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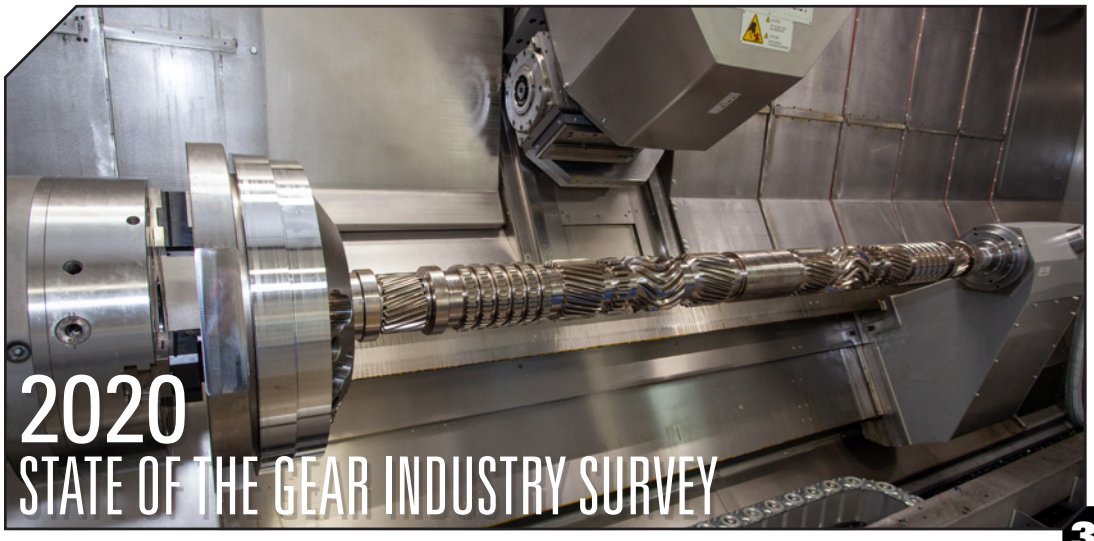

2020 STATE OF THE GEAR INDUSTRY SURVEY

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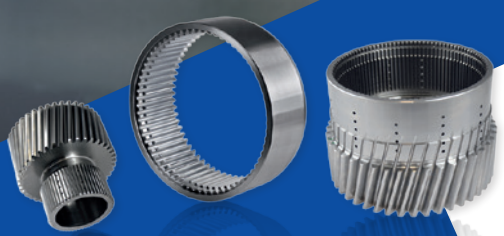

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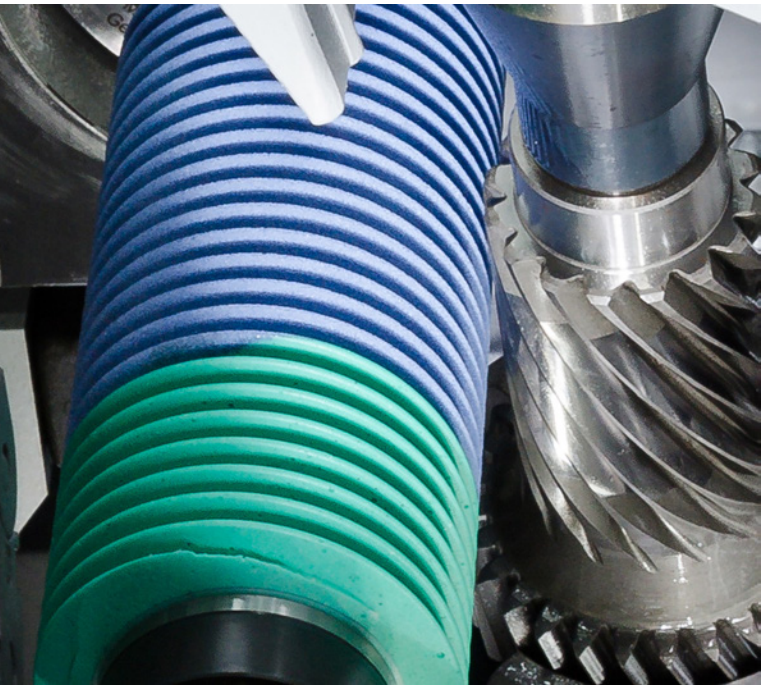

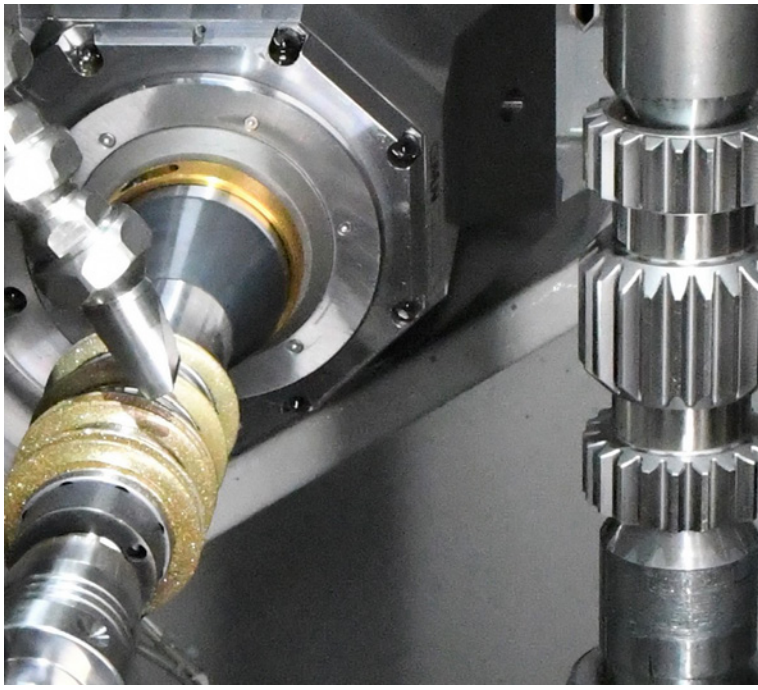

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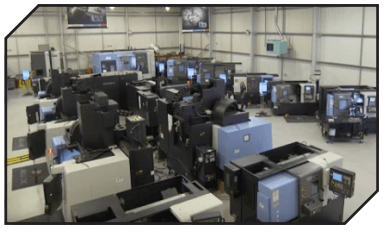
Solar Atmospheres Expansion

This video examines the recent expansion that has allowed Solar Atmospheres to expand its business on the West Coast. Visit *www.geartechnology.com/videos/Solar-Atmospheres,-California-/ for additional details.*

Open Gear Lubrication Analysis with Mobil

The right lubrication is essential for each gear application. This video examines Mobil's lubrication analysis and standard operating procedure for an open gear lubrication inspection. Learn more here: *www.geartechnology.com/videos/Open-Gear-Lubrication-Inspection-with-Mobil/.*

Event Spotlight: MACH 2020



MACH 2020 is the longest-running manufacturing and engineering exhibition in the UK, showcasing the largest variety of manufacturing technology solutions in the country, all under one roof. In 2018, the exhibition attracted more than 25,000 visitors during the five days of the show. For more information, visit *www.geartechnology.com/news/10097/MACH_2020_/.*

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Michael Goldstein founded *Gear Technology* in 1984 and served as Publisher and Editor-in-Chief from 1984 through 2019. Thanks to his efforts, the Michael Goldstein Gear Technology Library, the largest collection of gear knowledge available anywhere, will remain a free and open resource for the gear industry. More than 36 years' worth of technical articles can be found online at *www.geartechnology.com*. Michael continues working with the magazine in a consulting role and can be reached via e-mail at *michael@geartechnology.com.*

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10-4 GEAR SHAPERS

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The Tradition Continues

Publisher & Editor-in-Chief
Randy Stott

You may have noticed a few changes around here. Most notably, the face on this page isn't the one you're used to seeing here.

As you've probably heard by now, Michael Goldstein, founder and Publisher since 1984, has stepped back from his day-to-day duties and transferred the operation of *Gear Technology*, *Power Transmission Engineering* and *Gear Technology India* to the American Gear Manufacturers Association. Please read AGMA President Matt Croson's comments about this new beginning on page 10.

For those of you who don't know me, I began working for *Gear Technology* in 1994. I assumed the role of associate publisher and managing editor in 1998, and under Michael's direction, I've been managing, editing and overseeing the publication of the magazine since then.

But I'm not here to talk about myself. Rather, I'm here to reassure you that the *Gear Technology* you've come to know and love will continue. We're going to make sure that we remember, support and improve upon the traditions established in the first 36 years:

- **Free Knowledge Served Daily**. The Michael Goldstein Gear Technology Library, found at *www.geartechnology.com*, will continue to be available, free of charge, to anyone who wants to access it from anywhere in the world. This includes every article we've ever published, including the vast trove of technical content you can't find anywhere else.
- **Balanced, In-Depth Coverage of the Gear Industry**. Even with Michael stepping back, our editors average decades of experience in gear manufacturing, bringing unparalleled industry insight to our readers.
- **Focus on High-Quality Technical Content**. Our stable of technical editors help us choose the most relevant articles, make sure they're as unbiased as possible and ensure they're technically sound.
- **A Strong Desire to Support the Industry**. We take pride in being part of the gear industry, and we work hard to provide you with the best possible information about the latest technology and emerging trends.

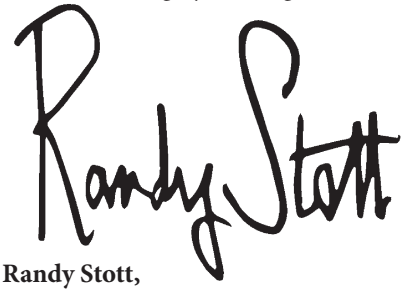
And all of this is enhanced by our connection with AGMA. As part of the association that's leading the world in power transmission technology innovation, we'll have even greater access to the technical experts, events and industry connections that help us continue and improve upon our mission.

I'd like to thank Michael Goldstein for creating this platform, for instilling in our staff the core values that will continue to serve us and the industry, and for ensuring that *Gear Technology* will have a home – and that the industry will continue to have this great resource – well into the future.

I'd also like to thank all of our advertisers and contributors, without whose support we wouldn't be able to do any of this.

Lastly, I'd like to thank you, our readers, because without you, none of the rest matters. My goal is to keep you happy, not just by continuing what we've always done, but by using that history and tradition as a foundation to build upon. We will continue to evolve and improve our products to keep them as relevant to your needs as possible.

To that end, I welcome your feedback, your ideas, your comments and criticisms. Don't be bashful. Let me know how we're doing by sending an e-mail to *stott@agma.org*.



Randy Stott,
Publisher & Editor-in-Chief

P.S. Michael Goldstein is still part of the team! He's working with us on a consulting basis to help guide us over the next year. You can contact him via e-mail at *michael@geartechnology.com*.

To Be Continued…..without question!

Welcome to a new era of *Gear Technology* magazine!

AGMA is proud to add *Gear Technology*, *Gear Technology India*, *Power Transmission Engineering*, the *Michael Goldstein Gear Technology Library* and supporting websites and circulation under its umbrella.

When Founder Michael Goldstein began a dialogue with AGMA leadership about his transition, we quickly agreed that the two organizations' visions were a close match.

AGMA's Vision: AGMA and its members drive power transmission innovation.

AGMA's Mission: We are the global network for technical standards, education, and business information for manufacturers, suppliers and end users of mechanical power transmission components.

Everything these publications do already fits within AGMA's Vision and Mission, so this change just made natural sense.

AGMA is a now a multi-faceted bridge from our technical communities to the markets we serve. Through its magazines, websites, and tradeshows, AGMA is at the center of the power transmission innovation world, and our programs provide strong communications platforms to share technical excellence.

Our standards and IACET-accredited technical educational programs are the underpinning to the innovations our industry creates.

Our business intelligence efforts are now greatly expanded to include reach into the supplier community, the open gear and gear systems communities, and the end user community.

Frankly put, there is no other organization in the world that connects all the parts together – and now, our opportunity is to ensure we continue to enhance the technical community with focused, pertinent, technically oriented content that delivers value to the entire supply chain.

That is a tall order – but one that I feel a 105-year-old organization like AGMA can handle.

Why do I have that confidence? Because AGMA is powered by people: The best engineers, the best CEOs, the most respected open gear companies, the most comprehensive systems providers, and the leading machine tool, lubricant and raw material suppliers.

We are united by working closely with affiliated groups like the ABMA, NFPA, and PTDA.

And our Board, along with the many individuals that serve on our 30+ committees, are laser focused on delivering on our Vision and Mission and looking forward to new opportunities with *Gear Technology* and *Power Transmission Engineering*.

I am pleased to announce that Randy Stott has accepted a position at AGMA – he will become Vice President, Media at AGMA, and will be Publisher and Editor-in-Chief for both publications.

The entire Randall Publications team is now part of the AGMA Chicago office. The same great people who delivered the strongest technical publication in the industry will continue; they will join the great people from the AGMA Alexandria office, and work collaboratively in order to deliver new value, leveraging the power of AGMA, as we strive for synergy and linkage.

With the acquisition, AGMA becomes much larger. We have 21 staff members in two locations, giving us greater reach and considerably more connections than ever before. Most importantly, those connections include you, the readers of *Gear Technology*, and we look forward to continuing to serve you.

But two things remain constant: AGMA and its members are at the center of power transmission innovation — and great people are actively guiding everything we do.

Matt Croson, President
American Gear Manufacturers Association

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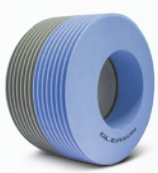


Total Gear Solutions Gleason

Last issue's farewell editorial by our founder and original publisher, Michael Goldstein, sparked a lot of feedback and comments from our readers. Here's a sampling of what your fellow subscribers had to say.

Dear Michael:

It has been a while since we shook hands – I think it was at the AGMA convention in Tucson some years back.

But I have enjoyed reading Gear Technology *all these years even though I did not understand many of the highly technical topics.*

The merger of your legacy with AGMA is the wonderful culmination of your work and your crew over many years and I want to congratulate you on this unique accomplishment.

I wish you all the best and hopefully our paths will cross once again!

Happy Holidays,
Herman Pfauter II

Good Morning Michael,

You and I were introduced to each other many years ago by one of our close friends Marty Woodhouse. I have been a subscriber to your magazine from that day.

I'm sure the gear industry wouldn't be the same without guys like you and Marty. Thanks for keeping all of us up to date on what is going on in the gear industry now and in the future.

Happy Retirement!

Best regards,

David Leslie, Manufacturing Manager
Star Cutter Company

Dear Michael,

I would like to say thank you for this magazine. Working in a very large organization that designs its own power transmission systems but no longer manufactures gears, this has been a valuable source of manufacturing information/education and importantly it is has done so in plain language that is accessible to the ordinary engineer.

I do hope you enjoy your retirement as well as the thought that you have done something worthwhile that has added to the sum total of humankind's knowledge. Real Ph.D. material.

Best regards and much thanks,

Mark Will, Transmissions Design SME
Rolls-Royce Plc
Derby, UK

Dear Mr. Michael,

Good Morning! I have been your ardent fan for almost a decade now.

Like in our greatest Epic Mahabaratha, there is a character by name Ekalavya the great archer, he had a GURU by name Dhronacharya.

For all of us, you are A DHRONACHARYA. We did see you only in prints and digital media. The articles, experiences, inputs shared in the magazine helped us a lot.

You were so good that you offered it to us for free. Thank you so much.

Please accept my salute to you.

My Guru Dhakshana would be to spread the knowledge to every other engineer, which I have been doing and will also continue to do.

Regards,

R. Senthilkumar, Deputy General Manager R&D
Greaves Cotton Ltd.

Michael,

Very nice editorial. I always looked forward to reading your words. You should be very proud of your accomplishments and this transition. It was well played from start to finish.

Cheers!

Mike McKernin, Sales & Marketing Director
United Stars Inc.

Michael,

Back in 1986, I started reading your magazine and enjoyed it all these 33 years. I enjoyed not only reading and learn from the various articles, I also enjoyed your Publishers Page and contacted some of the advertising companies. I admire you for being so determined and consistent with the wonderful magazine, which many of my colleagues enjoyed too.

Now, I am working in Thailand for the last 9 years and still enjoy the magazine

publisher's page

Gear Technology — To Be Continued

Publisher & Editor-in-Chief
Michael Goldstein

When I started *Gear Technology* more than 35 years ago, my intention was to create something of lasting value for the gear industry. It was a way of giving back to the industry that had been so good to me and my family.

As a third-generation machinery dealer who specialized in gear manufacturing equipment, I spent a lot of time traveling the world, and I saw first-hand a desperate need for knowledge and technical information about gear manufacturing. It was available and people needed the information, but they just weren't getting it.

Sure, there were technical conferences such as AGMA's Fall Technical Meeting, and papers were being presented at this and other conferences around the world. Unfortunately, that information wasn't being widely disseminated. Back then, the engineering manager for a big gear company might have attended one of those conferences. He'd go and listen to the presentations and come back to his office with new insights and a blue binder full of technical papers. The problem was, by the time he got back home, his desk was already piled high with all the work he'd missed, and the blue binder got put up on a shelf and forgotten while the engineering manager got back to catching up on the work nobody did while he was gone.

A lot of other people could have used that information, I thought. And so the idea for *Gear Technology* was born. In 1984, we published our first three issues, and we've never looked back.

In fact, we've come a long way since those first issues. Today, in addition to the print magazine, we communicate with you now via the Internet, e-mail and social media. In 2007 we launched *Power Transmission Engineering*. But through the years our core mission has never changed. Our goal is still to bring that educational information to the widest possible audience.

That's why one of the things I'm most proud of is the online library of technical content we provide to the industry, free of charge, and without any kind of restriction, registration or roadblock. Thousands of articles from our 35-year history are available for anyone who wants to read them.

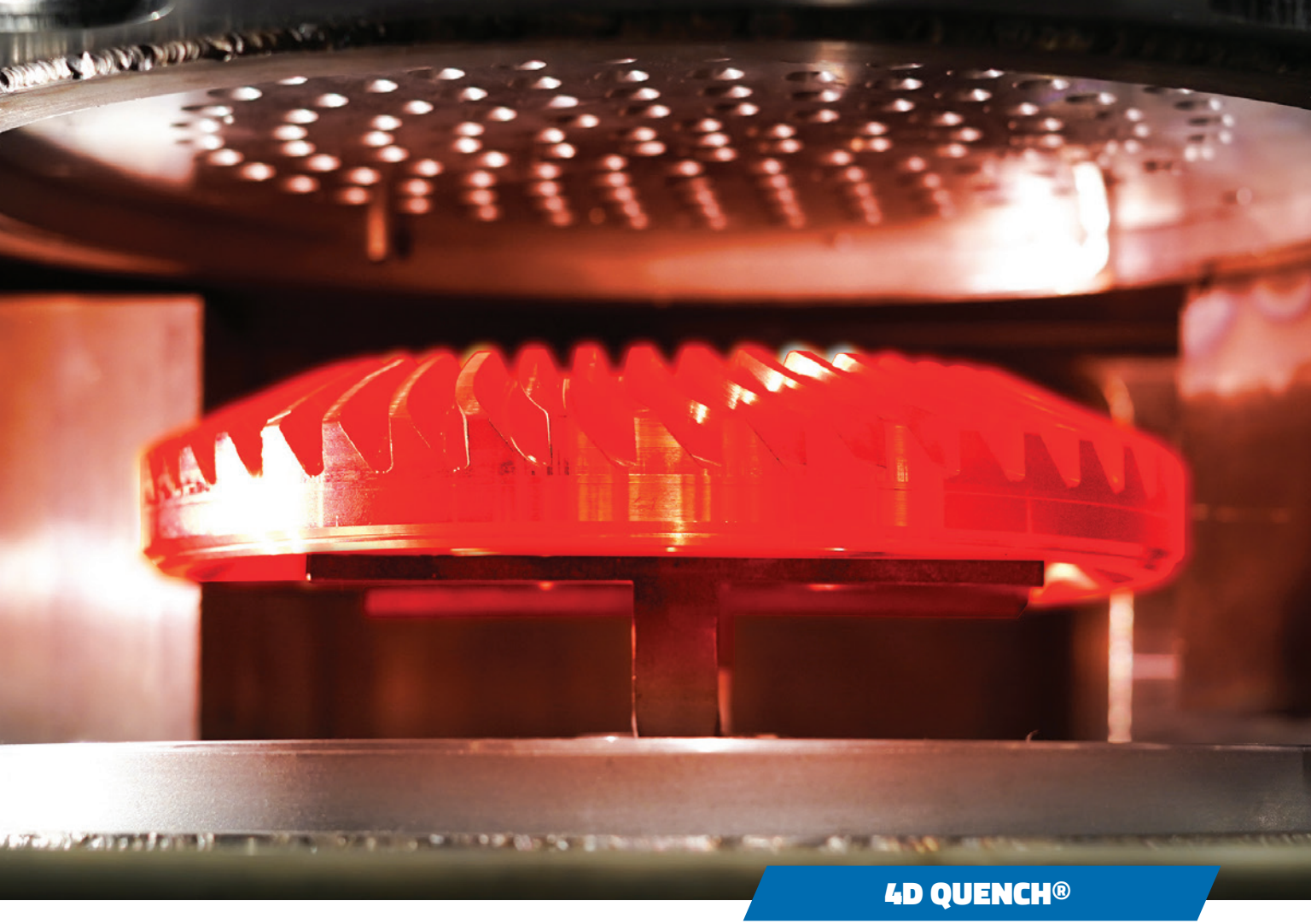
Some of the most valuable articles we ever published were the "Back to Basics" articles we ran in the early years. These articles explain in simple terms the interrelationships between cutting tools, parts and machines, making it easier to conceptualize the mechanics of how designs are transformed into gears.

All of our back issues have been painstakingly indexed and organized so that you can find articles on carburizing, crowning, carbide hobbing or any number of other subjects. More than 10,000 unique visitors make use of those articles on our website every month.

I consider that content to be my legacy, and I want it to be available forever.

No one wants to consider his own mortality, but in October I turned 77, and over the past couple of years I've been thinking a lot about how to ensure that what I've built not only will be

November/December 2019 | GEARTECHNOLOGY 9



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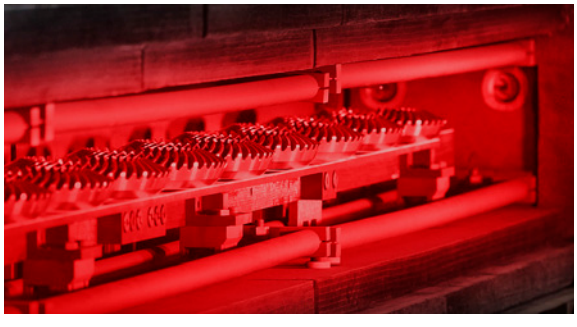

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but, being surprised to read your age and the change to AGMA, which might be a good plan for continuation of Gear Technology.

Turning soon 68 years old myself, I have also plans to retire sometime in a year or so.

Thank you for many years of Gear Technology *and I will continue reading the magazine even after retirement (Gear guys never retire!) of both of us. However, I wish you the best for the future including best health for many years to come.*

With best regards from Thailand,

Volkhard P. Scharpf

(formerly: Getrag Gears, Newton, NC)

Do YOU have something to say about an article you read or something you observed in the industry? Send your letter to Randy Stott, Publisher & Editor-in-Chief (*stott@agma.org*).

Reading Michael Goldstein's editorial in the December Issue of Gear Technology *magazine, I was moved by his comments. Michael has contributed so much to the gear industry. Like myself and many others, I am saddened by the fact that he is "stepping back" from his role at the publication. At the same time, I am very pleased that the AGMA will continue his legacy with the ongoing availability of the valuable assets he created. I can say personally that since 1985, I have both enjoyed and relied on the knowledge provided through the* Gear Technology *publication, and later with the digital library, and I take great pride in having had the opportunity to author some of these articles as well. I have found over the years that some people want to keep their technical information for job security, but what Michael has provided is a major contribution that all can benefit from.*

Michael, you have my most sincere appreciation and gratitude.

Joe Arvin, President

Arvin Global Solutions

Michael,

I can very much appreciate why you are stepping to one side in your roles — 77 is a good working run!

I backed into my knowledge of gears and gearing through a machinist's apprenticeship and I'm sorry to state that I was part of one of the last groups that was going to include instruction on gears and gearing including the making of some forms of gears.

That experience only made me want to learn more, which is part of what led me to Gear Technology. *I've saved every last issue although I find the electronic ones are far easier to search and store today.*

Thank you again for your sharing and willingness to include those who aren't at the center of the field in that sharing!!

Regards,

Darald Bantel, CEO

Bezal Metal

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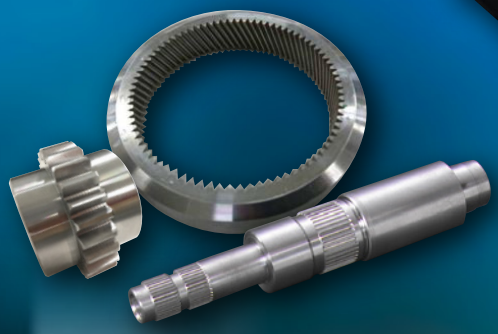
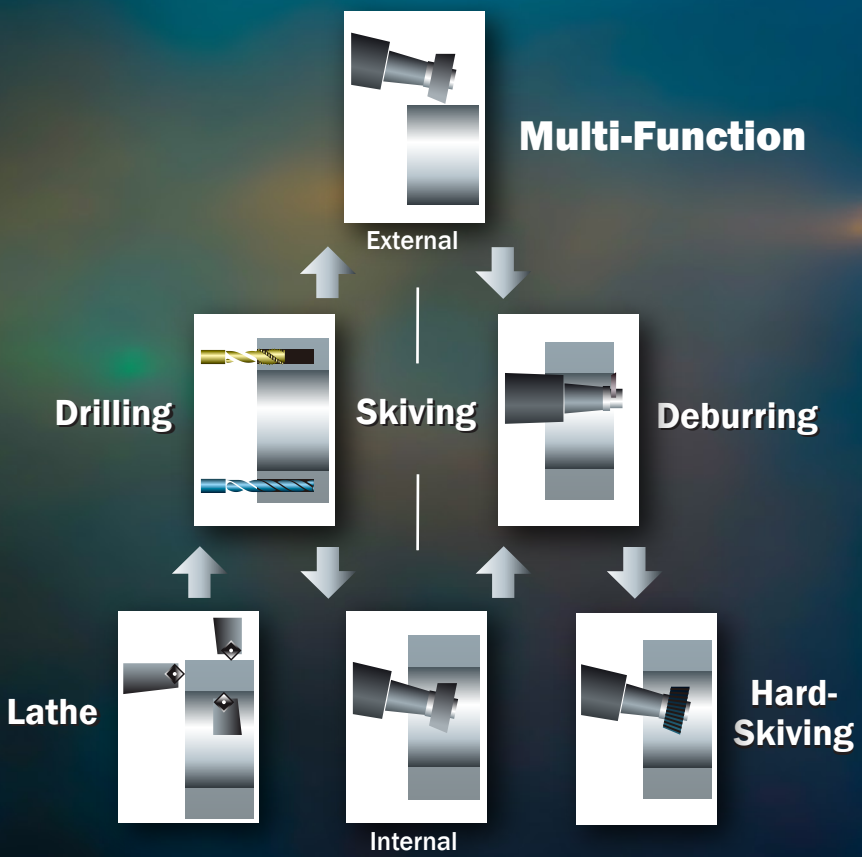
GMS200 Skiving Machining Center for Gears





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KAPP NILES DEVELOPS GEAR GRINDING PLATFORM THAT DELIVERS TIME SAVINGS, ENHANCED QUALITY AND INCREASED SYSTEM AVAILABILITY

Martin Witzsch

High volume production requires top quality at increasingly shorter processing times. The machines are already technically very advanced. Great savings potentials are no longer to be found among the processing techniques, but rather within upstream and downstream process stages such as set-up, measurement and communication between machine and measurement equipment. Therefore, Kapp Niles has developed a platform to tie together and automate these processes. Thanks to open standards such as umati and GDE, it even works on a multi-vendor basis.

There are different approaches to further increase the efficiency of production processes, for example by integrating as many process steps as possible into one machine. However, from a technical point of view, this is very complex and inflexible, and thus unreliable.

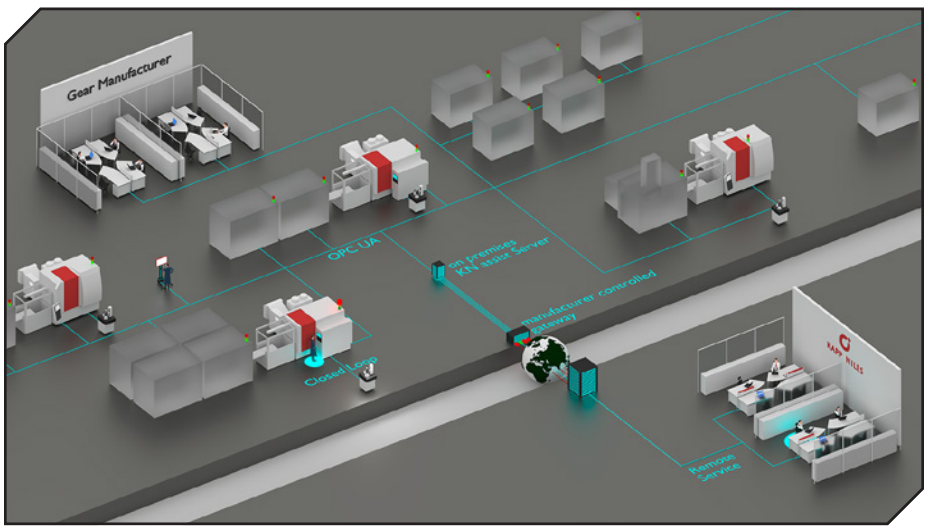
"Instead of integrated machines, we rather envision integrated production chains with as little manual handling between individual chain links as possible," said Konstantin Schäfer, head of product management. "Kapp Niles continues to develop from a pure machine manufacturer to a solutions provider."

This becomes apparent in the growing measurement technology sector, Kapp Niles Metrology. What's more, the existing portfolio is being optimized for production systems communicating with each other. Through the new KN assist platform, for example where control system software like KN grind supports the user from the project planning stage through production.

KN grind, a hands-on control system

As part of the project-related configuration, all required processing options are combined in one workpiece project. With the step-by-step intuitive user interface, concrete project data are collected. In a virtual set-up process, the user selects the gear type and the suitable tools from a component set. Each step is displayed on a conventionalized machine. Upon request, KN grind also offers technological suggestions.

"Unlike with previous releases, critical or incorrect values are displayed to the user. A sequential control allows for a straight-forward compilation of workflows via drag & drop. This comes in very handy for complex processing, for example, of workpieces with multiple processing positions within one project. These generated sequences can be used for automated processing as well as for set-up sequences," said Volker Zenker, software development manager.



The need for softkeys is replaced by a touch screen display control panel. All new machine generations feature this control system.

No data security compromises

Compared to highly automated production centers, it seems like a relic of the early days of industrialization if operating personnel have to walk from the measurement room to the machine to carry over measurement reports in order to manually type in corrected values. The fact that this is still practiced within a high-tech environment is due to the extremely high safety standards of users such as the automotive branch who have so far circumvented simple data integration. Moreover, the use of USB sticks is strictly prohibited. Another factor has been the lack of consistent data transmission standards to allow for secure data integration. That is why Kapp Niles has developed solutions that no longer require the installation of invasive software and thus allows users to retain control over their data at all times.

"This concept does not include any cloud services," added Schäfer. Applications that go beyond direct machine control are programmed in HTML5. This allows the user to apply them on both classic computers and mobile end devices.

KN assist: the bigger picture—which also applies to all manufacturers

The result of the above thoughts is the KN assist platform. Thanks to above mentioned HTML5 programming, KN assist runs without any further software requirements on a PC and mobile end devices alike. All the user has to do is to call up a single address on the Intranet and thus is granted access to the system through his browser or an app.

The data exchange takes place via the standard interface OPC UA (Open Platform Communications Unified Architecture) facilitating machine-to-machine communication with very little effort. As an overview of the overall system array, KN assist uses the open data exchange format such as GDE

(Gear Data Exchange) and umati (universal machine tool interface), developed by VDW in cooperation with project partners. This allows the exchange of basic gear/toothing data, modifications, assessments, etc. among manufacturers. Furthermore, the operating states of all machines in the plant are displayed. This gives each user from every location a production overview.

Kapp Niles KNM 2X measuring device for production-related applications. All photos courtesy of Kapp Niles.

An even more complex application is the data management of all component-specific parts such as clamping, dressing and grinding tools. Until now, set-up component data had to be manually entered at the machine to avoid the possibility of supplier data carriers accessing the production areas. In future, RFID or 2D codes will be attached to dressing rolls, worms or clamping tools that can be read by the machines. This reduces set-up times considerably and allows components to be clearly identified. Storage locations, service life, clamping cycles or assignments to a project in planning can be conveniently documented this way. In doing so, the response time to service requests and internal processes is reduced.

Quicker response times to service requests

The customer expects prompt service in case of a service request or system malfunction. However, the classic chain of messages is comparatively slow. Machine operators detect an error, notify the Service Department and describe the problem. The Service Department then contacts the manufacturer; the latter queries additional data — best case scenario — via a modem to be activated, however, more likely over the phone. In doing so, information can get lost or displays can be misread. That is how the first hour is spent: converted into idle time, this creates a costly situation. Moreover, the machine manufacturer will have to collect, update, and analyse the data first. A conventional data transmission via the internet would be feasible, however, it is considered not secure by most users.

Kapp Niles has taken remedial action for this process: The customer can now initiate the contact in KN grind. Christian Füger, manager of sales and service, described this option: "The

service request can be initiated via a button on the display of the machine, or via the web interface of any mobile end device. This allows the Service Manager, operator or planner alike to respond without delay," Füger said.

The service request is sent to Kapp Niles directly via a TÜV-IT-certified VPN connection. Diagnostic data, log files, etc. of the relevant machine will be provided to the customer upon explicit release, without losing the royalties over the process and the data.

In-process measurements via "closed loop". With the dark green area, drifting setpoint values can be detected and corrected, even during ongoing processes

Currently, the response time is around 12 hours. In other time zones without local representation, 24 hours at worst.

"We strive for end-to-end service with a response time of two to four hours. This can be done, as all information such as commission numbers, error patterns, measurement reports, etc. is already provided along with the service request," Füger said.

Turbo for the measurement technology

As previously indicated, the portfolio now also includes machines for production-related measurements, as significant time savings can also be achieved for follow-up work of grinding processes. During the classic process, random workpiece samples had to be taken from production to be carried to the measuring machine usually located in a different hall. Depending on the workload, the results would usually be available about 15–20 minutes later. Afterwards, the measurement report had to be taken back to the machine to manually type in the corrections. In order to reduce these times, Kapp Niles is drawing on multiple factors. The measuring machines are also designed for product-related applications. They can do without a climate chamber (see image). The individual axes and the workpiece are monitored via sensors for temperature compensation purposes. Air springs absorb vibrations. In doing so, the measurement accuracy meets the highest standards, even in high volume production.

"The machines can be accessed freely

by the operator from three sides, and thus is also suitable for automated loading. Flexible positionable counterholders are provided for the measurement of wave-shaped parts. In addition, the machines can be converted for a new workpiece in seconds with a quick-change clamping system," said Gerhard Mohr, managing director of Kapp Niles Metrology.

Automation also contributes at least as much to the time savings. The direct connection between the grinding and measuring machines is known as "closed loop" within the sector. The measuring machine provides data not only in form of reports, but also as GDE dataset. In the first version, these are the typical correction variables (fHα, fHß, tangent length correction /pitch correction) which will change in case of a temperature increase or tool wear. Compared to manual input, these data can be imported and analysed much quicker and with fewer errors via OPC UA in KN grind. If a new measurement result is provided, the operator will be notified and receives correction suggestions.

"What happens here is not a pure Target/Actual comparison. On the contrary, the operator receives the measured values prepared, which allows him — based on his experience — to decide whether and how he will intervene. Based on the project, automated tracking is another option," said Christian Graf of software development.

Overall, the described measures will significantly speed up and simplify the workflow. The user gains a better overview of the production process while taking advantage of the many benefits of the new software platform, even on a multi-vendor basis.

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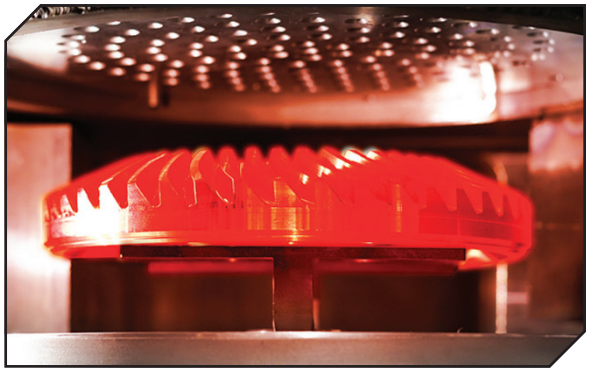
Seco/Warwick

INTRODUCES A MODERN ALTERNATIVE TO PRESS QUENCHING



The new UCM 4D Quench vacuum system introduced by Seco/Vacuum Technologies, a Seco/Warwick Group company, will replace traditional press quenching. The new furnace enables customers to achieve the same results or better as oil press quenching but with gas cooling after vacuum heating in a continuous, single-piece flow vacuum heat treatment system. 4D Quench is a cost-effective alternative for quenching and distortion control that cools as rapidly but without the issues associated with oil.

"Seco/Warwick's 4D Quench furnace is dedicated to those who want to avoid or eliminate press quenching and significantly increase quality and process integration of gears and other transmission components," said Maciej Korecki, VP, business segment vacuum heat treatment furnaces. "The 4D Quench system utilizes a proprietary arrangement of cooling nozzles that surround the part and delivers a uniform flow of cooling gas from all sides; top, bottom, and sides — for "3D" cooling. To complete the process, a table spins the part (the 4th Dimension), further enhancing quench uniformity."

The 4D Quench system solves the following process and product problems:

- Parts are quenched and cooled without the possibility of oxidation and without dirty oils
- Seco/Warwick's single-piece flow furnace with 4D Quench moves parts automatically and eliminates labor and product variations due to manual handling of parts
- The 4D process is perfect for through hardening and for hardening previously carburized parts with extremely low distortion
- The 4D Quench eliminates washing, chemicals, waste disposal, oil vapors and all the mess associated with quench oils; it also improves worker safety

How it Works

The entire nitrogen cooling system provides powerful and uniform quenching which results in repeatability and significant reduction of distortion and finally its control. Neither oil nor helium is required.

For more information:
Seco/Warwick
Phone: (814) 332-8520
www.secovacusa.com/4d-quench

Kennametal

OFFERS HARD TURNING INNOVATION

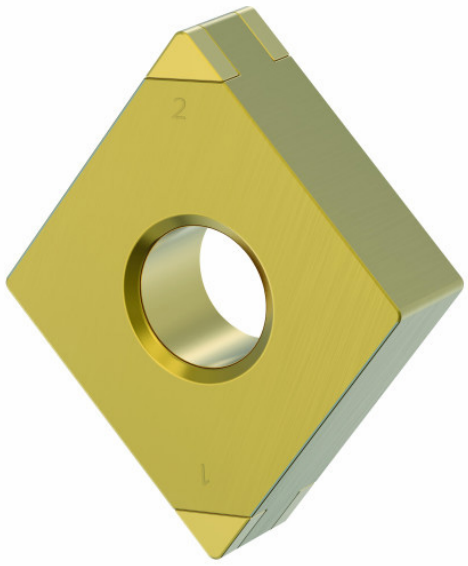
Kennametal recently announced its latest innovation in hard turning-KBH10B and KBH20B PcBN grades, double-sided inserts for materials up to 65 HRC. The new grades are specially designed to deliver higher productivity and longer tool life when turning tool steels and other hardened materials.

"Kennametal´s new KBH10B and KBH20B grade inserts are an excellent choice for high-volume production of hardened gears, shafts, bearings, housings, and other drivetrain components, where tooling cost per part is an important metric," said Robert Keilmann, product manager, turning.

Polycrystalline cubic boron nitride (PcBN) mini-tipped inserts have long been recognized as a great option for reducing part cost when turning hardened steel components. Kennametal´s new grades of PcBN inserts improve upon that value proposition by delivering increased productivity with a lower cost per part.

Features include:

- Patented ceramic binder structure and TiN/TiAlN/TiN coating that provides extreme wear resistance even at elevated cutting speeds.
- A gold PVD coating makes it easy to identify when an insert needs indexing, while the numbered corners assure that a machine operator won´t inadvertently switch to a used edge.
- Two edge preparations in a »trumpet» style hone for heavier and interrupted cuts, and a light hone for continuous turning. Both are free-cutting, further extending tool life and generating surface finishes down to 0.2 Ra.
- The PcBN mini-tips are offered in four insert shapes — three rhomboidal and one triangular — which means up to six cutting edges per insert.



For more information:
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www.kennametal.com

GMTA

ANNOUNCES EXPANSION TO PROFILATOR LINE

GMTA, the North American distributor of Profilator, has added new machines using the process modules it already supplies. Profilator is suitable when customers require complex machining processes to be carried out effectively, efficiently and with high precision.

Today, an operator working on a modern machine expects a flexible

Frenco GmbH

OFFERS HORIZONTAL SLIDE OPTION FOR SPLINE INSPECTION

Frenco GmbH is now offering a horizontal slide option for the inspection of internal and external splines with AVM and IVM gauging systems. Advantages of this new development include easier handling of long workpiece shafts through adjustable V-blocks with longitudinal travel and the repeatability for MdK averages of ≤ 1.3 µm. Frenco Gmbh has been in the spline metrology business since 1978. Euro-Tech Corporation is the exclusive North American distributor of Frenco splines and gears.

For more information:
Euro-Tech Corporation
Phone: (262) 781-6777
Eurotechcorp.com

manufacturing process, short cycle times, reduced investment and running costs. With these requirements in mind, Profilator offers polygon and face slot machining, gear tooth pointing, chamfering and deburring, gear and spline cutting, shifter stop machining and Scudding.

The polygon turning unit is used for castle teeth machining on automotive gearbox parts. The rotating cutterhead is synchronized with the workplace spindle and a front face coupling is produced with the carbide insert arrangement and the transmission ratio. With additional inserts on the same cutter head, the part can be deburred. In gear tooth pointing, the pointing tower can be used in both rotative and indexing modes. Settings and corrections are made through the new Ergo Control SIMPS (Profilator Simplified Integrated Machine Programming System). For the chamfering and deburring of splines, gear wheels and shafts, Profilator uses the ZEM series gear deburring machines. This vertical, single spindle gear deburring machine offers clear advantages over conventional deburring machines. Gear cutting is used both for the Profilator rotative gear cutting with inserts and for hobbing. Through the application of Schlagzahn tools and carbide inserts, customers achieve the most economical manufacture of splines, gears, involute gears and front face gears. The shifter stop is synchronized so that the tool machines each tool flank. Lastly, Scudding can be used for a wide range of symmetrical gear applications as well as non-symmetrical gear or profile applications such as belt pulleys and synchronize gears. The same machine can be used for internal and external Scudding applications.

Profilator developed the S-type machine. This is a compactly and modularly designed, vertical single spindle pick-up gear cutting machine. Machines in the S Series are better than broaching and most applications feature a dry machining process. All machine components are designed for especially high static stiffness and optimal dynamic behavior. Furthermore, the machine's twin spindle arrangement speeds up the process considerably. A control panel and a media container are installed on the rear of the machine bed. The workplace flow direction is variable. S-type machines are available in three sizes, namely Profilator S-150, Profilator S-250 and Profilator S-500. Profilator S-150 has a part diameter up to 150 mm, while Profilator S-250 and S-500 have a part diameter up to 250 mm and 500 mm, respectively.

For more information:
GMTA (Distributor for Profilator)
Phone: (734) 973-7800
www.gmtamerica.com

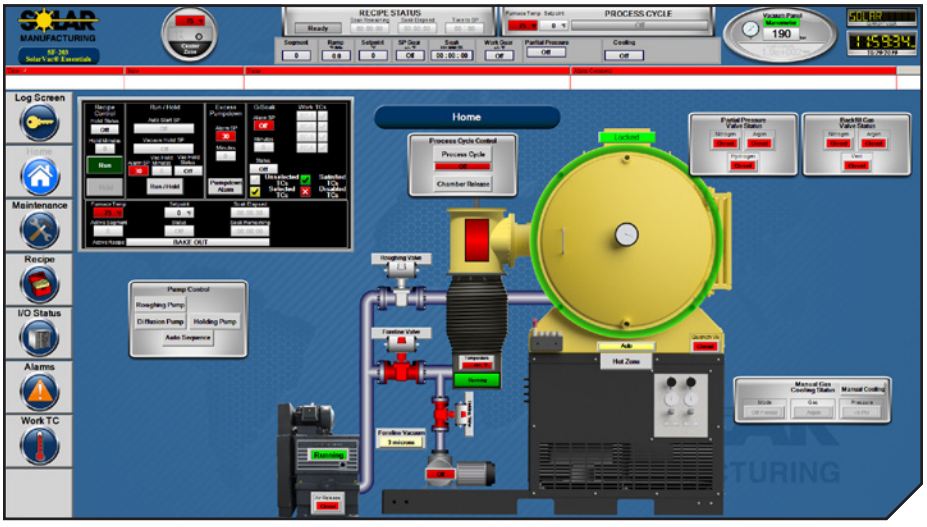
Improving Cost Efficiency in Heat Treatment

The Future Gives the Gear Market Plenty to Think About in Areas Like Automation, Additive Manufacturing and Machine Learning

Matthew Jaster, Senior Editor

Think about the future. It's not as scary as it seemed thirty years ago. Sure, robots are everywhere, humans are co-dependent on their smart devices and cars are driving themselves, but there's much more going on behind the scenes. Data, automation and additive are creating many new opportunities in industrial manufacturing.

Heat treating gears, for example, is going through some technological advances that allows the equipment to perform faster, better and more efficiently than ever before. Companies like Solar Manufacturing, Seco/Warwick and Ipsen are on the leading-edge of these new innovations.



Essentials program for Mentor. Courtesy of Solar Manufacturing.

Solar Ups the Ante on Automation and Control Advancements

Automation plays an essential role in ensuring quality and reliability, as well as improving cost efficiency, in heat treat processing.

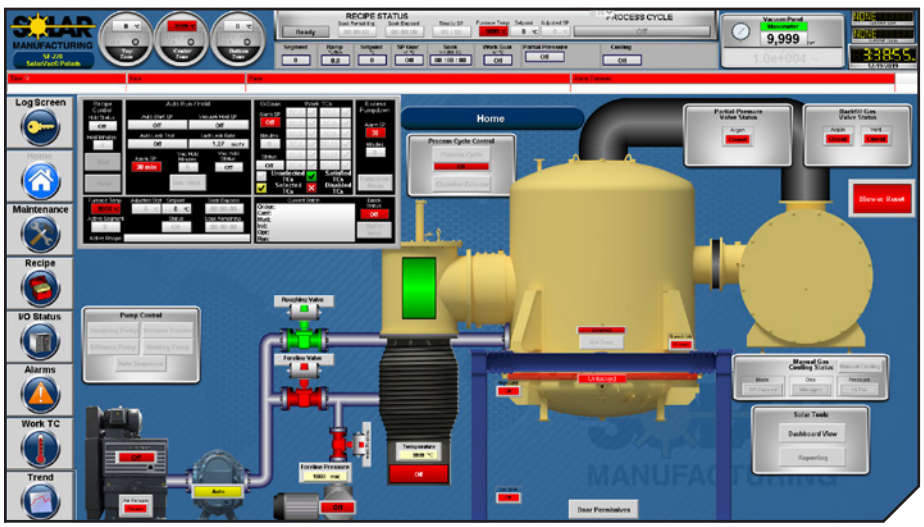
"No matter the type of gears being treated or their application, they are a critical portion of our customers' product, and automation adds a tremendous amount of value to the process. By predicting precise 'wheels up to wheels down' process times, the control system can monitor and alter the active process in real time when production runs start to fall short of their predicted model," said David Rossi, automation and controls engineer manager at Solar Manufacturing. "Because operator intervention can be reduced significantly, we can provide a more consistent, time-efficient product run, allowing higher utilization and throughput."

The company's *SolarVac Polaris Historian with Dashboards* is now included in all *Polaris* core control systems, providing a rich depth of (up to) 500 data points recorded every second. Maintenance personnel can easily identify equipment failures while following up on predictive alarm conditions received automatically via email or text, Quality Control can compare order run metrics to analyze variations in component performance, and Production can monitor batch-specific utility usage, ensuring furnaces are running within their targeted utilization / OEE goals.

"This data is presented via a customizable, easy to use web-based dashboard. Because the data is also available directly from the intrinsic SQL Server, customers can easily integrate the furnace live and historical data into their own MES/ERP systems via standard SQL queries," Rossi said.

Software is an additional area where Solar can unify the heat treat equipment on the shop floor.

"Expanding outside of the standard PLC/HMI offering to include our *Historian* software, we also offer optional batch reporting packages and centralized recipe management software that will integrate with our customers' business centers to help tie together all plant-wide Solar Manufacturing furnaces," Rossi said.



Maintenance personnel can identify equipment failures using Polaris. Courtesy of Solar Manufacturing.

Polaris dashboard (courtesy of Solar Manufacturing).

From a performance standpoint, *Historian* allows Solar's service technicians to conduct extensive troubleshooting of the equipment during factory acceptance testing and commissioning. Knowing how the furnace equipment performed at commissioning and comparing this with current performance metrics helps maintenance personnel identify changes and perform root cause analysis for any anomalous conditions.

"Based on customer requests, we are now leveraging integration with our customers' ERP and MES systems and have established a means for centralized recipe control and disbursement across all plant-wide Solar Manufacturing furnaces. We have also started development into augmented reality solutions that will tie live process data with web-based technical documentation," Rossi added.

Many of these new innovations received plenty of attention during the Heat Treat 19 show in Detroit (October 15–17). Rossi said that Low Pressure Carburizing (LPC) is significantly impacting the gear manufacturing market. This process is an improvement over traditional gas carburizing in terms of absence of inner granular oxidation (IGO), providing improved root-to-pitch ratios of the carburized depths, and when coupled with high pressure gas quenching, results in less part distortion. The LPC process also produces consistent carburizing and heat treating results which complements the benefits of automation and control advancements in the industry.

"We received an amazing amount of feedback this year on the aesthetics and long feature list of both our *SolarVac Polaris* and *Essentials* control system at this year's ASM show. Our Essentials system is a streamlined control platform that can scale from our popular skid-based Mentor furnaces up to the largest systems we manufacture. We proudly displayed our Mentor at this year's show," Rossi said.

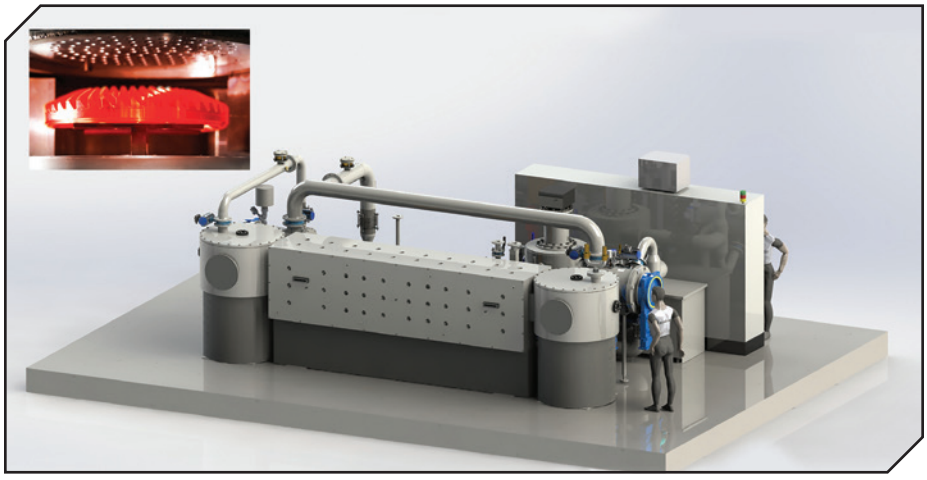
Additive manufacturing is another area that is getting more attention at Solar.

"Vacuum furnaces are an integral part of the Additive Manufacturing (AM) market. When using vacuum furnaces for this market, extremely tight temperature uniformity is critical, particularly at high sintering temperatures. Low vacuum levels and slow ramp rates can benefit from automated holds during the ramp to minimize outgassing of residual binders, and in some cases, we can introduce hydrogen partial pressure to the process. These are just some of the technologies offered to our customers," Rossi said.

He believes the AM market may have an impact on the brazing industry. Multiple components that were brazed together to form a single part can now be printed in one step. As the AM market continues to grow, raw material processing will be reduced and more near-net finished parts will be heat treated, according to an ASM paper entitled, "Vacuum Furnaces Were Made for Additive Manufacturing," by Robert Hill. The AM parts will need the processing advantages vacuum furnaces offer over atmospheric furnaces.

Solar is currently looking into both machine learning and augmented reality.

"Machine learning has the potential to provide automated anomaly detection, alerting maintenance to possible eminent equipment failure. In addition, this technology can assist the quality department by flagging batch runs that look different and may require additional analysis," Rossi said. "Augmented reality provides maintenance with immediate contextual access to manuals, drawings, and service documentation right at the equipment where it is needed. This has the potential to reduce time spent servicing equipment and training maintenance personnel."



Seco/Vacuum launched two two products in 2019 including the Super IQ and the UCM 4D Quench (courtesy of Seco/Warwick).

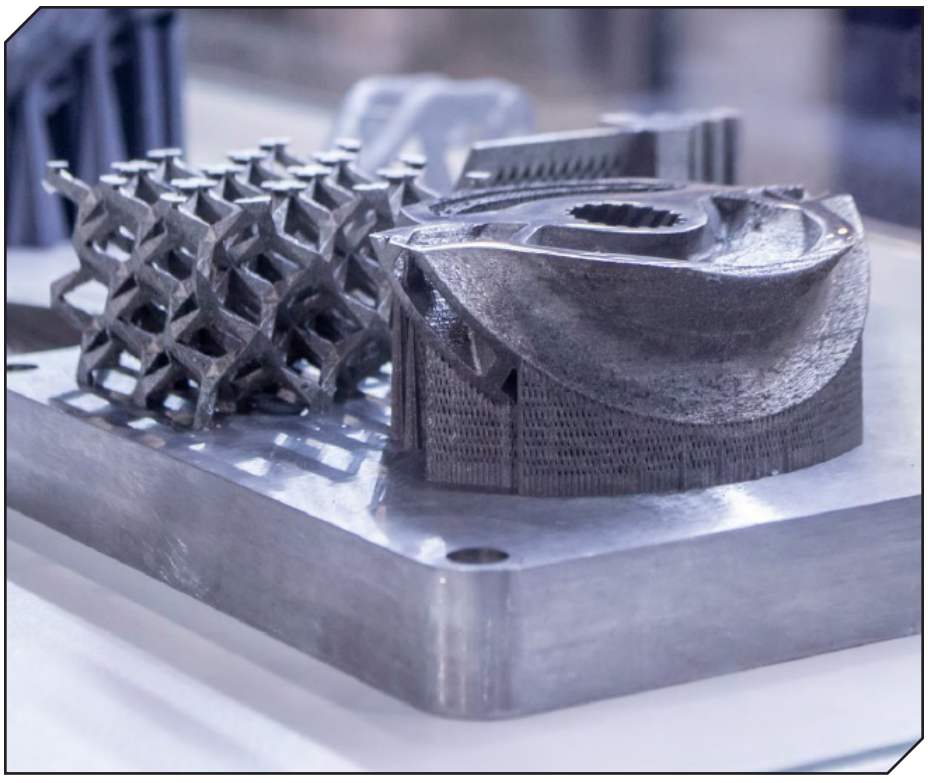
Seco/Warwick Examines Practical Use of Advanced Automation

The practicality of advanced automation is an area that Seco/Warwick has been focusing on for several years. "The development of automation continues on a strong and fast pace, as manufacturers shift their requirements towards logical, well thought out systems in conjunction with smart, autonomous solutions. These drivers make it possible to maintain production continuity while adapting quickly to emerging technologies when making key production, investment and business decisions," said Sławomir Wachowski, Seco/Warwick automation director.

One area of interest are the control cabinets considered the 'brain and nervous system' of an industrial furnace. An industrial computer installed in the control cabinet, comprised of an array of PLCs, acts as a process manager and an intuitive communication interface between the operator and the manufacturing process as well as with other control components and instrumentation to ensure safe and continuous operation of the equipment.

Another key technology is the control system which was recently updated in the automotive industry with one of Seco/Warwick's long-term furnace customers — NordGlass. The company is adopting a self-learning temperature control system that, thanks to the use of FuzzyLogic combines with over 2,000 control elements to adapt the glass bending temperature to the glass model. This technique ensures optimum production with maximum performance and eliminates waste while preserving the company's strict optical specifications.

According to NordGlass, the company had been looking for a control solution that would recognize the glass type, its shape, properties and texture, and would be able to independently adjust the correct temperature required for glass bending. The system was also supposed to work in non-linear product recognition mode, as one production line can be used for various glass from various manufacturers and belonging to different production models. Smart, adaptive learning was the most important requirement for the development of the furnace control system.



Ipsen has been working with 3D printer manufacturers for almost a decade and recognizes the importance of serving this rapidly growing industry.

According to Wachowski, the system proposed to NordGlass is more than just logic coded into the PLC. It is a system for processing large amounts of data that is the basis for executing control over thousands of precise heating elements. Process stages include recognition, interpretation, data use, adaptation and action. When executing the process, the system continuously learns, draws conclusions, interprets data and takes action; in other words, it autonomously selects and changes the glass bending temperature in order to give it the required features. This hints at how large a role automation and IIoT will play in heat treat systems now and in the future.

Seco/Predictive, based on predictive analytics, together with the Seco/Lens based on augmented reality technology, are some of the recent solutions supporting production and service processes. Awareness of the need to implement advanced and intelligent solutions, often called "the brains" of an entire production line, is constantly growing.

The company's augmented reality (AR) application Seco/Lens is an application that, based on Microsoft holographic computer — HoloLens, introduces heavy industry into the world of augmented reality. It can superimpose previously developed 3D model of the device for heat treatment of metals enabling its monitoring, diagnostics, maintenance of the production process, remote repair and planning the most optimal layout of the production line on the hall. Seco/Lens allows for very accurate visualization of Seco/Warwick solutions, as well as for conducting training on the operation of the device without the need for expensive and time-consuming travel.

Advancements and technologies to the furnaces themselves include the new Seco/Warwick UCM 4D Quench vacuum system. This enables customers to achieve the same results or better as oil press quenching but with gas cooling after vacuum heating in a continuous, single-piece flow vacuum heat treatment system. 4D Quench is a cost-effective alternative for quenching and distortion control that cools as rapidly but without the issues associated with oil. (learn more on page 19).

"Globally, a number of various industries use heat treatment in their day to day processes. Automotive, aerospace, energy, commercial heat treaters, heavy

construction machinery, and the tool and die sectors to name a few. As the years go on, together with the heat treatment market getting bigger and better, the needs and expectations, due to the digitalization and globalized standards, are changing," said Paweł Wyrzykowski, CEO of Seco/Warwick.

Ipsen Offers Titan Furnaces for Additive Manufacturing

Ipsen USA was recently awarded an order to supply a West Coast aerospace customer with four Titan H6 2 bar vacuum furnaces that will be used for heat treating additively manufactured parts in full-scale production. Ipsen shipped two of the furnaces in November and will ship the remaining two in early 2020.

"Ipsen has the industry's best lead time with the Titan furnace. This, coupled with a product designed specifically for the AM industry, made Ipsen the obvious choice for this project," said Ipsen's Vice President of Sales, Pete Kerbel in a recent press release.

Additive manufacturing (AM) is changing the landscape for production and design with the ability to produce complex components made to rigorous standards with short lead times. Heat treating is an important step in post-processing most metal AM parts to meet strength and material density requirements.

Ipsen has been working with 3D printer manufacturers for almost a decade and recognizes the importance of serving this rapidly growing industry. While AM has primarily been used for prototyping and low-volume production, companies are now looking to AM for high-volume, mass-produced metal parts.

Ipsen is committed to keeping pace with emerging technologies to build the next generation of furnaces. As additive manufacturing becomes more desirable, Ipsen is working to ensure customers have the right products for their evolving needs.

Additionally, Ipsen recently expanded its aftermarket services across the United States, Canada and Mexico. Five Regional Sales Engineers (RSEs) to assist customers with replacement parts, retrofits, upgrades, service and technical support for any brand of atmosphere or vacuum heat-treating system.

Ipsen's RSEs have diverse backgrounds with experience in engineering, machine repair, and metallurgical processes. The RSEs are supervised by Matt Clinite, customer service sales manager at Ipsen.

"They are each incredibly unique in their own individual strengths," Clinite says about the RSEs. "One common trait they all share is integrity and a 'customer first' attitude."

The RSEs fill a crucial role within the organization by creating a more efficient system for managing customers' needs and streamlining the process between new equipment sales, aftermarket service, and field support.

"Our team is here to identify risk points with our customers' equipment," says Clinite. "Our goal is to help our customers better prepare for maintenance planning and experience maximum furnace uptime and reliability."

Data, Automation and the Future

The end game is finding the right personnel and the right technologies to help gear manufacturers produce better gears. As our State of the Gear Industry Survey suggests (page 32), manufacturing is in a constant state of change, it's necessary to take a good, hard look at areas like data, automation, controls, and additive manufacturing to see what technologies and heat treat capabilities need to be considered heading into the next decade.

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Spraying to All Fields: Catching Up on Some Lubrication Trends and Issues

Jack McGuinn, Senior Editor

Lubrication—as it pertains to the gear industry—is a rather large universe, much, much more than the old double-entendre "the squeaky wheel gets the grease." Indeed, lubrication in this universe encompasses gear oils, coolants, greases, oils and sophisticated lubricants—intended for everything gear-related from bearings to gearboxes to pinions to couplings to machinery, and more. Add in the lubrication equipment—some of it quite sophisticated—used to deliver these various lubricants—including synthetics—to where they need to go, and it's easy to understand there's a lot going on.

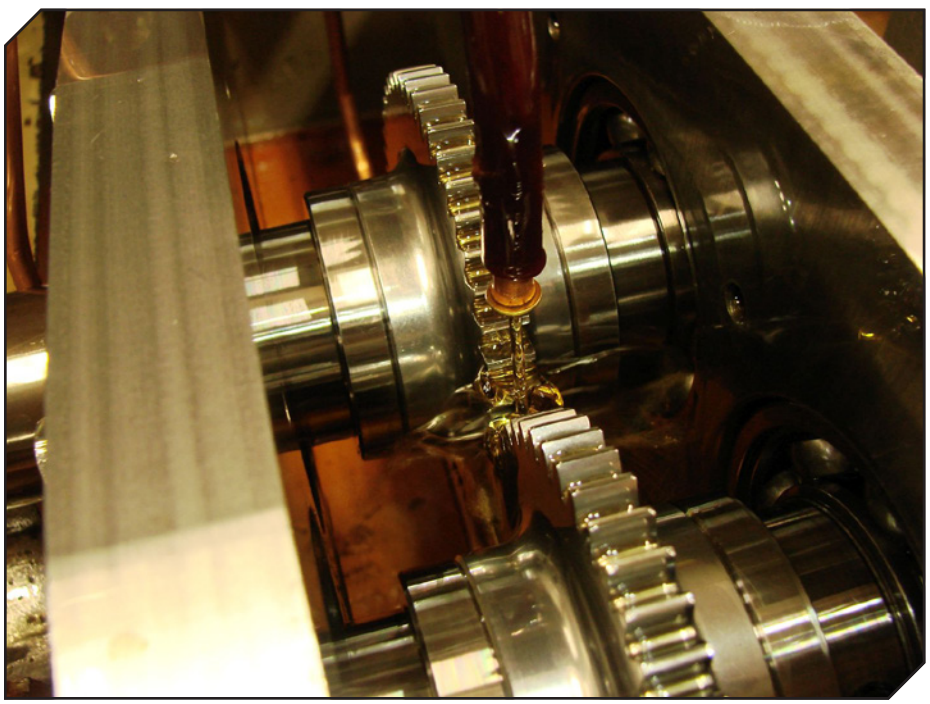
To try and bring some clarity to the situation, we enlisted several experts to offer their thoughts on a number of issues addressing lubrication. It's a general approach to seeking information on the current trends and challenges inherently relevant to lubrication technology and its ever-evolving development and usage.

Synthetic lubricants are now a front-and-center issue in the industry. The question that this presents is whether there is an industry-recognized definition of a "synthetic" lubricant. As you might expect, it's more complicated than trying to decide whether using a synthetic for your next oil change is a good idea.

"In Germany they define a synthetic PAO as 100% PAO," says Robert XX Errichello, president of GEARTECH. "In the U.S. and elsewhere, a synthetic PAO can be a blend of 1–30% PAO and mineral oil. Sometimes these PAOs are called semi-synthetic. PAG is considered synthetic oil in every country (Ref. 1).

Meanwhile, according to René Greschert, WZL gear testing engineer, "There has already been a legal dispute about (this)—but no industry-recognized standard. Therefore, the term 'synthetic' is used very creatively. However, completely chemically formulated oils are mostly referred as "full synthetic," (i.e.—mixtures of full synthetic) and mineral oils as "semi-synthetic." On the other hand, even hydro-crack oils, which are actually based on mineral oils, are often advertised as "HC-synthesis," probably to make them appear more valuable."

Fixed viscosity grades are another key consideration for lubricants—particularly relevant to micropitting protection. The question: what works best?



"PAG has the highest micropitting resistance, and mineral and PAO have less—but similar—micropitting resistance," says Errichello.

While on one hand Aaron Isaacson, Senior Research Engineer and Head of the Drivetrain Technology Center at the Applied Research Laboratory of The Pennsylvania State University and Managing Director of the Gear Research Institute, states, "I wouldn't think that film thickness would depend on base stock," Greschert offers that "The tendency for micropitting resistance and gearbox efficiency (correlates) with the EHL film thickness," adding, "therefore, the lubricant performance tends to improve in the order of mineral – PAO – PAG. However, it is possible to observe different trends in practice, since the lubrication is also affected by other factors as, for example, the additives of the lubricant as well as by their complex interdependencies and side effects."

Relatedly, EHL film thickness is another crucial component of lubrication. It requires determining the correct base stock (mineral, PAO, or PAG) for use in the application.

"It depends on the gear tooth temperature," Errichello states. "PAG has thicker films than PAO and mineral over the entire range of practical temperature. There is little difference between PAO and mineral for the range of 70–90°C. At <70°C, mineral and PAG have thicker films than PAO. At >90°C, PAO and PAG have thicker films than mineral (Ref. 2).

Gearbox efficiency is a condition that is constantly under industry-wide pressure for improvement. Expectedly, lubrication plays a significant role in that improvement. And what lubrication

parameter has the greatest impact on that efficiency?

"There are many ways to increase the efficiency of a gearbox," says Isaacson. "Generally, you want to decrease losses. Losses are due to friction, churning, and/or windage. Friction can be reduced by a number of methods — such as reducing surface roughness, adding low-friction coatings to rolling/sliding components such as gears and bearings, adding additives to the lubricant, and probably a handful more. Churning losses can be reduced by using a lower- viscosity lubricant, running at a higher lubricant temperature, or reducing the level of oil that rotating parts are forced to churn through. Windage losses can be reduced in jet-lubricated gearboxes by incorporating shrouding around the gears or adding drag-reducing features (air foil winglets!) to the gear design."

Errichello adds that "PAG has the lowest traction coefficient and therefore gives the highest efficiency. PAG with low viscosity and low traction coefficient generally result in the highest efficiency."

Relatedly, Greschert adds that "On the one hand, the viscosity grade is predominantly correlating with the no-load losses of a gearbox. Higher viscosity leads to higher churning losses and thus less efficiency. On the other hand, the choice of base oil and additives affects the lubrication regime especially concerning the load-dependent losses of a gearbox. In this context, PAG are reported to perform better than PAO and mineral oils. One possible explanation for that differentiation between the base oils is their different potential to establish elastohydrodynamic lubrication (EHL) instead of mixed lubrication."

Not surprisingly, a robust maintenance regimen is required for consistent-performance lubrication. Without it, downtime and costly repairs are in your future. So what constitutes robust maintenance?

"The basic laboratory tests are viscosity, acid number, water content, and spectrometric analysis," says Errichello. "If questions arise from the basic tests, other tests such as ferrographic, particle counts, and ferrous debris by PQ analyzer should be done."

"It really depends on your application," says Isaacson. "Are you generating a lot of debris or particulate? If so, then you'll likely want to monitor particle counts. Are you operating at high temperatures? If so, you may want to monitor the viscosity and additive contents. Are you concerned about picking up water content or other contaminants? If so, they you'll likely want to test for those. A great deal can be learned by partnering with a knowledgeable oil analysis company to recommend the proper tests and sampling intervals for your application. Interpretation of results is also not always straightforward. So, having a test lab that understands your goals is a must."

Finally, manufacturing processes and attendant requirements continue to advance at seemingly break-neck speed. Lubrication is no exception.

"Currently, lubricants and additives are quite good and should continue to improve in the future," Isaacson says. "Current research areas include nanoparticle additives, ionic lubricants, graphene- based friction reducers, ZDDP

additive optimization, viscosity index improvers and a long list of others — any number of which could result in the next big breakthrough in lubrication technology. However, your previous question on preventive maintenance would be where I would focus my efforts. Implementation of a lubrication monitoring system or routine sampling schedule will provide immediate payoff, whereas waiting for the next big thing could take a while."

WZL's Greschert explains, "We are currently observing efforts to optimize lubricant compatibility and to expand its functionality. Compatibility requirements are increasing as a result of legal standards (e.g. — compatibility with human organisms), or as a result of a more universal area of application (e.g. — compatibility with sealing elements). For example, metalworking fluids are more and more containing amounts of high-tech synthetic ester oils with excellent performance and sealing compatibility. However, machine tool manufacturers and users are very cautious in using them due to their bad experiences with the first naturally produced ester oils in the 1990's.

"Another interesting topic is the improvement or substitution of the run-in procedure at the beginning of the application. The most changes to the surface zone of a gear take place at the very beginning of its operation, e.g. — the surface roughness gets flattened, the microstructure is becoming fine-grained and the chemical composition is changed. We've had a big research program 2012–2018 (and a continuation starting in 2020 is planned) of more than 20 institutes trying to understand and improve the run-in procedure and its working mechanisms to improve the resource efficiency in the application of lubricants and machine elements."

And, "Yes," says Errichello, "electric vehicles require special lubricants because the lubricant acts as a coolant to cool the electric motor in addition to lubricating the gears and rolling element bearings in the gearbox. Because of the extreme heat in the motor, mineral, PAO, and PAG do not have the desired properties. This is currently a hot research topic. Perhaps a poly ester fluid, which has superior high temperature performance and increased lubricity that increases efficiency might fill the bill."

References

1. Swedberg, S., "Motor Oil's Day in Court," Lubes'N'Greases, Vol. 20, No. 4, April 2014, pp. 6–13.
2. Errichello, R., "Selecting Oils with High Pressure-Viscosity Coefficient- Increase Bearing Life by More than Four Times," Machinery Lubrication, Vol. 4, No. 2, Mar/Apr 2004, pp. 48–52.

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Dr.-Ing. René Greschert, is a gear testing engineer at WZL (Laboratory for Machine Tools and Production Engineering), RWTH Aachen University. He can be reached at R.Greschert@wzl.rwth-aachen.de.

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Lubrication Issues — New and Ongoing

René Greschert

What are some of the developing trends and newest and/or ongoing challenges regarding lubrication and its many applications? Not enough available space here to address that question comprehensively, but here, from WZL's Réne Greschert, are some good talking points.

Improvement of lubricant performance. For example, transmission fluids contain additives to improve their behavior regarding:

- Scuffing
- Micropitting
- Efficiency

For these three different points you also need three different types of additives, and you have to make sure that there are no interactions between them. If one ingredient of the lubricant is modified, you have to check all the points again to ensure that the overall performance is not changed.

Improvement of lubricant compatibility, for example:

- Reactive additives should not be harmful to humans
- Ester oils should not damage the sealants. These two (reactive additives and ester oils), especially, are excellent solutions to improve the lubricant performance, but they need to be carefully handled in terms of compatibility. Today's metalworking fluids contain minor amounts of high-tech synthetic ester oils with great performance and excellent sealing compatibility. However, machine tool manufacturers and users are very cautious in using them.

Improvement or substitution of the run-in procedure at the beginning of the application. The most changes to the surface zone of a gear take place at the very beginning of its operation, i.e.:

- Surface roughness gets flattened
- Microstructure is becoming fine-grained
- Chemical composition is changed

We have had a significant research program 2012–2018 (and a continuation starting in 2020 is planned) of more than 20 institutes trying to understand and improve the run-in procedure and its working mechanisms.

The Latest in Broaching

From standardization to automated, Industry 4.0 capable broachers, here's the latest in what's being developed in the field of broaching.

Alex Cannella, Associate Editor

BROACHING MACHINE SPECIALTIES MOVES TO STANDARDIZATION, ADOPTS NEW FRAME

Broaching machines have always been treated a little differently by buyers than other types of machine tools. Rather than purchasing a standard machine, buyers would often force a broaching manufacturer to customize their machines to meet rigorous specifications. Matt Egrin, president of Broaching Machine Specialties, has been observing this dichotomy for quite some time.

"[Gear manufacturing machines customers] are walking into a company like Mazak or Hardinge or any number of those big name guys…" Egrin said. "They're going in there and they are buying a standard machine off the floor. It's comes in this color, it's got these controls, and this is how it works. A lot of broaching machine customers don't look at broaching the same way. They don't walk into a broach company and say 'I want that machine standard off the floor.' Rather they send us a thick spec book or something many dozens of pages long and say you have to build your machine to our specs."

In his years of time at Broaching Machine Specialties, Egrin has seen plenty of tradeoffs that come with insisting on custom-made broaching machines: longer delivery times, more expensive machines, more complicated in-field service — which again means more expensive and slower repairs, and a lower resale value when the machine is no longer needed.

So in 2017, when Broaching Machine Specialties developed its latest product, the Dual Drive electro-mechanical table-up broaching machine, they drove to standardize the design wherever possible and have urged its customers to look at the machine like they look at other types of machine tools and purchase it standard. And according to Egrin, it's been working, with their most high-profile sale being a large multi-national auto supplier, which approved the new BMS machine to be used in its plants throughout North America without having to customize it to meet their company specifications.

Standardizing the machine's design has kept it price competitive, along with a host of other benefits that normally come with standardization: easier maintenance, faster part replacements, and faster machine delivery time — 16 weeks compared to BMS's previous 22–24.

None of these talking points are particularly controversial. On the contrary, they're manufacturing 101 maxims that have held true since the Model T and are already readily accepted elsewhere in the gear manufacturing industry, which is a core part of the Egrin's argument.

"If you're ok with buying a Mazak just the way it is...right off the floor, why can't you do the same for a broach?" Egrin said. "I'll save you money. I'll deliver it faster."

But to dispel what might be the most likely cause for potential trepidation about the Dual Drive, just because the machine itself is standardized doesn't mean its tooling has to be, as well. Broach tools, fixtures, automation, you name it — the Dual Drive can still mount custom tooling for different jobs, as well as tooling from other manufacturers.

The Dual Drive broaching machine from Broaching Machine Specialties.

But standardization isn't the Dual Drive's only selling point. While perhaps not as headline-grabbing, just as important is the machine's H-frame design. In older, traditional table-up machine designs, the workpiece is supported on an L-shaped bracket mounted on the slide, which results in a downward moment that can cause the bracket to deflect, resulting in a degradation of part quality. With the new H-frame design, the broaching force is centered between the two roller screws and in line with the part travel leading to improved part quality, with a bonus reduction to how much floor space is required for the new design.

Going forward, Egrin would like to continue pursuing further standardization, envisioning a future where each of BMS's broaching lines and varying size machines have been converted to standard models. But in the meantime, he says that the Dual Drive has seen a positive reception, and he'll keep trying to convince his customers that standardization can work in broaching.

For more information:
Broaching Machine Specialties
(248) 471-4500
www.broachingmachine.com

EVER SHARP TOOLS BRINGING EXPERTISE TO NORTH AMERICAN MARKET

Hard broaching comfortably established itself in the overall manufacturing hierarchy years ago, but according to Catherine Chen, CEO of Ever Sharp Tools, her company has been doing hard broaching since even before it was in vogue. EST touts over 20 years of custom hard broaching tool manufacturing knowledge, and they're looking to bring that expertise to the North American market.

EST develops hard broaching tools for automotive, machine and aviation industries and beyond. They primarily make solid carbide hard broaches for the finishing process of internal involute spline parts.

The latest addition to EST's catalogue is the ability to sharpen hard broaching shells. Alongside this offering, EST can design both carbide shells and their associated gauges to ensure components fit together properly.

"With our expert knowledge of involute splines, the capability to do test pulling and providing gear analyzer reports for all of our products, EST is able to offer a full range of green broaches and hard broaches as well as spline gauges to check green process parts and gauges to check final hardened parts," Chen said.

For more information:
Ever Sharp Tools
(810) 824-3323
www.est-us.com

MITTS & MERRILL KEYSEATING AND BROACHING MEETS TECHNOLOGY

Keyseating and internal broaching/splining of bores has always created a unique machining problem for manufacturers. For over a century, Mitts and Merrill, a member of the Fromag group, and Fromag have been producing machinery and solutions for the machining of these type parts. As the industry leader in this area of manufacturing, they have also met the demands of our customers with increased technology in our products. In 2020, they're offering the following product lines:

CNC Keyseating machines E and CNCE lines:

Mitts & Merrill's core line of keyseating machines can cut internal key widths ranging from .080" to 7.875" with a stroke "keyway length" of 16" to 78". Their 16" models do not require any foundational pit in the floor.

One key feature of these machines is a 15" touchscreen panel with on the fly speed and feed change, user friendly design and multiple language options. Users input work offsets, key requirements and workpieces dimensions into the panel and the program for machining is automatically calculated. Up to 600 of these "programs" can be saved for later retrieval.

The E and CNCE lines also feature indexing tables, including manual and automatic models. Mitts & Merrill's automatic indexing tables are fully integrated and provide the ability for users to machine splines and multiple keyed parts. During this process the machine will cut one full key to depth, and rotate to the next position(s) to begin the key process again. The indexing table also can be programmed to cut helical keyways in combination with special tooling.

Automatic workpiece recognition. This feature allows users to automatically set the cutter on the inside of the bore to establish a tool zero. The tooling automatically moves forward until making contact on the workpiece. This contact is established via electrical conductivity and a zero point is set.

All keyseating machines are also electromechanically driven allowing for precise tolerances, smooth and quiet operation, and no worry of hydraulic oils leaking. Additionally, the electro-mechanical design reduces power consumption greatly from that of a hydraulically driven machine.

In addition, these machines also have programmable tapered key cuts up to 3°, for which the user inputs the taper requirements and the machine calculates the program automatically; tooling retraction, allowing users to easily remove parts or check parts while still on the machine table; remote maintenance router allowing technical troubleshooting and repair of the machine from a remote location; upcutting in blind bores; automatic clamping and unclamping of workpieces; and Industry 4.0 compatibility. Machines up to 2" cutting width capacity are compatible with Mitts and Merrill style tooling, or with Fromag style tooling. In most cases, old tooling is interchangeable. Machines are also linkable and can be interfaced with robotics for loading/unloading operations and closed cell machining.

CNC Table up broaching machines – FTR line :

In addition to Mitts & Merrill's standard and short broaching machines, they now offer electro-mechanical table up broaching machines for users that have a need for a high production, space saving broaching machine. Contrary to conventional broaching machines, the broaching tool stays stationary

while the table, workpieces and workpiece clamping is moved upwards relative to the broaching tool. Parts are completed in one pass and broaches can be made to any technical specifications. Because of this design feature, these machines can be placed at ground level and do not need a foundational pit in the ground. These machines can be set up as stand-alone machines with either manual or automated feed, additionally they can be fully integrated into machining cells, applying robotics and handling devices.

Like the E and CNCE lines, the FTR broachers include a 15" touchscreen panel with on the fly speed and feed change, user friendly design and multiple language options. Users input work offsets, broach requirements and workpieces dimensions into the panel and the program for machining is automatically calculated. Also much like the E and CNCE lines, FTR machines are electromechanically driven, with no leaking hydraulic units, easier maintenance and significant cost savings over hydraulic units in the amount of power consumption used. The FTR is also designed for smooth, quiet operation, allows fast unloading of parts, can be integrated with Industry 4.0, closed cell units, and robotics and allows for remote maintenance available via router.

For more information:
Mitts & Merrill
(352) 343-7000
www.mittsandmerrill.com

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broaching
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2020 State of the Gear Industry

Reader Survey Results

Gear Technology's annual State-of-the-Gear-Industry survey polls gear manufacturers about the latest trends and opinions relating to the overall health of the gear industry. As in years past, the survey was conducted anonymously, with invitations sent by e-mail to gear industry companies – primarily in North America, but also including some respondents from around the world.

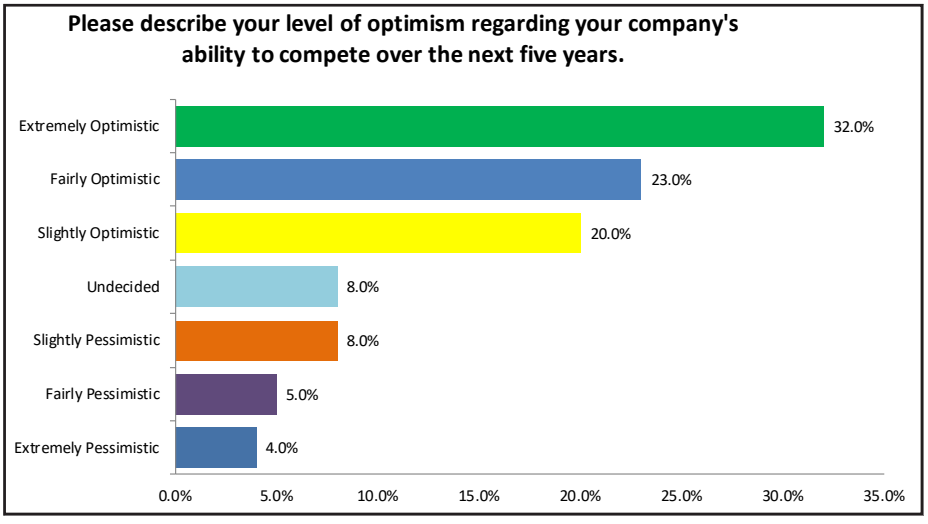
All of the responses included in these results come from individuals who work at locations where gears, splines, sprockets, worms and similar components are manufactured. They work at gear manufacturing job shops as well as captive shops at OEMs.

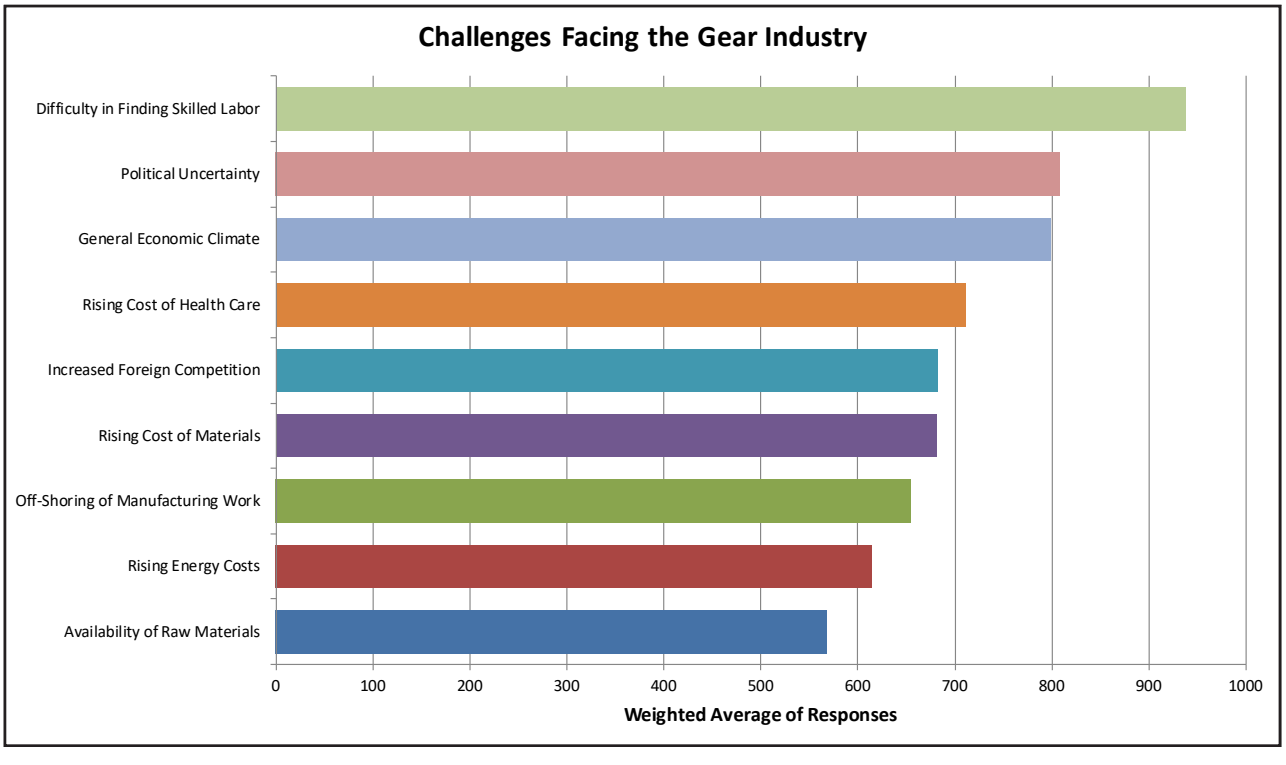
A full breakdown of the respondent demographics can be found at the end of this article.

Summary

Compared with previous years, the current level of optimism is low. When asked about their optimism concerning their companies' ability to compete over the next five years, only 75% of gear manufacturing companies indicated some level of optimism (compared with 85.8% last year and 83% in 2018 and 2017). The shift toward uncertainty and pessimism is clear in the results.

In addition, the challenges facing the gear industry seem to have grown in intensity. The difficulty in finding skilled labor is still top of mind with our respondents, and judging by our results, the problem is getting worse, not better. It's worth noting that both political uncertainty and the general economic climate have moved up the list in terms of the gear industry's concerns.





Significant Business Challenges

Here's a sampling of what our respondents had to say about the challenges facing the industry today:

"Ecomonic climate in heavy industry is not great."

"The American government and economy (we are located outside of the USA)."

"Volumes (Low volumes for Truck segment)."

"Finding employees."

"Tariffs."

"Finding skilled labor and new customers."

"Global cooperation over different sites."

"Improve quality and cost reduction."

"Poor economy."

"Tariffs continue to be a challenge because it is difficult to find competitive suppliers for simple, low-complexity gears."

"Improving efficiency."

"Labor shortage."

"Costs and sales."

"Adjusting for lower volume production."

"Adaptation to shifting market demands for gear manufacturing."

"Shortage of skilled labor."

"Fewer engineers and designers know the intricacies of gear teeth and rely on standard tables too much."

"Market predicting / production volume planning."

"Skilled people."

"Getting efficient communication between various departments."

"Sales."

"We're starting new sales program."

"Health care costs & political uncertainty."

"Brexit."

"Mew projects."

"Entering the EV market."

"Electrification of drive trains."

"Finding machinists to learn the trade."

"Incremental turnover."

"Meeting the bottom line numbers."

"Car industry is going down."

"External Investment."

"Skilled manpower."

"Controlling labor cost increase."

"Increase export business."

"EV."

"Staying in business!"

"Hiring skilled labor."

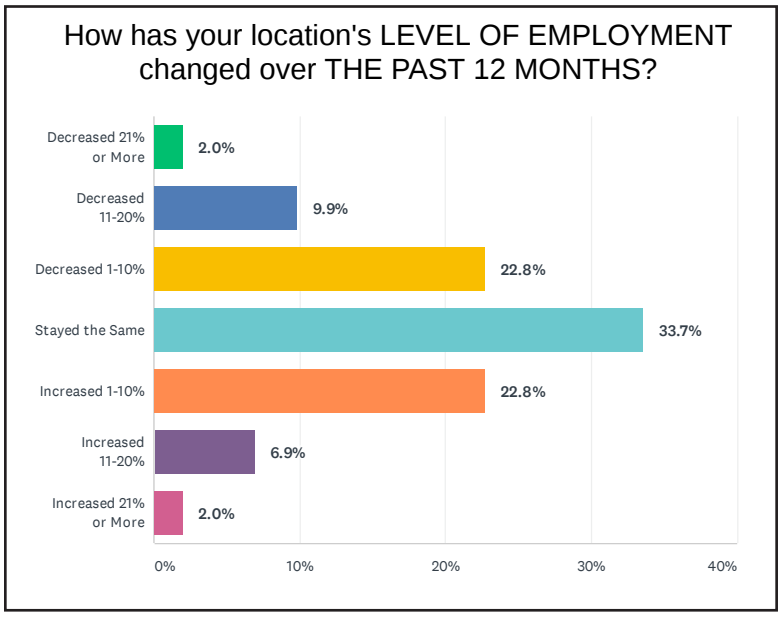
"Expansion."

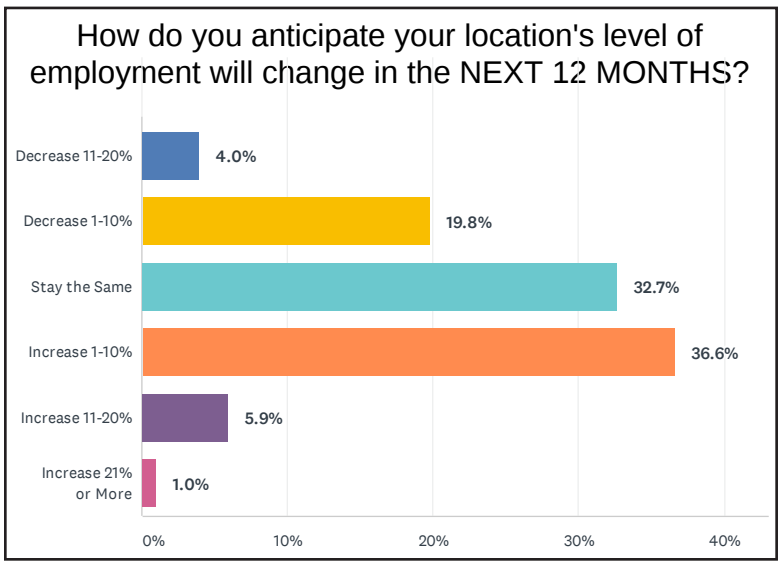
"We would be happy if we survive, and improve our efficiency."

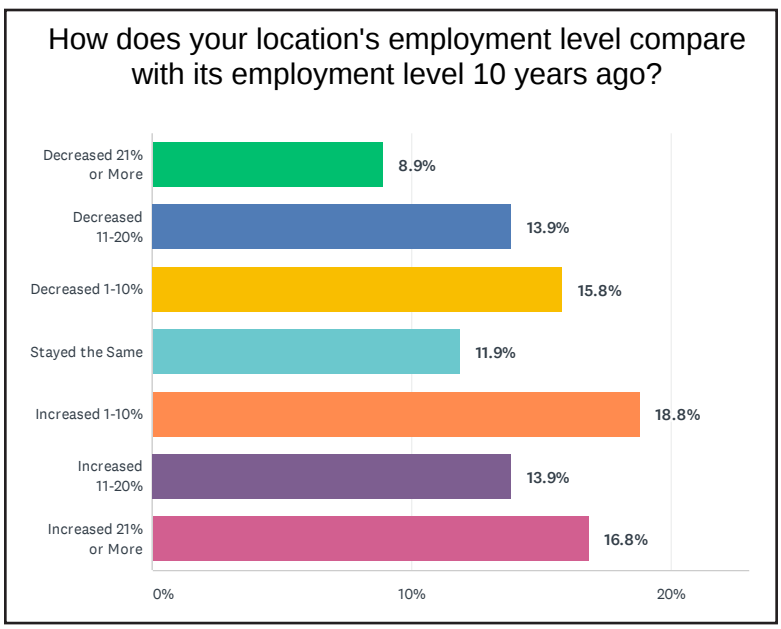
"Regulations."

"Retaining operators. Phase out of 2 products. Adding new OEM customers. Rearranging production equipment to make room for new business."

Employment







"Find skilled engineers with gear / splined shaft experience."

"Lack of new projects or capital spending. Government restrictions in new heavy industry projects and environmental legal challenges stopping projects and expansions."

"Increase sales."

"Finding good qualified technical people for employment."

"Adding business."

"Retaining, finding skilled labor and training new employees."

"New product introduction."

"Capacity constraints, Finding skilled labor."

"Taxes skyrocket with no control under the politician in power."

"LACK OF SKILLED LABOR."

"Economic challenges for our customers."

"Employees."

"Resolution of trade tariffs."

"To develop new projects."

"Booking new business and skilled labor."

"Hiring qualified workers."

"Throughput on the shop floor."

"Ramping up to customer demand."

"Stay ahead of Chinese products."

"Controlled growth."

"New business."

"SALES."

"Skilled manpower."

"Removing wastes in our processes."

"Finding skilled labor."

"New premises."

"Hiring enough skilled people."

"To replace the retired knowledge is the hardest thing to do!"

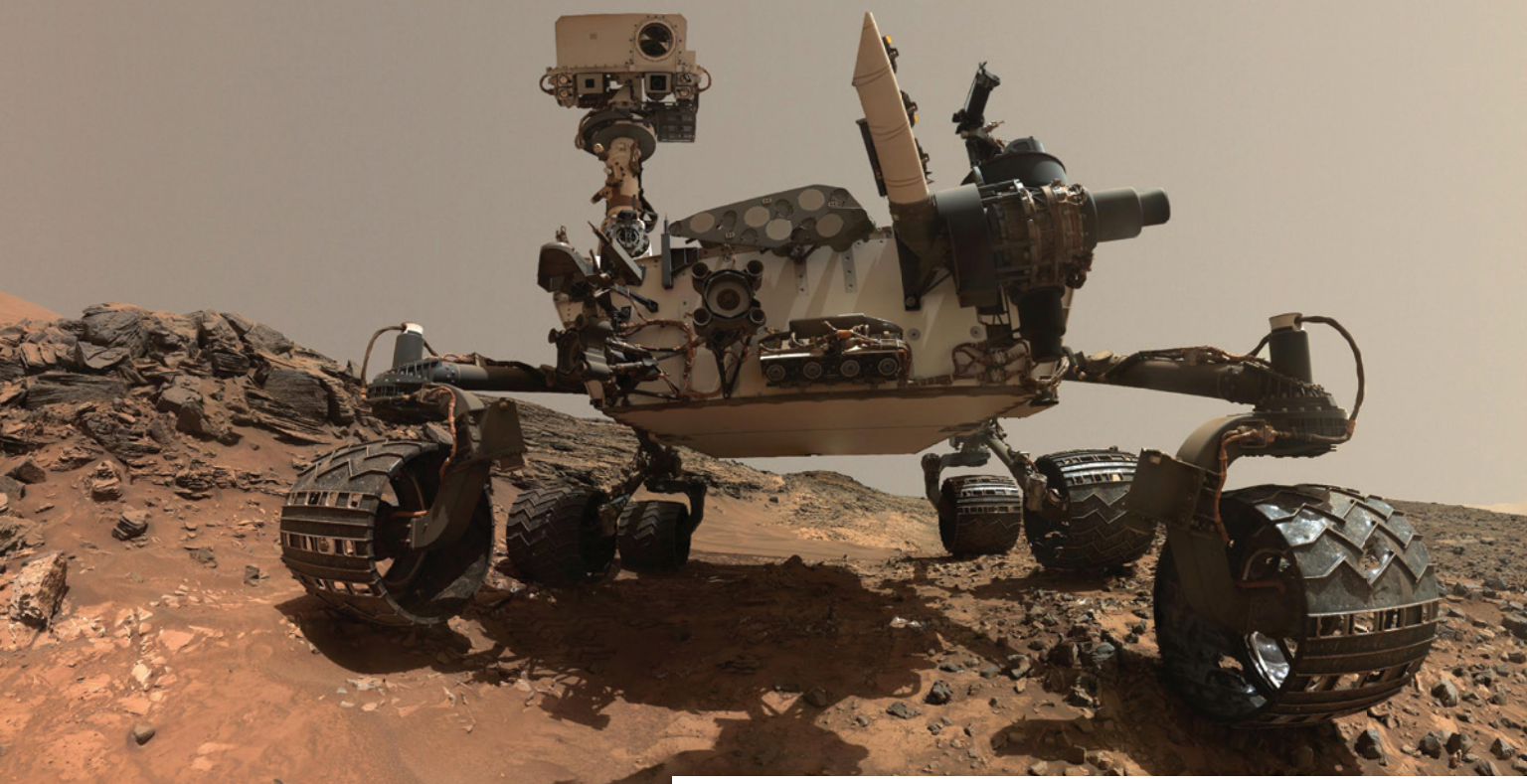
"Cash flow, staff."

"Competing in a world market."

"Technological competency."

"Financing new growth."

TRUSTED IN THE MOST HOSTILE ENVIRONMENTS.



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- Quality Assurance
- Engineering
- Sales

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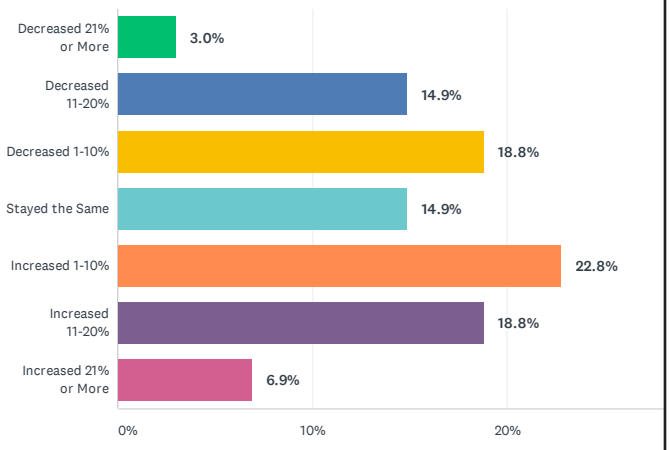
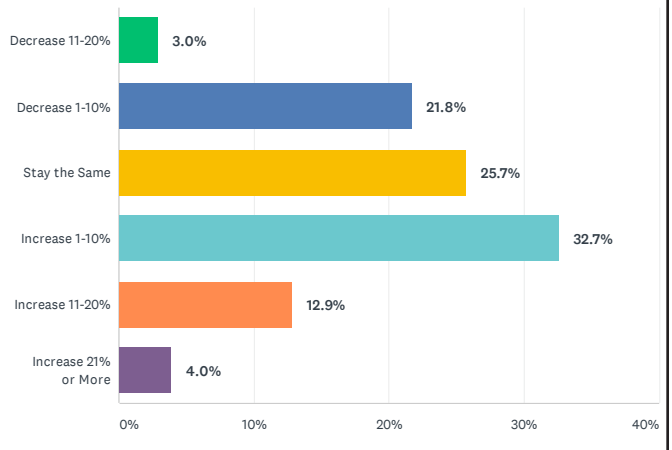
Production

How has total PRODUCTION OUTPUT (unit volume) changed over the LAST 12 MONTHS?

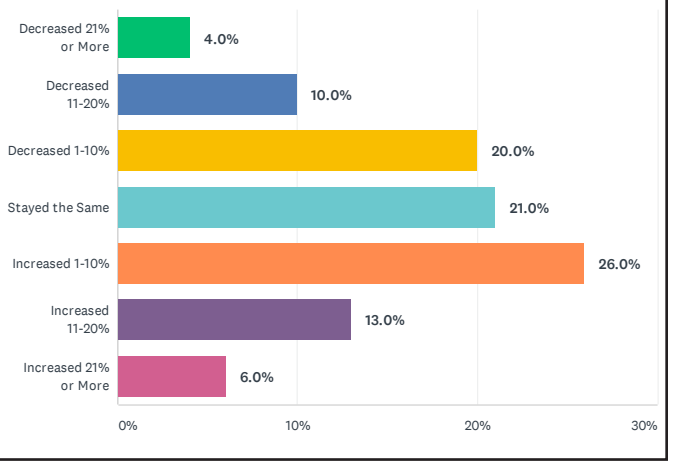


How much do you expect production output (unit volume) to change over the NEXT 12 MONTHS?

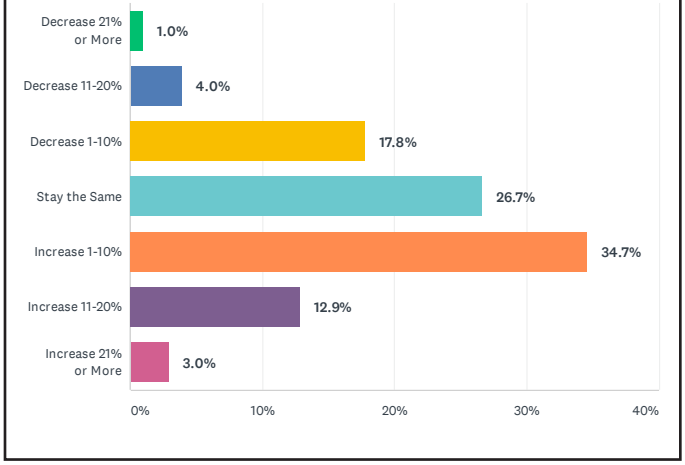


Sales

How has total SALES VOLUME changed over the LAST 12 MONTHS?

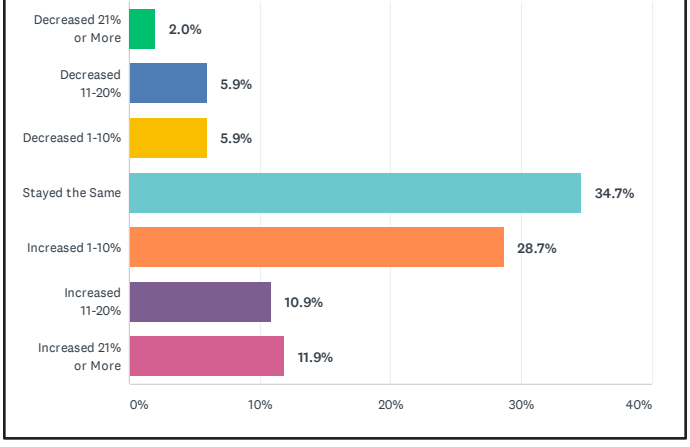


How much do you expect SALES volume to change over the NEXT 12 MONTHS?

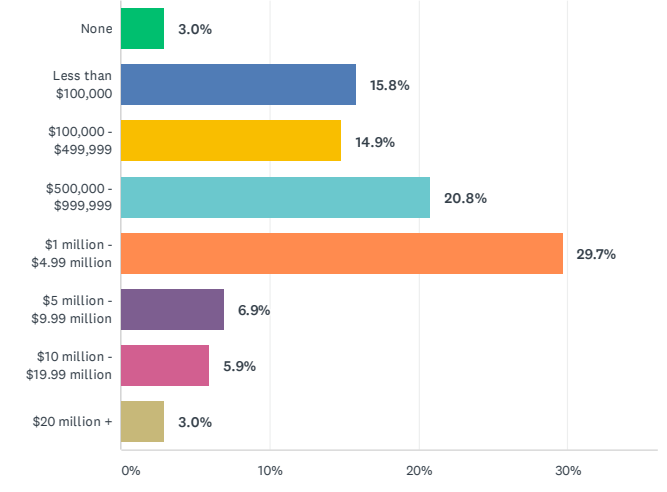


Capital Spending

How did your location's CAPITAL SPENDING in 2019 compare with 2018?



Please indicate your location's approximate level of capital spending in 2019:



Capital Spending

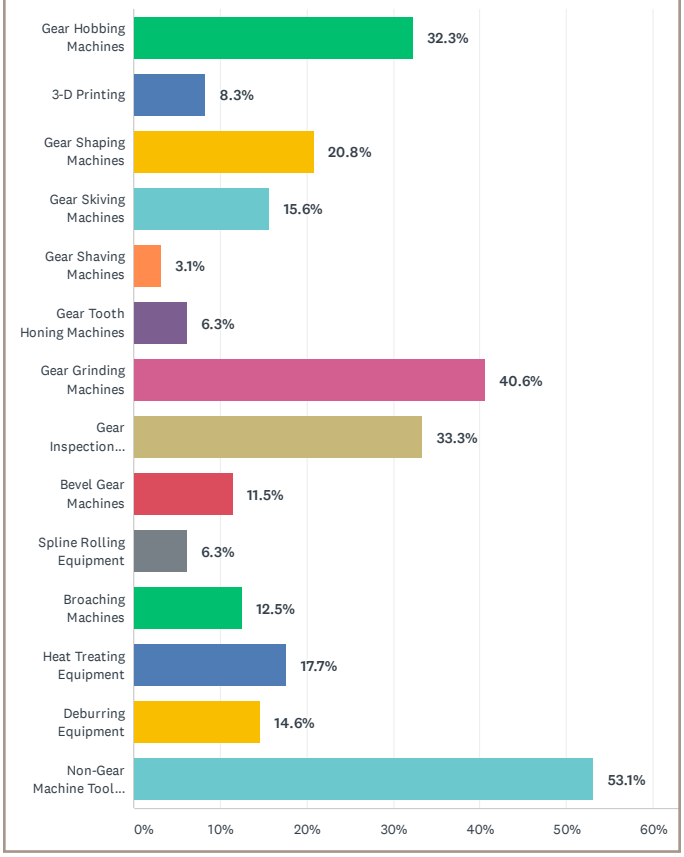
81% of respondents work at locations that spent more than $100,000 on capital equipment in 2019.

49% work at locations that spent more than $1,000,000.

14% of respondents' companies spent less than last year.

52% of respondents' companies spent more

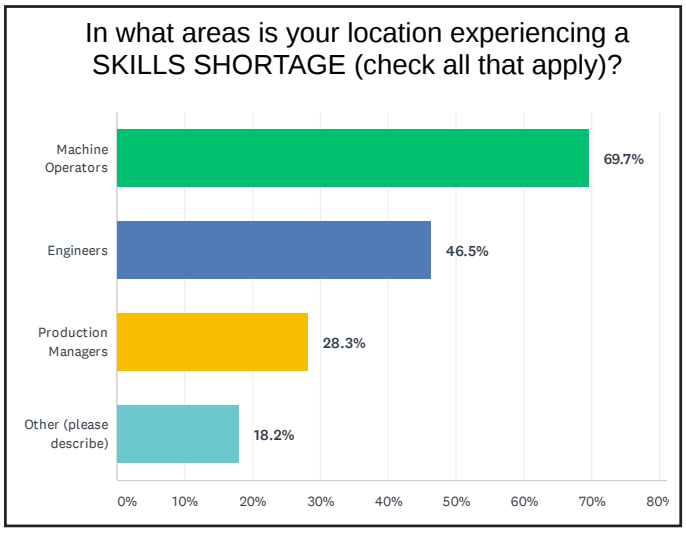
For which production functions do you expect to purchase equipment in 2020?

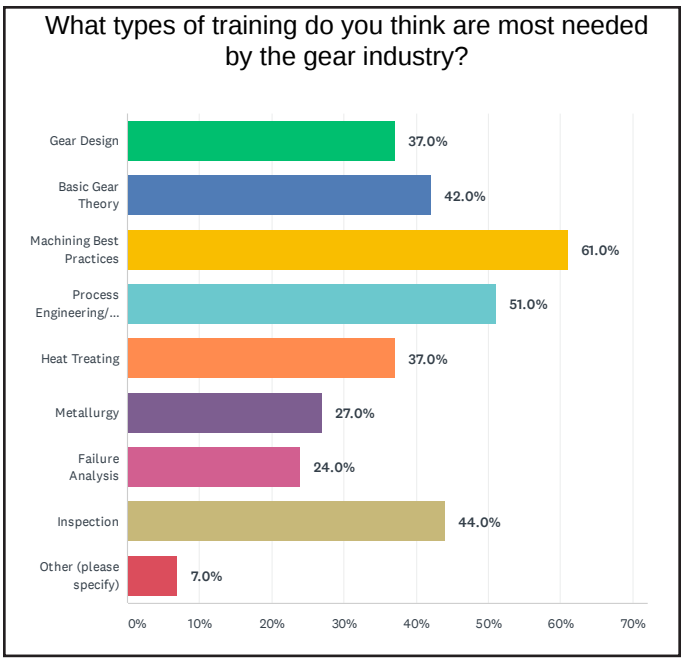


What is Your Company Doing to Address the SKILLS SHORTAGE?

"Working with local tech colleges to train and recruit."
"Internal training / retention plan."
"Recruitment efforts and training."
"Working with local community colleges to increase awareness of manufacturing opportunities."
"Active internal training and selective hiring."
"The strategy is not clear."
"Training."
"Complaining and overloading key employess."
"Using temps and more classroom training."
"Reaching out to schools & colleges."
"Off-shoring to India."
"Training on the job."
"Hire and train."
"Constant in-house training."
"Networking."
"Using staffing companies."
"Nothing."
"Strengthening cooperation with education entities."
"LinkedIn sourcing."
"Internal Training."
"Teaching employees by ourselves."
"Internal and external trainings."
"Training youngsters."
"Training."
"Seeking external suppliers and experts."
"Hiring skilled laborers."
"Pre-training & re-training."
"Soft Skill Development."
"On-the-job training."
"Training family."
"Working with local career colleges."
"Good question! We are looking for young engineers and technicians."
"On-the-job training."
"Training. Using local community college. Using our Japanese headquarters to horizontally deploy training. Fundamental gear training (don't assume engineers know anything about gears out of college)."
"Seeking employees through 3rd parties."
"Train within."
"Searching outside of geographical area."
"Recruit."
"Attending job fairs; contacting veteran associations; contacting alumni college associations; headhunters."
"Training in plant and outside training."
"In-house training."
"Recruiting overseas, UK and Asia."
"We host high school and engineering internships."
"Training. Reaching out to more educational settings."
"Trying to hire young graduates and train from bottom."
"Recruiting high school kids into the industry."
"Job fairs."

Skilled Labor





People, Training, Succession Are Primary Issues Facing Industry

AGMA Responds

By Matthew E. Croson, President, American Gear Manufacturers Association

As the *Gear Technology* State-of-the-Gear-Industry survey clearly reports, all aspects of the people puzzle are a primary challenge facing the industry and AGMA members.

AGMA and the AGMA Foundation are responding with programs that directly tackle these issues, including:

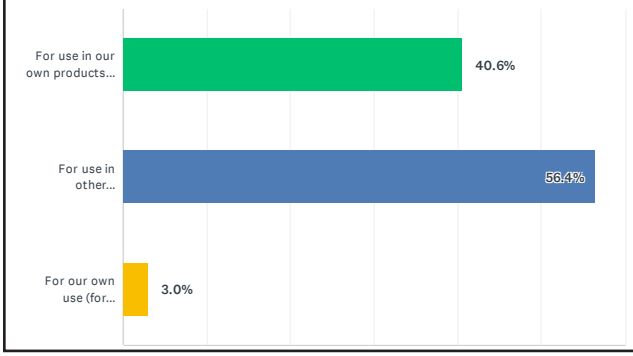
1. To secure people, the AGMA Foundation developed the "Get Into Gears" program, providing free of charge, a series of industry marketing pieces designed to attract technicians and engineers into the sector. From posters and brochures, to powerpoints and videos, the materials are downloadable on the AGMA Foundation website at www.agmafoundation.org and promote how great our industry is! The materials are customizable and, to date, more than 160 companies have accessed the materials and are using them at Career Fairs, internally, and at local job fairs.
2. To support education funding, the AGMA Foundation has continued its annual Scholarship Program, where approximately $50,000 in grant money is provided to engineers and technical students focused on gaining degrees in our space. Over the years, this program has been highly successful in securing workers, with 86% of scholarship recipients ending up working at an AGMA member company.
3. To support OPERATOR training, AGMA has created a National Training Center at Daley College. With grants from the AGMA Foundation, the association has created five new operator fundamentals courses touching on grinding, hobbing, heat treating and other important skills all operators need to have. The 10,000-net-square-feet facility will become the go-to training center for all levels of training, and because it's centrally located in Chicago, lowers the cost of travel for events.
4. To support ENGINEERING training, AGMA hosts more than 16 classes annually, including five new courses developed over the past four years, with funding from the AGMA Foundation. From gearbox design to gear failure, and everything in between, AGMA is a significant source of higher learning for engineers who need to gain insight into designing and manufacturing gears.
5. Giving Back – In 2018 Linda and Bipin Doshi announced a $100,000 grant to support a dedicated scholarship program managed by the AGMA Foundation – in 2020, we expect to grant our first scholarship from the funds provided, and it will support an engineer who shows academic excellence as well as passion for gears. We hope more industry leaders, who found success via the industry, will consider similar grants to support the future.
6. Spin it Forward – in March, the AGMA Foundation will announce the "Spin it Forward" program, whereby we are asking the gear community to support the AGMA National Training Center via machinery and materials donations, as well as financial support via contributions. We want the AGMA National Training Center to become a showcase for the power of training, leveraging machinery, materials and information to support the future of the industry.

These are just a small sample of the things the AGMA membership and staff are completing, via a collaborative process including input from the AGMA Foundation's Trustees, the AGMA Board, the AGMA Education Committee and the leadership at both Daley College and Ranken College. WORKING TOGETHER, we are responding to the primary challenge facing the industry, and would love your support: Join the AGMA, becoming involved on our committees or support the AGMA Foundation.

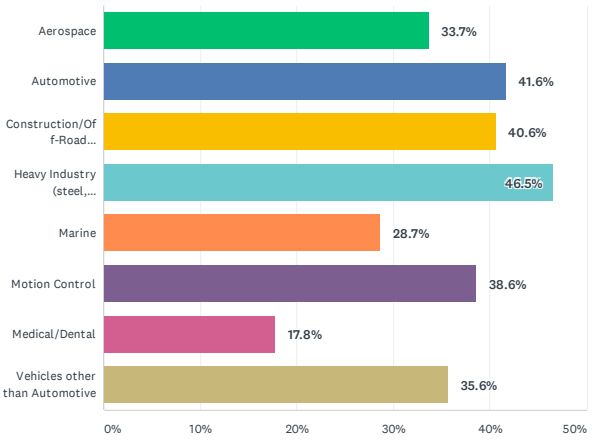
For more information:
www.agma.org
www.agmafoundation.org

Demographics

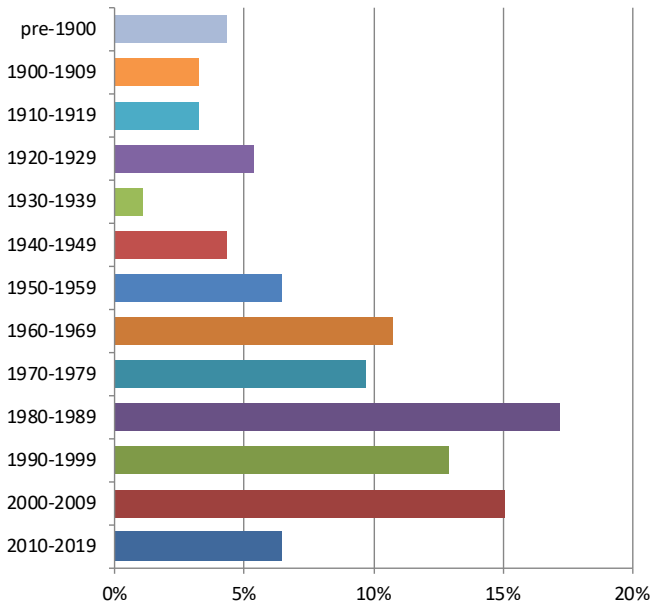
Gears (including splines, sprockets, worms and similar components) are manufactured at this location:



The gears (including sprockets, splines, worms and similar components) made at this facility are used for:



In What Year Was Your Location First Opened?



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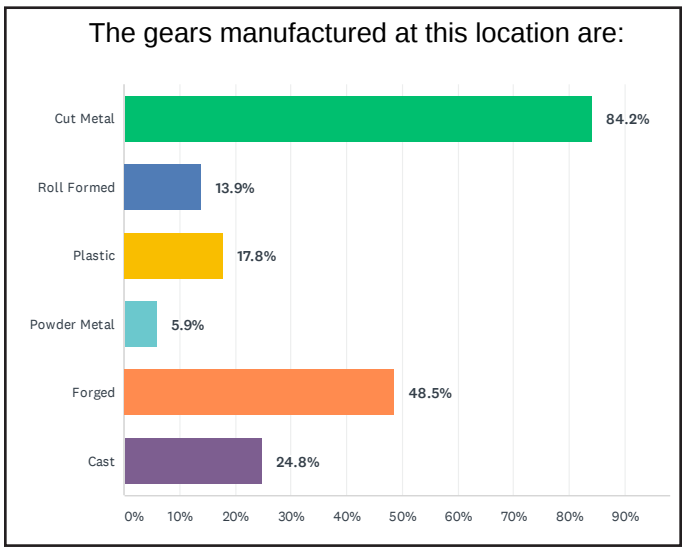

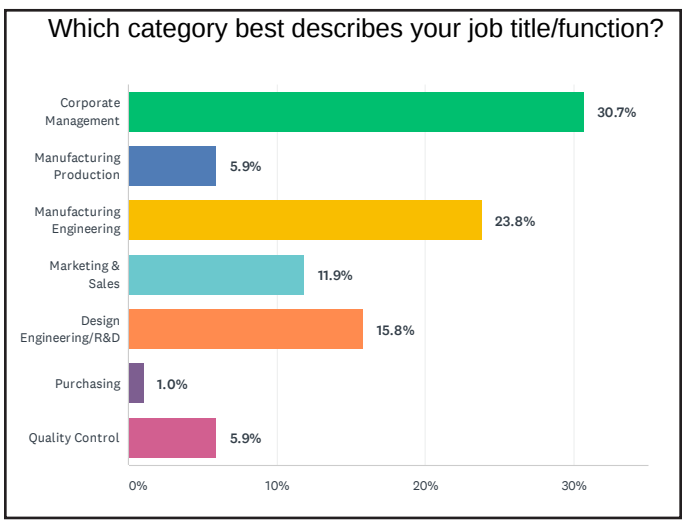

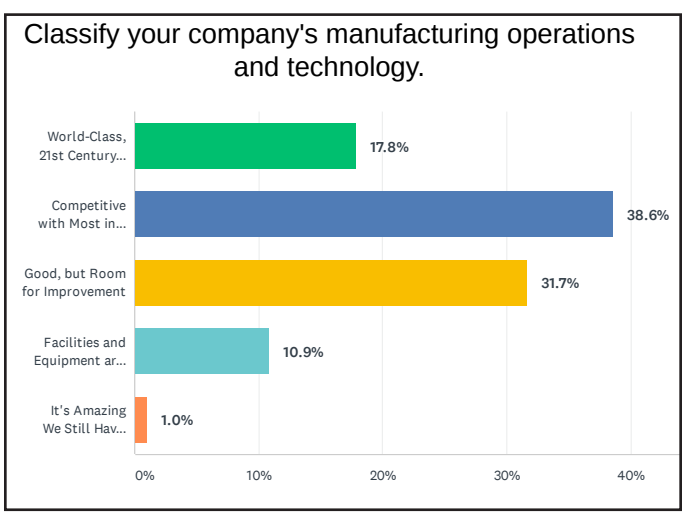

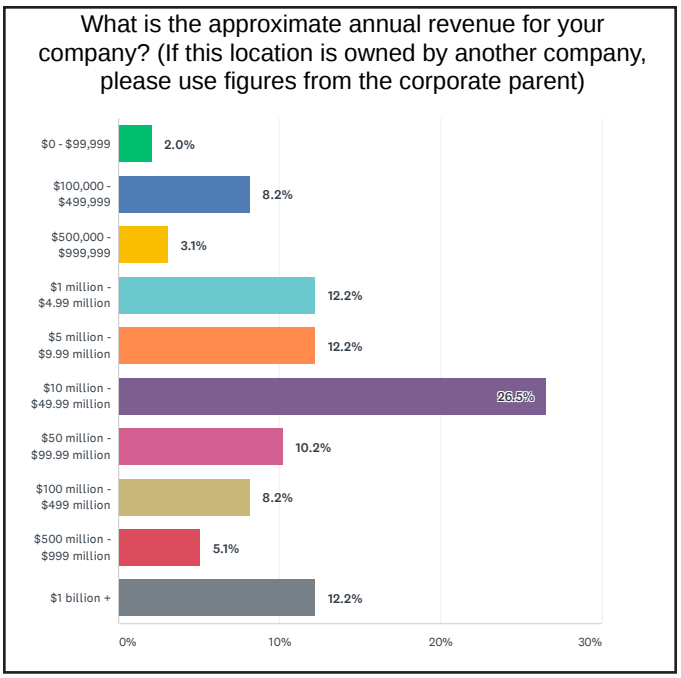

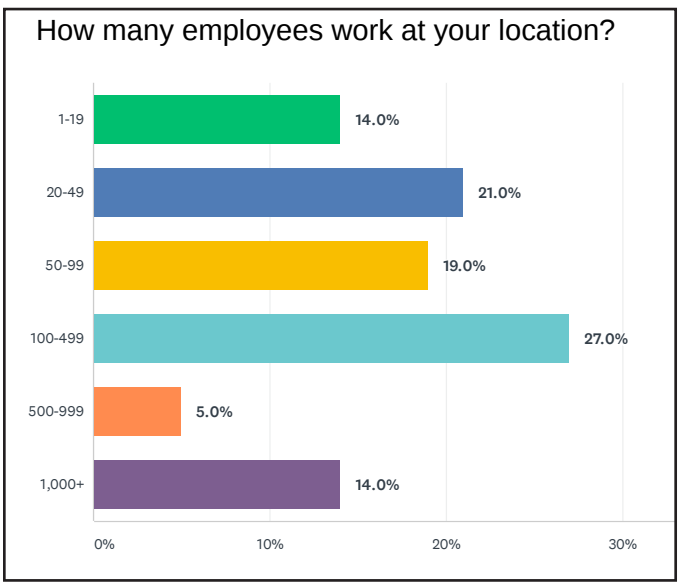

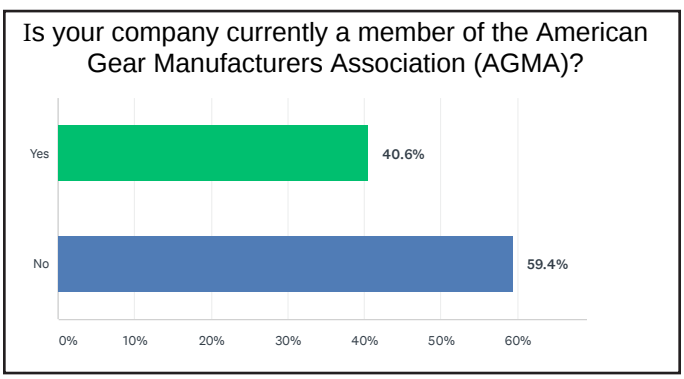

Thank you to all of our 2020 survey participants!

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Training–A Top Priority for Investment

Joe Arvin

Let me share a story with you.

Not long ago, I was visiting a gear manufacturing company. My visit started with a tour of the plant. What I witnessed was very impressive. They had a lot of new, state-of-the-art equipment in most of their departments. Their facility was neat and well-organized. I was told how they were integrating robotics and other digital factory initiatives. I saw a lot of work on the shop floor, and I was told that they have the largest backlog of work in their history.

Heading back to the office, I had the opportunity of meeting with a few members of their engineering team. Their experience and knowledge was equally impressive.

After the tour was completed, the president and I went back to his office. He closed the door and we sat down. I said, "What a great operation you have here. I can't imagine that you have a care in the world."

"I wish that were true," he said. "The fact is, we have a serious problem and I don't know how we're going to make it." He paused solemnly, and then continued.

"Here's our problem. Our older experienced operators are retiring, and we just can't find skilled people to replace them. Our only option is to hire unskilled workers, and our productivity just keeps getting worse and worse. We're plagued with scrap, rework, and late deliveries. Our largest customers are threatening to pull their orders."

Skilled Workers – The Key to Success

To be honest, this is not really the story of any one company, but rather a collective composite of what I have seen in the past few years. The harsh reality of manufacturing is this: You can have the best equipment, the best systems, and plenty of orders, but if you don't have skilled operators on the shop floor, it is very difficult to succeed in the market.

The skills gap in manufacturing is well-reported and the gear industry is certainly feeling this pain. Thankfully, there are numerous organizations working to address this problem.

For example, the programs of the American Gear Manufacturers Association (AGMA), including their National Training Center at Daley College in Chicago, show great promise.

According to AGMA President Matt Croson, "AGMA offers 13 different engineering level classes that cover the full spectrum of what a gear engineer needs to understand. In 2020, we are introducing our first four operator level training classes – something our members have also asked for AGMA to focus time and attention on as they need qualified operators to succeed. Many of the classes will be at our new space at Daley College. The 10,000 square foot facility will have both classroom space and 7,000 net square feet of operating equipment so participants get hands on training."

Another innovative approach to training is through the e-learning platform developed by THORS eLearning Solutions. They have a fantastic program for self-paced learning.

According to THORS Founder, Senthil Kumar, "THORS has developed an online learning solution that has captured the knowledge of industry experts. This knowledge is then presented through our interactive courses which utilize narration, graphics, and animation. This approach allows for self-paced learning that is measurable. Because gear manufacturing entails a thorough understanding of multiple manufacturing disciplines, the power transmission courses offered by THORS can be a valuable tool for substantially minimizing the learning curve of people new to the gear industry.

One learning resource that should not be overlooked is the Michael Goldstein Gear Technology Library. According to the magazine's founder, Michael Goldstein, this valuable resource is available for anyone wishing to access deep technical knowledge about gear manufacturing.

"The Gear Technology Library is an online digital archive which contains every technical article from the publication since 1984. Accessible from the main Gear Technology website, this library is searchable by subject and is the most comprehensive repository available for technical information on gear manufacturing. The library is a valuable resource for both new and seasoned people in the industry, and access to this information is available to anyone, free of charge. With around 4,000 articles we have over 11,000 unique visitors to this section of our website each month," Goldstein says.

Notably, in addition to the numerous articles from industry experts, the library also includes the *Back to Basics* series which was run during the first four years of the publication. This series covers the mechanical fundamentals of key processes such as hobbing, shaping, shaving, honing, and bevel gear generating. Much of this information was drawn from handbooks by the actual machine tool builders. This knowledge is essential in today's CNC environment as it provides a solid understanding of what is actually mechanically involved in these processes.

These are just a few of the many options out there. So why are companies still suffering from the skills gap? This is a complex question, but I would suggest that the problem stems from two main causes – the cost of training, and the resistance to change.

Let's talk about the cost of training first. The gear industry, as a whole, has been very busy in the past few years. Many managers are faced with the balancing act of having a person loading a machine (making money) versus taking that person off the machine and having them receive training (costing money). Coupled with the pressure to get work out the door, it can be very tempting to ignore training in the short-term, and simply hope that the inexperienced worker doesn't cause any serious problems.

Then there is the resistance to change from the way things have been done in the past. Historically, inexperienced people gained knowledge slowly

by "osmosis" over time. If they stayed around long enough, they would eventually pick up the essential knowledge of the fundamentals from their co-workers. This approach no longer works, and here is why: Today, with CNC machines, the training of new workers typically does not include the fundamentals, and the training is often limited to loading the tooling, loading the part, and hitting the cycle start button. An operator without the fundamentals will not be a strong asset to your operation.

That reminds me. When I was eighteen, I was working at a gear company while going to night school at Purdue. I remember standing behind the foreman when he asked one of the experienced operators to train me. I heard him tell the foreman, "I'm not training some snot-nosed kid. He can learn like I did." He was very serious about not wanting to share his knowledge, as I later discovered he had a notebook with notes on setting up the Reishauer.

The bottom line here is that if you want to succeed, you are going to have to invest the resources of money and time to train your workforce. Trained workers simply aren't going to show up at your door. Training needs to be an investment that is as high on your priority list as making sure you have the best equipment you can afford.

So you might be thinking, "Joe, you're living in La La Land. Where do you think I'm going to get the money to send all my new people out for training until they're ready? And then when I've paid for their training, they'll go to my competitors for $1.50 more per hour."

Yes, there you have the big challenge. Unless you have money trees on your property, it's simply not reasonable to have your workers in training 40 hours a week for months at a time. But on the other hand, you can't assume your workers are going to be magically transformed into skilled workers by hoping they will pick up the skills without formal training.

As a way of dealing with this dilemma, it is a common practice to have your experienced operators show "the ropes" to the new people. At first, this seems like a great solution because it gets you around the cost of training. However, the down side to this approach is that you're reducing the productivity of your best people. Secondly, they're not usually experienced trainers working with a carefully crafted training path for the new worker. This leads to very ineffective training efforts.

What's a manager to do?

Clearly, the required course of action for every situation is different. But it's logical to conclude that the best solution for your company will reside somewhere in the middle between full-time training and no training.

With that said, a manager must first identify what "training" is required for each individual and then define the specific training path for them. The manager must then identify the budget for the training – consisting of not only the hard costs of the training, but also the cost of the worker being away from their machine.

Finally, the manager must look at the different training methods and pair those with the training need. In doing so, a manager might consider the following options:

- **Off-Site Classroom Training.** Programs like those offered by the AGMA or Community Colleges
- **In-House Classroom Training.** Bringing Subject Matter Experts into your facility to present material to your people
- **In-House Hands-On Training.** Providing training sessions on the shop floor allowing workers to interact with an expert (either an outside resource or an internal person)
- **One-On-One Informal Training.** Providing direct individual instruction
- **Individual Self-Paced Training.** Providing the trainee with access to information about the training topic, possibly online or printed material, such as Gear Technology and their Library, videos, or elearning such as THORS.

Conclusion

If you want a trained workforce, you will most likely have to train them yourself. Furthermore, you must look at training as an essential investment in your organization.

With a carefully identified learning path, and the careful selection of training tools, you can experience the increased productivity and high quality work of a knowledgeable workforce.

Joe Arvin is a veteran of the gear manufacturing industry. After 40 years at Arrow Gear Company, Joe Arvin is now President of Arvin Global Solutions (AGS). AGS offers a full range of consulting services to the manufacturing industry. His website is *www.ArvinGlobalSolutions.com* and he can be reached by email at *ArvinGlobal@Gmail.com*.

A Final Word

If there is a topic you would like to have addressed in this column, please send me an email at ArvinGlobal@Gmail.com. Also, if you have a particular problem or question, please call me at 815-600-2633. I'm always happy to provide some free advice.

Also, if you missed any of my previous articles, here is a list of them by issue number and page. If you'd like for me to send you a copy, please send me an email or give me a call.

"Business Development for the New Year," Jan/Feb 2017 - Page 50.

"It doesn't matter how efficient your plant is! What matters is the accuracy of your quote!" Mar/April 2017 - Page 54.

"Can Lean Manufacturing Kill Your Job Shop? A Tale of Two Companies." May 2017 - Page 42.

"You Cannot Rely on Labor Efficiency Reporting!" July 2017 - Page 48.

"The Valued Troublesome Employee. To Terminate or Not To Terminate?" September/October 2017 - Page 22.

"Strategies for Building Your Business," November/December 2017 - Page 54.

"Solutions for Your Process Engineer Shortage," January/February 2018 – Page 48

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Vickers vs. Knoop Hardness Testers for Measuring Case Depth in Carburized Parts

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

What are the pros and cons of using Vickers versus Knoop hardness testers for measuring case depth in carburized gears?

Expert response provided by Dr. Michael Keeble. Both tests use a diamond indenter pressed into the specimen using a defined load and dwell time. After the removal of the load, the indent remaining in the specimen is measured optically.

The advantages and disadvantages of the two test methods come principally from the differently shaped indenters. Vickers testing uses a pyramidal diamond (Fig. 1) resulting in an indent with four nominally equal sides — or square-shaped. The diagonals of the square-shaped indent are both measured, and the average of those two values is used in the calculation of hardness. Knoop testing uses an elongated pyramidal indenter (Fig. 2), producing a rhombus-shaped indent. In this case, only the long diagonal is used in the calculation of hardness.

For both types of tests, there are practical constraints to consider; many of these are affected by the indenter shape.

Measurement accuracy. One of the largest sources of error in low-load Vickers and Knoop testing is the measurement of the diagonals. An error in measurement has a greater effect as diagonal measurements get smaller (with decreasing load or increasing hardness). For a 20µm diagonal, a 0.5µm error in measurement can result in a 5% error in the hardness reading. The Knoop test results in an indent more than twice the size of a Vickers indent for a given load. This by itself can improve the measurement accuracy by a factor of 2.

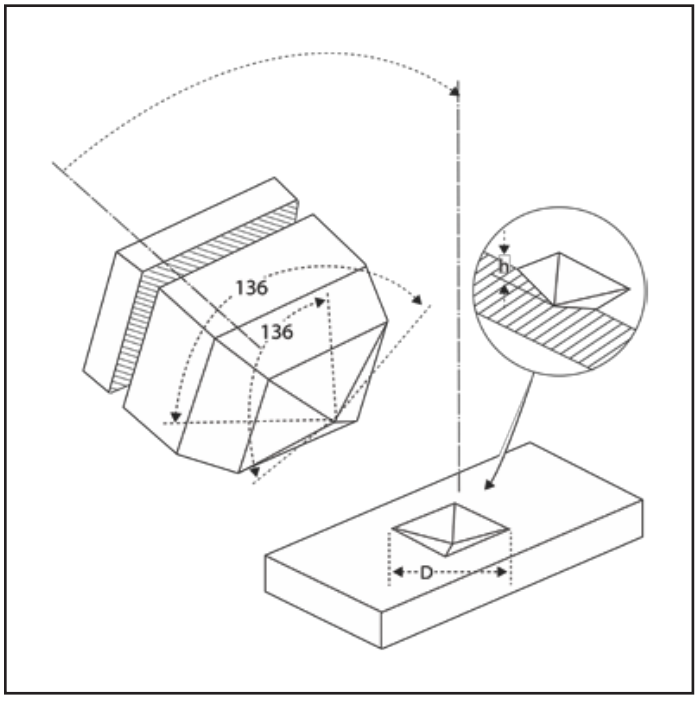

Figure 1 Illustration of the Vickers diamond indenter.

Indent positioning. Hardness tests are a measurement of the resistance to plastic deformation. When an indent is made in a ductile material, there is an area around the visible indent where deformation and stress are induced in the material. If that stress field is not fully within the undamaged material, you will get a different hardness reading. This means that the indent must be far enough from the edge of the sample, or even a different material within the sample. It also means that indents must be placed far enough away from each other that their stress fields do not overlap. Specific guidelines for minimum spacing are given in each of the ISO and ASTM standards, and are expressed in terms of multiples of the diagonal measurement of the indent. The opening angle of the Vickers diamond pyramid is defined in the standard as 136°, whereas the opening angle of the Knoop diamond pyramid is 172°. Thus, the depth of penetration is less using Knoop scales compared with Vickers, resulting in a less deep plastic deformation zone underneath and surrounding the indent. By aligning Knoop tests such that adjacent indents are made in line with the short diagonal, indents can be placed much closer together than using Vickers. Similarly, Knoop is ideal for tests on coatings. The difficulty with Knoop in some cases is correct alignment of the indenter with the specimen surface. This can be challenging if multiple case depth analyses are required in various positions around a curved surface.

Surface preparation. Surface preparation can affect the hardness reading in two ways. An irregular surface makes the edge of the indent more irregular, and can disguise the indent tip, making accurate measurement more difficult — especially for automated systems. In addition, surface deformation left from inadequate preparation can leave stress in the surface of the test material, which can change the hardness result. As the Knoop indenter is both narrower and shallower than the Vickers indenter, it will be more sensitive to surface preparation, given that a more carefully prepared surface is needed.

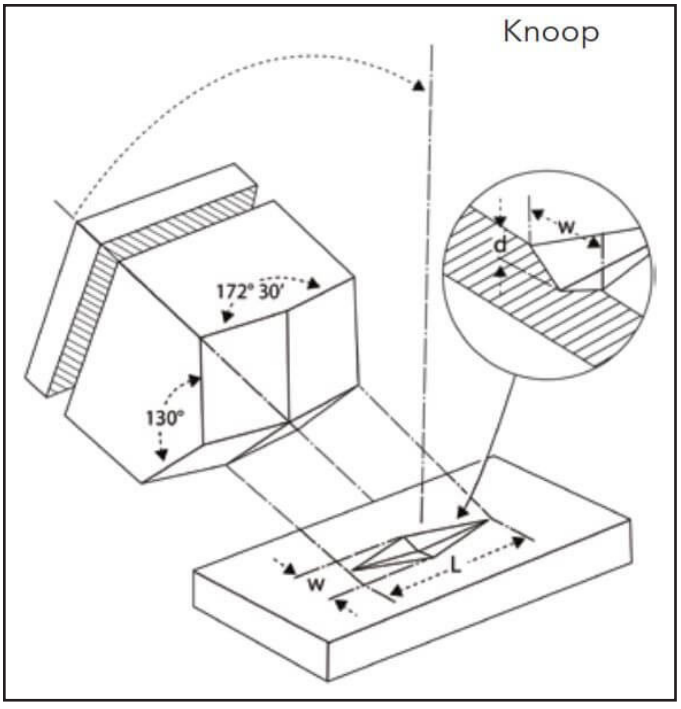

Figure 2 Illustration of the Knoop diamond indenter.

Conversion and comparison of test results. The Vickers test, in theory, gives the same hardness value for tests at all loads, due to the shape of the indenter; although in practice, variation tends to appear at very low loads, due to proportionally greater impact of variation in test conditions and measurement error. However, the Knoop test gives a different hardness when conducted at different loads. This can lead to constraints if conversion is required; Knoop conversion is restricted to 500gf tests or above—where included at all—in the ASTM E140 conversion tables.

Conclusions for carburized gears. It's usually an advantage to use Knoop testing to assess case depth in carburized gears. The ability to start indenting closer to the edge, to place indents closer together, and to improved measurement accuracy for a given load allows a far more detailed assessment of hardness change with depth. All of these are especially useful in quality-critical applications, process development, R&D and failure investigation. The use of Vickers is a perfectly acceptable alternative in applications where detailed measurement is less critical. The time saved in a high-throughput environment through reduced requirements for surface preparation, and easier placement of traverses on multiple locations of a gear, can make this a more practical option.

After a degree in Materials Engineering, **Dr. Michael Keeble** did a research Masters degree in Steel metallurgy and a Ph.D. in high temperature properties of aluminum and FE modelling of casting processes. After this, he worked in both Government and private research organizations in materials characterization, quality control testing and industrial process development. For the last 15 years he has been working with Buehler supporting metallographic characterization and hardness testing method development and product development. Keeble gives lectures and training courses globally, and is the current vice president of the International Metallographic Society, as well as working with industrial and national standardization bodies (ASTM and ISO).

Bevel Gear Generators Get Better with Age

Gleason Corporation

An economical modernization program gives Designatronics' tried-and-true Gleason No. 102 Coniflex generators a new lease on life for fast, reliable production of smaller precision straight bevel gears.

Rare is the industry where new technology hasn't supplanted what was considered state of the art just a few years ago. A better mousetrap is almost always right around the corner. Companies like the Stock Drive Products/Sterling Instrument (SDP/SI) Division of Designatronics count on it. The company invests anywhere from $1.2 to $1.5 million in capital equipment every year, all residing in a new, ultra-modern, 96,000-square-foot manufacturing facility at its headquarters on Long Island, NY. It's the only way they know of to meet the production challenges of a vast 87,000-component product line that includes custom precision gears for everything from 3D printers to the Mars Rover – and to produce them all with a 0.5% rejection rate that's well above industry standards.

But standing incongruously among all the gleaming new CNC machines are nine Gleason No. 102 Generators. These mechanical machines, and thousands like them, were built in the '50s and '60s and dedicated to one purpose only: producing smaller high-precision straight bevel gears using the Coniflex process. Today, straight bevel gears with diameters of an inch or less are in high demand for many of the motion control applications that SDP/SI caters to. More often than not, customer specifications call for these gears to be produced using the Coniflex process, which raises an important question for SDP/SI and hundreds of manufacturers still using the ubiquitous 102s: Keep using them to meet demand, or make a substantial investment in new technology?

Coniflex and CNC: Best of Both Worlds

SDP/SI has found the right answer, and it's a resounding "yes", according to President and CEO Robert Kufner. "Many of our customers, particularly for certain aerospace applications, specify what's commonly referred to as a 'Gleason-type' straight bevel gear, and the 102s certainly give us the most proven solution," says Kufner. "If these machines have an Achilles Heel, it's that they are, by nature, very time-consuming and difficult to set up, and require operator skills that are in increasingly short supply. This situation is exacerbated by the fact that we now routinely customize 40% or more of our standard product line to meet customer demand and need more changeover speed and flexibility to meet any production scenario, whether 'high mix/low volume' or 'low mix/high volume.' Fortunately, Gleason has given us the best of both worlds: a 102 Coniflex 'CNC' Generator that operates with many of the capabilities of today's most productive CNC machines."

Enter Gleason Regional Sales Manager Paul Peone, who was instrumental in selling Kufner and his team on the benefits of working with the OEM to rebuild and modernize one of the company's existing 102s and add FANUC CNC firepower. "For the many companies still using their Coniflex workhorses, the proven Gleason remanufacturing and modernization program for these machines makes total economic sense," explains Peone. "It fills the production void between these older machines that depend so much on the experience of the operator for setup and to run reliably, and the latest CNC machines that come with a much higher price tag."

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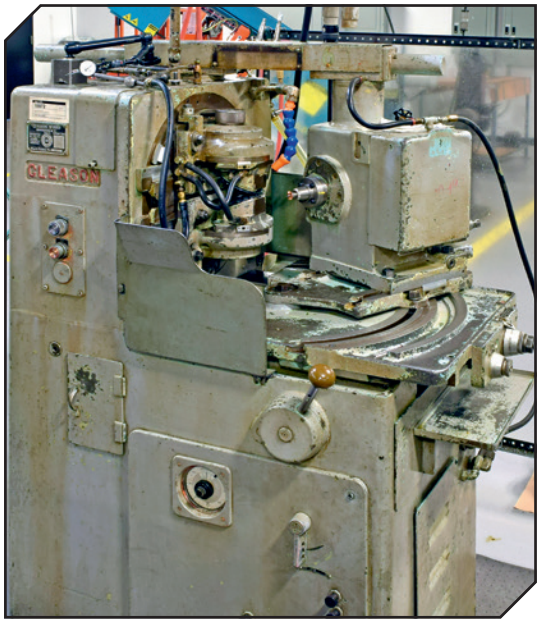

Figures 1, 2 (before and after] The Gleason Modernization Program is enabling SDP/SI to add Coniflex capacity by transforming its manual, 60s era 102 Generators into CNC machines that set up easier and run faster and more reliably.

A 102, Like New

According to Peone, the Gleason 102 modernization program runs like clockwork. The machine is shipped to Kanie & Co., Ltd., a Gleason subsidiary based in Japan that has specialized in remanufacturing, retrofitting and upgrading older Gleason bevel gear cutting machines for more than 50 years. The machine is completely torn down to its cast iron base frame, scraped, re-leveled, and ultimately re-assembled with rebuilt cutter head and work head assemblies. These assemblies now feature new spindle and ballscrew servo drives/motors to replace the mechanical components like feed cams and change gears that require slow, time-consuming changeover when setting up part-to-part. Most importantly, a FANUC 32i A CNC controller is retrofit, along with all the other components necessary to operate the machine via CNC program. As a result, the vast majority of the manual settings and adjustments that contribute to time-consuming, labor-intensive setup and operation are eliminated.

After run-off and acceptance, the machine is shipped back to the customer. The entire process typically takes from eight to nine months.

Now Open for More Coniflex Business

The first of these 102 'CNC' generators is now operating alongside its mechanical brethren, five of which are scheduled for the same rebuild program downstream. The CNC generator proudly wears its distinctive original Gleason nameplate, but otherwise bears little resemblance to its former self. Most significantly, the machine has more than lived up to billing. According to Kufner, it has cut the typical setup time to change from one part family to the next from four hours to just one. (It's important to note that the machine uses existing cutting tools and workholding, so no special tooling is required.) Additionally, cycle times have been improved, since the machine now can run again at the feeds and speeds it was originally designed for, and without repeated cycle interruptions for part quality checking/rechecking. And, going forward, much needed capacity has been added for the small, precision straight bevel gears that are in high demand.

"Hats off to the Gleason service team that had the machine installed and set up, and four operators trained, in about two weeks," says Kufner. "It is important to note that three of these operators had no hands-on experience with the old 102s. But that doesn't matter. Since the machine is now CNC and setup and operation are largely summary-driven, any of our operators can be trained and operating the machine productively practically overnight. The machine, and the others to follow, will help to further establish us as a go-to source for very reliable, very flexible Coniflex production."

For more information:
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Rochester, NY 14607
www.gleason.com

Stock Drive Products/Sterling Instrument (SDP/SI) is a Designatronics company. The company is ISO 9001:2015 + AS9100D certified, offers mechanical based design, engineering and manufacturing services for critical motion control and small power transmission applications, including aerospace, defense, robotics, industrial automation, and medical. Over 87,000 standard inch and metric small mechanical components are available for fast turnaround. SDP/SI specializes in high-quality machined parts, molded components, synchronous belt drives, precision gears and subassemblies. For more information go to: *www.sdp-si.com.*

Figure 3 The 102 CNC Generator is far less dependent on an increasingly scarce pool of operator experience for setup and operation. The Fanuc CNC retrofit enables an operator with just a week or two of training to run the machine more productively and with far less time spent on setup.

Figure 4 The 102 CNC Generator has cut setup time for different part types from an average of four hours to just one, helping SDP/SI meet increased demand for straight bevel gears 1" or less in diameter produced using the Coniflex process.

Figure 5 SDP/SI annually invests up to $1.5 million in capital equipment for its ultra-modern, 96,000-square-foot Long Island, NY facility.

CNC Manufacturing of Circular Faced Cylindrical Gears

C. Gosselin, E. Fritz and L. Seiler

Spur cylindrical gears are usually cut using a hob and therefore present an essentially straight face to which crowning can be added to prevent edge contact. Rather than using a rack or hob, it is possible to cut cylindrical gears with a face mill cutter. In the following presentation, these gears are termed "spurved," i.e. — a contraction of "spur" and "curved."

Significant qualities of spurved gears include the convexo-concave contact in the face-width direction, which can result in improvements such as better lubricating conditions and lower contact stresses, increased bending stiffness (because of the circular face), and a self-centering characteristic in which only one member need be located axially with a small thrust bearing.

This paper presents the basic equations needed to model spurved gears. It is shown that cutter tilt can be used to control the lengthwise dimensions of the contact pattern, which conditions contact stresses and lubrication.

An application demonstrates actual spurved gear sets cut on a CNC machine using standard face mill cutters with modified roll.

Introduction

Spurved gears are essentially spur gears generated using a face mill cutter. Spurved gears can theoretically be cut on conventional spiral-bevel gear generators and multi-axis CNC machines.

Because of their convexo-concave contact in the face-width direction, spurved gears offer strength and contact characteristics, making them interesting for certain parallel shaft applications where increased tooth bending stiffness is required.

Liu (Ref.1)looks at the basic geometry of spur gears with a circular shape along the face-width, using different cutters for the pinion and gear so as to obtain the desired contact characteristic. Wu et al. (Ref. 2)., Zhang et al. (Ref. 3), Jiang et al. (Ref. 4) and Chen et al. (Ref. 5) all consider the profile as being curvilinear, thereby increasing the load carrying capacity and improving lubricating conditions at the expense of increased sensitivity to center distance change.

Fuentes et al. (Ref. 6) rather consider standard face mill cutters with a straight edge and look at generation either using completing or fixed-setting cycles.

In this paper, a simple and readily applicable approach is applied where off-the-shelf face mill cutters are used to cut cylindrical gears. The unified model (Ref. 7) is the basis for the tooth flank generator where the same face mill cutter is used to generate both the pinion and gear. Cutter tilt is introduced to control the width of the contact pattern in the face width direction, while modified roll is used to control transmission error (TE) in order to guarantee relief at contact entry and exit. An application example shows the excellent agreement obtained between the theoretical model and the actual part.

The Tooth Flank Generator

A tooth flank generator can be described as a group of software functions defining the shape of a tool and its movements relative to a work piece. Since the vast majority of gears are generated, the generating process should be the basis of any tooth flank generator.

The generating process (Ref. 7) describes one cutter blade, representing one tooth of a theoretical generating gear, meshing with the work piece. This is written as:

$$\overline{N} \cdot \overline{V}_r = 0 \tag{1}$$

where the relative speed vector of the contacting tool to work surfaces is in a plane perpendicular to the common normal vector. When applied to the reference frames in Fig. 1, Eq. 1 yields an unbounded generated surface in a reference frame attached to the work piece. The surface is a function of the machine settings and three variables, respectively, cutter position α_c (angular or linear), work piece roll angle α_3 and S, the position of a point along the edge of the cutter blade:

$$S = f(\alpha_c, \alpha_3) \tag{2}$$

The solution of Equation 2 is a series of contact points between the cutter blade and the work that describes a line along the path of the cutter blade. The envelope of a series of such lines yields a generated tooth (Fig. 4). The tooth flank generator includes work and tool adjustments and movements found in gear cutting machines. In CNC machines, machine settings can be continuously altered during generation to allow improvements in gear kinematics. Figure 1 represents the most general case in the cutting process simulation and is therefore the basis for the general model. Vector $\vec{D}$ is the position of a point along a face mill or face hob cutter blade. Figure 2 shows the general representation of a face mill or face hob cutter blade from which vector $\vec{D}$ is obtained (Eq. 4).The implicit equation of the generated tooth surface is:

$$\vec{X} = \vec{D}[\alpha_c]_1[\tau]_3[J]_1[R][L_1 m]_1[\Gamma]_2[P][\alpha_3]_3[R_c]_3 \tag{3}$$

$$\vec{D} = \begin{bmatrix} S\cos(\varphi) \\ 0 \\ (R \pm S\sin(\varphi)) \end{bmatrix} \tag{4}$$

Similarly, Equation 5 defines vector $\vec{N}$, the normal to the cutter blade at point S; Equation 6 gives the transformations between the cutter blade and the work piece.

$$\vec{N} = \begin{bmatrix} \sin(\varphi) \\ 0 \\ \mp\cos(\varphi) \end{bmatrix} \tag{5}$$

$$\vec{N}_x = \vec{N}[\alpha_c]_1[\tau]_3[J]_1[R][L_1 m]_1[\Gamma]_2[\alpha_3]_3[R_c]_3 \tag{6}$$

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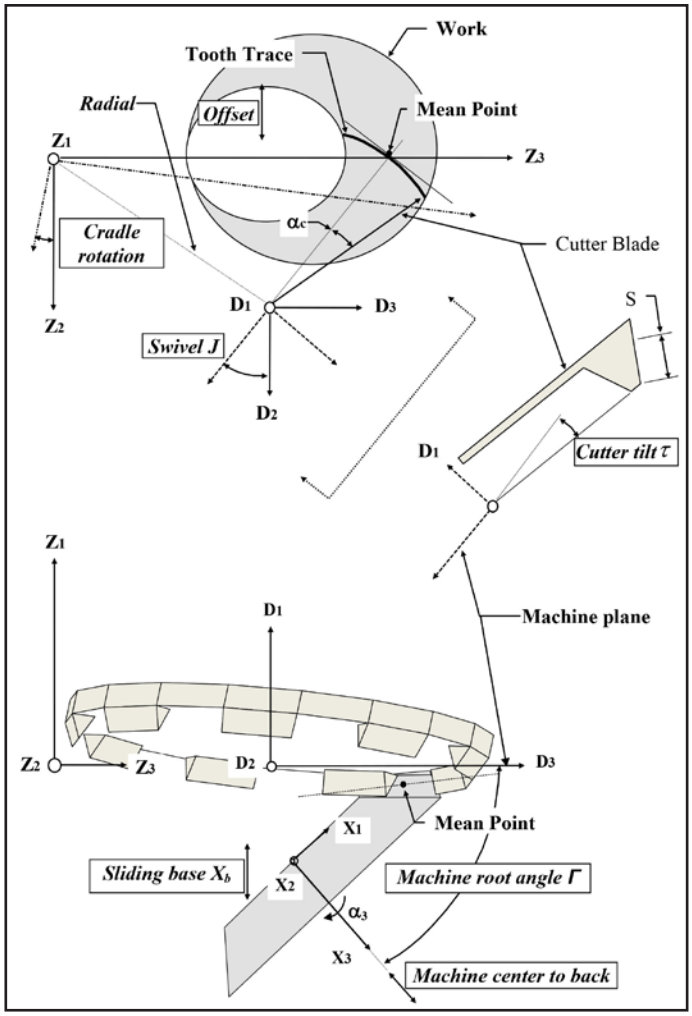


Figure 1 General reference frames.

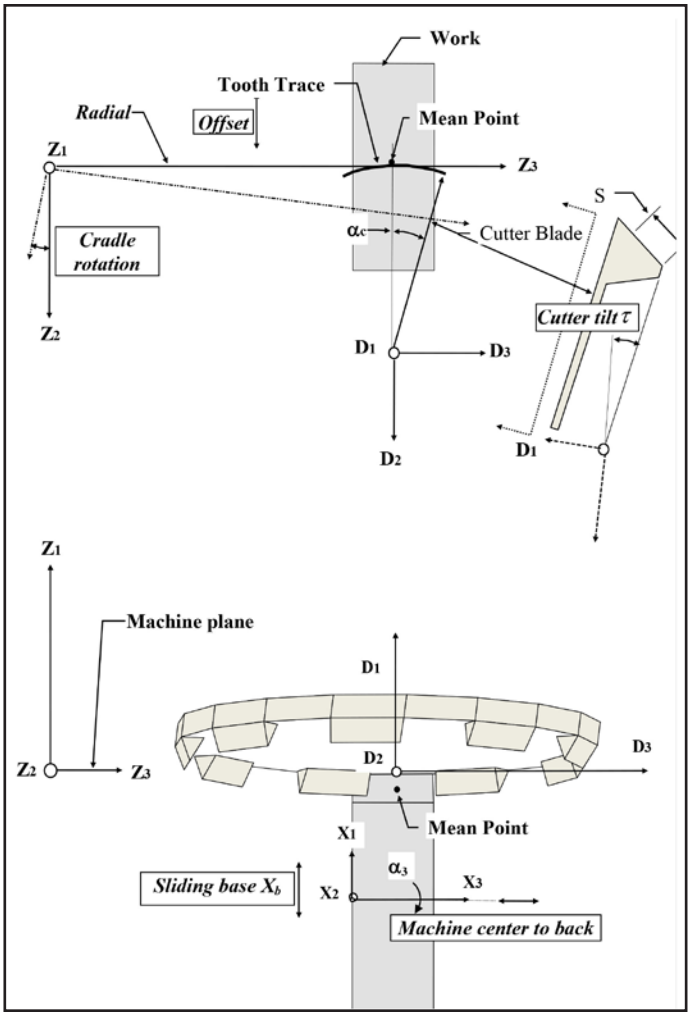


Figure 2 Spurved gear reference frames.

In Equations 3and 6, rotations and translations can be expanded in Taylor series to allow higher-order manufacturing flexibility on CNC machines. For example, the cradle rotation angle L_{1m} can be written as:

$$L_{1m} = a_3 R_r + A_2 (C_r - a_3 R_r)^2 - A_3 (C_r - a_3 R_r)^3 + A_4 (C_r - a_3 R_r)^4 - A_5 (C_r - a_3 R_r)^5 + A_6 (C_r - a_3 R_r)^6 \quad (7)$$

where α_3 is the roll angle of the work piece, R_r is the ratio of roll between the work piece and the cradle, C_r is the cradle angle given in the machine settings, and A_i are the coefficients for each term of the series.

For spurved gears, the terms involving cutter swivel J, root angle Γ and face hobbing rotation R_c are dropped from Equations 3 and 6, and the reference frames are simplified (Fig. 2); Figure 4 shows a spurved pinion model.

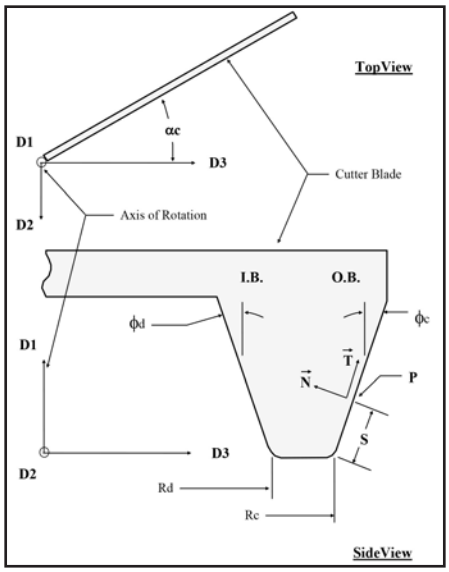


Figure 3 Cutter blade reference frame.

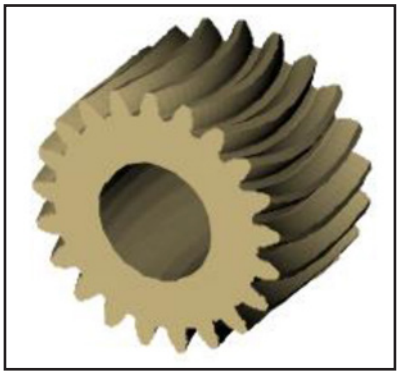


Figure 4 Spurved pinion.

Tooth Contact Analysis of Spurved Gears

At any contact point, the coordinates on the pinion and gear teeth must be equal and the normal vectors must be collinear and opposed in a common reference frame:

$$\vec{Z}_P = \vec{Z}_G \qquad \vec{N}_P = \vec{N}_G \quad (8)$$

A true conjugate point of contact exists where 1) tooth to tooth separation is minimum on the Ease Off and 2) all components of the pinion and gear normal vectors are equal. The series of true conjugate contact points yields the path of contact (PoC). All other contact points yield the Ease-Off surface (Fig. 5), which emphasizes the deviations in conjugacy

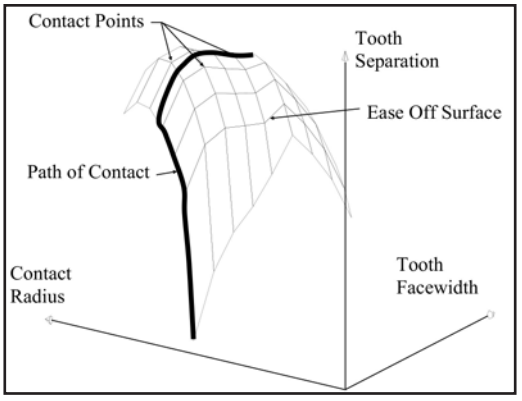


Figure 5 Ease-Off surface.

between the meshing pinion and gear teeth.

The transmission error (TE) is derived from the PoC. It is the expression of the difference between the actual and theoretical angular positions of the gear member (Eq. (9)):

$$\delta\varphi_3 = \varphi_3 \theta_3 m_g \quad (9)$$

where $\delta\varphi_3$ is the TE, φ_3 is the calculated angular position of the gear and θ_3 m_g is the theoretical angular position of the gear, based on the pinion angular position θ_3 and the gear ratio m_g. A negative result to Equation 9 means that the gear is late relative to the pinion, and is the desired situation in order to prevent premature contact entry.

If the gear tooth flank is coated with a marking compound, the succession of contact points as meshing proceeds leaves a trace indicating which part of the tooth flank comes in contact. This trace is called the contact pattern. The contact pattern is calculated as follows:

- The Ease-Off surface is calculated; from this, the path of contact and tooth profile separation are obtained for each point of the PoC;
- Each contact point of the Ease Off is checked to test whether separation is larger or smaller than the requested marking compound thickness. If separation is smaller or equal, the contact point is considered within the contacting area.

Design of Face Milled Spurved Gears

Similar to conventional spur gears, the basic design of spurved gears involves selecting the module, face width, and tooth numbers to achieve the desired gear ratio and tooth strength.

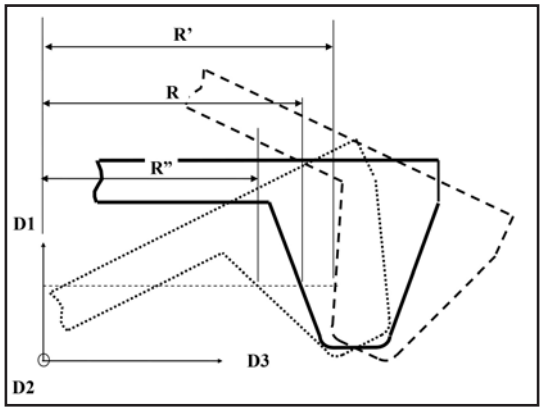


Figure 6 Effective cutter radius and cutter tilt.

However, the diameter and blade angles of the selected face mill cutter play an important role in the dimensions of the contact pattern, and therefore the load carrying capacity and sensitivity to positional changes of the gear set.

For a given operating pressure angle, selecting different angles for the convex and concave blades imposes cutter tilt. Cutter tilt changes the effective radius of curvature along the face width (Fig. 6) where the effective cutter radius R changes to R' or R" — depending on cutter tilt sign.

Therefore, changing the operating pressure angle and/or the cutter blade angles offers some control over the dimensions of the contact pattern. However, for a given cutter tilt angle, a smaller cutter diameter will generate a comparatively smaller contact pattern. Table 1 reflects this behavior where, for the given operating pressure angle and blade angles, a 4" cutter is shown to produce a significantly wider contact pattern than a 2" cutter. Module is 1.352 mm and face width 20 mm.

Table 1 Effect of cutter diameter on contact pattern size

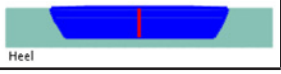
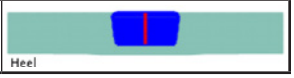
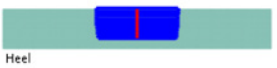
Characteristics	4" Cutter	2" Cutter
Oper. Pressure Angle	20"	20"
Convex Blade Angle	22"	22"
Concave Blade Angle	18"	18"
Contact Pattern		

Table 2 Effect of cutter tilt on contact pattern size

Characteristics	4" Cutter	2" Cutter
Oper. Pressure Angle	20°	20°
Convex Blade Angle	18°	18°
Concave Blade Angle	22°	22°
Contact Pattern		

Likewise, for a given operating pressure angle, inverting the values of the convex and concave blade angles reverses tilt and consequently modifies the effective cutter radius, thereby changing contact pattern size. Table 2 reflects this behavior where, for the same operating pressure angle as in Table 1, but with inverted blade angles, the contact patterns are seen to be significantly smaller than in Table 1.

By definition, spurved gears are fully conjugate at mid-face. This means that in the absence of modifications to the profiles of the cutter blades, TE will be null. This is shown (Fig. 7), where three TE curves (blue, red and pink lines) are shown on the 0.0 line.

TE is desired in gear sets in order 1) to provide smooth motion transfer between meshing tooth pairs when subject to positional errors, and 2) to avoid excessive stresses at contact entry and exit. TE can be introduced in a number of ways. For example: 1) using blade deviations such as TopRem; 2) using circular cutter edges, or 3) using higher order changes, such as modified roll Eq. (7), on a CNC-controlled machine. The latter is the preferred method, as standard cutters can be used. Figure 8 shows the TE for the same gear set as that in Figure 7, but 2nd-order modified roll has been applied to provide relief at contact entry and exit.

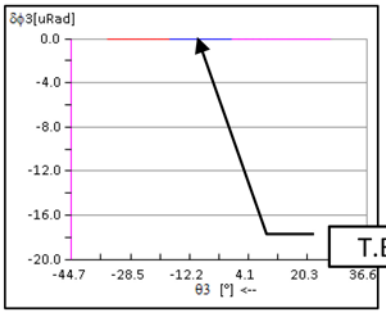


Figure 7 TE – basic gear set.

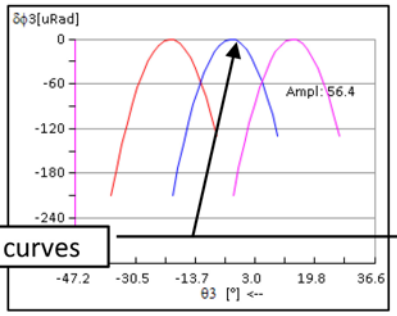


Figure 8 With modified roll.

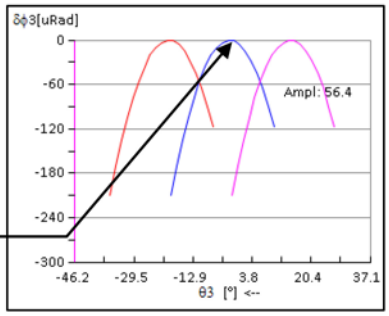


Figure 9 0.2 mm C.D. change.

Insensitivity to center distance change is a prime characteristic of spur gears. Spurved gears behave similarly, since they are fully conjugate in the mid-face section of the tooth where the PoC is centered. In Figure 9, the center distance of the gear set of Figure 8 was increased from 37.86 mm to 38.06 mm — thus a 0.2 mm increase for a tooth whole depth of 2.5 mm and yet, no change in the TE can be noticed.

Likewise, insensitivity to misalignment is essential in order to prevent toe and heel edge contact. Figure 10 shows the contact patterns of a spur and a spurved gear set having the same amount of lengthwise crowning, i.e. — 0.010 mm.

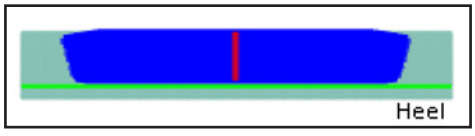


Figure 10 Contact pattern: spur gear.

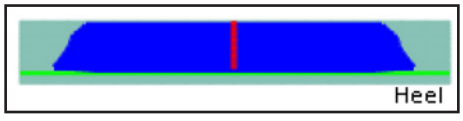


Figure 11 Contact pattern: spurved gear.

When subjected to the same amount of 2" misalignment (0.0333°), the contact patterns on both gear sets are shown to move in a similar manner (Figs. 12 and 13).

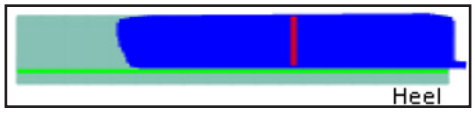


Figure 12 Contact pattern: spur gear.

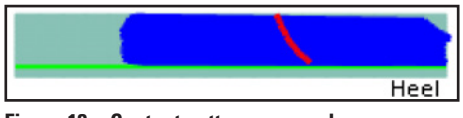


Figure 13 Contact pattern: spurved gear.

Likewise, when subjected to the same torque of 20 Nm, both the spur and spurved gear sets exhibit similar contact stresses if the Ease Off is comparable (Figs. 14 and 15).

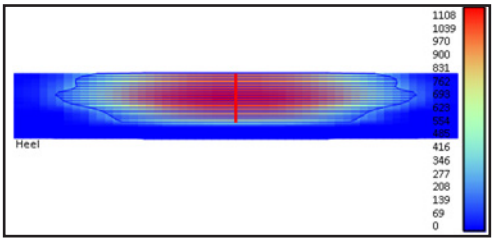


Figure 14 Contact stresses: spur gear.

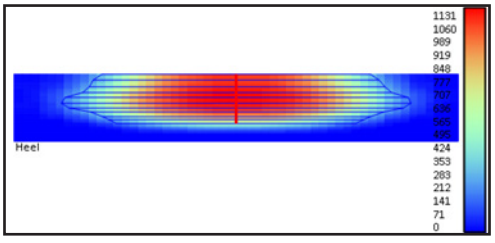


Figure 15 Contact stresses: spurved gear.

Application: CNC Manufacturing of Spurved Gear Sets

In order to illustrate the method, two spurved gear sets, $m = 1.352$ mm, were designed with the parameters listed in Tables 3 and 4. The spurved sets were manufactured on a 5-axis Doosan CNC machine. Figures 16 and 18 show the predicted contact patterns on the gear, and Figures 17 and 19 show the actual contact patterns obtained on the VH tester.

Table 3 Test #1: spurved gear set

Characteristics	Pinion	Gear
#Teeth	21	35
Cutter Diameter	2"	
Convex Blade Angle	22.5°	22.5°
Concave Blade Angle	17.5°	17.5°
Cutter Tilt	2.5°	–2.5°

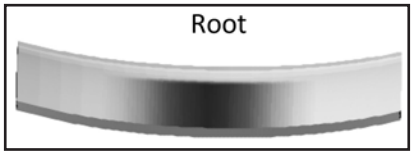


Figure 16 21x35 contact pattern simulation

Figure 17 21x35 actual contact pattern.

Table 4 Test #2: spurved gear set		
Characteristics	**Pinion**	**Gear**
#Teeth	41	41
Cutter Diameter	3.5″	
Convex Blade Angle	21.667°	21.667°
Concave Blade Angle	18.333°	18.333°
Cutter Tilt	1.667°	1.667°

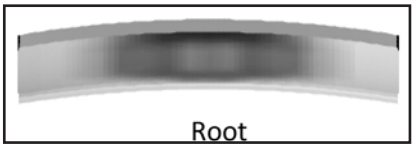


Figure 18 41x41 contact pattern simulation.

Figure 19 41×41 actual contact pattern.

Figures 16 to 19 show the excellent agreement between the simulation and the actual contact patterns. Figure 20 shows the CMM output, for the $Z_1 = 41$ pinion. Slight pressure angle error can be seen on the convex flank, which can easily be corrected by closed loop.

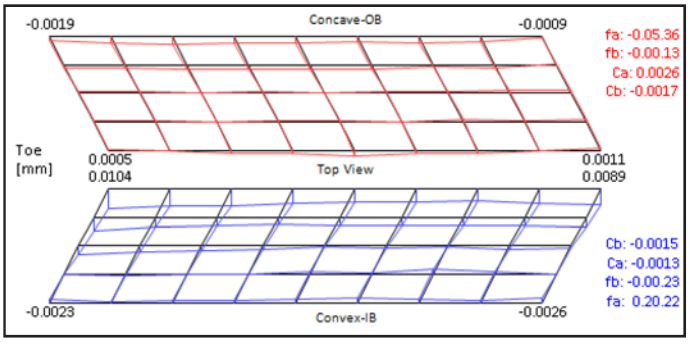


Figure 20 CMM output: $Z_1 = 41$.

Conclusion

The term "spurved gears" refers to spur gears with a curved face cut using a face mill cutter. In this paper, a general method is presented to design, analyze and manufacture spurved gears on a 5-axis CNC machine. Cutter tilt is used to control the size of the contact pattern, and modified roll is used to control transmission error. When the Ease Off and size of the contact pattern are comparable, spur and spurved gears behave in a similar way when subjected to the same center distance and misalignment errors. However, because of their circular face, spurved gears are expected to be stiffer than spur gears, and thereby may offer an advantage where sudden torque is applied. Examples show that model prediction for contact pattern shape and location correlate very well with that of actual parts.

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Optimum Carburized and Hardened Case Depth

Robert Errichello and Andrew Milburn

Abstract

The optimum carburized and hardened case depth for each gear failure mode is different and must be defined at different locations on the gear tooth. Current gear rating standards do not fully explain the different failure modes and do not clearly define the different locations that must be considered. Furthermore, they use different hardness values to define effective case depth and provide different values for recommended case depth. This paper explains why case hardening is beneficial; the risks involved and compares the methods for calculating and specifying case depth per the ISO 6336-5 and ANSI/AGMA 2101-D04 gear rating standards, and guidelines presented in the MAAG Gear Handbook. The paper shows the three locations that the case depth needs to be specified and presents separate calculation methods to determine the optimum case depth to avoid the failure modes of macropitting, subcase fatigue, bending fatigue, and case/core separation. For each failure mode there is a minimum case depth below which the load capacity drops off. On the other hand, an excessively deep case decreases load capacity, increases cost, and has other detrimental effects that are explained.

Introduction

This paper recommends case depth for carburized gears for the failure modes of macropitting, subcase fatigue, bending fatigue, and case/core separation. See ANSI/AGMA 1010 (Ref. 1) for more information on failure modes. However, the optimum case depth for each failure mode must be defined at different locations on the gear tooth, and the optimum case depth varies with the failure mode. Therefore, this paper discusses required case depth to avoid each failure mode separately considering critical locations for measuring case depth. For more information on the concept of optimum case depth (Refs. 2–3).

Definition of Effective Case Depth

The European definition for effective case depth is the distance from the surface to a point within the case where the hardness is 550 HV (approximately 52.3 HRC). This measurement is done with a Vickers microhardness indenter. The US definition for effective case depth is the distance from the surface to a point within the case where the hardness is 50 HRC (approximately 513 HV). This measurement is done with a Knoop or Vickers indenter, and the hardness values can be converted to HRC using a conversion chart such as ASTM E140.

Maximum grind stock removal must be accounted for when designing case depth to ensure the finished case depth is adequate. Therefore, a typical drawing specification is defined as the effective case depth to 550 HV or 50 HRC after final machining.

Note that the US definition is deeper than the European definition. Unfortunately, there is no easy way to convert between the two definitions because the slope of the hardness gradient varies with the dimensions of the specific gear, material hardenability, and heat treatment process including the quench rate. Consequently, to compare the two definitions, an actual microhardness gradient must be measured on the specific gear to determine how much deeper the 50 HRC case depth is compared to the 550 HV case depth. Some laboratories measure and report both depths to help resolve this issue.

The 550 HV definition for effective case depth is used in this paper because the recommendations for case depth are based on MAAG and ISO guidelines.

Definition of Total Case Depth

The total case depth is approximately 1.5 times and can be as much as twice the effective case depth based on the 550 HV definition. The total case depth is sometimes defined as the depth where the carbon gradient of the case is 0.04% above the core carbon content of the steel alloy.

Recommended Locations for Carburized Case Depth Measurements

Figure 1 shows the authors' recommended locations for case depth measurements and is based on Dudley's (Ref. 4, Fig. 4.8). The 30° line was added to define the location for case depth measurement at the root fillet.

- Location A, at approximately mid-height of the tooth, is the location for measuring case depth at the flank.

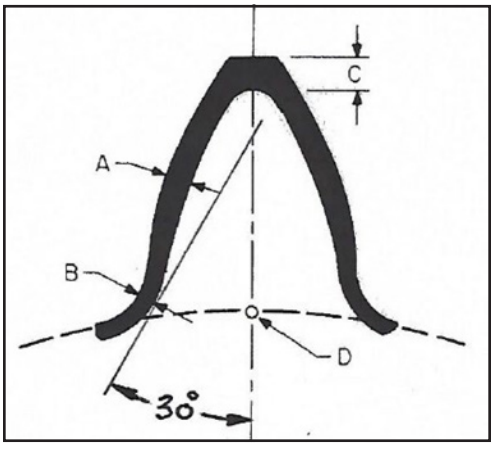

Figure 1 Locations for carburized case depth measurements.

- Location B is the location for measuring case depth at the root fillet.
- Location C is the location for measuring case depth at the tooth tip.
- Location D, on the root circle, is the location for measuring core hardness.

Another aspect besides failure mode that must be considered when specifying case depth is the fact that case depth can be different at the flank, root, and tip locations. Atmosphere carburizing produces case depths that depend on several factors including material hardenability, gear tooth geometry, furnace parameters, and quenching parameters, hence the variation between flank, root, and tip case depths varies widely; sometimes the same, sometimes quite different. Typically, the case depth will be less at the root than at the flank and less at the flank than at the tip locations. In contrast, vacuum carburizing can produce a nearly uniform case depth at every location.

Influence of Case Depth on Gear Tooth Properties

Benefits of carburizing. Carburized gear teeth have maximum macropitting and bending fatigue resistance because they have hard surfaces, and carburizing induces beneficial compressive residual stresses in the case. The compressive residual stresses are the result of the material expansion when austenite transforms to martensite and they effectively lower load stresses. However, the compressive residual stresses in the case are balanced by detrimental tensile residual stresses near the case/core boundary as shown (Fig. 2).

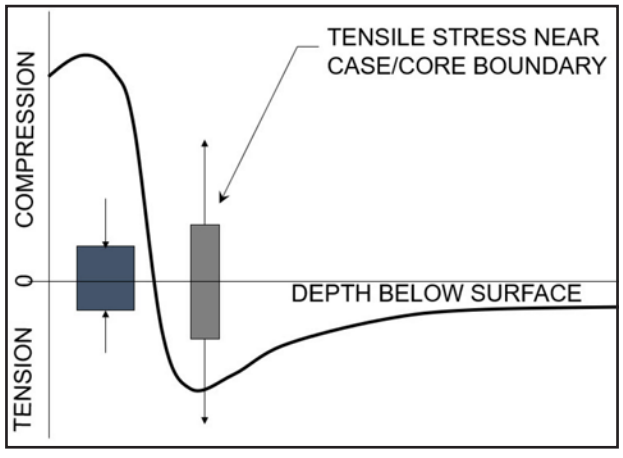

Figure 2 Residual stresses in carburized gears.

Optimum case depth. Generally, for each failure mode there is a minimum case depth below which the load capacity drops off (Refs. 2–3). On the other hand, an excessively deep case decreases load capacity (Refs. 2–3). Furthermore, deep cases require long carburizing times, which is undesirable for the following reasons:

- Intergranular oxidation (IGO) increases (especially with alloys containing Mn, Cr, and Si), which decreases bending fatigue resistance.
- Residual stress profiles are altered, which is especially detrimental because beneficial compressive residual stresses decrease, and both Hertzian fatigue resistance and bending fatigue resistance decrease.
- Grain size might increase, which decreases both Hertzian fatigue resistance and bending fatigue resistance.
- Excessively deep cases promote case/core separation.
- Distortion increases, which requires greater grind stock removal.
- Manufacturing costs might increase.

Macropitting

Macropitting might initiate at the tooth surface or at a shallow depth below the surface usually at a subsurface defect such as a nonmetallic inclusion. It is important to design the effective case depth to achieve high compressive residual stresses at the surface and within the case to mitigate the influence of nonmetallic inclusions. Table 1 gives several guidelines for minimum effective case depth to avoid macropitting.

Table 1 Different guidelines for minimum case depth to avoid macropitting

Reference No.	Source	Location	Material Grade	Note No.
5	MAAG	Fig. 6.12	---	1, 3
6	ISO 6336-5	Clause 5.6.2.a	ML, MQ, ME	1, 3
7	AGMA 2101-D04	Fig. 13	1, 2, 3	2, 3

1. Effective case depth is based on the 550 HV definition.
2. Effective case depth is based on the 50 HRC definition.
3. See Annex A for equations.

Macropitting recommendation. Figure 3 shows the authors' recommended effective case depth based on the MAAG (Ref. 5). See Annex B for the derivation of Figure 3 and a comparison to the ISO 6336-5 (Ref. 6) and ANSI/AGMA 2101 (Ref. 7) guidelines.

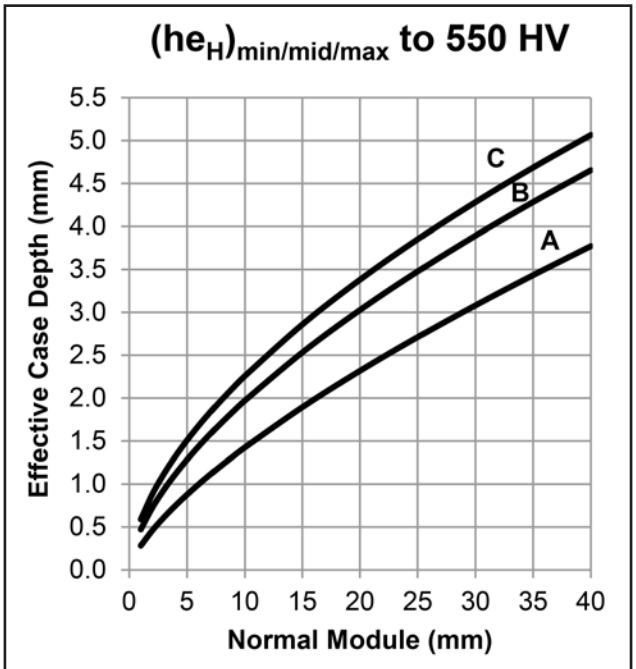

Figure 3 Effective case depth to avoid macropitting, $(he_H)_{min/mid/max.}$

Description of Figure 3. The lower curve "A" in Figure 3 is the minimum effective case depth measured at location A shown (Fig. 1). It is the case depth after all machining is complete and is the distance measured from the tooth flank surface to a depth where the hardness is 550 HV. Curve "A" is recommended for maximum macropitting resistance. However, the designer should provide a tolerance for case depth to accommodate manufacturing variation. The tolerance band width usually depends on the type of gear unit, the conditions imposed on it, the

facilities in the heat treat shop, and the uniformity of the heat treat results. Curves "B" and "C" are tolerance bands for maximum case depth obtained by adding a tolerance to the minimum effective case depth represented by curve "A". Curve "C" represents the maximum tolerance range customary in commercial gear drive design. Curve "B" is appropriate for the tolerance range for a precision gear drive design.

***Equations for Figure 3 curves*:**

Curve A $(he_H)_{min} = 0.2835(m_n)^{0.7016}$ (minimum to avoid macropitting)

Curve B $(he_H)_{mid} = 0.4730(m_n)^{0.6198}$ (maximum precision tolerance)

Curve C $(he_H)_{max} = 0.5899(m_n)^{0.5829}$ (maximum commercial tolerance)

Subcase Fatigue

The term "case crushing" was incorrectly used in earlier gear nomenclature for subcase fatigue. However, subcase fatigue is now the preferred term. See ANSI/AGMA 1010 (Ref. 1) for more information.

Case depth, Hertzian stress, residual stress, and material fatigue strength influence subcase fatigue. The subsurface distribution of residual stresses and fatigue strength depends on case hardness, case depth, and core hardness. Optimum values of case depth and core hardness give proper balance of residual stresses and fatigue strength to maximize subcase fatigue resistance (Refs. 2–3).

To prevent subcase fatigue, the steel alloy must have adequate hardenability to obtain optimum case and core properties. Furthermore, it is especially important to use clean steel because inclusions can initiate fatigue cracks if they occur near the case/core interface in areas of tensile residual stress (Fig. 2).

Overheating gear teeth during operation or manufacturing (such as grind temper) can lower case hardness, alter residual stresses, and reduce resistance to subcase fatigue. In fact, grind temper is often the root cause of subcase fatigue failure.

Table 2 gives guidelines for minimum effective case depth to avoid subcase fatigue.

Table 2 Different guidelines for minimum case depth to avoid subcase fatigue

Reference No.	Source	Location	Material Grade	Note No.
6	ISO 6336-5	Clause 5.6.2.c	ML, MQ, ME	1
7	AGMA 2101-D04	Eq. 43	1, 2, 3	2

1. Clause 5.6.2.c has $U_H = 66{,}000$ N/mm2 for grades MQ and ME, which is based on case depth = 2.1 times the depth to the maximum shear stress, and $U_H = 44{,}000$ N/mm^2 for grades ML, which is based on case depth = 3.2 times the depth to the maximum shear stress.
2. Eq. 43 has $U_H = 44{,}000$ N/mm^2, which is based on case depth = 3.2 times the depth to the maximum shear stress.

Subcase fatigue recommendation. It is the authors' opinion that the AGMA guideline is too deep for the reasons given previously (for more information see References 2 and 3). Therefore, it is recommended that the ISO 6336-5 (Ref. 6) equation in clause 5.6.2.c be used, which is given in Annex A and repeated here as Equation 1 for convenience.

$$(he_s)_{min} = \left\{ \frac{\sigma_H d_{w1} \cdot sin(\alpha_{wt})}{U_H \times cos(\beta_b)} \right\} \cdot C_G \quad (1)$$

Where $U_H = 66{,}000$ MPa for ISO quality grades MQ and ME (AGMA grades 2 and 3) and $U_H = 44{,}000$ MPa for quality grade ML (AGMA grade 1). Note that Equation 1 is based on the 550 HV definition of case depth and is for the flank (location A).

The Hertzian stress σ_H should equal the maximum stress actually applied in service. For applications with heavy shock loads, the required minimum effective case depth can be significantly higher than that shown by curve A (Fig. 3). Therefore, σ_H must be carefully chosen because an excessively deep case will decrease both macropitting resistance and bending fatigue resistance. This requires an analysis of the subsurface gradients of strength, residual stresses, and Hertzian stresses due to applied loads.

Figure 4 shows the effective case depth based on the recommended subcase fatigue criteria at two different contact stress numbers and additional lines, which have been added for reference. The gear geometry used for the subcase fatigue calculations is shown (Table 3). The AGMA heavy line was multiplied by 0.9 to adjust it from the 50 HRC definition to the 550 HV definition of case depth.

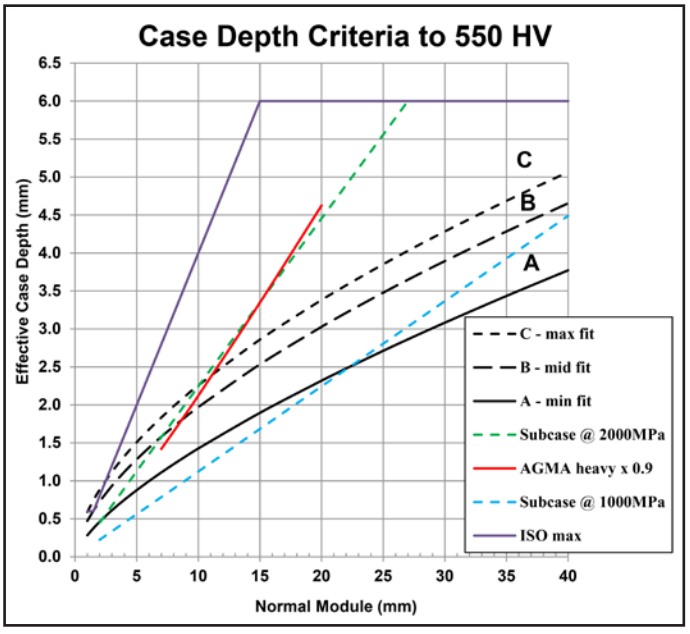

Figure 4 Effective case depth based on subcase fatigue criteria at two different contact stress numbers.

Table 3 shows the gear set geometry used to calculate the subcase effective case depth data points in Figure 4 and the maximum effective case depth data points using pinion topland thickness in Figure 7.

Bending Fatigue

Case hardening by carburizing is especially beneficial because carburizing induces compressive residual stresses that reduce net tensile bending stresses. In addition, shot peening can be used to enhance the compressive residual stresses at the surfaces of the root fillets. For carburized gears there are optimum values of case hardness, case depth, and core hardness that give the proper balance of residual stresses and fatigue strength to maximize resistance to bending fatigue (Refs. 1–3). Note that the optimum case depth to avoid bending fatigue is less than the optimum case depth to avoid macropitting. Therefore, it is important to measure the root case depth in addition to the flank case depth. Table 4 gives several guidelines for minimum effective case depth to avoid bending fatigue.

Bending fatigue recommendation. Figure 5 shows the authors' recommended minimum effective case depth to avoid bending fatigue. See Annex C for the derivation of Figure 5 and a comparison to ISO 6336-5 (Ref. 6) guideline for optimum case depth to avoid bending fatigue.

***Equation for Figure 5 curve*:**

$$(he_F)_{min} = 0.2016\ (m_n)^{0.7994} \quad (2)$$

Table 3 Gear data used for subcase fatigue and tooth tip thickness calculations

Module	mm	2		10		40	
Center Distance	mm	98		500		2,000	
Reference Pressure Angle	Degrees	20		20		20	
Operating Pressure Angle	Degrees	22.942		22.942		22.942	
Cutter Addendum		1.4×Module		1.4×Module		1.4×Module	
Cutter Tip Radius		0.3×Module		0.3×Module		0.3×Module	
		Pinion	Gear	Pinion	Gear	Pinion	Gear
Number of Teeth		25	73	25	73	25	73
Profile Shift Coefficient		0.516	0.556	0.516	0.556	0.516	0.556
Operating Pitch Diameter	mm	51.02	148.98	255.10	744.90	1,020.4	2,979.5
Tip Diameter	mm	55.91	152.09	279.60	760.40	1,118.4	3,041.6
Tooth Thickness at Tip	mm	1.12	1.46	5.56	7.30	22.29	29.18
AGMA Pitting Geometry Factor		0.127		0.127		0.127	
AGMA Bending Geometry Factor		0.457	0.421	0.440	0.421	0.433	0.421

Table 4 Different guidelines for minimum case depth at root fillet to avoid bending fatigue

Reference No.	Source	Location	Material Grade	Note No.
4	Dudley	Eq. 4.2a	1, 2, 3	1
6	ISO 6336-5	Clause 5.6.2.b	ML, MQ, ME	2
7	AGMA 2101-D04	Table 9	2, 3	3

1. Reference 4 recommends a case depth of 0.16(m_n) at position B on the root fillet (Fig. 1).
2. Reference 6 states: "The optimum effective case depth relating to permissible bending stress for long life at the root fillet on a normal to the 30° $_{tangent}$ after tooth finishing: 0.1–0.2(m_n)."
3. Reference 7 recommends 50% of minimum specified case depth at 1/2 tooth height for grade 2, and 66% for grade 3.

Subsurface-Initiated Bending Fatigue

Classic bending fatigue failures initiate at the surface of the root fillet on the tensile side of the gear tooth. However, when a bending fatigue crack initiates at a location significantly above the root fillet, where the nominal bending stress is much lower than at the root fillet, it is likely that the root cause of failure is a material flaw, such as a nonmetallic inclusion. Hard un-deformable inclusions such as calcium aluminate have a lower thermal expansion coefficient than steel and they develop tensile residual stresses concentrated around each inclusion as a result of hardening heat treatments. The tensile residual stresses from the inclusions and the existing tensile residual stresses below the case/core boundary add to the nominal bending stress from the applied load. Therefore, a nonmetallic inclusion can shift the location of the crack origin from the surface of the root fillet to below the case/core boundary or other areas. Consequently, nonmetallic inclusions are often the root cause of bending fatigue cracks that initiate at a subsurface location below the case/core boundary. Typically, the crack initiates at a nonmetallic inclusion that is located at a depth of approximately 2.5 times the depth of the effective case depth in an area of high tensile residual stress (Fig. 2). The deeper the effective case depth is the further from the surface the potentially damaging tensile residual stress peak. This relationship, along with the fact that applied stresses diminish with distance from the surface, reduces the chances of a fatigue failure initiating near the core/core boundary. Currently, there is no industrial standard for assessing the risk of subsurface-initiated bending fatigue. However, ISO/DTS 6336-4 (Ref. 8) is a draft technical specification that is currently under development to address the failure mode.

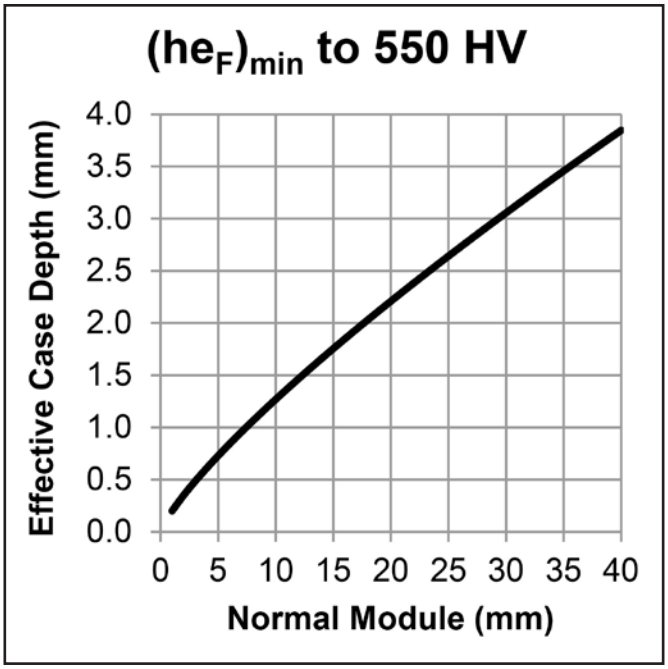

Figure 5 Effective case depth to avoid bending fatigue *$(he_F)min$*.

Case/Core Separation

Figure 6 shows a case/core crack that occurred in a carburized gear tooth below the case/core interface near the tip of the tooth. Case/core separation occurs when compressive residual stresses in the case exceed the tensile strength in the core near the tooth tip due to excessive case depth at the tip. Internal cracks can propagate causing corners, edges, or entire tips of teeth to separate. Cracks can appear immediately after heat treatment, during subsequent handling or storage, or after time in service.

If tensile residual stress is high and ductility is low, brittle fracture can occur and tips of teeth can separate explosively. If conditions are less severe, cracks might arrest before reaching tooth

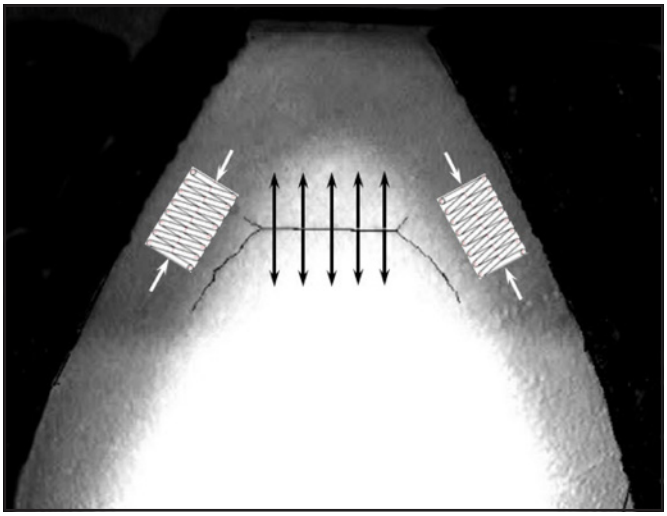

Figure 6 Image of case/core separation crack and arrows showing location of residual compressive and tensile stresses.

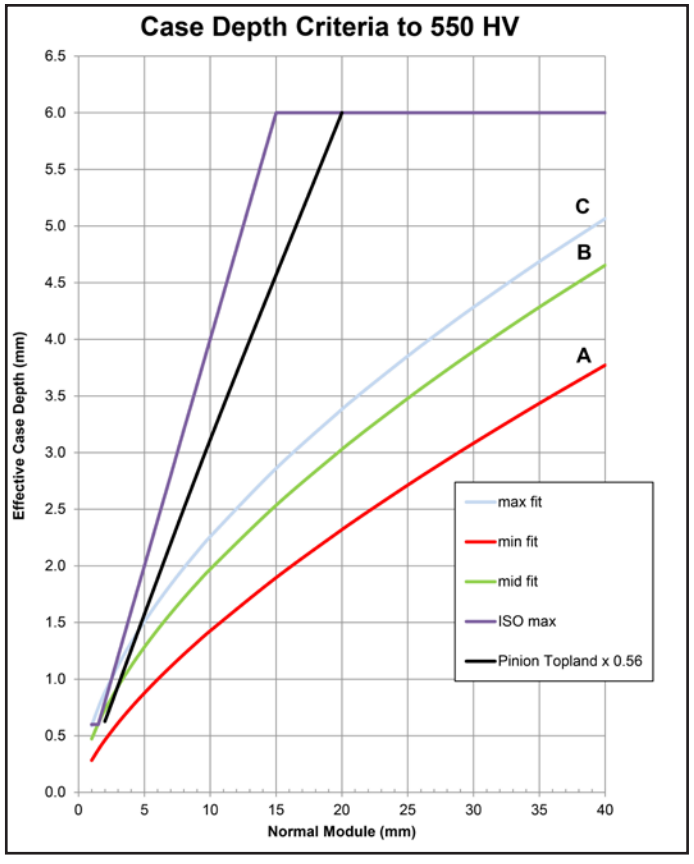

Figure 7 Black line shows maximum effective case depth based on 0.56 times the pinion topland width for the example gear sets.

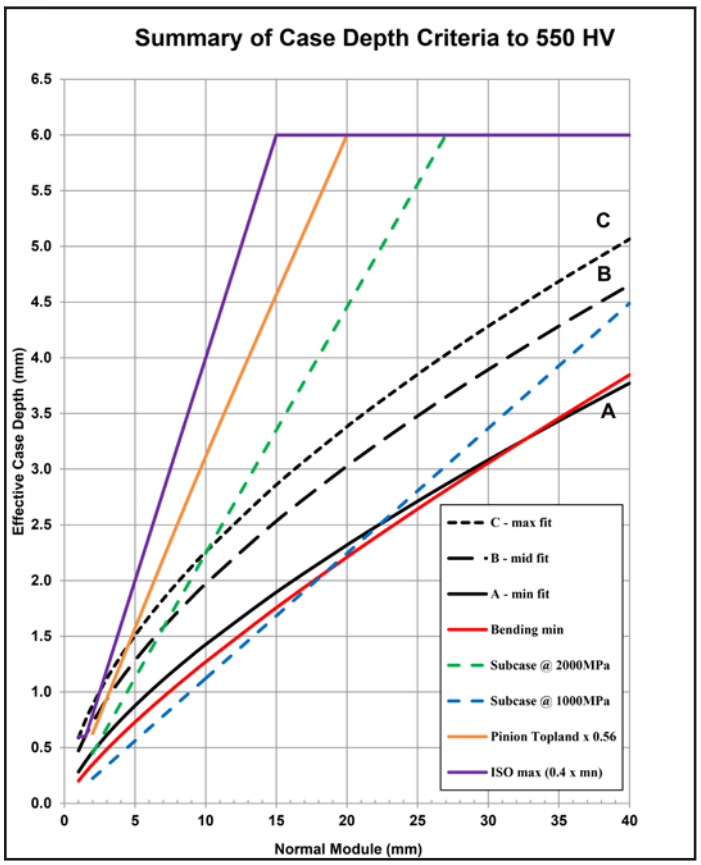

Figure 8 Summary plot showing recommended effective case depth for four different failure modes.

surfaces. Inclusions promote case/core separation — especially when they occur near the case/core interface in areas of tensile residual stress (Fig. 2). Hydrogen can accumulate at inclusions and cause brittle fracture. Stresses in service can cause cracks to grow by fatigue. The risk of case/core separation can be reduced by avoiding narrow toplands or masking toplands with copper plate to restrict carbon penetration during carburizing to prevent overly deep cases.

Case/core separation is a brittle fracture. Therefore, to avoid case/core separation, it is important to ensure the material has high fracture toughness. The best toughness properties are obtained with 3%NiCrMo steels with core hardness in the range of 30–40 HRC. Toughness can be maximized by using vacuum-melted steel and keeping carbon, phosphorus, and sulfur content as low as possible. See AGMA 1010 (Ref. 1) for more information.

Table 5 gives several guidelines for maximum effective case depth to avoid case/core separation. Unfortunately, there are conflicts between ISO 6336 (Ref. 6) and AGMA 2101 (Ref. 7), which both allow $0.4(m_n)$ maximum effective case depth at the tooth flank, whereas Dudley (Ref. 4) and AGMA 911 (Ref. 9) recommend $0.4(m_n)$ maximum effective case depth at the tooth tip.

Table 5 Different guidelines for maximum case depth at tooth tip to avoid case/core separation

Reference No.	Source	Location	Material Grade	Note No.
4	Dudley	Eq. 4.4a	1, 2, 3	1
6	ISO 6336-5	Clause 5.6.2.d	ML, MQ, ME	2
7	AGMA 2101-D04	Eq. 44	2, 3	3
9	AGMA 911-A94	Clause 9.12	1, 2, 3	4

1. Reference 4 recommends a maximum effective case depth of 0.40(m_n) at position C at the tooth tip (Fig. 1).
2. Reference 6 allows a maximum effective case depth of 0.4(m_n) at position A at the mid-height of the tooth or 6 mm maximum.
3. Reference 7 allows a maximum effective case depth of 0.4(m_n) at position A at the mid-height of the tooth or 56% of the normal topland tooth thickness — whichever is less.
4. Reference 9 states: "The case must not be so great as to result in brittle teeth tips and edges, or high residual tensile stresses in the core. Maximum case depth at the tooth tip should be limited to 56% of the tooth topland thickness."

Case/core separation recommendation. The case depth at the tooth tip is critical for the case/core separation failure mode. Therefore, the authors recommend that the maximum effective case depth to 550 HV at the tooth tip (position C in Figure 1) be limited to $(he_T)max = 0.40(m_n)$ or 56% of the topland thickness — whichever is less.

Figure 7 shows a line based on the criteria of 0.56 times the pinion tip thickness. Note that this criterion is now based on a depth to 550 HV whereas the current AGMA 2101 uses the same criteria based on a depth to 50 HRC. Calculations were made for three different gear sets with the geometry summarized in Table 3.

Figure 8 is a summary plot that shows recommended case depths for all four failure modes discussed in this paper.

Conclusions

1. Since the effective case depth can vary depending on where it is measured, the authors recommend it be specified at three different locations (Fig. 1).
2. The optimum case depth at each location depends on the failure mode being considered.
3. The paper compares case depth guidelines from several different sources and presents the author's recommendations for four different failure modes.

Annex A: Equations for Effective Case Depth Nomenclature for Equations:

Root nomenclature:

$(h_{eF})_{min}$ = AGMA root minimum effective case depth to 50 HRC after finishing based on bending fatigue.

$(h_{eF})_{min}$ = Dudley root minimum effective case depth to 50 HRC after finishing based on bending fatigue.

$(h_{eF})_{min}$ = MAAG root minimum effective case depth to 550 HV after finishing based on bending fatigue.

$(h_{eF})_{opt}$ = ISO root optimum effective case depth to 550 HV after finishing based on bending fatigue.

Flank nomenclature:

$(h_{eH})_{max}$ = MAAG flank maximum (commercial tolerance) effective case depth to 550 HV after finishing based on macropitting.

$(h_{eH})_{mid}$= MAAG flank maximum (precision tolerance) effective case depth to 550 HV after finishing based on macropitting.

$(h_{eH})_{min}$ = AGMA flank minimum effective case depth to 50 HRC after finishing based on macropitting (normal and heavy case depths).

$(h_{eH})_{min}$ = MAAG flank minimum effective case depth to 550 HV after finishing based on macropitting.

$(h_{eH})_{opt}$ = ISO flank optimum effective case depth to 550 HV after finishing based on macropitting.

$(h_{eS})_{min}$ = AGMA flank minimum effective case depth to 50 HRC after finishing based on subcase fatigue.

$(h_{eS})_{min}$ = ISO flank minimum effective case depth to 550 HV after finishing based on subcase fatigue.

Tip nomenclature:

$(h_{eT})_{max}$ = AGMA tip maximum effective case depth to 50 HRC after finishing based on case/core separation.

$(h_{eT})_{max}$ = Dudley tip maximum effective case depth to 50 HRC after finishing based on case/core separation.

Equations for Flank Case Depth

AGMA 2101 (Ref. 7) Figure 13 (flank 50 HRC):

Normal case depth

$(he_H)_{min} = 3.046349\,(25.4/m_n)^{-0.86105} = 0.1880\,(m_n)^{0.8611}$

Heavy case depth

AGMA 2101 (Ref. 7) Based on Subcase Fatigue Eq (43) where U_H = 44,000 MPa:

$(he_S)_{min} = [\sigma_H d_{w1} sin(\alpha_{wt})/U_H cos(\beta_b)]C_G$

ISO 6336-5 (Ref. 6) Figure 17 Optimum Case Depth (flank 550 HV):

$(he_H)_{opt} = CHD_{H,opt} = 0.15\,(m_n)$ for module range $2 \le m_n \le 10$

$(he_H)_{opt} = CHD_{H,opt} = 0.083(m_n) + 0.67$ for module range $10 < m_n \le 40$

ISO 6336-5 (Ref. 6) Based on Subcase Fatigue Clause (5.6.2.c) where U_H=66,000 MPa for Quality Grades MQ/ME and U_H=44,000 MPa for Quality Grade ML (flank 550 HV):

$(he_S)_{min} = [\sigma_H d_{w1} sin(\alpha_{wt})/U_H cos(\beta_b)]C_G$

MAAG (Ref. 5) Empirical Formula Clause (6.422) (flank 550 HV):

$(he_H)_{min} = (m_n/2 + 1.1)^{½} - 1$

Equations of Curves Fitted to MAAG (Ref. 5) Figure 6.12 (see Annex B) (flank 550 HV):

$(he_H)_{min} = 0.2835(m_n)^{0.7016}$ (minimum to avoid macropitting)

$(he_H)_{mid} = 0.4730(m_n)^{0.6198}$ (maximum precision tolerance)

$(he_H)_{max} = 0.5899(m_n)^{0.5829}$ (maximum commercial tolerance)

Equations for Root Case Depth

AGMA 2101 (Ref. 7) Table 9 (root 50 HRC):

$(he_F)_{min} = 0.50\,(he_H)_{min}$ for grade 2

$(he_F)_{min} = 0.66\,(he_H)_{min}$ for grade 3

ISO 6336-5 (Ref. 6) Optimum Case Depth Clause (5.6.2.b) (root 550 HV):

$(he_F)_{opt} = CHD_{F,opt} = 0.10\,(m_n)$ *to* $0.20\,(m_n)$

Dudley (Ref. 4) Optimum Case Depth Eq. (4.2.a) (root 50 HRC):

$(he_F)_{min} = 0.16\,(m_n)$

MAAG Minimum Case Depth to Avoid Bending Fatigue (see Annex C) (root 550 HV):

$(he_F)_{min} = 0.2016\,(m_n)^{0.7994}$

Equations for Tip Case Depth

Dudley (Ref. 4) Maximum Case Depth Eq. (4.4.a) (tip 50 HRC):

$(he_T)_{max} = 0.4\,(m_n)$

ISO 6336-5 (Ref. 6) Maximum Case Depth Clause (5.6.2.d) (flank 550 HV):

$(he_T)_{max} = CHD_{max} = 0.4\,(m_n)\,(\le 6\,mm)$

AGMA 2101 (Ref. 7) Maximum Case Depth Eq. (44) (flank 50 HRC):

$(he_T)_{max}$ = the lesser of $0.4\,(m_n)$ *or* $0.56\,(t_{no})$

Annex B: Derivation of Figure 3

MAAG Guidelines. Figure B-1 shows the original MAAG [5] Figure 6.12.

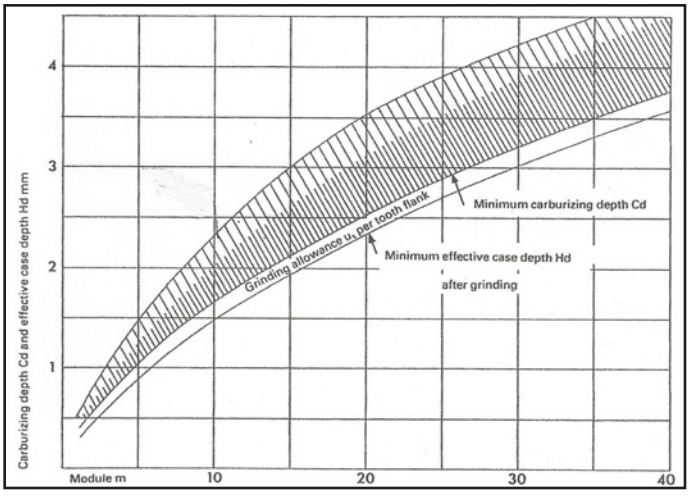

Figure B-1 MAAG Figure 6.12.

Method Used to Derive Figure 3. The following text and Figure B-2 explain the methodology used to derive Figure 3 of this report.

- The lower green line in Figure B-2 conforms to the MAAG (Ref. 5) equation: $(he_H)_{min} = (m_n/2 + 1.1)^{½} - 1$
- The lower red line is an *Excel* power curve fit of the MAAG equation, redefined here as MAAG_min_fit.
- The upper green line and the middle blue line were obtained from the upper and middle curves in MAAG (Ref. 5) Figure 6.12. Values were manually read from Figure 6.12 since no equations were given for these two lines.
- The upper red line and the middle black line are *Excel* power curve fits of the upper green line and middle blue line respectively.
- The lower blue line represents the difference between the upper and lower green lines. Note that the lower blue line does not steadily increase with increasing module. This inspired the *Excel* power curve fits to smooth the final upper and lower red

lines.
- The purple line represents the difference between the upper and lower red lines. Note that the purple line steadily increases with increasing module.

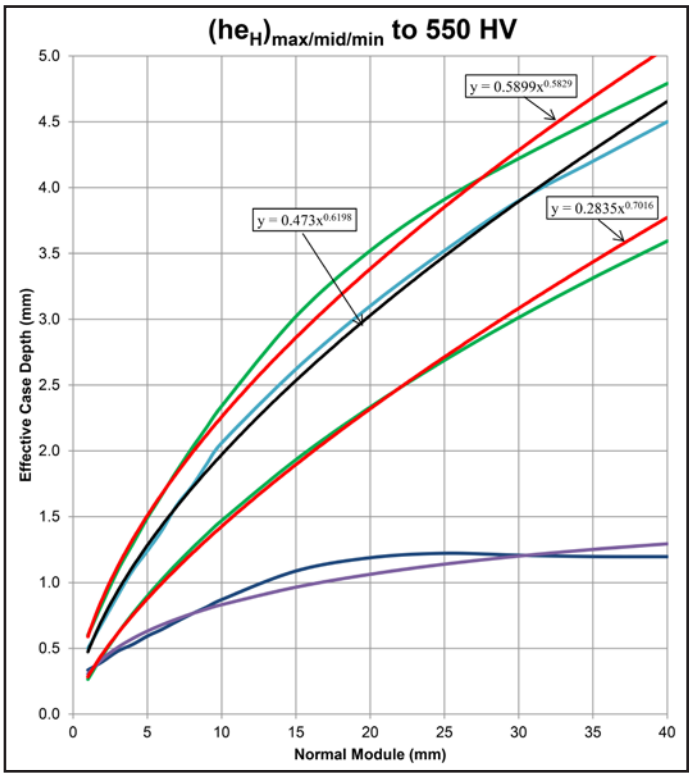

Figure B-2 Derivation of Figure 3.

Comparison of MAAG, ISO 6336-5, and AGMA Guidelines. Figure B-3 compares the $MAAG_{min\_fit}$ (Ref. 5) (black line) and ISO 6336-5 (Ref. 6) optimum (red line) guidelines for minimum effective case depth to 550 HV to avoid macropitting. The MAAG guideline has a long history of successful application. Figure B-3 shows that the $MAAG_{min\_fit}$ and ISO guidelines are very similar over the range of 8–25 normal modules. For modules less than 8, the $MAAG_{min\_fit}$ guideline recommends deeper case depths, and for modules greater than 25 the ISO guideline recommends deeper case depths. Also included are the AGMA normal case depth (blue lines), heavy case depth (green lines), and ISO maximum lines (purple lines). The solid blue and green lines were obtained by multiplying the dashed blue and green lines by 0.9 to adjust the AGMA guidelines from the 50 HRC definition to the 550 HV definition of case depth. It is obvious that the AGMA 2101 Heavy guideline is significantly deeper than $MAAG_{max\_fit}$ tolerance range for modules greater than 10, whereas the AGMA 2101 Normal guideline is similar to the $MAAG_{min\_fit}$ guideline for maximum macropitting resistance, considering that the 50 HRC case depth is deeper than the 550 HV case depth. Note that without data on actual hardness gradients it is not possible to accurately compare case depths based on the 50 HRC definition with the 550 HV definition. Therefore, the comparisons shown in Figure B-3 are only qualitative.

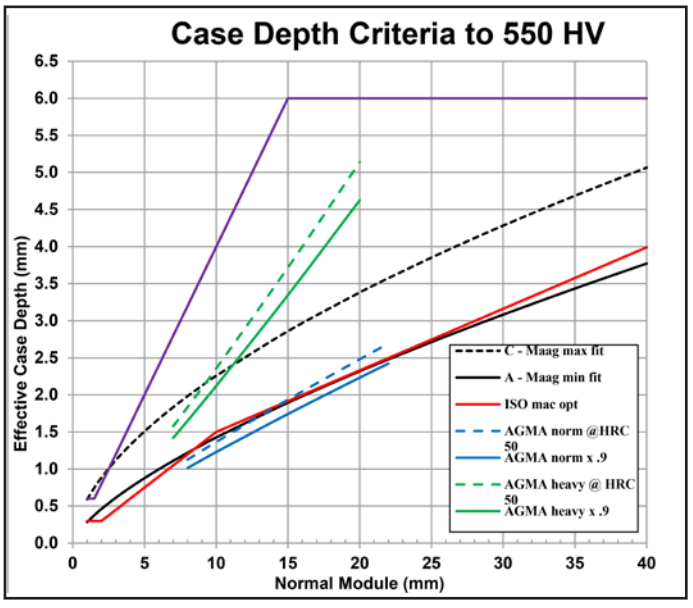

Figure B-3 Comparison of MAAG, ISO, and AGMA flank case depths

Annex C: Derivation of Figure 5

Method used to derive Figure 5 for maximum bending fatigue resistance. The following text and Figures C-1 and C-2 explain the methodology used to derive Figure 5. The lines shown in Figure C-1 are as follows:
- The upper line conforms to the ISO equation $(he_F)_{opt} = 0.2\,(m_n)$ for maximum case depth for bending fatigue resistance.
- The next line down conforms to the MAAG min case depth for maximum macropitting resistance $(he_F)_{min} = 0.2835\,(m_n)^{0.7016}$.
- The red line is the case depth for maximum bending fatigue resistance defined by the equation $(he_H)_{min} = 0.2016\,(m_n)^{0.7994}$. This line was chosen to be slightly lower than the MAAG min case\depth for maximum macropitting resistance and within the ISO limits of $0.1\,(m_n) \le (he_F)_{opt} \le 0.2\,(m_n)$ for maximum bending fatigue resistance.
- The line below the red line conforms to the ISO equation $(he_F)_{opt} = 0.1\,(m_n)$ for minimum case depth for bending fatigue resistance.
- The two lower lines conform to the AGMA 2101 equations for minimum case depth for bending fatigue resistance:
  - $(he_F)_{min} = 0.50\,(he_H)_{min}$ (50% of MAAG min fit) for grade 2
  - $(he_F)_{min} = 0.66\,(he_H)_{min}$ (66% of MAAG min fit) for grade 3

Figure C-2 is an enlarged view of Figure C-1 for $m_n \le 10$. It shows that the equation $(he_F)_{min} = 0.2016\,(m_n)^{0.7994}$ for maximum bending fatigue resistance gives a case depth that is about midway between the ISO limits of $0.1\,(m_n) \le (he_F)_{opt} \le 0.2\,(m_n)$.

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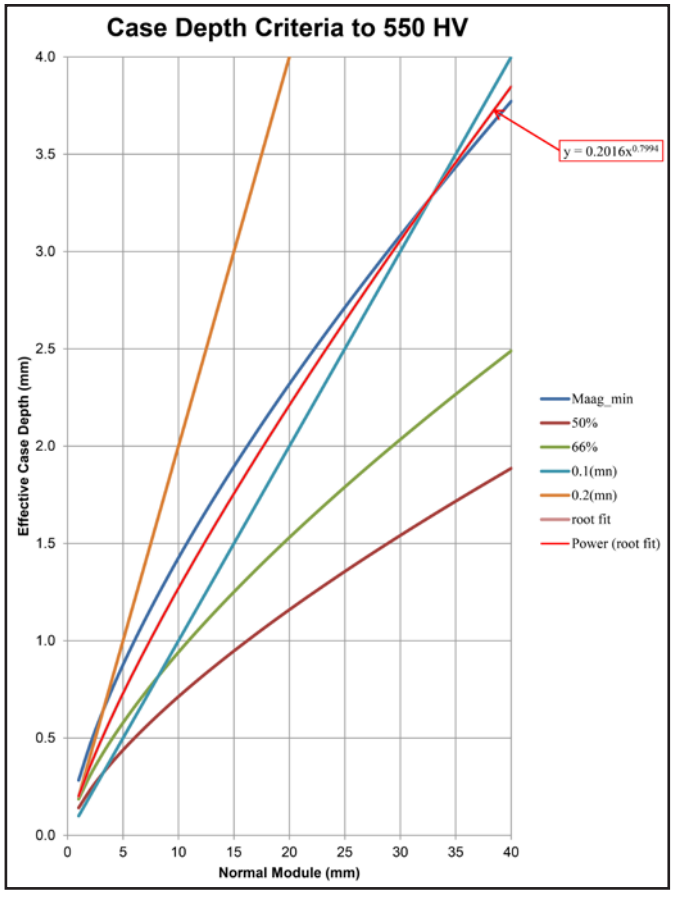

Figure C-1 Derivation of Figure 5.

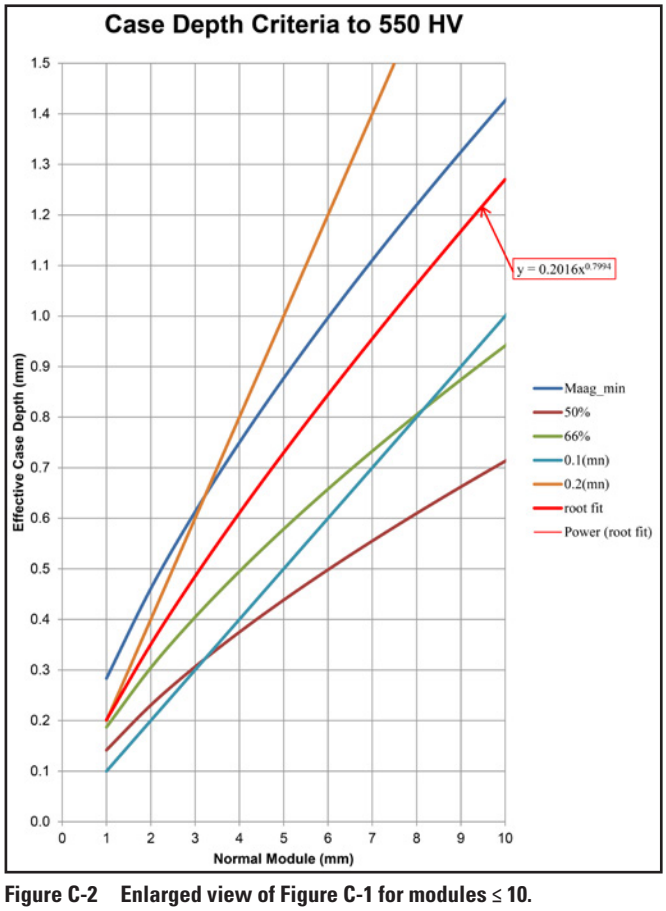

Figure C-2 Enlarged view of Figure C-1 for modules ≤ 10.

Robert Errichello, PE, heads his own gear consulting firm — GEARTECH — and is a founder of GEARTECH Software, Inc. A graduate of the University of California at Berkeley, he holds B.S. and M.S. degrees in mechanical engineering and a master of engineering degree in structural dynamics. In his more than 50 years of industrial experience, Errichello worked for several gear companies; he has also been a consultant to the gear industry for more than 40 years and has taught courses in material science, fracture mechanics, vibration and machine design at San Francisco State University and the University of California at Berkeley. He is also a member of ASM International, STLE, ASME Power Transmission and Gearing Committee, AGMA Gear Rating Committee and the AGMA/AWEA Wind Turbine Committee. Errichello has published over 100 articles on design, analysis and the application of gears, and is the author of three widely used computer programs for the design and analysis of gears. He is also a longtime technical editor for Gear Technology magazine and STLE Tribology Transactions, and has presented numerous seminars on design, analysis, lubrication and failure analysis of gears. Errichello is a past recipient of the AGMA TDEC award, the STLE Wilbur Deutch Memorial award, the AGMA Lifetime Achievement Award, the E.P. Connell Award and the STLE Bisson Award.

Andy Milburn is currently president of Milburn Engineering, Inc., a consulting firm located near Tacoma, Washington and has 45 years experience in the design and analysis of gears and gearboxes. Prior to starting his own consulting firm in 1989 he worked at The Gear Works in Seattle, WA for 15 years and was involved in all aspects of gear manufacturing, gear failure analysis and designed many custom industrial gearboxes. As a consultant he has investigated numerous gear and bearing failures, and helped clients improve their gear products. During the past 18 years he has been very active in the wind industry investigating gearbox failures, developing gearbox modifications and participating in due diligence design reviews. He was a U.S. delegate to ISO TC66, working on the new international gearbox standard, IEC 81400-4. He is a registered Professional Engineer in the state of Washington, a member of AGMA, ASME, ASM and STLE and a member of the AGMA Helical Gear Rating Committee. Milburn is currently one of the moderators of the AGMA Gear Failure Analysis course.

Grinding Wheel Wear, Dressing, Tip Advance and Work Phase Angle Adjustment after Corrections: Are there Rules to Aid in Grinding Process Optimization?

Dr. Hermann J. Stadtfeld

The following is another chapter from Dr. Hermann J. Stadtfeld's new book, *Practical Gear Technology,* part of an ongoing series of installments excerpted from the book. Designed for easy understanding and supported with helpful illustrations and graphic material, the e-book can be accessed for free *at Gleason.com*.

The question about rules for bevel gear grinding was asked many times, and also the question if a help tab could be developed which aids to solve the problems on a grinding machine For example, a setup person or manufacturing engineer experiences a problem like losing size after grinding only a few slots, without that the spacing and size compensation could help. There are rules and hints to improve bevel gear grinding results. This chapter is a compilation of practical grinding experiences which will be the basis of help tabs which are being developed for Gleason machines.

Adjustment and Optimization of the Dresser Speed Ratio.

The dresser speed ratio is calculated by dividing the dress roller surface speed by the grinding wheel surface speed. The diagrams of dresser speed ratio versus surface roughness (Fig. 1, top) and dresser speed ratio versus the force between the grinding wheel and the ground flank surfaces (Fig. 1, bottom) show two interesting graphs which are non-linear and not intuitive. Preferred areas in the two diagrams are between –0.65 and –0.85 for highest surface finish and between +0.65 and +0.85 for highest productivity.

There is no optimal compromise between the two areas to the contrary, in the center of the diagrams is a large area; where dressing is not possible. The first extreme point in Figure 1 is at dresser speed ratio of 0.0, where the dress roller is not rotating and will be destroyed if dressing at this setting is conducted. The second extreme point is at a dresser speed ratio of 1.0, where a pure crushing of the grinding grit out of the ceramic wheel bond occurs. It has to be noted at this point, that the kind and composition of the grinding wheel will influence the optimal dresser speed ratio. Some highly optimized grinding wheel types like for example Cubitron II might require to reverse the sign of the dresser speed

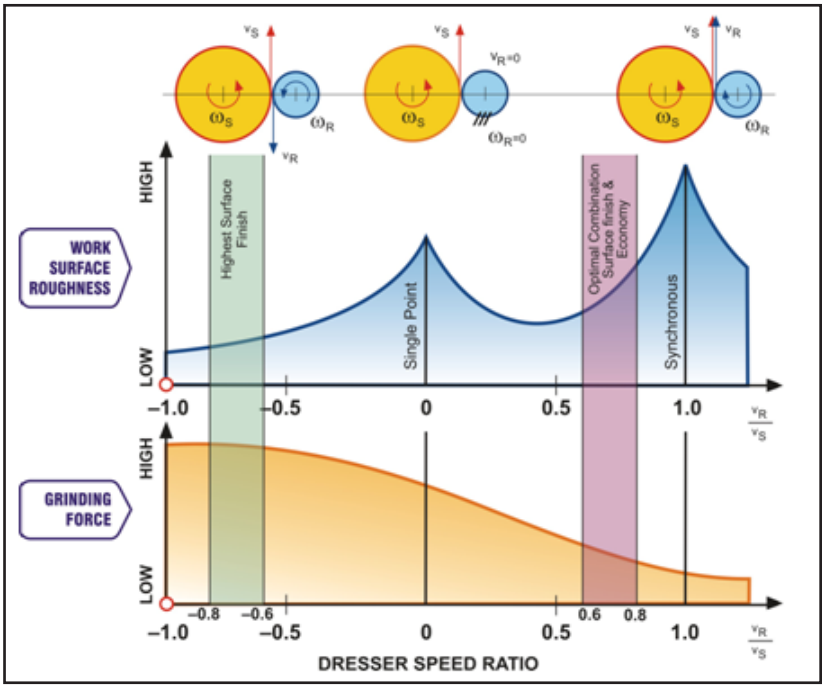

Figure 1 Dresser speed ratio versus surface roughness and grinding force.

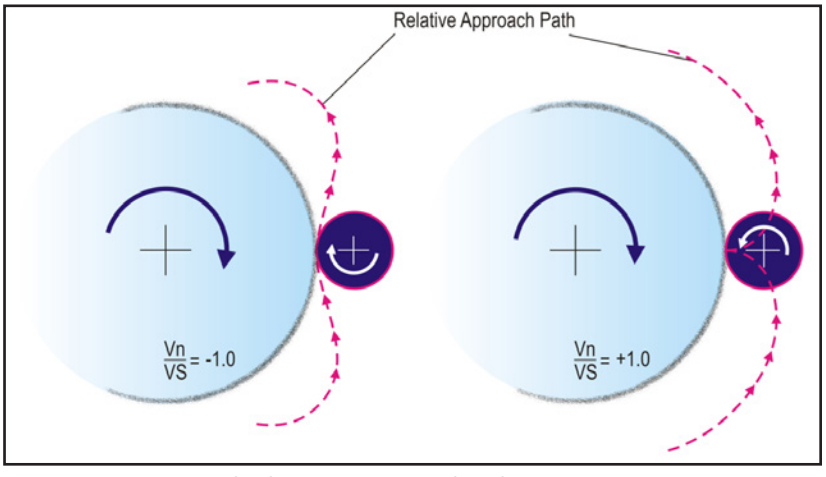

Figure 2 Pure shearing (left) and pure crushing (right).

ratio although the original setting worked well for a traditional style grinding wheel.

A comparison of the approach paths in case of a dresser speed ratio of –1.0 and +1.0 is shown (Fig. 2). The left side graphic in Figure 2 demonstrates a pure shearing of the abrasive grit particles with a trochoidal shaped relative approach path between dresser particle and wheel grit particles. This results in a dull, but stable wheel surface. (See the shearing fracture in Fig. 3). Such a wheel surface can be advantageous in the last cycle "stations" of an aircraft grinding cycle. It will achieve an excellent surface finish and a precise flank surface as long as material removal amount per time unit is very low. The right side graphic in Figure 2 demonstrates a relative approach path with the shape of an epicycloid. The result is a splitting of the abrasive grains or a levering effect which will remove entire grain particles out of the ceramic bond. Levering or crushing will not only consume the grinding wheel fast; it will also result in a not very stable bond of the grit on the wheel surface, leading to flank form inaccuracies (Ref. 1).

The following rules are based on the physical effects explained above and will help to find a better suitable dresser speed ratio in connection with other important grinding parameters:

Grinding of non-generated gears using Waguri ►	• Start with negative dresser speed ratio depending on wheel type positive dresser speed ratio may be optimal
Grinding of generated gears without Waguri ►	• Positive dresser speed ratio
Pinion grinding without Waguri ►	• Positive dresser speed ratio
If the surface finish is too rough ►	• Reduce the dress roller traversing feed rate • Move to the left side of the dress roller speed ratio band • Change to negative dress roller speed ratio, but now go first to the right side of the dress roller speed ratio band and use high dress roller traversing feed rate to preserve some open poor surface structure • Apply a dual rotation cycle without redressing
If spacing of first to last tooth is bad ►	• Increase dress roller traversing feed rate • Move to the right side of the dress roller speed ratio band • Change to positive dress roller speed ratio,but now go first to the left side of the dress roller speed ratio band and use a low dress roller traversing feed rate to preserve a high surface finish
Burn marks on pinion surface or root ►	• Increase dress roller traversing feed rate • Move to the right side of the dress roller speed ratio band • Change to positive dress roller speed ratio, but now go first to the left side of the dress roller speed ratio band and use a low dress roller traversing feed rate to preserve a high surface finish
Burn marks on Formate gear surface or root ►	• Increase dress roller traversing feed rate • Move to the right side of the dress roller speed ratio band • Reduce grinding plunge feed rates
Grinding from solid ►	• Requires a sharp wheel surface with open pores – dresser speed ratio between +0.8 and +0.9 • Wheel wear will be high in order to achieve sufficient material removal • Dressing after 3 to 6 slots required • Rough grinding to full depth in one rotation with higher dress frequency is most efficient

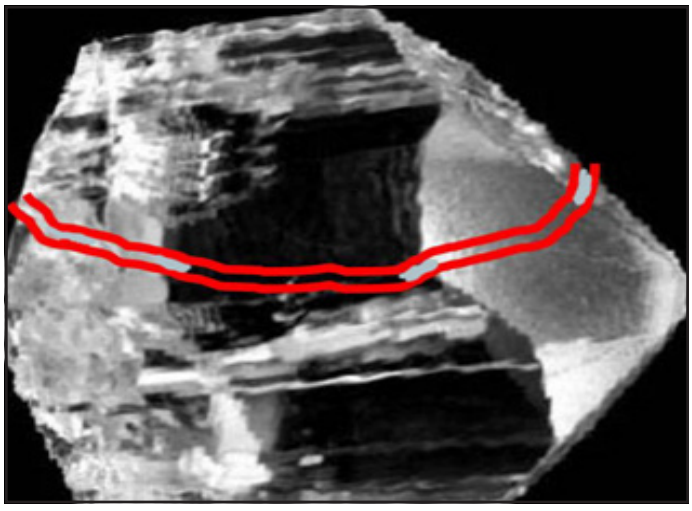

Figure 3 Principal appearance of a grain shear fracture.

The Grinding Wheel Tries to Tell You Something!

Keys to efficient grinding are the abrasive material and the abrasive bond. Recommended for bevel gear grinding are grinding wheels with an 80 grit sintered aluminum oxide abrasive with an open pore, soft ceramic bond. Results of extensive process development have shown that non-uniform particle size, e.g., 80 grit wheel specification which contains particles between 80 and 240 size, increase the grinding wheel wear and the need for redressing. Uniform particle size e.g. between 80 and 120 grit (for an 80 grit wheel specification) require fewer re-dressings because the grinding wheel keeps its shape and dimension longer (Ref. 2).

The automatic re-sharpening effect of a wheel is based on the radial and tangential cutting forces onto the abrasive grinding grain. The causes of wheel wear are:

Case 1	►	Grain breaks out of ceramic bond, e.g. — (bulk wear) (wheel stays sharp but loses size)
Case 2	►	Grain dulls (attritions wear) (wheel keeps dimension, surface finish improves, grinding force is high, risk of burning)
Case 3	►	Grain fracture of mono crystal (fracture wear) (wheel dulls somewhat and loses dimension somewhat)
Case 4	►	Grain fracture along particle boundaries of sintered grain (dimension is stable, wheel is always very sharp)

Case 1	If the dresser speed ratio has already been optimized, then a wheel which is sintered with higher temperatures or higher force with a harder ceramic specification will solve the encountered problem.
Case 2	Grain hardness might be too high in combination with too high bonding forces. If increasing a positive dresser speed ratio shows no improvement, then grinding wheel with different specification (softer bond).
Case 3	Wear like in Figure 3. Change to sintered aluminum oxide instead of mono crystal is recommended.
Case 4	Is the desirable case which can be achieved in most cases with sintered aluminum oxide grains in connection with an optimized dresser speed ratio.

Dressing of Profiles with Blended Toprem.

Blended Toprem with small Toprem radii and large Toprem depth creates a profile clean-up problem, especially when the profile pressure angles are low (below 15°). Figure 4 shows that only a significant increase of the dressing amount can help to solve this problem.

The proof that the grinding wheel profile cleaned up during the dressing cycle can be obtained by using fast-drying blue shop spray paint which is applied to a section of the wheel at the inside and outside profile before re-dressing. In case of insufficient clean-up, witness marks of the paint will be visible in the area marked "Undercut of Intermediate Dressing Profile" (Fig. 4). The required axial dress amount can be a multiple of the dressing amount required to re-sharpen and re-shape the wheel in case of a lack of blended Toprem.

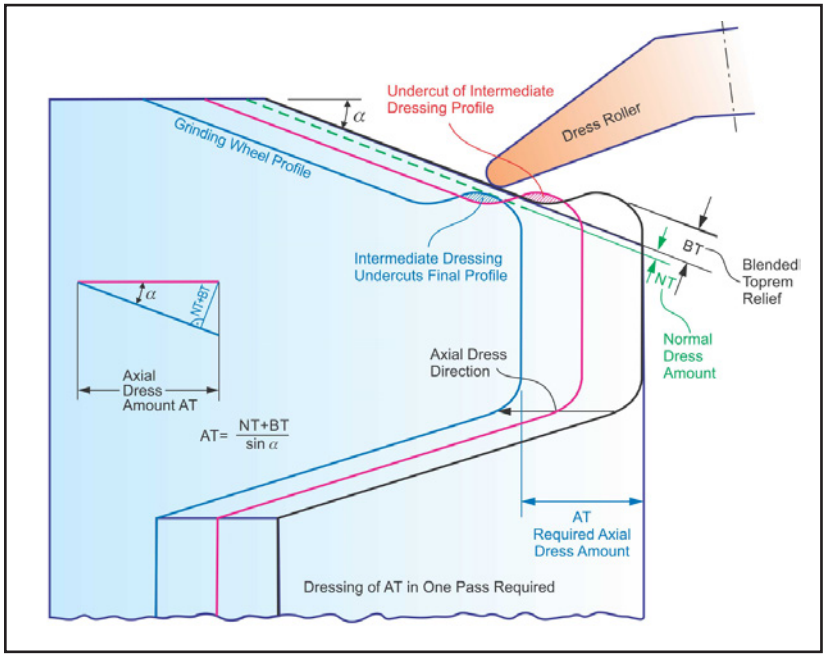

Figure 4 Undercut on grinding wheel profile due to blended toprem.

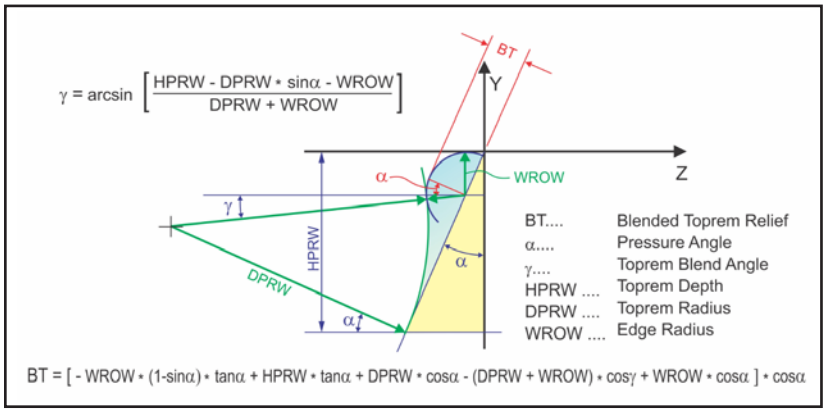

Figure 5 Calculation of minimal dressing amount to avoid undercut.

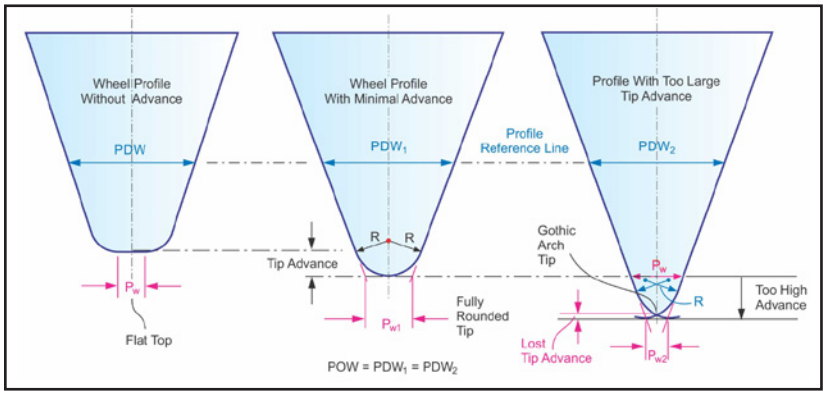

Figure 6 Wheel tip truncation due to tip advance.

Blended Toprem with small Toprem radii and large Toprem depth creates a profile clean-up problem, especially when the profile pressure angles are low (below 15°). Figure 4 shows that only a significant increase of the dressing amount can help to solve this problem.

The blended Toprem relief BT has to be added to the minimal required dressing amount NT. The result is divided by the sin of the wheel pressure angle, resulting in the axial dressing amount AT (see formula in Fig. 4). If this amount appears too large for an optimal wheel dressing, then it is not possible to dress the wheel in two or more passes. The purple profile (Fig. 4) shows how an intermediate dressing step would not clean up the profile and will in addition cause that the final profile (blue in Fig. 4) will not clean up.

The only possibility to reduce the normal or axial dressing amount is to reduce the blended Toprem radius or the blended Toprem depth or both. It is advisable in cases where a change of more than 10% Toprem radius or Toprem depth is required to redevelop the blended Toprem parameters in the design program in order to avoid an undesirable change in the gear set performance.

In order to calculate the axial dressing amount AT, the precise value of the blended Toprem relief is required in addition to the normal dressing amount. The mathematical relationship between Toprem relief BT and the Toprem parameters depth and radius has been derived in Figure 5. The formula appears complicated and long for a rather simple appearing task. However, the geometrical relationship of a blended Toprem circle blending with the tip edge radius on the one side and the main cutting edge on the other side is complicated. Simplified, approximate calculations have been tried out but showed not to be reliable.

Dressing of a Tip Advance.

The Gleason design and summary calculation programs determine the largest edge radius which fits the tip of a cutting blade or grinding wheel (Dimension Sheet). If this "Max. Radius - Cutter Blades" is applied to the grinding wheel, then the wheel tip will show a fully rounded tip (Fig. 6, center). Only in the case of smaller tip radii than the maximal limit of the Dimension sheet (tip with flat top, Fig. 5, left), a tip advance is possible, to the point, where the flat top has disappeared and the wheel tip is fully rounded (transition from left to center in Fig. 6).

Wheel tip advances beyond this point will cause a truncated wheel tip, which not only deliver an unsatisfactory root appearance, but also cause fast tip break down, reduced tooth depth and possible burning in the root during the grinding process.

Work Phase Angle Adjustment after G-AGE Correction.

Formate ring gears require after each flank form correction for example with *G-AGE* an adjustment of the work phase angle in order to re-establish the correct stock division. Of course this applies only to grinding, but it is time- consuming and disturbs the grinding production. A correction of the work axis phase angle *A* is used to re-establish a correct stock division position.

It is difficult to analyze from the *G-AGE* corrections, which different elements of corrective settings have been superimposed in order to eliminate flank form deviations. In a first step the phase angle influence of the two most common corrections, spiral angle and pressure angle changes is captured (Fig. 7) and a correction value ΔA is calculated.

In a second step, root angle changes in connection with a machine center to crossing point change and the changes from Figure 7 have been analyzed with the graphic in Figure 8. From the V-H setting changes in Figure 8 a formula which is valid for all cases was developed. The A-axis angular position is corrected after each *G-AGE* correction by adding the value ΔA. The work axis correction is calculated in the machine control and applied automatically.

Summary

This chapter was written to answer the frequently asked questions about the influence of the grinding wheel dressing parameters to the grinding process performance and features like surface finish, root blends and surfaces without thermal damages. Of course, the characteristics of wheel breakdown are also vital to the produced part quality. The wheel wear compensation will eliminate the spacing and tooth thickness variation, but only if a "healthy" fast wear and total wear are exhibited.

Spacing errors and tooth depth errors are not the only result of a not well compensated wheel breakdown. A tip breakdown which is common in cases of small wheel point width and wrong dressing parameters in combination with none optimal grinding wheel specifications cannot be compensated during the grinding of the slots of a single part. Even after one part is finished, the restoration of the wheel tip might require 2 or three dressing cycles in order to re-establish the correct tip specifications.

Wheel specification and wheel dressing are the key factors for a robust grinding process. The machine summary is created in the grinding summary program and delivers more than a good

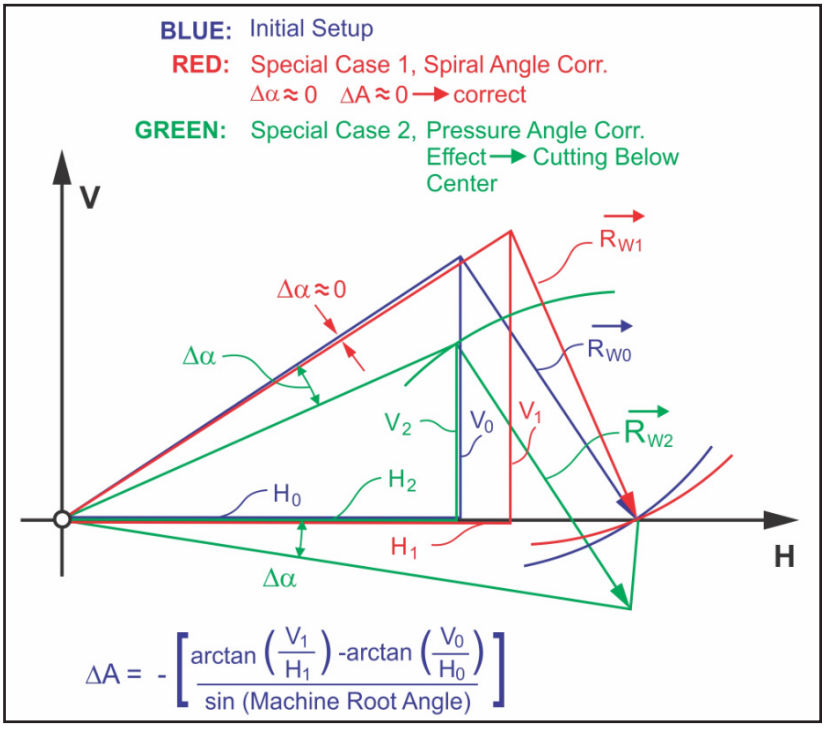

Figure 7 Only V-H corrections.

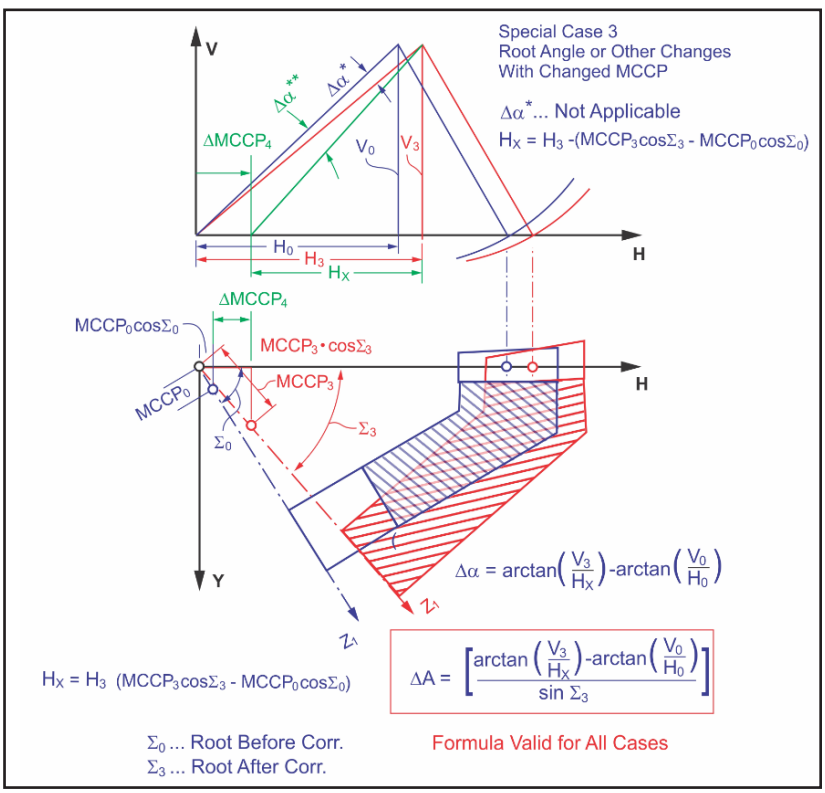

Figure 8 Universal phase angle adjustment.

starting point. The technological data input in the summary program should reflect an experienced based control of the parameters like surface speed, roll rates and plunge feed rates. It is recommended to use the process data from developed processes, which worked efficient and delivered stable part quality. If such technological data are applied in the grinding technology data input of similar gearset designs, then a successful grinding of a brand new design will be the result, provided that the coolant application and the grinding wheel specification also reflects the best practices from other successfully ground jobs.

However, many factors concerning the grinding wheel condition are not captured in the grinding summary. The different sections in this chapter try to give hints and provide rules for the grinding wheel observation and help to find conclusions for the optimization of the wheel dressing and the grinding conditions. Many of those rules and conclusion are "soft facts" and are therefore not always obvious and straight forward.

In order to sustain the effort of giving the manufacturing engineers and the machine setup specialists useful hints for the improvement of the bevel gear grinding process, a help function on Gleason grinding machines is being developed, containing the information and illustrations in this chapter, and making them easily accessible during a process optimization.

For more information. Questions or comments regarding this paper? Contact Hermann Stadtfeld at *hstadtfeld@gleason.com.*

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Dr. Hermann J. Stadtfeld is the Vice President of Bevel Gear Technology and R&D at the Gleason Corporation and Professor of the Technical University of Ilmenau, Germany. As one of the world's most respected experts in Bevel Gear Technology, he has published more than 300 technical papers and 10 books in this field. Likewise, he has filed international patent applications for more than 60 inventions based upon new gearing systems, gear manufacturing methods as well as cutting tools and gear manufacturing machines. Under his leadership and guidance, the world of bevel gear cutting has converted to, environmentally friendly, dry machining of gears with significantly increased power density due to non-linear machine motions and new processes. Those developments also lower the noise emission level and reduce the degree of energy consumption. Over a span of over 35 years, Dr. Stadtfeld has had a remarkable career within the field of Bevel Gear Technology. Having received his Ph.D. with summa cum laude in 1987 at the Technical University in Aachen, Germany, he became the Head of Development & Engineering at Oerlikon-Bührle in Switzerland. Dr. Stadtfeld held a Professor position at the Rochester Institute of Technology in Rochester, New York From 1992 to 1994. In 2000 as Vice President R&D he received in the name of The Gleason Works two Automotive Pace Awards, one for his high speed dry cutting development and one for the successful development and implementation of the Universal Motion Concept (UMC). The UMC brought the conventional bevel gear geometry and its physical properties to a new level. In 2015, the Rochester Intellectual property Law Association elected Dr. Stadtfeld the "Distinguished Inventor of the Year" by. Between 2015 and 2016 CNN-Networks featured him as "Tech Hero" in a Website dedicated to technical innovators for his accomplishments regarding environmentally friendly gear manufacturing and technical advancements in gear efficiency. Currently, he continues next to his Senior Management position at Gleason Corporation to mentor and advice graduate level Gleason employees, and he supervises Gleason sponsored Master Thesis programs as Professor of the Technical University of Ilmenau, helping to shape the future of Gear Technology.

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Kapp Niles

CELEBRATES 18 YOUNG INVENTORS

In the middle of the "Theme Week of Education," 18 students from Coburg and Neustadt received the Dr.-Ing. E. h. Bernhard Kapp Prize, endowed with 6,900 €.

On his 80th birthday in 2001, Dr. Bernhard Kapp, founder of today's Kapp Niles group and founder of the prize, sent a clear signal to strengthen engineering by launching this competition with a generous donation. A total of 200,000 € was paid into the foundation, so that we can look forward to many more inventions from the students.

After a brief introduction to the Kapp Niles Group by managing partner Martin Kapp, Thomas Engel from Rotary Gemeindedienst e.V. described the importance Dr. Bernhard Kapp attached to engineering. "In order to strengthen the valuable reputation of the globally recognized seal of quality 'Made in Germany,' our country must be at the forefront in the race for the 'best minds.' For this reason, it is important to promote young people's interest in the engineering professions during their school years. A holistic approach should be pursued, because nothing is worse than to construct something that the world does not need," says Thomas Engel.

Following this approach, the pupils have dealt with the following points within the framework of an independent project: Problem recognition — idea — solution — sensible application — marketing.

Dr. Jan Ungelenk was already awarded the Dr.-Ing. E. h. Bernhard Kapp Prize in 2002 and described his life in an exciting and entertaining presentation.

Climate change and the associated problems of energy supply were already an important topic 17 years ago. In order to find an answer to this social question, Dr. Ungelenk looked for a replacement for conventional energy storage in his work. His idea was to use the fuel cell as an accumulator replacement for "portable small devices," today better known as "smartphones." After graduating from high school, Dr. Ungelenk studied nanostructural sciences in Kassel, did his doctorate at the Karlsruhe Institute of Technology and is currently working for BASF. His wife, with whom he has two children, was also awarded the Dr.-Ing. E. h. Bernhard Kapp Prize in 2002, which gave the couple additional importance to the effectiveness of promoting young talent.

The second highlight of the event was the students' presentations, in which they presented the essential aspects of their work.

The first prize was awarded twice this year. Florian Zosig from the Regiomontanus School received one of them for the development and production of a Bluetooth hands-free kit for a motorcycle helmet. In his presentation, he demonstrated numerous advantages of his system compared to existing solutions. On the one hand his development is completely integrated into the motorcycle helmet, whereby no disturbing wind noises occur during the telephone call. On the other hand, it offers a price advantage of 497 € compared to a commercially available branded device.

Another first prize went to Viktor Neumaier, Fabian Beck and Leopold Franz from the Ernestinum Gymnasium for examining 3D-printed objects for their suitability for high-vacuum applications. The vacuum chamber produced by additive manufacturing was tested for vacuum suitability using various methods. The object showed properties similar to those of conventional models made of steel or aluminum. Such vacuum chambers must be able to withstand extreme temperature differences and are used, among other things, in space research to simulate the real conditions of space.

The second prize was awarded six times. Jonas Göbel, Erik Harmgarth and Jonathan Romankiewicz from Ernestinum High School started a series of tests in which conventional sealants in a piston compressor were replaced by magnetofluids in order to minimize the friction forces and thus the wear intensity.

At the same time as the first-mentioned project, Harmgarth and Leon Migge were working on the development of an artificial neural network to classify physical objects.

The work of Tobias Birk, Dominik Edel and Paul Weber dealt with a currently important topic in the field of energy saving in buildings. The students of the Gymnasium Casimirianum developed a system which regulates the heating operation by means of sensor monitoring.

David Preßel, Lukas Scheler and Philipp Wetstein from the Gymnasium Casimirianum showed that the subject of "electricity generation through pressure or movement" has not yet been exhausted. In their project, they researched the possibilities of generating electricity using fitness equipment.

Elisabeth Dittrich from Arnold Gymnasium reported on her work on the determination of colorants in food using various commercially available beverages.

Maja Bernhard, also from Arnold Gymnasium, dedicated her project to the food additive riboflavin, which helps regulate the energy balance in the human body during the breakdown of carbohydrates.

The third prize was awarded twice to students of the Arnold Gymnasium. Niklas Forkel carried out a long-term study of the relationships between weather and bee activity and made concrete suggestions on how bees can be protected through preventive action.

Anton Römhild focused on to the production of lacquers from polystyrene waste. He succeeded in producing a varnish for wooden surfaces that proved to be durable and resistant to acids and bases.

Following the exciting presentations, the event coordinator, Prof. Dr. Gerhard Lindner, announced the awarding of next year's prize and explained two changes of the framework conditions. In view of the sophisticated technical equipment required to support the student projects, the schools will receive an expense allowance of 100 € for each project with a first to third placement, limited to 500 € per school and year.

The second change will allow students to take advantage of help from external companies. For example, they can use the companies' resources or ask for ideas about possible problems. Of course, the extensive equipment of the Creapolis "Makerspace" in the Coburg director's villa is also available to the students.

In addition to the six prize winners, the Casimirianum Gymnasium sent two other students to the awards ceremony: Nathanael Illies (piano) and Jannis Bock (saxophone) provided the perfect musical setting.

Martin Kapp thanked all the lecturers for their challenging work and encouraged the young pupils to sometimes push themselves into the unknown in future research projects without being sure of the outcome of their work. (*www.kapp-niles.com*)

Solar Atmospheres

CONSTRUCTS NEW BRAZING/ASSEMBLY ROOM

Solar Atmospheres of Western PA has completed construction of a new brazing and assembly room. Though built primarily to accommodate a large aluminum brazing project for a specific customer, the room will be used for other brazing and assembly work, as well.

The temperature- and humidity-controlled room provides a clean environment for the critical assembly and alloying methods employed by Solar. All inventories of the clean components for final assemblies will be safely stored within the new space.

Bob Hill, president of Solar Atmospheres of Western PA, states: "During successful development and prototype runs, our customer, along with Solar management, understood that in order to bring this critical aluminum brazing project to full production a separate braze/assembly room would be needed. We worked together with our customer to develop the best space that is in close proximity to the vacuum furnace being utilized." (*www.solaratm.com*)

Klingelnberg

ADDS DATES TO 2020 TRAINING PROGRAM

As a system provider, Klingelnberg provides a wealth of knowledge to its customers through a wide array of seminars that are subdivided into practical and theoretical courses. The practical courses are designed to get operators and setters "up to speed" with various production technologies; the theoretical courses, aimed at technologists and developers, cover fundamental principles and in-depth knowledge with a focus on bevel gears and the KIMoS (Klingelnberg Integrated Manufacturing of Spiral Bevel Gears) calculation software. The technical expertise in all courses comes directly from real-world experience: The instructors are experienced application engineers from the Klingelnberg Technology Center, who give their best every day to develop trendsetting machine designs and who pass this knowledge directly on to customers.

Dates and registration

The four-day seminars are offered in German or English at the Zurich Training Center. Other courses are held upon request — at the customer's premises, if desired. The registration form for scheduled trainings is available on the Klingelnberg website below. (*www.klingelnberg.com/en/news/training*)

Starrett

APPOINTS METROLOGY SYSTEMS VICE PRESIDENT

The L.S. Starrett Company has announced the appointment of **David Allen** as vice president, Starrett Metrology Systems, effective November 18, 2019. In this newly-created role, Allen will be responsible for the strategy, growth and profitability of the advanced metrology systems including Starrett Bytewise, Starrett Tru-Stone Technologies, Starrett-Kinemetric Systems,

[www.geartechnology.com]

metrology software development, force measurement systems and Starrett Special Gage Department.

"We are excited to have found a leader to provide focus on our high-end metrology businesses," said Douglas A. Starrett, president and CEO of Starrett. "David has deep experience with products and channels similar to Starrett, a global perspective and a growth mindset that will help these businesses grow faster and more profitably."

Allen has spent nearly twenty years in commercial and general management of highly engineered product businesses. Most recently, he served as vice president, energy and industrial markets for Mott Corporation, an employee-owned manufacturer of porous metal filtration and flow control products. Prior to that, he spent 13 years with the Danaher Corporation in general management, marketing and engineering leadership roles in the U.S., Europe and China. Early in his career he was a manager with the Boston Consulting Group and an Active Duty U.S. Army officer. Allen has Bachelor's degrees from the University of Pennsylvania and a Master of Business Administration from the Tuck School at Dartmouth. He will be based out of Starrett corporate headquarters in Athol, Massachusetts and reside with his family in central Connecticut. (*www.starrett.com*)

Fives

OPENS CENTER OF COMPETENCY FOR CONTROLS ENGINEERING

At a grand opening ceremony, Fives DyAG Corp. (Smart AutomationSolutions Division) celebrated the inauguration of its new center of competency for controls engineering in Greenville, South Carolina.

The new facility replaces Fives DyAG Corp.'s previous operations in Charlotte, North Carolina, bringing automation support closer to existing customers, while expanding visibility within the region's commercial manufacturing; meeting the growing demand to provide expertise for controls engineering, project management, maintenance and equipment installation support.

A diverse collection of customers and industry partners attended the opening ceremony. Participating exhibitors from Bertelkamp Automation Inc., Wesco, McNaughton-McKay Electric Company and the AddUp Group (Fives and Michelin joint venture in 3D Printing Solutions for metal Additive Manufacturing systems) showcased a variety of innovative products and technology solutions. Guests enjoyed "Tech Talks" exploring various technologies supporting automation such as machine vision systems, the process of laser powder bed fusion for metal additive manufacturing, and a new multi-camera vision solution from Fives DyAG Corp. — TruIVS.

"Within Fives Group, Smart Automation Solutions Division is committed to helping industry's rapidly increasing demand for engineering and technology services, supporting a dynamically growing manufacturing environment" said Luigi Russo, deputy chief executive officer, Fives Smart Automation Solution division. (*www.fivesgroup.com*)

Big Kaiser

RAMPS UP GREEN INITIATIVES

As part of an ongoing effort to make processes and products more environmentally friendly, Big Kaiser is making modifications to production materials and packaging. Specifically, they have switched to unleaded steel and recyclable packaging. The new steel uses a Bismuth composite instead of lead. Additionally, new boring head packaging will use cardboard or recyclable PET instead of current Quadro packs with polypropylene.

"These adjustments to our materials and packaging will go a long way toward reducing the environmental footprint of our business and, more importantly, our customers," said Jack Burley, vice president of sales and engineering. "It's part of company-wide commitment to care for our customers without sacrificing quality or performance."

Big Kaiser was recently recognized by the Village of Hoffman Estates for the green efforts at its U.S. headquarters; these include recycling, reducing paper usage, energy and water efficiency, and HVAC monitoring. (*www.bigkaiser.com*)

Liebherr

CELEBRATES 50 YEARS IN THE UNITED STATES

Liebherr in the United States is celebrating 50 years of success as a leading manufacturer in North America this year. With its 50th anniversary theme "United by Success," the manufacturer remains focused on its commitment to U.S. customers. Liebherr has been producing in the U.S. since 1970. The company is one of the leading North American suppliers of construction machinery and other technically advanced, user-oriented products and services. The manufacturer sells and distributes products throughout its own locations and through an independent distribution network.

Liebherr has built its U.S. business on a foundation of trust, innovation and engagement with customers. Five decades later, Liebherr's growth, diversity and stability are evidence of how the company is united by success with customers as they work on the challenges of tomorrow and focus on the future together.

Throughout 2020, Liebherr will focus on 10 innovative product divisions across the U.S. in addition to its commitment to the success of customers, business partners and employees.

"The 'United by Success' campaign shows that our customers and our company are one through each other's successes and are stronger together," said Torben Reher, managing director of Liebherr USA, Co.

Plans for 2020 include Liebherr completing the expansion of its Newport News, Virginia campus, introducing new technologies and equipment, and having a major presence with customers during industry trade shows.

The anniversary campaign will engage with customers on web, social media and industry events, including a dedicated U.S. anniversary landing page and video. Liebherr will also unveil special anniversary exhibits and host VIP events to thank customers for their loyalty throughout the last five decades.

The exhibits and VIP events will be held at CONEXPO-CON/AGG (Las Vegas, March 10–14) and MINExpo (Las Vegas, September 28–October 1).

To keep pace with its growth, a new $60 million state of the art expansion will be completed in spring 2020 in Newport News, Virginia, which will be home to Liebherr USA, Co. The new site is adjacent to the company's current facilities, where Liebherr has operated for its first 50 years. The new buildings will add more than 251,000 sq. ft. to the existing 560,000 sq. ft. campus. Additionally, Liebherr has 13 other locations across the U.S. (*www.liebherr.com*)

Timken

EXPANDS MANUFACTURING CAPABILITY OF SOUTHEAST REGIONAL GEAR REPAIR FACILITY

The Timken Company has announced that renovations are complete and new services operational at the Philadelphia Gear Southeast Regional gear repair facility in Birmingham, Ala. The project includes an isolated assembly bay, the addition of a retractable paint booth and a large industrial parts washer, all designed to facilitate a "clean assembly" environment. "We evaluated our operation from the ground up," said Jay Alexander, manager of the Philadelphia Gear manufacturing and service center. "Our renovated facility is streamlined to simplify production and improve efficiency, and more importantly, expand our service offering."

The newly renovated assembly bay features 3,500 square feet of isolated assembly space, new floors and a crane system capable of handling up to 5-tons. The portable, retractable paint booth includes an integrated air filtration system that can expand to 400 square feet to accommodate all sizes of gearboxes. The paint booth addition is an environmental and quality improvement in the painting process. The other major investment was a large industrial parts washer that can hold gearboxes and components up to 7,000 lbs. It

features a 72-inch turntable, 150 psi of washing pressure and 180 degree washing temperature. This unit will reduce cleaning time by four hours per gearbox over manual methods and eliminate the need for outsourced sand or bead blasting. "We're excited about the improvements in our Birmingham location," said Alexander. "This upgrade will fill a niche in the paper mill industry and provide even better, "cleaner" services for customers across all markets. We are committed to our goal of becoming the trusted, full-service advisor for gearbox repair and service in the Southeast." (*www.timken.com*)

February 12–15—National Farm Machinery Show 2020 Louisville, Kentucky. The National Farm Machinery Show offers the most complete selection of cutting-edge agricultural products, equipment and services available in the farming industry. Business professionals from around the world gain knowledge and hands-on access to various technological advancements needed for the upcoming farming season during the four-day show. The Kentucky Exposition Center is filled with 890 exhibitors, making it the country's largest indoor farm show. Nearly every major line of farming equipment will be on display allowing attendees to compare products side by side. The most innovative technology and new product launches are available to agribusiness professionals, as well as alternative energy information and solutions to the challenges facing today's agribusiness industry. In addition to seeing the newest products on the market, visitors can attend free seminars led by industry experts. For more information, visit *farmmachineryshow.org*.

February 13–15—IPTEX 2020 Pune, India. Designed to meet the growing need for excellence in all aspects of the gears and power transmission to an imperative for all players to stay competitive. IPTEX 2020 is an important event for all relevant stakeholders in automobile, aerospace, or energy as well as manufacturers, buyers, partners, and consultants. Focus industries include mechanical power transmission, electrical power transmission, linear motion drives, fluid power and IoT/smart technology. IPTEX will provide a consistent channel of communication to the members of this industry to come together under one roof and participate in technical seminars, share knowledge and expertise with industry leaders and to be a part of discussion on policy codes, standards and challenges faced by the industry. A technical seminar organized by the AGMA will include educational topics such as steels for gear applications and the implementation of Industry 4.0 in gear manufacturing. Grindex 2020 is co-located with IPTEX 2020. For more information, visit *www.iptexpo.com*.

February 18–20—AGMA Fundamentals of Worm and Crossed Axis Helical Gearing Alexandria, Virginia. Provides an introduction and emphasize the differences between parallel (the experience base) axis and worm and crossed axis helical gears. Describe the basics of worm and crossed axis helical gears, their fundamental design principals, application guidelines and recommendations, lubrication requirement, a discussion of accuracy and quality and summarize with a brief review of common failure modes. Class will take place at AGMA Headquarters and class times will be 8:00 am–5:00 pm each day. The course will be instructed by William "Mark" McVea, president and principal engineer at KBE+, Inc. For more information, visit *www.agma.org*.

March 7–14—IEEE Aerospace Conference 2020 Big Sky, Montana. The International IEEE Aerospace Conference, with AIAA and PHM Society as technical co-sponsors, is organized to promote interdisciplinary understanding of aerospace systems, their underlying science and technology, and their application to government and commercial endeavors. The annual, week-long conference, set in a stimulating and thought-provoking environment, is designed for aerospace experts, academics, military personnel, and industry leaders. The 2020 conference is the 41st in the series. Conference topics include aerospace systems, military, civilian or commercial aerospace endeavors, government policies, aerospace engineering and management, and more. The event features over 175 hours of technical sessions and 20 hours of networking events. For more information, visit *aeroconf.org*.

March 10–14—IFPE 2020 Las Vegas, Nevada. IFPE is the leading international exposition and educational resource dedicated to the integration of fluid power with other technologies for power transmission and motion control applications. IFPE exhibits showcase the latest technologies and innovations in equipment, products and services for fluid power/motion control/power transmission. The show also features product-focused exhibit pavilions and international exhibit pavilions. IFPE is owned by the National Fluid Power Association (NFPA) and the Association of Equipment Manufacturers (AEM). AEM is show producer. For many attendees, part of the IFPE show experience includes participation in IFPE's education program, including college courses and timely sessions to help them stay on top of their game. New this year, attendees will be able to mix and match sessions between both IFPE and CONEXPO-CON/AGG. Attendees will be able to pay one price and select education from both shows. Presenters for IFPE's education sessions come from across the United States from distinguished universities. For more information, visit *www.ifpe.com*.

March 16–19—AeroDef 2020 Fort Worth, Texas. AeroDef Manufacturing is an aerospace manufacturing and defense manufacturing conference and trade show for the aerospace and defense manufacturing industry. Produced by SME, in partnership with industry OEMs, the show's mission is to foster innovation across the extended enterprise to reduce costs, expedite production times and maintain manufacturing competitiveness in the global economy. Conference topics include additive, automation, composites, assembly, coatings, quality, smart manufacturing and more. For additional information, visit *www.aerodefevent.com*.

March 19–21—2020 AGMA/ABMA Annual Meeting Lake Buena Vista, Florida. Join 300 of your industry peers to grow every aspect of your company while staying up on the latest technologies and innovations in the gear and bearing industries. Along with technical meetings, committee meetings and special luncheons and dinners, the Annual Meeting will feature a diverse group of speakers including A.B. Stoddard (Real Clear Politics), Dave Hataj (Edgerton Gear, Inc.), Dominique Dawes (Olympic gymnast and public speaker), Jim Meil (ACT Research), Peter Zeihan (Zeihan on Geopolitics) and Todd Palmer (Diversified Industrial Staffing). For more information, visit *www.agama.org*.

March 24–26—AGMA Steels for Gear Application Alexandria, Virginia. Attendees will gain a basic understanding of steel and its properties. They will learn to make use of steel properties in an application and understand the potential that different steel and heat treatment options can offer. They will explore how performance of the material depends on how the steel is produced. Class will take place at AGMA Headquarters from 8:00 am–5:00 pm each day. The course will be taught by Goran Nystrom, executive vice president, Ovako. For more information, visit *www.agma.org*.

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The Race to the Biggest Ferris Wheel

Alex Cannella, Associate Editor

Architecture has always had a degree of global one-upmanship to it, but most of the time, you see it happening in the form of skyscrapers. Ever since they were first possible, they've been used as displays of affluence and ingenuity, hundreds-meters tall "hey look what I can do"s. Modern wonders of the world, if you will.

What you might not expect, however, is that that same one-upmanship has started drifting into other fields. It's also become a point for the last few decades with Ferris wheels.

And this is the weirdest trend to actually try to go back and follow, because it came out of nowhere. When the first Ferris wheel was created in 1893, not a whole lot of competition ever rose to follow it. For almost a full century, things wouldn't get any bigger than the 100-meter tall Grande Roue de Paris built in 1900.

And the Grande Roue itself wouldn't even still be around to be eclipsed in the first place, having been dismantled nearly 70 years before its would-be competitor rose. Nor would any of its competition. In perhaps the most amusing anecdote, the Wiener Riesenrad, the longest-lasting wheel of its generation of record-holders, was supposed to be torn down in 1916, and the only reason it lasted until it burned down on its own in '44 was because there weren't enough funds to dismantle it (though in an even more ironic twist, it was also rebuilt a year later). For all intents and purposes, you would think the Ferris wheel was beyond dead, or at least the race to brag about how big your's was should have been.

The High Roller currently holds the crown for tallest Ferris wheel in the world, but with the Dubai Eye nearing completion, it's a title it probably won't hold for long. (Photo taken by Tony Webster, CC BY 2.0).

And then, almost randomly, taller and taller Ferris wheels began springing up in Japan one after another. First came the Technocosmos in 1985, but Japan wouldn't build a world record-sized Ferris wheel until the Cosmo Clock 21. Part of the 1989 Yokohama Expo, it was a giant, 107.5-meter tall wheel that also doubled as the world's biggest clock, built smack in the middle of Japan's bubble economy. But even after that bubble burst, Japan kept building more Ferris wheels. In '92, one in Otsu just barely squeaked out a half meter taller than the Cosmo Clock. Then another record-holder in Osaka in '97. Then one in Odaiba in '99.

Since then, the title of tallest Ferris wheel has gone on a world tour — England, China, Singapore, and finally, the U.S., where the High Roller in Vegas has worn the crown since its completion in 2014.

And with all these massive Ferris wheels come some massive components. The High Roller has some monstrous 8.8 ton spherical roller bearings, some of the largest SKF's ever made.

But on the gearing front, things are a little bit smaller. Instead of building increasingly larger equipment, most Ferris wheels go with the more practical option of using multiple gearboxes to get the job done. The recently cancelled New York Wheel, for example, was supposed to be rotated by 32 planetary gearboxes from Dana, who also provided the High Roller's gearboxes.

That New York Wheel, in fact, was meant to eclipse the High Roller as the tallest Ferris wheel in the world, so it's no surprise that the manufacturer for one project would be the natural first pick to be tapped to try and one-up themselves. And of course, even if the New York Wheel's been cancelled, that doesn't mean the High Roller can rest easy on its throne, because of course, there's another contender already under construction that wants to dethrone the king. You'll be shocked to learn that it's in Dubai.

The Ain Dubai (Dubai Eye in English) is a 210-meter tall monstrosity. It doesn't just edge out the High Roller, it's a full 25 percent taller. It's the centerpiece for Dubai's Bluewaters Island, which is itself a colossal manmade construction, an entire artificial island just off of Dubai's coast meant to be a premiere entertainment and tourist district.

As a Chicago local, I've heard this one before. A supersized Navy Pier sounds like a pretty spectacularly frivolous way to blow billions of dollars, but nobody said architectural-measuring contests were pragmatic exercises. While I can't imagine the Dubai Eye being much more than a tourist trap, the real prestige comes from saying they've got the biggest wheel, that they pushed the boundaries of architecture further than it's ever gone. And while they're pushing those boundaries, these ever-taller Ferris wheels will keep forcing component manufacturers to push theirs.

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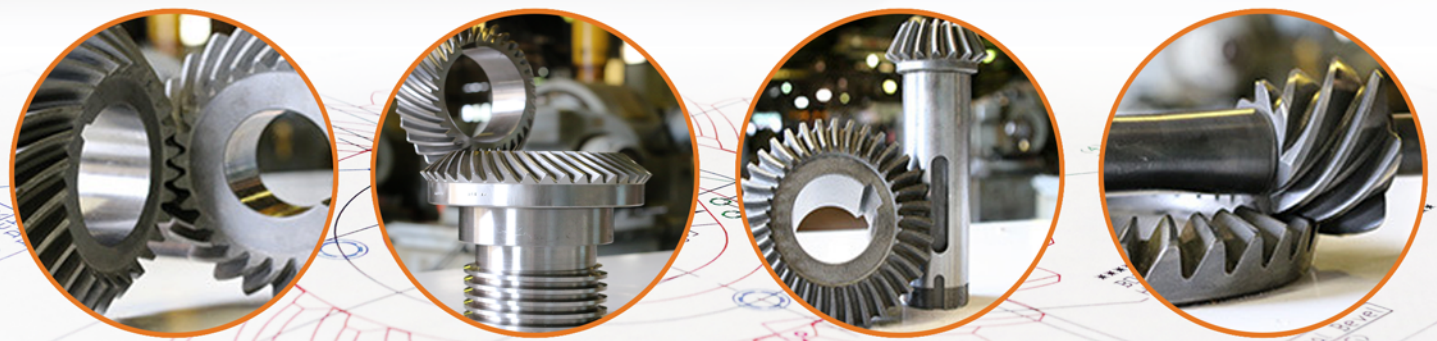

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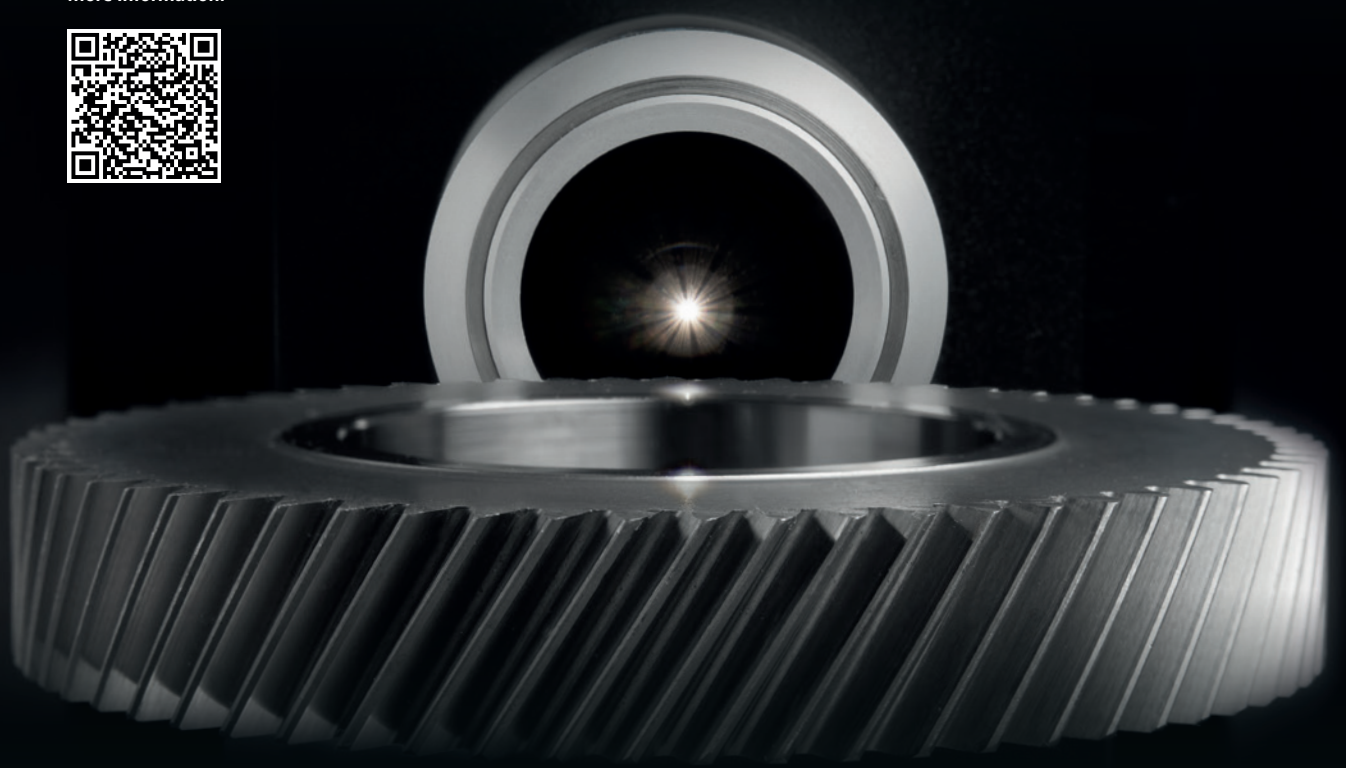

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