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Center Distance Variation
Automotive Differential Gears

ADDENDUM

What We Learned at IMTS

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THE JOURNAL OF GEAR MANUFACTURING

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Vol. 29, No. 7

departments

Kapp ZX 1000

Photo by David Ropinski


Think Big!
Grind Big!
LIEBHERR
LIEBHERR
LCS 700
IMTEX Bangalore, India
24.01.2013 - 30.01.2013

THE GEAR INDUSTRY'S INFORMATION SOURCE

www.geartechnology.com

Gear Technology—Content Kings!

Gear Technology was chosen as the first entry in Niche Media's "20 for 20" feature (20 niche magazines in 20 days sharing their secrets to success). The online article describes how *Gear Technology*'s goes the extra mile to provide our readers with the most in-depth, technically accurate and relevant content available.

blog.nichemediahq.com/?p=1220

Sandvik demonstrated their new Invomilling tools for gear manufacturing, both in their booth and at DMG/Mori Seiki:

www.geartechnology.com/videos/Sandvik-Gear-Machining-Tools

Did You Miss IMTS? Catch Up Online

There was a lot of interesting technology on display at IMTS 2012. We've posted a number of videos on our website highlighting some of the gear-related machines and tooling from the show. Just visit the home page or follow the links below:

Star-SU displayed the new Star PTG-6L Tool and Cutter Grinder, the Bourn & Koch 100H Horizontal Hobbing Machine and the MAG H400 CNC Hobbing Machine at the show. For a complete overview of Star-SU's gear machines, tooling and services, check out their latest video:

www.geartechnology.com/videos/Star-SU-IMTS-Overview

Ask the Expert — Now's Your Chance

By now you've seen our "Ask the Expert" feature in the magazine (see page 38 for this issue's installment). We know you've been dying to give it a try. So go ahead. Send us your best gear-related technical stumper. Our experts are waiting…

www.geartechnology.com/asktheexpert.php

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BPA WORLDWIDE™


Mars Rover Curiosity
discovers what she's made of
oooOOOOOooooh...

My Glass is Half Full

Publisher & Editor-in-Chief
Michael Goldstein

When people become apprehensive about their future, the first thing they do is put their hands over their wallets. And between the upcoming U.S. presidential election and the mandatory tax increases and enormous government budget cuts set to go into effect at the end of this year (the so-called "fiscal cliff"), there's plenty of apprehension to go around.

Many are hoping that between now and the end of the year, Congress will manage some kind of compromise that will allow us to avoid the fiscal cliff, or at least to soften the landing. But no matter who wins the election, there are no guarantees. Some economists have predicted that in a worst case scenario, the tax changes will cause a 2013 recession. Because nobody can predict exactly what will happen, both consumers and businesses are holding onto their cash and delaying long-term decisions in case they have to weather difficult times ahead.

But I'm an optimist, and there are reasons to believe that the current economic pause *is* just a pause.

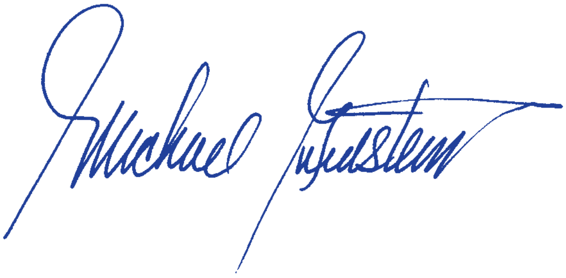
For example, home construction has begun to grow. It's nowhere near where it was, or where it should be, but we seem to have finally found equilibrium in that part of the economy. And growth in housing has a positive impact on the rest of the economy far beyond the money spent on the housing itself. Someone who moves into a new dwelling typically spends a lot of money on furnishings, carpeting, window treatments, appliances, etc., all of which injects money into various parts of the economy. In addition, existing home prices are rising in various sectors of the country.

But if you're looking for something more concrete—more real—upon which to base your hopes, then you need look no further than the recently held IMTS. There, on the show floor, I saw with my own eyes that manufacturing is still alive and well. The show attracted more than 100,000 registered attendees—more than any IMTS in more than a decade, and 21.6% more than the previous show.

And these weren't just casual curiosity seekers. They were buyers—real manufacturers with projects in hand, needing machine tools and technology to improve and expand their operations. I talked to many exhibitors, and from them I got a sense that the quality of the attendees at this show was much higher than at previous shows—including when IMTS previously reached 100,000 visitors more than 10 years ago.

Exhibitors in our industry—both large and small—were almost universally busy at IMTS, and they'll be busy for months more following up on the quality leads they received. The ones I've talked to have told me the show was extremely successful and one of the best in recent memory.

So no matter what happens—with the election and the politics surrounding the decisions that will have to be made regarding the fiscal Armageddon—I'm confident that we'll enjoy a strong manufacturing economy for some time to come.



P.S. Congratulations to Paul McHenry of Tri-City Machine in Peoria, Illinois. He was the winner of our iPad giveaway at IMTS! Thanks to all who stopped by our booth to learn more about *Gear Technology*, *Gear Technology India* and *Power Transmission Engineering*. If you missed the show, you can still sign up or renew your FREE subscription at *www.geartechnology.com/subscribe.htm*.

A Quick-Start Approach for Implementing Lean in Job Shops

Dr. Shahrukh Irani, Director, IE Research,
at Hoerbiger Corporation of America

In the August issue of *Gear Technology*, we examined the lean tools that will and will not work in high-mix, low-volume manufacturing facilities. Now, we will examine how to implement the tools that will work in the job shop with an approach that expands the capabilities of value stream mapping.

A Quick-Start Approach for Implementing Lean in Job Shops

Figure 1 presents a flowchart for a "Quick-Start" (Q-S) approach for implementing lean in job shops. Perhaps the biggest departure from value stream mapping is the use of product-process matrix analysis of the entire product mix to find a clear-cut, significant and stable part family. Using a sample of routings from this particular part family, several industrial engineering analyses are done: (1) a spaghetti diagram to understand the flow disruptions due to the layout and building architecture, (2) a process flow chart to break down the product flow into activity elements and delays that are not captured in a value stream map, (3) a material handling analysis chart to understand the flow disruptions due to the material handling equipment and containers being used, (4) absence of Line-Of-Sight between key workcenters, (5) communications and logistics that support schedule execution, etc. The use of a video camera to make a live video recording of a "gemba walk" of the entire value network for the routings that were selected is strongly recommended.

Another unique feature of this approach is that in a job shop, where batch-and-queue flow is often the norm, it is advisable to use Theory of Constraints (TOC) to focus the initial Continuous Improvement events (kaizens) on the bottleneck work center used by this family of parts. There is a good chance that the bottleneck for this single part family could very well be the bottleneck for the entire facility. In which case, efforts to improve process yield, standardize tools and fixtures, error-proof machine settings, apply 5S, improve materials delivery schedules, reduce setup times, etc. on this workcenter will have widespread benefits. The bottleneck splits the value stream (or network, if the part routings are not identical) and helps to break up the material flow logistics into two parts: [Receiving → Bottleneck] and [Bottleneck → Shipping]. These two portions of the value network for the part family can be controlled using multi-product multi-machine pull scheduling mechanisms like CONWIP (CONstant WIP), drum-buffer-rope and finite capacity scheduling (my favorite method). By integrating the part family concept and TOC, the Q-S approach has always been an effective investment for evey job shop that has hired a student intern to implement JobshopLean during a three-month appointment.

A Comprehensive Approach for Implementing Lean in Job Shops

The real challenge is to implement JobshopLean in a comprehensive manner, unlike the quick-start approach. Figure 2 presents a flowchart for a comprehensive approach for implementing lean in job shops. At the core of this iterative approach is the expectation that (1) a job shop will utilize production flow analysis and/or group technology to identify the stable part families

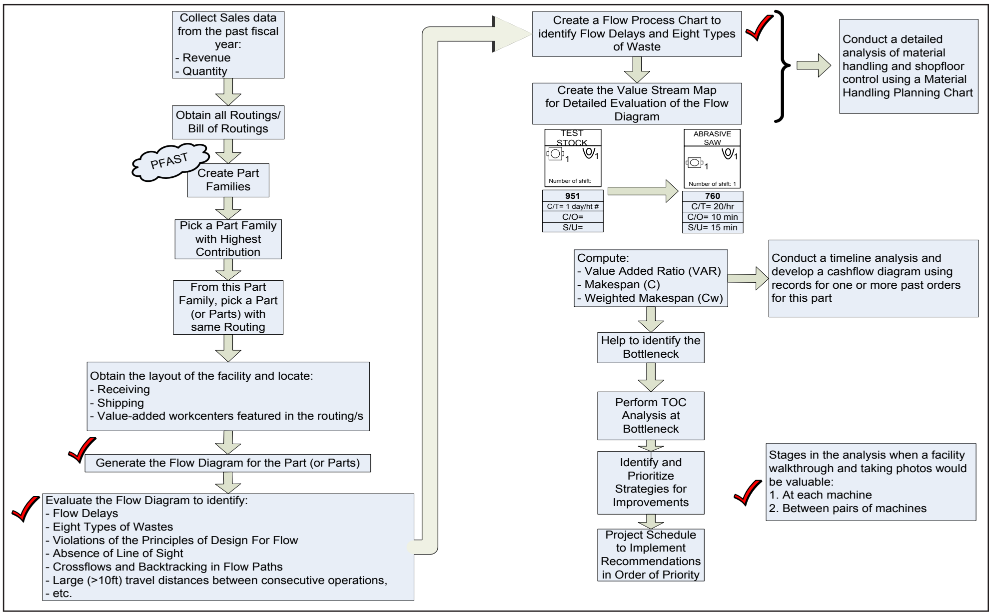


Figure 1 A Quick-Start Approach for Implementing JobshopLean.

in its product mix, and (2) will implement a flexible manufacturing cell to produce each part family. In theory, each iteration of the design process will result in a standalone flexible manufacturing cell dedicated to producing a part family. In reality, numerous constraints in the current state will need to be broken (e.g., operators will need to be trained to operate multiple machines in a cell and suitable group incentives put in place to ensure that the cell's team becomes autonomous) or will remain unbreakable (e.g., raw material single-sourced from China or heat treatment furnaces that cannot be placed inside a cell next to a CNC grinder). After a few iterations of this approach, a job shop would typically end up being divided into at least two areas: one area consisting of flexible manufacturing cells, with each cell dedicated to a product family and the other area being a "remainder shop" where the spare parts, prototypes and one-off orders are produced. By dividing the job shop into these two areas, two benefits are gained: (1) the cells provide unquestionable quick response, high quality, teamwork and other advantages that lean has amply demonstrated are gained from mixed model assembly cells and (2) instead of the entire business being managed as a complex job shop, a smaller portion of the same business now remains a complex job shop.

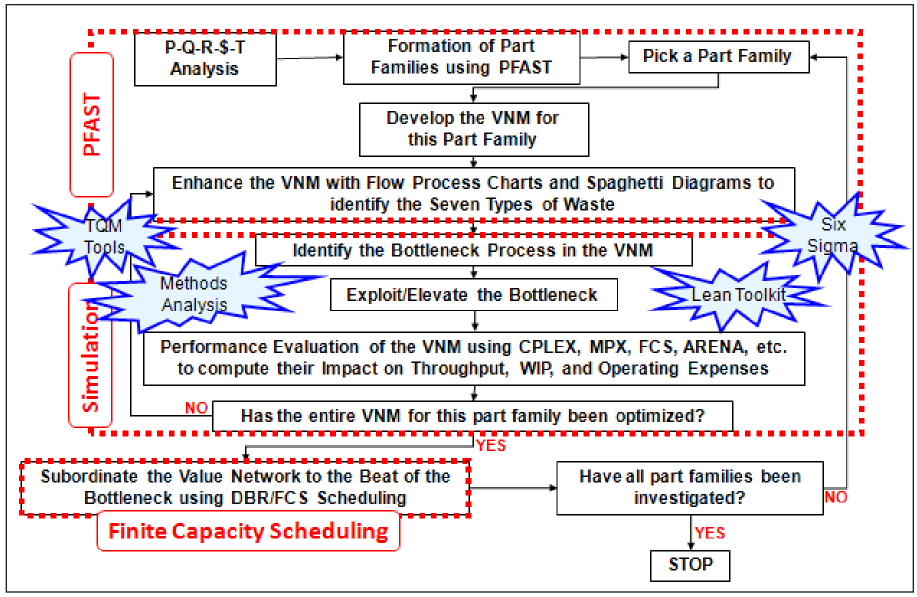


Figure 2 Comprehensive Approach for Implementing JobshopLean.

Cells: Building Blocks of JobshopLean

The cells are "mini job shops" and not mixed-model assembly cells, so they may not allow perfect one-piece flow. Still, due to increased proximity between consecutively used workstations, small batches of parts can be easily moved by hand or by using wheeled carts, short roller conveyors or Gorbel cranes. Recall that the amoeba and paramecium are single-cell organisms that are self-sufficient. Similarly, a manufacturing cell must be empowered to operate autonomously as a multi-prod-

uct multi-machine job shop. This is where lean tools, such as 5S, SMED, TPM, Poka-Yoke, Standard Work, etc. dovetail with JobshopLean *(Editor's Note: These were listed as "Tools that will work in any job shop" in the previous article that appeared in the August 2012 issue of* Gear Technology*)*. They ensure that the cell can become a self-sufficient business unit whose operations are not disrupted by defective materials, machine breakdowns, long setups, etc.

Key Steps in the Comprehensive Approach

This section briefly describes some of the key steps in the comprehensive approach for implementing lean in a job shop (Fig. 2). Product mix segmentation is the first step. The method used is PQR$T analysis (P = products, Q = demand, T = time over which the demand was recorded, R = routings, $ = sales). Segmentation helps the job shop to focus on a manageably large portion of its entire product mix that accounts for at least 80 percent of the total quantity of parts that were shipped and 80 percent of total earnings.

The sample of products selected by PQ$ Analysis is then analyzed using product-process matrix analysis to identify part families and the machine group that would constitute a flexible manufacturing cell to produce each part family. Each part family and its corresponding machine group appears as a block. The result of this analysis helps to identify the part families and machine groups that will constitute the flexible manufacturing cells (Fig. 3) where each cell would be dedicated to a product family. Now this is where the problem arises --- this analysis will highlight which resources will need to be shared resources by two or more cells. Not to worry! That problem becomes the "guiding light", the very basis for breaking the constraints that prevent the implementation of any cell. This product-process matrix analysis, which helps to visualize hundreds of value streams at the same time, is how any job shop could routinely pursue continuous improvement.

Finally, what does one do about the remainder of the product mix that was ignored by the PQ$ analysis? There is no cookie-cutter strategy that can be recommended. This is where each job shop's leadership team can exercise their creativity to develop unique, innovative strategies that they are willing to invest in implementing and sustaining. But, in a nutshell, here are some options: eliminate or outsource their manufacture, even if your company is listed as their supplier; seek additional business for them so they can be moved into one of the existing cells or utilize unused capacity in the cells to produce them.

Finally, having implemented the cell, it is required to schedule daily operations in each cell as well as coordinate the schedules of the cells with those for the shared resources, and, far more crucial, the vendors. This is best done using Gantt charts (Fig. 4) which was produced by a commercial finite capacity scheduling (FCS) tool, Preactor, that downloaded the firm orders and their due dates quoted to customers obtained from an ERP system (SAP). After the schedule generated by Preactor is released to the shop floor, it is monitored in real-time using our MES (Manufacturing Execution System) tool, Factoryviewer, to achieve shop floor control. Interested readers can contact the author to receive the contact information for the person who

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has implemented this system at the Pompano Beach facility of Hoerbiger Corporation of America.

Lean and IT-Enabled Automation Must Co-Exist

Despite the incorporation of computer-aided data analysis, flexible automation, IT enablers, etc., people and the standard lean tools are absolutely essential for successful implementation of JobshopLean. IT-enabled systems, flexible automation, etc. demand an even greater reliance on a process of continuous improvement to eliminate the myriad problems that arise when computer-aided process execution is disrupted by the vagaries of the dynamic shop floor. For example, one vagary that will disrupt any computer-generated schedule is the non-availability of an operator to run a job on a machine right at the time when the schedule requires it. Why? For reasons such as skill grade, absenteeism, breaks, etc. Add other vagaries such as machine breakdowns, missing tools, defective parts requiring rework, scrapped parts, vendor delivery failures, etc. At my company, IT is an enabler and supporter, not a replacement, for the minds of our employees!

(Editor's Note: The original draft had to be edited due to space constraints. Readers interested in receiving the full-length version of this article may contact the author at shahrukh.irani@hoerbiger.com*).*

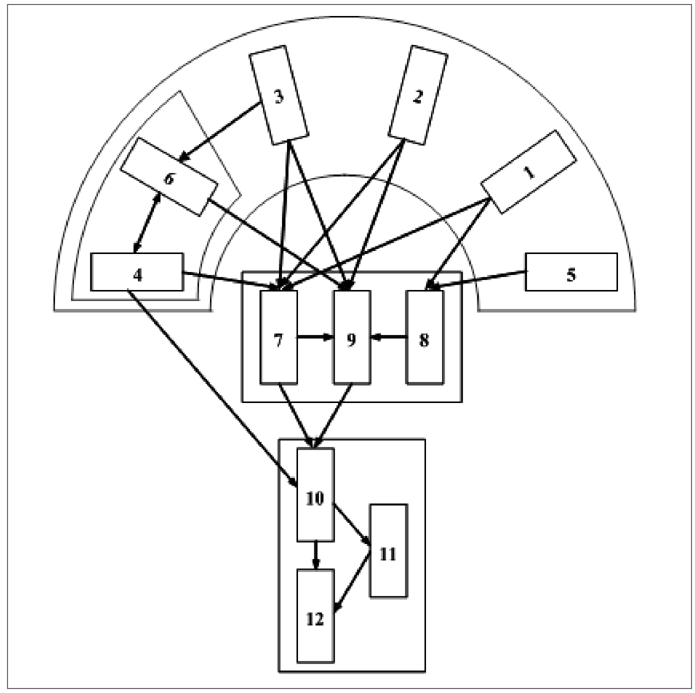


Figure 3 **Example of a Flexible Machining Cell.**

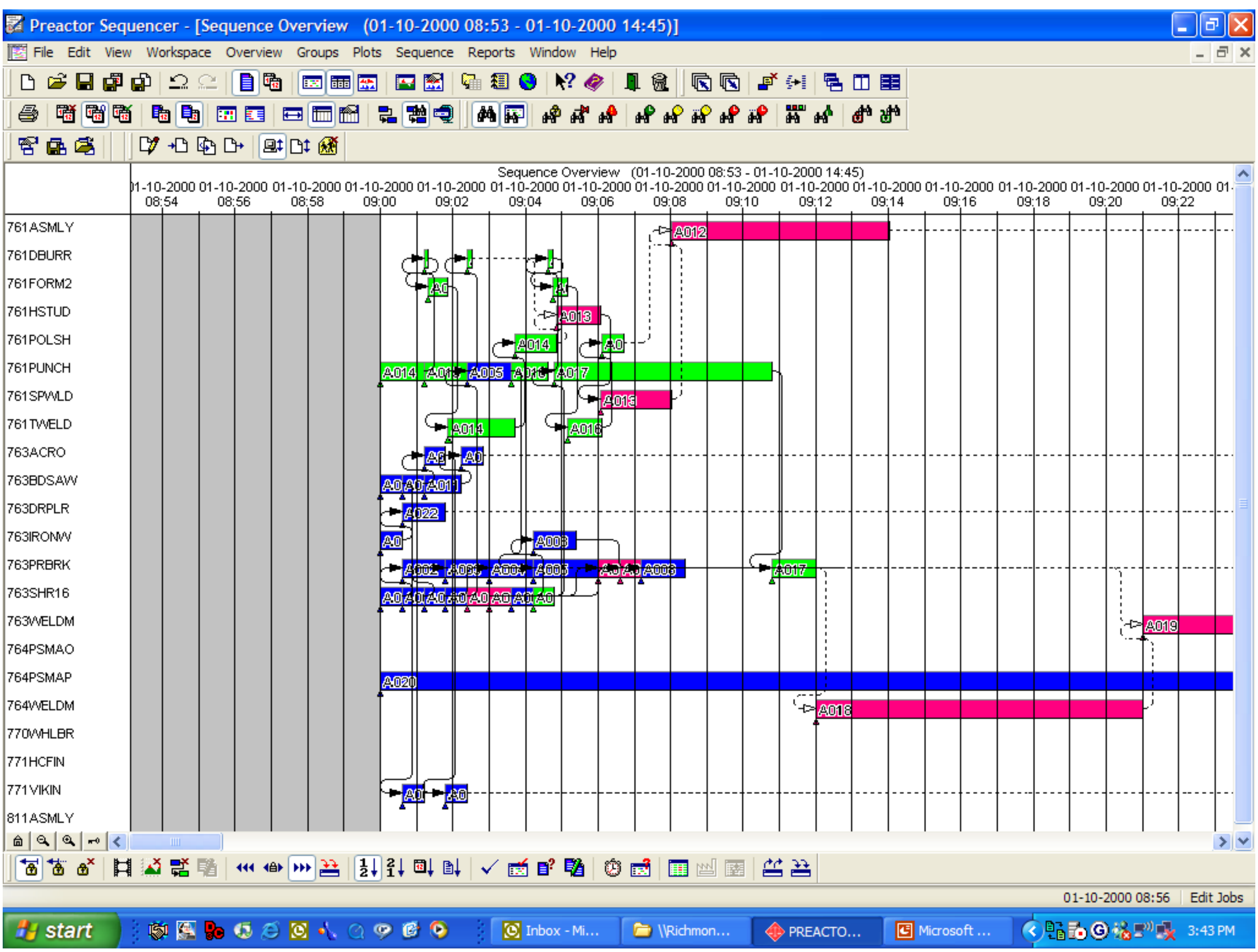


Figure 4 **Finite Capacity Schedule displayed as a Gantt Chart.**

Sunnen

OFFERS MULTI-FEED HONING TECHNOLOGY

Sunnen's newly patented multi-feed honing technology gives users a choice of tool-feed modes to achieve the shortest cycle times, lowest part cost, and longest abrasive life. Multi-feed combines Sunnen's new controlled-force tool-feed with its controlled-rate feed system. The two different tool-feed modes allow the user to select the better option to suit the workpiece geometry, material and tool type/size. Multi-feed technology is available as an option on new machines in Sunnen's SV-1000 and SV-500 series, as well as a retrofit for existing machines.

Controlled-force honing, a new feature in multi-feed, works like cruise control to ensure the optimum cutting load on the honing abrasive throughout a cycle, irrespective of the incoming part's hardness, geometry or size variation. The company states that, depending on the application, controlled-force honing cuts cycle times by as much as 50 percent, lengthens abrasive life for lower consumable cost, and allows finer control of surface finish parameters. Controlled-force technology eliminates glazing of the abrasive, due to too little force, and maintains a steady, free-cutting, self-dressing condition for maximum metal removal in the shortest possible cycle time.

"In our development work, we found that more-durable abrasives could often be used, resulting in more parts per set of abrasives and lower cost per part," said Dennis Westhoff, Sunnen's global business development manager. Controlled-force is a good choice for applications using segmented diamond or super-abrasive honing tools, or where incoming workpieces have slight variations in hole diameters, hardness and geometry. "An established honing process can be thrown off balance because of incoming part variations caused by upstream machining, heat treating or plating," Westhoff explains. "Controlled-force honing always maintains optimum feed force on the honing abrasive under these conditions to eliminate wasteful 'air cutting' glazing or tool damage. The beauty is that if conditions allow, for example with a batch of parts requiring less stock removal, the honing cycle will be shortened significantly and automatically."

Controlled-force's ability to control the cutting load within a very fine range also allows much tighter control of final surface finish parameters. "We have been able to cut the variation of final surface finish measurement by half or more," Westhoff added. Controlled-force honing works with Sunnen's mmT, PH and new KRQ tools.

Controlled-force honing is an enhancement of Sunnen's controlled-rate system for tool wear compensation, which is already capable of adjusting tool size in increments as fine as 0.1 µm (0.000010"). Controlled-rate tool feeding is typically used with plated-diamond CGT honing tools, which use a sleeve of abrasive for full contact with the bore surface. CGT tools are frequently used on cast iron and powder metal workpieces, segmented bores, or parts with multiple lands, ports, keyways or crossholes in the bore. Sunnen's machine control provides up to five feed expansion profiles that can be used during a cycle for rapid part touch, cutting, sizing, finishing and spark-out.

For more information:
Sunnen Products Company
7910 Manchester Ave.
St. Louis, MO 63143
Phone: (314) 781-2100
www.sunnen.com

Nexen

RELEASES COMPACT HARMONIC GEARHEAD

Nexen Group, Inc. has announced what it believes to be the industry's shortest and most compact automation gearhead. The new Nexen Harmonic Gearhead directly replaces much larger, high-ratio planetary gearheads utilizing the latest harmonic, strain wave gearing technology. In addition to its extremely short, compact size, the Harmonic Gearhead has numerous significant advantages over planetary gearing including high torque, true zero backlash and extremely precise positional accuracy.

Nexen's patent-pending, gearing-forward design overlaps components and allows the gearing to be integrated into the same plane as the bearing, resulting in an extremely short and rigid gearhead. This narrow, rigid design is combined with a large, rugged, crossed-roller output bearing, designed to handle all combinations of radial, axial and overturning moment loads in a single, compact envelope. The company states that the Nexen Harmonic Gearhead is the most durable and accurate available, achieving positional accuracy and high torque with true zero backlash directly to the motor.

With space at a premium in machine tools and automation equipment, the new Harmonic Gearhead can fit virtually any machine with key applications in products and machinery requiring a minimal footprint, such as machine tools, robots and robotic arms, medical equipment, rack and pinion systems and numerous general industrial positioning and motion control applications. In many applications, the Nexen Harmonic Gearhead can operate in less than half the space of conventional planetary gearheads. It is also extremely easy to integrate with a standard ISO 9409 output flange that fits most standard components and end effectors.

Also significant, the new Harmonic Gearhead is available with the Nexen Roller Pinion System (RPS). The gearhead is integrated directly into the pinion without adding any length to the system, resulting in a drive solution that maintains zero backlash from the driving motor shaft thru to the driven load for both linear and rotary motion. This combination also adds significant simplicity, thus saving the extensive time and expense of integrating a gearbox into the motion system; the user can simply bolt and go. Specifically engineered to meet diverse and demanding motion control challenges, Nexen's RPS delivers high-accuracy positioning with zero backlash and virtually eliminates cumulative error. The RPS surpasses traditional rack and pinion systems with a unique roller pinion/rack combination that can be easily adapted to any application. The pinion consists of bearing-supported rollers that engage a unique tooth profile. Two or more rollers connect with the rack teeth in opposition at all times, eliminating backlash. The RPS rollers approach the tooth face in a tangent path and then smoothly roll down the tooth face, greatly reducing noise levels associated with other linear motion systems, such as tooth slap or ball return noise. The low-friction design delivers more than 99 percent efficiency in converting rotary to linear motion, greatly reducing wear and providing longer service life at high speeds up to 11 m/sec (36.1 ft/sec).

For more information:
Nexen Group, Inc.
560 Oak Grove Parkway
Vadnais Heights, MN 55127
Phone: 651-484-5900
www.nexengroup.com

Mahr Federal

ADDS WIRELESS SYSTEM TO INDICATORS

Mahr Federal has added its new MarConnect Integrated Wireless data transmission system to its family of MarCator Digital Indicators at prices that compete with typical wired systems. New low-power data transmission technology has allowed the transmitter to be built into the digital indicator. The digital indicator sends its data to a small i-stick receiver, resembling a common USB flash drive. *MarCom* software makes data acquisition even simpler: just take a measurement and transmit your measuring data directly into *MS Excel* or via a keyboard code into any Windows program without cumbersome cables.

Integrating the transmitters with MarCator Digital Indicators eliminates expensive, power hungry add-on transmitters that can bulk up gages and interfere with portability. Each MarConnect i-stick wireless receiver supports up to eight digital indicators with a range of up to 12 meters, perfect for most bench-top or workstation applications. And since i-stick receivers are so inexpensive it's now possible to add a receiver to every workstation in the shop.

The MarConnect integrated wireless interface is active as soon as the i-stick is plugged in, and each indicator is identified by signal coding in the *MarCom* software so there is no confusion as to signals. Data transmitters are built into the MarCator 1086 and 1087 digital indicators, so no interface boxes or additional batteries are required. Plus, integrating the transmitters into the indicators' electronics makes the units extremely energy efficient, and can extend battery life up to 50 percent longer than competitive systems.

Integrated wireless gives more freedom of movement. For example, when measuring on or at the machine, or with large workpieces, cables do not obstruct. Plus, initiation of signal transmission can be made either from the indicators or directly from the PC. This can be very handy if, for example, you have a large gage set up with multiple indicators. Rather than having to send data from each indicator individually, the *MarCom* software can gather all measurement data with a single click. Successful data transmission is confirmed with a message on the digital indicator's display.

MarConnect Integrated Wireless is now available on Mahr's popular MarCator 1086 series of digital indicators with large display and integrated tolerance functions, and on the MarCator 1087 series of multi-functional digital indicators with combined analog and digital display, as well as tolerance and dynamic measuring functions. Both lines are equipped with Mahr's innovative reference system in which the zero position only has to be set once, and with a lock function that prevents unintentional activation of an operating button.

For more information:
Mahr Federal Inc.
1144 Eddy Street
Providence, RI 02905
Phone: (401) 784-3100
www.mahr.com

Hardinge

OFFERS SUPER-GRIP POWER CHUCKS

Hardinge Inc. manufactures a line of lever-operated, counter-centrifugal and dynamically balanced Sure-Grip Power Chucks. The lever-operated design of the Hardinge chuck has several advantages over the wedge-type design most commonly found on low-cost, non-counterbalanced chucks that are supplied with the initial purchase of many chuck-style lathes. In the Hardinge lever-operated system, the drawtube is connected to the jaws through a pivoting lever that is mounted on pins inside the chuck body. The lever system has reduced friction and increased mechanical advantage compared to a wedge-operated chuck for a given draw bar pressure. In other words, a lever will always have greater actual gripping power at the jaws than a wedge-operated chuck, for any given draw bar pressure.

The lever system also has reduced internal bearing surface over the wedge-operated closure, making it less sensitive to lack of lubrication. The greater efficiency of the design results in reduced wear on the operating cylinder, dramatically increasing component life. For this reason, a lever-operated chuck system (chuck and operating cylinder) will usually have a longer life than that of a wedge-operated system.

In the Hardinge counterbalanced chuck design, weights are incorporated into the actuating levers of the chucks at the opposite end of the fulcrum or pivot-point of the jaws. Centrifugal force acts upon this weight just as it does on the top jaws. However, since the weight is at the opposite side of the lever from the top jaws, the upward thrust generated counteracts some of the jaw force loss. Thus, the counterbalanced lever design has substantially more gripping force at high RPM than that of a non-counterbalanced style.

The major advantage of the Sure-Grip power chuck is the configuration of the drawtube that actuates the chuck. Since Hardinge machines all have collet spindles that do not require a collet chuck or adaptor, it is a simple matter to remove the collet and quickly mount the 3-jaw Sure-Grip power chuck when needed. The chuck's drawtube threads directly into the machine's draw bar, just as a collet would. This changeover can be accomplished in ten minutes or less. Other designs can take hours. The Sure-Grip power chuck is also available for non-Hardinge lathes that do not have collet style spindles.

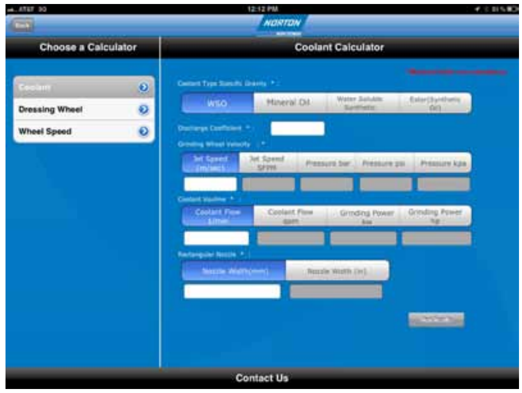
Hardinge manufactures its chuck components to high accuracy and repeatability standards. The repeatability of a chuck is the measure of its ability to repeat the performance, either from job-to-job or from part-to-part. Most models of Hardinge Sure-Grip power chucks have an accuracy (T.I.R.) of .0005 in.and repeatability of .0005 in., making them suitable for close tolerance turning requirements. Hardinge Sure-Grip power chucks are competitively priced, while demonstrating distinct advantages over the wedge style chuck.

For more information:
Hardinge Inc.
One Hardinge Drive
Elmira, NY 14902-1507
Phone: (607) 734-2281
www.hardingeus.com

Saint-Gobain

INTRODUCES GRINDING APP

Saint-Gobain Abrasives has recently introduced a Norton Abrasives Grinding App. This application includes three calculators: a wheel speed conversion calculator, as well as a coolant and dressing parameter calculator for abrasives applications. The Norton Grinding App also features a right angle grinding product selector and distributor locator. A link to Norton's abrasives connection and website to find and order product, check orders and inventory is available, in addition to a convenient button to contact Norton. "With the increasing use of handheld digital technology, we are pleased to offer our customers with a convenient, simple-to-use grinding app," said David Long, director of marketing and strategy at Norton Abrasives. "The app is designed for manufacturers to quickly simplify the process of calculating the requirements for their grinding application." The new Norton Grinding App is available for IOS and Android operating systems on mobile devices.



For more information:
Saint-Gobain Abrasives
One New Bond Street
P.O. Box 15008
Worcester, MA 01615-0008
Phone: (508) 795-5000
www.sgabrasives.com

Flexible Abrasive Wheels

BLEND AND FINISH IN SINGLE OPERATION

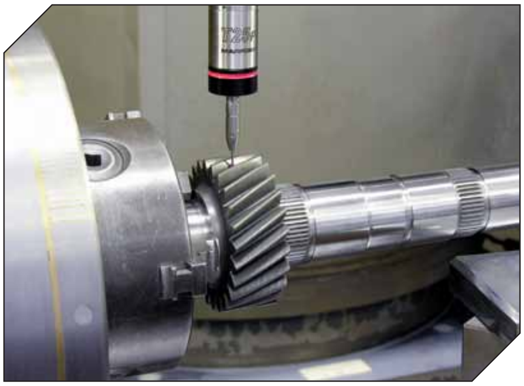
An upgraded line of blending, finishing, and polishing wheels that operate at higher rpms for use in automated and hand finishing operations has been introduced by Rex-Cut Abrasives of Fall River, Massachusetts. Rex-Cut Smooth Touch

Blending and Polishing Wheels feature non-woven cotton fiber construction that constantly exposes fresh abrasives as they work, are flexible, conformable, and provide smooth control. Suitable for use on stainless steel, exotic metals, and aluminum requiring a high finish, they are available in standard coarse, medium, and fine grits for use at speeds up to 30,000 rpm, depending upon diameter and thickness. Incorporating a proprietary bond that provides a single density for applications comparable to conventional 2-9 density unitized wheels, Rex-Cut Smooth Touch Blending and Polishing Wheels are available in 2", 3", 4", and 6" dia. sizes, ⅛", ¼", and ½" thick. They will also last up to five times longer than conventional unitized wheels, claims the firm. Rex-Cut Smooth Touch Blending and Polishing Wheels are priced according to grit, size, and quantity. Samples and pricing are provided upon request.

For more information:
Rex-Cut Products, Inc.
960 Airport Road
P.O. Box 2109
Fall River, MA, 02722
Phone: (800) 225-8182
www.rexcut.com

Marposs
INTRODUCES TOUCH PROBE SYSTEM

Marposs Corp. announces the new Mida T25P ultra-compact, high accuracy touch probe for machine tools with piezoelectric technology. Although piezoelectric sensors are well known in various metrology applications, the new T25P is the first touch probe for machine tool applications to incorporate this technology. The T25P touch probe's excellent multi-directional response characteristics make it ideal for high accuracy machining applications such as tool and cutter grinders and sharpeners.



Specifications of the T25P probe include unidirectional repeatability of (2σ) 0.25 µm, 2-D lobing in X/Y: ±0.25 µm, and 3-D lobing in X/Y/Z: ±1 µm (based on use of a 35 mm length stylus). The T25P touch probe consists of three basic components—the tripod kinematics, the piezoelectric sensor, and a microprocessor circuit board. The tripod kinematics supplies stylus mechanical overtravel and provides double crash protection. Unlike other touch probes that require triggering of a switch, the T25P probe operates by means of a change in voltage. Upon detecting a contact by the stylus from any direction, a pulse signal of constant duration is generated that is elaborated by the PCB's microprocessor and made available for output to the probe's interface with the machine tool's CNC.

The T25P probe has very low trigger force and zero pre-travel, therefore the time between the point of contact by the T25P probe and the resulting signal is significantly reduced compared to traditional mechanical touch probes. Because the trigger point is identical in every direction, it is only necessary to calibrate the probe in one axis regardless of the number of axes or approach directions. The T25P probe is protected from temperature variations, high-pressure coolant and harsh environments.

For more information:
Marposs
3300 Cross Creek Pkwy
Auburn Hills, MI 48326
Phone: (248) 370-0404
www.marposs.com

Ipsen

SHIPS CUSTOMIZED TURBOTREATER

Ipsen has recently shipped an H3636 2 bar TurboTreater furnace to a commercial heat treatment company in the southeastern U.S. The state-of-the-art, high-temperature furnace included a 2-inch thick carbon composite/graphite felt hot zone with a nominal work zone of 24" × 24" × 36" (610 mm × 610 mm × 914 mm) and a gross load capacity of 1,500 pounds (680 kg), configured for 460 volts, 60 hertz, 3 phase. The furnace was equipped with the user-friendly CompuVac supervisory control system, as well as a nitrogen and argon partial pressure system.

The TurboTreater offers patented mechanical features such as the Ipsen unique quarter-twist graphite heating element support hanger, which provides metallic support for ceramics; the flared locking rim for molybdenum cooling gas nozzles, which secures them in place into a rounded extrusion in the plenum wall; and the cooling system design, which generates the highest heat transfer coefficient of any vacuum furnace on the market.

The convenient and efficient TurboTreater line operates as a "build-your-own" furnace, allowing customers to order furnaces specified to their unique needs. Possible modifications include variations on features such as the hot zone insulation package, heating elements, pumping systems, cooling gases, plant voltage, control system and loaders. This allows for the line to be used for a number of processing capabilities including: hardening, annealing, surface treatment, brazing, coating and tempering. These alterations, along with Ipsen's simplified installation, start-up, operation and troubleshooting, are just some of the ways that Ipsen delivers the best, so customers can be the best.

For more information:
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984 Ipsen Road
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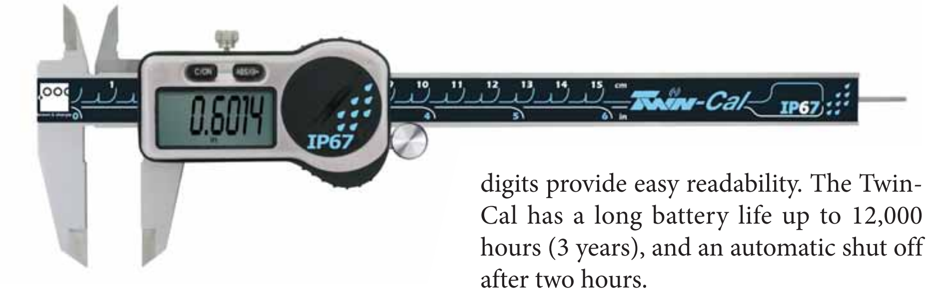
www.ipsenusa.com

Hexagon Metrology

RELEASES TWIN-CAL IP67 CALIPERS



Hexagon Metrology recently released the new Brown & Sharpe Twin-Cal IP67 calipers with a built-in output connection. This electronic measuring tool is IP67 compliant with its main components encapsulated and protected from shop floor contaminants such as dust, oil and coolants. The adaptable calipers can be used wirelessly or with a cable using the new plug-and-play TLC (TESA Link Connector). This digital caliper is suitable for countless applications in the metrology laboratory or on the production floor, often in combination with mechanical instruments or stationary machines.

The new plug-and-play TLC allows the user to send measured data from the instrument to the computer via USB, Twin (TESA Wireless Interface, available Q1, 2013) or Digimatic option. The USB cable connection allows the caliper to be directly connected to a computer. The wireless module is integrated in the battery cap and enables the operator to retrieve data for optimal SPC monitoring. Digimatic output is a cabled connection that allows Brown & Sharpe instruments to work with any competitor's interface. For the same cost, the adaptable calipers are available with any of the interface options. The TLC also has an IP67 rating to withstand the same harsh conditions as the caliper.

"This evolutionary, adaptable instrument will revolutionize connectivity thanks to its Twin concept," says Martin Hedman, TESA group managing director and CEO. "Brown & Sharpe hand tools have a solid reputation for quality, dependability and workmanship. We have produced hand measuring tools for more than 150 years. The new Twin-Cal IP67 caliper is just another example of our market leadership in innovation."

The Twin-Cal has an instant inch/metric conversion option, with a measuring range of 150 mm/6 in., 200 mm/8 in. and 300 mm/12 in. The caliper maintains a resolution of 0.01 mm/0.0005 in. with repeatability of 0.01 mm. The absolute measuring system retains a zero setting so the calipers are ready to measure when turned on. Soft touch features allows for consistent, smooth measurements. With the largest LCD to date, 11-millimeter digits provide easy readability. The Twin-Cal has a long battery life up to 12,000 hours (3 years), and an automatic shut off after two hours.

For more information:
Hexagon Metrology
250 Circuit Drive
North Kingstown, RI 02852
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Gear Grinding Gets Integrated at IMTS

Matthew Jaster, Associate Editor

More than 100,000 visitors arrived to IMTS in Chicago from September 10–15, making it the strongest showing for the manufacturing technology trade show in over a decade. For those focused on gear manufacturing, the North Hall's Gear Generation Pavilion was a great place to get a head start on the competition. In just a few short steps, an eager attendee could seek out the latest grinding wheel solutions, view demonstrations of faster machine tool set-up changes and witness gear accuracy with much less noise. Machine integration was the topic of choice throughout the four halls with a focus on tooling, machine upgrades and energy efficiency.

"Attendees and customers were looking for expert partners," said Bill Miller, vice president of sales at Kapp Technologies. "Several were acutely aware they needed to add gear grinding capability. We met with a company that does not currently grind and is being considered for a huge contract involving grinding. Still another had a need to modernize their internal tooth grinding capability."

"Customers are looking for technologically cutting edge solutions at a competitive price. But above all else they're looking for process flexibility," said Enrico Landi at Samputensili S.p.A. "For us, this means providing them with advanced solutions that ensure the highest accuracy and functionality over the years without becoming obsolete over a short period of time."

"Our customers are seeking any features or capabilities that provide quality, productivity, flexibility and total cost ownership. The specific features and capabilities to facilitate these improvements will vary by supplier, process and machine type," said Al Finegan, director, marketing at Gleason.

"Customers were looking for possibilities to improve their grinding times without sacrificing gear quality. Further discussions centered on how to reduce the tool costs per part. Finally, for manufacturing of high-end gears, the possibility to grind twist-free or with special twist was what our customers were looking for," said Andreas Mehr, technology development engineer, at Liebherr.

At the Reishauer booth, Dennis Richmond, vice president said, "Most manufacturers I spoke to were looking for total process responsibility from a single source, meaning one supplier for the machine, dressing tool, grinding wheel, process parameters and tool management."

The G 250 from Samputensili has been developed for top-quality and efficient mass production of gears with outside diameters up to 250 mm and shafts with lengths up to 500 mm (courtesy of Star SU).

A Strong Single Platform

Faster setup times, higher productivity and maximizing machine utilization are concepts that were often discussed during IMTS.

"It's apparent that gear grinding technology is following the path of integrating multiple processes into a single machine platform," said Kapp's Miller. "It is not easy to do this well and even harder for attendees to evaluate."

"At Samputensili we address the needs of two very different sectors: the automotive field and job shops," Landi said. "Automotive customers are constantly striving to improve productivity and process integration, whereas job shops especially focus on process flexibility. Guaranteeing flexibility means continuously investing in research and development, accurate project flexibility and quality workmanship."

Finegan at Gleason believes machine integration and multifunctional capabilities are long-term trends that will be the focus for the foreseeable future. "Customers are seeking profile grinding, continuous (threaded wheel) grinding, and other combinations of both on the same machine. In addition, on-machine gear inspection, wobble compensation, digressive infeed, adaptive grinding and other features and capabilities, all which positively affect quality, productivity, flexibility and total cost of ownership," Finegan said.

On the LCS 500 gear grinding machine, Liebherr displayed a type of error-proofing called *Collision Control* which many attendees found valuable (courtesy of Liebherr).

Höfler is well known as a supplier of form grinders and showcased its first grinder for the threaded gear grinding method during IMTS. Both form grinding and threaded wheel grinding can be utilized on the Rapid 1250 W, giving it an advantage in the machine integration process. Additionally, the Helix 400 SK boasts the ability to utilize two different grinding wheels in one setup. This is a significant advantage for customers demanding high quality levels with two different gears.

Kapp's ZX 1000 features a large ductile iron bed and torque motor for high load capacity (photo by David Ropinski).

Gear Grinding Tech

The emphasis on innovation at IMTS had exhibitors showing off their latest grinding capabilities with booth demonstrations, video displays and application and design engineers on-hand to answer questions. Here are a few gear grinding highlights from the show:

Mitsubishi Heavy Industries featured the ZE40A, a universal gear grinding machine capable of numerically controlled (NC) high-precision machining of post-heat treatment gears. The ZE40A was designed for both table and grinding spindles and offers gear accuracy within its diameter capacity of 400 mm.

"Liebherr's new fast dressing process on the LFG 1250 profile grinding machine, especially the second dressing spindle offering up to two times faster dressing times, was of great interest to our customers," said Mehr. "A further time saving option on this machine is the possibility to grind with a high speed axial feed rate of 18,000 mm/min. With this value the LFG is ready for the future, when new abrasives will achieve higher Q-prime (Q'w) values."

On the LCS 500 gear grinding machine, Liebherr displayed a type of error-proofing called *Collision Control* which many attendees found valuable. "This software feature reduces or eliminates damage between the tooling and other machine components like clamping fixtures, etc. Also the workpiece is saved from harm. Heavy and expensive machine crashes, often caused by mistakes in programming or manual jogging of axes, are avoidable with this Liebherr-developed system," Mehr adds. All CNC-axes can be controlled with the *Collision Control* software. This software is not only available for Liebherr gear-grinding machines, but also offered on Liebherr gear hobbling and shaping machines as well.

The RZ 60 on hand at IMTS in the Reishauer booth was optimized for automotive applications. The machine's structure was based on the larger RZ 260 model, allowing for aggressive grinding parameters without negative effects on workpiece quality. "The RZ 60 was being loaded by the Felsomat FSC 600 loader," Richmond said. "We were grinding a 23-tooth pinion in just under 12 seconds floor to floor; do the math, that's five parts per minute!" High spindle speeds (3,000 rpm) make it possible to spin the grinding oil off the part during the turret rotation when the grinding operation is completed. All axis movements have been optimized to reduce unproductive cycle segments. With the assistance of the FSC 600 loader, the RZ 60 can exploit high productivity and operate autonomously without operator intervention and the system can be integrated into the Reishauer and Felsomat FlexLine.

At Kapp Technologies, Miller noted that customers were drawn to the technology of generating grinding that the company showcased. "Our new KX100 Dynamic drew huge interest for the integrated loading and setup time savings," Miller said. Additionally, the company featured the KX 500 Flex incorporating an indexing table with a direct-drive work spindle, tailstock support and dressing spindles. The ZX 1000 was also on the show floor, boasting a large ductile iron bed and torque motor for high load capacity.

Using video and other media, Gleason promoted both its bevel and cylindrical gear grinders including its wobble compensation technology that addresses the time consuming step of manually aligning the workpiece. Gleason wobble compensation technology allows customers to maintain and in some cases improve the quality of their grinding operations while simultaneously improving production throughput. This improves the quality, enhances operator performance and reduces overall fixture costs.

Improving its existing sales and service activities in North America has been a priority for Höfler. Ralf-George Eitel, CEO of Höfler America Corp., emphasized as much during the exhibition.

Kapp's ZX 1000 shares common machine elements and software with the KX 500, and comes standard with the same process flexibility for profile or generating grinding (photo by Dave Ropinski).

"Höfler customers benefit from the continuous engineering and sales support that we provide, particularly when flexibility is a priority. Our engineers travel and assist with customers long after a machine has been sold."

At the Star SU booth, Landi said that Samputensili registered positive feedback for its vertical grinding machine, the G 250. The G 250 has been especially developed for very low cycle times and for top-quality and efficient mass production of gears with outside diameters up to 250 mm and shafts with lengths up to 500 mm. The secret behind the machine's efficiency is the dual work spindle concept, which eliminates non-productive auxiliary times almost completely. By means of the dual work spindles, the loading/unloading process of a workpiece is carried out in masked time, while simultaneously the manufacturing process proceeds on another workpiece. The G 250 can equally use form and worm grinding wheels, both in ceramic and in electroplated CBN.

Market Trends for 2013

Though Miller notes that investments seem to pause during major elections, he believes the gear manufacturing market is in a good place. "Most forecasts point to a strong aerospace market. Other than wind energy and mining, our customer base seems to be operating at a strong and sustainable level."

"Customers from mining, heavy equipment, energy and automotive were present at our booth," says Scott Yoders, vice president sales at Liebherr. "A highlight feature for coarse-pitch gearing was the automation of heavy parts. For example, on the LCS 500, a ring loader with high payload capacity was shown. This ringloader design is actually installed and in production for gear applications up to 800 mm and 1,000 kg."

"In today's uncertain and tumultuous global economy, where markets experience strong growths as well as sudden halts, we need flexible products, i.e. products that can be easily configured according to the particular needs of that application," said Landi. "Thanks to the flexibility of our grinding machines, we can supply any manufacturer of gears, shafts, screws and rotors, no matter what market they are active in."

Richmond at Reishauer added, "Automotive and tier one suppliers will continue to use a lot of our manufacturing capacity in the near term; these projects can have multiyear impacts from initial concept to installation and implementation."

Several machine demonstrations during IMTS solidified what the manufacturing industry is trying to accomplish regarding machine integration: Smaller equipment that handles multiple operations, easier setup changes and simpler operations and maintenance procedures. Add to the mix strong service and training support and you've found the blueprint for future success in gear grinding. "Customers are struggling to find trained personnel," Miller said. "Setup time is a huge variable of equipment utilization and that focus will continue. Equipment reliability, expert training and support are perennial requirements."

"Our customers attach an ever increasing importance to process automation," said Landi at Samputensili, "which is and will be a strategic feature in gear grinding for years to come."

Sidebar: IMTS Impressions

Now that gear industry suppliers have returned from the trade show circuit, *Gear Technology* was curious what they thought about IMTS 2012:

"We were very pleased with the traffic in our booth and it was evident early on in the week that attendance for this year's show had jumped significantly over 2010," said Mark Parillo, director of marketing at Star SU. "The general pulse of our visitors was very positive leaving us with many reasons to be encouraged heading out of IMTS and into the coming year."

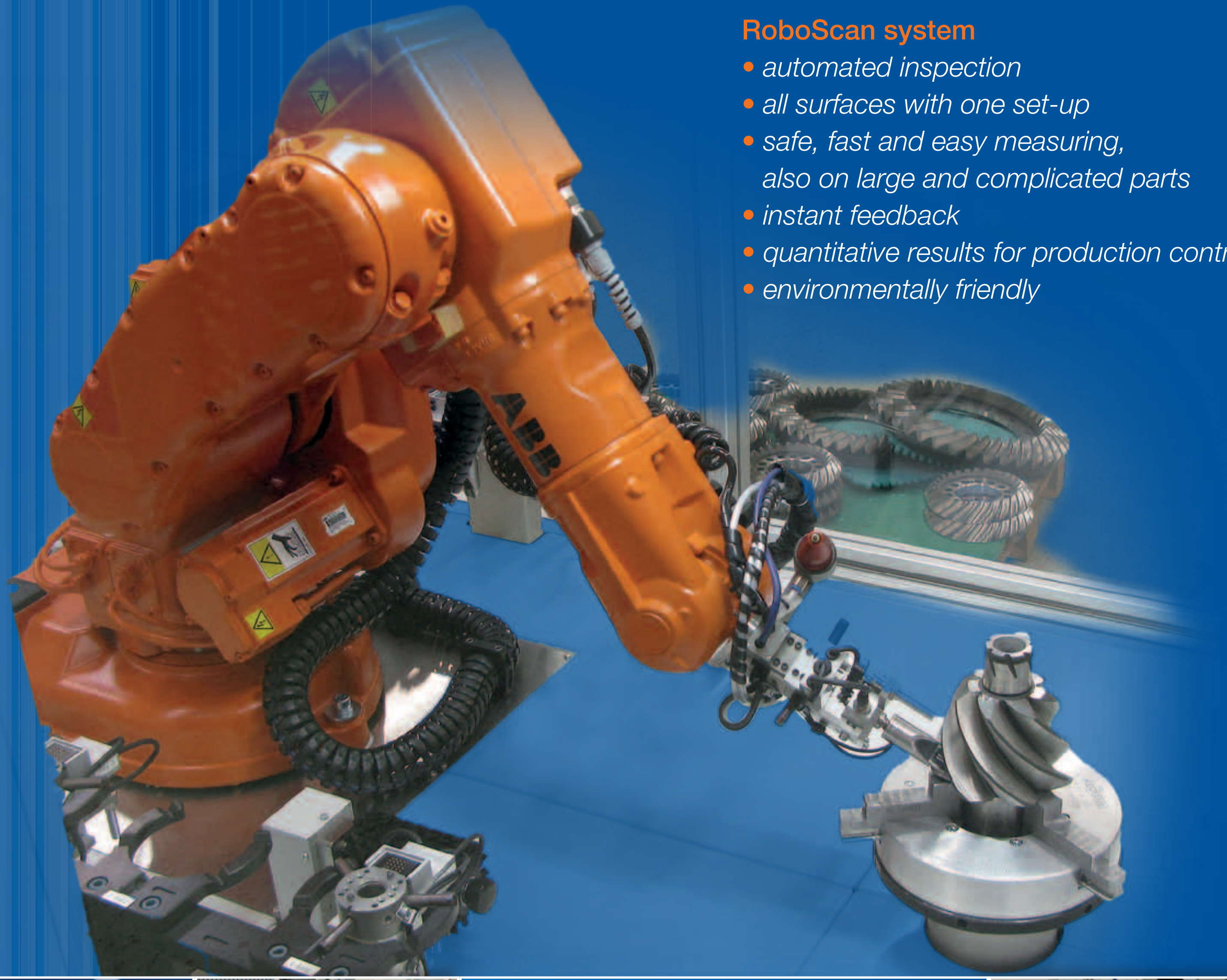
"IMTS was well attended and the weather always seems to cooperate to make this a significant week," said Bill Miller, vice president of sales at Kapp Technologies. "I can only assume the other gear pavilion exhibitors were also satisfied, although our booth activity didn't permit even a short tour."

"We found IMTS 2012 to be generally positive and upbeat, although it seemed like overall attendance dwindled as

The MHI ZE40A was designed for both table and grinding spindles and offers gear accuracy within its diameter capacity of 400 mm (courtesy of Mitsubishi).

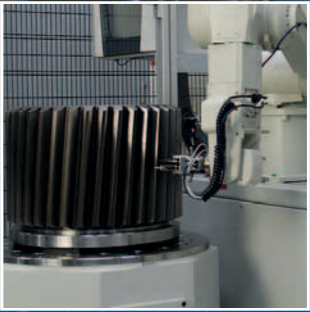
Gear Up Your Quality Control

Robot systems for quality control of surface treatment such as grinding and shot peening by Barkhausen Noise and X-ray stress measurements.



RoboScan system

- *automated inspection*
- *all surfaces with one set-up*
- *safe, fast and easy measuring, also on large and complicated parts*
- *instant feedback*
- *quantitative results for production control*
- *environmentally friendly*



For residual stress testing by X-ray diffraction

Xstress Robot

- *reaches hard-to-reach areas*
- *handles complicated and large parts easily*
- *provides maximum flexibility and easy positioning*
- *is fast and precise*

stresstech group

www.stresstechgroup.com

the week wore on," said Al Finegan, director of marketing at Gleason. "The gear pavilion included most of the major suppliers of gear manufacturing technology, but it continues to shrink through industry consolidation and cooperative relationships."

Total registration for the six-day event was 100,200, which is a 21.6 percent increase over 2010, marking the largest show-to-show increase ever for IMTS. Additive manufacturing, multi-spindle machines and multi-tasking machines were stars on the show floor. The productivity improvements and accuracy showcased by dozens of exhibitors with new offerings in multi-spindle and multi-tasking machines and automation drew serious attention.

"The energy level among visitors and exhibitors was at an all-time high," said Peter Eelman, IMTS vice president – exhibitions and communications. "The most exciting take-away from IMTS 2012 is what it says about the prospects for manufacturing over the next year. The overall activity and buzz indicates that we are entering a period of sustained growth that will fuel economic prosperity and job creation. Visitors came to find solutions and innovative approaches to their manufacturing challenges."

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Star SU LLC.
5200 Prairie Stone Parkway Ste 100
Hoffman Estates, IL 60192
Phone: (847) 649-1450
www.star-su.com

Reishauer's RZ 60 in combination with Felsomat Flex Stacking Cell FSC 600 allows for the automated production of planetary pinions in the auto industry (courtesy of Reishauer).


Gleason
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1200G
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GOT A GEAR QUESTION?

Ask the Expert!

Welcome back to *Gear Technology*'s Ask the Expert—our popular regular feature intended to help designers, specifiers, quality assurance and inspection personnel in addressing some of the more complex, troublesome gearing challenges that never cease to materialize—whether on the drafting table or the shop floor. Simply email your question—along with your name, job title and company name (if you wish to remain anonymous, no problem)—to: *jmcguinn@geartechnology.com;* or submit your question by visiting *geartechnology.com*.

QUESTION #1

Center Distance Variations for Internal Gears

(While) external involute gears are very tolerant of center distance variations, what are the center distance constraints/parameters for internal gears?

One of the beauties of the involute tooth form is its ability to operate smoothly on a relatively inaccurate center distance. This is a result of the tooth flank "unwinding" from the base circle. Conjugate tooth action can take place anywhere along the involute curve, so long as root interference is avoided and enough "profile overlap" remains to get the next tooth pair into action. Profile overlap ratios of as low as 1.20 have been successfully used, but I recommend a minimum of 1.40 to avoid the set feeling "toothy" during rotation.

This situation applies to both internal *and* external gears. To the casual observer it might appear that internal gear sets would have other constraints, but as far as the teeth are concerned, root interference is root interference. While it is common practice to reduce the operating addendum on internal gears as much as 5 percent to minimize the possibility of root interference with the mating external pinion or planets, it is not always required. The inside diameter of the internal gear—also known as the addendum circle—is sometimes enlarged to avoid trimming by the shaper cutter; but this is not a center distance issue.

No clear guidance exists on what is an appropriate "tolerance" for a given center distance; some companies have design practices that apply a fixed plus/minus value to all center distances—regardless of size. Others only apply a "plus" tolerance. It is very helpful for the gear designer to know the process capability of the machinery involved with making the housings the gears will be operating in.

This author's practice for industrial gearboxes is to vary the center distance tolerance by size. A plus/minus tolerance of .0010" is used for centers from 1.5 to 4.0 inches, with an additional .00025"/inch tolerance as the housing gets larger. Thus a 6.000 inch nominal center distance has a +/-.0015 tolerance, while a 12.000 inch nominal center distance has a +/-.0030" tolerance. These tolerances are used on both internal and external gears. The tolerance values are within the process capabilities of most well-maintained, computer-controlled milling machines.

Best regards,

Charles D. Schultz, PE

Chuck Schultz is a *Gear Technology* technical editor and gear industry consultant *(chuck@beytagear.com; www.beytagear.com)*, and is an active member of AGMA's Helical Gear Rating, Epicyclic Enclosed Drives and Wind Turbine Gear committees.

QUESTION #2

Differential Gears

Bevel gears used in differentials seem to be forged in most automotive applications. Old developments are Gleason Coniflex-cut developments, but it seems modern developments are computer-generated. I have never seen (literature) about who does this and wonder if it is true and why it is not (discussed).

Automotive differential gears are generally Gleason Revacycle designs. Revacycle gears are cut by a large circular broach, which is extremely productive (Fig. 1). Typical features of differential gears are the high pressure angle of 22.5° and coarse-pitch teeth with near-miter ratios. The wide root fillets of the Revacycle gears have a fully rounded radius for maximum root bending strength. The Revacycle process form-cuts the tooth profiles; the broach cutter moves from toe to heel during the roughing portion of the cycle and then back to the toe in a climb-cutting mode in order to finish the flank surfaces and generate a straight root line. However, the flank profile of the Revacycle blades has a radius that approximates the involute in order to create some profile crowning at the same time. Differential gears require the highest power density of all bevel gear types.

The variety of differential gears compared to hypoid gears in automotive axle drives is rather limited. This opened the door for forging companies to offer forged differential gears, which can be manufactured both in high volumes and very economically. The first electrodes for the spark erosion process of the forging dies were Revacycle-cut copper gears. The promoter of forged differential gears pointed out the possible advantages regarding strength attributable to the grain flow in material structure. Plus, forging presents the possibility to form webs on both toe and heel (Fig. 2) in order to reduce root bending stress and, consequently, further increase power density. However, the webs prevent the free bending that can initiate cracks in the web transition to the teeth; this also promotes early pitting due to the elimination of a "contact breathing" under varying loads. Figure 3 shows a typical forged differential gear with pittings on the left flank. Although there are geometry freedoms like the webs that can be applied in forging—but not in cutting, due to the constraints of a rotating cutter—the forged differential gears with highest strength are those that simply duplicate the Revacycle geometry.

Although forged differentials have near-net quality—thus requiring a calibration process step—the flank surface variations in production parts are significantly larger when compared to parts manufactured by the cutting process. This also influences tooth thickness and backlash; the backlash of differential gears should be zero. During the tool life of a die, the tooth thickness changes and may lead to unwanted backlash and jerking in the drivetrain of a vehi-

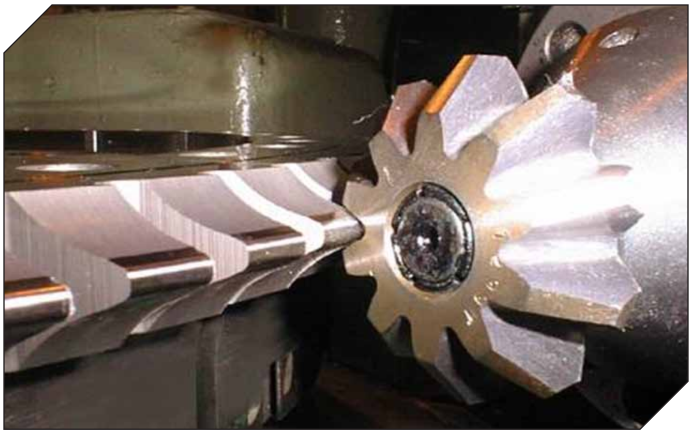
Figure 1 **Broaching of a differential gear with Revacycle.**

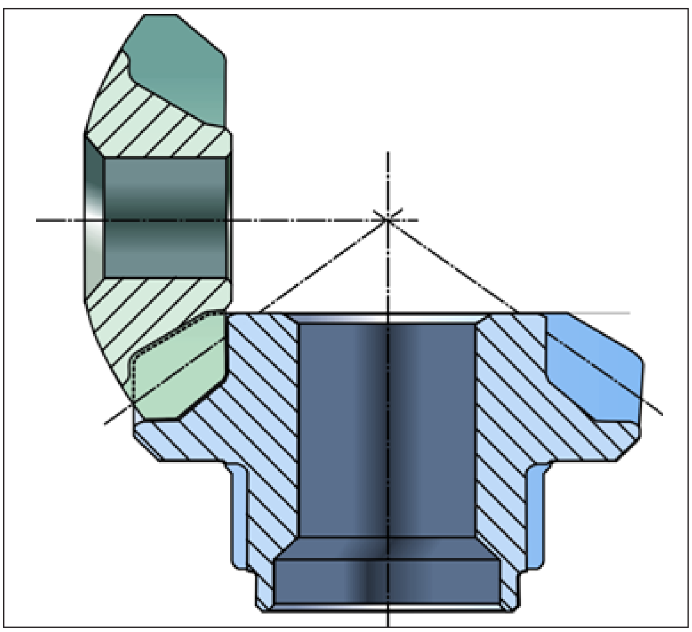
Figure 2 **Cross-sectional drawing of forged differential gear pair with web-closed heel.**


Figure 3 **Forged differential gear with pitting.**

cle. Also, noise unique to forged differentials is greater than that of cut parts. To address this problem, a practice was adopted combining two *forged* and two *cut* differential gears—an approach that provided excellent lubrication properties and low noise.

Today, however, some manufacturers of premium vehicles use either four Revacycle or a combination of two Revacycle and two forged differential gears. Most manufacturers of mass-produced differentials, however, use only forged differential gears.

Many truck applications, depending on the quantity, and all differentials for special applications, are still manufactured with Revacycle gearing or the alternative method—Coniflex—a Gleason process developed for cutting industrial straight bevel gears. Coniflex enables a close match of the Revacycle geometry. In the past, mechanical cradle-style machines with many setup axes were used to cut Coniflex gears—a rather slow process (Fig. 4).

The latest development is the ConiflexPlus technology. A single carbide stick blade cutter is used in a high-speed dry cutting process on freeform Phoenix machines (Fig. 5), which are also used for spiral bevel and hypoid cutting.

The gear design is made with *Windows* software that features analysis of tooth contact calculation, undercut check, calculation of backlash, clearance and more. Nominal tooth surface grids for a CMM are also a standard of the new software. If the measured flank form deviates from the theoretical target, then corrections can be calculated with *G-AGE* software, residing on the CMM computer. Thus the latest closed correction loop methods can be applied for Coniflex straight bevel gears.

Mathematically precise tooth surface definition and contact analysis (Fig. 6) helped to develop a modern version of the Coniflex design with increased strength and improved rolling behavior. US-Gear, a division of AxleTech International, is one of the manufacturers that offers this technology in the axle units for high-power density truck differentials.

Best regards,

Hermann J. Stadtfeld

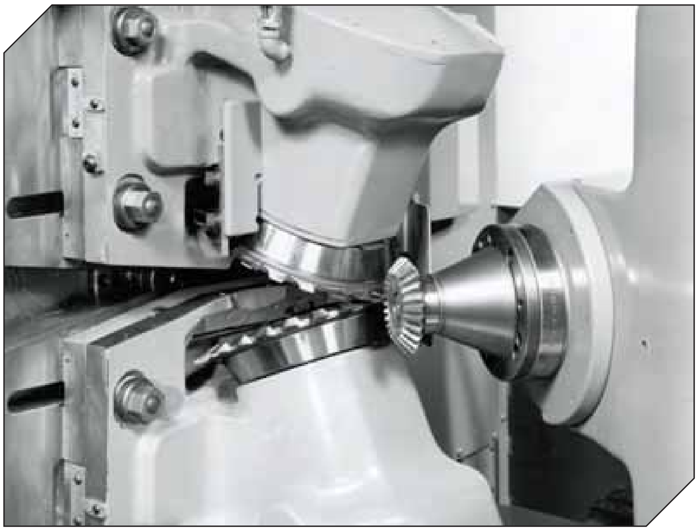

Figure 4 **Coniflex cutting with interlocking HSS cutter disks.**

Figure 5 **ConiflexPlus high speed dry cutting on a Phoenix 275HC machine.**

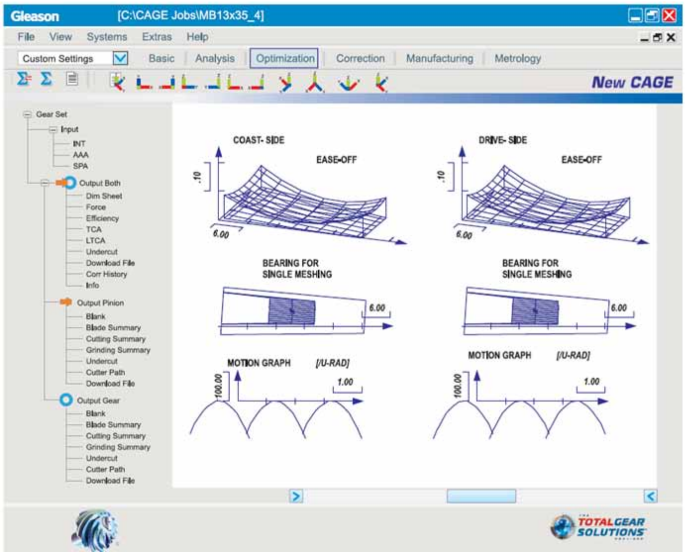

Figure 6 **Coniflex design and analysis software.**

Dr. Hermann J. Stadtfeld is vice-president, bevel gear technology R&D for Gleason Corp. and a frequent contributor to *Gear Technology* magazine.

Pitting Resistance of Worm Gears: Advanced Model for Contact Pattern of Any Size, Position, Flank Type

Prof. Dr.-Ing. K. Stahl, Prof. Dr.-Ing. B.-R. Höhn,
Dr.-Ing. J. Hermes, Dipl.-Ing. A. Monz

An experimental and theoretical analysis of worm gear sets with contact patterns of differing sizes, position and flank type for new approaches to calculation of pitting resistance.

Nomenclature

a	Center distance	(mm)
l_{eff}	Effective width of line contact	(mm)
n_1	Input rotational speed	(min^{-1})
u	Gear ratio	(-)
E'	Reduced e–module	(N/mm^2)
F_N	Normal force	(N)
K	Stribeck rolling pressure	(N/mm^2)
L_{hI}	Pit lifetime in Phase I	(h)
N_{LI}	Stress reversals in Phase I	(-)
ρ_E	Equivalent radius of curvature	(mm)
σ_H	Hertzian stress	(N/mm^2)
σ_{Hm}	Mean Hertzian stress	(N/mm^2)

Introduction

In highly loaded, steel-bronze worm gear sets, their maximum capacity is determined primarily by the types of damage incurred; i.e., "tooth breakage" and "pitting." In practice, larger-size worm gears are those with a center distance of more than 200 mm. Unlike a steel-steel or steel-cast iron material combination, pitting damage to a bronze worm wheel does not necessarily lead to teeth failure. Rather, the pitting area may in fact decrease due to the gradual, abrasive wear of the affected surface. Though pitting initially reduces the meshing area of both worm and worm wheel, it will induce noise and reduce gear set efficiency. Therefore precise knowledge of the pitting lifetime of large, high-efficiency worm gear sets is an important design criterion.

To facilitate actual assembly of a worm gear, convex—i.e., shell-shaped—contact patterns are typically produced—although smaller when compared to a completely formed contact pattern. Thus the initial position of the contact pattern between worm and worm wheel is more easily determined and optimally adjusted. Most often, the transmissions are immediately exposed to system operating conditions and rarely subjected to run-in. Because the abrasive wear on the worm wheel of large-size gear sets is minor, no complete contact pattern is formed for most of its lifetime. And, as no mathematical proof determining early pitting resistance of worm gear sets caused by insufficient contact pattern has yet to be documented, providing such mathematical proof has been the main motivation for this research.

The State of the Art

Calculation of pitting lifetime is primarily based on the analysis of Rank (Ref. 12), which is contained in the calculation method DIN 3996 (Ref. 4). Calculation of pitting lifetime is recommended according to (Ref. 4) if the calculated pitting safety is $S_H < 2.0$. This is usually the case—especially for large worm gear sets with typical low wear intensity. Rank (Ref. 12) subjects his test gear sets to a long run-in with reduced load and achieves a full contact pattern between worm and worm wheel without prior deterioration of the flanks. Current technology requires therefore a completely formed contact pattern between worm and worm wheel in the calculation.

Pitting is generally ascribed to a surface spalling of the material due to repeated overstepping of the allowed fatigue limit and the material's so-called "rolling strength." Pitting occurs on the weaker of the two rolling contact partners—typically the worm wheel bronze. Rank (Ref. 12) explains this procedure by the changing mechanical stresses in the claimed surface areas in the tribological system tooth contact. The local Hertzian stresses in the tooth contact between worm and worm wheel are not constant and change continuously. If the yield stress is exceeded, they begin with the first operating phase and through the adaption of the worm wheel flank to the worm flank by abrasive wear and a local yielding of the worm wheel material. This means that the appearance of initial pitting damage can always be explained by the overload of a discrete flank section. Depending on the present rolling strength of the worm wheel material, these loads are able to bear a specific number of stress reversals until the flank area quarries out in the form of pitting. According to (Ref. 12), pitting and its associated wear intensity can be subdivided into three characteristic sections. The pitting area described by the pitting parameter A_{P10} on the worm wheel can be used to define these sections. A_{P10} represents the average pitting area of the most damaged teeth in percentage; the value is deduced from the overlap and is approximately 10% of the worm wheel teeth. The lifecycle begins with Phase I—i.e., the stage of no pitting and low wear intensity. At this point there is no damage to the wheel flanks; the gear set, with its still fragmentary contact pattern, is run-in during this phase; the contact patterns grows; the cutting marks and roughness peaks of flanks are straightened; and the resulting peaks of Hertzian stress are partially reduced. By local exceeding of the

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rolling strength, surface cracks appear that may cause pitting. The end of Phase I is defined with $A_{P10} = 2\%$.

In Phase II—during which pitting growth occurs—in linear terms the pitting area enlarges approximately to a maximum-area A_{P10max}. A maximum-value A_{P10max} of 60–80% is usually benign and trouble-free operation of the gear set results.

However, when the maximum pitting area is reached, wear intensity increases, leading to Phase III—i.e., decreasing pitting and comparably high wear. The incipient sliding wear—clearly exacerbated due to the significantly reduced meshing area—in turn reduces the pitting area. Upon further operation, end-of-teeth lifetime is eventually reached due to collateral damage such as wear limit, tooth breakage or impermissible, high-transmission errors and induced vibrations and noise.

Rank (Ref. 12) analyzes the influencing variables of pitting and its proliferation and devises a wear-based approach for predicting the pitting lifetime of the three pitting phases described above. He affirms the reports of Niemann (Ref. 9), stating that the essential influence at play in the pitting of worm gear drives is Hertzian stress in tooth contact and, thus, premature pitting damage begins with growing Hertzian stresses. Experiments examining variation of the sliding speed of the teeth show that the beginning of pitting is barely influenced by such sliding speed and concerns can be dismissed for the lifetime of Phase I. The speed of the pitting increases in Phase II due to low sliding speed. From these coherences (Ref. 12) derive approximate formulas for lifetimes in the three pitting phases relevant to mean sliding speed and mean Hertzian stress. Here it is assumed that a finished run-in of the worm wheel flank leads to a consistent distribution of Hertzian stress—an approach based on Predki (Ref. 11), who derived the physical parameter p^* from calculation of the pressing distribution in teeth contact—and assuming that Hertzian stress along the lines of contact—which are in contact at the same time—are constant. Conversely, Bouché (Ref. 2) detected an irregular pressure distribution based on an approach of a wearing of the friction lining for a run-in worm gear set. He compares the results with the experiments of Böhmer (Ref. 1). In doing so he discovered a good correlation of the maximum values for Hertzian stress and pitting location; Wilkesmann (Ref. 16) calculated similar results for pressure distribution. And, Octrue (Ref. 10) and Hermes (Ref. 5) affirm this correlation based upon their own calculation approaches. Rank (Ref. 12) diversifies further the location of the primary contact pattern between worm and worm wheel. As a result, pitting location depends essentially on the location of the primary contact pattern; i.e.—the time until initial pitting and its subsequent spread to a maximum-area-of-damage the size of the primary contact pattern. Through the work of Lutz (Ref. 8), Weisel (Ref. 15) and Sievers (Ref. 13), it is possible to calculate pressure distribution for incomplete contact patterns. Weisel (Ref. 15) conducted numerous experimental inquiries and formulated an approach for calculating development of contact pattern, wear-carrying capacity and efficiency of worm gear sets with complete contact pattern during operation. He (Ref. 15) compares the calculated results to Rank's (Ref. 12) global calculation of pitting lifetime and determines that pitting lifetime—which was achieved in the examination—is much lower than once thought.

And yet, an all-embracing approach for contact patterns of any size, position and Flank-Type—offering a reliable prediction for the onset and location of pitting—does not yet exist.

Such an approach is introduced in the following.

Test Stand Operations

This analysis presents a method for predicting the location and pitting lifetime of worm gears of all sizes, positions and Flank-Types. Accordingly, a battery of Phase 1 tests were conducted on worm gear sets with knowingly uncompleted contact patterns and then evaluated; the results were compared to the new method. The initial contact patterns of the worm gears are comparable in position and size to those typically found in industrial applications.

Test conditions. The operations were carried out with cylindrical worm gear sets with Flank-Type I and C with a center distance between 100–315 mm and a gear ratio of 6.6–24.5. The tests with a center distance of $a = 170$ mm, $a = 180$ mm and $a = 250$ mm were run on Siemens test rigs. The tests with a center distance of $a = 315$ mm were conducted at FZG (*Forschungsstelle für Zahnräder und Getriebebau—Prof. Dr.-Ing. K. Stahl—TU München, Garching)*. The re-evaluation of testing conducted by (Refs. 12 and 15)—which should serve to validate the new approach for completed contact patterns—was also done at FZG. Testing with the reference standard teeth—(Ref. 4)—and with reduced contact pattern—was also done at FZG. Additional research of pitting and pitting growth was conducted by Jacek (Ref. 7) on worm gear sets at LMGK (*Lehrstuhl für Maschinenelemente, Getriebe und Kraftfahrzeuge—Prof. Dr.-Ing. W. Predki—Ruhr-Universität Bochum, Bochum*). These, too, were used for validation of the new calculation approach. Thus the experimental matrix covered the scope (Ref.4) for concave-convex and convex-convex wheel sets and expanded it for greater center distances ($a >$ 250 mm).

Case-hardened worms made of 16MnCr5 and gear rims made of CuSn12Ni2-C-GZ were used, with the required bronze meeting the high quality standards of the "worm gears research group" of FVA that were developed and optimized in the framework of numerous research projects. Polyglycols (viscosity classes ISO VG 220 and 460) were used as lubricants. The gear sets were operated with differing input rotational speeds and with comparatively high output torques within their catalogue nominal torque. The mean Hertzian stresses (Ref. 13) were in the range of $\sigma_{Hm} = 344$ and 496 N/mm^2. Table 1 addresses the entire experimental matrix—i.e., the essential specifications of load and teeth for the analyzed gear sets, as well as contact pattern positions and sizes.

Evaluation of the test. Testing was done at continuous output torque and continuous input rotational speed. Rotational speeds and torques at the input and output shaft were measured continuously throughout the test sequence. In periodic time steps the flanks of the wheels were photographically documented. Wear revealed by testing with a center distance of $a = 315$ mm

No. [-]	Size a [mm]	Gear Ratio z_2 / z_1 [-]	Flank Type [-]	Input Speed n_1 [min^{-1}]	Output Torque T_2 [Nm]	Mean Hertzian Stress σ_{Hm} [N / mm²]	Contact Pattern [-] Inlet Side Outlet Side
1	100	41 / 2	I	1500	860	451	
2	170	33 / 5	C	1500	1755	344	
3	180	49 / 2	C	1500	2920	374	
4	250	55 / 2	C	870	9000	410	
5	250	55 / 2	C	870	9000	496	
6	315	37 / 2	C	1500	15750	447	
7	315	37 / 2	C	1500	15750	422	
8	315	41 / 2	I	1500	15750	420	
9	315	41 / 2	I	1500	15750	395	

Table 1 Test gear sets data.

was detected by incremental encoders in periodic time steps. The evaluation of the tests carried out here—(Refs. 7, 12 and 15)—was based on the information set out there and on the test documentation.

The values of the mean Hertzian stresses allowing for an uncompleted contact pattern at the beginning were calculated by the program *ZSB* (Ref. 14) and modified (Ref. 13). On that basis the calculation of pitting lifetime in Phase I is in line with the proven method (Ref. 4), based on the parameter for mean Hertzian stress p^* (Ref. 11).

The distribution of pressure in the meshing area of the worm and worm wheel was calculated by the program *SNETRA* (Refs. 8 and 15). Accordingly, the maximum values of the Hertzian stresses in the entire meshing area for the gear set without run-in were examined. The results were used to compare the simulation with the documented location of pitting during the test runs.

Test Results

Development of contact pattern and wear. The worm gear sets for the test runs were designed and manufactured to show the earliest contact patterns, with typical size and position. Because of the low wear of the analyzed center distances, the contact pattern grows very slowly during run-in and pitting begins. Figure 1 shows an example of the characteristic development of contact pattern and of the wear of $a = 315$ mm worm wheel with Flank-Type C. The figure also shows the expected development of contact pattern and the pressure distribution over lifetime, which is determined by the program (Ref. 15).

Further, the worm wheel has an almost-constant wear intensity of about 12 µm-per-one-million-load cycles after approximately 0.6 million load cycles. Considerable run-in wear—typical for worm gear sets of smaller center distances—does not exist at that point. The smoothing of surfaces—by virtue of reducing the roughness peaks and adaption of the worm wheel flanks to the geometry of the worm—are finished as completely as possible. Weisel (Ref. 15) detects similar values for the abrasive wear on worm wheels with Flank-Type I of similar size, total sliding speed, lubrication and Hertzian stress.

In Test 6, 106 µm flank abrasion is necessary for attaining a complete contact pattern. Based on the wear rate referred to above, this complies with about 6 million load cycles; but there is already a pitting area of $A_{P10} = 2\%$ on the flank after 2 million load cycles.

A calculation using the approach for completed contact pattern (Ref. 12) is not possible because no completed contact pattern exists and the occurring Hertzian stresses are considered too low. This approach therefore requires an overly long calculated pitting lifetime of about 6 million load cycles. As such, this calculation—as it currently exists—cannot be used for this typical, practical case.

Location of pitting. Following are statements made about the location of pitting on worm wheel flanks using calculated pressure distribution (Ref. 15). Such statements can often be found in the existing literature, indicating the beginning of pitting on the outlet side of the worm wheel and then growing in the direction of the inlet side during further operation. This statement is based—more on observation and less on the fact—on the premise that maximum pressure can be localized on the outlet side of the chosen gear set. To describe clearly the direct correlation between location of maximum Hertzian stress and location of initial pitting, the distribution of Hertzian stress that was calculated (Ref. 15) was systematically evaluated and compared to the test results in this study.

The local Hertzian stress σ_H in the teeth contact is calculated according to Equation 1, based on Stribeck rolling pressure K and the reduced module of elasticity of the material combination of worm and worm wheel E'.

$$\sigma_H = \sqrt{K \cdot \frac{E'}{\pi}} \quad (1)$$

For calculating the pressure distribution of the entire meshing area, the worm and worm wheel were divided into numerous pieces along a contact line; for these pieces the local Hertzian stresses were calculated. Equation 2 shows that the Stribeck rolling pressure K behaves inversely proportional to the equivalent radius of curvature if the normal force F_N on the considered section of the contact line and the length of the bearing section l_{eff} are the same; Hertzian stress σ_H behaves accordingly. A large equivalent radius of curvature thus leads to a low Hertzian stress, and vice versa.

$$K = \frac{F_N}{2 \cdot \rho_E \cdot l_{eff}} \quad (2)$$

If the contact pattern of a worm gear is reduced, the line load F_N increases in approximate measure for the entire contact area. Due to the slightly different—yet equivalent—radius of curvature of nearby flank points, the local Hertzian stress increases proportionally in accordance with Equations 1 and 2. If the contact pattern is large enough, it is allowed to determine the location of pitting for reduced contact patterns between worm and worm wheel, and also from the pressure distribution of a completed contact pattern. Figure 2 shows the equivalent radius of curvature (Ref. 15) of four different worm gearings with Flank-Type I and a center distance of $a = 100$ mm over a gear ratio range of 8 and 50. The lower part of Figure 2 shows the distribution of Hertzian stress along the worm wheel flank (Ref. 15). In that the stiffness of the worm wheel is already considered, i.e.—along the contact line—a variable line load is calculated that is dependent on the mesh position.

It is very clear that the location of maximum Hertzian stress is essentially determined by the location of the minimum equivalent radius of curvature; this accordance is described in (Refs. 5, 9, 10 and 16) as well. It is also clear that the equivalent radiuses of curvature on the whole flank show significantly different values, and yet are very similar in neighboring areas. It is also readily apparent that the ratios vary in the position of the minimum-equivalent radius of curvature, and in the position of the maximum-occurring Hertzian stress.

It is seen that the local equivalent radius of curvature influences the pitting location. The equivalent radiuses of curvature are basically determined by Flank-Type, gear ratio and profile shift. Figure 3 shows the comparison of pitting for Flank-Type C and I with the calculated development of the contact lines and of the pressure distribution of Tests 7 and 8; both gearings have comparable gear ratios. This comparison makes clear the fact that the pitting occurs in the tooth root with Flank-Type C and, with Flank-Type I, on the outlet side.

The pitting locations in the tests corresponded very well with the calculated (per *SNETRA,* Refs. 8 and 15) location of the maximum Hertzian stress. Depending upon Flank-Type and gear ratio, this can be positioned in various places. For this reason, assumptions regarding pitting location can be confirmed both empirically and arithmetically and, therefore, be pre-calculated. Based on this coherence, flanks of worm and worm wheels can be optimized systematically in consideration of the pressure distribution.

Pitting growth on worm wheel flanks. Figure 4 shows extremely advanced pitting in lifetime Phases I and II on four uniformly distributed teeth around the circumference of a test gearing of size $a = 170$ mm with Flank-Type C (Test 2, Table 1).

Thus, pitting occurs almost simultaneously on all teeth of the worm wheel. In addition, the pitting location is almost the same for all teeth. In Figure 4 the location of pitting is illustrated by horizontal lines. Pitting begins at the place of maximum Hertzian stress and continues growing from there towards the inlet side. If the reason for the pitting was defective areas in the bronze, its location would to some degree be statistically distributed around the circumference of the worm wheel. Also, the pitting growth in the affected areas of the tooth flanks is very consistent; i.e.—no tooth of the worm wheel has an appreciably larger pitting area than the other teeth. This behavior was evidenced in every reviewed gearing test for this study. A high-quality worm wheel bronze with few defective areas and homogeneous microstructure—and gearing with fractional tooth deviations corresponding to gear tooth quality 7 according to DIN 3974 (Ref. 3) or better—are preconditions for such evenly distributed pitting.

Point-of-time of pitting (end of Phase I). As expected, premature pitting occurred on the worm wheel flanks during all test runs. This was due to the reduced contact patterns; a complete contact pattern was not built in any test run.

It was also shown that the pitting location coincides with the pre-calculated maximum Hertzian stress in the engagement region of the gearing. The current benchmark requires a complete contact pattern and, therefore, cannot address the influence of a reduced-size contact pattern on the existing Hertzian stress. If the contact pattern decreases, the minimum/maximum values of the flank-occurring Hertzian stress converge due to the equivalent radiuses of curvature (Eq. 1). In the extreme case of a punctiform contact pattern—e.g., crossed helical gears—the maximum and mean Hertzian stress would be the same. It is therefore permissible to use the mean Hertzian stress—calculated for incomplete contact patterns—as significant load under the simplifications (Ref. 11).

Figure 5 shows the Phase I lifetime of all conducted tests, depending on the calculated mean Hertzian stress and the appropriate 15% scatter band in the form of a Woehler diagram. The calculation of the mean Hertzian stress is conducted (Ref. 13) with reference to the contact patterns shown in Table 1. Further, the results of experiments (Refs. 7 and 12) are illustrat-

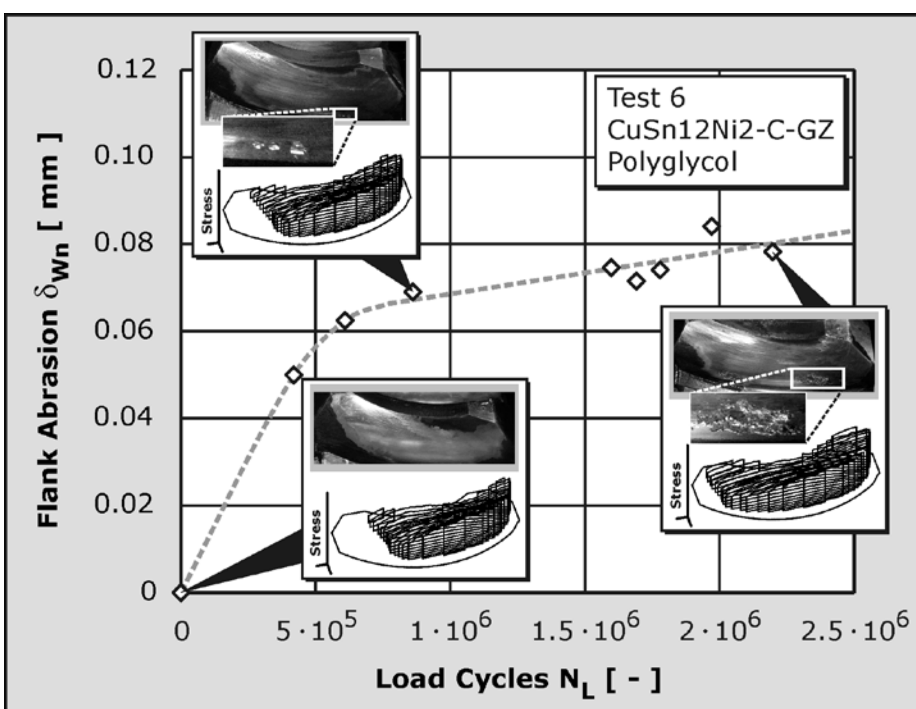

Figure 1 Wear and development of contact pattern: Test 6.

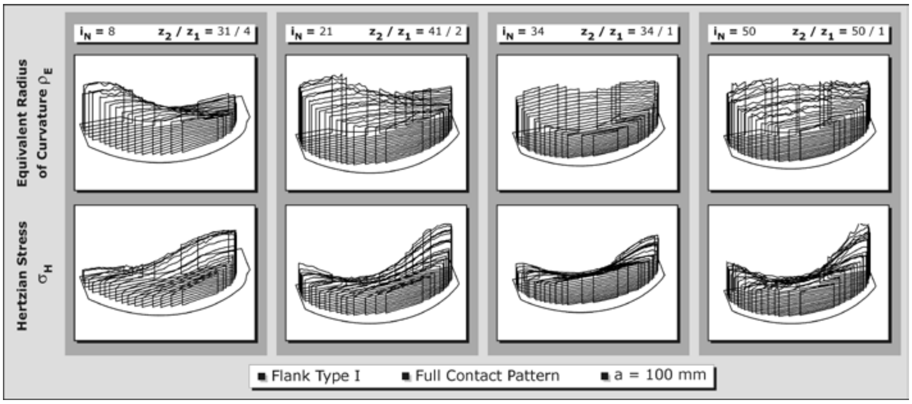

Figure 2 Equivalent radiuses of curvature for worm gear sets with different gear ratios.

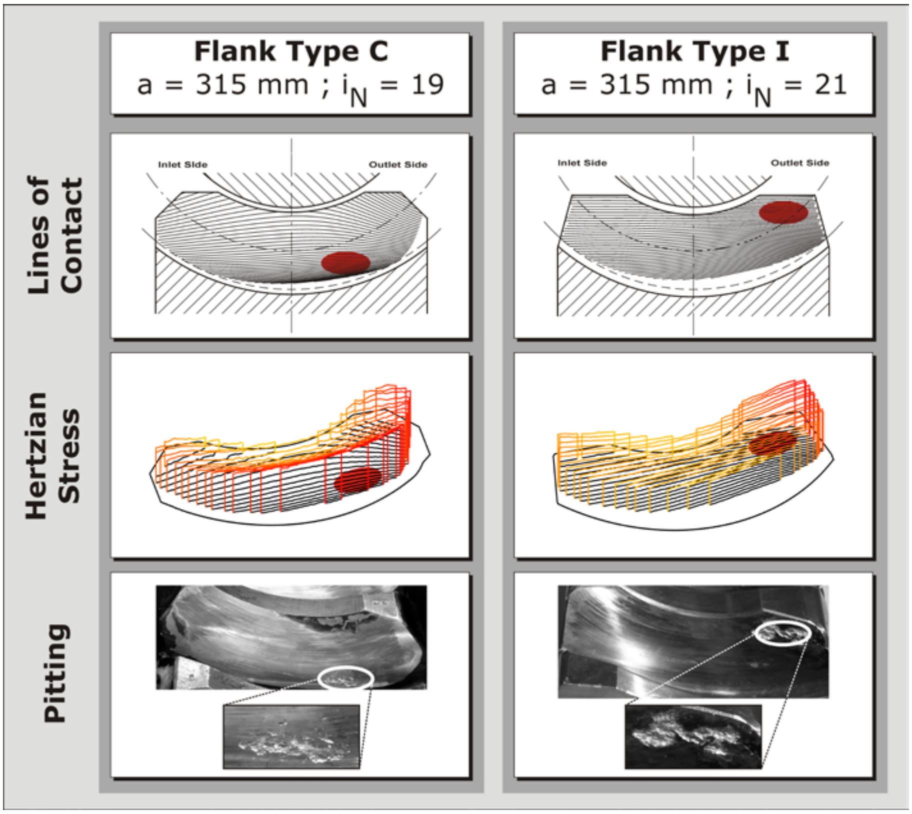

Figure 3 Location of pitting dependent upon flank type: Tests 7 and 8.

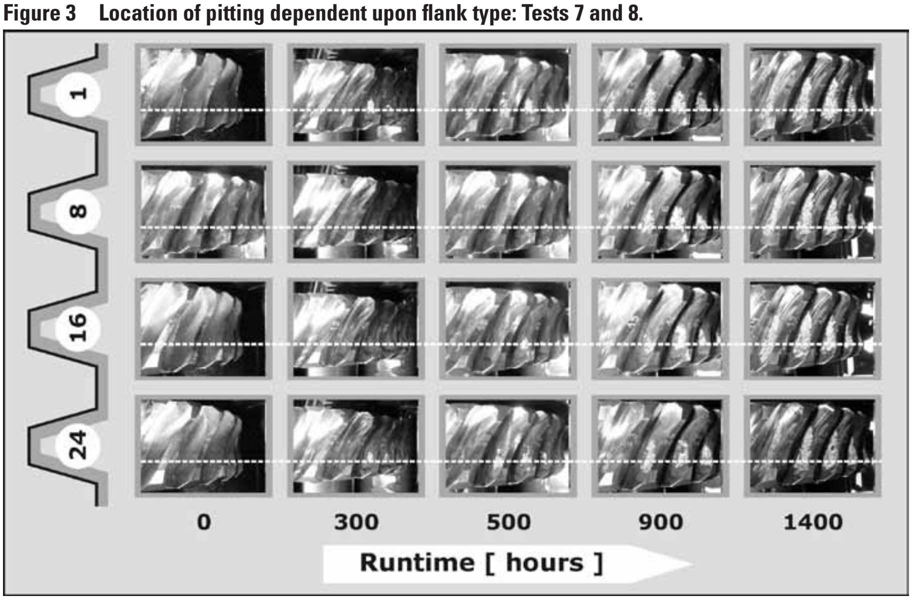

Figure 4 Pitting on test wheel: A = 170 mm; Flank Type C, $z_2/z_1 = 33/5$ (Test 2, per Fig. 1).

ed based on the mean Hertzian stress for a complete contact pattern.

An upper limit for the mean Hertzian stress 500 N/mm^2 was assessed. Beyond this value, deformations under load (Ref. 12) are no longer purely elastic and the adaptability of a direct coherence of pressure and stress reversals cannot be confirmed. Thus, flowing effects arise in the material of the worm wheel that provide—through redistribution of the worm wheel material—a partial reduction of local Hertzian stress. However, because all gear sets are operated with their catalogue-nominal torque, and stay so far below the limit of pressure, the method covers the most commonly used worm gear sets. The newly established function shows very good dependency of the reachable stress reversals in lifetime Phase I on the mean Hertzian stress. Furthermore, it became apparent that this method delivers reliable results for complete contact patterns as well.

Therefore, the sliding speeds in the contact—which occur differently during live testing (Table 1)—have in Phase I no measurable influence on the initiation point of pitting. This confirms similar results of (Ref. 12).

Equation 3 describes the functional coherence between stress reversals N_{LI}—until reaching the $A_{P10} = 2\%$ criterion—and the mean Hertzian stress σ_{Hm} calculated (Ref. 13) for worm wheel bronze CuSn12Ni2-C-GZ lubricated with polyglycol.

$$N_{LI} = \left(\frac{2650}{\sigma_{Hm}}\right)^{7.8} \textit{für}\ \sigma_{Hm} \leq 500\ \frac{N}{mm^2} \qquad (3)$$

According to Equation 4, the onset of pitting L_{hl} is prevented with the gear ratio u and input rotational speed n_1 calculation.

$$N_{LI} = \frac{N_{LI} \cdot u}{n_1 \cdot 60} \qquad (4)$$

Conclusions

In practice, worm gears evidence a reduced contact pattern at the outset. The local high Hertzian stress—combined with the low wear rate of larger center distances—leads quickly to localized pitting. The until-now-accepted calculation for pitting lifetime, however, requires a completely run-in contact pattern between worm and worm wheel.

On the basis of experimental and theoretical investigations of the tooth contact of worm gearings, a new method for calculating pitting lifetime is presented, which also can be used on incomplete contact patterns. It enables—*for the first time*—the calculation of practical, incomplete contact patterns as they apply to pitting lifetime and provides enhanced optimization of worm gears.

The Hertzian stress in the tooth contact between worm and worm wheel is assessed as significant load. This new method can also be applied for complete contact patterns. Accordingly, the results of previous research in this field with complete contact patterns can be comprehended and calculated as well.

In the above-described calculation method, existing calculation approaches for the location of pitting were applied, systematically verified and approved by virtue of experimental results. It is now therefore possible—also for the first time—to reliably predict the location of pitting of worm gear sets with contact patterns of any size, position and Flank-Type with a broad area of validation. Indeed, optimal load distributions of a worm gear set can now be directly determined and load-carrying capacity enhanced.

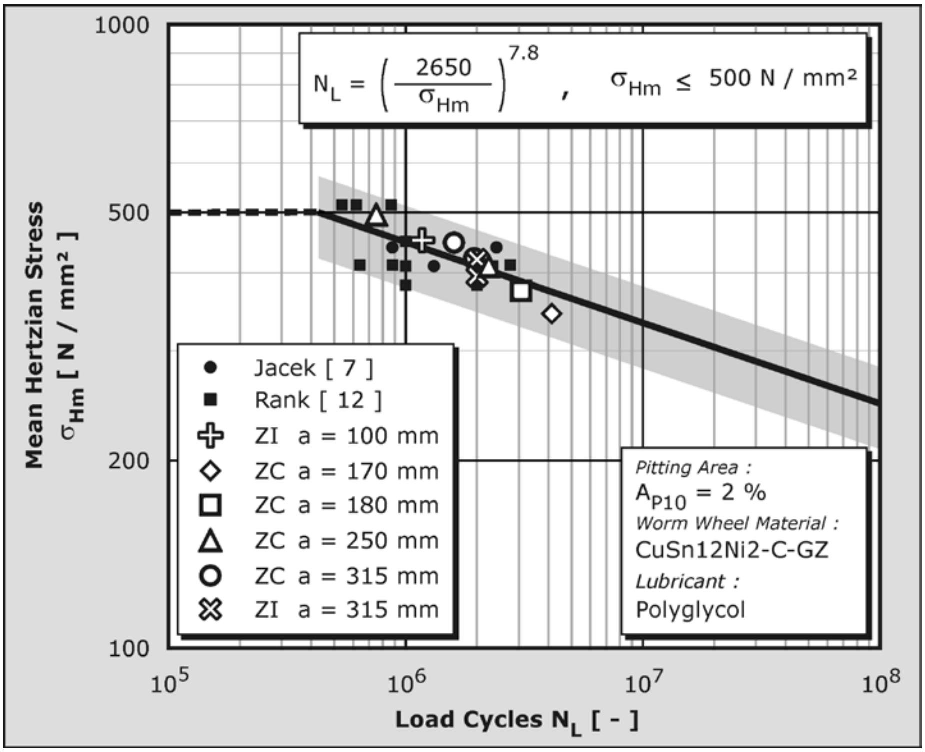

Figure 5 Part of Woehler diagram for end of pitting lifetime: Phase I.

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Prof. Dr.-Ing. B.-R. Höhn studied mechanical engineering at the Technical University Darmstadt (1965-1970) and served as an assistant lecturer (1970-1973) at the Institute for Machine Elements and Gears at the Technical University Darmstadt prior to becoming an assistant professor at the university (1973-1979); in 1978, he received his Ph.D. (Dr. Ing.) in mechanical engineering. In early April, 1979 Höhn worked as a technical designer in the department for gear development of the Audi, and by 1982 was head of the department for gear research and design for the automaker. In 1986 Audi named Höhn department head for both gear research and testing of automotive transmissions, until his departure in 1989 to become head of both the Institute of Machine Elements at the Technical University and of the Gear Research Centre (FZG). Since 2011, he has served as director emeritus of the Institute. Höhn has also served as vice president for VDI for research and development, as well as leader of working groups 6 and 15 for ISO TC 60—calculation of gears.

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Repair of High-Value/ High-Demand Spiral Bevel Gears by Superfinishing

Eric C. Ames

Following is a report on the R&D findings regarding remediation of high-value, high-demand spiral bevel gears for the UH–60 helicopter tail rotor drivetrain. As spiral bevel gears for the UH–60 helicopter are in generally High-Demand due to the needs of new aircraft production and the overhaul and repair of aircraft returning from service, acquisition of new spiral bevel gears in support of R&D activities is very challenging. To compensate, an assessment was done of a then-emerging superfinishing method—i.e., the micromachining process (MPP)—as a potential repair technique for spiral bevel gears, as well as a way to enhance their performance and durability. The results are described in this paper.

Introduction

Spiral bevel gears are high-precision, high-cost components that are used in the main powertrain of nearly all modern rotorcraft. Production of these gears is a complex process, beginning with a forged shape of high-quality aerospace steel, such as AMS 6265. The shape is rough-machined into a precise 3-D geometry and heat-treated to achieve the desired strength characteristics that provide the desired combination of surface durability and bending fatigue resistance. The final geometry and surface finish are achieved by finish-grinding and shot peening. The complete processing cycle can take from six to nine months, creating a significant lead time for the acquisition of new production parts.

Production of new aircraft—coupled with the overhaul of aircraft returning from service in both Iraq and Afghanistan—has created a situation where the demand for new-production spiral bevel gears is very high. Available gear assets are closely monitored by both the OEM and the government to ensure that an adequate supply is available for new-production and overhaul purposes. This situation creates significant challenges in acquiring spiral bevel gear assets with which to conduct research and development programs.

A prior study (Ref. 1) showed the potential of existing superfinishing methods (chemically assisted vibratory processes) to remediate the active tooth surfaces of spur and helical gears with light surface damage. Significant cost savings could be realized if more rejected gears could be reclaimed and put back into service.

The genesis of this investigation began with an evaluation of the overload capacity of the UH–60 helicopter tail rotor drivetrain. The UH–60 tail rotor drivetrain layout, which consisted of six separate spiral bevel gears in three individual gearboxes, is illustrated in Figures 1 and 2. The evaluation consisted of two separate, 25-hour high-load endurance tests at 150% of the rated continuous power, with an additional test at 170% power with transients up to 200%.

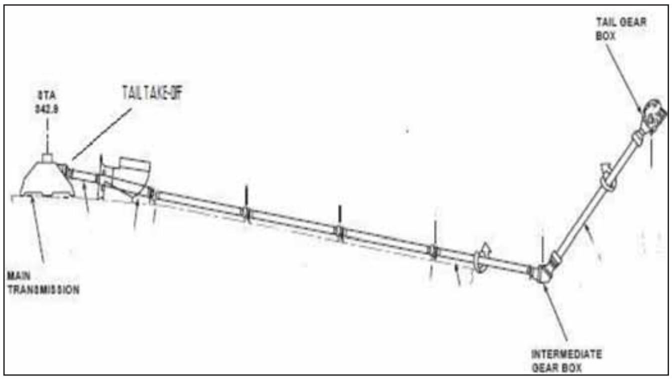

Figure 1 UH–60 tail drivetrain layout.

Figure 2 UH–60 tail drivetrain spiral bevel gears.

Block I: Overload Test Results

The first block of testing was conducted back in March 2010 and utilized a mixture of new-production gears and some with very low service usage. Testing revealed that the tail take-off bevel gear mesh had limited tolerance to sustained operation at these high-overload conditions. Near the end of the test, a tooth fracture of the tail take-off (TTO) bevel gear was observed. This fracture likely resulted from a line of micropits that formed on the root of the gear due to high contact pressures from the tip of the mating pinion. Figure 3 shows the post-test condition of both the TTO gear and its mating gear. Teeth of the TTO bevel gear were all heavily scuffed, and heavy wear, polishing and scuffing were observed on the TTO pinion teeth.

Figure 3 TTO bevel gear and pinion post: Block I overload testing.

Block II: Overload Testing

Acquisition of the new-production gears needed to conduct the second block of testing proved to be very difficult; several specific gears had delivery times of more than 12 months. Two specific gears—the TTO pinion and the tail rotor gearbox output gear (TRGBX)—proved to be in extremely high demand at the time, with all existing production parts being assigned to either new-production aircraft or those undergoing overhaul.

In order to conduct the Block II overload testing in a reasonable timeframe, an effort to remediate several TTO pinion spiral bevel gears previously rejected at overhaul was undertaken. Additionally, an effort to remediate several TRGBX output gears, previously run in a Naval Air Warfare Center–Aircraft Division (NAWC-AD) research effort was also undertaken. The candidate UH–60 TTO spiral bevel pinion gears were provided by the U.S. Army's Aviation & Missile Command (AMCOM) Storage, Analysis, Failure Evaluation and Reclamation (SAFR) program at Corpus Christi. Candidate-TRGBX output spiral bevel gears were provided by the NAWC-AD Propulsion and Power Division at the Naval Air Station, Patuxent River, MD. These gears were utilized to support previous UH–60 drivetrain-seeded fault testing at NAWC-AD. Only the results of the remediation work on the TTO bevel pinions are presented in this paper, as the approach for the two different configurations was very similar.

The Army's SAFR program provides expert parts failure analysis, repair development and remediation solutions to military aviation maintainers in support of their critical supply needs. SAFR accomplishes this by collecting "select mission-essential" candidate parts removed at CCAD or other depot maintenance facilities. These candidate parts no longer met current technical repair criteria or were "beyond economical repair" (BER) due to funding, maintenance capability or obsolescence issues. SAFR does not collect crash-damaged or mutilated parts. Candidate-parts selection is based upon critical supply need, complexity to manufacture, raw materials availability and/or long procurement lead times. The high cost and demand for rotorcraft spiral bevel gears makes them a significant item for the SAFR program.

Costs of the six individual gears in the UH–60 tail drivetrain are shown in Table 1. These costs were obtained using the Defense Logistics Agencies Integrated Mobile Database Quick Search Application and were acquired in January 2010. While a detailed MMP treatment cost for each of these specific gear configurations had not yet been developed, it was estimated that the processing cost should be less than $1,000 per part, based upon processing quantities of 20 or more parts in sequence.

Table 1 Cost of UH–60 tail drivetrain gears

Gear	Part Number	Cost
TTO Bevel Gear	70351-38167-101	$9,436
TTO Bevel Pinion	70351-48148-101	$7,291
IGB Bevel Pinion	70357-06314-101	$6,643
IGB Bevel Gear	70357-06315-101	$7,117
TRGB Bevel Pinion	70358-06619-101	$6,613
TRGB Bevel Gear	70358-06620-102	$18,521

Superfinishing Via Micromachining Process

The MMP superfinishing method is a technique originally developed in Europe for creating appearance-enhancing finishes for the luxury watch making, high-end jewelry and premium eyewear markets (Ref. 2). MMP is a physical-catalyst surface treatment applied to items placed inside a treatment tank. The process uses a unique formulation of media developed in-house by the company BESTinCLASS. The MMP process has been available in the United States through MicroTek, which formed a joint venture with BESTinCLASS in 2009. Potential advantages of the MMP are uniform material removal—heal-to-toe and root-to-tip—and a very smooth surface finish on the order or 0.5 micro inches.

Characterization of Candidate Gears

Four candidate TTO bevel pinions were provided by the SAFR program office for evaluation. Each of these four gears (Fig. 4) had varying degrees of surface damage and wear. Photographs of the driving side of a select tooth from each gear are shown (Fig. 5).

The candidate pinions were first sent to Overhaul Support Services (OSS), East Granby, Connecticut for nondestructive

Figure 4 Candidate-TTO pinions as received from SAFR.

Figure 5 Driving tooth surfaces of candidate pinions.

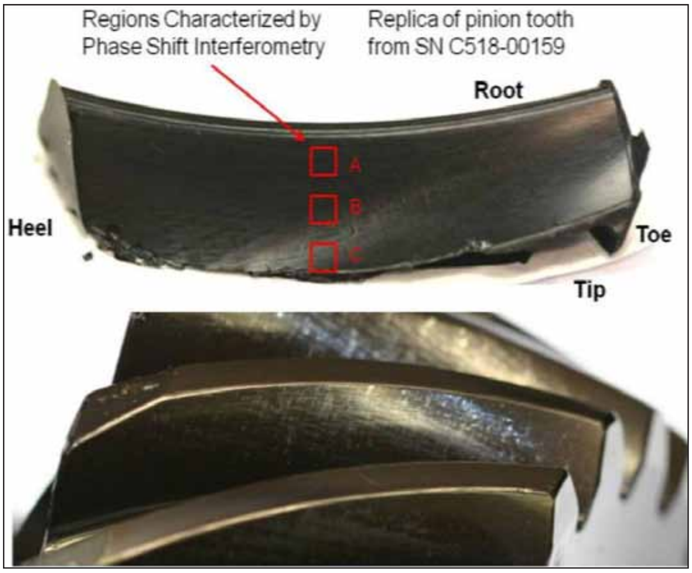

Figure 6 Silicone replica of TTO bevel pinion SN C518–00159.

testing and ranking of the candidates in terms of suitability for repair and re-assembly into the test gearbox. OSS is an FAA-certified overhaul-and-repair facility specializing in dynamic components for Sikorsky Aircraft. Each of the pinions was subject to a magnetic particle inspection and found to be free of cracks. OSS ranked the damage of each of the pinions and recommended that two pinions (SN C518–00159 and SN A518–00011) were best suited for repair, with SN C518–00159 being the least damaged.

These two pinions were then sent to Wedeven Associates (WA), Edgmont, Pennsylvania for a detailed characterization of the gear tooth surfaces. The techniques used by WA involved making silicone replicas of the gear teeth surfaces and subsequently using a phase-shift surface interferometer to create 3-D representations of the tooth surfaces. These digital surface

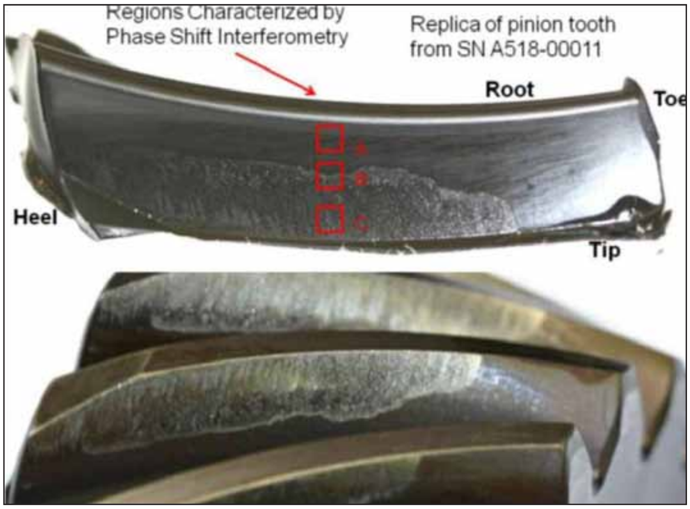

Figure 7 Silicone replica of TTO bevel pinion SN A518–00011.

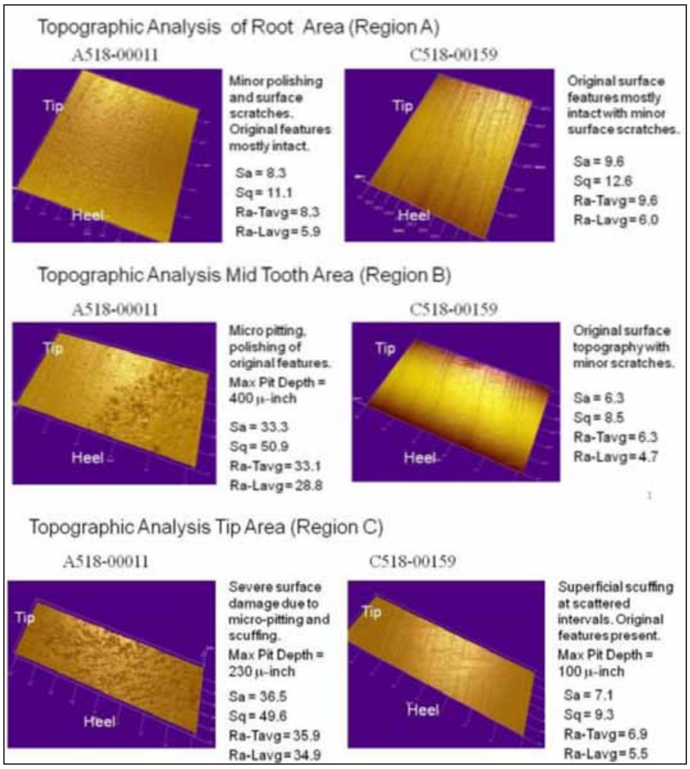

Figure 8 As-received surface finish and topography of candidate-TTO bevel pinions.

models were then analyzed to determine features such as overall roughness, wear and the maximum depth of specific defects or pits.

The replica material utilized, 101RF (general purpose/fast curing), was manufactured by Microset Products, Ltd., Warwickshire, U.K. This product has been shown to have extreme sensitivity that can allow replication of the surface within 10 nanometers. Close-up photographs of the gear tooth surfaces and the associated silicone replicas are shown in Figures 6 and 7.

The approximate tooth height from root to tip is 0.31 inches. Three-dimensional analysis of the replicated surfaces was conducted at mid-span of the tooth facewidth, as shown in the figures. Specific regions near the root, center and tip were analyzed for mean surface roughness (Sa) and maximum pit depth (Fig. 8). To enhance the visual appearance of the surface features, a 20× magnification in the *Z* direction (depth) was applied.

It should be noted here that the surface roughness measurements acquired by various optical methods discussed in this paper (phase-shift surface interferometry and confocal microscopy) are shown as 3-D parameters based upon an analysis of a defined local area of the gear tooth surface. The Sa parameter is the arithmetical mean height of the surface area and the Sq parameter is the root mean square height of the surface area. Other surface roughness measurements acquired by contacting methods are 2-D parameters and are relative to the direction in which the probe is moved across the surface. Ra is a measurement of the average roughness or the height of the peaks from the mean surface. Rt is the total height of the profile from the lowest valley to the highest peak.

The surface of the TTO pinion SN C518–00159 was generally characterized as having minor damage consisting of surface scratches and some scattered superficial scuffing near the tooth tip. The surface of the TTO pinion SN A519–00011 showed severe micropitting and scuffing originating from the mid-section of the tooth out to the tip. The depth of damage in this region was 100-200 micro-inches, with a maximum pit depth of 400 micro-inches.

MMP Treatment Results

Upon completion of the surface characterization, both pinions were delivered to MicroTek's facility to undergo MMP surface treatment. The MMP process produced a very highly polished surface with a high degree of reflectivity (Fig. 9). The effect appears to be uniform, as the root and fillet areas have the same appearance as the tooth faces and top lands. To the casual observer the part may appear to have been chrome-plated, post-MMP.

The pre- and post-MMP surface roughness of both candidate-TTO bevel pinions were measured by MicroTek using a stylus-based surface profilometer. Figure 10 shows the results for the TTO bevel pinion C518–00159; the values shown are an average of six individual measurements. It should also be noted that the drive- and coast-side measurements are in the transverse direc-

Figure 9 TTO bevel pinion post-MMP treatment.

Figure 10 Pre- and post-MMP surface roughness of TTO bevel pinion C518–00159.

Figure 11 **Pre- and post-MMP surface roughness of TTO bevel pinion A518–00011.**

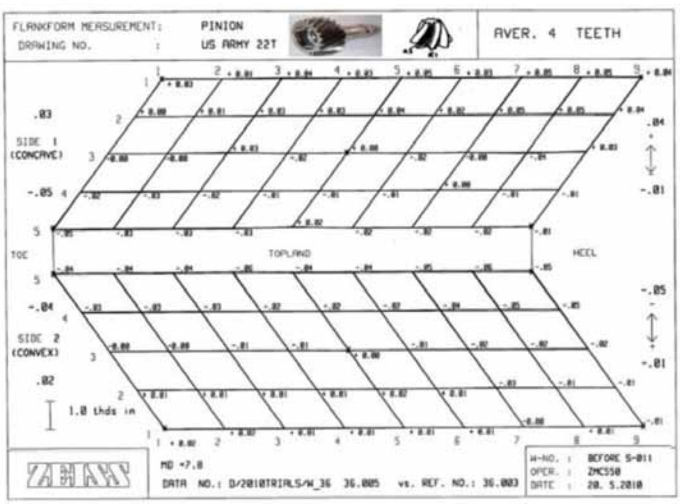

Figure 12 **TTO Bevel Pinion A518–00011 flank form analysis after initial MMP treatment.**

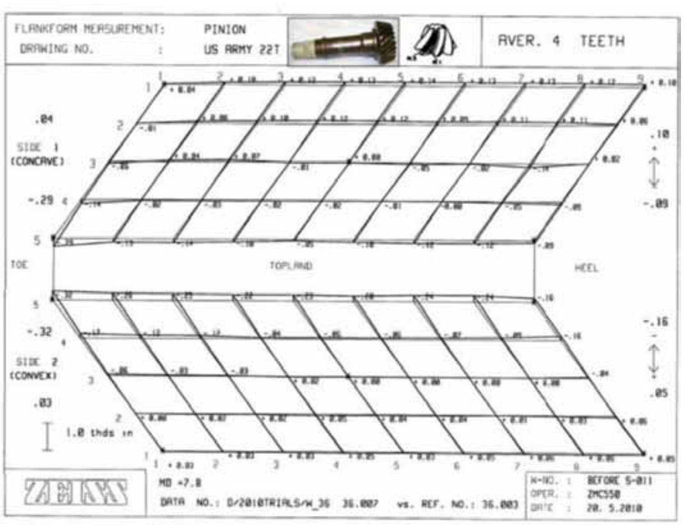

Figure 13 **TTO bevel pinion A518–00011 flank form analysis after final MMP treatment.**

tion, relative to any original finishing (grinding) features which tended to be longitudinally oriented (heal-to-toe) in nature. The longitudinal grinding features can be seen in the surface topography of the as-received C518–00159 (Fig. 8). The root measurements were taken longitudinally or parallel to the lay of the grinding features.

The TTO bevel pinion A518–00011 proved to be more challenging for the MMP treatment as the surface damage was much more pronounced. This was the first time that MicroTek had attempted to reclaim a part of this particular material and geometry, so MMP method was conducted in two stages. The initial processing was deliberately light to assess the material removal rate versus time. Figure 11 shows the results obtained after both initial and final processing. The remnants of the original pitting damage (Fig. 7) can clearly be seen on the tooth surface after the initial MMP treatment. The second (final) treatment essentially removed evidence of the damage, providing a very smooth surface finish.

Topographical Inspection

Both candidate gears were subject to a topological inspection to assess the total amount of material removed, and to assess gear conformance to the drawing specifications. The TTO bevel pinion A518–00011 was sent to Gleason Works for inspection at three different points in the process; i.e.—1) prior to the initial MMP treatment, 2) after the initial and 3) final MMP treatments. The TTO bevel pinion C518–00159 was inspected post-MMP treatment by Sikorsky Aircraft against their digital master gear.

Figure 12 shows the effect of the initial MMP treatment on the tooth topography of bevel pinion A518–00011. As expected, the changes were minimal with a maximum of 0.00009 inches being removed from the top land on the concave (driving) side of the tooth. It should be noted that Gleason's analysis selected a center point on the tooth as a zero point. The positive values indicated in the root must be added to the negative values shown on the tip to arrive at the total amount of mate-

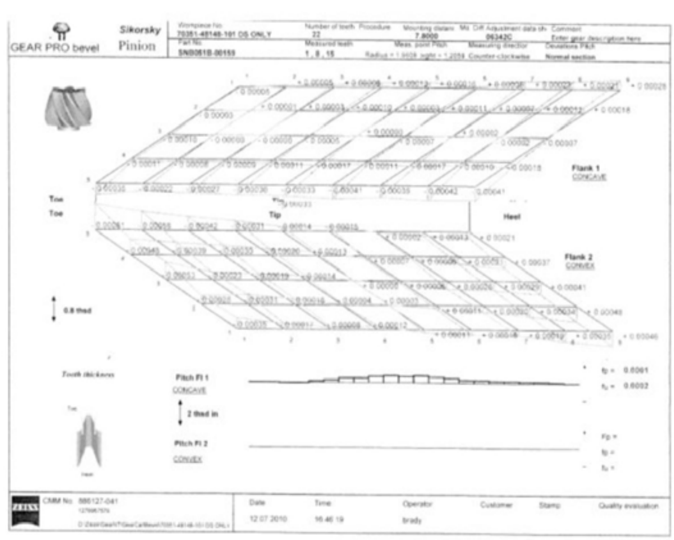

Figure 14 **Flank Form Analysis of TTO Bevel Pinion C518-00159 after MMP treatment.**

rial removed. Figure 13 shows the results of the topographical inspection performed after the second MMP treatment of A518–00011. The material removal is significantly greater than that achieved in the initial processing. The distribution of material removal was generally uniform from the root up to approximately 75% of the tooth height and also from heel to toe. In the tip region of the tooth, more material was removed with a maximum reduction of 0.00039 inches on the toe end of the concave (driving) side and 0.00019 inches on the tip of the heel. Observation of the convex (coast) side of the tooth showed a very similar pattern, with nearly equal material removal characteristics and the same toe bias. The amount of material removal was consistent with the depth of damage identified during the initial tooth replication and surface analysis (Fig. 6). Based upon the Gleason analysis, the change in tooth thickness was determined to be minimal and on the order of 0.0001 inches.

The results of the Sikorsky topological measurements of pinion C518–00159 are shown (Fig. 14); they are the total deviations from the digital master gear geometry. The maximum deviation on the concave (drive) side of the tooth is -0.00041 inches on the tip of the heel. This is within the 0.0005 inches tolerance allowed by Sikorsky for the drive side of primary power gears of this class and size. While the concave (coast) side of the tooth had significantly more deviation from the master gear, it too was well within tolerance as the requirements for the coast side are double (0.001 inches) that of the drive side. Measurement of the tooth thickness revealed that the change was very small and the pinion would provide a backlash of 0.055 inches when mated with its driving gear. The tolerance on backlash was 0.04–0.06 inches.

Post-MMP Surface Analysis

Surface replicas were made of the same teeth on each pinion after the MMP treatment; replicas were evaluated by Wedeven and the results are shown (Figs. 15 and 16).

The surfaces of the gear teeth had a significantly improved finish and exhibited a nearly isotropic texture, with only faint remnants of the original wear and machining features. It should be noted that pinion A518–00011 had several randomly distributed pits in each of the three regions. The depth of these pits was approximately 10–20 micro inches (0.23–0.45 microns) and was probably a remnant from the original surface damage as received (Figs. 7 and 8). Additional MMP treatment may have been able to reduce further the number of these pits. This type of investigation was not possible during the effort, due to the small quantity of available assets and associated risk of removing too much material and driving the gear physical geometry past the allowable minimums for tooth thickness and deviation from the desired tooth topography.

Pinion Selection and Gearbox Assembly

While both pinions met the drawing specifications, pinion C518–00159 was the first to become available and was thus selected for assembly and testing. In hindsight, this may have been fortuitous since it appeared to have less residual surface pits than A518–00011. Assembly of the test gearbox was performed by OSS for many models of Sikorsky helicopters, including the H–60 line of aircraft. Assembly was completed without

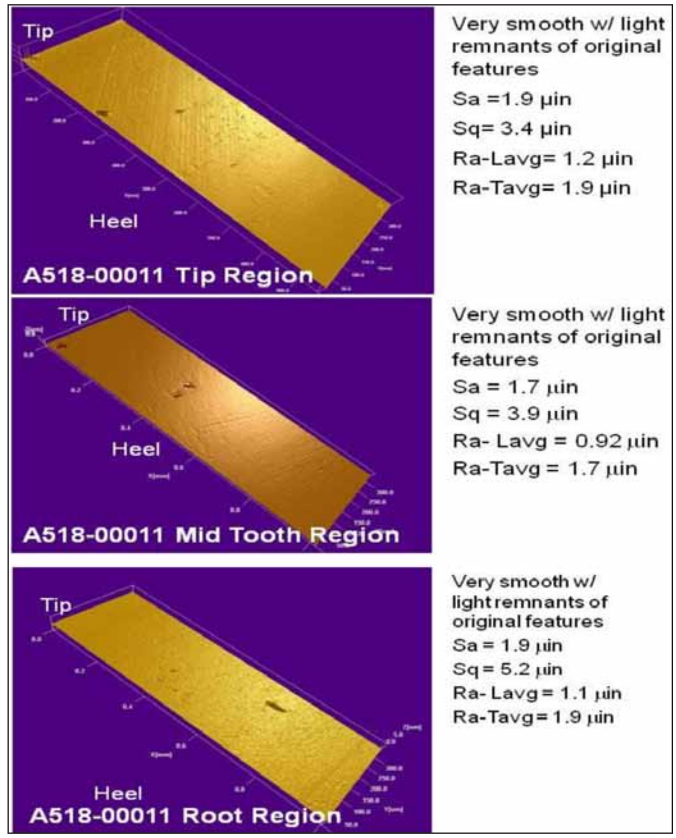

Figure 15 Pinion A518–00011 post-MMP surface finish and topography characteristics.

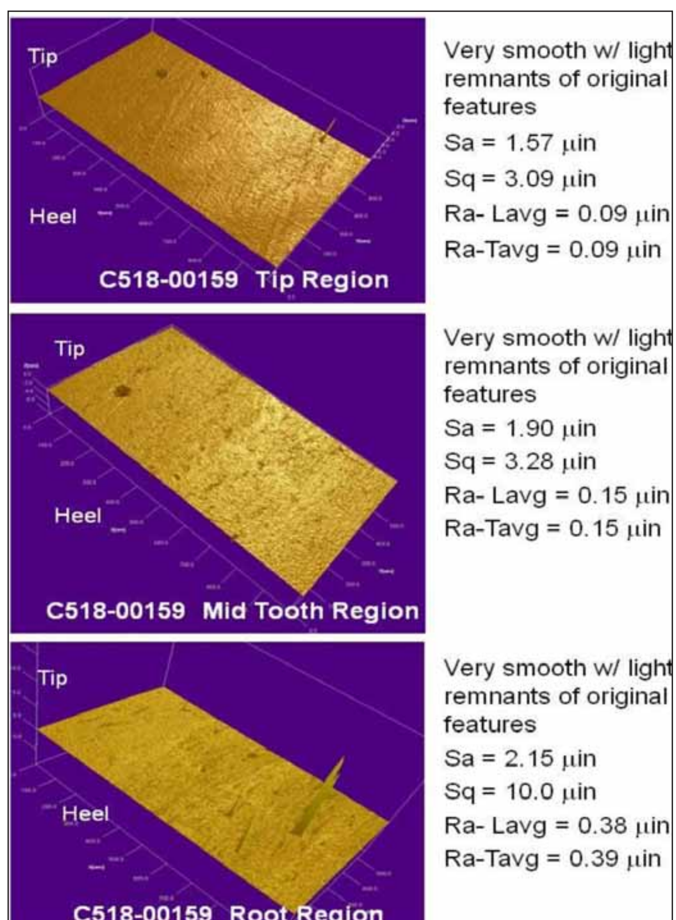

Figure 16 Pinion C518–00159 post-MMP surface finish and topography characteristics.

Figure 17 Contact pattern achieved during assembly with pinion C518–00159.

Figure 19 Post-test TTO pinion and bevel gear.

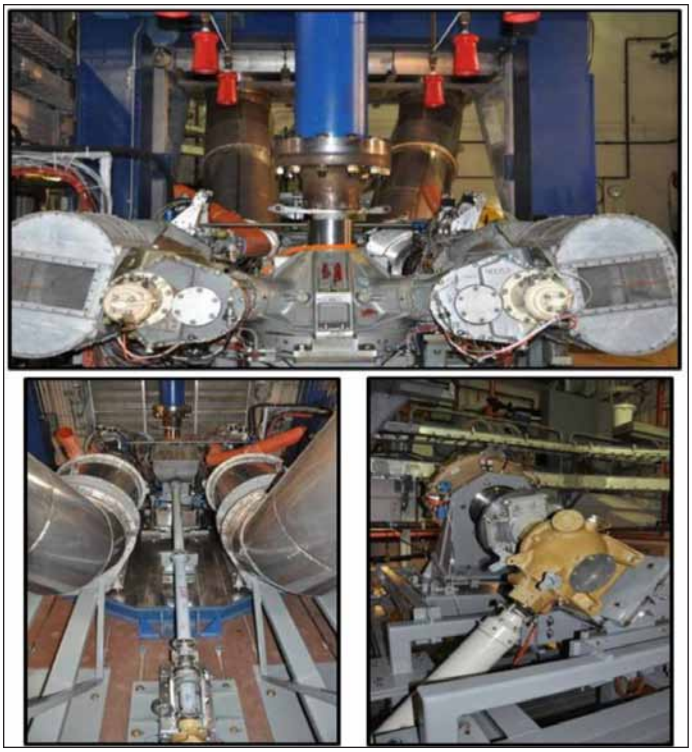

Figure 18 HeDS facility with test gearboxes installed.

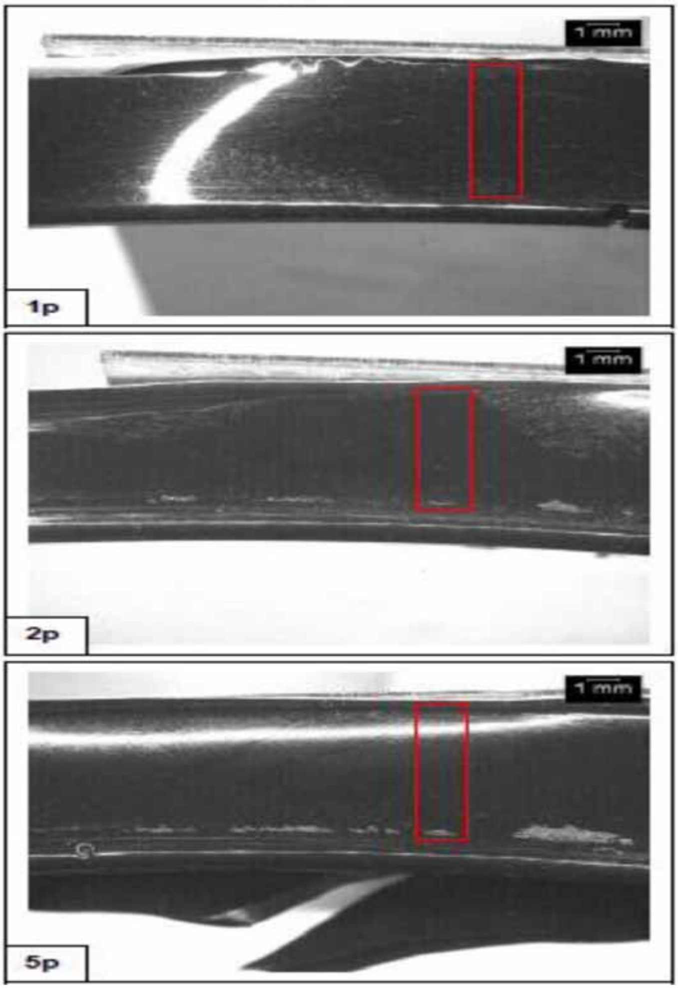

Figure 20 Replicas of TTO pinion C518–00159 taken at two hours (1p), 12.5 hours (2p) and 33.5 hours (5p) of test time.

issue. An acceptable contact pattern was achieved and is shown (Fig. 17); the full gear mesh can be seen (Fig. 2).

Gearbox Testing

The tests were performed at the Naval Aviation Warfare Center–Aircraft Division (NAWC-AD), Helicopter Drive System (HeDS) test facility located in Patuxent River, Maryland. The HeDS consisted of a structural rig capable of physically supporting the MH-60K Main Gearbox MGB, the input modules, the IGB, and the TGB. Two T700-GE-701C (one engine operation was adequate for providing the necessary HP to the tail drive system) engines were used to drive the test gearboxes. The horsepower developed by the single engine was transmitted through the main input module and MGB. The IGB and TGB were driven as they are in the aircraft by the tail rotor take-off flange out of the MGB. The MGB was only lightly loaded for the test. The IGB and TGB were loaded through a single-disk waterbrake dynamometer manufactured by The Kahn Company. The test gearboxes as installed in the HeDS facility are shown in Figure 18. Testing was completed in September 2010. Approximately 32 hours of total operation was accomplished, with 16 hrs accumulated at 800 hp, 1 hr accumulated at powers exceeding 900 hp, and 47 minutes at powers slightly exceeding 1,050 hp. It is worth knowing that the TTO gear mesh is currently qualified for maximum continuous operation at 524 hp. Figure 19 shows the post-test condition of the TTO pinion and mating bevel gear.

Gear Tooth Finish and Topography Changes During Testing

In order to observe the changes in surface finish and topography as the gear mesh accumulated cycles, silicone replicas were taken at several intervals during the test. This process included removal of the TTO pinion and thorough cleaning of both the pinion and the driving gear to get a quality replica. This proved to be a challenge for the TTO bevel gear as it was only accessible through the TTO pinion housing bore. After some trial and error, HeDS technicians were able to develop a technique that produced high-quality replicas. Replicas of the MMP- treated pinion and the mating gear were taken after the two-hour break-in run, after 12.5 hrs of running at 800 hp, and after 33.5 hrs of running which included the 900 hp operation and the transient runs to 1,050 hp. Photographs of the replicas themselves are shown (Fig. 20). The development of a line of micropits can clearly be seen in replica 2p which was taken at 12.5 hrs of running. This area corresponds to the root area of the actual pinion and is likely the result of an area of high contact stress due to the lack of adequate tip relief at the very high overload conditions applied during the testing. The growth of the line of these pits along the root of the pinion face can be clearly seen in replica 5p, which was taken at the conclusion of testing. A replica taken of the mating gear at the conclusion of the testing is shown (Fig. 21). There were no indications of damage to the gear. The directionality of the surface topography of the gear, which was a new production part without the MMP treatment, can clearly be seen in the replica. The directionality of the surface was a direct result of the original grinding process.

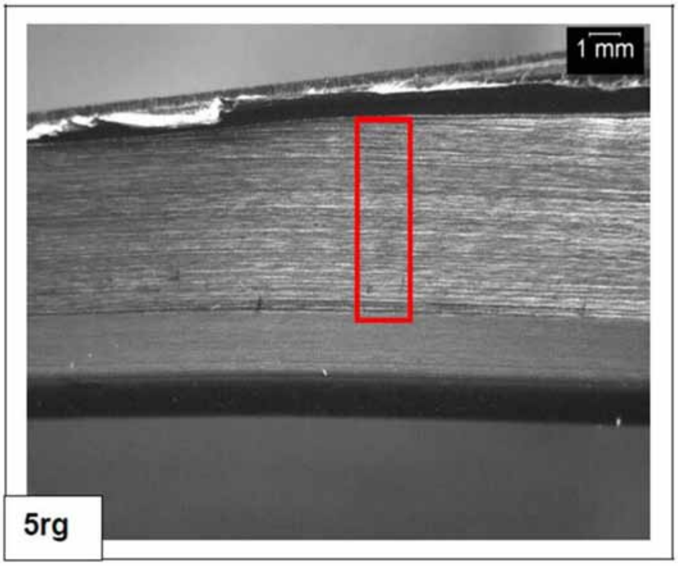

Figure 21 Replicas of TTO gear taken at 33.5 hours (5p) of test time.

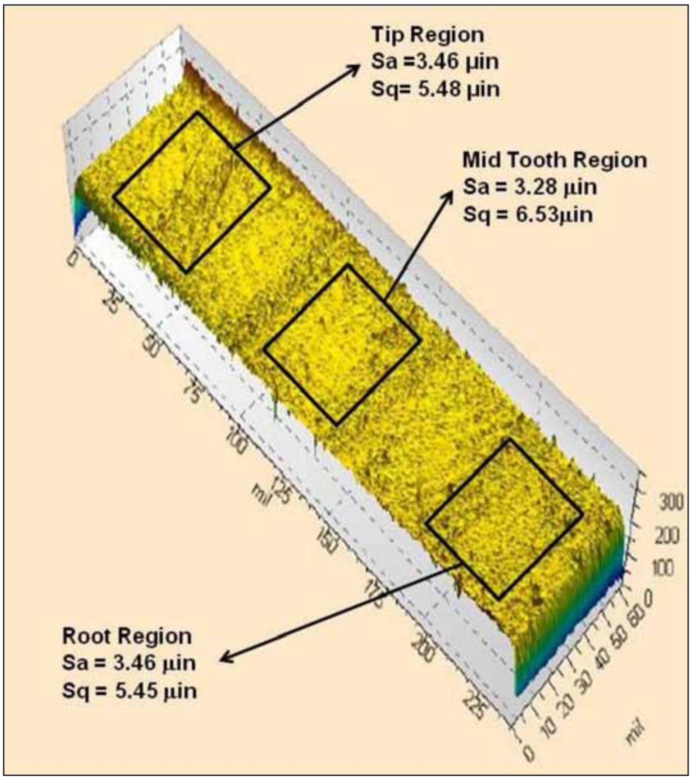

Figure 22 Surface roughness and topography of TTO pinion after two hours of testing.

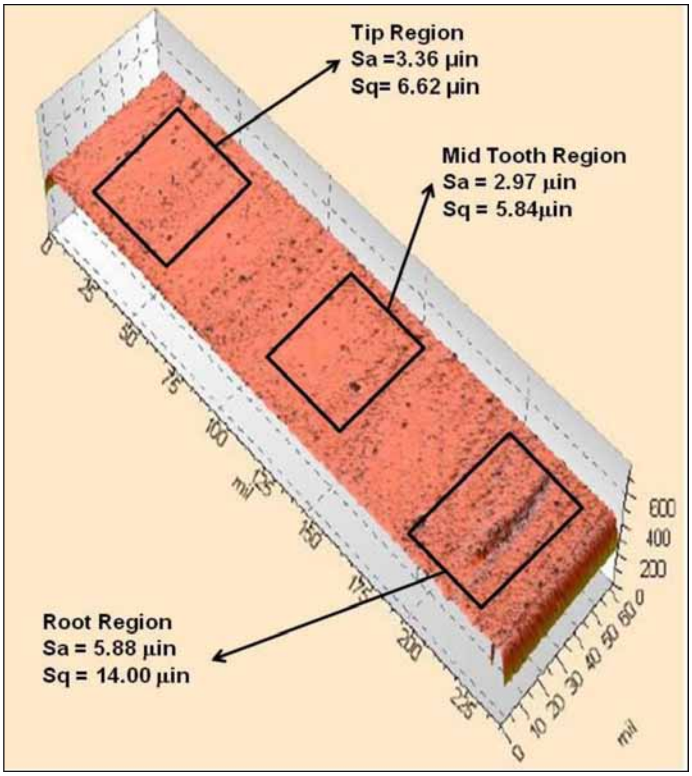

Figure 23 Surface roughness and topography of TTO pinion after 12.5 hours of testing.

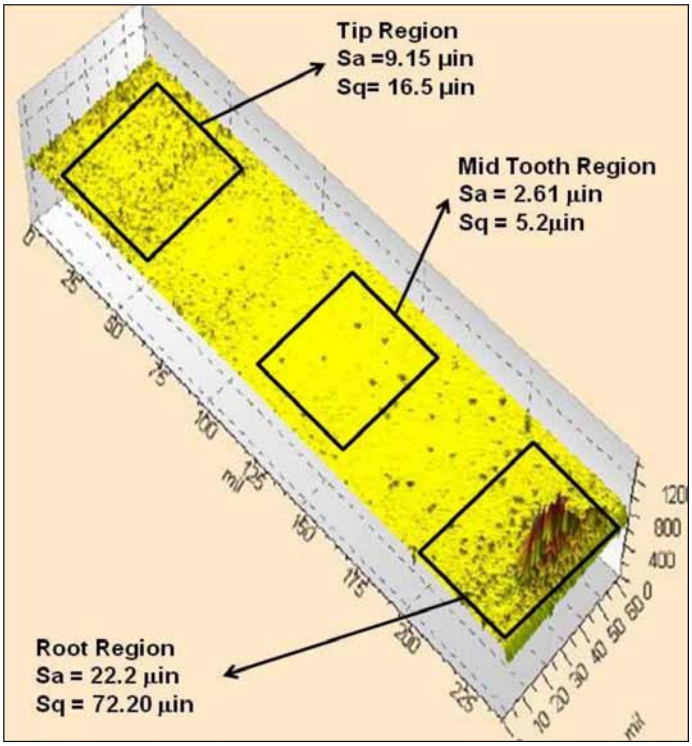

Figure 24 Surface roughness and topography of TTO pinion after 33.5 hours of testing.

A detailed 3-D analysis of these replicas was performed by Coubrough Consulting, LLC Independence, Ohio. The replica surfaces were measured using a NanoFocus µsurf topometer employing confocal technology. Localized regions of the tooth tip, mid, and root areas were evaluated similar to the pre-test evaluation; the pinion surfaces are shown (Figs. 22–24). The roughening of the tip region, slight polishing of the mid tooth region, and formation of a line of micropits in the root area can clearly be seen. The surfaces of the TTO gear that mated with the pinion are shown (Figs. 25 and 27–28). The TTO gear replica taken after two hours of testing was of poor quality and prevented detailed analysis. Figure 25 shows the surface roughness and topography of the TTO bevel gear prior to testing. The surface finish was measured as 15 micro inches (Sa). It should be noted that the TTO gear was not shot peened. Measurements of a production intermediate gearbox spiral bevel pinion, which was ground and shotpeened (Fig. 26) show a surface roughness of 12 micro inches (Sa). While the measured Sa values were similar, the texture of the two surfaces was clearly different, with the shot peened surface having less directionality as the peaks of the grinding features were reduced. As the endurance testing progressed, a dark line developed on the root area of the TTO bevel gear (Fig. 19). The replica analysis failed to show indications of any change in topography associated with this feature, which may be an oil stain. The effect of additional running at 800 hp and the higher transient loads appeared to have little further influence upon the TTO gear surface finish and topography, with only slight changes in surface finish (Figs. 27–28).

Conclusions

The use of the MMP superfinishing technique showed strong potential as a cost-saving refurbishment method for high-value spiral bevel gears for rotorcraft.

The MMP technique provided a significant reduction in surface roughness that is well known to enhance the surface durability of high-power aerospace gearing.

The superior performance of the MMP-treated TTO pinion in the Block II testing versus the baseline gears in the Block I testing showed potential for the refurbished gears to have enhanced performance. It is likely that this same performance upgrade can be achieved in new-production gears.

The amount of material removed by the MMP technique was controllable, thus requiring gears with varying degrees of damage to be refurbished only to the degree necessary to remove the deepest damage.

The use of silicone replicas to record the condition of gear tooth surfaces combined with 3-D surface analysis by either phase-shaft interferometer or confocal techniques can provide significant insight regarding the effects of surface finish and topography on spiral bevel gear performance.

Recommendations

Additional research into the surface durability of damaged tribological surfaces refurbished with the MMP treatment holds promise for the performance of repaired gears.

While the gear tooth surfaces repaired by the MMP process may conform to the desired finish and geometry characteristics, additional metallurgical tests such as nital etching should

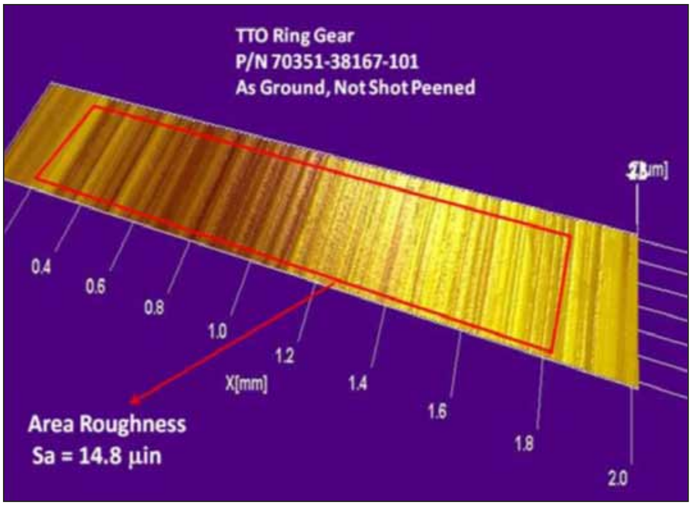

Figure 25 Surface roughness and topography of TTO gear prior to testing.

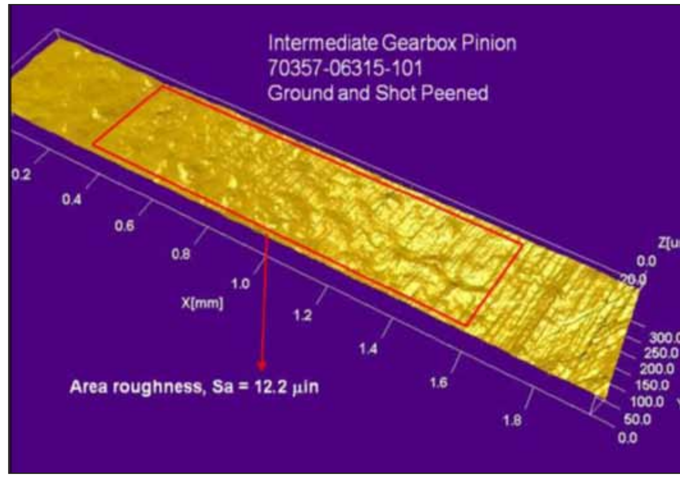

Figure 26 Surface roughness and topography of new-production IGB pinion.

be performed to evaluate the potential for more severe surface damage such as large areas of scuffing to have tempered or softened the surface.

Additional research to fully characterize the degree of gear tooth surface damage that can be economically repaired will enable a more accurate determination of potential cost savings.

(Ed.'s Note: Coming in 2013: an update on the latest developments in superfinishing.)

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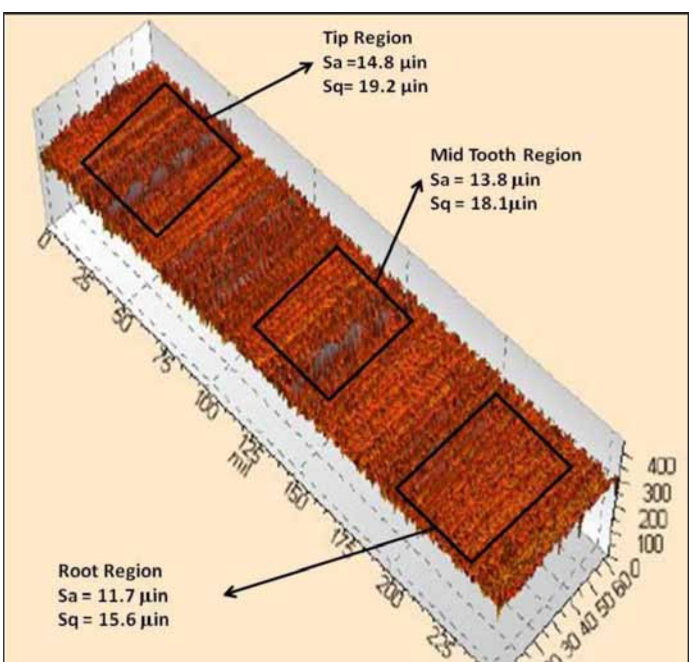

Figure 27 Surface roughness and topography of TTO gear after 12.5 hours of testing.

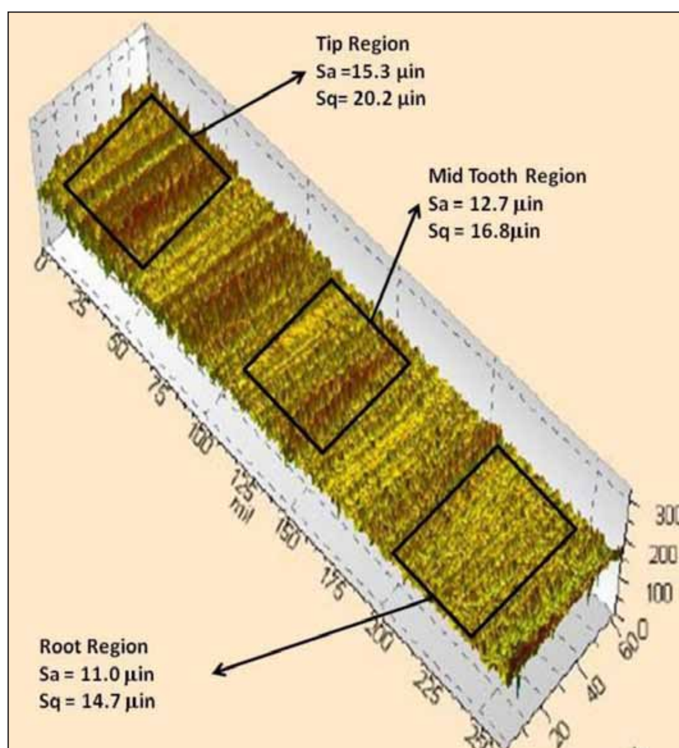

Figure 28 Surface roughness and topography of TTO gear after 33.5 hours of testing.

Ajax Rolled Rings

OPENS NEW MANUFACTURING FACILITY

Ajax Rolled Ring & Machine is bringing new jobs to York County, South Carolina as it opens a new manufacturing facility at its York location. The $2 million facility is the first significant plant expansion for Ajax since beginning operations in York in 1980. Ajax Rolled Ring & Machine CEO Simon Ormerod says up to 25 new positions will be added over the next two years to operate the new machining facility. Five positions have already been filled. "This expansion will allow us to provide a more precisely manufactured product in a much shorter lead-time to our customers." Ajax Rolled Ring & Machine is a supplier of seamless steel forged rings ranging from 12 inches to 100 inches in diameter. The large rings can weigh more than a ton. These rings are primarily used for large gears and bearings, such as are used in large mining vehicles and wind turbines. The new 15,000-square-foot climate-controlled facility allows Ajax to machine to the tight tolerances - within 1/1000th of an inch

- that their customers require. The climate-controlled conditions allow for tighter accuracy and control of the machining operation. The new facility also allows the company to expand its portfolio to produce new configurations and shapes of rings. "We have the capability to expand the new machining facility even more in the future - up to 20,000 square feet. Opening this facility is important to our longterm growth strategy," added Ormerod. For more information, visit *www.ajaxring.com*.

Schafer Gear Works

ADDS NEW DIVISION

Schafer Gear Works has acquired the assets of Dana Holding Corporation's leisure, all-terrain and utility vehicle axle and differential business, including their related manufacturing facilities in Fredericktown, Ohio, and Blacklick, Ohio. The new division of Schafer Gear will be called Schafer Driveline LLC. The acquisition was announced jointly by Schafer Gear President Bipin Doshi and Stan Blenke, the company's executive vice president.

The manufacturing facilities include a 120,000-square-foot assembly plant in Fredericktown, producing axles for leisure, all-terrain and utility vehicles; transmissions and transaxles for ATVs; and related off-highway brake components and assemblies. The Blacklick plant, a 30,000-square-foot facility, is a machining operation producing aluminum gear housings, ductile iron differential cases and ductile iron brake components for the leisure, all-terrain and utility vehicle markets. Collectively, the two plants have 158 salaried and hourly employees.

According to Blenke, the purchase of the Dana operations was an opportunity that aligned with Schafer's strategic objective to expand its product mix through vertical integration. "For nearly 80 years, Schafer has been involved in providing gears nationally and internationally for many applications and customers, including those in transportation-related industries," said Blenke. "Adding gearboxes and axles to our product mix is a logical step in our company evolution and it provides us with more depth and flexibility in meeting the needs of our customers."

Blenke added that the transaction process was completed with unprecedented speed. "Dana was already a customer of ours so we knew their operation well. That certainly helped expedite the transaction. And we can't say enough about the cooperation we received from Dana officials in moving this process along expeditiously. The same goes for the management team and employees at the plants. The enthusiasm for this new venture is as high at our new Ohio plants as it is here at our headquarters."

Tom Troyan, plant manager of both Ohio facilities, will assume the position of general manager under the new ownership. "Tom Troyan has been highly effective in his role as manager of the Fredericktown and Blacklick operations," said Doshi.

"He and his team have been very successful in building exceptional standards for safety, quality and productivity. We are delighted to have him on the Schafer team."

Schunk

CELEBRATES 20 YEARS IN NORTH AMERICA

Schunk founded its United States facility in 1992 and has been manufacturing toolholding products and providing sales and support to local customers from the Morrisville, North Carolina facility for the past 20 years. This success in North America spurred the development of two more entities, Schunk Canada and Schunk Mexico, in 2006. Schunk is headquartered in Germany and has more than 1,900 employees who bring knowledge, skill, and commitment to the company. Schunk combines the features of a family-owned company, a renowned technological leader, and a global player, all in one. The company is close to its customers with subsidiaries and distribution partners in more than 50 countries, who all provide comprehensive and expert advice. "The first 20 years in the U.S. have been remarkable. Through a dedicated team of engaged employees focused on customer satisfaction, the United States has become a home market for the Schunk group," said Henrik Schunk, managing partner for Schunk GmbH & Co. KG.

Vision Quality Components

SET TO CELEBRATE 10 YEAR ANNIVERSARY

Vision Quality Components Inc., Clearfield, Pennsylvania, a producer of cost-effective powder metal gears of many types, including precision pump gears fully finished machined to extremely close tolerances in-house, celebrates 10 years in business Jan 1, 2013. Vision feels their business success came from partnering only with potential customers having the same high quality and superior service attitude that the Vision management has. Vision has met their performance goals set at start-up in both quality and delivery of 98 percent or better each of the last five years through 2011. They believe this, and providing customers high-tech materials, continuous improvement leading to cost reduction, and design and engineering support, will lead them to further growth in the next 10 years. All of their gear products are produced in the United States. For more information, visit *www.visionqci.com*.

AMT

ISSUES SECOND EDITION OF MANUFACTURING MANDATE

As part of its effort to solidify the renaissance in American manufacturing, the Association for Manufacturing Technology (AMT) has issued the second edition of the Manufacturing Mandate. The Manufacturing Mandate was introduced in 2009, just as the recession was ending. Since then, the U.S. manufacturing sector has been the driving force behind the economic recovery. Today, policymakers, industry leaders and academia agree on the major aspects of a national strategy that will accelerate and sustain this manufacturing resurgence. They are aligned with the Manufacturing Mandate's core principles of incentivizing R&D and innovation; increasing global competitiveness and building a "Smartforce" that is equipped with the knowledge and skills necessary for careers in manufacturing.

The Manufacturing Mandate underscores the importance of collaboration as central to the implementation of a national strategy. The Obama Administration's recent announcement of a new public-private institute for manufacturing innovation in Youngstown, Ohio, is a prime example of the important role government can play in facilitating that collaboration between the public sector, academia and industry. This new partnership, the National Additive Manufacturing Innovation Institute (NAMII), was selected through a competitive process—led by the Department of Defense—to award an initial $30 million in federal funding, matched by $40 million from the winning consortium, which includes 40 manufacturing firms, nine research universities, five community colleges, and 11 non-profit organizations from the Ohio-Pennsylvania-West Virginia "Tech Belt." The NAMII aims to enhance a successful transition of additive manufacturing technology to manufacturing enterprises within the U.S.. The effort is led by the National Center for Defense Manufacturing and Machining. AMT and the MTConnect Institute are key launch partners in this innovative project. "AMT will continue to invest significant resources in a secure future for manufacturing in this country," said Douglas K. Woods, AMT president. "There is still much work to be done, but this type of support from the federal government is precisely the type of project the Manufacturing Mandate recommends. It certainly bodes well for America's future as the world's manufacturing innovator." For more information, visit *www.amtonline.org.*

Douglas K. Woods

Metaldyne

RECEIVES QUALITY RECOGNITION FROM FORD

Metaldyne, LLC recently announced that its operation in Valencia, Spain received special recognition from Ford for outstanding quality. For nearly a decade, Metaldyne Sintered Components Espana, S.L has delivered several million forged powder metal connecting rods for certain Ford Duratech engine lines in Europe. During this time, Metaldyne had zero-parts-per- million in defects and 100% on-time delivery--an exceptional performance record. Ford congratulated Metaldyne Sintered Components Espana, S.L's "outstanding quality record" in the award presentation by the leadership of Ford's engine plant in Valencia, Spain. "This award represents Metaldyne's commitment to operational excellence and dedication to support Ford by the hard working men and women at our Valencia, Spain operations," said Thomas Amato, president and CEO, Metaldyne. "This recognition is an example of the exceptional standards Metaldyne strives to achieve for all its customers."

Hunter Automated Machinery

MAKES FEF DONATION

Hunter Automated Machinery recently announced a donation to the Foundry Educational Foundation (FEF), raising the current endowment to $25,000, in memory of Al Hunter, founder of the company and father of current owner Bill Hunter. Bill made this donation on August 9, presenting a check to the FEF Executive Director, Bill Sorensen. Hunter Automated has been a contributor to the FEF for many years. Upon the death of Al Hunter in 2011, the family asked that donations be made to the foundation in honor of him. Once the contributions were collected, the Hunter family asked that FEF establish an endowment to honor Al's memory, with scholarships provided at selected schools. The first school chosen was the University of Alabama. It provides a deserving student a scholarship in Al Hunter's name. FEF is a non-profit organization and the foundry industry's first link to the college campus. The foundation uses funds contributed from the foundry industry to encourage the pursuit of metalcasting as an academic endeavor at schools across the country. Hunter has pledged to donate $500 every year to FEF, going forward. As Sorensen explained, "Students will benefit not only from the scholarship monies, but also from getting to know the contributions Al Hunter made to the industry and the substantial legacy he left behind." Al Hunter held over 80 patents in his lifetime and was chiefly responsible for the development and implementation of automatic matchplate molding machine technology in the North American and ultimately the global foundry market. Bill Hunter presented the check to Bill Sorensen at Hunter headquarters in Schaumburg, Illinois (Chicago) on August 9, 2012. "It is our privilege to help fund this scholarship program that both encourages young people to enter the foundry industry and continues to honor the technological contributions made by Al Hunter," Bill remarked. Sorensen further noted that approximately 90 percent of the students who have received FEF scholarships continue to pursue their careers in metalcasting. For more information, visit *www.hunterauto.com*.

Bill Hunter, left, president of Hunter Automated Machinery, presented a check to Bill Sorensen, executive director of the Foundry Educational Foundation.

AMB 2012 Focuses on Technology Integration and Education

A large number of technologies aimed primarily at higher productivity were presented by exhibitors at the AMB, International Exhibition for Metal Working at the Stuttgart Trade Fair Centre in September. Following the successful 2010 show, AMB 2012 boasted further developments in energy and resource efficiency, higher productivity, life cycle performance, quality assurance and user-friendliness.

Energy-Efficient Gains

The Blue Competence Initiative of the German Engineering Federation (VDMA) was the focal point of a presentation during AMB 2012. "This Initiative has clearly shown that the German machine tool industry is a pioneer in the area of energy efficiency," said Prof. Dr.-Ing. Eberhard Abele, head of the Institute for Production Management, Technology and Machine Tools (PTW) at Darmstadt Technical University. "This Initiative has also ensured that many customers now think far more about energy-efficient machine tools than they did in the past."

Machine tool builders that participate in the Blue Competence Machine Tools Initiative commit themselves to optimizing the use of energy and other resources to enable faster, better and higher quality manufacturing in end-user industries. "This landmark initiative underlines the willingness of European machine tool builders to make a leap forward towards a better and greener manufacturing perspective. Production technology and equipment supplied by the machine tool industry are the key enablers of resource-efficient processes in all other manufacturing industries," said Martin Kapp, president of CECIMO and CEO of the Kapp Group. "Now, our manufacturers are taking on a firm commitment to align, in a holistic approach, their products, processes and business models with sustainability principles."

Multitasking Machining Solutions

Emco's presentation at Stand 5B34 in Hall 5 included the Hyperturn machine series for complete machining of complex workpieces and a revamped version of the Linearmill 600 5-axis machining center. Technology integration was also one of the key aspects of the exhibition program for MAG-IAS at Stand 5A11 in Hall 5. Martin Winterstein, marketing manager at MAG-IAS said that "Thanks to the combination of complementary machining technologies on one machine platform, we are creating value for our customers." Examples include honing on milling centers or chamfering, deburring and drilling on hobbing machines parallel to machining time. Machine competence and process and system know-how were also emphasized during the show. Multitasking, i.e., the combination of many different machining technologies and processes based on standard machines, is also the focus at Heller where the company showed off the new CP 8000 from the C Series for milling and lathe turning, which has a workspace of 1,250 × 1,200 × 1,400 mm. The leading companies in the mechanical engineering industry are coming ever closer together.

Developing the engineers and manufacturers of tomorrow was a key topic during AMB 2012 (courtesy of AMB).

European Skills Shortage Examined

Bertram Brossardt, managing director of the Bavarian Industry Association, believes there will be a shortage of almost three million people in the German labor market by 2015. He also said that finding and retaining skilled personnel posed a "great challenge for industry and society." Under the motto "Mechanical engineer – a job with power," the VDW (Association of German Machine Tool Manufacturers) Educational Foundation for Young People recruited youngsters at AMB 2012. In cooperation with six partners, the VDW invited school students in Baden-Württemberg from the final classes of technically oriented grammar schools, intermediate schools, comprehensive schools and vocational schools with training in metal working occupations to the exhibition. During the special show in the atrium of the Stuttgart Trade Fair Centre, these students had the opportunity to obtain information on recognized trainee occupations in the metal working industry, training and work content, engineering courses and career prospects in the area of machine tool manufacture. The VDW Educational Foundation for Young People is financially supported, for example, by such renowned companies as Index, Hermle, Trumpf, DMG, Siemens and Heidenhain. Project Manager Dr. Marina Kowalewski said before the show, "Through their involvement, the cooperation partners support the objectives of the VDW Educational Foundation for Young People, i.e., to improve vocational training in mechanical engineering and recruit young qualified engineers for the industry." The VDW Educational Foundation for Young People has therefore developed action-oriented school student documents for the area of computer-aided manufacturing that can be used by the lecturers during the lessons.

AMB 2012 closed its doors in Stuttgart on September 22 after posting a record number of exhibitors and visitors. Around 90,000 trade visitors from 65 countries, 12 percent of them from abroad, and 1,356 exhibitors from 29 countries, 27 percent of them from abroad, presented their new products and innovations at the Stuttgart Trade Fair Centre. According to various reports, AMB 2012 was the most successful in the trade shows history.

For more information, visit *www.messestuttgart.de*.

November 13–15—Methods, Practices, Application and Interpretation for the Design Engineer. Hard Rock Hotel and Casino, Las Vegas. Raymond Drago, chief engineer–gear technologist, Drive Systems Technology, Inc., will instruct attendees on the methods used to manufacture and inspect gears, including external and internal spur, single and double-helical gears, as well as bevel and worm gears. A description of each basic manufacturing and inspection method is provided. Both the methodology and underlying theory are explained. The seminar also covers the methods of specifying the data required to control both the manufacturing and inspection processes on an engineering drawing and in a specification. This includes the data to be defined and its presentation on the engineering drawing. It is critical that the design engineer understand the manufacturing and inspection processes that will be employed so that the intent of the design can be successfully translated into practice. Most gear inspection centers on gear tooth geometry; however, various nondestructive and destructive tests (such as ultrasonic, magnetic particle, acid etch, etc.) are also required to ensure the quality of the basic gear material and the results of various heat treatment procedures. In this seminar the basics of a variety of these tests will be covered, including their underlying theory, application techniques and, most importantly, interpretation of the resultant data. This seminar aims to narrow and possibly close the information gap by providing gear design engineers with a good foundation in both manufacturing and inspections processes and procedures. For more information, visit *www.agma.org*.

November 14–15—AWEA Wind Energy Fall Symposium. Chandler, Arizona. The AWEA Wind Energy Fall Symposium sets the stage for sharing successes, strategies and lessons-learned with wind energy industry peers. This executive-level event is one of the only venues where AWEA's committees, working groups, and board of directors convene face-to-face – it's a "Who's Who" of those who are driving the wind energy industry forward. This year, expert speakers discuss recent challenges the industry is facing, what these uncertain times mean for the future of wind energy and your business, and how best to realign your thinking and strategies to emerge from this period even more successful. General session speakers include political analyst and commentator, Paul Begala and former White House Press Secretary, Ari Fleischer. For more information, visit *www.awea.org*.

December 4–6—Detailed Gear Design – Beyond Simple Service Factors. Crowne Plaza Old Towne Alexandria, Alexandria, Virginia. Raymond Drago, chief engineer–gear technologist, Drive Systems Technology, Inc., will instruct attendees on a basic introduction to gear theory and standardization of AGMA/ISO analyses. This will include practical considerations and limitations associated with the application of standard AGMA/ISO durability rating analyses and investigation of the differences in stress states among the various surface durability failure modes including pitting, spalling, case crushing and subcase fatigue. Attendees will improve gear design, better understand gear rating theory and discuss time dependent and time independent failure modes related to tooth design. For more information, visit *www.agma.org*.

December 10–13—Gear School Fundamental Gear Course. Loves Park, Illinois. Gleason Cutting Tools offers this parallel axial gear course dealing with fundamentals of gears, gear inspection, use and care of cutting tools and materials and coating for these tools. The course is recommended for any person in the gear industry who wants knowledge of the fundamentals of gears. The past attendance varied from people in the purchase of gear products, sales of the gear products, gear engineers and gear manufacturing engineers. Course includes gear history, gear types, involute gear geometry, gear tooth systems, general formulas, mathematics, high speed steels and coatings, gear cutting, gear inspection and much more. In addition, attendees will receive a Gleason Cutting Tools plant tour and an optional offsite tour of a complete gear manufacturing facility. For more information, visit *www.gleason.com*.

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What We Learned @IMTS

The Addendum team recently spent six successful days roaming Chicago's McCormick Place during IMTS 2012.

If the foot traffic was any indication, (the 100,000th registrant stopped by on the last day of the show) the manufacturing sector is set for bigger and brighter things in 2013. While attendance was the big news, the real stars of IMTS were the exhibitors. Here's a quick tongue-in-cheek rundown from the six-day manufacturing technology event:

- A three-man crew can build a rally car in six days in between photo ops, television interviews and annoying questions from over-caffeinated B2B editors.

Through the use of an online open design platform, Local Motors co-creates innovative components and vehicles, like the Rally Fighter built during IMTS.

- Enticing America's youth for engineering and manufacturing positions is extremely vital, particularly when one company's 92-year-old engineer is putting in 60-hour work weeks.
- Multifunctional machining is getting crazier by the second. Soon, these machine tools will completely machine a part, serve you Starbucks coffee and schedule to pick your kids up from school.
- One attendee suggested changing the name of the South Hall to "DMG/Mori Seiki and Friends" after getting lost in the middle of their booth.
- McCormick Place is no place to be without a comfortable pair of shoes.
- MAG-IAS cryogenic machining demonstration reminded us of Han Solo getting frozen in carbonite—if Han Solo was a cutting insert.
- Hologram trade show presentations are equal parts cool and creepy.
- It took the same amount of time to find the shuttle service as it did to walk to the East Hall and back.
- In related news: It took the same amount of time to walk the East Hall as it did to catch a cab.
- IMTS attendees love pens. It doesn't matter if they're actually giveaways or just a couple of old Bics. They'll take whatever is not anchored to the table. Stock accordingly.
- Were the high school and college kids scouring the booths for career information or just looking to sign up for all the I-Pad raffles?
- Blackjack dealing robots are coming soon to a casino near you.
- Did anyone else need a compass, a map and perhaps GPS to find the IANA conference at the back of the East Hall?
- If a Chicago Bear and Green Bay Packer fan can eat lunch together at IMTS without incident, we should be able to put politics aside and fix U.S. manufacturing.
- Ingersoll Cutting Tools knows how to get a large group of people to stop what they're doing and hang out in their booth (cue the music).
- Is it a good or bad idea to have sparks flying across a crowded walkway during a North Hall machine demonstration?
- IMTS Suggestion Box: Sandvik Coromant and FANUC trade in their signature "yellow" for "fuchsia" in 2014 (just to mix things up).

Science fiction and manufacturing collided head-on at the Yaskawa Motoman booth during IMTS in Chicago (all photos by Dave Ropinski).

- Is it too soon to send out a press release on IMTS 2014?

All kidding aside it was a great show and congrats goes out to AMT and Gardner Business Media for another successful event. Thanks to everyone who stopped by the *Gear Technology/PTE* booth or joined us at our "The Perfect Mesh" cocktail reception. Hope to see everyone again in 2014. Please feel free to share your insights and observations of IMTS 2012 by sending an e-mail to *publisher@geartechnology.com*.

Photos by David Ropinski