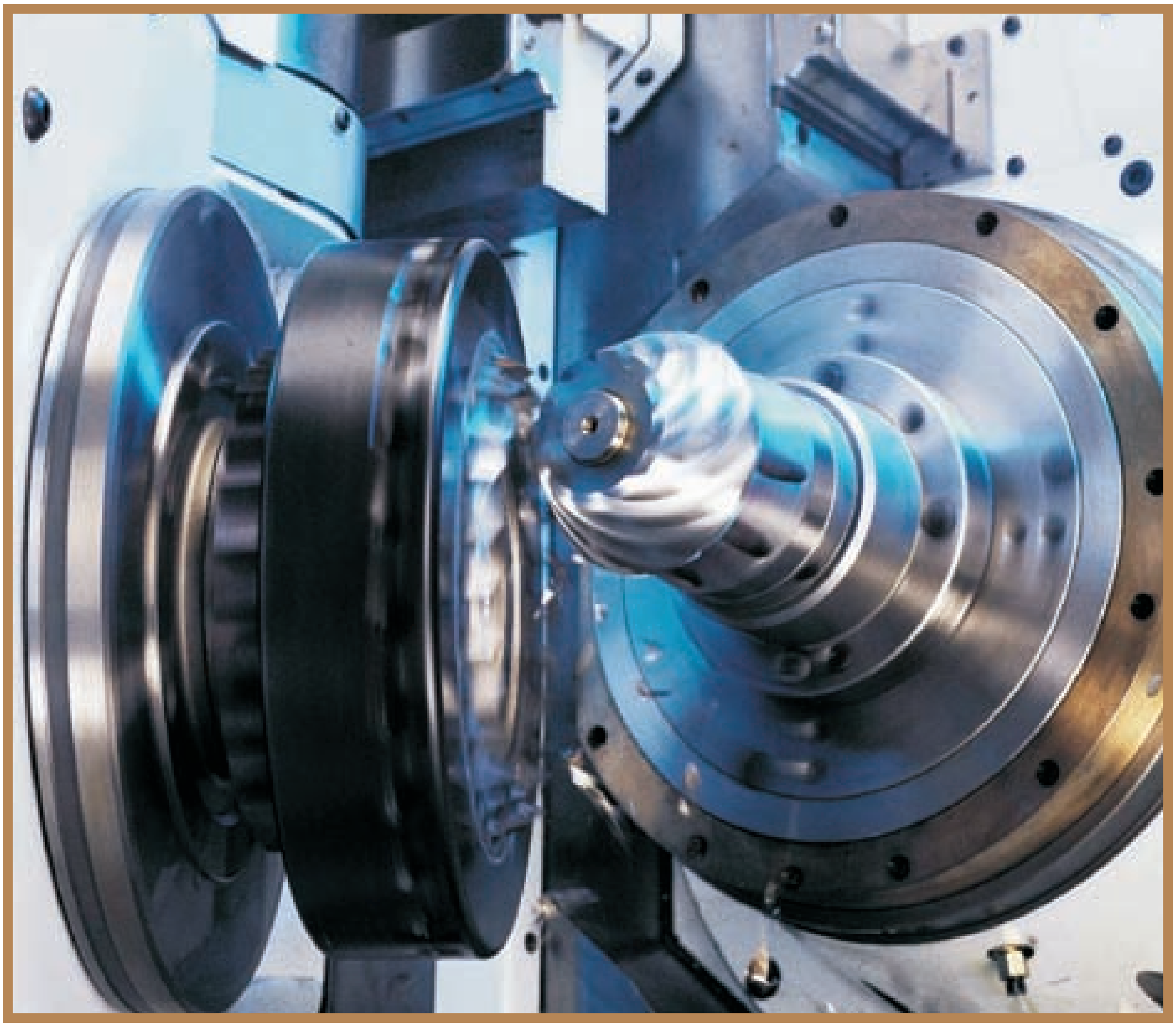
Spiral Bevel and Hypoid Gear Cutting Technology Update

T.J. "Buzz" Maiuri



Management Summary

Spiral bevel and hypoid gear cutting has changed significantly over the years. The machines, tools, processes and coatings have steadily advanced to the current state of the art. This article will cover the progression from mechanical machines with complex drivetrains that used the Five Cut method of cutting gears with coolant, to machines with direct-drive CNC technology dry cutting gears by the completing method with carbide and high speed tools. The latest cutting tool materials and tool coatings will be discussed. Production examples from the automotive industry will be provided as well as examples from the gear jobbing industry.

Introduction

Up until the 19th century, gear manufacturing was an art. Almost all gears were handmade and cut with form cutters shaped to correspond to the spaces between the teeth (Ref. 1). The first known gear cutting machine was developed by Juanelo Torian (1501–1575). He was able to produce up to three gears per day on his hand-powered machine, using cutting tools that were nothing more than rotary files (Ref . 2). In 1910, a machine was invented for cutting spiral bevel teeth with face hob cutters using the continuous index process. In 1913, a process and machine were introduced making it commercially practical to produce spiral bevel gears using a circular face mill cutter and an intermittent index of the blank. In 1927, a patent was granted for the first successful method of producing hypoid gears (Ref. 3). The first machine capable of producing either face milled or face hobbed gears was introduced in 1988, and shortly thereafter, full CNC control machines were introduced. Today, gears are made on high-production, automated machines with direct drives and precision cutting tools.

Face Mill (Single Index) and Face Hob (Continuous Index). There are two main methods of producing spiral bevel and hypoid gears in the production environment today. There is the single indexing method referred to as face milling (Fig. 1), and the continuous indexing method (Fig. 2) referred to as face hobbing.

Differences in geometry exist between the gears produced by the two methods, as can be seen by the accompanying figures.

Face Milled Geometry (Single Index). Typically, gears produced by face milling have a tapered tooth depth (the tooth is usually deeper at the heel, shallower at the toe) and may have a constant slot width (Fig. 3 and Fig. 4). The tooth thickness is tapered, and the curvature along the face width is that of a circular arc (Fig. 7).

Face Hobbed Geometry (Continuous Index). Gears produced by face hobbing have a constant tooth depth and a tapered slot width (Figs. 5 and 6). As with face-milled gears, the tooth thickness is tapered. The curvature along the face width is that of an extended epicycloid (Fig. 7).

Face Hobbing or Face Milling

There may be possible strength benefits in face hobbing due to what is known as the small cutter effect. The small cutter effect is good for strength because the tooth pattern is "pocketed" near the center of the tooth under load. Face-hobbed gears are also more conducive to the lapping process due to the direction of the generating flats on the tooth surface. Face-hobbed gears can also be finished by skiving. Grinding is not recommended for face-hobbed gears, as discussed later in the paper.

Face hob cycle times are often faster than face milling due to the continuous indexing method, and face hobbing is always a completing process.

In face milling, one slot is cut at a time,

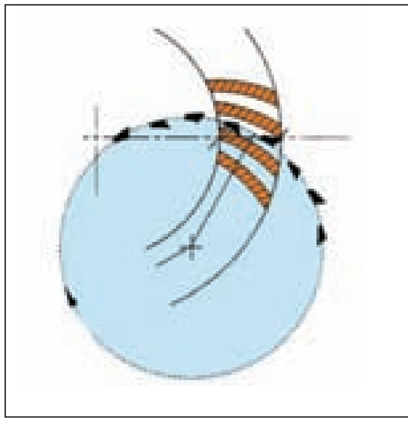


Figure 1—Single indexing.

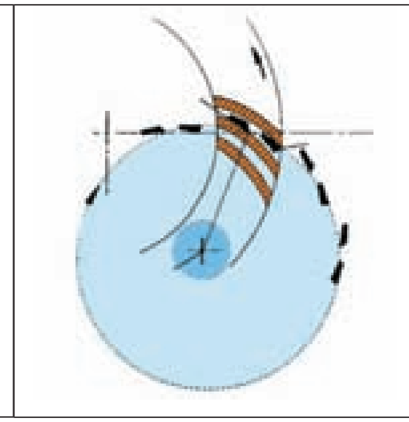


Figure 2—Continuous indexing.

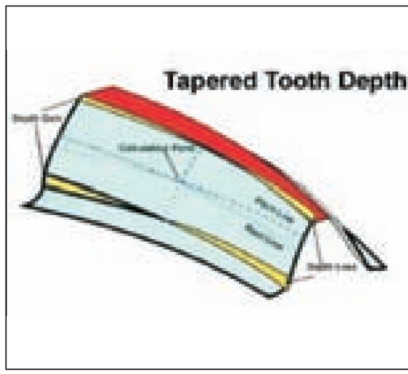


Figure 3—Tapered tooth depth.

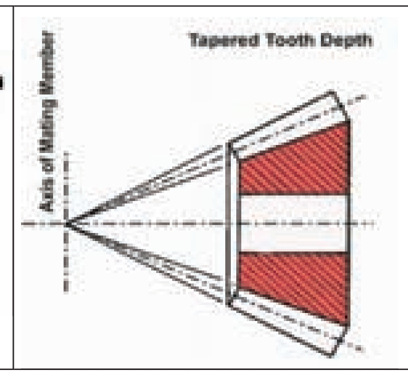


Figure 4—Tapered tooth depth—cross section.

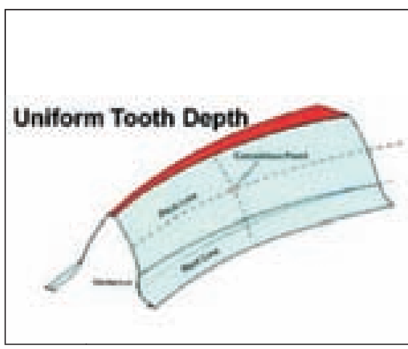


Figure 5—Uniform tooth depth.

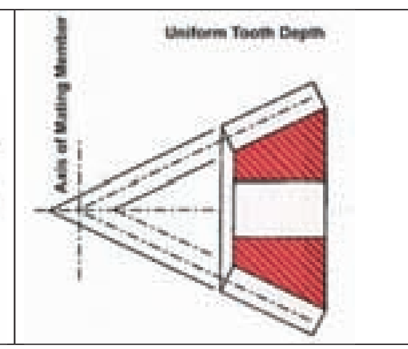


Figure 6—Uniform tooth depth—cross section.

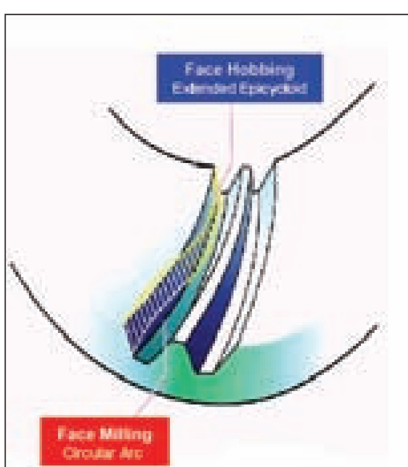


Figure 7—Face hobbed gears have an epicycloidal shape along the face width while face milled gears have a circular arc along the face.

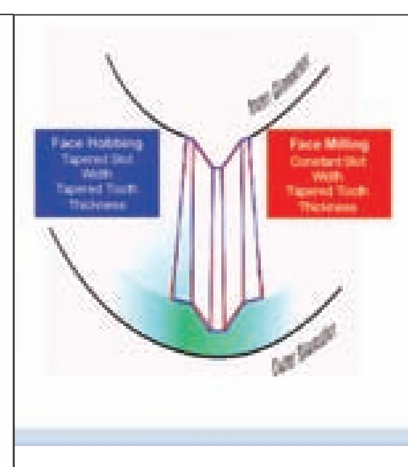


Figure 8—Face milled gears have a constant slot width while face milled gears have a tapered slot width.

Figure 9—Inserted blade cutter for face milling.

Figure 10—Face milled inserted blade cutter with parallel and shim used for mounting and truing blades on cutter head.

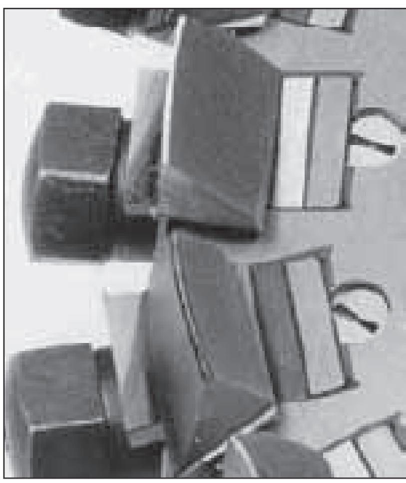


Figure 11—Inserted blade face mill cutter with alternate inside and outside blades.

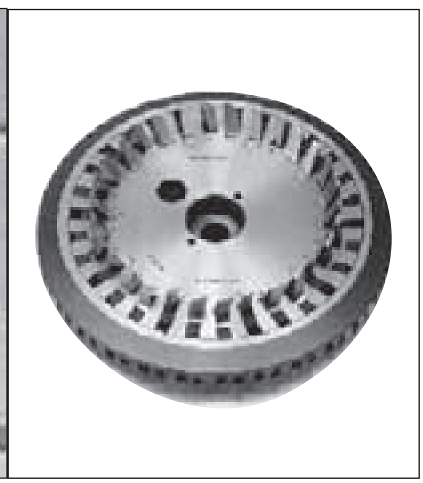


Figure 12—Stick blade cutter system for face milling.

and the cutter must withdraw and then index to the next slot. Face-milled gears can be lapped, skived or ground.

Hard Finishing of Cut Gears

The differences in geometry from the design and method of production play an important role in how the gears may be finished. As mentioned above, face-milled gears can be lapped, skived, or ground. Face-hobbed gears should only be lapped or skived for the finishing operation.

Although it is possible to grind a gear cut by face hobbing, it is not recommended. The reason can be seen in Figures 7 and 8. The face-hobbed gear will have an epicycloidal shape along the face width. The grinding operation would remove the epicycloidal shape and leave a circular arc. This would result in a gear with an uneven case depth after the grinding process. In some cases, it may turn out that all or most of the case depth would be removed in some areas of the tooth and not even touch (clean up) the tooth surface in other areas. A similar problem with uneven case depth will exist because of the differences in tooth depth between face-hobbed gears (parallel depth) and face-milled gears (taper depth).

Five-Cut Process and Completing Process

The manufacturing of face-milled spiral and hypoid gear sets can be accomplished by using the "Five-Cut Process" or by the "Completing Process."

Early production of face-milled gears utilized the Five-Cut Process, which consists of five independent operations—two operations to finish the gear, and three operations to finish the pinion. The gear is roughed out using an alternate blade roughing cutter, then finished in a second operation with an alternate blade finishing cutter. An alternate blade cutter has an inside blade in one slot in the cutter head and an outside blade in the adjacent slot, so both sides of the tooth slot are cut in one operation. The first operation on the pinion is a roughing operation with an alternate blade roughing cutter. The second and third operations on the pinion involved cutting each flank separately in different operations. The pinion convex flank is finished with a cutter having inside blades only, and the pinion concave flank is finished with a cutter having only outside blades. Many companies are still utilizing the Five-Cut Process in production; however, most companies have switched to the completing process.

In the completing process, both sides of the tooth slot are finished with a single cutter in one operation from a solid blank. The cutters used for completing have alternate blades (inside and outside). Some cutter systems also use what is called a bottom blade in addition to the inside and outside blade. The completing process is applicable to either face milling or face hobbing.

In 1996, a significant improvement was introduced in the production of spiral bevel and hypoid gears. At the IMTS Show in Chicago, Powercutting was introduced. By definition, Powercutting is the process of producing gears at high speeds with or without the use of coolants. This is achieved using stick blades made out of carbide material with a special tool coating. Since its introduction, almost all bevel cutting machines manufactured today are arranged for high-speed cutting with carbide blades without the use of any coolant. The advantages of high-speed cutting with carbide are significant. The cycle times are reduced, the tool life is improved, the gear quality is better, and the elimination of the coolant in the cutting process is environmentally friendly. (The production analysis example in the online Appendix 1 expands on this.)

Cutter Systems

There are different cutter systems to choose from, depending on the method of producing gears and the supplier of the cutter system. In the early days of producing spiral bevel gears by the single-indexing method, cutters were available in three general types—integral blade, segmental or inserted blade. Integral blade cutters are also called solid body cutters with the blade solid with the head. Segmental cutters have groups of blades bolted to the cutter head. Inserted blade cutters have individual blades bolted to slotted heads as shown in Figures 9–11.

The inserted blade circular face mill cutters can be used for single-side cutting (fixed setting) by using all inside blades or all outside blades in the cutter head. They can also be used for roughing and completing by using alternating inside and outside blades. Some cutter systems offer a third blade in the group, called a bottom blade. The blades have curved side relief and are sharpened in the cutter head by grinding the face of the blade only. The blades are bolted radially to the circumference of the cutter body. Parallels and tapered shims between the blade and cutter body are used for mounting and truing the blades (Fig. 10).

A stick blade cutter system for face milling was introduced in the 1970s (Fig. 12). Stick blade systems allow for more blades to be placed in the cutter head. The cutter heads (cutter body) have precision-ground slots for exact radial and angular location of the blades. Stick blade systems for face milling include the Gleason RSR® and Klingelnberg ARCON® systems (Ref. 4). Klingelnberg has a face mill system called Twin Blade that utilizes blades with zero degree rake angle and a blade width such that each blade cuts both the convex and concave flanks of the work (Ref. 5).

Stick blade systems for the face hobbing operation (Fig. 13) are always used in a completing process where the tooth slot is completed in one cut. The cutter head slot loca-

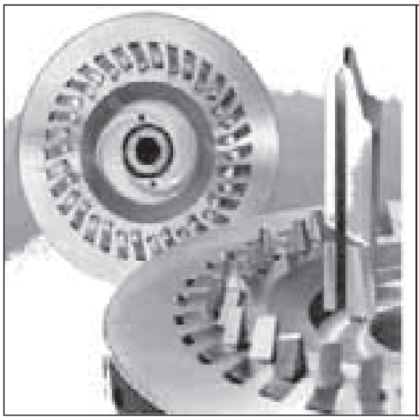


Figure 13—Stick blade systems for face hobbing are used during the completing process where the tooth slot is completed in a single cut.

Figure 14—Gleason's PENTAC® stick blade cutter system.

Figure 15—Gleason stick blades.

tions and orientation for face hobbing are more complex than for face milling. Early cutter systems utilized a three-blade configuration in the blade grouping consisting of an inside blade, outside blade and a bottom blade. Current cutter systems such as the Gleason TRI-AC® system and Klingelnberg SPIRON® system use only an inside blade and an outside blade for face hobbing (Ref. 4).

Stick blades cannot be sharpened in the cutter head, but all relief surfaces are ground during sharpening, which means blade pressure angles and blade curvatures can be changed during the sharpening process. This is a significant advantage over the circular face mill cutters shown in Figures 9–11.

In the late 1990s Gleason introduced a stick blade cutter system called PENTAC® (Fig. 14), which has a positive three-point seating surface with a 60º / 30º pentagon-shaped

Table 1—Details of high-speed steel materials in use today.

	C	Cr	W	Mo	V	Co	HRC
CPM M2	1.0	4.2	6.4	5.0	2.0	-	64
ASP 2023	1.3	4.2	6.4	5.0	3.1	-	64
CPM M4	1.4	4.3	5.8	4.5	3.6	-	64
CPM REX 54	1.45	4.3	5.8	4.5	3.6	5.0	65
CPM REX 45	1.3	4.1	6.3	5.0	3.1	8.3	66
ASP 2030	1.3	4.0	5.0	6.5	3.0	8.0	66
CPM T15	1.6	4.0	12.3	-	5.0	5.0	66
CPM REX 76	1.5	3.8	10.0	5.3	3.1	9.0	67
CPM REX 86	2.0	4.0	10.0	5.0	5.0	9.0	68
ASP 2060	2.3	4.0	6.5	7.0	6.5	9.0	68
CPM REX 121	3.3	3.8	10.0	5.3	9.0	9.0	70
M35V (Conventional)	1.2	4.1	6.0	5.0	3.0	5.0	66

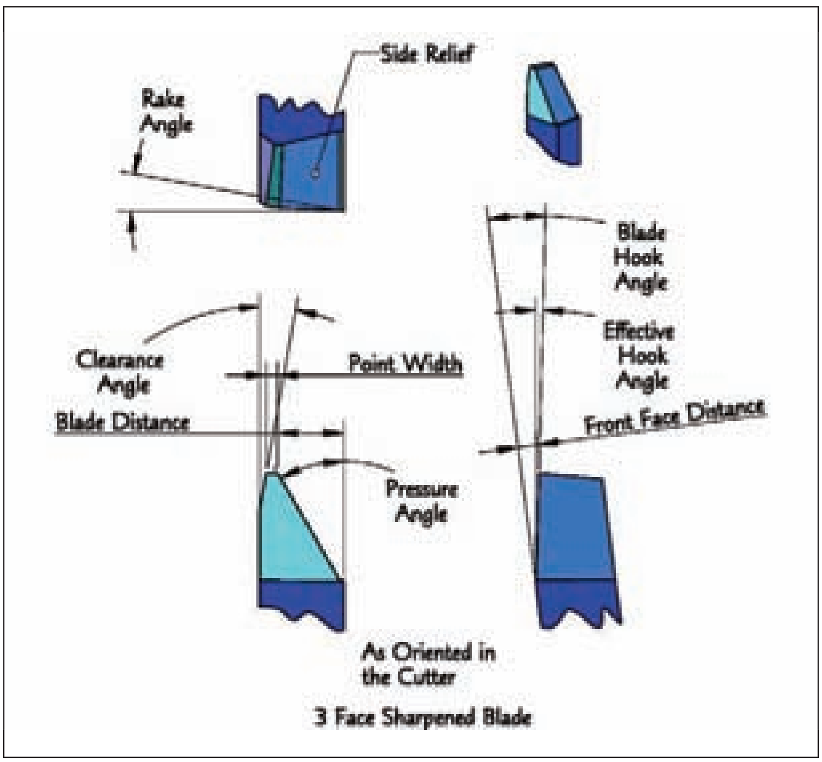


Figure 16—A three-face sharpened blade.

stick cross-section (Fig. 15). The cutter head and blade design offer a more rigid system and allow for easier cutter building and truing. PENTAC® style blades are available for either face milling or face hobbing. This cutter system offers improved ease of assembly and blade truing over the other stick blade systems.

Profile (Two-Face) and Profile Plus Front Face (Three-Face) Sharpening.

Some stick blade systems have pre-raked front faces. If new blades are coated, it is only necessary to sharpen the top, pressure angle and clearance angle of the blade, which is the traditional method of sharpening. This method of sharpening preserves the coating on the front face, and it is not necessary to coat the blade after every sharpening.

It has been demonstrated that with fully coated (all-around coated) blades, the tool life can be improved by a minimum of 50%. When considering re-coating of blades after every sharpening, it is necessary to consider the additional cost of stripping, recoating, and stocking additional blades. These costs must be evaluated against the benefits of additional tool life.

One of the difficulties with using all-around coated blades is the effective reclaiming of the surfaces for re-coating. Most chemical or mechanical means of stripping blades often result in surface finish deterioration, and cobalt leaching in the case of carbide blades. It is possible to mask the substrate so that the coating is applied only to the sharpened profile. A reliable method of reclaiming the surface is to add the grinding of the front face during sharpening. This additional step will remove the coating off all surfaces, and thus the blade is automatically reclaimed for all-around coating.

Cutting Tool Materials

Early cutting tool materials (from the 1900s–1940s) consisted of high-speed steels designated as 18-4-1, which consisted of 18% tungsten, 4% chromium and 1% vanadium (Ref. 6). Today, we have many materials to choose from. Table 1 lists high-speed steel materials in use today, their chemical composition and Rockwell C hardness.

With the advent of cutting gears without coolant, carbide materials are the choice for bevel gear cutting operations today.

Cemented carbides are a range of composite materials that consist of hard carbide particles bonded together by a metallic binder.

The proportion of carbide phase is generally between 70–95% of the total weight of the composite.

From experience gained over many installations using dry carbide cutting, the ISO "K" grade extra-fine grain carbide is found to be the most appropriate grade for bevel gear cutting operations. ISO "K" grades of carbide are a simple two-phase composition consisting of tungsten carbide (WC) and cobalt (Co). A typical composition of a "K" grade carbide is 90% WC and 10% Co by weight. "K" grades have good edge stability and abrasion resistance with a grain size range of 0.5–0.9µm.

When initial trials for dry carbide cutting began, experiments were conducted on a variety of carbide grades and a range of 6–12% cobalt. At that time, 10% cobalt was selected as the best compromise for a "standard" blade material. More recently, cutting high wear-resistance steels has indicated an advantage using carbides with 6% cobalt. However, the increase in brittleness can lead to edge chipping in production. Note that increasing the cobalt content increases the toughness of the material, but decreases the wear resistance (Figs. 17 and 18). Other carbide specifications may be an advantage for a particular application based on the material composition, structure, and hardness.

The following figures show some of the relative material properties of carbide and steel.

The density of carbide (Fig. 19) is nearly twice that of steel. This means that a carbide blade with the same geometric characteristics as a high-speed steel (HSS) blade is much heavier.

Carbide is also much harder (Fig. 20) than steel, and is not as tough (Fig. 21). Think of toughness as the ability to resist fracture. This means that if you drop an HSS stick blade you may just put a ding on the blade, but if you drop a carbide blade it may shatter into pieces. Because of these properties, you must take certain precautions with the carbide blades that you normally would not take with the conventional HSS blades.

The linear expansion of carbide (Fig. 22) is less than half that of steel. This is not a significant characteristic as it relates to bevel cutting, but it is in the world of cylindrical hobbing. This is due to the fact that if you are using a shell-type carbide hob with a steel hob arbor, the hob arbor will expand at a greater rate than

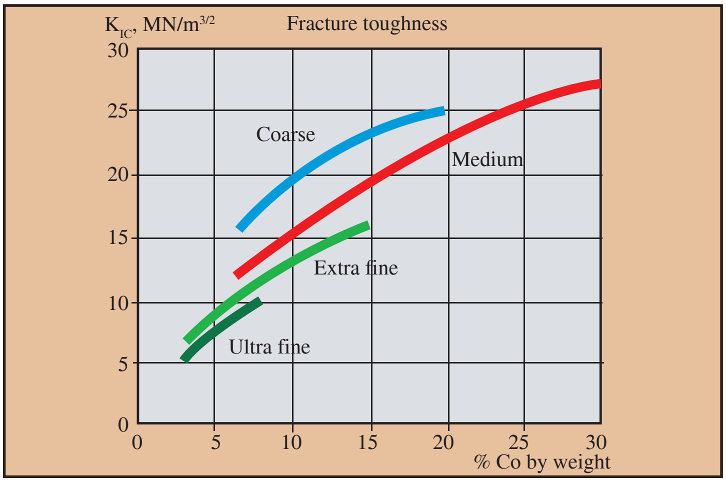


Figure 17—Fracture toughness as a function of the Co content for different WC grain sizes.

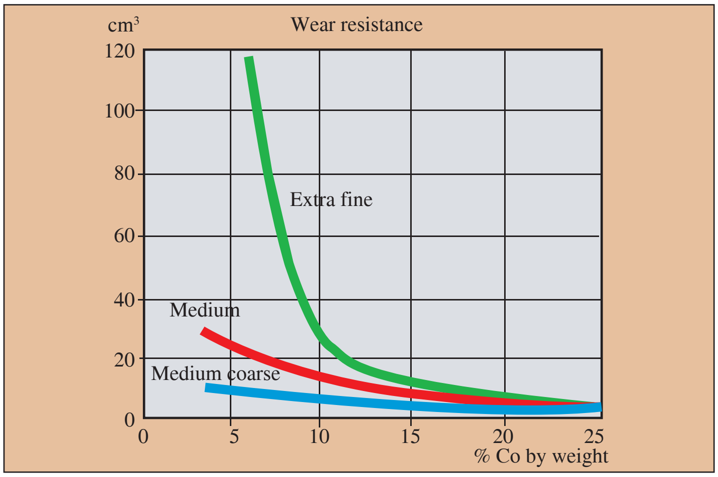


Figure 18—Wear resistance as a function of the Co content at different WC grain sizes according to ASTM B611-85 test method.

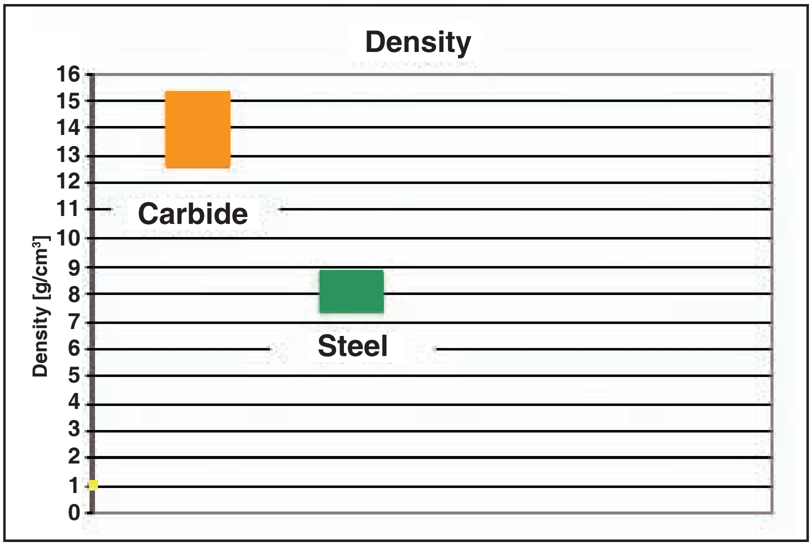


Figure 19—Carbide density is double that of steel.

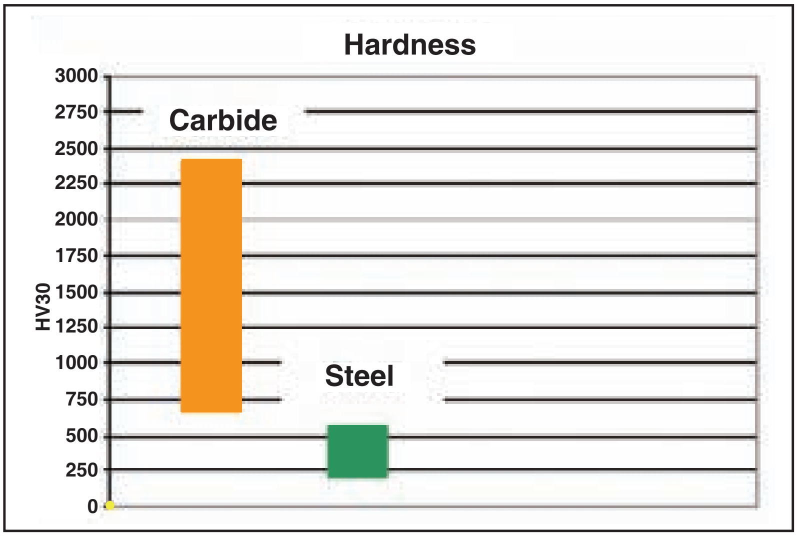


Figure 20—Carbide hardness is greater than steel.

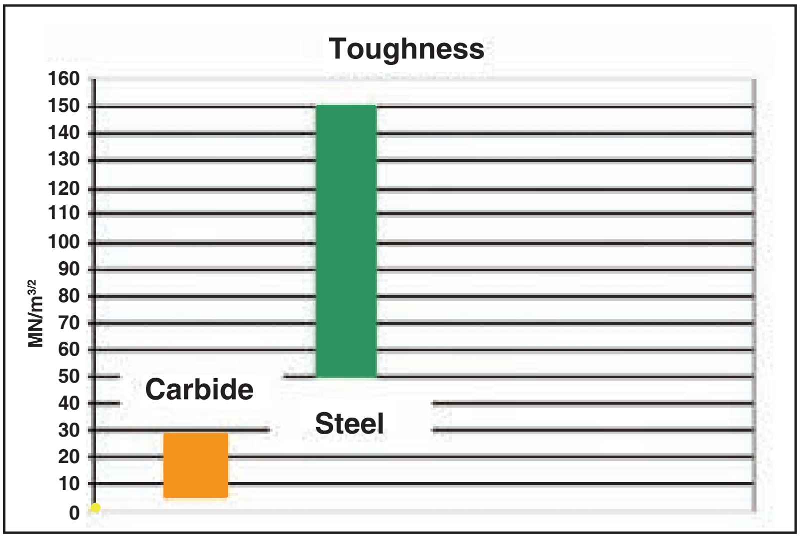


Figure 21—Steel is tougher than carbide.

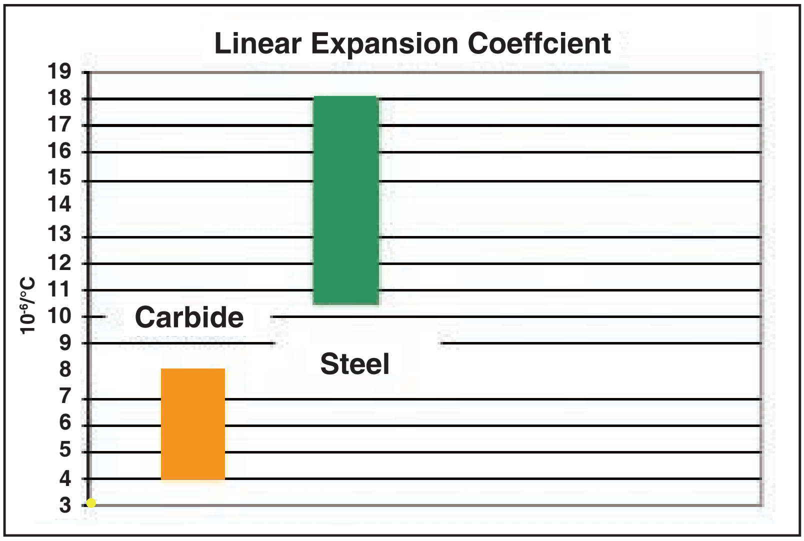


Figure 22—The linear expansion of carbide is less than half that of steel.

the carbide hob, and you must account for this thermal expansion difference in the clearance between the hob bore and the steel arbor. Otherwise, the hob may shatter (Ref. 7).

Coatings

Tool coatings came to the market in the 1980s. The most popular at the time was TiN (Titanium Nitride). This coating served well for high-speed steel applications used with a coolant.

Titanium Aluminum Nitride (TiAlN) was developed in the mid-eighties and gained popularity in the 1990s as a coating for blades for use in cutting hard materials and high-heat applications. It proved to be the coating of choice for dry carbide cutting applications. The coatings used in gear production today are primarily AlNite® (Balzers Balinit® FUTURA NANO), TiAlN-X (Balzers Balinit® X. TREME), and AlCroNite™ (Balzers Balinit® ALCRONA). The performance of AlNite® and TiAlN-X are about the same, although some customers prefer one over the other. AlCroNite™ (Balzers Balinit® ALCRONA) has shown advantages for a number of applications over the other coatings. Trials with Balinit® X.CEED and Hardlube were also conducted, but did not show any significant advantage.

Following is a brief description of coatings used for gear cutting tools:

AlNite® (Balzers Balinit® FUTURA NANO)—AlNite® is a single-layer TiAlN coating with a nominal 50:50 ratio of Titanium to Aluminum. It has high thermal stability and can be used for cutting all steels, cast iron and stainless steel, and may be used wet or dry.

AlNite®-X (TiAlN-X, Balzers Balinit® X. TREME)—AlNite®-X is a single- layer coating of TiAlN. It is specialized for carbide mills for hardened steel workpieces (>50 HRC). It may also be used wet or dry. See Figure 23.

TiAlN-X.CEED (Balzers Balinit® X. CEED)—X.CEED is a high deposition temperature, high aluminum single-layer coating, appropriate only for cemented carbide substrates. It is designed for aerospace materials including Titanium and Inconel.

Hardlube (Balzers Balinit® Hardlube)—Hardlube is a duplex coating consisting of a wear-resistant TiAlN base layer and a high-lubricity (low friction coefficient) WC/C top layer designed for ease of chip extraction in deep hole drilling/tapping applications.

AlCroNite™ (Balzers Balinit® ALCRONA)—ALCRONA is a high- performance, titanium-free coating (AlCrN) of the G6 generation. It has exemplary wear resistance under both conventional conditions and severe mechanical stresses.

nACo® (Platit)—nACo is a true nanocomposite coating comprised of AlTiN nano sized particles embedded in an amorphous (non crystalline) matrix of silicon nitride (Si_3N_4). This coating has the highest reported oxidation resistance of any current coating and is ideal for dry machining. It is readily strippable and environmentally friendly from both high-speed steel and K-grade carbide materials.

Table 2 lists some of the properties of coatings in use today (Ref. 8).

Yesterday's and Today's Cutting Machines

The early mechanical machines used to produce spiral bevel gears were known as traditional cradle-style machines. The cradle concept was used by all manufacturers of bevel and hypoid gear machines. The early machines consisted of many components, as shown in Figures 24 and 25, such as machine base, work head column, cutter head column, cradle, eccentric swivel drum, tilt mechanism, hypoid offset slide, swinging base and work axis.

These machines also had very complex gear drive trains, as shown in Figures 26 and 27.

As you would expect, today's cutting machines are radically different from earlier machines. The modern machine employs CNC controls, has high-speed spindles for both the work and cutter, and utilizes direct-drive technology. Today's machines produce gears at very high speeds, but the machine itself may not contain any gears. The machines are very ergonomic—easy to load and unload parts, and easy to change cutters. Many machines today are equipped with various configurations of automation for loading and unloading parts. Robots are also employed for loading, and they sometimes handle more than one machine.

Figure 28 shows the latest concept in machine design. The monolithic column design represents leading edge technology to design for chip flow, ergonomics, stiffness, cutting process, and maintainability. Figure 29 depicts an actual cutting machine based on the monolithic design. Note the location of the cutter and workpiece for easy loading and unloading.

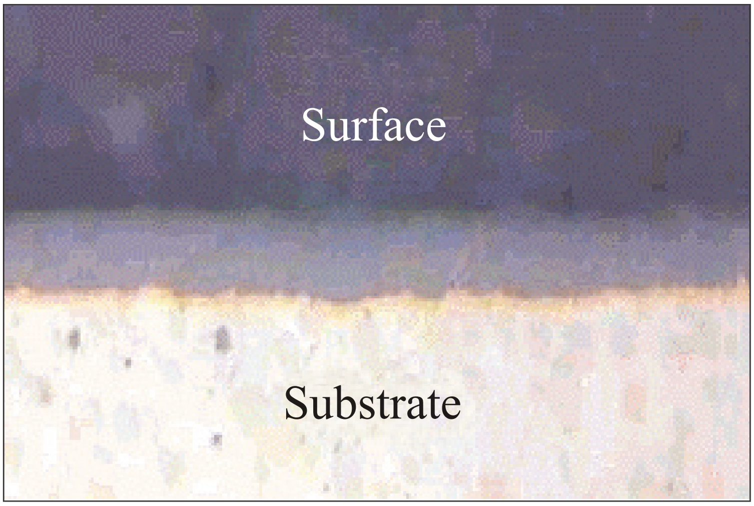


Figure 23—Single layer X.TREME coating.

Table 2—Properties of coatings in use today.

	TiN	TiCN	AlNite®	AlNite®-X TiAlN-X	TiAlN-X-CEED	TiAlN-+WC/C	AlCrN	nACo
	Balzers BALINIT® A	Balzers BALINIT® B	Balzers BALINIT® Futura Nano	Balzers BALINIT® X.TREME	Balzers BALINIT® X.CEED	Balzers BALINIT® HARDLUBE	Balzers BALINIT® ALCRONA	Platit
Hardness (HV 0.05)	2300	3000	3300	3500	3300	3000	3200	4590
Coefficient of Friction	0.4.	0.4	0.30–0.35	0.4	0.4	0.15–0.20	0.35	0.45
Max. Service Temp	600°C 1112°F	400°C 725°F	900°C 1652°F	800°C 1472°F	900°C 1652°F	800°C 1472°F	1100°C 2012°F	1200°C 2192°F
Coating Color	Gold	Blue-Grey	Violet-Grey	Violet-Grey	Blue-Grey	Dark Grey	Blue-Grey	Violet-Blue
Coating Structure	Mono-layer	Multi-layer	Nano	Mono-layer	Mono-layer	Multi-layer	Mono-layer	Nano

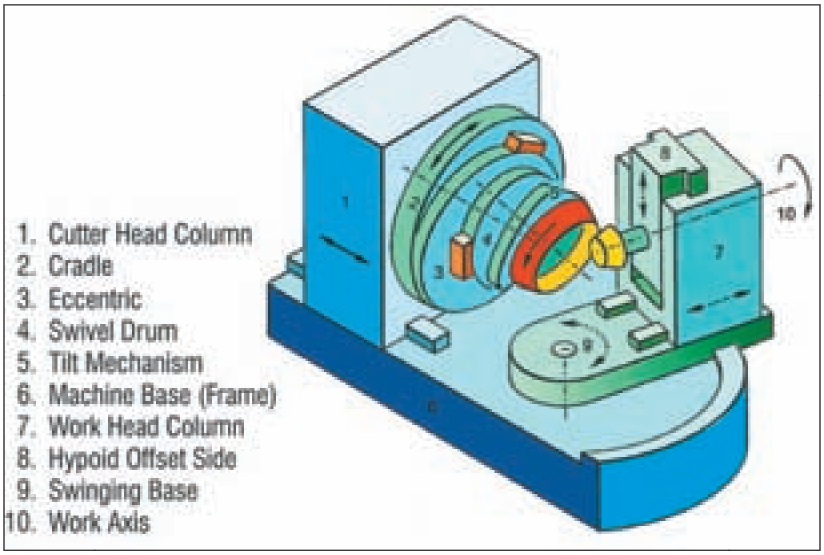


Figure 24—Early cutting machines consisted of many components.

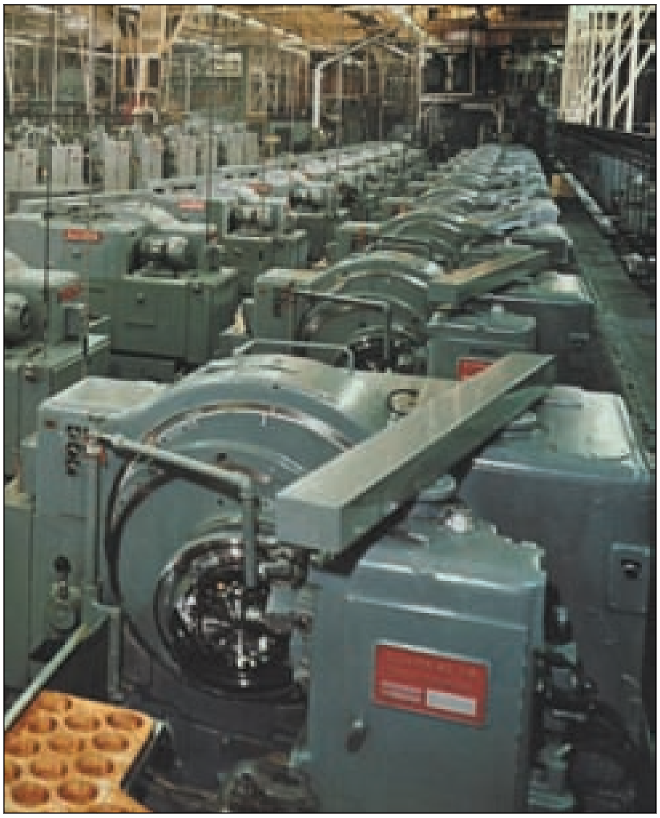


Figure 25—Some of the components in the early cutting machines are machine base, work head column, cutter head column, cradle, eccentric, swivel drum, tilt mechanism, hypoid offset, swinging base and work axis.

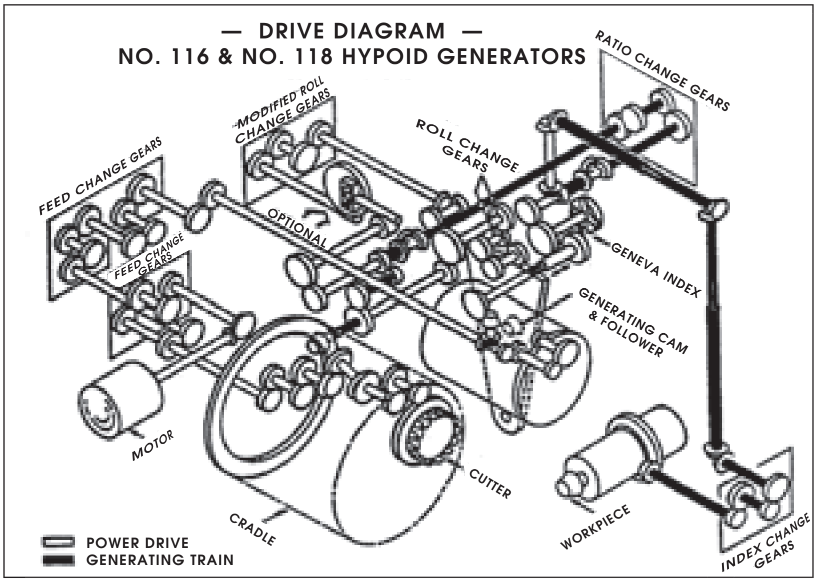


Figure 26—A drive diagram of a hypoid generator.

Machine Runoff Requirements

Machine tool manufacturers supplying machines to the gearing world have been in existence for many years. The machines have changed, and so has the acceptance criteria for the machines. Before the 1980s, the criteria for virtually all machine acceptance was either a supplier's standard test job or the supplier producing one or two of the customers' parts to within a print tolerance. Around 1984, requirements were given to perform a capability analysis for a machine acceptance on a cylindrical hobbing machine.

Capability requirements for bevel machine acceptance did not occur until several years after that. Today, virtually every customer requires a capability study on at least one parameter for at least one type of part.

Since the introduction of capability requirements for machine acceptance, the goal post has moved. Initially the requirement was for a Cp or Cpk of 1.33 using a Six Sigma analysis. Now we have seen requirements of a 1.67 or 2. 0 Cp or Cpk with a Six, Eight or Ten Sigma analysis on tolerances that have been tightened from the original tolerance. This can cause some real headaches for the machine tool supplier, and that is why it is very important for the supplier to understand the true machine and process capability before agreeing to any capability requirement (Ref. 9).

Additional Considerations for Producing Bevel Gears

Just having a cutter body, blades, and a cutting machine is not enough for gear production. The blades need to be sharpened, inspected, assembled, and trued in the cutter head. Modern equipment exists today for all the abovementioned activities, and examples are depicted in the figures below.

Figure 30 is a stick blade sharpening machine. Using dressable wheels, the machine can sharpen stick blades of high-speed steel or carbide material. The process can sharpen blades for two-face or three-face applications in less than two minutes. Block blades (blades with no profile form) can be sharpened to a finished profile economically, taking between four and ten minutes per blade, depending on the blade size and material. The blade grinder is network-capable for closed-loop design, inspection and correction systems, as will be discussed later. Figure 31 is a close-up of the grinding wheel and stick blade. Figure 32 demonstrates the variety of sizes and types of blades that are used in production today.

Blade inspection machines exist that can measure the key characteristics of a stick blade: pressure angle, clearance angle, hook and rake angle, blade distance, top width, TOPREM® etc. These machines can also measure the blade shank integrity. Results can be stored for SPC evaluation, and hard copies of the results can be printed.

Figure 33 is a machine used to assemble stick blade cutters in their heads, true the cutter, and inspect the blades in the head. The unit will measure the axial and radial runout of the assembled blades. In general, it may take 40–45 minutes to build, true and inspect the cutter assembly, depending on the accuracy desired.

Spiral Bevel and Hypoid Gear Inspection

Figure 34 is a CMM (Coordinate Measuring Machine) used to inspect the gear or pinion. Flank form, spacing characteristics, tooth thickness, etc., are characteristics that are measured. See Appendix II (online) for a typical CMM output. Figure 35 is a close-up of a pinion being measured.

Figure 36 is a direct-drive CNC test machine that can auto mesh a gear set, set the backlash automatically and test the set for contact pattern, single flank or structure-bourne noise.

Networking Machines and Automated Corrections

PCs or servers running gear software programs can be networked to the various gear production equipment described above for closed-loop gear design, production, inspection and correction. Figure 37 is an example of a network arrangement and data flow.

The application or design engineers use a WINDOWS®-based bevel design software package to input basic gear parameters, tooling, manufacturing methods and machinery. The design software can include TCA (Tooth Contact Analysis) and FEA (Finite Element Analysis). Machine settings are generated and electronically transferred to the cutting/grinding machine. Likewise, inspection data is generated and transferred to the inspection machines. If corrections to the inspected gear, pinion, or blade are required, the software will automatically calculate the new machine settings and transfer these new settings back to the machines, completing the closed-loop design and manufacturing process.

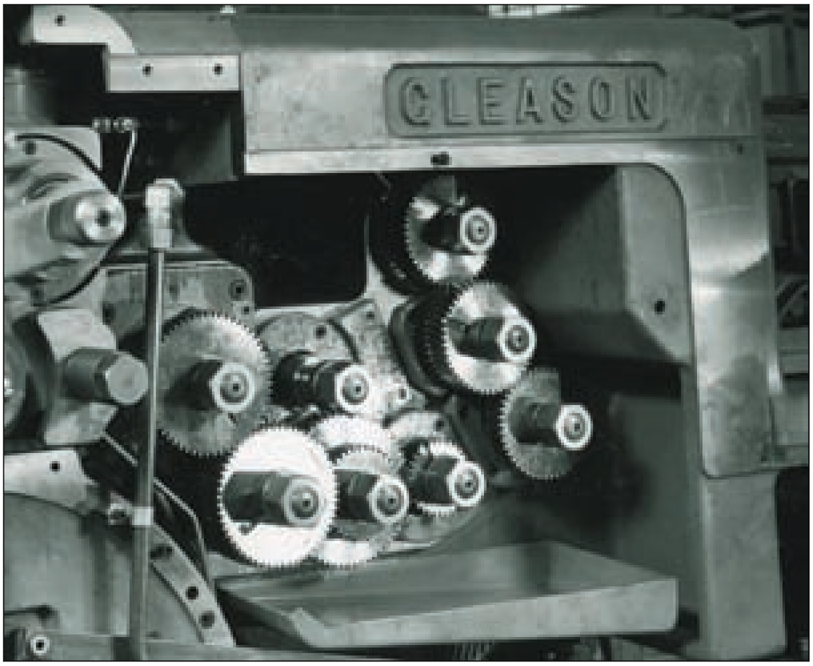


Figure 27—The complexity of a gear train.

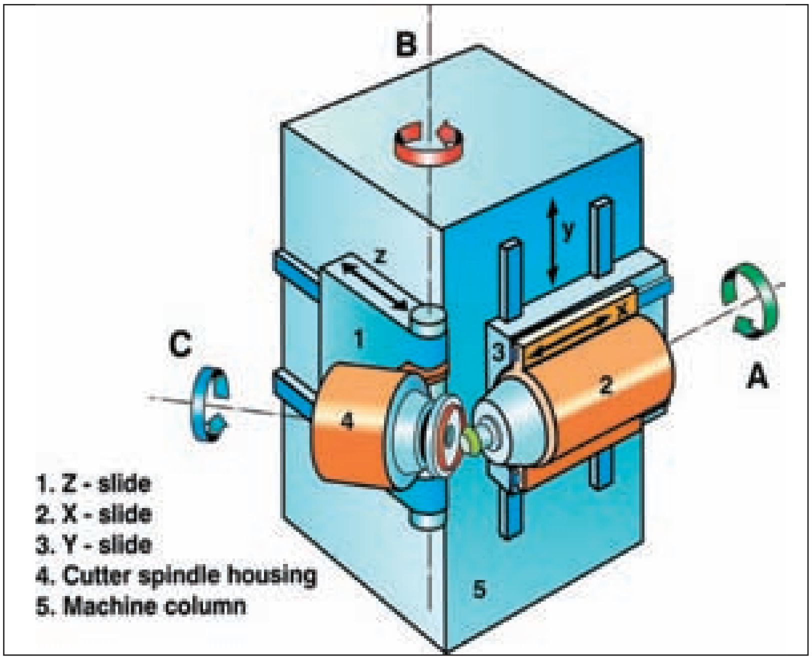


Figure 28—Monolithic column design shows modern technology that's designed for chip flow, ergonomics, stiffness, cutting process and maintainability.

Figure 29—Real-life cutting machine based on a monolithic design.

Figure 30—Stick blade sharpening machine.

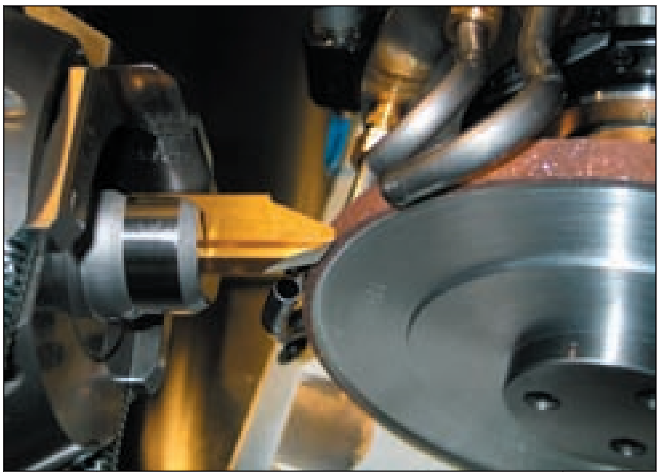


Figure 31—Sharpening a stick blade.

Figure 32—Various sizes and blade types can be used in production today.

Figure 33—Machine used to assemble, true and inspect stick blade cutters.

Figure 34—CMMs inspect various parameters on a gear.

Figure 35—Close-up of a pinion being measured.

Figure 36—Direct-drive CNC test machine.

Conclusion

Gear cutting technology has advanced over the years with improvements in machinery, software, cutting tools and coatings. Today, one machine cutting gears or pinions without coolant using coated carbide tools can replace three to four machines cutting the same gear/pinion with conventional high-speed steel tools. What lies ahead is a continuation of the cycle—more innovations in the machines, new tool materials and even better tool coatings, resulting in the improved economy of gear production.

Appendices (Editor's note: The author has prepared five graphics with additional technical data, which can be accessed online at *www.geartechnology.com/issues/0707/appendices.htm*)
Appendix I
Automotive Gear Application
Appendix II
CMM Flank Form and Spacing Results for the Automotive Gear Application
Appendix III
Dinging Ball Results for the Automotive Gear Application
Appendix IV
Automotive Pinion Application
Appendix V
Jobbing Application for an Automotive

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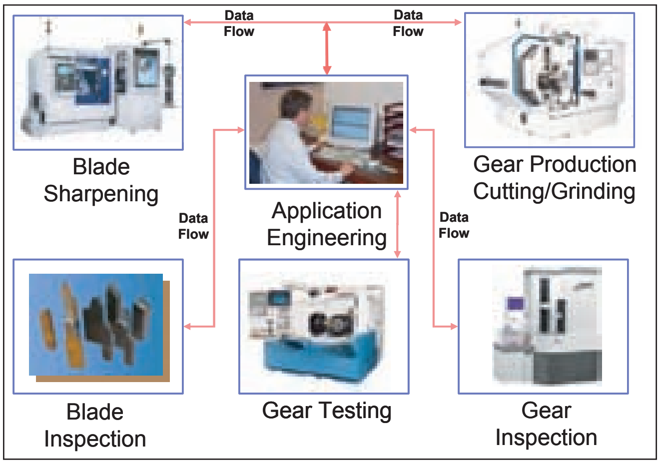

Figure 37—Network arrangement and data flow.

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Experience with Large, High-Speed Load Gears

Erwin Dehner and Francois Weber

Management Summary

The main theme of this article is high-capacity, high-speed load gears in a power transmission range between 35 MW and 100 MW for generators and turbo-compressors driven by gas or steam turbines. These gears run in continuous duty at tip speeds between 140 and 180 m/sec. A high level of operational safety and availability is expected from this type of gear.

Experience shows that, in addition to the design of the gear teeth, the gear manufacturer should pay considerable attention to the load conditions of the shaft.

This article demonstrates the importance of paying careful attention to power transmission elements with regard to computation, choice of materials, heat treatment, quality control and production.

Introduction—State of the Art

Large, high-speed load gears are predominantly manufactured with case-hardened, double helical teeth and supported by plain bearings in welded steel gear casings. Since gear widths can become very large at these power transmissions levels, double helical gears have come to predominate over single helical gears, because:

- The face width is divided into two tooth halves.
- No free axial forces result from the helix angle of the teeth.
- A considerably larger helix angle can be used (25–30° compared to 10–15°) to give a high face contact ratio and an improvement in acoustic behavior.
- Bearing forces are symmetrical with no tilting moment. (Single helical gearing has a tilting moment, which is the result of the helix-angle-produced thrust force acting at the pitch diameter.)
- No thrust bearing is required on the pinion and gear wheel—only a guide bearing is needed on the wheel set, and this can be located on the shaft with the lowest speed.

In terms of materials, the case hardening grade 18CrNiMo7–6 (former designation 17CrNiMo6) is almost universal. The wheel set is designed as a single piece due to the high tip speed of ≥ 150 m/sec., i.e., wheel and shaft are a single forging and as a matter of principle the pinion is cut from a single piece of material.

Shaft support takes the form of offset or tilting-pad bearings.

Failure Mechanisms

Typical failures on the gear wheel are tooth breakage and damage to the tooth flanks. Tooth breakages can be impact fractures or fatigue fractures. Tooth flank damage is a symptom of wear and can lead to fatigue fractures. The types of failure are shown in Figure 1.

Figure 1 includes erosion as a surface disturbance failure mode. Erosion is material removal associated with liquid impingement from oil jets in high-speed gearing. Erosion can be avoided by using special nozzles with a soft oil-jet flow to spray the gear mesh.

Since the subject transmissions have very high tip speeds, which promote the build-up of a good film of lubricant on the gear flanks, they are relatively insensitive to pitting and micro-pitting. Preconditions for the avoidance of these failure modes are, of course, the use of the correct lubricant and the surface condition (roughness) of the tooth flanks.

In the experience of the authors, in the subject transmissions, special attention must be paid to freedom from cracking (friction cracks) and adequate resistance to erosion and flank fractures.

The flank fracture is shown in Figure 2 as a micro section. It originates within the material, predominantly at non-metallic inclusions below the hardened layer and/or in the transition from the hardened exterior to the non-hardened parent metal. The path of the fracture is inclined at 45° to the flank with its point of emergence approximately at the pitch circle. Fractures principally occur in areas of high load concentration. Such areas can result in the shaft during operation under unfavorable stress conditions. Unfavorable stress conditions are thermal stresses in the rotor due, for example, to cold start-ups or uneven temperature distribution over the width of the teeth.

Ideas and Recommendations—Methods of Computation

As a matter of principle, the gear tooth design should be computed for:

- Tooth-bending strength.
- Surface durability (pitting).
- Scuffing.

Methods for calculation of the prevention of tooth bending and flank pressure are dealt with at length in AGMA 421.06, API 613 and ISO 13691. AGMA 421.06 was replaced by ANSI/AGMA 6011–G92, and this was again refined by ANSI/AGMA 6011–H98. As regards API 613, in this paper we address API 613 Fifth Edition 2003. Although it is an American national standard, it is applied worldwide. This is the case since there is no standard like DIN 3990 or ISO 6336 exclusively concerned with the computation of gear teeth, but also containing complete design instructions for the transmission, based on experience and failure statistics of machines operating in the field. Modeled closely on API 613 Fifth Edition, the ISO 13691 standard has emerged as an international standard.

For the design of gear teeth, ISO 6336 Parts 1–5 serve as a basis, whereby careful attention must be paid to the fact that transmission size is identical according to both API and ISO. In this way, the API Service Factor also corresponds to the Selection Factor of ISO 13691. In the meantime, since February 2003 there has existed API 613 Fifth Edition, which, conversely, has taken over various aspects from ISO 13691. It thus has a more international character but remains nonetheless a national norm. It is regrettable that both standards compete with each other instead of ISO and API working together to produce an international standard on the subject. The disadvantage of a national standard is that for different countries (i.e., outside the United States), various deviations have to be discussed and accepted during contract negotiations.

For the calculation of scuffing, there are the integral-temperature and the flash-temperature methods, which are dealt with in the Technical Reports ISO/TR 13989-2 and ISO/TR 13989-1. No particular procedure is favored, but the suggestion is to use the procedure with which the transmission builder is most experienced.

Tooth Corrections

To achieve the most even load distribution possible, corrections are necessary in the direction of tooth height and tooth width. In the direction of height, the correction on the tip of the tooth of the driving gear serves to attenuate meshing impact

In the lateral direction, the cor-

Tooth Breakage	General Mode	Specific Modes Flank Failure
Overload Breakage	**Impact Fracture**	
Fatigue Fracture	Surface Disturbances	**Scuffing** **Erosion** **Overheating** *Tempering, Hardness Loss* **Poor Contact Pattern**
	Scuffing	
	Surface Fatigue	**Pitting** **Micropitting** **Flake Pitting** **Spalling**
	Fissures and Cracks	**Grinding Cracks** **Fatigue Cracks** **Overload Cracks**

Figure 1—Failure mode classifications for gears according to ISO (10825).

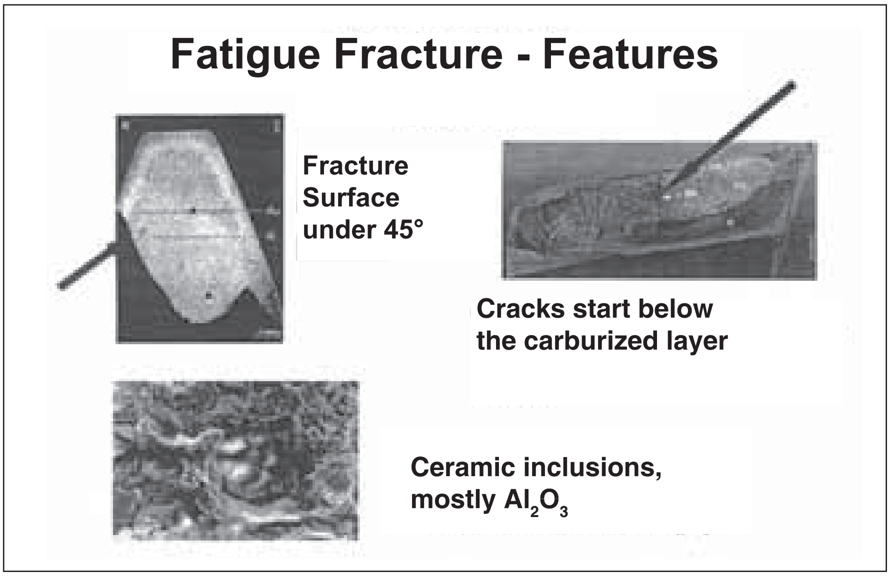

Figure 2—Typical interior fatigue fracture.

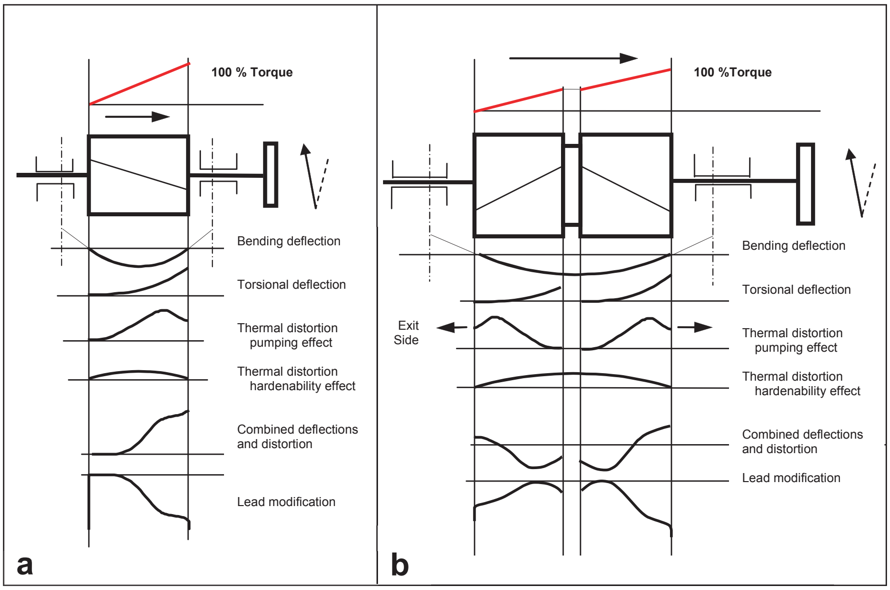

Figure 3a—Lead modification, single-helical gear. Figure 3b—Lead modification, double-helical gear.

Table 1—Mechanical Properties

Material Class	Rm MPa	Re MPa	A %	KCU (J/cm2)	K1C MPa $m^{1/2}$	ΔHRC	Tempering (°C)
18CrNiMo7-6	1400	1040	13	85	78	> 9	150 / 180
16NiCrMo13	1380	1100	13	90		< 9	150 / 180
20NiCrMo13	1490	1080	13	90	95	< 3	150 / 200
15NiMoCr10	1390	1110	13	85	95	< 3	230 / 280
31CrMoV9	1080	750	>12	KV=50	97	<3	>580
33CrMoV12-9	1250	1050	>16	110	108 / 120	< 3	≈ 600
32CrMoV5	1250	1150	>15	100	80 / 110		≈ 600

Rm : Tensile Strength
Re : Yield Strength at 0.2% Rp0.2
A : Elongation
KCU : Impact Energy
K1C : Toughness
ΔHRC : Hardenability based on Jominy Test, where ΔHRC = HRC (Value at 1.5 mm) – HRC (Value at 40 mm)

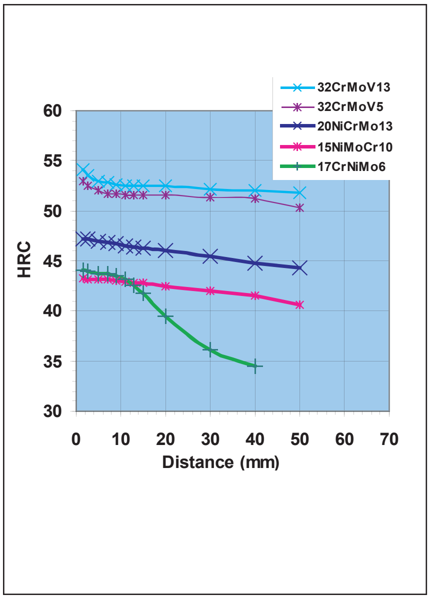

Figure 4a—Hardenability (Jominy test).

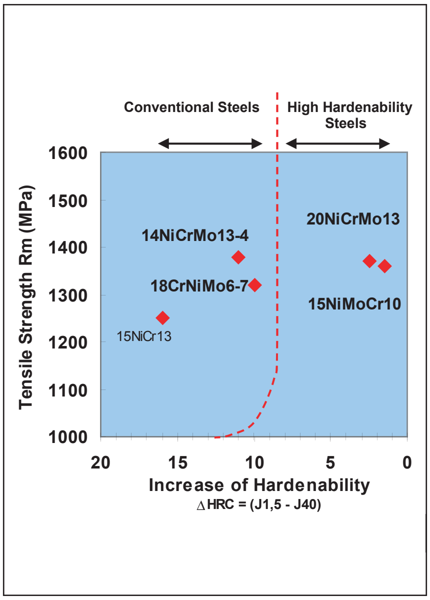

Figure 4b—Classification of carburizing steels.

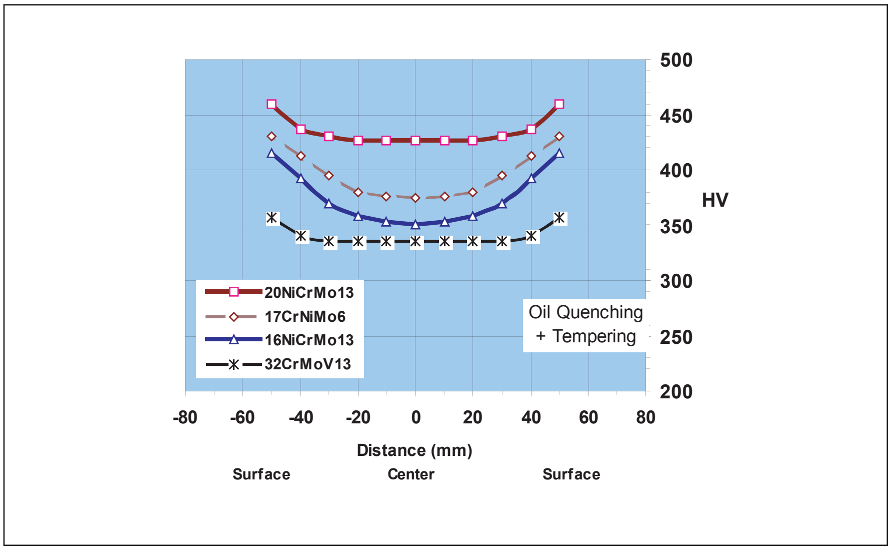

Figure 4c—Hardening intensity curves (100 mm diameter).

rection of angle takes account of the deflection and twisting of the rotor as well as the temperature distribution in the teeth over their width and the influence of residual stresses.

The qualitative types of longitudinal corrections are shown in Figures 3a and 3b.

(*Note: For steels of low hardenability ΔHRC > 8 (hardness difference between HRC40 and the maximum hardness HRC1.5), the thermal deformation which results from the relief of the residual stresses is to be taken into account. The better the hardenability, the flatter will be the hardness line of the Jominy curve and the lower ΔHRC (see Fig. 4a).*)

Materials

In addition to the standard materials for case hardening and nitriding, Tables 1 and 2 show alternatives that give improvements in fracture toughness and ductility. For case hardening these are the materials 20NiCrMo13, 15NiMoCr10 and AISI 9317, and for achieving greater nitrided depths during nitride hardening, the materials are 32CrMoV13 and 32CrMoV5.

These materials all have good hardening characteristics (ΔHRC). The flatter the hardness line of the Jominy curve and the smaller the ΔHRC, the greater is the hardenability (Fig 4a).

For case hardening (carburizing) steels with around the same Rm (tensile strength) of 1,300–1,400 MPa, those of low ΔHRC value should be favored, especially for solid parts (Fig. 4b).

To minimize internal stresses, complete through-hardening should be achieved. From the results of the Jominy test, predictions can be made regarding the progression of the hardness curve, i.e. the so-called "U-curve." (See Figure 4c, based on the example of a round bar of 100 mm.)

Heat Treatment

For high-performance gears, only carburizing or nitriding are considered. The most economic form of heat treatment is undoubtedly case hardening. It allows an almost unlimited range of adjustments to the desired hardness depth and in all standards has the highest values for long-term resistance to pitting and tooth flexure.

The advantages and disadvantages of hardening processes are compared in Table 3.

It can be seen from Table 2 that carburizing shows the highest admissible fatigue strength values, and therefore the components are smaller than with nitride hardening. A disadvantage, however, is the high risk of distortion of the components during quenching, which may result in unknown residual stresses.

Nitriding, on the other hand, is a low-distortion hardening method where the whole heat treatment process is made below the transformation temperature. It is unfavorable, however, that only small hardness penetration depths can be obtained, ranging from 0.5–0.6 mm with normal nitriding steels and up to approximately 1.4 mm with special steels. Moreover, it can be seen from Figure 5 that the hardness progression curve in the nitriding process drops very steeply towards the base material. It is therefore indispensable to determine the position of the maximum transverse strain, which is, according to the Hertzian stress theory, below the tooth surface.

In particular with nitriding, but also with carburizing, the transverse strain progression must be checked, and care must be taken that its maximum will be inside the hardened layer.

Figures 6 and 7 show test results of Hertzian stress on a wheel disc and a test gearbox dependent on the ratio

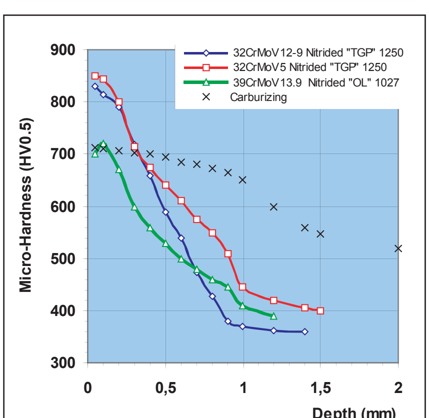

Figure 5—Hardness profile comparison, carburizing vs. nitriding.

Table 2—Composition or Typical Analysis (%)

Material Class	C	Ni	Cr	Mo	Mn	Si	Cu	V	Main Applications
CARBURIZING									
Cr basis—Hardenability ΔHRC >8/10									
18CrNiMo7-6	0.14/ 0.19	1.40/ 1.70	1.50/ 1.80	0.25/ 0.35	0.5 nom.	—	—	—	P < 50 MW
Ni basis—Hardenability ΔHRC > 8/10									
14NiCr14	0.12/ 0.17	3.25/ 3.75	0.60/ 0.95	0.15 max	0.40/ 0.70	0.35 max			
14NiCrMo13-4 16NCD13 (*)	0.11/ 0.17	3.00/ 3.50	0.80/ 1.10	0.10/ 0.25	0.30/ 0.60	0.40 max			
AISI 9310	0.13/ 0.18	3.00/ 3.50	1.00/ 1.40	0.08/ 0.15	0.45/ 0.65	—	—	—	USA—critical aerospace gear
Ni basis—High Hardenability ΔHRC < 8									
AISI 9317	0.15/ 0.20	3.00/ 3.50	1.00/ 1.40	0.08/ 0.15	0.45/ 0.65	0.20/ 0.35	—	—	USA—critical aerospace gear
Ni basis—High Hardenability ΔHRC < 2/3—High Toughness									
20NiCrMo13 20NCD13 (*)	0.18/ 0.22	3.00/ 3.50	0.80/ 1.20	0.30/ 0.50	0.30/ 0.60	0.15/ 0.40	—	—	P > 50 MW, Centerline Distance > 600–800 mm
High Tempering Temperature>250°C—High Hardenability ΔHRC < 2/3—High Toughness									
15NiMoCr10 (*)	0.15	2.50	1.00	2.00	—	1.00	—	0.28	P > 50 MW, Centerline Distance > 600–800 mm Mechanical Drive
17NiMoCr9	0.14/ 0.19	2.00/ 2.50	0.55/ 0.70	0.65/ 0.85	—	?	—	?	
NITRIDING									
2.5% Cr basis—Very High Hardenability ΔHRC < 2/3—High Toughness									
31CrMoV9	0.28/ 0.34	—	2.30/ 2.70	0.15/ 0.25	0.40/ 0.70	—	—	0.10/ 0.20	P < 40 MW
33CrMoV12-9 32CDV13 (*)(**)	0.29/ 0.35	—	2.80/ 3.20	0.80/ 1.20	< 0.60	< 0.35	— —	0.25/ 0.35	P > 30 MW PowerGen + Mechanical Drive
CrMo basis—Very High Hardenability ΔHRC < 2/3									
32CrMoV5 (*)	0.32	—	1.40	1.20	—	—	—	0.30	Deep nitriding
(*) Aubert et Duval and (**)Normes Françaises AMS6481									

Table 3—Carburizing vs. Nitriding		
Characteristic	Carburizing	Nitriding
Hardening temperature	In the transformation zone > 900°C	Below the transformation zone at 500–550°C
Depth of hardening	Optimally adjustable for every application caser, 0.3–8mm	Normally 0.5–0.6 mm, 1.0–1.4 mm attainable with special steels
Modulus value	3.0–30	1.5–15
Surface hardness *HV*	600–800	650–900
Max. tempering temperature °C	18CrNiMo7-6—170–180 20NiCrMo13—180–200 15NiMoCr10— <280	≈ 600
Core strength *HRC*	25–30, depending on the material	35–40
Fracture toughness MPa m1/2	18CrNiMo7-6—ca. 75 20NiCrMo13—ca. 95 15NiMoCr10—ca. 95	32CrMoV13—ca. 105–110 32CrMoV5—ca.105–110
Hardenability (Jominy test) ($\Delta HRC=HRC1.5–HRC40$)	18CrNiMo7-6—ca 8–10 20NiCrMo13—ca. 2–3 15NiMoCr10—ca. 2	32CrMoV12-9—ca. 2 32CrMoV5—ca. 2
Sensitivity to oil contamination Debris of 280 µm / σH = 2,500 MPa	Spalling	No Spalling
Allowable bending stress numbers according to DIN 6336-5 (MPa)	Grade MQ—450 Grade ME—520	Grade MQ—420 Grade ME—470
Allowable contact stress numbers according to DIN 6336-5 (MPa)	Grade MQ—1500 Grade ME—1650	Grade MQ—1250 Grade ME—1450
Scuffing Resistance—X_w according to ANSI/AGMA 2101-C95	1.0	1.5
Strength Life-time factor Y_{NT} Bending at endurance strength	2.5	1.6
Durability Life-time factor Z_{NT} Flank at endurance strength	1.6	1.3

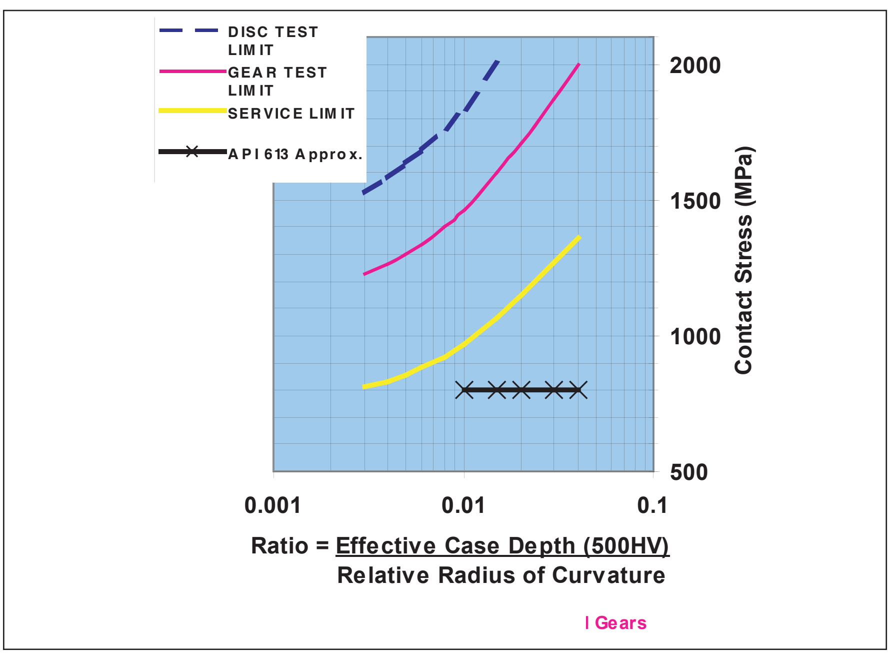

Figure 6—Service experience with nitrided gears, showing allowable Hertzian stress dependent upon case depth relative to shaft size.

of the effective hardness penetration depth to the equivalent radius of curvature in the pitch point. In addition, the calculated limiting curves of ISO 6336-5 and API 613 are shown. These tests and experimental values show that the Hertzian stress is a variable which depends on the gearbox size. Figure 7 shows typical speeds and power ranges for nitrided gears?

Nitrided surfaces are harder and show more brittleness in case of shock strains than carburized ones. Also, the damage curve in the fatigue strength for finite life in nitrided gears is very flat in comparison to carburized ones. This factor influences the rating of gears for starting, shock and short-circuit torques. (See Table 3 for factors Z_{NT} and Y_{NT}). The fatigue strength values in regard to quality MQ and ME, however, do not much differ from carburizing. The recalculation of a 75 MW gas turbine gearbox shows that in high-performance gearboxes, the residual stresses have much influence on total strain. Mainly in the case of carburizing, the residual stresses can be different. It is the main advantage of nitriding that the inner residual stresses are very low.

Rating of Shafts

Experience shows that for gear units with wheels of high volume concentration, an inspection for mechanical fracture properties is indispensable, besides the usual strength hypotheses.

Shaft Designs

There are various shaft design concepts, which have influences for the rotor vibration and the quality of the gear. The most used designs are:

- Shrink-fit design.
- Pinion and wheel in one-piece design

Shrink-Fit Design. The shrink-fit design is the most used shaft/hub connection, as the optimal material can be chosen for shaft and wheel. The shaft is transmitting the torque. Therefore a through-hardened steel with the appropriate strength properties will be used.

The usual materials are 42CrMoV4 and for elevated requirements 26NiCrMoV14-5, 30CrNiMo8, or

35NiCrMo16.

The gearing is hardened, i.e. carburized or nitrided steel.

The most used wheel materials (Table 1) for carburizing are 18CrNiMo7-6, 20NiCrMo13 or 15NiMoCr10. The most used materials for nitriding are 31CrMoV9 and 32CrMoV12-9, 32CrMoV5 or 39CrMoV13-9 for extended nitriding depths.

However, the shrink-fit design is limited by the influence of centrifugal forces, and API 613 as well as ISO 13691 do not accept the shrink-fit design for pitch-line velocities over 150 m/sec. In those cases, the one-piece version must be applied. It should be mentioned here that pinions are always made from one piece.

Wheel and Shaft in One Piece. In gear units with transmission powers of 70 MW and more, the one-piece design requires a forging with much weight and much volume concentration, especially in the gearing base area. It is important that such forgings, including pre-turning and ultrasonic testing, are ordered directly from the steel manufacturer.

A specification must be prepared in common, determining all the manufacturing process steps like melting, analysis, ingot size, forging ratio, heat treatment, purity regarding oxides and sulfides, mechanical properties as well as test conditions and acceptance criteria.

Figure 8 shows how the forging should be configured in the gearing area in order to be sure that any flaws or gas bubbles due to blowholes do not exist.

The wheel shaft can be a solid-shaft or hollow-shaft design; due to better hardenability, the hollow-shaft design is preferred. The explanations below show the differences of the two designs with regard to strength behavior.

Solid Shaft. In the solid shaft, stresses are lower, as can be seen from Mohr's circle. Figure 9 shows the stress comparison between solid and hollow shafts, under centrifugal force, of a 75 MW gas turbine gearbox. Figures 10

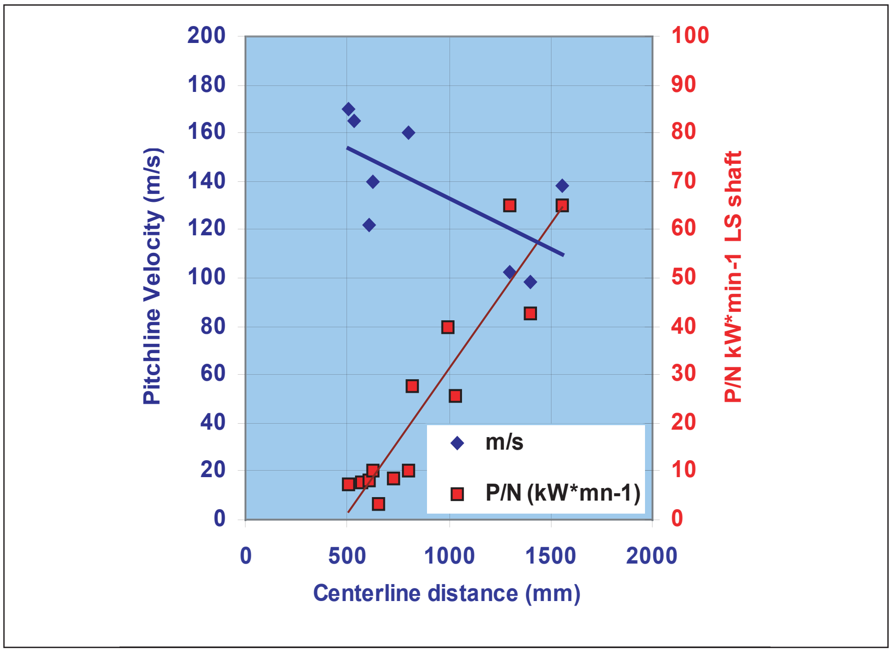

Figure 7—Service experience with nitrided gears, showing speed and power ranges.

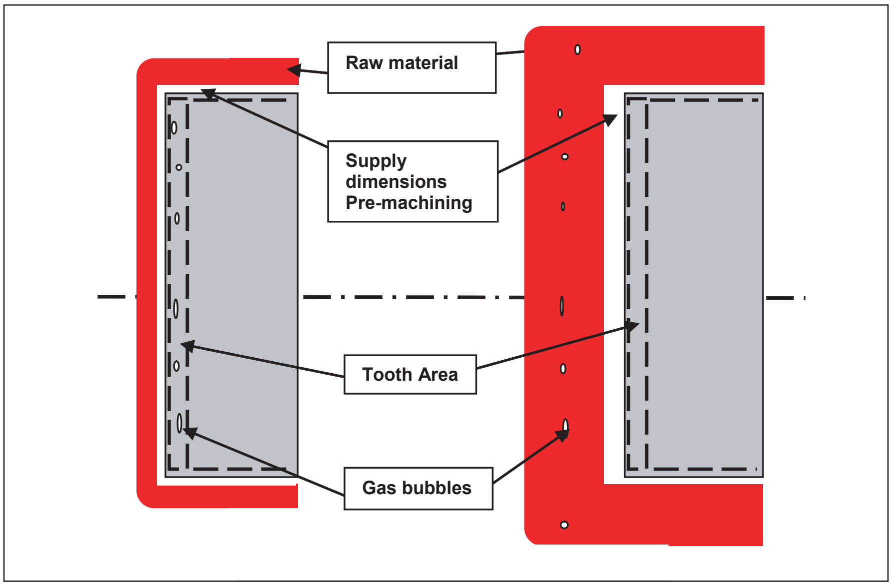

Figure 8—Design of gear forging.

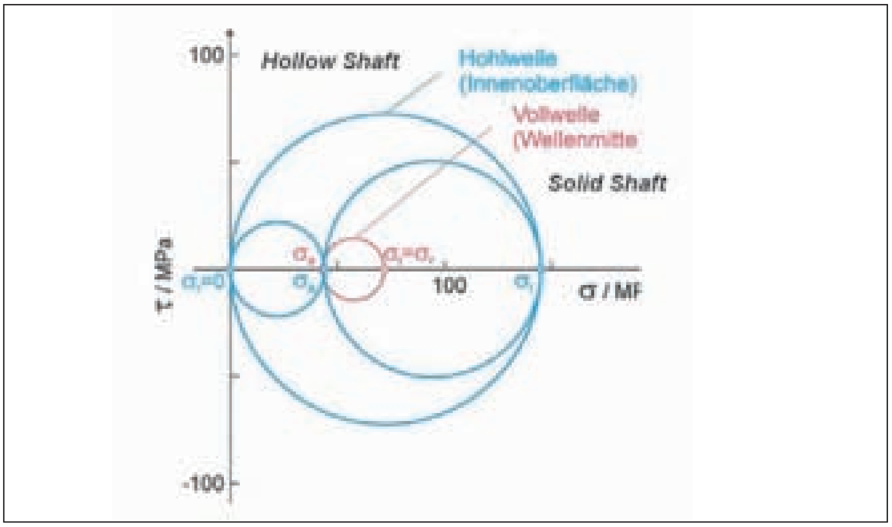

Figure 9—Stress curves according to Mohr for a solid-shaft and a hollow-shaft gearbox.

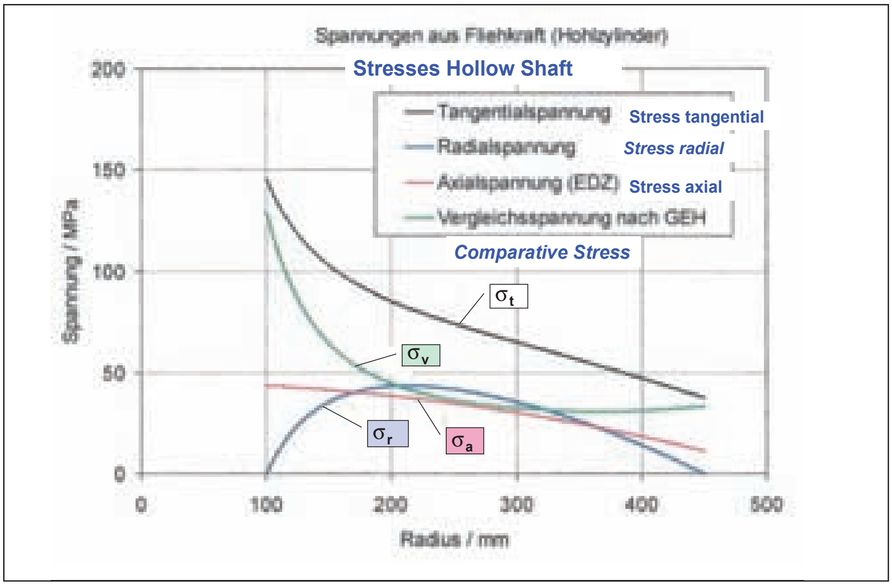

Figure 10—Progression of stresses for a hollow shaft under centrifugal force.

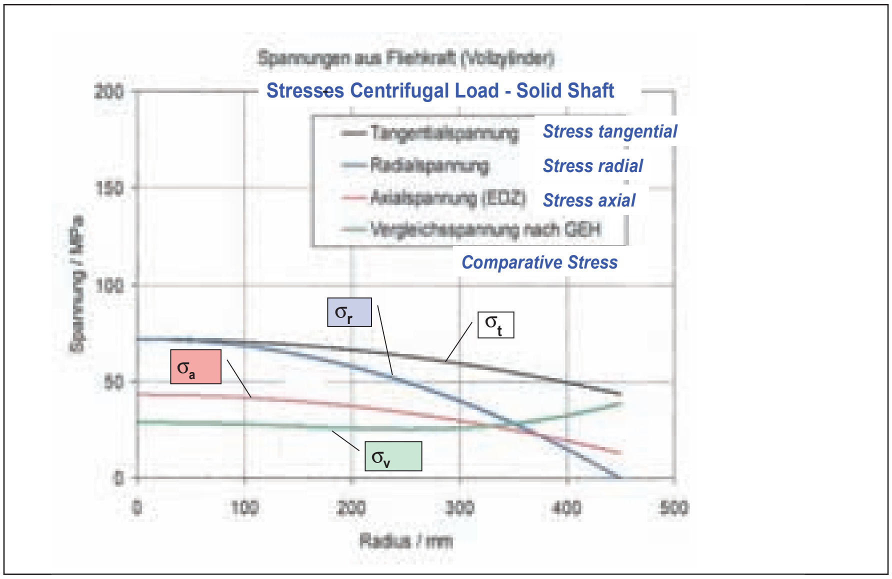

Figure 11—Progression of stresses for a solid shaft under centrifugal force.

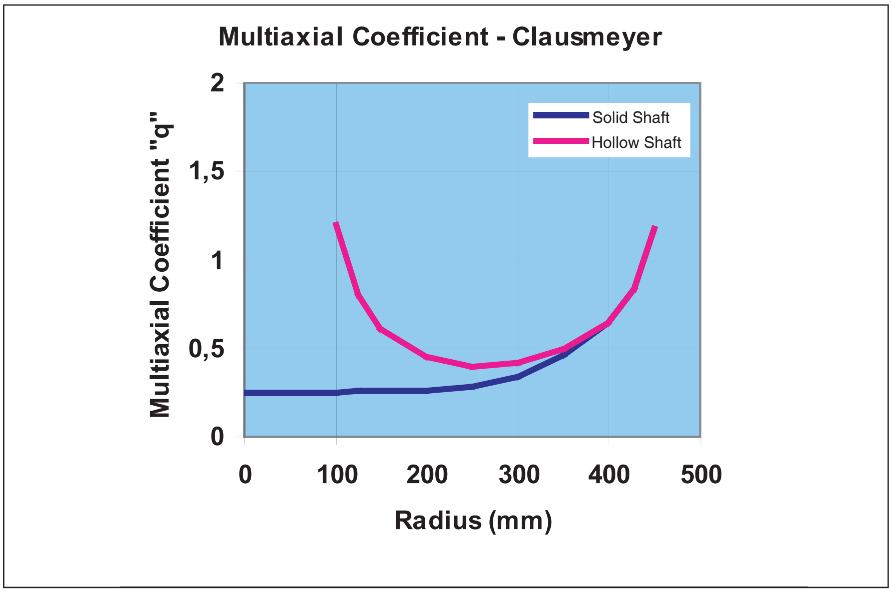

Figure 12—Multiaxial quotient *q* according to Clausmeyer.

and 11 show the progression of the individual stresses. To be added are the residual stresses due to heat treatment and thermal stresses due to temperature gradients in the wheel body.

A disadvantage when using solid shafts is the risk of non-metallic inclusions in the core as well as—in the hardening process—the risk of ferrite contents in the structure of the core area (insufficient core hardening) and thus insufficient strength.

Hollow Shaft. (See also API 613, 5th Edition, 2.5.3.3.) Here the stresses are higher, as can be seen from Mohr's circle (Fig. 9), but due to the internal bore, the core problems of the solid shaft are eliminated.

Figure 10 shows the progression of the individual stresses, and Figure 12 shows that also with the multiaxial quotient *q* according to Clausmeyer, the hollow shaft is less favorable than the solid shaft.

To be added for both shaft designs are the residual stresses after carburizing and thermal stresses due to the temperature gradient in the wheel.

In the solid shaft, these are residual tensile stresses, while in the hollow shaft a shifting to the desired pressure area takes place in the bore surface.

Calculation Methods. In this section, the calculation of a shrink fit is left out and assumed to be known.

In particular, gears are concerned in which gearing and shaft are a unit, which means that both parts are made of the same material and remain always together during heat treatment.

The dimensioning of the shaft is made preferably according to the transverse strain hypothesis for bending and torsion:

$$\sigma_v = \sqrt{\sigma_x^2 + 4_\tau^2} < \sigma_{zul}$$

where

σ_v comparative stress (N/mm²)

σ_x bending stress in x-direction (N/mm²)

τ transverse stress (N/mm²)

σ_{zul} yield strength (N/mm²)

The yield strength is applied as admissible stress for failure due to plastic deformation.

Because of possible internal defects in those large forgings, a mechanical fracture assessment must be made.

The following calculation example applies to the bull gear of a gas turbine gearbox with a transmission power of 75 MW and a speed of 3,000 rpm (generator speed).

Total stress of solid shaft

	σ_C	72.8 N/mm²
+	$\sigma_{residual}$	350 N/mm²
+	$\sigma_{thermal}$	156 N/mm²
=	σ_{total}	578.8 N/mm²

where:

σ_C Centrifugal force stress (solid shaft)

$\sigma_{residual}$ Residual tensile stress (assumed)

$\sigma_{thermal}$ Operating thermal stress ($\Delta T = 135°C$)

σ_{total} Total stress

This total stress must be subjected to a mechanical fracture assessment. In Equation 1, the admissible stress is determined by means of the fracture toughness of the material and a specified maximum defect size, and it is compared with the existing total stress.

$$S = K_{IC} / K_I > S_{min}, \quad S_{min} = 1.5$$

$$\sigma_{zul} = K_I / \sqrt{\pi * a / Q} \quad (1)$$

where:

K_I Stress intensity in the component

K_{IC} Fracture toughness N/mm$^{3/2}$ (characteristic value of material)

Q Crack shape factor

S Actual safety factor

S_{min} Minimum required safety factor

a Minor radius of the elliptical failure (defect)

The crack shape factor Q is determined by:

$$Q = 1 + 1.464 * (a/c)^{1.65} - 0.212 * (\sigma / R_p)^2 \quad (2)$$

where:

σ / R_p Efort relation (for conservative assessments, a value of 0.9 is used)

a Minor radius of the elliptical failure (defect)

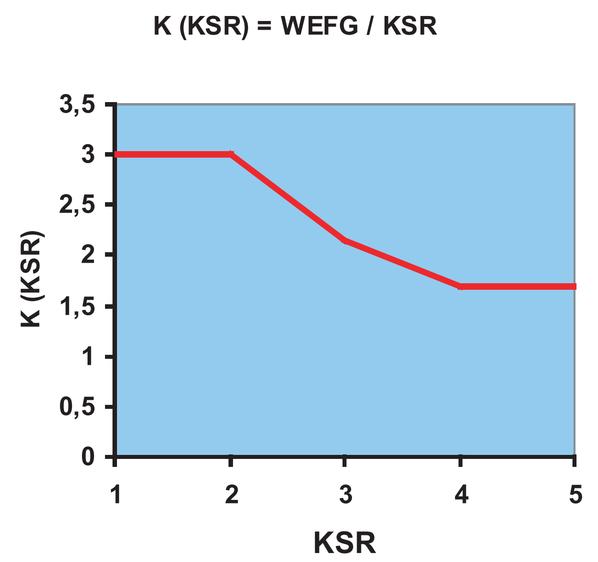

Figure 13—Relationship of actual defect size (WEFG) to KSR (CRR).

c Major radius of the elliptical failure (defect)

The Wahre Ersatzfehlergröße (*WEFG*) represents the diameter of a theoretical circle with the same area as the ellipse of the defect. Translated, *WEFG* stands for "True Equivalent Defect Size," and it is derived according to Equation 3:

$$WEFG = 2 * \sqrt{\pi * c} = 2 * a / \sqrt{a/c} \quad (3)$$

WEFG, i.e., the actual defect size (represented by a circle of equal area) has been determined by the evaluation of many tests, in dependence on the *KSR* value, by the relation (Fig. 13):

$$WEFG = k(KSR) * KSR$$
$$k(KSR) = 3 \text{ for } KSR < 1.5$$
$$= 3.78 - 0.52 * KSR \text{ for } 1.5 < KSR < 4$$
$$= 1.7 \text{ for } KSR > 4 \quad (4)$$

For the above-mentioned shaft of 18CrNiMo7-6 and a *KSR* value of 3 as well as with elliptical defect shape ($a/c = 0.4$), the Equations 1, 2, 3 and 4 result in the below-mentioned admissible stress values.

For example, a lower value of K_{IC} (for example, 2,000 N/mm$^{3/2}$) for 18CrNiMo7-6 and a *KSR* of 3 result in σ_{zul} = 556.1 N/mm². An upper value of K_{IC} (for example, 2,200 N/mm$^{3/2}$) results in σ_{zul} = 611.7 N/mm².

The value of actual strain is in between, at 578.8 N/mm². It follows that the material 18CrNiMo7-6 for one-piece gears with much volume concentration is within the limit range.

Summary and Recommendations

When looking at the Jominy curves in Figures 4a, 4b and 4c, it can be seen that—with regard to hardenability—there are still other alternatives to 18CrNiMo7-6 which provide higher mechanical material parameters.

For further increased operational safety, nitride hardening can be considered. It offers the advantage that the whole heat treatment process is made below the transformation line, which means no risk of distortion and no risk of high residual stress.

To sum up, one can say that the mastery of such gears requires the following conditions:

- Material with fracture toughness $K_{IC} \geq 80$ Mpa$^{1/2}$.
- Yield strength $Re > 750$ MPa.
- Sufficient ductility.
- Structure hardenable to the core.
- Proof of sufficient potential hardness increase adapted to U curve (Intensity of potential hardness increase).
- Low distortion during hardening process.
- Reduction of residual stresses by subsequent machining, e.g., excavation.

- Selection of a low-distortion hardening method such as gas nitriding.
- Use of special steels for increased hardness penetration depth when nitriding.
- Requirement: Steel production and forging of the ingot to be in the same factory.
- Material Quality: MQ or better ME.
- Melting: Vacuum degassed or remelting according to ESU.
- Cleanliness: P_{max} 0.007, S_{max} 0.007, K4 = 20 (Oxide + Sulfide).
- Forging ratio: ≥3.5.
- Grain size: Fine grain, predominantly 5 and finer.
- Heat treatment: Hardening and Tempering.
- Non-destructive testing (see Fig. 14)*: Rough machined and finished, followed by ultrasonic inspection test to enhanced SEP 1923 or ÖNORM 3002–class 2–group B7 surface crack test.
- Test mechanical properties :
  - o Optimizing notch value and dilation.
  - o Optimizing Jominy-Curve for high alloy steel—restricted hardenability band (H).
  - o $\Delta HRC = HRC1.5 - HRC40 <$ 2–3 max.

Fig. 14 shows that the check of the shaft core for inclusions and cracks can be detected only by using special sensors for different sound-angles. An ultrasonic inspection test of radial and axial angles with 0° is not sufficient.

From these requirements, the authors give some advice for the material selection as well as for the hardening method, shown in Figure 15 and Tables 4–7. Such advice only presents ideas for the design of high-energy gear boxes which are based on many years of experience.

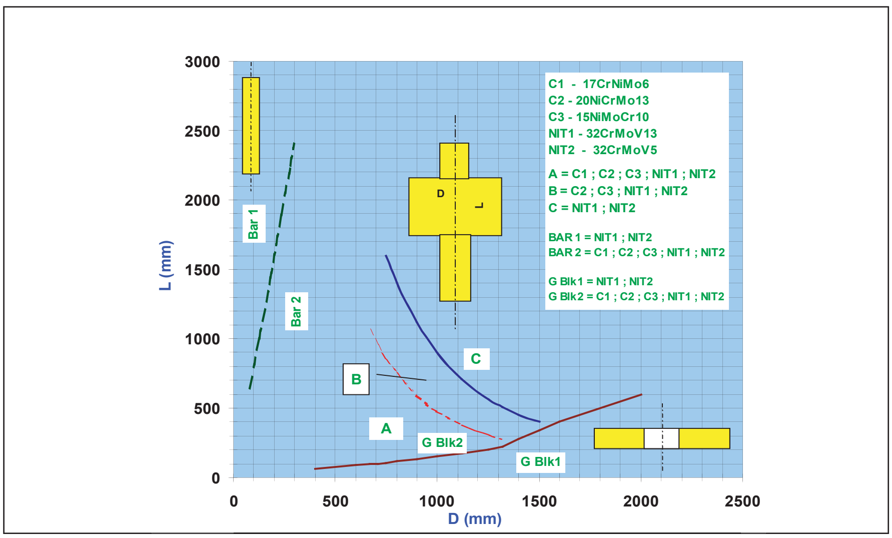

Figure 15—Heat treating recommendations for blank, pinion, gear and integrally forged gear elements.

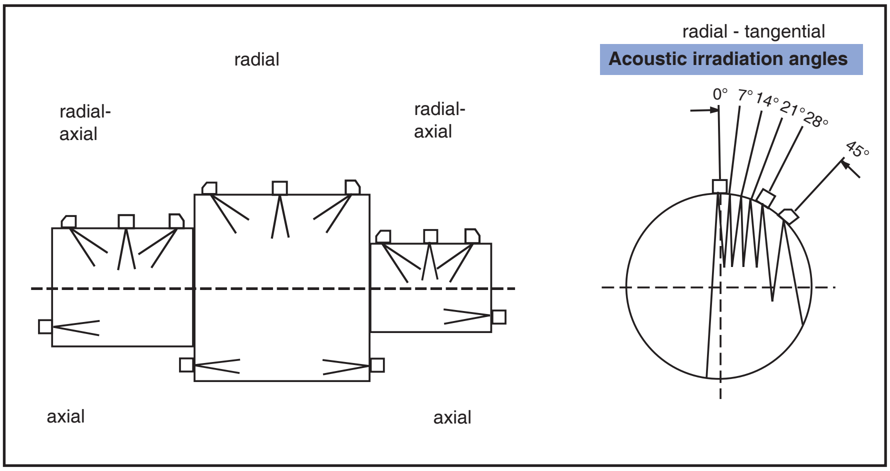

Figure 14—Ultrasonic inspection of integrally forged gear element.

Standards:

AGMA 421-06, AGMA Standard Practice for High Speed Helical & Herringbone Gear Units, January, 1969.

AGMA 2101, Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth.

AGMA 6011, Specification for High Speed Helical Gear Units.

API 613, Special Purpose Gear Units for Petroleum, Chemical and Gas Industry Service, Fifth Edition, June 2003.

ISO 13691, Petroleum and natural gas Industries—High-speed special purpose gear units, First Edition, 2001-12-15.

ISO/TR 13989–1, Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears, Part 1: Flash temperature method.

ISO/TR 13989–2, Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears, Part 2: Integral temperature method.

ISO 6336–5, Calculation of load capacity of spur and helical gears, Part 5: Strength and quality of materials.

ISO 1328–1, Cylindrical gears—ISO systems of accuracy—Part 1: Definitions and allowable values of deviations relevant to corresponding flanks of gear teeth, 1995.

SEP 1923, Ultrasonic testing of forgings for higher requirements, in particular for turbines and generators.

ÖNORM 3002, Ultrasonic testing of steel forgings—Performance inspection coverage, quality level.

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Table 4—HEC (High Energy Criterion) value.

HEC (J/cm²) = 0.25*M*V² / D*L

M : Mass (kg) D : Pitch diameter (m) V : Pitchline velocity (m/sec) L : Total width plus gap at double helical

MATERIAL CLASS	HEC	Fracture Toughness K_{IC} MPa*m$^{1/2}$
18CrNiMo7-6	< 2,600	78
20NiCrMo13 **15NiMoCr10**	2,600–3,700	95
32CrMoV12-9 **32CrMoV5**	> 3,700	108 / 120

Table 5—Bulk operating temperature recommendations.

Toothing Operating Temperature @ Material Tempering Temp.

$$\theta_{MESH\ OIL\ SIDE\ EJECTION} \approx 0.4\, v_t + \theta_{OIL\ INLET}\ (°C)$$

$$\theta_{BULK} \approx 1.72\, \theta_{MESH\ OIL\ SIDE\ EJECTION} * A * B$$

σH	A	m_n	B
550	0.92	6	0.73
575	0.96	8	0.87
600	1.00	10	1.00
625	1.04	12	1.13
650	1.08	14	1.27

for single helical
L or F_W : < 600 mm β = 7–15°

for double helical
L or F_W : < 2 x 550 mm β = 25–30°

v_t = 100 to 200m/s u=1.5 to 2.5 Oil ISO VG32 for α_n=20°

MATERIAL CLASS	$\theta_{Tempering}$ (°C)	$\theta_{Tooth\ Operating}$ (°C) *Bulk Temperature*
18CrNiMo7-6	150 / 180	< 180
20NiCrMo13	180 / 200	< 200
15NiMoCr10	240 / 260	< 260
32CrMoV12-9 **32CrMoV5**	> 600	< 300

Table 6—Forging, material class recommendations (Use with Figure 14).

	SHAFT/BLANK CONSTRUCTION							
	Pinion		Gear					
MATERIAL CLASS	Bar or Forging		Forging	Solid on shaft pinion or gear blank				
	BAR 1 L/D>8	BAR 2 L/D<8	GBLK 1 D/L>7	GBLK 2 D/L<7	A	B	C	
18CrNiMo6-7			Yes		Yes	Yes		
20NiCrMo13			Yes		Yes	Yes	Yes	
15NiMoCr10			Yes		Yes	Yes	Yes	
32CrMoV12-9	Yes		Yes	Yes	Yes	Yes	Yes	Yes
32CrMoV5	Yes		Yes	Yes	Yes	Yes	Yes	Yes

: Hardenability (Residual stresses)

Table 7—Power, pitchline velocity recommendations.			
MATERIAL CLASS	RATINGS		APPLICATIONS
	POWER	PLV	
	MW	M/s	
18CrNiMo6-7	35 / 50	< 130	Conventional Turbogears
20NiCrMo13	40 / 100	< 160	High hardenability, high core hardness and high fatigue strength, ideally suited for critical High Energy Turbogears.
15NiMoCr10	40 / 100	< 180	Combination of high-temperature performance, deep hardenability, good core properties and high fatigue resistance, ideally suited for very critical High Energy Turbogears.
32CrMoV12-9	> 30	> 180	Combination of high-temperature performance, high strength, high toughness and fatigue resistance of the core. Furthermore very deep cases with high compressive residual stresses. Suited for High Energy Turbogears with severe loading in terms of service temperature or lubrication.
32CrMoV5	> 30	> 180	Similar to 32CrMoV13 with reduction of the duration and the cost of nitriding.

Erwin Dehner *is the former managing director of BHS Cincinnati, where he was employed for more than 30 years. He also spent 30 years as a member of the advisory group of the FVA (union for research and gear development within the VDMA). He served as convenor of the ISO working group WG11 "High-Speed Enclosed Gear Drives" from 1993–2001. That group's work resulted in the ISO standard 13691. Dehner also served from 1995–2001 as a discussion leader at the Turbomachinery symposium held each year in Houston. He has written for numerous publications about ships, turbogears and bearings, mainly in German. Although retired since 2001, he has since then served as a consultant and as an instructor in a seminar for epicyclic gears at the Technische Akadamie Esslingen.*

François Weber *is a former member of the board of management of Flender-Graffenstaden, where he worked for 40 years. Prior to serving on the board, he was managing director for sales and design. He has served for 20 years as a member in the advisory group "Gear Development" of UNITRAM (the Association of French Manufacturers of Mechanical Power Transmissions), and he has also served on committees and working groups of national and international standards bodies. He has written for numerous publications about design, material selection and best practices for turbo-load gears and steam turbines. Since retiring in 1999, he has worked as a consultant on turbogear problems.*

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SURE, YOUR QUALITY IS TIER 1.

But How's Your Lead Time?

Jack McGuinn, Senior Editor

A picture is worth 1,000 words. A "before-and-after" photo clearly demonstrating the effective result of 5S / Lean changes to Precipart's shipping department processes.

The gear companies enjoying the most success in today's global market are those that firmly believe quality is much more than expert craftsmanship and foolproof inspection methodologies. For them, success is defined—indeed, dictated—by how well they supply their customers with a total quality experience. From the initial design stage and production to on-time delivery to the customer's doorstep, all are elements of one interdependent, continuous improvement universe—quality.

Think of it in terms of holistic health care, where doctors devote care and attention not only to patients' symptoms, but also to their entire well-being. So too with today's gear industry, which is working literally night and day in the development of total quality systems that ensure all of a customer's expectations are met. Got price? Sure. Top quality? You bet. Good lead times? Uh, let's talk. If you are a gear maker and still in the "let's talk" category, your Achilles heel is showing. Your production team can make the finest-precisioned gears that money can buy, but if, say, the packing and shipping departments drop the ball one too many times, it can be the poison that infects a customer's confidence and good will. In today's omnipresent, extraordinarily competitive global economy, every single department involved in the sale, production and delivery of a part must take ownership of its quality-driven responsibilities.

Quality Mixology.What does it take to get there? Essentially, a quality cocktail whose main ingredients are typically ISO certification (all four companies included in this article are ISO-certified), Lean, Six Sigma, 5S (from the Japanese), etc., either in their totality or in some combination from that list. And with that, also needed is the development of unquestioned metrics and benchmarks that clearly demonstrate where you are, and where you need to be.

Wes Prosser is quality manager at Boston Gear Company's Charlotte, NC production facility. He believes the trifecta of Lean, Six Sigma and ISO certification is an effective combination that helps remove product flow bottlenecks while simultaneously enhancing Boston Gear's continuous improvement efforts.

"I just went to a really interesting ASQ (American Society for Quality) meeting where they talked about how you have to have (Lean and Six Sigma) to be effective," he says. "You need the Six Sigma to eliminate variations, get your processes under control, including continuous improvement. You also have to have the Lean program to eliminate waste and remove obstacles from process flow. Otherwise you've got a quality product that you can't push along to other departments or you're pushing along bad product. It takes Lean and Six Sigma to flow good product."

ISO is also key to the mix. Often mistaken for a quality assurance program, it is really a management system. But that system, and its collection of priceless data in a central repository, is often what is needed to impose order over chaos. And yet, ISO alone is not enough, according to Prosser.

"ISO helps make in-house process owners more responsible, and it supplies them with a resource to help them do that. (But) if, as a quality department, you're only doing (ISO), then you're working for the system instead of the system working for you."

Daniel Rudolf, director of continuous improvement for Swiss-based Precipart Corp.'s Farmingdale, NY facility, also believes ISO to be quite useful. But he, too, believes it is perhaps only a half-step towards achieving optimal productivity and quality. He also finds it too forgiving and a bit old-school.

"(ISO) does make you collect the data, but it really doesn't do anything with it," he says. "ISO takes you only as far as you really want to do it. If you want to satisfy your (ISO) registrar, it's not always that difficult. It is a very, very good system and a very good tool, but if you want to go beyond that and want to be in the 21st century, then that alone isn't going to do it." And so the fact that Precipart and Rudolf are true believers in Lean, Six Sigma, etc., comes as no surprise. Failure mode and effect analysis (FMEA) is also a big part of Precipart's quality system. It helps Rudolf determine whether established metrics and benchmarks are being met and exceeded.

"In order to verify, we really need to conduct FMEAs. But since we have a very diverse customer base, it's very difficult for us to do parts FMEAs. So we came up with a process FMEA. We identify nine steps and we do FMEAs with four teams going at once, and when one is complete, we add another (analysis), and this is a two-and-a-half-year program for us."

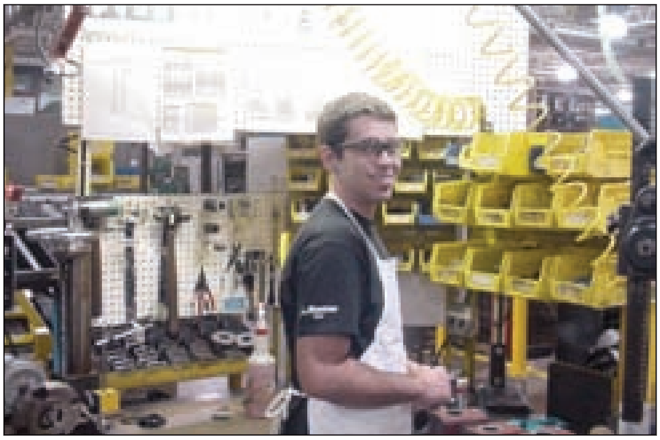
How individual gear companies approach Lean practices is a matter of company culture. Some are eager to talk about their Lean implementation while others play down the formal Lean principles, but practice them all the same.

South Bend, IN-based Schafer Gear Works is a good example of a company that doesn't talk the Lean talk, but practices it all the same.

"We've dabbled in Lean concepts but we're not totally

continued

Boston Gear's Carl Teague III at his gear-cutting machine.



Boston Gear's Jerry Leadbetter at his speed reducer assembly station. Note the Lean-inspired shadow board in the background with job-specific tools in perfect order. Note, too, the trays in the foreground containing job-relevant parts, another Lean principle.

embedded with Lean," says Doug Fozo, Schafer Gear's quality manager. "Lean isn't something where you just say, 'We're all Lean.' Lean is perpetual, always changing, so we're always trying to change with it. But we use a lot of Lean concepts; we're going more and more towards smaller batches, less inventory, etc."

Whatever a company's approach, and whatever they call it, company-wide continuous improvement is the bottom line.

"It's survival in the business world, in my opinion," says Fozo. "You've got to continue to satisfy your customers, and to satisfy your customers you've got to have the systems in place to do it and improve it. You've got to have the systems in place to be checking and verifying your parts throughout the process, and ensure before they go out the door that they meet the customer's requirements."

Gear companies attempting to hit the always-moving-target that is customer expectations are implementing other measures as well. At Boston Gear, Prosser points to robust, in-house, twice-weekly audits of its 43 machining cells. The auditors' 10-point inspection documents print specs, bore size, gage calibration, routing and print revisions, and more, including proper finished part storage.

"I think it's important that whenever you do auditing that you stay as close to the process as possible," says Prosser. "I feel this is a very, very important audit that we do. We used to audit more after a finished operation, but of course then it is too late to do anything about it."

Added to that is yet another pre-emptive quality check, recently implemented at Boston Gear.

"We've gotten a fair amount of internal auditors certified now," says Prosser. "So we're taking a step up from that and starting an ISO coordinators program. We take a member from each department and make them ISO coordinators, and some of the things they'll be involved in are internal and external (ISO) audits. They'll look at their documents and records to ensure that they're being reviewed and are up to date."

Quality plastic is not an oxymoron. If all of the above seems challenging, the same applies for injection molded, plastic gear manufacturers. Rod Kleiss, president of Kleiss Gears in Grantsburg, WI, explains how making molded gears is similar yet different from metal gear manufacture.

"In plastics, we have another huge step or hurdle before getting to final product," says Kleiss. "We make a cavity, and we make it with all of the accuracy and precision that a person would make the metal gear with, but that will not be the shape of our final gear. Our final gear will shrink away from that—change, distort—and what we're after is a big step away from there. Somehow we have to target a shape and make another shape that's different in order to get what we want."

Rod Kleiss, hands-on owner and operator of Kleiss Gears.

Kleiss, too, is a Lean practitioner, especially regarding labor costs and human error.

"Lean to my mind implies automation, and I can't afford to have a person go in and do a job that can be done by a machine. Primarily because the machine is going to do it more repeatedly and more accurately than a person. And if you have things set up so that a machine can always do it, that means you must have a pretty stable process. And so whenever I see someone opening a door to a molding machine or doing some manual operation, I know we have an issue that has to be dealt with. Repetitive work deadens the mind, dulls the senses, and you're going to see more errors. And the fact that they're doing the work is going to cause more errors."

The clean-as-a-whistle shop floor at Kleiss Gears.

Another challenge for molded gear makers is longer lead times specific to injection molding, necessitated by the often complex development of precision molds. Given the prevailing "I-want-it-yesterday" mindset of today's customer, that's

continued

a problem with no magic bullet fix.

"The customer is always looking for proper fit and function of the final product," says Kleiss. "Quite often they don't know what they must have in (plastic) gears to achieve those goals. Additionally, there isn't a lot of history for plastic molded gears concerning questions of noise, wear, or load. Even materials are poorly researched for gear applications, or at least poorly reported in the industry. To a large extent, the customer must rely on the molder to answer gear design, material, and inspection questions correctly."

Schafer Gear's training room, with wall-mounted instructional panels. In-house, on-the-job training is a necessity for today's gear manufacturers.

Precipart's QC inspector Mihai Burucea (foreground) working at a digital height-gaging machine, while Ken Gentry monitors a CMM machine.

Jose Talavera (foreground), gear manager, and operator Julio Reyes in Precipart's gear department.

As for lead times, says Kleiss, "Delivery is a tough nut to crack. We are also challenged to provide even quicker prototypes. We have tried SLA (stereolithography) with some success for some applications." Kleiss mentions other things the company is doing to speed along the process, such as what he calls a lead time-shortening "gear-on-a-stick" molding tool that allows for quicker change outs for cavities and core pins. But the reality that remains, according to Kleiss, is that "In today's world, it is rare to be given more than 10 weeks to produce final product. Quite often the desire is for half that time. Five years ago, we could take 10 to 12 weeks for tooling and on-time was virtually 100%. We are still close to 100% on-time, but tooling has gone down to six to eight weeks for most jobs."

Capabilities upgrades have quality consequences. Of course, the traditional gear companies discussed in this article have their own unique production quality issues—grinding, for example. It's become a major element of finished gear products over the past 10 years or so, as applications have become both more sophisticated and demanding in terms of noise, load, and other issues. Today's reality is that high-precision gears are also expected to meet specifications involving cosmetics, MSDS constraints and functionality.

At Schafer Gear (and Boston Gear), where most grinding is done in-house, those demands have led in turn to proactive improvements in the grinding department's quality procedures.

"The biggest (quality) upgrade has been in the gear grinding, and it's causing us to look at a lot of our internal quality system because everything got upped a notch," says Schafer's Fozo. "The quality of the finished gears, the quality of the lead, the profile; everything that we do was kicked up a notch. The market demanded it, and that's why we went in that direction."

Boston Gear, as we've already seen, addresses the quality issues attached to grinding by its comprehensive use of in-house auditors.

But as mentioned earlier, robust quality standards must be company-wide in today's market. And so gear companies like Schafer, Boston, Precipart and Kleiss are also looking—quoting Mr. Shakespeare—"with a lean and hungry look" at streamlining their packing and shipping departments.

"By putting in a designated storage location and stockage level for shipping supplies, we have not run out of packaging," says Robert Doshi, Schafer's production manager. "We have standardized the work instructions on all work orders to ensure the quality and consistency of our packaging." Doshi adds that they've also reorganized the shipping department to "facilitate the flow of materials into and out of " that area. One result, according to Doshi, has been the ability to ship more same-day priority parts. Another is a drop in past due deliveries by 75%.

At Precipart, a job shop where small quantities of specialty precision parts are the rule, grinding is not done in-house, but by a nearby, trusted supplier. Precipart's Rudolf, however, admits that "It is becoming more of a problem for us because you have no control over delivery times." Which is one reason Lean practices are so important there. Purchasing is one of many departments where Lean can help tremendously.

"If you have 12 weeks to do a job and you burn three weeks (in Purchasing) getting material, getting work orders together, you've just lost three weeks," says Rudolf. "So that process has to be looked at and streamlined with Lean principles."

But Rudolf harbors no illusions over where the competitive edge exists these days.

"Right now the main customer expectation is lead time because I don't see quality or price being an issue anymore, meaning that if your price or quality aren't there there's nothing to talk about. So now you hear, 'This guy can give it to me in 10 weeks but I want it in eight.' There's tremendous pressure in the industry with lead time because no one wants to keep inventory anymore. So it has to flow."

Rudolf says that Precipart—as do many other companies—relies on detailed value stream mapping to track every job sequence on its journey from Purchasing to Shipping. He adds that, at Precipart, lead time improvement is tracked on a "client and/or project" basis, pointing to a value stream-mapped project for a customer in which lead time was reduced by four weeks.

At Boston Gear, improvements in the shipping department have been kaizen-intensive, leading to various Lean tools integration.

For instance, says Prosser, "One project was to match pick location with product popularity. After performing numerous time studies, we were able to determine the inventory locations with the easiest—and quickest—pick times. We then defined our products into three categories—'A' items are frequently picked; 'B' items are seldom picked; and 'C' items are rarely picked. We then moved our 'A' items to the most desirable locations in the warehouse, based on picking speed and ease of picking." And so forth. Another kaizen-inspired upgrade was a "visual picking board," which allows supervisors to track in real time the workload of each on-shift picker. That information is then used to assign picking orders to those handlers with the available time and opportunity relative to an order's priority. It's a classic application of Lean principles.

And on it goes. Gear shops everywhere continue to explore any means possible to get leaner and faster, to continually improve, and to keep their customers coming back for more. In truth, companies no longer have much choice in the matter.

"If you're not continuously improving, I don't know how a company can survive, I really don't," says Fozo. "Even if you are a 'Ma and Pa' shop, you still face the pressure of

Fue Thauo of Boston Gear at his lathe.

The quality lab at Schafer Gear. Carts with project-specific parts staged for transport to the production area can be seen at lower left.

outside competition. And if you're not doing anything to better yourself or improve, I don't know how you can survive in today's global economy. Somebody's always going to be out there trying to beat you."

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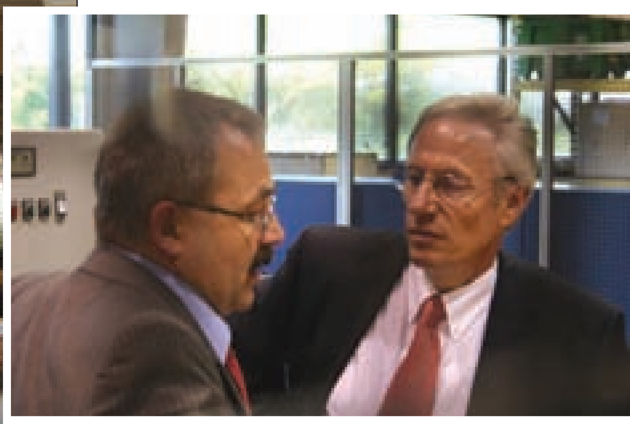
Sigma Pool
Hosts Gear Seminar, WZL Event

Dr.-Ing. Andreas Mehr (Liebherr-Verzahntechnik Kempten) presents a lecture on "Grinding Technology—Basics and the Future."



Prof. Dr.-Ing Fritz Klocke and Dr.-Ing Alois Mundt, managing director of Liebherr-Verzahntechnik Kempten, catch up during the tour of Liebherr's Saline, MI facilities.

Thierry Guertin of the Klingelnberg-Oerlikon Tech Center enlightens the crowd on bevel gear prototyping.

Prof. Dr.-Ing. Fritz Klocke and the young engineers that comprise the WZL Aachen Gear Conference pose with Dr.-Ing. Klaus Finkenwirth of Liebherr-Verzahntechnik Kempten and Dr.-Ing Hartmuth Müller of Klingelnberg GmbH Hückeswagen.

More than 120 attendees from the American gear community congregated in Saline, MI, last month for the 2007 Sigma Pool Gear Seminar.

The three-day event consisted of two full days of addresses by Sigma Pool employees on various gearing technologies. The first day focused on bevel gear technology and the third on parallel axis gearing technology. Sandwiched in the middle was the WZL Aachen gear conference, a bi-annual event that presents research results in 10 sessions.

"It's always surprising to me that we get so many busy people who are willing to take three days out of the office and listen to the Sigma Pool explain our way of thinking," says Andreas Montag, marketing manager at the Sigma Pool. "They're not all local to the Detroit area and we're very pleased that so many people are willing to make the trip."

Among some highlights of the bevel gear day were a presentation by Günter Mikoleizig, Klingelnberg's manager of design and development for gear inspection machinery, on the company's new *GINA* software, which provides quicker and more accurate gear measurements. In some of the other 30-minute sessions, Dr. Joachim Thomas, the company's head of application engineering, presented on the correlations he has found between design and road tests and Dr. Alexander Langvogt, technical director in charge of running test machines, shared some smart and fast test methods for bevel gears.

Interestingly enough, Montag thought some of the event's most productive moments took place during the between-session coffee breaks. "At the shows, people walk by and maybe stop for an hour to talk, then walk over to the competitor and talk to them for an hour. In this environment, we have them for eight hours and the coffee breaks provide a wonderful opportunity for people to talk to our engineers as well as interact with their friends and competitors."

July 16–18—Powder Metallurgy Basic Short Course. Penn Starter Conference Center Hotel, State College, PA. Highlights include technical sessions discussing designing for PM; how metal powders are produced; different designs used in compacting tools; use of sintering to develop functional properties; injection molding of metal powder; various secondary operations; and MPIF standards. Note: Participants do not need a technical background. MPIF members receive preferred rate of $1,375 ($1,475 after June 15). For more information, contact the Metal Powder Industries Federation online at *www.mpif.org* or by phone at (609) 452-7700.

July 24–27—India Machine Tools Show 2007. Pragati Maidan, New Delhi, India. Exhibitor profiles include heavy machinery; machine tools; CNC and SPM; hand tools; cutting tools; power tools, pumps and valves; hydraulics and pneumatics; air compressors/gears, motors and drives; material handling; electrical; electronics; instrumentation, wire and cables; testing and measuring equipment; switch gears; controls; water treatment and specialty chemicals; adhesives, welding and welding consumables; woodworking machinery; plastics; printing and packaging; and CAD/CAM software technology. For more information, contact K&D Communication Ltd. online at *www.engimach.com.*

August 21—Gear Manufacturing Technology Seminar. Lyon Oaks Golf Course Club House. Wixom, MI. Hosted by Mitsubishi Heavy Industries America Inc. Program includes seminars covering gear basics; Mitsubishi's philosophy with regard to super-dry cutting tools and applications; evaluating potential errors from hobbing and shaping; and generating gear grinding. The featured guest speaker is Paul Suwijn of Gear Resource Technologies, who will present a lecture entitled "Important Principles for Workholding Success." The free seminar runs from 7:30 to 5 and includes breakfast and lunch. A limited number of tee times at the club have been reserved at a rate of $33 for nine holes after the seminar. For more information, contact Mitsubishi Heavy Industries by telephone at (248) 669-6136 or by sending e-mail to *karen.armstrong@mitsubishigearcenter.com.*

September 4–7—10th International Power Transmission and Gearing Conference. Rio All-Suite Hotel, Las Vegas, NV. The conference program is separated into 10 areas including gear design and analysis; gear strength and durability; gear dynamics and noise; gear diagnostics; gear manufacturing; gear lubrication and efficiency; engineered surfaces and tribology; transmissions; chains, belts and traction drives; couplings, clutches and bearings. Registration fees range from $75–$800. To date, there are 118 technical papers slated for presentation. For more information, contact the ASME online at *www.asme.org*.

September 12–14—Basic Gear Noise Short Course. Department of Mechanical Engineering, Ohio State University, Columbus, OH. Offered for gear designers and noise specialists who encounter gear noise and transmission design problems. Attendees will learn how to design gears to minimize the major excitations of gear noise: transmission error, dynamic friction and shuttling forces. Fundamentals of gear noise generation and gear noise measurement will be covered along with topics on gear rattle, transmission dynamics and housing acoustics. Course includes extensive demonstrations of specialized gear analysis software in addition to the demonstrations of Ohio State gear test rigs. An interactive workshop session invites attendees to discuss specific gear and transmission noise concerns. $1,550. For more information, contact the GearLab by telephone at (614) 292-5860 or by e-mail at *harianto.1@osu.edu.*

September 17–18—Advanced Gear Noise Short Course. Department of Mechanical Engineering, Ohio State University, Columbus, OH. This advanced session is an extension of the Basic Gear Noise Short Course. This advanced course will be taught through lectures on selected topics coupled with a series of hands-on workshops. Based upon their interests, the attendees may select from the following topics:

- Analytical and computer modeling (prediction of gear whine excitations, general system dynamics, bearing/ casing dynamics, gear rattle models).
- Experimental and computational approaches (modal analysis of casings, acoustic radiation, advanced signal processing, sound quality analysis, transmission error measurement).

This course is $1,050 or $2350 if both the basics and advanced course are taken together. For more information, contact the GearLab by telephone at (614) 292-5860 or on the Internet at *www.gearlab.org.*

September 17–20—Basics of Bevel and Hypoid Gears. Zurich, Switzerland. This course is limited to 10 participants and conducted in German. Topics include gear cutting systems, gear geometry, offset and hand of spiral, ease off, load related deflections, bias and gear measurement and closed loop. 2,000€. For more information, visit the company's website at *www.klingelnberg.com.*

September 17–22—EMO Hannover. Hannover Fairgrounds, Hannover, Germany. Leading worldwide bi-annual trade fair for the metalworking technology sector. A special emphasis is placed on cutting, splitting, milling and metal forming machine tools, manufacturing systems, precision tools, automation components, computer technology, industrial electronics and accessories. Sponsored by the VDW (German Machine Tool Builders' Association). Day ticket is 27€, season ticket is 48€.

For more information, visit the official show website at *www.emo-hannover.de.*

October 7–10—Gear Expo 2007. The only trade show completely devoted to the complete gear manufacturing process. Jointly sponsored by the American Gear Manufacturers Association and American Bearing Manufacturers Association. The Solutions Center will feature 22 free presentations on gear-related topics all day on October 8–9. Registration is $25 in advance and $50 on-site. For more information, visit the show's website at *www.gearexpo.com* or contact customer service at (301) 694-5243.

November 21–22—Gear Finishing Technology Seminar. Aachen, at the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Aachen, Germany. The seminar is for managers and experts for development, engineering, designing, researching, supplying, planning and manufacturing who deal with gear finishing. This conference will be offered with simultaneous translation into English. The topics covered are:
• Green Finishing and Heat Treatment of Gears
• Hard Finishing in Serial Production: Gear Grinding
• Hard Finishing in Serial Production: Gear Honing
• Hard Finishing of Large Module Gears
• Gear Quality Evaluation
The conference fee 795€; 20% rebate is available for participants from WZL Gear Research Circle member companies. For more information, contact the Aachen University of Technology by e-mail at *K.Fausten@wzl.rwth.aachen.de* or on the Internet at *www.getriebekreis.de*.

Correction 1

In the May issue, *Gear Technology* reported the purchase of Lambert-Wahli with the headline "Monnier + Zahner buys Lambert-Wahli". As explained further on in the article, it is actually Monnier + Zahner's holding company, Mayco Holding, that purchased Lambert-Wahli. *Gear Technology* regrets any confusion this may have caused.

Correction 2

In the May *Gear Technology* feature on CIMT, the name and web address for AMT-The Association for Manufacturing Technology were incorrect. The web address is *www.AMTonline.org*. *Gear Technology* regrets the error.

— The Editors

New! CNC Single Flank Bevel Gear Testing Machine

EFPG- 1250

EFPG-1250:

The new EFPG-1250 Bevel Gear Tester provides the potential for complete control of all single flank inspection requirements. With over 1,400 Ft./LBS. of pinion torque, and over 2,200 Lbs of gear torque, the EFPG-1250 has the power to most accurately simulate the assembled speeds and loads on the more highly developed gear drives now demanded by today's industry.

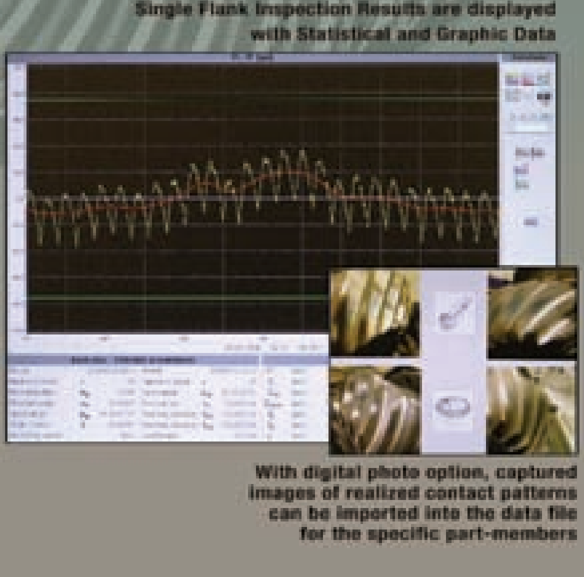
PRINCIPAL CAPACITIES:

Nominal Work Diameter of Gear	1250 mm	49.20"
Max Distance - Center of table to front of pinion spindle	1325 mm	52.16"
Min Distance - Center of talbe to front of pinion spindle	375 mm	14.76"
Max Distance - Center of pinion spindle to table surface	730 mm	28.74"
Min Distance - Center of pinion spindle to talbe surface	130 mm	5.12"
Maximum Hypoid Offset	120 mm	4.72 +/-
Angle between Axles (Fixed)	90 Degrees	
Diameter x Length of Pinion spindle bore	Ø 12.205" x 39.370 / Ø 8.660" x 7.870"	

SOFTWARE:

With the Windows-based software program, the user is able to select determined test programs and associated gear parameters, with the results stored per each test for future evaluation, or output onto varied displays or printed formats. The user-friendly menu permits evaluations of Fi' (Tangential composite error) fi' (Long Wave Component), fk' (Short Wave Component), Deviation Spectrum, as well as Backlash, Pitch Deviation, Roundness, and Photographed Parameters for the concave and/or convex tooth flanks.

Single Flank Inspection Results are displayed with Statistical and Graphic Data



With digital photo option, captured images of realized contact patterns can be imported into the data file for the specific part-members

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ZF

RECRUITS 250 NEW ENGINEERS

With the objective of launching a hybrid drive system on the market within the next few years, ZF is concentrating on orders for the German and European automotive market.

Approximately 100 new employees will be added to the hybrid team before the end of 2007. According to the company's press release, ZF plans to create more jobs by 2009 in response to the growing number of orders and requests for hybrid drives triggered by the current CO2 debate.

CEO Hans-Georg Harter says, "With our response to these projects and requests, we will position ZF as the hybrid technology supplier to the automotive industry. In order to achieve this, we need new professionals as well as experienced engineers."

ZF says it is primarily looking for engineers specializing in electronics, electrical engineering, mechanical engineering and vehicle construction.

Technologies for commercial vehicles and passenger cars are developed at the main ZF engineering centers located in Friedrichschafen, Schweinfurt, Passau, Dielingen and Schwabisch Gmund, Germany as well as in Detroit. Approximately 60% of all ZF employees work at sites in Germany.

For more information, contact ZF by telephone at +49-754-772-528 or online at *www.zf.de.*

Bison Gear

WINS COMMUNITY LEADERSHIP AWARD

Bison Gear & Engineering Corp. received the Business Leadership Award from the River Valley Workforce Investment Board in June

"We are pleased to be recognized for this award and value the relationship we have with the River Valley Board in developing our Skilled Workforce Initiative," says Ron Bullock, Chairman and CEO of Bison Gear.

The River Valley Workforce Investment Board brings together employment, training and educational resources in Kane, DeKalb and Kendall counties in Illinois.

The award was presented to Bison Gear at the 3rd annual River Valley Workforce Investment Board Recognition Dinner on June 21. The evening's program featured Keynote Speaker Paul G. Kuchuris, President and CEO of the Lincoln Foundation.

NEWS

Bodycote

ACQUIRES SECOND CHINESE HEAT TREATMENT COMPANY

Bodycote acquired Ningbo Jiangdong Ruiahong Heat Treatment Co. Ltd., a Chinese heat treatment company. This is the second company the group added to its Chinese heat treatment division as part of its strategy to expand heat treatment operations in emerging countries.

RHT operates two facilities in the Yangtze River Delta, approximately 300 km south of Shanghai and the existing Wuxi heat treatment center. The company provides protective atmosphere heat treatment services and associated testing support to local suppliers in the automotive, power tools and agricultural sectors.

Voith

ANNOUNCES PLANS TO BUY BHS GETRIEBE GMBH

Voith Turbo announced plans to take over the gear manufacturer BHS Getriebe GmbH in Sonthofen, Germany, from majority shareholder Halder, effective retroactively to Jan. 1, 2007.

According to Voith's press release, it intends to operate BHS Getriebe GmbH within the Group Division Voith Turbo as a product group of its "Industry" division. The company will trade as an independent unit under the name Voith Turbo BHS Getriebe and will be managed jointly be the current managing directors of BHS Getriebe, Dieter Groher and Lothar Hennauer. The organization's headquarters will remain in Sonthofen, Germany.

BHS Getriebe GmbH manufactures turbo transmissions as well as couplings and rotary turning gears primarily used for energy generation, the extraction of oil and gas and the petrochemical industry. Annual sales for 2006 were reported at 69 million euros.

Voith Turbo specializes in hydrodynamic drive, coupling and braking systems for road, rail and industrial applications as well as ship propulsion systems.

Metal Improvement

EXPANDS HEAT TREATMENT CAPABILITIES

Metal Improvement Co. has added equipment and capabilities at three of its Midwest heat treating facilities.

In Wichita, KS, the company installed a new vacuum furnace with a working zone of 48" x 48" x 60".

The Ft. Wayne, IN, heat treating facility upgraded its mesh belt furnace with infrared gas analysis for feedback control. According to the company's press release, this feature will maintain tighter control of heat treating parameters. The Ft. Wayne facility performs carbonitriding, carburizing, neutral hardening, carbon restoration, stress relieving and annealing. The facility is Ford W-HTX-compliant and ISO 9001:2000-registered.

A new "Super 36" integral quench batch furnace and associated temper furnace was added to the facility in Columbus, OH. The increased capacity will enable faster turn times. The Columbus facility is CQI-9 approved to perform heat treating services for General Motors, Ford and Daimler Chrysler Tier 1 and Tier 2 suppliers.

Paulo Products

RECOGNIZED AMONG TOP FIVE IN QUALITY LEADERSHIP

Paulo Products Co. was recognized in the top five among over 800 participating companies in this year's Quality Leadership 100 as published by *Quality* magazine.

According to Paulo's press release, companies were surveyed on criteria such as scrap and rework as a percentage of sales, reject parts per million shipped, contribution of quality to profitability, the number of quality programs in place, registration to various standards and other key indicators.

Cinetic Landis Grinding

PLANS TO MODERNIZED FACILITY

Cinetic Landis Grinding Corp. is relocating its headquarters and manufacturing/assembly facility approximately 15 miles to Hagerstown, MD.

The new state-of-the-art facility will include 85,000 square feet of manufacturing space and a two-story, 24,000-square-foot office complex.

Cinetic Landis Grinding manufactures precision grinding systems for automotive and diesel powertrain customers, including powertrain suppliers. Core technologies include precision hydrostatic systems, CNC axis control, multi-axis service coordination, machine/sensor integration, motorized spindles and advanced software design.

The company had been operating in a Waynesboro, PA, facility under a lease agreement since being acquired by Groupe Fives-Lille in 2005.

"Groupe Fives-Lille has provided Cinetic Landis Grinding with the opportunity to build a modern, cost-effective facility that better fits our business model. Major factors considered during the site selection process included the proximity to the current facility and existing workforce as well as the availability of business services, access to transportation, governmental considerations and community features," says Daniel L. Pheil, president and CEO of Cinetic Landis Grinding.

The company expects to be in the new facility in July 2008.

Headquarters will be situated on a 28 acre site in the Newgate Industrial Park.

ONLINE

News is updated daily at

www.geartechnology.com

Stackpole's Automotive Gear Division

TAKES TOP PRIZE AT MPIF COMPETITION

Stackpole Automotive Gear Division, Mississauga, Ontario, Canada, and its customer Magna Powertrain, New Process Gear Division, East Syracuse, NY, received the Grand Prize for a high-precision PM steel clutch hub at May's Metal Powder Industries 2007 Conference.

Stackpole selected a special, low-cost, lean-alloy material to meet strict dimensional control, compressibility, and durability requirements in a demanding performance environment.

The complex six-level part operates in the clutching system of an active four-wheel drive transfer case in light trucks and SUVs. The clutching system replaces a manual synchronizer system to allow full-time active control of torque transfer. It facilitates variable torque distribution to the vehicle's front wheels on the fly.

According to the MPIF's press release, high-temperature sintering provides the following properties: a minimum density of 7.0 g/cm^3, 165,000 psi tensile strength, yield strength of 150,000 psi, and an apparent hardness of 35 HRC.

The complex castellated geometry required tooling to precisely control lengths, diameters, densities, weight, and run-out, as well as an even density distribution throughout the part. Annual production exceeds 600,000 parts.

Hangsterfer's

APPOINTS NEW PRESIDENT

Leslie Jones was appointed as president of Hangsterfer's Laboratories, effective May 1.

According to a company press release, Jones started with Hangsterfer's in 1974 and recently held the position of vice president of manufacturing and finance. She is past president of the Independent Lubricant Manufacturers' Association and active in the Society of Tribologists and Lubrication Engineers. Hangsterfer's Laboratories researches, develops and manufactures metalworking lubricants.

Automation Tooling Systems

ANNOUNCES TWO NEW APPOINTMENTS

Automation Tooling Systems announced the appointment of two senior executives to the positions of COO and vice president of strategy and human resources.

Ron Keyser was appointed COO. Most recently, he worked as vice president of information technology operations for Magna Services, the shared services unit of automotive components manufacturer Magna International.

Lynne Brenegan was named vice president of strategy and human resources. She worked for the past 15 years in consulting management for high technology engineering and joined ATS last year.

Chrysler and GETRAG

ANNOUNCE JOINT VENTURE FOR 700,000 DUAL CLUTCH TRANSMISSIONS

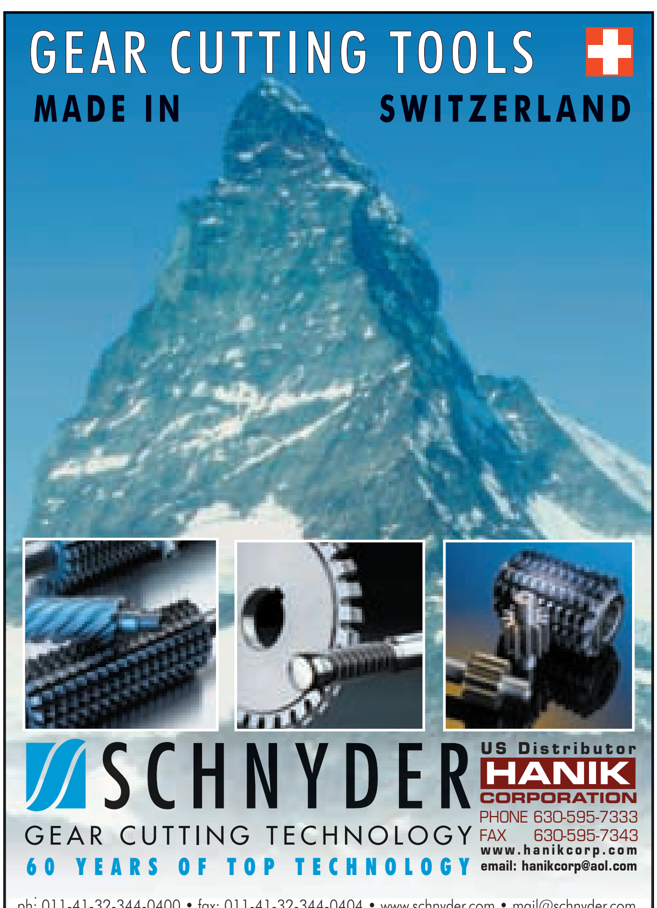
Chrysler Group's vice president of powertrain manufacturing Richard Chow-Wah joined Indiana Gov. Mitch Daniels to name Tipton County, IN, as the site of a new dual-clutch transmission manufacturing plant with partner company Getrag.

According to a Chrysler press release, Getrag will have

operational leadership of the plant, which will employ 1,050 full-time Chrysler Group UAW-represented workers and 120 management employees from both companies.

The plant is expected to produce 700,000 dual clutch transmissions annually. Additionally, an approximate 230 employees at Kokomo Casting and Kokomo Transmission will be producing parts for the Getrag plant. Construction of the 804,000 square foot facility began June 27 with production expected in 2009.

"Dual clutch transmissions provide much better shift quality, driving comfort and superior fuel efficiency compared to more conventional technologies such as torque converter automatics and/or CVTs," says Ulrich Kohler, Getrag Transmission Corp.'s vice president of manufacturing. "DCT's replace the energy-sapping torque converters of automatic transmissions with two wet or lubricated clutches—one that engages first, third and fifth gear and the other that engages second, fourth and sixth. As a result, the transmission can deliver 5–10% improvement in fuel economy."



Daniel Rudolf

PROMOTED AT PRECIPART


Daniel Rudolf

Precipart Corp. announced the promotion of Daniel Rudolf to director of continuous improvement in mid-June.

According to the company's press release, Rudolf assisted the first ISO registration in 1997 and continues to promote its quality management systems by representing the company on a steering committee for lean initiatives at the Long Island Forum for Technology (LIFT), an association of Long Island manufacturing companies that partner with local colleges in training programs.

Rudolf joined Precipart's Farmingdale, NY, office when he came from Switzerland 22 years ago as a screw machine operator. He was first promoted to department manager before being promoted to lead the continuous quality improvement efforts.

Rush Gears

OFFERS ONLINE 3-D CAD DESIGN FILES

Rush Gears redesigned its website to allow users to download a 3-D solid model and 2-D drawing from 150,000 pre-engineered worm gear and spur gear sizes.

According to the company's press release, once downloaded and saved in one of 50 available formats, users may modify the 3-D solid model and insert it directly into the assembly. The free online tools ensure fit and function without prototyping and tooling changes.

For more information:
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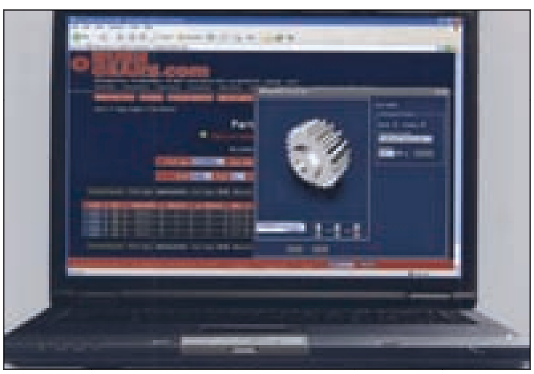


Highway Machine Co.

ACQUIRES NORTH AMERICA'S FIRST SIX-METER FORM GRINDER

HMC announced its recent acquisition of the first six-meter, (240"), Höfler Form Grinder in North America, which will be installed and run off by the first quarter of 2008.

The Höfler Rapid 6000 will allow HMC to finish gears internally/externally up to 240" diameter with tolerances of AGMA 15.

According to the company's press release, the Höfler Rapid 6000 will facilitate HMC in its ability to manufacture large

pinions of any pitch and face widths of up to 85".

John Schnarr, sales manager of HMC, says the new machine will introduce capability to chart tolerances for lead, pitch, profile, and runout, on gears of 240" diameter.

Wall Colmonoy

APPOINTS NEW GENERAL MANAGER


Ami Zelcher

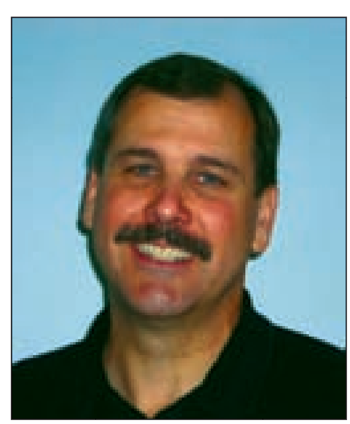
Ami Zelcher was appointed general manager of Wall Colmonoy's Ohio Aerospace Group.

According to the company's press release, Zelcher has 20 years' experience in the aerospace industry as a general and operations manager, engineering and business development manager and head of quality control for suppliers of major components for the aircraft industry.

REM

CERTIFIED AS SUPPLIER TO ALL MAJOR AEROSPACE COMPANIES

REM announced its recent certification as a supplier to all major aerospace companies in the U.S., a status that was obtained due to its patented Isotropic Superfinish process.


Mark Michaud

"Manufacturers of gas turbine engines, helicopters, APUs and accessory drives need their gears, bearings and airfolds superfinished for their aerospace applications. These companies recognized the improved performance, durability and cost saving benefits from ISO processed components," says Mark Michaud, REM president.

REM Chemicals develops custom processes and manufactures specialty chemicals for the surface engineering industry.

Wheelabrator

NAMES NEW SERVICE MANAGER

Wheelabrator announced that Allen Austin was named the service manager for Wheelabrator Plus, the after-sales division of Wheelabrator Group that provides services, replacement parts, training and equipment upgrades for all equipment users.

Allen Austin

Prior to this new role, Austin launched and managed the Parallel Parts Program, which offers replacement parts for non-Wheelabrator equipment.

In this new role, Austin will work closely with inside and outside sales, and his global perspective from the product management standpoint will be executed to drive sales and relationships within Wheelabrator Plus. He will also support the Equipment Modernization Program (EMP). Prior to joining Wheelabrator in February, Austin worked in the electronics industry for 15 years. His most recent management role was global product manager within the Tyco Electronics Division of Tyco International. Prior to that, Austin worked for Hughes Georgia Inc. (now Raytheon Defense Systems Texas) as a program manager and Underwriters Laboratories Inc. where he was a project engineer.

Seco Tools

INTRODUCES COMPONENT ENGINEERED TOOLING PARTNERSHIP

Seco Tools Inc. announces Component Engineered Tooling (CET), the newest offering from its Seco Business Solutions service provisions made available to Seco customers to improve profitability. CET is geared toward minimizing machining time and production costs by involving the Seco team early in the process, from component design through full floor production.

"We look at the entire picture–the component material, the machining methods, the machine tool, the cutting tool, inventory," says Julian Adams, technical marketing services manager, "and help bridge the gap that often can occur when organizations aren't able to keep pace with the rapid development of machine tool technologies or tooling applications. We pull together the pieces of the puzzle to manufacture the highest quality part in the most cost-effective manner."

The CET program involves a number of services including:

- Methodology and technology evaluation (including simulation) of current and potential tools and processes;
- Functional testing in Seco labs early in the lifecycle to reduce risk on the plant floor;
- Collaboration with the machine tool builder,
- Tool management and technical support
- On-site installation and delivery of complete tooling package including run-off tests, production training and documentation.

With simulation as part of the CET offering, advanced CNC modeling and other virtual tools can remove the risk from experimenting with "what if" scenarios. Possible results can include increased throughput or discovering that a different process, such as hard-turning versus grinding or thread milling

Illinois Tool Works

PURCHASES QUASAR INTERNATIONAL

Illinois Tool Works purchased Quasar International, inventor of the PCRT (Process Compensated Resonant Testing), a new non-destructive test method.

According to the company's press release, Quasar will continue to operate independently, keeping in consistency with ITW's decentralized organization structure. Operations in Albuquerque and Detroit will remain essentially unchanged and existing distribution and customer agreement will not be affected. Quasar will be associated with Magnaflux, a division of ITW that supplies magnetic particle equipment, dye penetrant inspection equipment and associated chemical produced for nondestructive testing.

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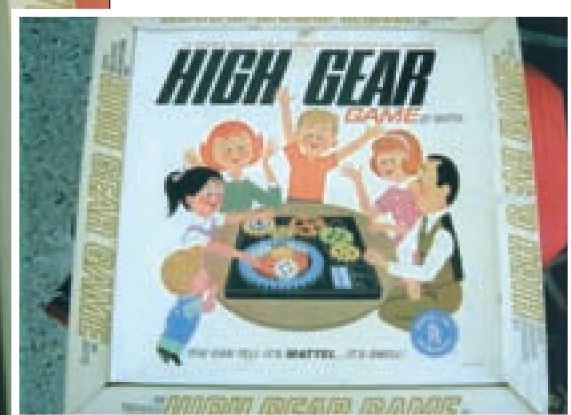

Loyal *Gear Technology* reader and Interstate Castings vice president Greg Bierck came across "High Gear" at a vintage toy store in Indianapolis, IN. "High Gear" was introduced by Mattel in 1962. In the game, players compete to work their four pegs through the ten meshed gears. (The box says there are 35,568 possible gear combinations.)

An excerpt from Bierck's letter…

I am a collector of toys and really don't remember ever seeing this game when it came out. My first thought was that it might not have been a big seller. My second thought was what a good way to show and teach a child how mechanical things work with such a game. I wondered how many people now in the gear industry may have played with this game as a child? I admit to being 53 years old and would have been 9 years old at the time, but would have really enjoyed it, as I like mechanical things. I also got to thinking what a child of 9 years old would think about this game today. I would think that since it's not high-tech enough, there would be little to no interest from today's typical 9 year old.

My point being that gears make the world we know work. I'm in the foundry business, and castings also make the world function as we know it today. Yet, how many people really know anything about our industries, the challenges we face, or that we need to continue to find young people who may be interested in what we do to carry on? Hands-on, fun learning tools like this game just are not out there anymore to challenge our youth at an early age to use their imaginations and actually experience how things may work.

Who will actually be dreaming, designing and manufacturing anything in this country in 15 years? Will it all be done by other countries? I'm afraid so. And when it happens, we will no longer be a leading industrial world country. It's happening now. Would toys and games that stimulated hands-on learning at an early age, much like the Mattel game, keep us a world leader? Maybe.

Bierck's musings lead us to wonder if any of our other friends in the gear industry remember playing "High Gear" in the 1960s. *Gear Technology* would love to hear from any of the game's original enthusiasts.

Send your comments to
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