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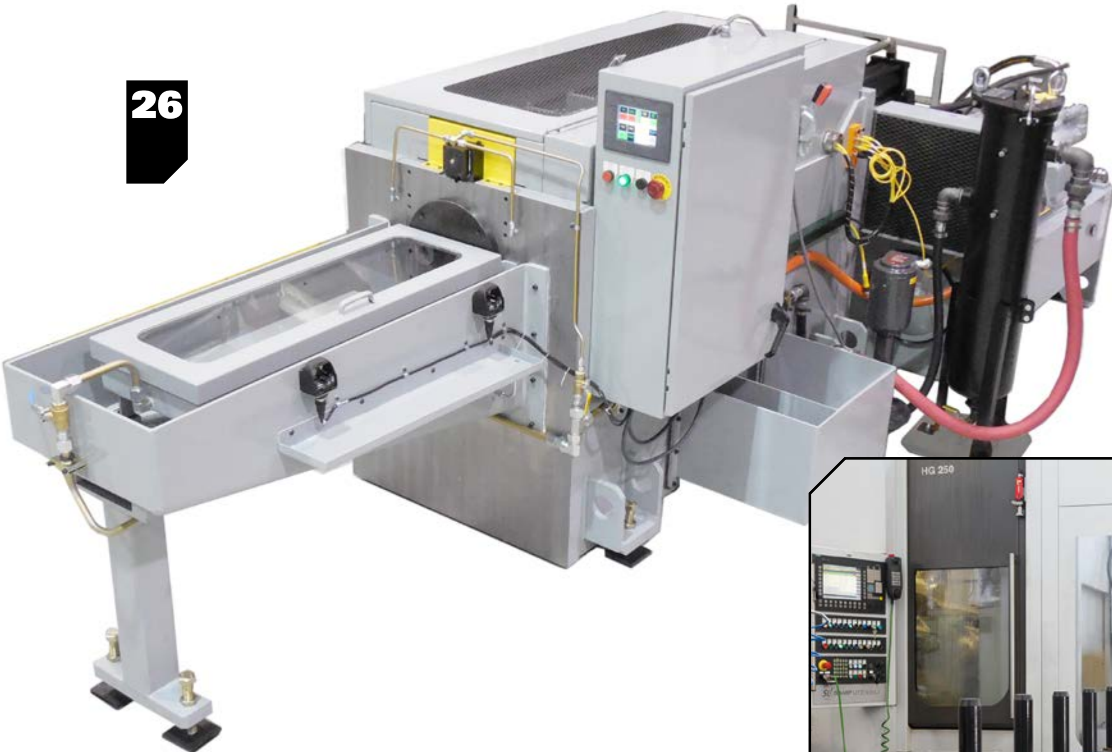

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Cover image by David Ropinski


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Gearbox Test Center

GearScan 500 allows for fast detection of common manufacturing problems such as grinding re-temper burn, heat treatment, and stress related defects. With the GearScan 500 it is easy to control quality of helical and spur gears with Barkhausen Noise. Check out the video at:

www.geartechnology.com/videos/GearScan-500---Barkhausen-Noise-Analysis-for-Gear-Inspection-/

The PTG-1L Hob Sharpening and Tool Reconditioning Grinder is an affordable solution for hob sharpening and in-house tool maintenance. Equipped with a manual HSK spindle, this machine is ideal for repetitive jobs without changes in setup, particularly during the manufacturing and resharpening of straight and spiral gash hobs, dish, shank and helical gear shaper cutters as well as a wide range of round tools. Learn more at: *www.geartechnology.com/videos/Star-PTG-1L-Hob-Sharpener-/*

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New to gears? Our in-depth GT Library features introductory technical and feature articles on hobbing, gear metrology, worm gears and more. Check out our archive that goes back to 1984 here: *www.geartechnology.com/subjects/basics/*

Gear Talk:

Resident blogger Charles Schultz continues sharing informative and entertaining posts on helical gears, bevel gears and worms. Check out the latest entries at the link here: *www.geartechnology.com/blog/*

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RANDALL PUBLICATIONS LLC
1840 JARVIS AVENUE
ELK GROVE VILLAGE, IL 60007
(847) 437-6604
FAX: (847) 437-6618

EDITORIAL

Publisher & Editor-in-Chief
Michael Goldstein
publisher@geartechnology.com

Associate Publisher & Managing Editor
Randy Stott
wrs@geartechnology.com

Senior Editor
Jack McGuinn
jmcguinn@geartechnology.com

Senior Editor
Matthew Jaster
mjaster@geartechnology.com

Associate Editor
Alex Cannella
alex@geartechnology.com

Editorial Consultant
Paul R. Goldstein

Technical Editors
William (Bill) Bradley, Robert Errichello, Octave Labath, P.E., John Lange, Joseph Mihelick, Charles D. Schultz, P.E., Robert E. Smith, Mike Tennutti, Frank Uherek

DESIGN

Art Director
David Ropinski
dropinski@geartechnology.com

ADVERTISING

Associate Publisher & Advertising Sales Manager
Dave Friedman
dave@geartechnology.com

Materials Coordinator
Dorothy Fiandaca
dee@randallpublications.com

China Sales Agent
Eric Wu, Eastco Industry Co., Ltd.
Tel: (86)(21) 52305107
Fax: (86)(21) 52305106
Cell: (86) 13817160576
eric.wu@eastcotec.com

CIRCULATION

Circulation Manager
Carol Tratar
subscribe@geartechnology.com

Circulation Coordinator
Barbara Novak
bnovak@geartechnology.com

RANDALL STAFF

President
Michael Goldstein

Accounting
Luann Harrold

BPA WORLDWIDE℠ BUSINESS

Annual Report

Publisher & Editor-in-Chief
Michael Goldstein

At most family reunions, everyone gets along, everyone puts on a good face, and everyone celebrates their togetherness. The AGMA annual convention held at the end of April was a lot like that.

After all, I've been a member, going to these annual meetings, since 1987, 31 years ago. The overall sentiment I heard from gear manufacturers who attended was that business is very good in the gear industry. Much of that has to do with continued high levels of production in the automotive industry. As one of the major gear cutting tool manufacturers told me, they can't produce the cutting tools fast enough. At least in that sector, a lot of gears are being cut.

And even those who aren't directly involved in the automotive industry seemed to be in a good mood. Maybe that's just the effect of the annual convention. Most everybody in the gear industry knows each other. They get together once a year and it's like a family reunion.

At most family reunions, everyone gets along, everyone puts on a good face, and everyone celebrates their togetherness. The AGMA annual convention is a lot like that. But often at family reunions, there are also some uncomfortable topics that nobody really wants to talk about. I sensed a little of that at the convention, too.

In our case, it isn't about skeletons in the closet or things that have happened in the past. It's about the things that *could* happen in the near future. There is definitely some apprehension in the air, particularly surrounding politics and international affairs. Things happening in Korea, Iran, Russia — and yes, here in the USA — could affect the global gear industry in a variety of ways. The U.S. steel tariffs have already driven up prices of raw materials, and the real worry is that the worst is yet to come.

The fact is, even though business is good for most, there are a lot of potential destabilizing factors that are keeping more than a few gear manufacturers awake at night.

Of course, one of the biggest factors is the one we haven't talked about yet: finding skilled workers.

I spoke to one plant manager who described some of his struggles. Recently, he'd begun training a new machine operator. This individual was dedicated, motivated to learn and responsible. It seemed that things were going well, until one day one of the machines crashed that the new operator was running.

"It was my fault," the manager said. Despite the new operator's diligence and attention, he lacked the basic mathematics to understand some of the parameters he was entering. "I've got to do a better job of teaching him."

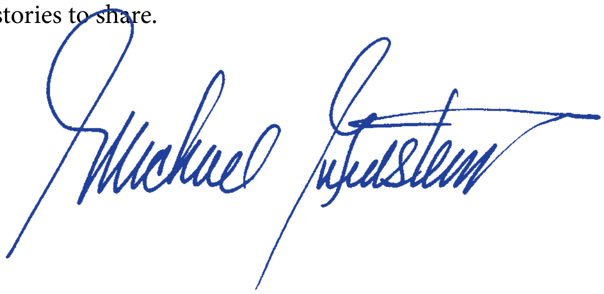
Fortunately, the AGMA is here to help. In fact, the AGMA's educational efforts were one of the most consistent themes of the convention, and I'm pleased to say that the AGMA continues to increase its offerings and improve its programs. Many of these are geared toward training plant floor personnel. President Matt Croson detailed the AGMA's plans to revamp and overhaul the AGMA Gear School program at Daley College in Chicago, as well as increasing partnerships with other organizations that can help in the training effort.

The good news is AGMA classes are available to both members and non-members. For AGMA members, some of the offerings are free. Examples include the Online Workforce Training Series ("Fundamentals of Gearing," "Hobbing," and "Parallel Gear Inspection") and the extensive collection of recorded webinars available online (more than a dozen different titles).

If you have operators or engineers you'd like to train, the AGMA is a great resource. There's no excuse not to take advantage of some of these programs, especially if your company is an AGMA member.

Also, don't forget about the GT LIBRARY, available for free at *www.geartechnology.com*. More than 11,000 users per month visit this section of the website to read articles from our magazine. It's easy to find what you're looking for. For example, just type "basics" into the search box, and you'll see a plethora of high-quality articles suitable for helping your next generation of engineers and operators understand the technology.

A lot of the things that worry us are beyond our control. But this one isn't. If you want to keep the good times rolling, you *must* train your people. When they are performing at the highest level, your company will, too. And next year when it's time again for our extended family reunion, you'll have lots of success stories to share.



Haimer

SAFE-LOCK ENSURES SAFE CUTTING TOOL CLAMPING

The Haimer Safe-Lock pull out protection system ensures safe cutting tool clamping. Special drive keys in the tool holder perfectly match the spiral shaped grooves on the cutting tool shank, thus creating frictional clamping forces and a positive locking form-fit. This effectively prevents the cutting tool from pulling out of the tool holder. Furthermore, it increases the productivity through faster permissible speeds and increased tool life.

By now Safe-Lock has become a de-facto standard in the area of tool holding for milling operations. Within the last ten years, since the introduction of the Safe-Lock system, it has been confirmed over and over that this method of clamping the tool is often clearly superior to conventional Milling Chucks and Weldon shanked tool holders. This is proven by a large number of license partners including Walter, Widia, Sandvik Coromant, Seco Tools, Sumitomo, Kennametal, Helical, Emuge Franken, Data Flute, Niagara, OSG and Mapal.

In 2017, Iscar and Ingersoll also decided to offer tools with the Safe-Lock shank. Furthermore, the shrink, collet and hydraulic chuck Safe-Lock tool holder portfolio has become much larger within the last few years. In addition to the Safe-Lock hydraulic chucks from Kennametal, Mapal is already working to introduce its hydraulic chuck offering with Safe-Lock to the market.

Andreas Haimer, managing director of Haimer GmbH said, "We are proud that our Safe-Lock pull out protection system has established itself as the new standard in the heavy duty and rough milling industry and is also becoming more and more important in other areas such as trochoidal milling. We are also very happy about our new license partners, who help expand the Safe-Lock portfolio and also make it available for more end-users."

Successful in the Aerospace Industry

Safe-Lock has emerged from the requirements of heavy-duty machining, which is a daily challenge in the aerospace and energy producing industries. Innovative materials such as various titanium alloys are not only light, but also very rigid, corrosion resistant and difficult to machine. This doesn´t only affect the machine concepts and processes, but also the cutting tools and tool holders that are being used.

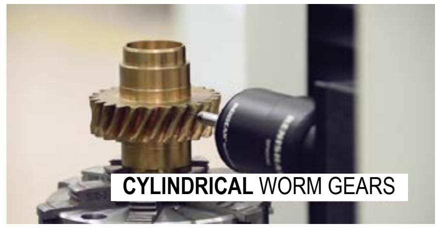
Many workpieces are made from a solid block - during this milling process up to 90% of the material is being removed. In order to optimize the process economically as well as qualitatively and in order to achieve a high metal removal rate, high torques and feed rates with low rpms are chosen. But during this High Performance Cutting operation (HPC), high pulling forces occur. In combination with high cutting forces and aggressive feed rates, a flexing movement of the tool in the tool holder is created which in the end increases the risk of tool pull out. This especially affects all the tool holder designs which provide accurate clamping and a high run-out accuracy, like for example shrink, hydraulic or milling chucks.

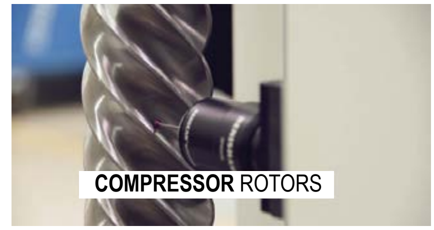
As a consequence Safe-Lock is now widespread within the aerospace industry. Alexander Steurer, senior manager NC - Programming Stator Components at MTU Aero Engines in Munich, explains the decision to use the Haimer system:

"Through the introduction of Safe-Lock and the shrinking technology from Haimer, we can guarantee process reliability even with milling challenging high temperature materials. This is a prerequisite to guarantee smooth processing during manufacturing of frames and castings, given our high degree of automation."

The combination of pull-out protection and highest concentricity of the Safe-Lock™ system leads to low vibration and as a result, a very stable machining process. Due to the increased cutting depths and feeds, the metal removal rate can be increased significantly. And thanks to the improved runout accuracy of Haimer shrink fit chucks, tool life is improved by up to 50%.

The benefits of less than 3 μm runout, that the symmetrical Safe-Lock design provides, coupled with optimum balance and the possibility for easy length presetting were substantial reasons for MTU to switch to the Haimer system instead of continuing to use Whistle Notch or Weldon tooling systems. While these other systems do in fact prevent tool pull out, both are unsymmetrical by design, hence providing insufficient runout and balance accuracy.





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Higher Productivity with Safe-Lock

However, Safe-Lock has not only found enthusiastic followers in the aerospace industry. Working at Glätzer, Daniel Rautenbach knows how fiercely competitive and thorough the automotive industry can be. The Managing Director of the CNC-Machining Specialists located in Solingen explains: "Perfect quality and delivery reliability are the basic requirements in order to quote in our industry. Pricing is highly competitive." Therefore, in his business, the difference between profit and loss comes down to process efficiency. Hence quality without compromise is a must.

Through one of the biggest projects in this area Ingo Schulten, operation manager, became aware of the Haimer Safe-Lock pull out protection system and started using it in the middle of 2013. The specific application was a part for a pneumatically operated truck disk-brake which consisted of spheroidal-graphite cast iron, Type EN-GJS-800-2. In order to mill concave contours the contact between cutting tool and the workpiece isn´t just punctual, but it actually covers between 30 or 40 percent of the tool.

"The extremely high engagement and cutting forces cause the tool to want to pull out from the holder," said Schulten. The utilized Weldon Chucks ensured that the cutting tool stayed in the holder, but the side lock screw prevented the tool from achieving good runout accuracy. According to Schulten "The tool life was very unstable which even led to tool breakage."

Benefits of High Speed Cutting

Safe-Lock is also becoming increasingly popular in other industries and during HSC machining with high-helix end mills as well as in trochoidal milling. During trochoidal milling operations, where the cutting speed and axial depth of cut can be increased through software support, the productivity is significantly improved. Thus milling operations are carried out three times faster with deeper depths pf cut, even when it comes to hard and difficult to machine materials.

However this also increases the danger of tool pull out. Even though only a thin chip is usually removed during trochoidal milling operations, often the entire length of the cutting tool edge is used during the process. This results in higher axial forces which force the operator to pay attention to safe cutting tool clamping. A shrink fit chuck with Safe-Lock is the ideal solution since it offers more security than the Weldon system, is easier to install and can be clamped very precisely. The ideal balancing and runout characteristics of the shrinking technology in combination with the clamping safety of the Safe-Lock system permit the possibility of greater productivity achieved through faster permissible speeds and increased tool life all with complete tool security assurance.

For more information:
Haimer USA, LLC
Phone: (630) 833-1500
www.haimer-usa.com

POWER SKIVING

Ring Gear production in practice

With the skiving centre PITTLER PV315, a globally operating manufacturer of drive systems found the ideal solution for the turning and gear cutting of hollow wheels. The requirement was to cut the internal gearing and then turn the bearing carriers in one clamping with the aim of achieving as perfect a concentricity of the gearing to the bearing carriers as possible by avoiding reclamping errors. In addition, PITTLER POWER SKIVING technology was expected to cut the gearing of the hollow wheels quickly, reliably and with very high quality.

Precise and efficient gearing

On account of the efficient design of the PV315 with upstream and downstream machining processes through to complete machining, the drive manufacturer decided in favour of a PITTLER PV315 following initial test machining. He is now producing the component with a gearing quality AGMA 10 and DP 31.7. Gear cutting is carried out in 30 seconds, the bearing carriers are turned in 60 seconds. Other ring gear types with gearing sizes between DP 63.5 and 7.2 are manufactured using the same machine.

Hard skiving integrated

To achieve even higher gear cutting qualities, hardened components can be also be cut using the hard skiving method on the PITTLER PV315.

PITTLER PV315

- Power Skiving for inner and outer gearings
- Integrated tool magazine for complete machining
- Single clamping operation for highest precision

CONTACT US:

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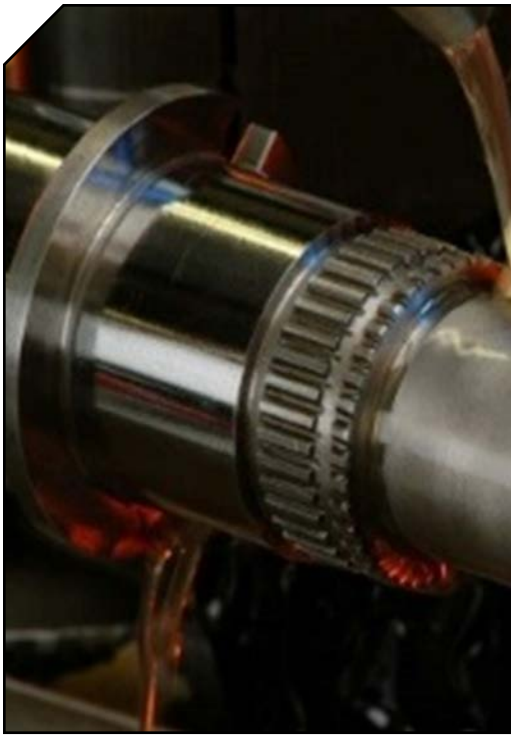
Nagel

RESPONDS TO GROWING TREND IN SUPERFINISHING



Whether to reduce friction losses or improve hygiene the surface quality of components is always in demand. As a result, superfinishing technologies have grown in significance. Nagel Maschinen- und Werkzeugfabrik GmbH in Nürtingen has responded to this trend by increasing capacities for process development and contract manufacturing in the area of superfinishing.

The growing demand for high-quality surface finishes has far-reaching consequences for many metal processing companies: their process chain becomes longer due to the required superfinishing. Existing capacities no longer suffice, but expansion is associated with costs. In such a situation, contract manufacturing has become a viable alternative.

"Contract manufacturing in the area of superfinishing has been growing for years now for us," explains Marcel Bosch, process development superfinishing at Nagel Maschinen- und Werkzeugfabrik. "That is why we have expanded our capacities in process development as well as our machinery. We are equipped for all applications, from the smallest rolling elements all the way through to large crankshafts for utility vehicles. We are also always open to new materials and workpieces as well as any quantity desired."

The automotive area application has always been the most heavily represented at Nagel. However, the superfinishing specialists are also discovering that sectors such as the bearing industry, the aerospace sector and medical technology are growing. In medical technology, the main focus is surfaces for implants. Here, a complete lack of grooves is crucial so that germs have no way of establishing themselves. In vehicle technology, the demand is for a minimisation of CO_2 emissions, which requires tribological – friction-optimized – surfaces for the cylinder linings, which are honed, but also for all bearings for crankshafts, camshafts and gear shafts. The magnitude of achievable emission reductions may be minute, but small amounts add up over the entire vehicle. So, if the objective is to reduce

friction losses as far as is technologically possible, superfinishing becomes a key technology. Grinding as an upstream process cannot possibly contribute to this objective any further.

"The quality and design of surfaces for bearings is frequently a question of manufacturing philosophy," says Marcel Bosch. "Some manufacturers tend to produce reflecting surfaces, such as in medical technology, while others produce defined microstructures."

Some background: Microstructures support the possible formation of a lubrication film. In order to reduce friction or wear and tear when running in a bearing, the process of plateau finishing, for example, gains significance. During this process, the peaks of a rough profile are burnished to plateaus. If the peaks remained, they would be stripped relatively quickly during operation and the result would be the typical wear and tear associated with running in. This is a problem in the event of frequent start-stop cycles in particular. Plateau finishing basically pre-empts the process of running in. Plateau structures are the perfect example of tribological surfaces.

Diligent process development is required so that the result is right in the end. "We don't simply supply machines and tools; we also develop the processes," said Bosch. Rz values of around 0.5 µm must be realized. The task becomes even more challenging if certain requirements with regard to dimensional accuracy are added to the mix. One example is spherical bearings. Nagel has a proven solution for this: the dFlex band finishing tool.

"We do not yet know what kind of challenges the future of superfinishing holds. But we do know that the demand for high-quality surfaces, tailored to their function, is growing continuously," Bosch said.

For more information:
Nagel Precision Inc.
Phone: (734) 426-5650
www.nagel.com

EMAG

MACHINING PROCESSES SEPARATED INTO CATEGORIES FOR MODULAR MANUFACTURING SYSTEMS

"We have separated the machining process for gears into four easily manageable sub-processes," says Peter Loetzner, president and CEO at EMAG L.L.C. "In OP 10 and OP 20, we use the VL 3 DUO dual-spindle vertical turning center to machine both sides of the gear blanks. In OP 30, we do the gear hobbing on our VL 4 H gear hobbing machine. The final chamfering and deburring of the finished gear in OP 40 is done on our VL 2 RC or VL 2 CC, depending on what technology is used, Chamfer-Cut or Roll Chamfering.

The pick-up automation system integrated into each modular machine features a parts storage unit for blanks and finished parts, from which the machine is automatically loaded. With this system the machine can achieve chip-to-chip times of only a few seconds. The vertical construction of the machine not only guarantees an ideal chip flow, but also prevents the formation of chip clusters, contributing to a consistently high quality of production.

The interlinking of machines is easy to implement due to the consistent transfer height between the automation systems of individual machines. In addition, the separate energy cabinet allows the use of the new EMAG TrackMotion automation system specially developed for modular machines. The automation system located directly behind the machining area transports the parts and also operates as a flip-over unit, which increases the flexibility of the entire system.

For more information:
EMAG LLC USA
Phone: (248) 477-7440
www.emag.com

BVL Cleaning System

ENSURES RELIABILITY WITHOUT SETUP WORK FOR GEARBOX PARTS

A Spanish supplier for a large German gearbox manufacturer requires a further cleaning system for a new project. The cleaning requirements for the six different and complex aluminum die-cast parts from the automobile sector are very demanding. On the basis of the positive experience that the company has already had with the BvL cleaning system, this project has once again been realized in collaboration with the experienced Emsbüren-based manufacturer and the Spanish partner Edeltec of Barcelona.

A NiagaraDFS basket washing system from BvL forms the basis of the new cleaning solution, which has been equipped with a specially designed retainer in the basket seating. This universal system allows individual parts handling without additional set-up work. The production of six different workpiece holders at BvL means that the basket seating delivers absolute accuracy of fit for the various die-cast components. Replacement of the workpiece holders and components with those from the previously supplied first system is also possible without much set-up work.

After the components have been automatically loaded and fed in via a roller conveyor, the loaded workpiece holder is moved into the cleaning chamber. A combination of spraying, flooding and ultrasound processes ensures a thorough washing and rinsing process in accordance with the preset parameters.

For more information:
DeLong Equipment Company LLC (U.S. BvL Rep)
Phone: (800) 959-5009
www.delongequipment.com

GMTA (U.S. BvL Rep)
Phone: (734) 973-7800
www.gmtamerica.com

Koepfer America

OFFERS GEAR DEBURRING WITH CNC AUTOMATION

The Tecnomacchine ("TM") 200 R3 gear deburring machine offers a flexible solution for all job shops with gears up to 7.874" diameter (alternative TM models can accommodate larger workpieces). 5 work stations are utilized: 1 for loading and unloading, 2 for deburring (top and bottom), and another 2 for finish brushing (top and bottom).

This machine produces finished work pieces in as little as 20 seconds (3" diameter parts) or 55 seconds (7.8" diameter parts).

The dual rotary magazines each comprise 8 easily adjustable towers. Each tower can hold parts up to 17.7" high. For example, 283 pieces can be loaded assuming a 0.5" face width gear. This allows the machine to deburr unattended for hours.

The TM 200 R3 is designed for easy setups and adjustments. Changeovers can be completed in under 30 minutes, which minimizes machine idle time.

Both end mills and cutoff wheels can be used for deburring. Brushes are used for finishing with automatic tool wear compensation. With complete control of tool pressures, speeds, and positions, a wide variety of components can be processed.

The machine's SPC station allows an operator to check quality mid-process. Additionally, for small lot sizes, the machine can also be used in manual-mode. In this case, the SPC station allows easy loading and unloading of a single workpiece.

For more information:
Koepfer America
Phone: (847) 931-4121
koepferamerica.com

More Solutions, Greater Challenges

As coating technology improves to handle harsher conditions, cutting tool manufacturers are faced with new challenges during the resharpening process.

Alex Cannella, Associate Editor

Cutting tools have come far. They operate at blinding speeds and can cut workpieces in a matter of seconds. Productivity has increased almost tenfold. We've even developed methods of dry cutting that don't require lubrication. And even while moving at increasingly dizzying speeds, they're accurate down to the micron. The way we cut gears has fundamentally changed since a few decades ago, and cutting tools are at the center of that change.

But as cutting tools themselves move ahead in leaps and bounds, there's another field that's working to keep pace: cutting tool coatings.

As they've been introduced over the years, new methods of cutting gears have required tools to move at higher RPMs and generate more heat, and accordingly, cutting tool coatings have stepped up to meet the increasingly rigorous demands of these methods. In order to do so, however, they've had to use different, heavier materials. First coatings suppliers introduced aluminum, then eventually carbide, and a growing issue started becoming increasingly pronounced: While heavier coatings were protecting the tool better during operation, it was becoming more difficult to strip the coatings without damaging the base material and just ruining the tool altogether.

That might not sound like too big a deal at first glance. Some manufacturers don't even repair their tools, and instead just toss and replace them once they wear down.

"When you talk to coating people or cutting tool people normally, they only look for the coating as a one-time solution," Keith Liston, VP of tooling sales at Gleason, said. "So they use the tool, such as inserts...and then the tool gets thrown away. From the gear cutting side, we are looking into coatings in a different way."

It doesn't take a whole lot of math to

Cutting tools have become increasingly sturdy over the years to keep up with increasingly rigorous demands, and their coatings have become more durable with them.

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coatings
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see why resharpening a tool is better than buying a brand new one. Resharpening is cheaper, can be repeated multiple times to extend a tool's life, and if your service provider does their job right, that tool should come back just as sharp and effective as when you first got it.

But for those who get their tools resharpened (and if you want to get the most bang for your buck, you should be one of them), tool recoating becomes a critical issue. When it comes time to resharpen, a coating likely will not have worn down evenly, which leads to two issues during the resharpening process. If there's residual coating left on the tool, it sharpens unevenly, as you have to grind your way through the coating before you can start sharpening the tool, and exposed surfaces where the coating has already worn off start getting sharpened before surfaces where the coating is still intact. And then the new coating itself could be uneven, as well, with remnants of the old coating still underneath. In addition, stripping the coating before you start grinding exposes fresh material on the substrate that hasn't been touched by any of the chemicals involved while it was being used to grind gears, meaning no surprises during resharpening due to any past chemical contact.

"In any respect, if you take a hob, if you take a shaper cutter, if you take a power skiving tool, these tools get a new coating in the beginning, but also at the end, they come back for reconditioning several times…" Liston said. "So, any time you return the tool to be resharpened it has to be stripped, reground and recoated again. I think this is a totally different approach to the coating than what you would normally hear when talking to large coating manufacturers."

And when an average tool will be sharpened over a dozen times over the course of its lifetime, "uneven" or "inconsistent" are not adjectives you want describing your process. If resharpening an individual tool repeatedly is a primary way to stretch your dollar as far as possible, damaging a tool on its second sharpening drastically reduces savings and isn't an option. Cutting tool manufacturers are painfully aware of this, and endeavor to make sure that resharpening, and by extension,

recoating, is a reliable, repeatable process that makes the tool good as new again.

"These tools are reground 10, 15, 20 times perhaps throughout the entire life of their existence," David Goodfellow, president of Star SU, said. "And then recoated each time. And if you don't recoat it with the proper preparation of the cutting edge and the surface finish, you will not achieve the same tool life from the first use of a new tool, to the last use of a tool 10 or 15 times after it's been reground."

The issue gets compounded when you realize how much thinner the margin for error has become with newer cutting methods. When working at the higher speeds demanded by gear cutting today, a tool's fail state comes sooner — and happens faster.

"The risk of catastrophic failure now is by far greater if you don't do all these processes properly," Tom Ware, product manager of gear cutting tools at Star SU, said. "Historically when they were running low speeds, your tool life was a curve that went up after a few pieces, leveled off, and then wear started to gradually occur 10, 20, 30 thousandths wear on the flank, and then you pulled the tool and resharpened it. Now that curve is pretty steep, so if you get more than 10 or 15 thousandths of wear, you could get into a catastrophic failure very quickly, so we have to control the process much more closely."

"You can go from five thousandths edge wear to fifty thousandths edge wear in literally a matter of seconds," Goodfellow added. "So it's very important to know that critical point and to stay below it so that you don't risk destroying the tool."

When the margin of error is thin and the life of the tool is at stake, you can see why cutting tool manufacturers are very serious about their resharpening process. And why they don't take any chances with uneven sharpening caused by residual coatings.

According to Mark Duykers, cutting tool sales manager at Liebherr, the resharpening process is all about preparation.

"Just like anything else, preparation is the key to quality," Duykers said. "Electrochemical stripping must be monitored very closely so as to remove all of the coating, yet not damage the substrate. Whether grinding a new cutter or resharpening a used one, edge prep is critical: it is very important to remove any micro-burrs prior to coating."

That means that instead of just slapping a new coating on, you need to take the time to strip the coating off first. Then you can go about resharpening the tool, and finally after all that, you reapply an entirely new coating. The entire process is more or less about returning a tool back to the state it was when it was

The resharpening process is about more than just regrinding the cutting edge. You also have to remove the coating, perform proper edge prep, and then reapply it."

brand new, and the best way to go about that is to perform each step of the process with the tool in the same condition it was when it was first being manufactured. When the tool is being sharpened, it's already been stripped of its coating and you're working directly on the base material. When it's time for the coating to be reapplied, the tool has already been sharpened back into its ideal state—the same state it was in when its original coating was applied.

But the first step of the process, stripping the coating, got a lot more complicated once heavier coatings started coming into the market. Tool manufacturers tend to use chemical methods to strip the coating off, but once materials such as carbide get introduced, the coating becomes more stubborn and difficult to remove, and manufacturers are left with an increasingly tight balancing act. Leave the tools in the solution too long, and you damage the substrate underneath the coating and ruin the tool. Take it out too early, and you still have remnants of the coating on the tool, which leads to uneven sharpening and recoating and subpar performance once the tool returns to the spindle.

"The decoating process for carbide is very challenging," Julius Habermeier, product manager of cutting tools Americas for Oerlikon Balzers, said. "For different coating types you need different stripping processes so that you don't damage the carbide (e.g. cobalt leaching). We developed special stripping processes and also stripping equipment for different coatings that we can assure the quality."

Dry processes such as skiving often necessitate tool coatings that improve a tool's heat resistance.

Fortunately, tool manufacturers and coating suppliers are aware of this pain point, and they've been making great strides over the past few years in handling it. The most notable solution to the problem has been the advent of aluminum chromium nitrite coatings—most notable among them being Oerlikon Balzers' flagship coatings, Altensa and Alcrona—which have many of the benefits of older aluminum and carbide-based coatings, but are still easier to strip and reapply. The chrome in the coatings is significantly easier to break down via an acid-based stripping system than aluminum, and even though the latter is still technically present in the coating, the overall makeup makes ACN coatings much easier to work with.

When making tools for grinding gears, tool manufacturers need to be cognizant of of not just how that tool's coating will perform in the field, but also during maintenance.

"The key is time in solution," Goodfellow said. "You can do it with heavier concentrations of acids, but then that has its problems. They've been doing some work with trying to activate that solution with electrolysis... but the whole key is to limit the amount of time in solution, which then minimizes any potential for surface damage of the base materials."

The challenges continue into the sharpening stage, as well. Namely, if the cutting tool isn't sharpened properly, the coating still won't be reapplied evenly, even if you'd successfully stripped the old coating off without damaging the tool. This part is all about edge prep, making sure to remove any sharp corners from the tool.

"We've kind of taken a page out of the carbide insert world with the edge prep, and found that we can enhance the coating adhesion, rather than having a sharp corner, having a bit of a rounded, honed edge," Goodfellow said. "And depending on the application and the different coatings, that amount of edge prep is a factor in the performance of the tool."

According to Momper, removing small, residual burrs on a tool with just 10-20 microns of edge prep can affect a hob, shaper or power skiving tool's life by up to 50 percent, and is only going to become more and more important with carbide hobs on the market.

And then finally comes the recoating process, which has its own considerations. Most notably, you have to consider which coating to use. According to multiple sources, about 80 percent of applications just use ACN, but for those one-in-five edge cases, cutting tool manufacturers need to choose a coating that can cater to their customer's needs. In addition, they have to consider a tool's base material. For example, a powder metal substrate won't be able to handle higher temperatures during the coating process, while carbide has a higher hardness and isn't as sensitive to heat in the coating process. But then when it comes time to strip the coating during resharpening, carbide is more susceptible to being damaged during the stripping process, while you'll have a much easier time with powder metal.

And it's here that a coating's stubbornness rears its head again. The final consideration when choosing what coating to apply is how easily it can be removed when it inevitably comes time to sharpen the tool. After all, if the supplier can choose a coating that meets the customer's requirements and is easier to remove, they save both the customer and themselves a lot of headache down the line.

"We not only simply apply the coating, we have to also think about how to remove the coating, which is completely unusual," Liston said. "What is the effect of removing a coating from a PM material? And what is the effect of removing a coating from a carbide material?"

Now, after reading all that, one might start to wonder: Why bother with all this at all? Why not just keep using lighter coatings on your tools that aren't so difficult to remove? The answer is the other major concern facing cutting tools right now: heat resistance.

As cutting processes have continued to evolve, they've begun to work at higher and higher speeds, generating more heat. And as dry cutting methods gain prevalence and the usage of coolants wanes, the onus to prevent a tool from overheating falls increasingly on the coating. Over the years, coatings suppliers have had to develop heavier duty, more temperature-resistant coatings to meet customer demands for higher temperature tolerances. But while coatings suppliers have done a pretty good job meeting this demand, as Eric Sevareid said so long ago, the chief cause of problems is solutions. Cutting tool coatings have been doing a pretty good job solving the temperature problem, but the next difficulty along the chain of causation is how to properly remove the most stubborn of coatings, and that one's still an ongoing discussion.

For more information:

Gleason Cutting Tools Corp.
(585) 473-1000
www.gleason.com

Liebherr Gear Technology
(734) 429-7225
www.liebherr.com

Oerlikon Balzers
(847) 619-5541
www.oerlikon.com/balzers

Star SU LLC
(847) 649-1450
www.star-su.com

Broaching in the 21st Century

All Dressed Up with Places to Go

Jack McGuinn, Senior Editor

Back around 2005-2010, the most exciting things that were happening in broaching had little to do with broaching. What was happening — and continues to evolve today — was the emergence of on-the-edge CNC, software and servo drive technology. Together, they practically transformed a metalworking process as old as water into a viable, alternative consideration for producing high-volume part runs. Add to that enhanced tool coatings capabilities (which also just keep getting better) and broaching found itself enjoying a bit of a relevance Renaissance.

But what about now — in 2018? Ten years is an eternity in today's manufacturing operations, with new technology breakthroughs occurring seemingly faster than one can keep up with. Is broaching still in the equation in a meaningful way?

Indeed it is — and then some.

"Yes, broaching remains one of the fastest methods of cutting production parts," says Leon Agan, project engineer/estimator for American Broach & Machine, Inc. "High accuracy remains consistent as long as tools are properly maintained."

Michael Slovak, sales manager/machine tools division for Nachi America Inc., adds additional evidence.

"CNC, servo, and software technology continue to improve and provide additional impact on power savings, high efficiencies, and high-precision mechanical systems. Nachi's primary developments include: Hard broaching to minimize distortion after heat treat. Also, Nachi green and hard skiving, including lathing, drilling and taping, with (6) station automatic tool changer — is a multi-process alternative to broaching on lower part volume requirements. (And), the smaller GMS200 is currently moving into the introduction process."

Given the above, broaching certainly remains a part of gear manufacturing. But, even with the mentioned bells-and-whistles add-ons, can broaching crack manufacturing's 21st century lineup of Smart Manufacturing, IoT, and Industry 4.1?

"Customers now almost always ask for a communication link in the broaching machine control system, which they can utilize

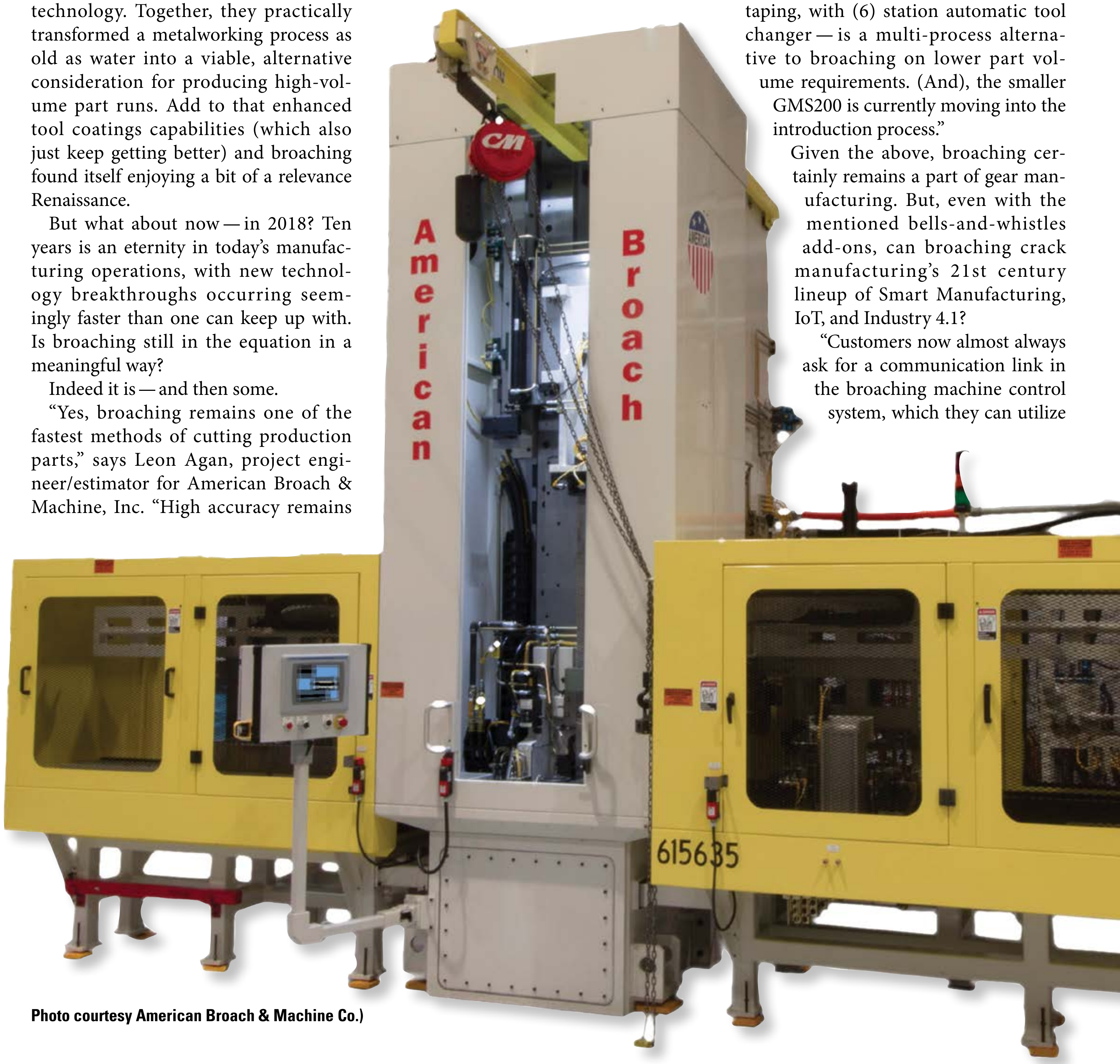

Photo courtesy American Broach & Machine Co.)

in whichever factory management system they are using," says Agan. "Most broaching machines use PLC rather than CNC control, and even those are outfitted with a link for plant connection."

Nachi's Slovak points out that "While the new buzz phrases define a specific characteristic, the technology to participate in these areas has been available to machine makers for many years, and broaching is included. Providing critical data over a secure network to key individuals, optimizing production functions, and increasing automation continue to be improved and utilized."

Not to get too far off message, the thought occurs of how protracted steel tariffs on foreign steel might impact broaching's world — especially tooling.

"As with any change in such policy there is always potential for price impact and broaching must be reviewed on an ongoing basis," says Slovak.

As for American Broach's Agan, see above answer — with this added proviso: "The price of broach tools will be affected if tariffs remain on European tool steels. Broaching machines use large volumes of structural steel, so there will probably be a significant impact on their pricing."

With the techy add-ons, have there been any new applications happening for broaching? Generally no, but those add-ons go a long way towards ensuring that broaching maintains its viability and retains its existing place in the gear machinery universe.

"Most applications remain traditional, but the amount of automation required for production cell integration has increased," Agan says. "Customers want to eliminate broaching machine pits and operator stands, and minimize operator involvement. They ask for features such as onboard measurement of parts. Also, we have come up with several designs to make changeover faster and easier."

Slovak believes "Broaching with 'techy add-ons' can apply to any market that requires high annual volumes and high capability." Looking forward, he also states that "Electric vehicle components may be the largest emerging new application."

Given the fluids involved in broaching, and the maturity of the broaching process, you would think broaching is a particularly down-and-dirty process. But that's not quite the case if proper steps are taken to alleviate the situation.

(Photo courtesy of Nachi America, Inc.)

American Broach's Agan explains that "Normally, cutting fluid is splashing around freely inside a broaching machine. The process requires a flood of coolant, rather than a high-pressure blast. The current guarding designs do a good job of containing the cutting oil (normally water-soluble), and air blow-off stations can be added to reduce coolant carry-off. Dry broaching methods are being developed, but for now, most customers are still using gallons of cutting oil.

"The typical oil or oil soluble cuttings fluids may not be known as producing a 'clean process,' says Slovak, "(but) steps can be taken to minimize or stop the escape of cutting fluids outside of the machine being utilized. MQL (minimum-quantity lubrication), where available, is contributing to a much cleaner and more cost-effective process."

Back in 2010, what might be considered "old-school" hydraulic machines ruled regarding large-component applications. In 2018? Still very much in the game in a big way.

"Hydraulic machines will always have a role — especially high tonnage long stroke machines," Agan affirms. "They have a fairly simple design and are very reliable. About half of the customer base considers an electro-mechanical machine for small-to-mid-range applications." He further explains that "Electro-mechanical usually wins when floor space is an issue, or when a plant needs to minimize the amount of hydraulic oil in use."

"Old-school" hydraulic machines still rule in any application where part specification allowances and CapEx budgets drive such a decision," says Slovak.

Is new machinery still a relevant part of the broaching industry? Or re-engineering/retrofitting existing machines? "New machines are about two-thirds of our machine sales," says Agan. "Most of the time, we can offer our customer a completely rebuilt used machine as a lower-cost alternative. The frames of old machines last a long time, and with careful restoration of sliding surfaces and the addition of modern controls, we can confidently offer the same warranty that we provide with a new model."

"New machinery is relevant based on highly engineered part specifications and quality capability requirements," Slovak says. "Complete rebuilding of an existing machine can be an attractive, economical solution, (but) when the right frame is not available a new machine is recommended."

From the technological mindset of what have you done for me lately, have there been additional software, CNC, servo upgrades in this decade that have further enhanced broaching capabilities in a significant way?

Slovak cites "Continued improvements in human machine interface capability and programming can allow for improved and more efficient setting of processing requirements. The CNC, servo-operated machines continue to allow development in processing speeds, achieving faster machine cycle times."

As for Agan, he presents a somewhat less sanguine view. "Broaching does not benefit a whole lot from CNC advancements in the number of controlled axes, the ability to coordinate axes, or more sophisticated part programming software. We have a straight line application for the most part." But also offers that "Many control systems have become more open to industry standards and interoperable with motors from other brands."

As mentioned, broaching is intended for high-volume production runs. So what goes into identifying the high-volume break-even point that determines whether broaching is more cost-effective than other cutting technologies?

"Ten thousand pieces is still considered to be very low volume in the broaching industry," says Agan. "Considerations are: new vs. used machinery; initial tooling cost; the total length of cut expected between sharpening; the number of runs-per-tool; and the cost of sharpening. American Broach can provide specific information when quoting a job to help a potential customer decide if broaching offers the best value."

Add to that, according to Slovak: "Reviewing the part volume against initial CapEx costs; amortizing schedule; ongoing perishable tooling costs; regularly planned machine maintenance costs; ongoing utility costs — as compared to the alternative cutting technologies using the same factors."

So broaching not only has a long history; it would also appear to have a strong future. The new wine in old bottles metaphor seems to apply here in a meaningful way — or is it *old* wine in *new* bottles? — (never can get that one straight). According to American Broach's Agan, "There has been a great increase in the number of customers seeking a hard broaching (a recent vintage) solution. We have been working with several to develop a process which is most effective for them."

Nachi America's Slovak's outlook is positive as well, but points out that there is much due diligence involved to keep it that way and to maintain market share.

"The markets are requiring broach builders to supply finishing processes with high speed, on a wide variety of parts, and lower volume production runs. We have moved toward market demand with CNC broach machines (mass production), compact hard broach machines, small or large helical broaching machines, and skiving (wide part variety, lower production) machines. We are also able to offer integrated solutions with robotic (Nachi Robotic Systems) load/unload automation for all machine types. Our broaching machines and skiving machines are solutions for covering customer process trends."

For more information

American Broach & Machine Company
575 South Mansfield
Ypsilanti, Michigan 48197
Phone: (734) 961-0300
Fax: (734) 961-9999

Nachi America Inc.
North American Headquarters
(Machine Division)
46200 Twelve Mile Rd.
Novi, MI 48377
Phone: (248) 835-5688
www.nachiamerica.com

Photo courtesy American Broach & Machine Co.

Types of Broaching

(*Courtesy American Broach & Machine*)

- **Pot (external spline or profile).** A part is pushed up through a circular array of surface broaches, resulting in a gear or similar form on the outside circumference; high throughput with good surface finish.
- **Horizontal.** A broach tool is pulled horizontally through a part placed in a fixture or on a work horn. Commonly used for cutting keyways and windows, but can also be used for internal splines with looser tolerances.
- **Vertical Table Up Broach**. The part is set in a fixture on a ram which carries it over and past a stationary broach tool. The advantage is a convenient load height for the operator, as no pit or operator platform is required.
- **Vertical Pull-Down Broach.** The part is placed in a fixture, and a broach tool is pulled downward through it to produce an internal form. These machines are very rigid and can produce cuts with tight tolerances and very good surface finish. The disadvantage is that the work table is very high relative to the floor.
- **Vertical Surface Broach**. The part is clamped in a fixture, and a set of flat broach tools on the ram slide move past and cut into the external surface. This process can produce flat surfaces or complex forms, such as spline racks or turbine hub "fir tree" slots.
- **Twin-Cylinder Pull-Down Broach.** This is a form of pull down broach which has a pair of cylinders (or linear actuators) mounted to the work table and stroking downward into the base of the machine. The ends of the cylinder rods are bridged, so that they can carry the pull head. This system keeps the pull force in line with the broaching axis, which eliminates cantilever effect inherent in other systems. The pull lug is also guided on ground posts, maintaining a high degree of broaching accuracy.
- **Table Top Broach.** This is another form of pull-down broach with a small footprint and compact design. Instead of a ram slide, a pair of ball screws on each side of the broaching axis moves the pull lug. American Broach & Machine Company builds this "TT" model, which has many of the same high end features as larger machines.

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The Road to Reliability

Gear Industry Steps Up to Automation Challenges in Auto Industry

Matthew Jaster, Senior Editor

Automotive parts are always moving. They are zipping across conveyors, smashing into each other in bins and traveling across the production chain before ending up inside an automobile. For gears, this can be a somewhat precarious situation as they tend to run best when they're free from nicks, abrasions, cracks or other damages.

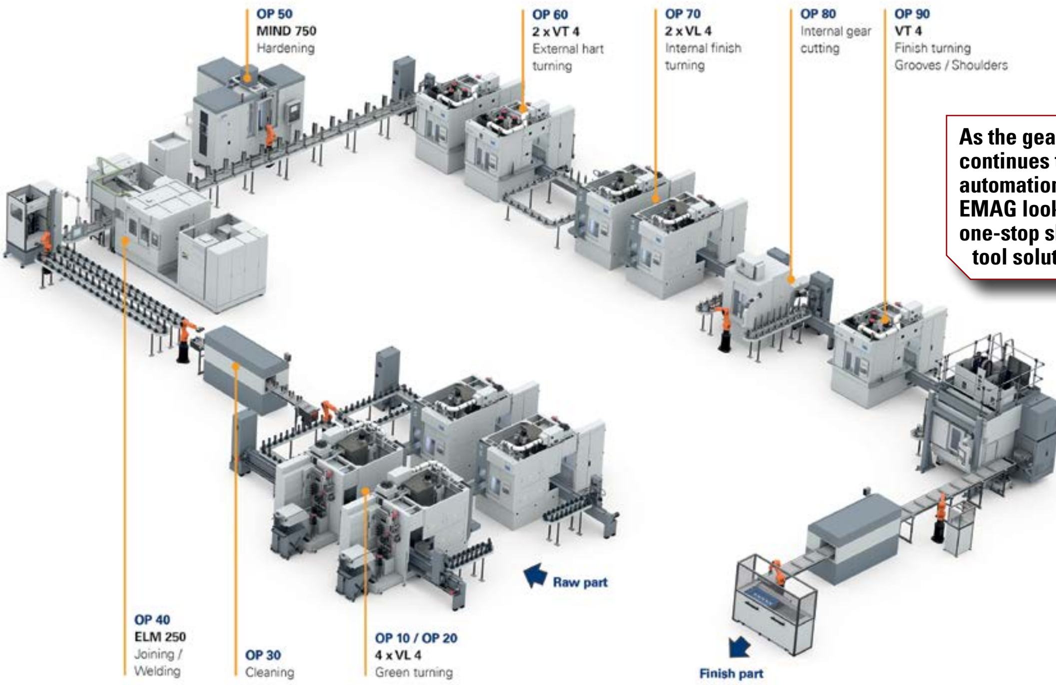
While automation and process reliability is relevant to every aspect of manufacturing, the automotive industry gets special consideration due to the complex systems and production lines required. In short, they need to make gears faster, more efficiently and at the highest level of quality without errors or unnecessary downtime. This is where automation comes into play.

"If you're talking about a factory making 10,000 transmissions a day and there are 30+ gears in that transmission—that's a lot of components to work with," said David Goodfellow, president and CEO at Star SU. "The work needs to be done as quickly and efficiently as possible."

This means combining gear operations together such as hobbing/grinding, hobbing/shaving or hobbing/chamfering and deburring. The challenge becomes moving these parts across production cells, in and out of machine tools, changing workholding, cutting tools, etc. and somehow meeting rigorous deadlines in the process. In some situations, engineers must consider these concepts way back during the design phase of the machine tool.

"Everybody is trying to combine as many operations as possible," Goodfellow added. "Different applications have different requirements, however, so there isn't a single solution that will fit every customer. One of the key developments today is quick change tooling and quick change setups, both a critical part of high-speed automation."

Companies like EMAG, Felsomat,



As the gear industry continues to increase its automation capabilities, EMAG looks to provide a one-stop shop for machine tool solutions.

Gleason, Liebherr and Star SU offer automation technologies across several industries, but the following article will examine those used specifically in the automotive sector in 2018, particularly the benefits, challenges and future considerations.

The Need for Improved Setup Times

Time lost on an automotive factory floor doesn't bold well when it comes to production. Setup time is one area where quick changeover features will help keep everything moving faster and more efficiently.

One way to improve setup time in gear manufacturing is to remove it from other machining operations, according to Matthew Skelton, vice president of sales at Felsomat USA, Inc.

"Since our solutions are decoupled from other machining operations, operators do not need to wait for any other equipment to be free before changing over. This strategy allows them to continue cutting chips on all other machines except the one which is being changed over which means more parts and profit for our end customers," Skelton said.

Felsomat's customers also demand that their new equipment purchases are able to rapidly changeover between part types without tools.

"Our automation solutions are providing our customers with an "on the fly" changeover which requires no operator involvement. This design allow operators to concentrate on any gear production machine tooling changeovers that they may have while making the time between producing the last part to the next new part minimal," Skelton added.

Same goes for Star SU where quick changeovers are pivotal in automotive applications.

"An 8-speed transmission might be used in a passenger vehicle, a light truck or an SUV and they all have different gear ratios," Goodfellow said. "The part changeover requirements need to be completed without using wrenches, hammers, screwdrivers, etc. So we've developed machine tools that will hydraulically release the fixture at the push of a button."

Christian Sterner, chief engineer at

Liebherr Automation combines several gear operations into a single production cell to improve setup times and production.

Gleason Automation Systems believes setup times are improved by technologies such as quick-change gripper fingers, which eliminate the need to turn fasteners with a tool.

"There are further options that allow for quick setup as well – like automatically recalling previous settings by the touch of a button. The automatic purge function will purge the loader of any current part type without the need for manual intervention," Sterner said. "The automatic tool changer also recalls previous tool data and forwards details to the machine tool for instant setup."

In cells where part type changes are frequent, Dan Demlow, vice president, Liebherr Automation System, Co., said that Liebherr's automation systems are capable of using a single reference point that would need to be verified after the tooling changes are complete.

"A simple part type change in the control module by the operator will then complete the setup portion of the automation cell in order to begin machining the new part type selected. Verification with the machine program will be automatic and create a message if the part types do not match between the machine and automation," Demlow said.

External and Internal Automation Options

Automation systems can combine robotics with conveyors, basket stackers etc., but each system greatly depends on the specific needs of the customer.

Sterner said that automotive applications call for the integration of fast internal motions within the machine which allow for minimum chip-to-chip times in high-volume production. External automation can become favorable if simple external end-of-arm tooling can be applied so that only one hand is required to connect to the external handling requirements.

"The ability to tend more than one machine at a time with external automation is key because it is effectively decoupled from the machine tool operation, reducing external automation costs," Sterner said.

With EMAG vertical pick-up machine technology the workholding chuck is used to load the part. The system does not require gantry arms or robots to load and unload workpieces.

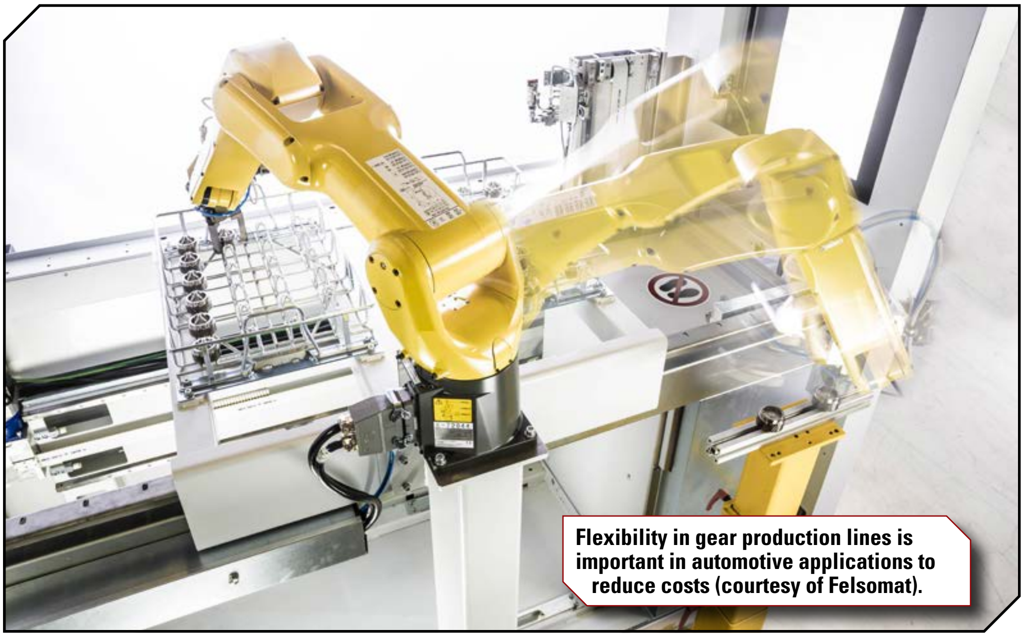
"This pick-up solution tied with our Trackmotion systems allows complete flexibility in gear production lines. Part marking systems, post-process inspection gauging, part buffers can be easily added to the system. For infeed –e step feeding systems can be integrated to work with our Trackmotion. Also traditional stacker tables can be used for those larger gears or blanks which are pre-turned. For outfeed we offer stacker tables or gears can be placed on outbound conveyors. If next operation is an external heat treatment EMAG also offers systems which can stack parts into racks," said Jeff Moore, regional sales manager, Canada at EMAG.

As processing cycle times for gear production continue to be reduced, no concerns with coolant or oil escaping from the machine which allows us to offer the most compact solutions for our customer's applications," Skelton said.

"Usually cycle times are very critical with gear manufacturing. Any time you can decouple movements from the gear cutting process and concentrate machining activities within the machine and do peripheral activities outside of the machine (deburring, blow-off, gaging) using automation; it increases overall productivity," added Demlow at Liebherr.

Goodfellow believes that both external and internal automation strategies are worth consideration.

"The automation system in an automotive plant needs to be robust enough to manage every aspect of gear production. We have to be able to connect to the machine, get the part in and out or



Flexibility in gear production lines is important in automotive applications to reduce costs (courtesy of Felsomat).

Felsomat aims to be as close as possible to the machine spindle with internal automation. "This close proximity allows us to reduce automation content and floor space requirements for our customers," Skelton said.

Felsomat believes in this automation concept so deeply, it has developed a line of dry hobbing, turning, and welding machines with this principle in mind.

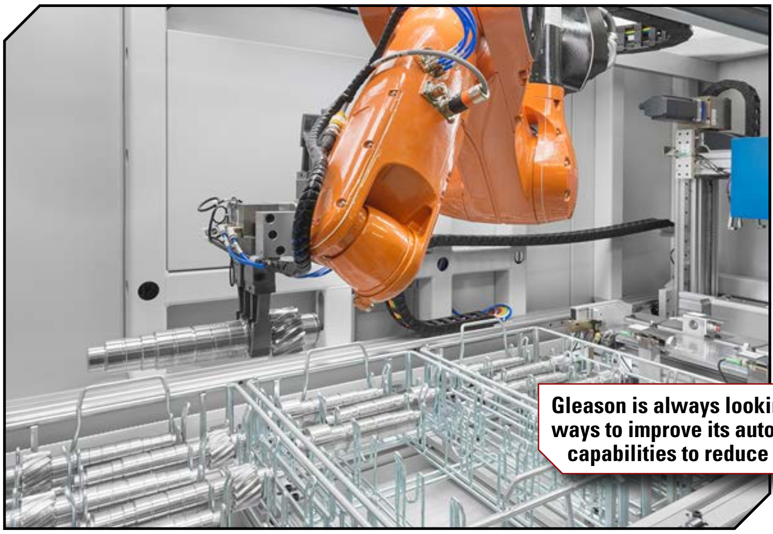
"Our two spindle machines have been designed with automation in mind. Since these processes are dry, there are

in a queue so that the machine is never sitting and waiting for a part. The structure of our SG 160 Skygrind best illustrates this where you have two spindles actuated by linear motors and a chip-to-chip time less than two seconds," he said.

How Smart is the System?

As is the case with every other aspect of manufacturing, smarter automation or intelligent automation holds the key to gear manufacturing in the future.

"In 2018, we are making automation



Gleason is always looking for ways to improve its automation capabilities to reduce costs.

systems more efficient by closing the loop between them. For example, our machines can talk to metrology machines and streamline the connection between such systems. Data is transferred directly - simple and fast. This reduces errors and provides time savings which ultimately leads to productivity gains," said Sterner.

In the future, Sterner sees automation systems having capabilities to diagnose and predict failures to reduce unplanned downtimes. This involves collecting, monitoring and analyzing the right data to be able to see patterns that indicate potential issues.

Moore at EMAG says that Industry 4.0 is all about networking – networking between several system components on one hand, and networking between machines and the people who direct the value chain on the other. "Focus areas include monitoring, analytics, evaluation , control, service and maintenance," Moore added.

"Industry 4.0 initiatives have only begun to affect automation systems and manufacturing in general. In the future, all of this data that can and will be collected will allow manufacturers to better reduce downtime and inventory of spare parts as they are able to see failures arising faster as well as allow them to see the availability from their suppliers of the spare parts they need. Automation equipment will be fixed faster in the future as self-diagnosis in some cases will eliminate the need for a technician to come in and trouble shoot many automation downtime issues. The need for internet access security will also become important as manufacturers must avoid the possibilities from remote contact to their equipment affecting machine uptime and efficiency," said Skelton at Felsomat.

Wireless and remote capabilities are also on the rise, according to Demlow.

"Our systems are equipped with optional scheduling capabilities that allow the system to optimize spindle utilization of the manufacturing machines. Remote access is possible to reconfigure these schedules and provide immediate feedback to current conditions within the system (i.e. tool life, tool availability, cycle status, etc). Wireless capabilities may soon make it possible to do these functions with an app on your phone by authorized users if desired."

Taking the Next Step in Automation

Each company is looking at ways to improve automation solutions in the coming years. Manufacturing can expect troubleshooting tools built into automation systems approaching Al-like capabilities, an increase in the use of collaborative robots and shrinking footprints by the elimination of guarding. Expect a significant increase in the use of AGVs (automated guided vehicles) to handle material flows on the shop floor.

"We see a clear trend to automated solutions to reduce cost and minimize error sources. At the same time, we see a cleaner and safer environment with more visual information at the fingertips of operators and supervisors. Information technology supported by 4.0 initiatives will support closed loop manufacturing," Sterner said.

EMAG has seen the global auto industry pushing suppliers to decrease mass and reduce the overall size of driveline systems, specifically differentials. Lightweight construction in the automotive industry is a fight for every pound.

"More of today's automobiles are offering an all-wheel drive or on demand four wheel drive system that require an added differential. CVT transmissions are becoming increasingly popular in the American and Asian markets. And with industrial megatrends including electromobility we're positioned to meet the demands of our customers. Transmission manufacturing is among the most innovative areas of passenger vehicle production," said Moore.

Demlow at Liebherr believes the current environment of the manufacturing sector could use more automation capabilities.

"Low unemployment leaves companies with unfulfilled opportunity because of the lack of personnel. Automation provides solutions that can be operated with minimal human interaction and can increase production during off shifts and weekends with "lights-out" capabilities," Demlow said.

In the end, the technology will need to adapt to the trends of the automotive industry. No one knows for sure how that's going to look down the road.

"Electric vehicles are coming. The gears will still need to be high-quality, but there will not be as many. This is going to be a big change for us in the gear industry," Goodfellow said. "How these vehicles look 20 to 30 years from now will determine how our solutions might change in the future."

For more information:

EMAG LLC USA
Phone: (248) 477-7440
www.emag.com

Felsomat USA, Inc.
Phone: (847) 995-1086
www.felsomat.de

Gleason Corporation
Phone: (585) 473-1000
www.gleason.com

Liebherr Gear Technology, Inc.
Phone: (734) 429-7225
www.liebherr.com

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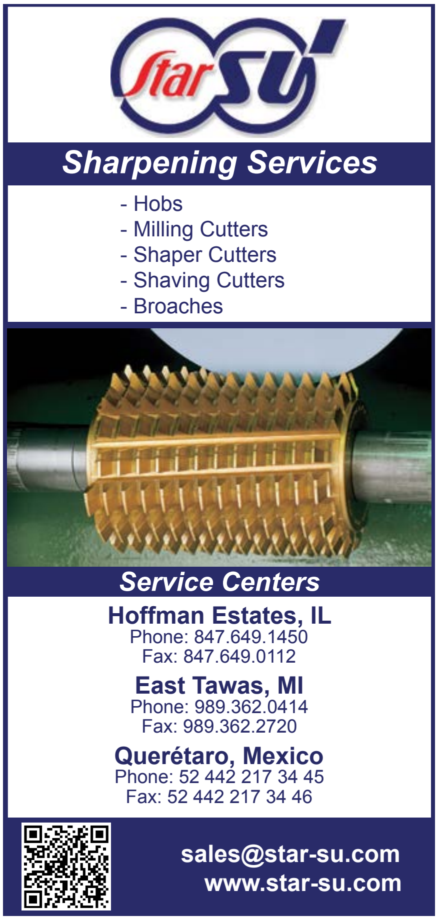
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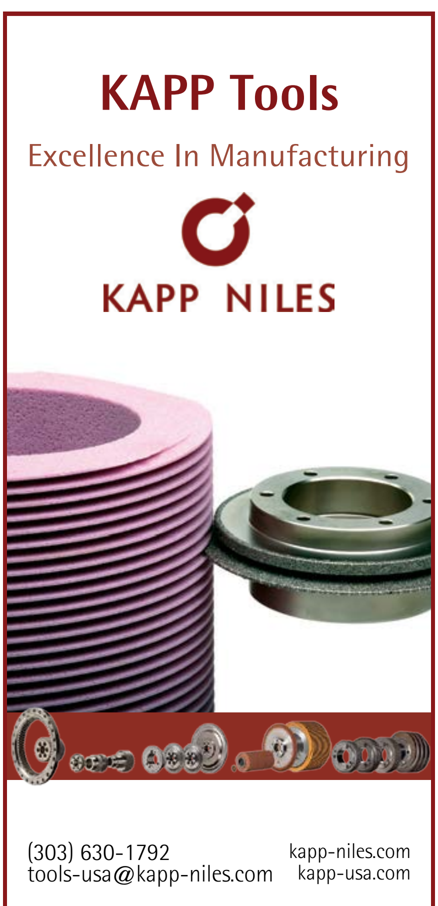
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Calculated Gear Life Values

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

I have a query (regarding) calculated gear life values. I would like to understand for what % of gear failures the calculated life is valid? Is it 1-in-100 (1% failure, 99% reliability) or 1-in-one-thousand (0.1% failure)?

Expert response provided by Hanspeter Dinner, gear consultant and KISSsoft representative in Asia:

In gear rating per ISO, DIN or AGMA standards, permissible stresses for a required life or cycle number are calculated from the S-N curve. The S-N curve itself is determined along procedures described in the mentioned standards, using just a few values (e.g., the endurance limit and the material type) to describe the S-N curve. The basis of the S-N curve is measurements done at different gear labs, e.g. — at the Technical University of Munich — where gear strength was measured both for finite and infinite life.

The original S-N curves, as measured, are based on probability of failure of $P_a = 50\%$. Obviously, this high probability of damage is not suitable for a gear design in most cases and the S-N curves included in the mentioned standards have a far lower probability of damage or higher reliability. There, the basis is a probability of damage of $P_a = 1\%$ for a safety factor of $S = 1.00$. This means that if a safety factor of $S = 1.00$ is used, one out of 100 gears should fail by design within its design life for the rated load.

This probability of damage of $P_a = 1\%$ may be higher than acceptable or it may be lower than necessary. If it is too high, (as in a helicopter transmission, where the consequence of failure is catastrophic), a safety factor $S > 1.00$ should be introduced, thus reducing the allowable stress number. If it is lower than required (as in a gearbox of a low-cost power tool), higher allowable stress numbers may be introduced in the gear design, resulting in smaller gears at lower cost and accepting a higher probability of damage.

It is therefore of interest to convert allowable stress numbers — as listed in gear rating standards for probability of damage $P_a = 1\%$ or reliability $P_ü = 99\%$ — to other reliability levels. While the AGMA 2001 series includes a factor K_R for this conversion, DIN 3990 and ISO 6336 do not. Some guidelines are provided below on how values can be converted to different levels of reliability for ISO 6336 (and DIN 3990), based upon the scattering of strength values as given in the listed references and some statistics.

The S-N Curve for Root and Flank Strength

The concept of the S-N curve. S-N curves are measured for a probability of survival or reliability level of $P_ü = 50\%$. Correspondingly, the probability of damage is of the same value — $P_a = 50\%$. They are measured with a scatter in terms of achieved life at a constant stress in the limited life domain (where the curve has a slope p and a scatter in terms of achieved stress level for long life (where gears in test no longer fail), expresses as the standard deviation of the allowable stress number σ (Fig. 1). The scatter in terms of achieved life is far greater than the scatter in terms of achieved stress for long life. The

Abbreviations and symbols

Abbreviation	For
σ	Standard deviation
σ	Stress
σ_{Flim}	Allowable stress number, root, ISO definition
σ_{Hlim}	Allowable stress number, flank, ISO definition
AGMA	American Gear Manufacturers Association
CHD	Case hardness depth
DIN	Deutsches Institut für Normung
f_{xF}	Factor for conversion of allowable stresses for different reliabilities, root
f_{xH}	Factor for conversion of allowable stresses for different reliabilities, flank
ISO	International Organization for Standardization
K_R	Reliability factor along AGMA 2001
ME	Material quality level, highest level
ML	Material quality level, lowest level
MQ	Material quality level, normal level
p	Life exponent, slope of the S-N curve in the limited life domain
P_a	Probability of failure
$P_ü$	Probability of survival, reliability
S	Safety factor
s_{ac}	Allowable stress number, root, AGMA definition
s_{at}	Allowable stress number, flank, AGMA definition
S-N	Stress – cycle curve
Y_Z	Reliability factor along AGMA 2101
z	Standard score for normal distribution

comments below are valid for the long-life domain.

If a large number of measurements is available, S-N curves — not only for $P_ü = 50\%$ — may be determined, as may, for example, $P_ü = 10\%$ and $P_ü = 90\%$ as lower and upper bound. Alternatively, S-N curves for other reliability levels may be estimated from the S-N curve for $P_ü = 50\%$ and a standard deviation σ based on literature (which should then be based on a large population of other tests). Factors to convert the S-N curve, or rather the allowable stress number for root and flank, from one reliability level to another, have been reported (Refs. 6–11) and are explained in the following text.

Probability of damage in ISO 6336, S-N curve. Allowable stress numbers for the flank and the root, σ_{Hlim} and σ_{Flim}, as given in ISO 6336-5 (Refs. 1–2), are valid for 1% probability of damage P_a. Probability of survival (or reliability) is therefore $P_ü = 1 - P_a = 99\%$. This value is applicable for a safety factor of S = 1.00.

As per ISO 6336-5:2016 (Ref. 2), it is permissible to use σ_{Hlim} and σ_{Flim} values for other reliability levels. It is stated that "statistical analysis enables adjustment of these values in order to correspond to other probabilities of damage." It continues, "When other probabilities of damage (reliability) are desired, the values of σ_{Hlim}, σF_{lim} and σ_{FE} are adjusted by an appropriate "reliability factor." When this adjustment is made, a subscript shall be added to indicate the relevant percentage (e.g., σ_{Hlim10} for 10% probability of damage)." It is recommended to use methods described in ISO 12107 (Ref. 3) for this.

ISO 6336 does not give further guidelines on how to calculate allowable stress numbers for other reliability levels. No formulas or factors are given for a conversion of the allowable stress numbers from, for example, 1% to 10% probability of damage.

Reliability factor in AGMA 2001. Allowable stress numbers in this standard "are determined or estimated from laboratory tests and accumulated field experiences. They are based on unity overload factor, 10 million stress cycles, unidirectional loading and 99 percent reliability." This means that the probability of damage associated with the S-N curves is the same as in ISO 6336 and DIN 3990.

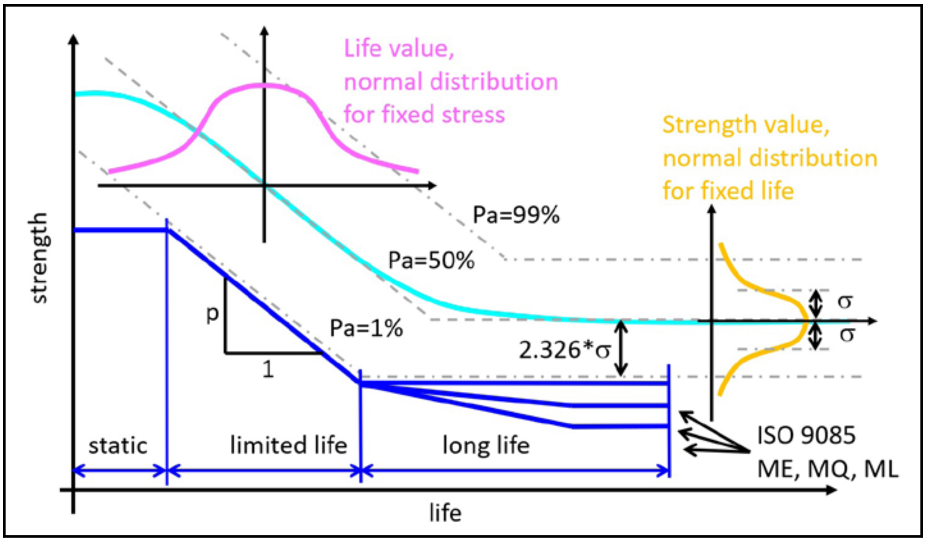

Figure 1 **Measured S-N curve for a probability of damage of P_a = 50% (cyan). S-N curves along ISO 6336 for probability of damage P_a = 1% (blue). Normal distribution of life in the limited life domain (pink). Normal distribution of endurance limit in the long life domain (yellow).**

The AGMA 2001 series (Refs. 4–5) is, however, more detailed in this regard; they include a factor that allows for gear rating for different reliability levels. A reliability factor K_R (Y_Z in AGMA 2101; Ref. 5) is introduced; it may be used to modify allowable stresses for another reliability level. The numbers are reportedly based on data developed by the U.S. Navy (Table 1).

The allowable stress number for root s_{at} and for flank s_{ac} for a desired reliability is then calculated from the s_{at} or s_{ac} value, as listed in the AGMA standard (valid for $P_a = 1\%$) divided by above reliability factor K_R. The reliability factor increases in a more or less linear fashion if reliability is increased in orders of magnitude (Fig. 2).

Allowable Stresses for Different Reliability Levels

Conversion of allowable stress numbers to reliability levels other than 50%. The data derived from measurements at $P_ü = 50\%$ needs to be transformed to a probability of survival of $P_ü = 99\%$, as used in ISO 6336 (or DIN and AGMA standards). The allowable stress numbers σ_{Hlim} for flank and σ_{Flim} for root for a probability of damage of 50% may be converted to a probability of damage of x% using factors f_{xH} and f_{xF} as follows (Ref. 9):

$$\sigma_{Hlim}(P_ü = x\%) = \sigma_{Hlim}(P_ü = 50\%) * f_{xH}$$
$$\sigma_{Flim}(P_ü = x\%) = \sigma_{Flim}(P_ü = 50\%) * f_{xF}$$

Values for f_{xH} and f_{xF} are listed (Tables 2 and 3) for x% = 99%. Values are taken from different sources (all of them originating from Germany) but they probably are based on the same data basis.

The standard deviation σ of the measured allowable stress number σ_{Hlim} for flank is reported (Ref. 10) at $\sigma = 2.8\%$ (for higher case hardness depth [CHD]) and $\sigma = 4.3\%$ (for lower CHD). For the allowable stress number σ_{Flim} for root the values reported are $\sigma = 3.4\%$ for shot peened gears and $\sigma = 6.0\%$ for non-shot peened gears. (*Be careful to note that the same symbol σ is used to denote the standard deviation and stress!*) This is in line with values reported (Ref. 12) for shot peened gears, where the standard deviation of the allowable stress number for the root σ_{Flim} is $\sigma = 3\%$. Note that these values are applicable for the "long life" section of the S-N curve.

An example calculation. Let us consider an example. Assume that $\sigma Flim = 500$ MPa (i.e. — a case-carburized gear with high core strength, quality grade MQ; see ISO 6336-5, Fig. 10, line "MQ, a"). This means that only 1% of the gears will have a strength lower than 500 MPa and 99% of the gears will have a strength higher than 500 MPa. Let us use the abovementioned standard deviation of $\sigma = 6\%$ (for non-shot peened gears, which is the underlying assumption in ISO 6336-5, Fig. 10).

Assuming normal distribution, we know the negative z-score for $P_a = 1\%$ ($P_ü = 99\%$) is $z = -2.326$ (use a "negative z score table," e.g. — from Ref. 13 to find this value). This means that between the mean value for σ_{Flim} with $P_ü = 50\%$ (as originally measured in experiments) and the value for σ_{Flim} with $P_ü = 99\%$, a distance of -2.326*σ exists. (See Fig. 1 black vertical arrow between grey lines denoting S-N curve for $P_a = 50\%$ and $P_a = 1\%$. Or: σ_{Flim} ($P_ü$ = 99%) = σ_{Flim} ($P_ü$ = 50%) -2.326*6%*σ_{Flim} ($P_ü$ = 50%), giving σ_{Flim} ($P_ü$ = 99%) = 0.86*σ_{Flim} ($P_ü$ = 50%).

From this we find the value σ_{Flim} ($P_ü$ = 50%) = σ_{Flim} ($P_ü$ = 99%)/0.86 = 50 0 MPa/0.86 = 581 MPa. See the vertical orange, dashed line (Fig. 2) indicating the mean value for the allowable stress number, root, of 581 MPa. The standard deviation σ is 6% thereof (assuming gears are not shot peened) σ = 35 MPa (see horizontal blue arrow (Fig. 3)).

The distance between this mean value for the allowable stress number, σ_{Flim} ($P_ü$ = 50%) = 581 MPa, and the value for $P_a = 1\%$ (as used in ISO 6336) is 2.326*σ = 2.326*35 MPa = 81 MPa; it is indicated in cyan color (Fig. 3).

Thus the above factor $f_{xF} = 0.86$ is nothing but: $f_{xF} = 1 + z$ (P_a = 1%)*σ = 1–2. 326*0.06 = 0.86 (note $z < 0$)

If we now want to determine σ_{Flim} ($P_ü$ = 90%), as sometimes used, for instance, in vehicle transmission design, we find the z-score (Ref. 13) for $P_a = 10\%$ is $z = -1.282$. From this we find σ_{Flim} ($P_ü$ = 90%) = σ_{Flim} ($P_ü$ = 50%)– 1.282*6%*σ_{Flim} ($P_ü$ = 50%) = 581 MPa*(1– 1.282*0.06) = 536 MPa. (Fig. 3) indicating this value and the horizontal pink arrow of length |z|*σ = 1.282*35 MPa = 44.7 MPa).

Comparison and recommendations. We have calculated the allowable stress number for the root for $P_a = 10\%$ at σ_{Flim} ($P_ü$ = 90%) = 536 MPa for a case carburized, non-shot peened case. This was done by using the base line value σ_{Flim} ($P_ü$ = 99%) = 500 MPa along ISO 6336 and conversion factors based on the standard deviation of the measured strength values.

Table 1 Reliability factor K_R along AGMA 2001

Requirements of application	Reliability factor K_R
Fewer than one failure in 10,000	1.50
Fewer than one failure in 1,000	1.25
Fewer than one failure in 100	1.00
Fewer than one failure in 10	0.85
Fewer than one failure in 2	0.70

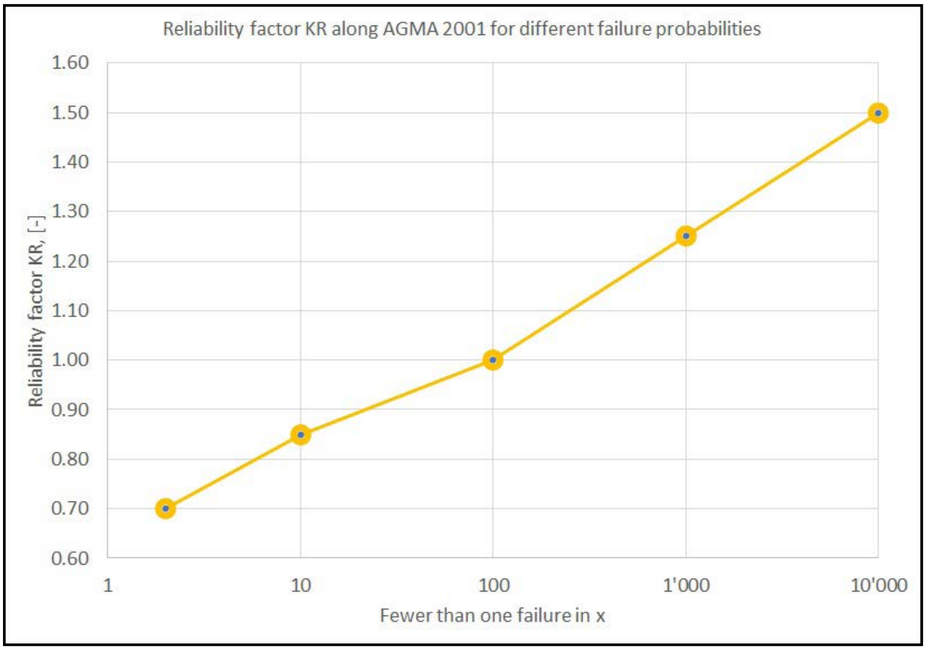

Figure 2 Reliability factor KR along AGMA 2001; reference value is K_R=1.00 for less than one failure in 100, or a reliability of 99%.

Now let us compare this value with the value determined along the AGMA approach. There, $K_R = 0.85$ for the conversion from $P_a = 1\%$ to $P_a = 10\%$ is applicable (Table 1). If we apply this factor to the allowable stress number (per ISO notation), σ_{Flim} ($P_ü$ = 90%) would then be σ_{Flim} ($P_ü$ = 90%) = σ_{Flim} ($P_ü$ = 99%)/ K_R = 500 MPa/0.85 = 588 MPa. This value is higher than the value of 536 MPa reported earlier in this presentation, and so is, best-case — less conservative, and worst case — unsafe. While it cannot be determined whether the literature cited or AGMA 2101 is more trustworthy, there is indication that at least the values for K_R should be used with caution.

ISO 6336 also cautions the user of such reliability factors. While it allows their use, it also states that "such adjustments need to be considered very carefully and may require additional, specific tests or detailed documentation of the source of the information used to derive the confidence level of the failure probabilities." This means that for the average gear engineer, "tuning" that results by "playing" with different reliabilities is not encouraged.

Table 2 Factor f_{xF} to convert allowable stress numbers, root, for $P_ü$ = 50% to other reliability levels, according to different sources

	Factor for root, f_{xF}	Reference
case hardened gears	0.86, for $P_ü$ = 99%, not shot peened	[6], average value read from graph
Unhardened gears	0.90, for $P_ü$ = 99%, not shot peened	[6] , average value read from graph
Case hardened gears	0.86, for $P_ü$ = 99%, not shot peened	[9] , average value read from graph
Unhardened gears	0.90, for $P_ü$ = 99%, not shot peened	[9] , average value read from graph
FVA guideline	0.86, for $P_ü$ = 99%, not shot peened 0.92, for $P_ü$ = 99%, shot peened	[8], tabulated value

Table 3 Factor f_{xH} to convert allowable stress numbers, flank, for $P_ü$ = 50% to other reliability levels, according to different sources

	Factor for flank, f_{xF}	Reference
Different materials, ground gears	0.84…0.90, for Pü = 99% 0.91…0.95, for Pü = 90% 0.05…1.08, for Pü = 10%	[7] , tabulated values

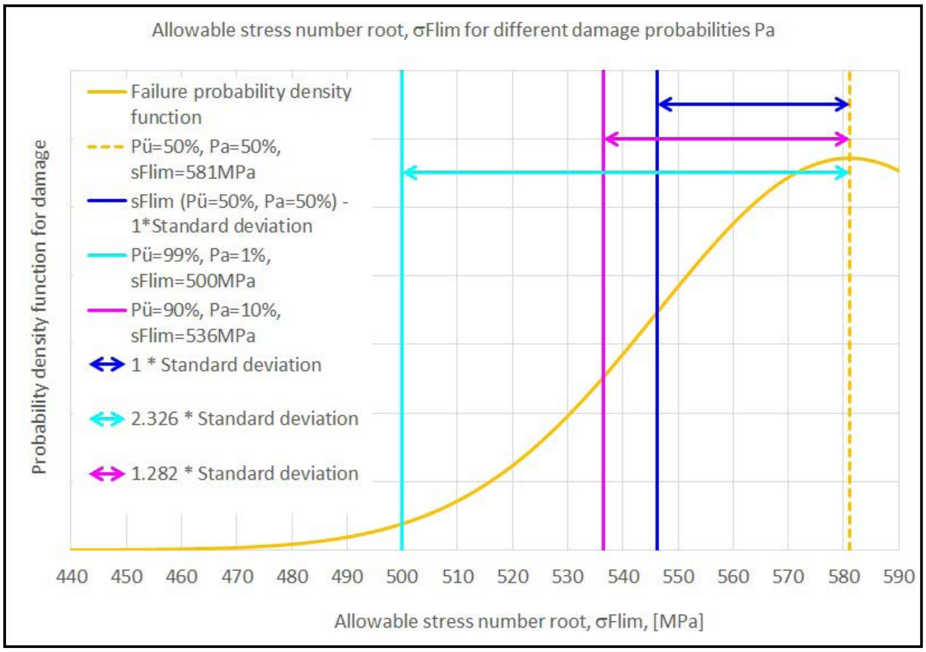

Figure 3 **Normal distribution of the allowable stress number, resulting allowable stress number for different probability of damage; standard deviation of the distribution.**

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Hanspeter Dinner works as a gear consultant and represents KISSsoft in Asia. His firm EES KISSsoft GmbH is located in central Switzerland but frequent travels find him in places like India, Korea, China, Japan, Singapore and all over Europe. After his studies in Zürich and Singapore on biomedical engineering, he worked with engineering consultancies doing FEM calculations. He joined KISSsoft AG as support and project engineer, giving trainings on the software and pushing international sales. As head of sales at KISSsoft AG, he built up the software business in Asia. Ten years ago, he started his own company and has since managed some 100 gear projects, ranging from plastic gear optimization for kitchen appliances to 6MW wind turbine gearboxes. Other areas of interest include large bearings, FEM analysis and tractor transmissions.

Prediction of Dynamic Factors for Helical Gears in a High-Speed Multibody Gearbox System

Niranjan Raghuraman, Dr. Sharad Jain and Chad Glinsky

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Introduction

Accurate prediction of gear dynamic factors (also known as K_v factors) is necessary to be able to predict the fatigue life of gears. Standards-based calculations of gear dynamic factors have some limitations. In this paper we use a multibody dynamic model, with all 6 degrees of freedom (DOF) of a high-speed gearbox to calculate gear dynamic factors. We investigate the influence of system dynamics, model fidelity, operating speed, and torque on dynamic factors. We also determine if torsional-only dynamic models that are commonly used to study gear dynamics are adequate to predict gear dynamic factors. The effect of manufacturing errors like shaft runout, tooth spacing error on the dynamic behavior of the system are also studied in this paper to show the importance of tolerance and accuracy in the manufacturing process. The findings from this paper will help engineers to understand numerous factors that influence the prediction of dynamic factors and will help them to design more reliable gears.

Dynamic tooth loads influence the durability of gears, particularly at high speeds. The gear rating standards consider the effect of dynamic tooth loads on gear durability by multiplying the quasi-static stress by a dynamic factor (also known as K_v factor). Accurate calculation of dynamic factor is important to be able to assess the durability of a gear. Standards-based calculation of dynamic factor only considers the influence of operating speed and gear manufacturing quality. The influence of torque and system resonance modes is generally ignored.

In this paper we analyze the influence of operating speed, torque, and system dynamics on the dynamic factors of a high-speed gearbox. We show that the dependence of dynamic factor on torque is significant and must not be ignored. We also show that the system effects are important and that the presence of system resonance modes increases dynamic factors. The dynamic factors calculated in this study are compared with the dynamic factor values suggested by ISO and AGMA standards.

We perform the analysis using a multibody dynamic model of a high-speed gearbox. The model includes shafts, bearings, and helical gears. Traditionally, multibody models with only torsional degrees-of-freedom are used to calculate dynamic gear forces. These models only consider the torsional dynamics of the system and ignore the shaft bending and lateral deflections. In this study, we investigate the influence of shaft bending and lateral deflections on the dynamic factors, particularly at high speeds.

We also look at the effect of manufacturing errors like shaft runout, tooth spacing error on the dynamic behavior of the system to assess the importance of quality grades and accuracy of the gears.

This study will help engineers: (a) to understand the effect of various operational and design parameters on gear dynamic factors; (b) to identify the limitations of standards-based dynamic factor calculations; (c) to create multibody dynamic models which are appropriate for dynamic factor calculations by considering all the relevant physics; (d) to improve gear durability for high-speed applications.

System to Analyze

For this study we chose a high-speed electric-vehicle gearbox with two helical gear stages to perform our investigations. The gearbox consists of an input shaft, intermediate shaft, and output shaft connected by two gear pairs (Fig. 1). All three shafts are supported by rolling element bearings. Input shaft is driven by an electric motor. The rotor of the electric motor is mounted on the input shaft. The output shaft is essentially a differential, but to simplify, the side pinions and side bevel gears are not captured in the model. Since the vehicle is driven by the output shaft, a high inertia ($2\,kgm^2$) is appended to the output shaft to represent the vehicle inertia. The gear geometries of the input and output gear pairs are tabulated in Tables 1 and 2.

To calculate gear dynamic factors, we create a multibody dynamic model of the system described above. In the dynamic model all the shafts are discretized into Timoshenko beam elements. Gear blanks are treated as rigid discs. Gear-mesh compliance is modeled using a linear spring, acting along the line-of-action. Gear mesh compliance is more complicated, as it includes a tooth bending stiffness term that changes with the location of contact line along tooth height and a nonlinear contact stiffness term. The rotor of the electric motor is modeled as a rigid disc directly connected to the input shaft. The electromagnetic interaction between the rotor and stator is ignored in this study. It is important to capture the mass and inertia of the rotor to accurately predict the dynamic behavior of the system. The bearings are represented

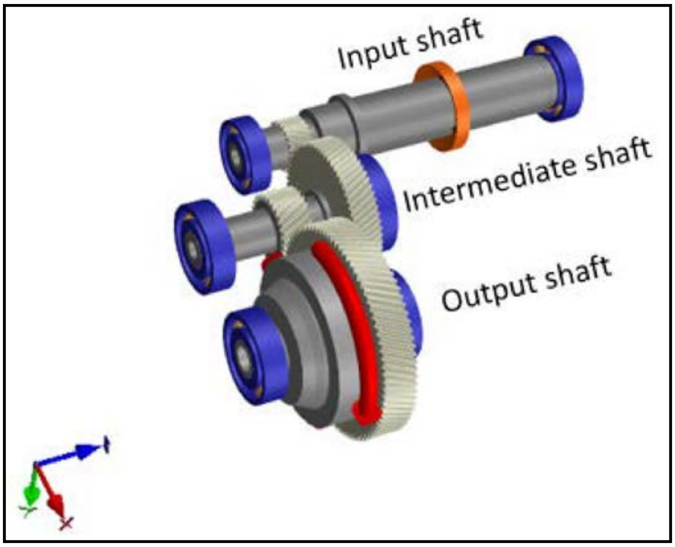

Figure 1 Layout of the gearbox.

Table 1 Input gear mesh geometry

Parameter	Gear 1	Gear 2
No. of teeth	22	65
Module (mm)	1.63	
Pressure angle (deg)	22	
Helix angle (deg)	25	
Outside diameter (mm)	43.15	119.43
Root diameter (mm)	34.29	111.78

Table 2 Output gear mesh geometry

Parameter	Gear 1	Gear 2
No. of teeth	22	65
Module (mm)	1.63	
Pressure angle (deg)	22	
Helix angle (deg)	25	
Outside diameter (mm)	43.15	119.43
Root diameter (mm)	34.29	111.78

as linear springs with constant stiffness matrices. The bearing stiffness matrices and gear mesh stiffness values are obtained from the *RomaxDESIGNER* (Ref. 1) software for different torque levels. The bearing stiffness calculation in *RomaxDESIGNER* is based on a nonlinear contact model that considers internal clearances, the local elastic deformation of the rolling elements and raceways and system-level effects such as raceway misalignments. The gear-mesh stiffness calculation in *RomaxDESIGNER* also uses a detailed mathematical model that includes tooth bending stiffness and nonlinear contact stiffness. The output of this calculation is a mesh stiffness that is the function of gear rotation angle. In this paper, we just take the mean value of this fluctuating mesh stiffness to model the gear-mesh compliance. This is not unreasonable because we do consider the fluctuating nature of mesh stiffness by applying a transmission-error excitation, which is described in the next section. A 5% modal damping is used for all the dynamic simulations presented in this paper.

Modeling Transmission Error Excitation

To calculate the gear dynamic factors from our multibody dynamic model, we apply transmission error (TE) excitations to all the gear meshes. Transmission error is caused by numerous factors, including variation in the tooth compliance as the contact point moves along the tooth height; change in the mesh stiffness as the number of teeth in contact change; any tooth profile modifications; and manufacturing errors. In this study we use the *RomaxDESIGNER* software to calculate the static transmission error for all the gear meshes for various torque levels. These static transmission errors are then used to excite the multibody dynamic model of the system (Fig. 2). The method of using static transmission errors to excite a dynamic model has been widely used in the literature (Ref. 2).

Load Cases to Analyze

An analysis of four different torque levels is conducted, as shown in Table 3. These are torques acting on the input shaft. The speed of the input shaft is varied from 0 rpm to 18,000 rpm, which is maximum operating speed of the electric motor.

For each of the torque levels, the dynamic factors are computed using our multibody dynamic model mentioned above and are compared with the dynamic factors predicted by ANSI/AGMA 2001-D06 (Ref. 3) and ISO 6336 (Ref. 4) standards.

Table 3 Torque levels

Loading side	Torque (Nm)
Drive	50
Drive	80
Drive	120
Drive	160

Gear Dynamic Factor Results and Discussion

The dynamic factor results presented in this section are based on the following definition:

$$\text{Dynamic factor} = \frac{\text{Dynamic mesh force}}{\text{Static mesh force}}$$

Static mesh force is the force acting

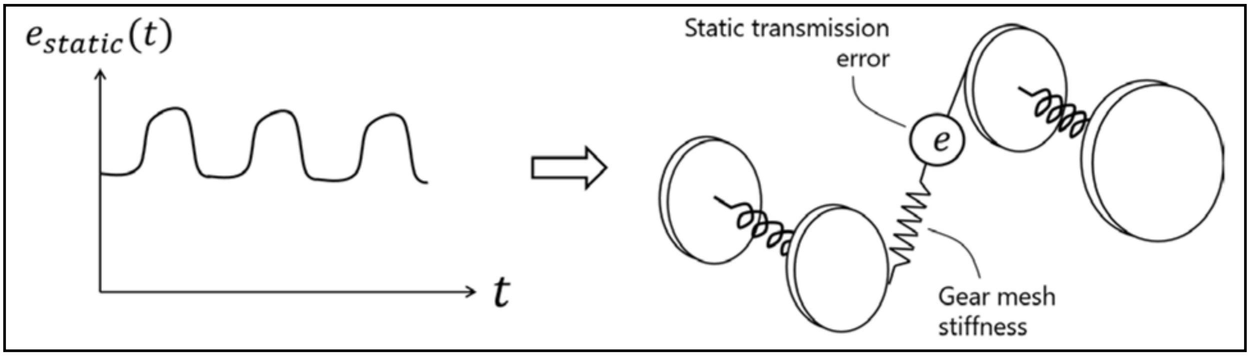

Figure 2 Inclusion of static transmission error as source of excitation of the dynamic model.

in the line-of-action of a gear mesh in a static equilibrium condition. Dynamic mesh force is the sum of static mesh force as well as dynamic fluctuations in the mesh force caused by the transmission-error excitations.

Influence of system effects on dynamic factors. To study the influence of system effects on gear dynamic factors, let us first consider the 50 Nm load case. The static transmission error trace for one mesh cycle for a drive torque of 50 Nm is shown in Figure 3. The peak-to-peak values are 2.86 µm and 0.96 µm for the input and output meshes, respectively.

These static transmission error traces are used to excite the multibody dynamic model of the system. The dynamic model includes 6 DOF for all the components in the system. Figure 4 shows the dynamic factors for the input and output gear meshes for an input torque of 50 Nm in the drive direction predicted by a 6 DOF dynamic model.

The dynamic factors for the input gear mesh are higher than that of the output gear mesh because of the following two reasons:

a) The peak-to-peak variation in the static transmission error is higher for input mesh than output mesh. Since the static TE acts as the source of excitation, a higher TE will produce a higher response.
b) The tooth-passing frequency for the input gear mesh is higher than the output mesh. Therefore the input gear mesh will excite more system resonances than output mesh within a given operating speed envelope.

The dynamic factors predicted from our simulations in Figure 4 show a number of peaks at various operating speeds for both input and output gear meshes. These peaks are caused by the excitation of system resonance modes. For a given speed, if the tooth-passing excitation frequency (or its higher harmonics) of a gear mesh is close to a system resonance mode, then that mode will become excited. The excitation of a resonance mode might increase the dynamic response at gear meshes, which will result in higher dynamic factor.

The red and blue circles in Figure 4 highlight the peaks that occur at input shaft speeds of 5,910 rpm and 13,600 rpm, respectively. The corresponding dynamic factors are 1.08 and 1.13, respectively. Figure 5 shows the mode shape corresponding to the resonance speed of 5,910 rpm.

The peak in the dynamic factor at 5,910 rpm is due to a combination of torsional and bending modes (Fig. 5). At

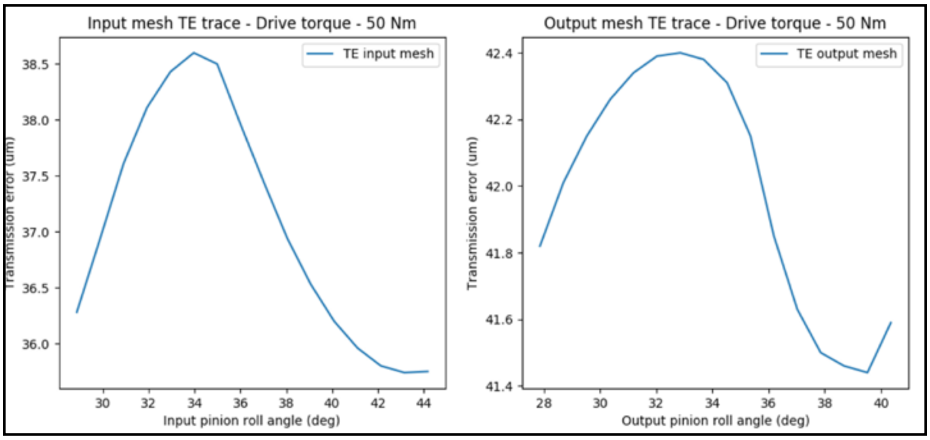

Figure 3 Static transmission error trace for 50 Nm input drive torque for the two gear meshes.

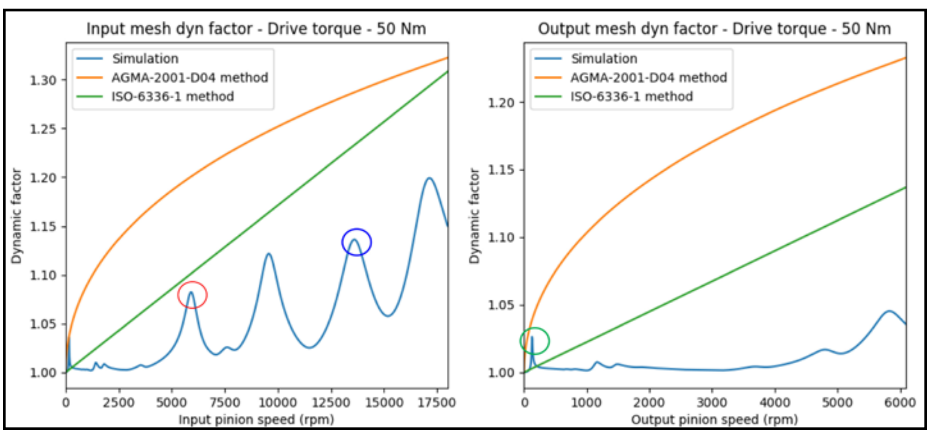

Figure 4 Dynamic factors for input torque of 50 Nm for two gear meshes. The factors are calculated using three methods: (a) multi-body simulation (blue); (b) AGMA standard (orange); (c) ISO standard (green).

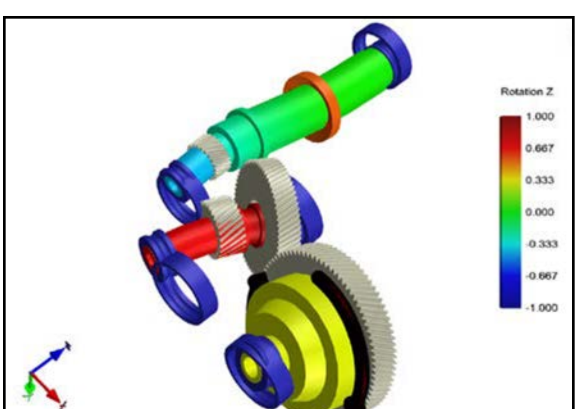

Figure 5 Mode shape corresponding to resonance speed of 5,910 rpm.

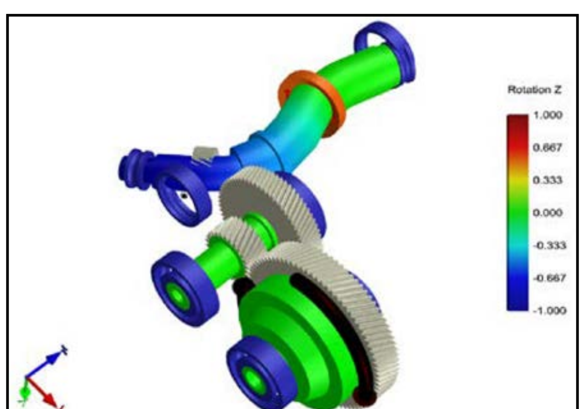

Figure 6 Mode shape corresponding to resonance speed of 13,600 rpm.

the input gear mesh node, the normalized rotational displacements (θ_Z) are in the opposite directions for the input shaft and intermediate shaft, respectively, which causes a reinforcing action followed by a spike in the dynamic force. The peak in dynamic factor is influenced by both bending and torsion modes, with a slightly higher contribution from torsional mode. This illustrates the importance of the inclusion of all degrees of freedom in the dynamic model.

Figure 6 shows the mode shape (normalized displacements in x, y, z, and θ_z directions) at the input resonance speed of 13,600 rpm, highlighted by the blue circle in Figure 4.

Contrary to the previous mode shape at 5,910 rpm (Fig. 5), the contributions from the bending modes to the dynamic factor at 13,600 rpm are low, indicating that the torsional mode is the major contributor to the dynamic factor. Using a similar approach, the modal contributions can be studied for every local maximum in the dynamic factor.

The output gear mesh exhibits a peak in the dynamic factor at the resonance speed of 160 rpm (Fig. 4). Figure 7 shows the mode shape of the three shafts corresponding to this resonance speed. The intermediate shaft exhibits a torsional mode (normalized θ_z ~1) while the output shaft shows no torsional mode. The output shaft drives the vehicle with a high polar inertia, making it resistant to any torsional vibration, although few bending modes can be observed at certain natural frequencies. The intermediate shaft also moves in the axial direction, relative to the other two shafts, which also contributes to the dynamic factor at that mesh frequency.

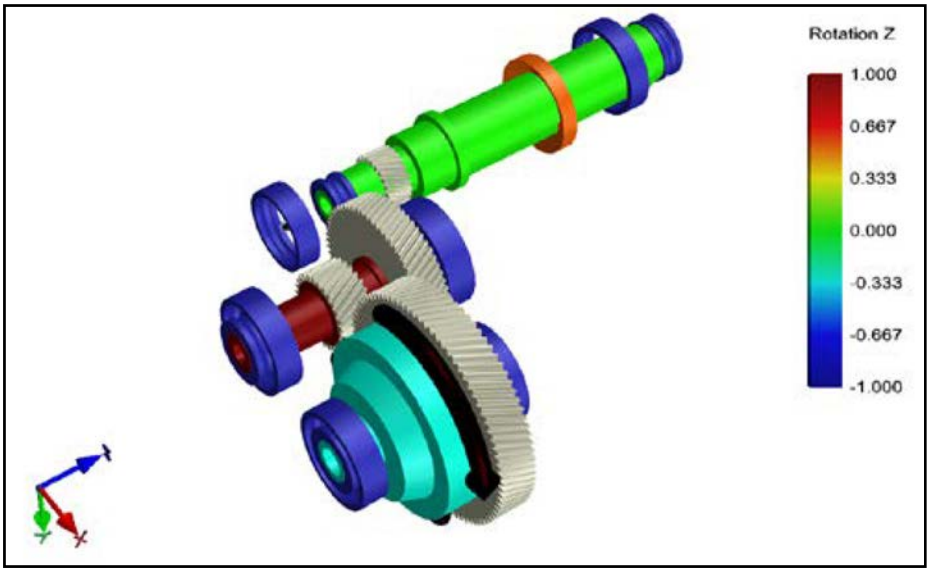

Figure 7 Mode shape corresponding to resonance speed of 160 rpm.

Comparison of dynamic factors obtained from dynamic simulations with gear standards. Figure 4 also shows the dynamic factors calculated using the methods prescribed in ISO-6336 and AGMA-2001 standards. The methodology prescribed in the standards is simplistic in nature, intentionally conservative to cater to a wide range of scenarios, and cannot be written to present specific excitations in a gear mesh. The dynamic factors predicted by the standards are much higher than the dynamic factors predicted in the model, which might lead to over-designing a system in some situations.

Torsional-only model vs. 6 DOF models. Torsional-only models are commonly used to study gear dynamics and to calculate gear dynamic factors (Refs. 5-7). In this section we compare the dynamic factors calculated from a torsional-only multibody model with our full 6 DOF models to determine whether a torsional-only representation is good enough or not.

Figure 8 shows the dynamic factors of the input and the output gear meshes predicted by a multibody model with only torsional DOF. There are three resonance modes that get excited within the given operating speed range (0 - 18,000 rpm) of the input shaft. The peak in the dynamic factors, highlighted by the red circle in Figure 8, is investigated by looking at

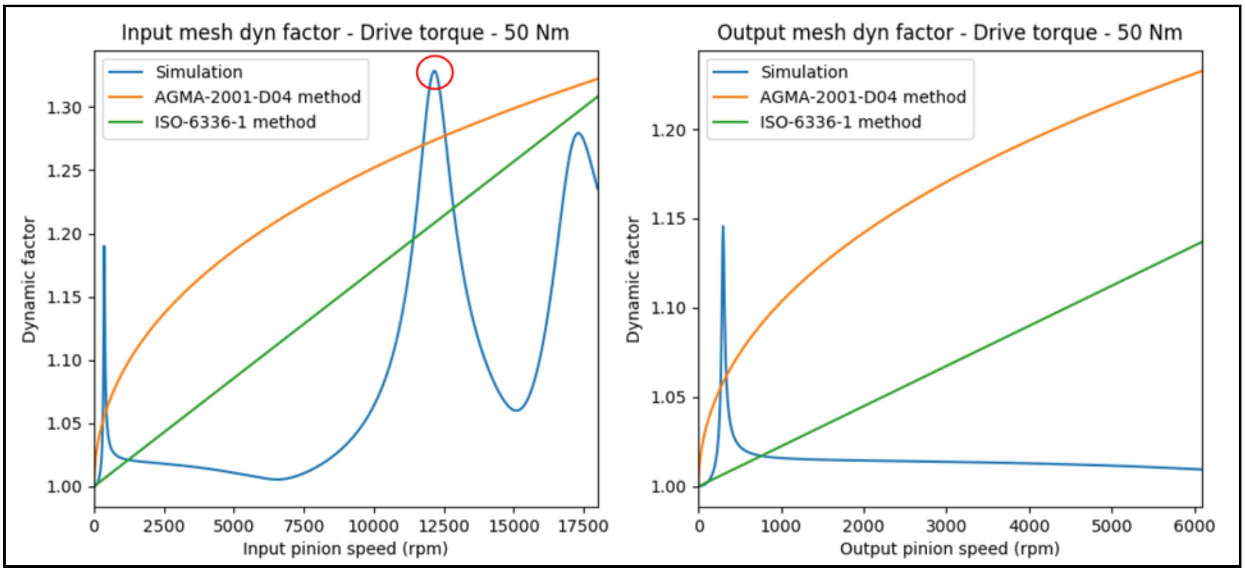

Figure 8 Dynamic factors calculated using a torsional-only dynamic model.

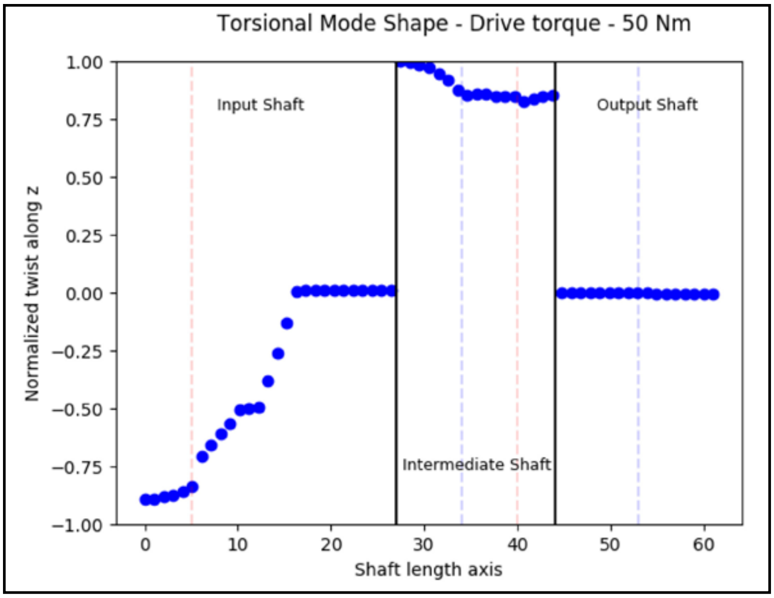

Figure 9 Mode shape of the highlighted section of the resonance mode in Figure 8.

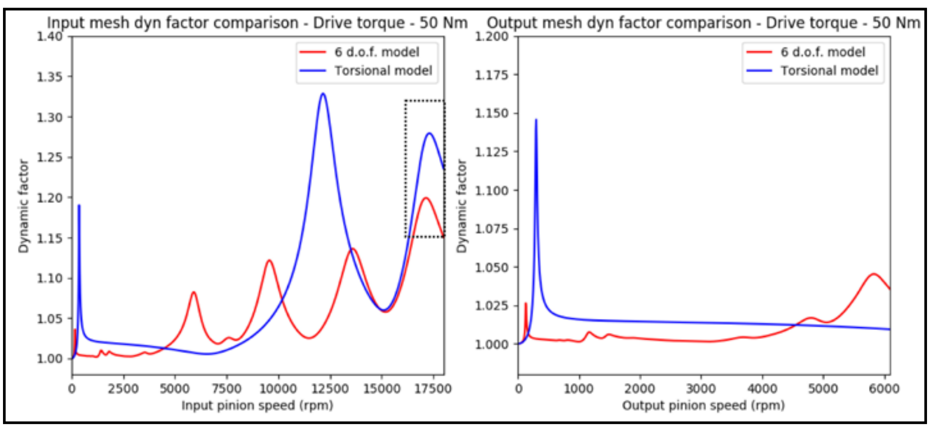

Figure 10 Comparison of dynamic factors calculated using a full 6 DOF model (red) and torsional-only model (blue) for both input and output gear meshes; the mode at 17,000 rpm in the dotted box is dominated by torsional deflections.

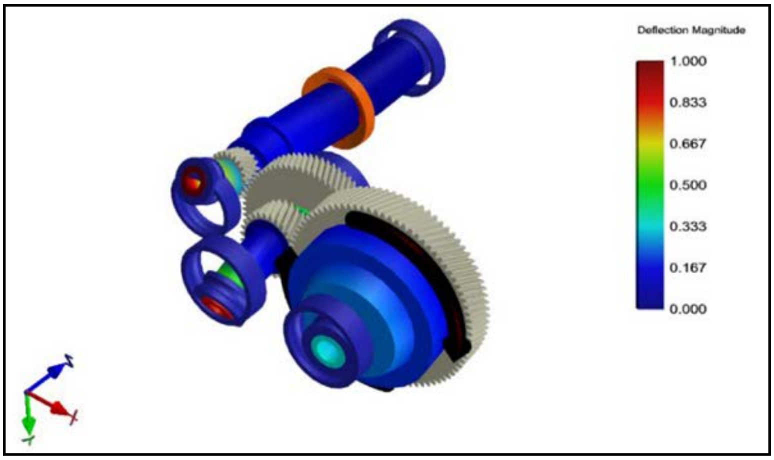

Figure 11 Mode shape for full 6 DOF model corresponding to the 17,000 rpm resonance speed (highlighted by dotted box in Fig. 10).

the mode shapes at that resonance frequency (Fig. 9). The red line represents input mesh node on the shaft and the blue line represents the output mesh node in the shaft.

Figure 10 shows the comparison between the dynamic factors calculated using a full 6 DOF model and torsional-only model. The torsional-only model does not capture any of the bending modes, and all the energy is stored in gear meshes and shaft twisting. In a 6 DOF model, part of the energy is stored in bending the shaft away from the gear mesh, resulting in lower dynamic factors. Hence, the dynamic factors predicted by the torsional only model will be higher than the ones predicted by a full 6 DOF model. Also, the full 6 DOF model has more resonance peaks than the torsional model. This is expected, as the torsional model ignores all the bending modes. However, some modes that are dominated by torsional deflections are present in both models at roughly the same frequency; for example, the mode in Figure 10 that is highlighted by a dotted box.

Figures 11 and 12 show the mode shapes for the highlighted resonance mode (Fig. 10) for the full 6 DOF model and torsional-only model, respectively. Both models predict very similar torsional modes for the three shafts, albeit a slight shift in the peak in dynamic factor curves. In the 6 DOF model the bending modes at the input gear mesh location contribute slightly to the dynamic factor, although the major contributor is the torsional mode. The contribution made by the bending modes is not captured in the torsional-only model, and so it is important to include all six degrees-of-freedom to accurately predict the dynamic behavior of the system.

Effect of torque on dynamic factors. The effect of load on the dynamic factor of the gears is shown in this section. The torque conditions that are simulated to study the effect of load on the dynamic behavior of the system are shown in Table 3.

Figure 13 shows the dynamic factor as a function of torque for the input and output mesh, using the 6 DOF model. The x-axis of the graphs (Fig. 13) represents the gear mesh frequency to illustrate the natural frequencies being shifted to the right as load increases. This is due to the increase in gear meshes and bearings stiffness values with load.

Figure 14 shows the static transmission error traces for the input and output gear meshes for different torques. For input gear mesh, the peak-to-peak TE decreases with torque by a small amount. For output gear mesh, however, the peak-to-peak TE increases substantially with torque.

Figure 13 also shows that as we increase the torque, the dynamic factors decrease. There are two factors that determine the variation in dynamic factors with torque:

a) Change in the static TE trace with torque. Static TE acts as an excitation source for the dynamic model. If the peak-to-peak static TE decreases with torque, this will lead to reduction of the dynamic response at the gear mesh. On the other hand, if the peak-to-peak TE increases with torque, then we will get higher dynamic mesh forces because of increased dynamic response.
b) Dynamic factor is a ratio between total mesh force (static + dynamic) and static mesh force. So, for a fixed dynamic force, if we increase the static force, dynamic factor will reduce.

Figure 15 illustrates the effect of torque on the dynamic factors calculated using a torsional-only model. Similar shifts towards higher frequencies are seen in the dynamic factor peaks, which are reasoned by the increase in system stiffness values at higher loads. The variation in the dynamic factor values with torque is also in agreement with the trends we observed for full 6 DOF model.

Time Domain Simulations

The dynamic factors were calculated at different speeds and torques, as shown in the previous section using a frequency domain approach. Frequency domain solvers are advantageous, as they take less time to solve and inherently assume that the response is caused by one single excitation at a given frequency. In a complex model where there are multiple gear meshes at different mesh frequencies, the net response at a given operating speed can be calculated using the super position principle. This is one of the main limitations of the frequency domain approach; since only one frequency of interest is considered at a time,

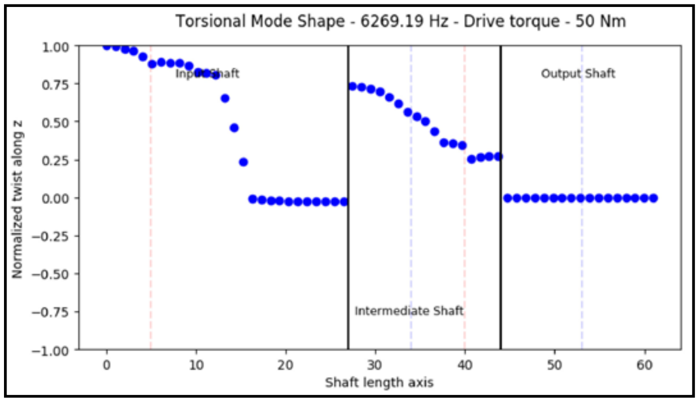

Figure 12 Mode shape for the torsional-only model corresponding to 17,000 rpm resonance speed (highlighted by dotted box in Fig. 10)

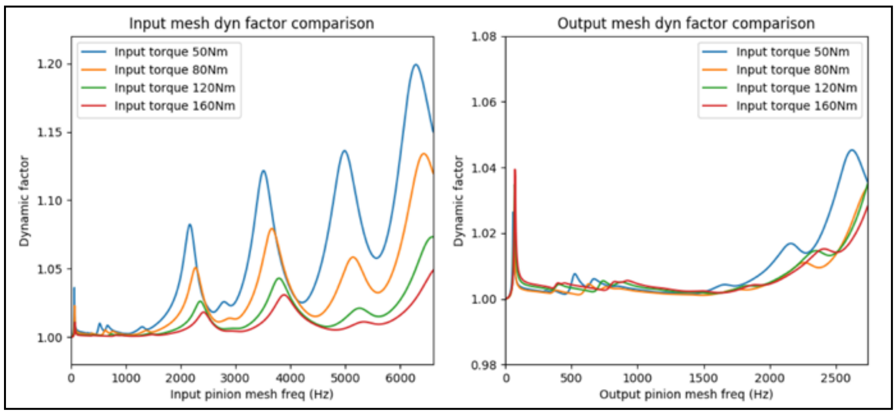

Figure 13 Dynamic factors calculated using a 6 DOF model at four different torque levels for input and output gear meshes.

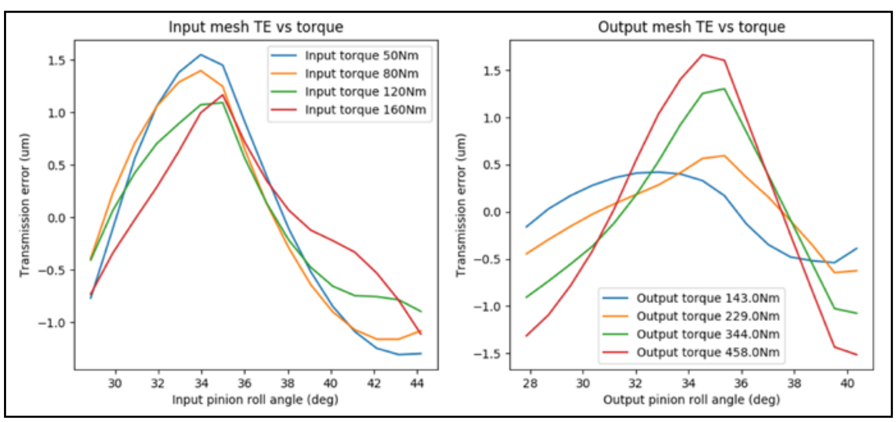

Figure 14 Static transmission error (removing the DC component) traces for different torques.

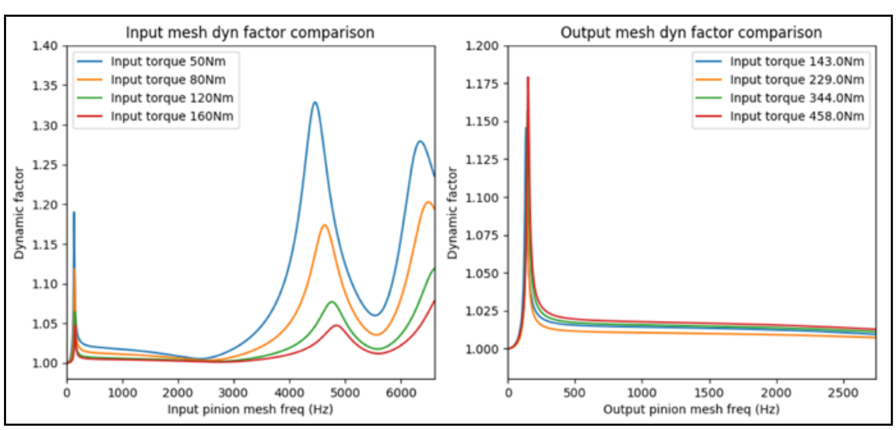

Figure 15 Dynamic factor as a function of torque for input and output mesh using torsional-only model.

the effect of multiple harmonics on gear mesh excitation is hard to capture using this approach.

One other approach is to use time domain simulations where the system response is calculated at every instant of time. The dynamic factors obtained by this method are elaborated in this section. The system is excited by static TE at both the gear meshes simultaneously and the response is calculated for every time step. Comparisons are made between the responses using time domain and frequency domain approach to show the advantages and limitations of one over the other.

Dynamic factors as a function of speed for 50 Nm torque using time domain approach. As shown earlier in this presentation, the system is excited by a static TE at both the input and output gear mesh at a given operating speed. The excitations at the input and output meshes are shown (Fig. 16).

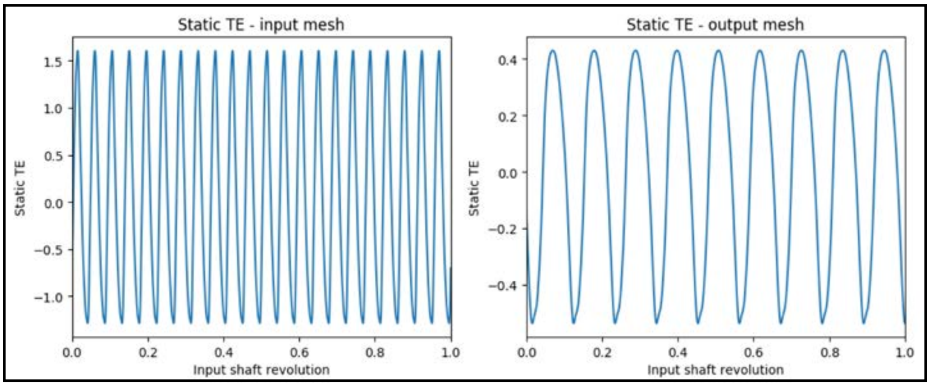

Figure 16 TE excitations in microns at input and output gear meshes.

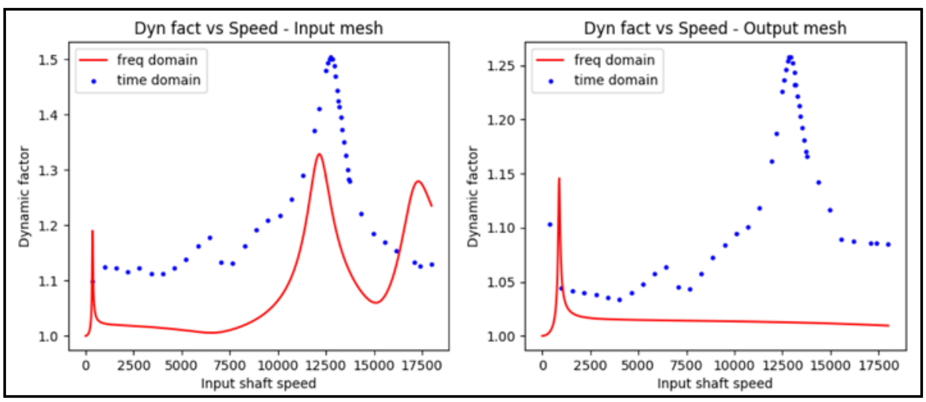

Figure 17 Dynamic factors—time domain vs. frequency domain—torsional only mode.

Table 4 Simulation conditions—input shaft speed

Input shaft speed (rpm)	Input mesh dynamic factor
3,500	1.002
14,100	1.11

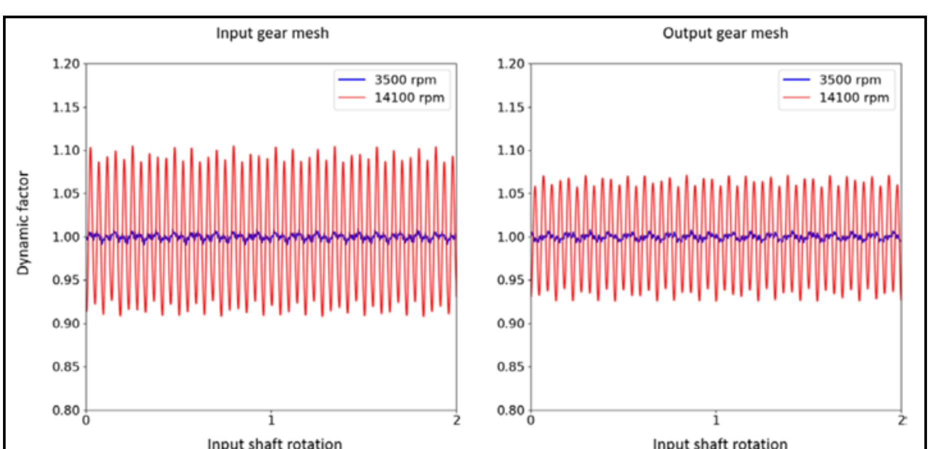

Figure 18 Dynamic factor 50 Nm, torsional DOF.

Using the above excitation, the dynamic factors are calculated using time domain approach (Fig. 18) and considering only the torsional mode. The dynamic factor varies with the rotation of the input shaft periodically and the reported dynamic factor (Fig. 17) is the maximum value over 1 rotation of the input shaft. The dynamic factors follow a similar trend between the two approaches. The peak dynamic factor has shifted slightly to a higher speed in the time domain approach due to the contributions of multiple modes of the system and higher harmonics of the gear mesh frequencies.

The dynamic factors predicted using time domain approach are higher than predicted using the frequency domain approach. This is due to the contribution of higher harmonics of the gear mesh excitations, which is not accounted for in the frequency domain method.

A peak in the dynamic factor is observed in the output mesh at around 12,842.9 rpm of input shaft speed. This corresponds to 1,956 Hz output mesh frequency and 4,709 Hz of input mesh frequency. The frequency domain approach considers only one excitation frequency at a time, and the response is calculated at that frequency. Since the excitation frequency for the input and output mesh is different for the same operating input shaft speed, the frequency domain approach fails to capture the response at output mesh due to an input mesh excitation of 4,709 Hz. In time domain simulations the transient response is calculated based on the mesh excitation force at every instant of time. This clearly illustrates the limitations of the frequency domain approach over the time domain approach where the difference in dynamic factors is substantial.

With the trends in dynamic factors for input mesh matching between the time and frequency domain approaches, the system response at a torque of 50 Nm is elaborated in the following sections using the dynamic model by including all degrees of freedom.

System response at 50 Nm torque using time domain simulations. This section shows the system response as a function of shaft rotation for an input torque of 50 Nm at two different operating speeds of the input shaft as shown in Table 4. 3,500 rpm corresponds to an input shaft speed where the dynamic factor is lowest from 0 to 18,000 rpm range and 14,100 rpm corresponds to an input shaft speed where the dynamic factor is highest due to resonance.

The system is excited by a static TE force at the two gear meshes, as shown previously. Figure 18 shows the dynamic factors as a function of input shaft revolution for the input and output gear meshes at 3,500 rpm, and 14,100 rpm at 50 Nm, considering all degrees of freedom.

The resonance can be clearly seen in the dynamic factor plots when the system is excited at 14,100 rpm (5,170 Hz) input speed. Figure 19 shows the mode shape at 5,164.5 Hz with the contours representing normalized rotation about the *z* direction (as per the coordinate system in the figure). It is evident that the mode at 5,164.5 Hz is highly torsion-dominated (albeit the slight bending of the input shaft can be seen), which will represent the greatest contribution to dynamic factors than the bending modes.

Effect of Manufacturing Errors on Dynamic Factors

Manufacturing errors like run-out and pitch errors in gears influence the dynamic factors, and this has been studied in the past by Velex, et al (Ref. 8) using analytical models and Kahraman (Refs. 10–11) et al experimentally for spur gear pairs.

In this paper the effect of pitch errors in gear dynamic factors is studied by using the time domain models, as described previously. Pitch error is essentially tooth spacing error and this affects the timing of approach and recess of contact at every tooth cycle, depending on the magnitude of the pitch error. This directly affects the contact parameters (like TE, contact stress) and induces excitations at a frequency different from the mesh frequency, depending on the variation of pitch errors.

Pitch errors are usually related to gear quality and are usually within a band and random in magnitude for every tooth in a gear. Therefore, it will be necessary to look at the system response for ‘n’ rotations of the gear until the same pair of teeth is in contact again. When hunting ratio is maintained, the number of cycles for the same pair of teeth to come into contact again is very high.

It is impractical to use a frequency domain approach to study the effect of pitch errors, since the harmonics of TE trace is not just an integral multiple of mesh frequency, but also other random frequencies, depending on the pitch error trace which may or may not dominate over the mesh frequency component and its harmonics.

In this study two scenarios of manufacturing errors are analyzed. The error profiles for both the conditions are shown (Fig. 20). In the first scenario a combination of random error and a sinusoidal pitch error is applied to the input gear where the sinusoid can be considered as a representation of the runout,

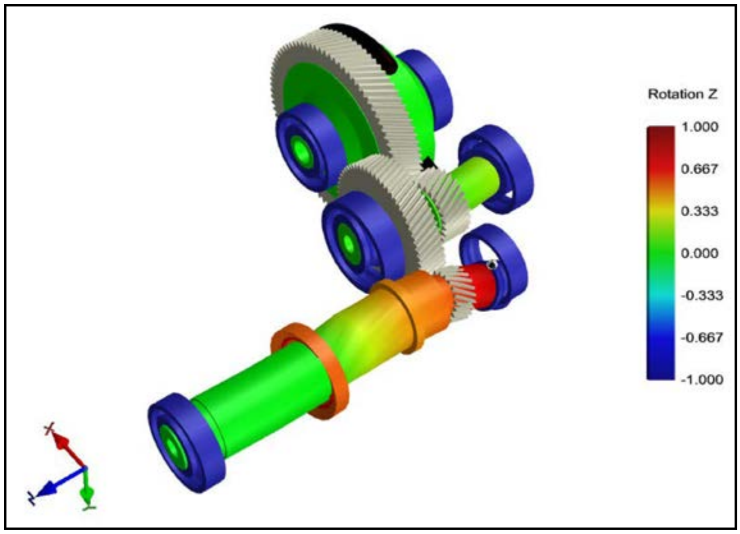

Figure 19 Mode shape at 5,164 Hz showing normalized θz rotation contours.

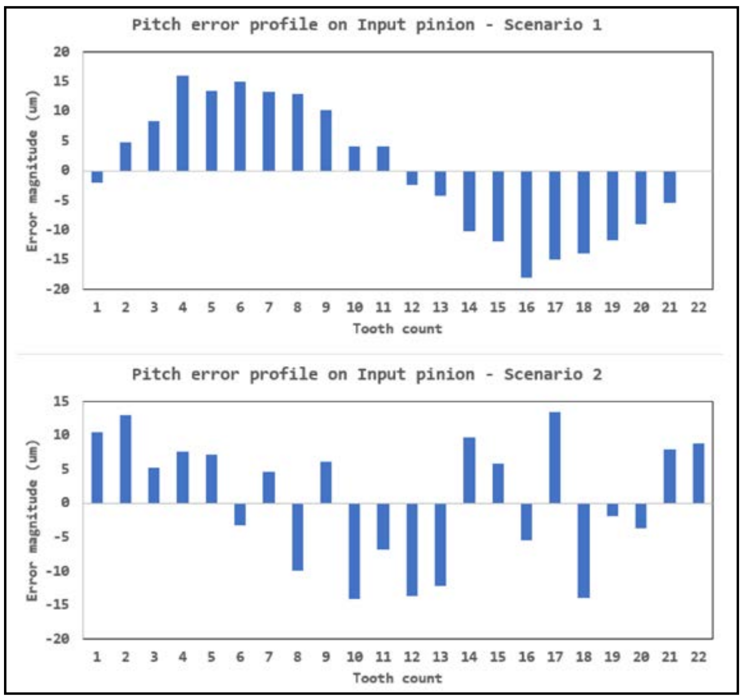

Figure 20 Pitch error profiles.

Table 5 Component orders relative to input and output mesh frequency

Input shaft frequency	Input mesh frequency	Intermediate shaft frequency	Output mesh frequency
0.045	1	0.015	0.415
0.109	2.407	0.037	1

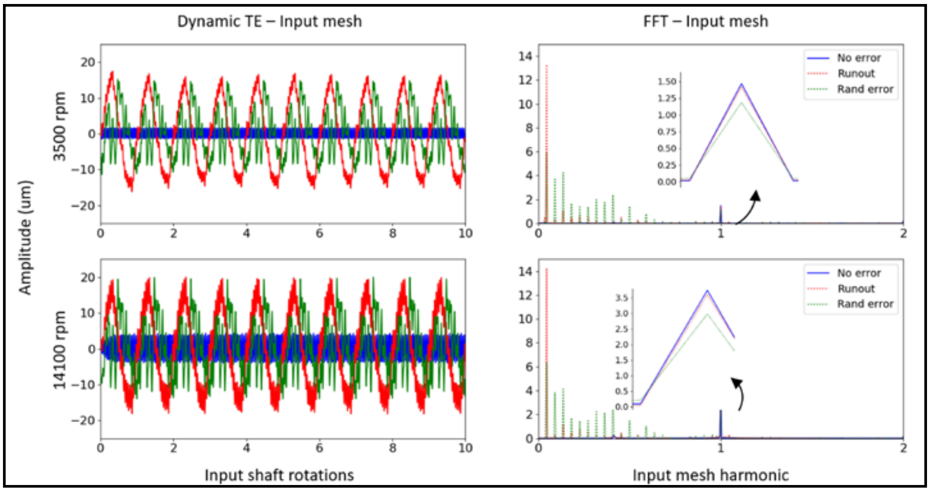

Figure 21 Dynamic TE — input mesh.

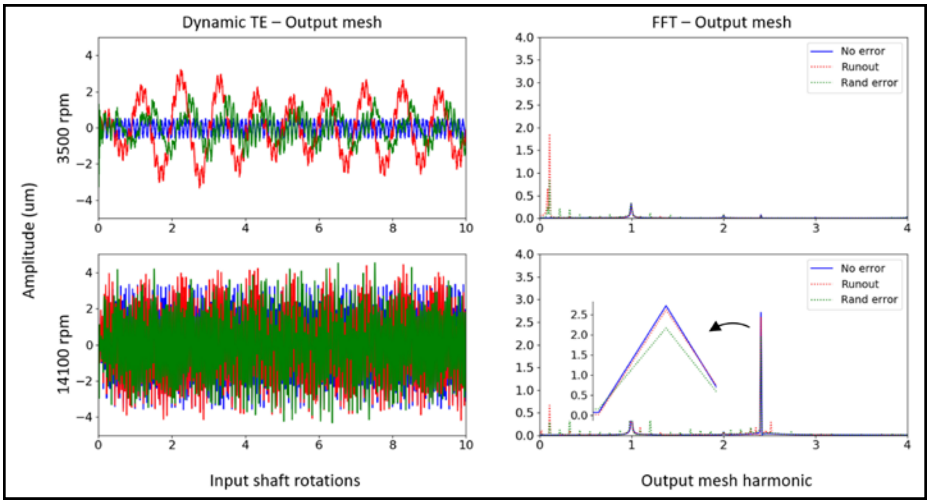

Figure 22 Dynamic TE — output mesh.

Table 6 Input mesh order amplitudes of input mesh and output mesh dynamic TE at 14,100 rpm

	Input mesh harmonic of Input mesh dynamic TE (µm)	Input mesh harmonic of Output mesh dynamic TE (µm)
No error	3.74	2.71
Runout	3.6 (3.7 % reduction)	2.61 (3.7 % reduction)
Random error	2.97 (20.58 % reduction)	2.14 (21 % reduction)

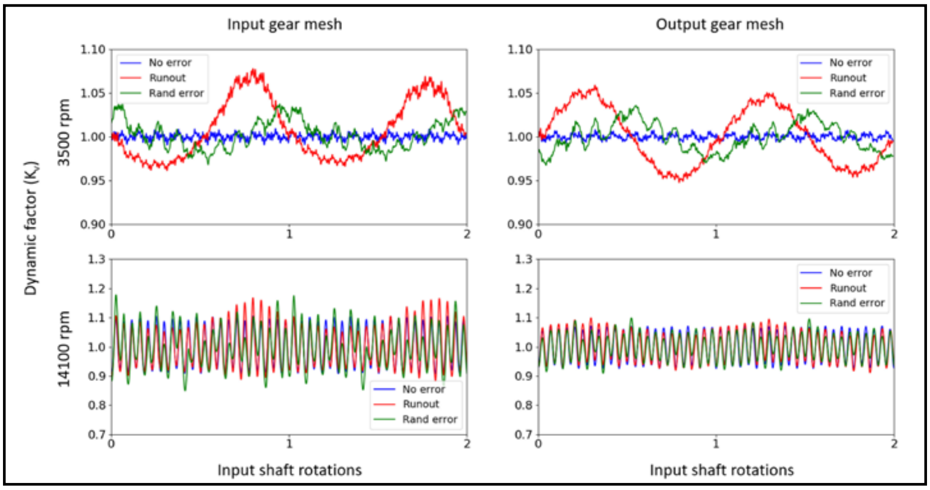

Figure 23 Dynamic factor as a function of input shaft rotation for three error cases and two speed conditions for input and output mesh.

i.e. — the amplitude of the sinusoid is 15 µm and the random distribution is between (−5, 5 µm). The second scenario is a purely random pitch error between (−15, 15 µm).

The effect of both scenarios on dynamic behavior is studied and is compared with the case without any errors. Two speed conditions are chosen, shown in Table 4 — 3,500 rpm and 14,100 rpm. Table 5 shows the component frequencies as a function of input and output mesh frequencies. This information is useful in gaining a better understanding of dynamic transmission error plots that follow.

Figures 21 and 22 show the dynamic mesh deflection of the input gear mesh and output gear mesh, respectively, as a function of input shaft rotation for three error conditions and two speeds and corresponding FFT to show the different harmonic content. The speeds are chosen such that 14,100 rpm corresponds to the input mesh frequency, being close to a natural frequency of the system. Without any tooth errors only the mesh orders excite the system. The TE amplitude of the 1st harmonic of input mesh frequency is higher by 2.5 times at 14,100 rpm, compared to 3,500 rpm indicating that the system is operating at resonance. This can be clearly seen in Figure 22, where order 2.4 of the output mesh frequency has a higher amplitude (2.7 µm) for 14,100 rpm than the system at 3,500 rpm (where the amplitude is just 0.1 µm). It is also interesting to note that the dynamic TE of the output mesh has components of the input mesh frequency which is a direct effect of system behavior.

With the introduction of a runout error in the input pinion, dynamic TE has components of input shaft order, which can be expected since runout is an excitation at shaft frequency. At the output mesh the TE amplitude of the input shaft harmonic (abscissa 0.109 in the FFT plot; Fig. 22) is 3 times higher for 3,500 rpm than at 14,100 rpm. This can be explained since the system is excited by the runout in the input gear (at input shaft frequency of 3,500 rpm (58.3 Hz) which is very close to a natural frequency. Due to this near-resonance at 3,500 rpm, a "beating" phenomenon is observed (dynamic TE plot in Fig. 22), which is a classic behavior when a system is excited near resonance.

This "beating" pattern eventually dampens out if the source excitation is consistent at the same frequency near resonance.

When random pitch errors are introduced in the system, multiple shaft orders are excited and the dynamic TE is a combination of the mesh harmonic and multiple harmonics of the input shaft frequency. At 14,100 rpm speed of the input shaft, the 1st harmonic of the input mesh frequency is high compared to 3,500 rpm case indicating resonance at 14,100 rpm.

Table 6 shows the input mesh order amplitudes (abscissa 1 in FFT plot in Fig. 21 and abscissa 2.04 in FFT plot in Fig. 22) of the input and output mesh dynamic TE for the three conditions of pitch error at 14,100 rpm operating speed. Introduction of pitch errors reduces the mesh harmonic component of dynamic TE and the reduction is seen higher for the case of random pitch error than for the case of runout in the input gear. This can be explained from an energy perspective. With the introduction of errors, the energy is spread over multiple shaft harmonic frequencies, thereby reducing the main mesh harmonic component. With a runout error in the input shaft, only the 1st harmonic of shaft frequency is excited, whereas with a random error distribution in the input gear, multiple shaft harmonics are excited, which leads to greater distribution of energy over multiple frequencies and therefore greater reduction in dynamic TE mesh harmonic.

Figure 23 shows the dynamic factors for the three error conditions and two speeds for the input and output gear mesh, respectively. The effect of resonance can be clearly seen in the dynamic factor of both the input and output meshes. Introducing errors to the system increases the maximum dynamic factor, and the increase depends on the nature and magnitude of the manufacturing error in the system.

To completely understand the effects of manufacturing errors in the system, the dynamic factors were calculated using a 6 DOF model solved in time domain and was plotted against operating speed, as shown in Figure 24 for cases with and without manufacturing errors.

A random distribution of error is applied to the input pinion (Fig. 20) to generate the above plots. Each point on the coordinate in Figure 24 is the maximum value of the dynamic factor (which is a function of time) for every speed point. Manufacturing errors increase the dynamic factor of the mesh, and the magnitude of increase depends on the nature and amplitude of the error. Additional peaks in the dynamic factors are revealed when errors are introduced to the system, indicating that the system is excited by shaft orders and its harmonics, which is not the case when there is no error. The additional peaks can be quite significant — depending on the nature of the error, type of gear (spur/helical), etc.

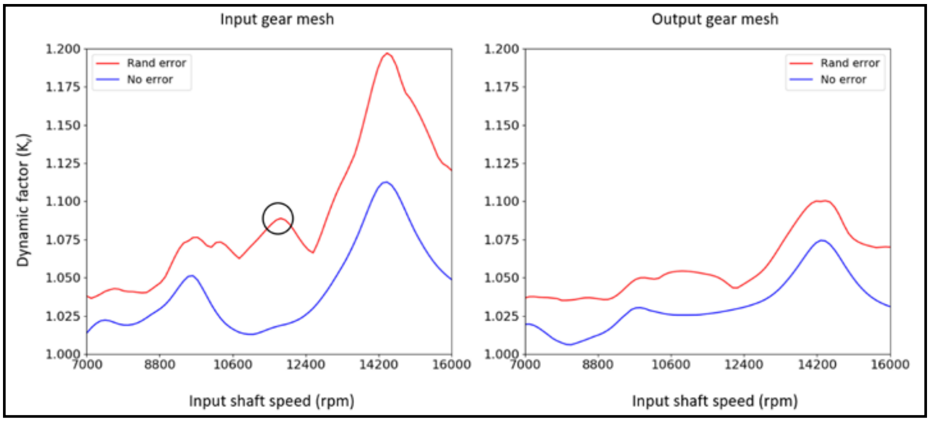

Figure 24 Dynamic factor for input and output mesh as a function of speed — with and without manufacturing errors.

Conclusions

The dynamic behavior was studied for a high-speed, electric-vehicle gearbox using a multibody dynamic model. Based on the dynamic factor results, the following conclusions can be made:

- System effects and system dynamics play a key role in the dynamic factor predictions. System resonances that fall within the operating speed range increase the dynamic factors substantially. Any model that only considers the dynamics of just the gear pair of interest, and ignores the system-level effects, is likely to give incorrect dynamic factors.
- Standards (AGMA or ISO)-based calculations for dynamic factors are simplistic in nature and there can be cases where a detailed system level analysis is required of, for example, manufacturing errors in the system, multiple simultaneous gear mesh excitations, etc.
- Bending modes are important, and a torsional model that ignores the bending deflections is not adequate for the prediction of gear dynamic factors.
- The differences between the time domain and frequency domain approaches were compared and this paper illustrated the limitations of the frequency domain approach in some scenarios.
- Manufacturing errors cause several shaft orders to be excited, which results in higher dynamic factors at system resonances. However, the mesh harmonic component of the dynamic transmission error slightly reduces with the introduction of errors in the system.

Future Work

- Correlation of simulation results with published experimental data (Refs. 10–11)
- Calculate dynamic stress and compute dynamic factors based on the stresses (root/contact), rather than using forces as seen in this study
- Include the effects of flexible gear blanks and housing
- Extend this model to planetary gear sets

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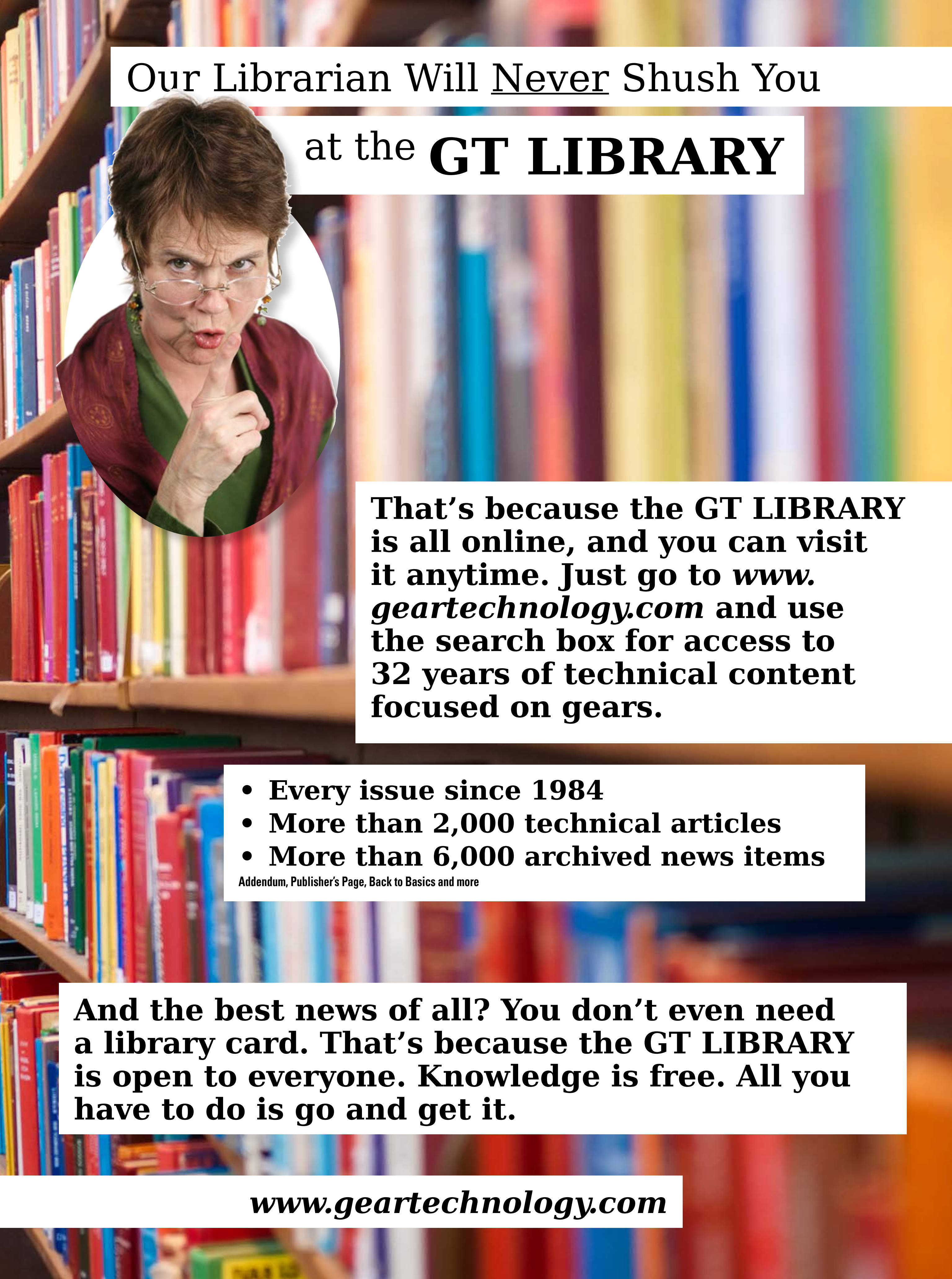
Niranjan Raghuraman is working as an engineering analyst for Romax Technology located in Boulder, CO. His background includes powertrain dynamics, parallel and cross axes gearing, plastic gearing, heat transfer and thermodynamics. At Romax, Niranjan is involved in Solving problems pertinent to gear whine, gear rattle and gear dynamics in transmissions for conventional and electric automotive and other sectors including wind energy, aerospace, etc. Prior to joining Romax, Niranjan worked for Chrysler, as a Powertrain Simulation Engineer, on durability studies for automotive rear axle drive unit and development of energy management models for vehicle powertrain. Niranjan earned his master's degree from The Ohio State University. He worked on predicting surface temperature on spur and helical gears using Finite Difference Methods as a part of his masters at The Gear and Power Transmission Laboratory with Dr. Don Houser.

Dr Sharad Jain joined Romax in 2007 after graduating from Indian Institute of Technology Roorkee, India in Mechanical Engineering. He also has a Ph.D. in engineering from University of Cambridge, UK. During his Ph.D., Sharad worked on dynamics of high-speed bearings and planetary gearboxes. Sharad has 9 years of experience in mathematical modelling and dynamics and vibration of rotating machines. His areas of interest include bearing dynamics, contact mechanics, automatic discretisation of continuous structures for dynamic analysis, and dynamics of electro-mechanical drivetrains. Currently, Sharad is leading the development of an object-oriented toolbox for multi-physics dynamic analysis at Romax.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Grieve

MOURNS THE LOSS OF PAT CALABRESE

The entire family of The Grieve Corporation mourns the loss of its longtime President, **P.J. "Pat" Calabrese,** who died on February 17, 2018 in Lake Forest, Illinois at the age of 90. Pat was the president of Grieve, a world leader in industrial ovens and furnaces, from 1958 until his retirement in 2008. He worked closely with the company's founder, Price Grieve. Pat's son Frank is currently the vice president of sales and marketing, while Price's son Doug is the president and CEO of the company, founded by Grieve in 1949.

Pat was born in Chicago, graduated in 1949 from the University of Illinois with a BS in Mechanical Engineering and was awarded that school's prestigious Distinguished Alumni Award in 2001. He also held a number of positions with various industrial, business and Catholic charitable organizations.

Pat began his career at Grieve in 1958 as National Sales Manager, becoming President in 1968 and finally Chairman in 2006, following the death of Mr. Grieve. During his tenure as President, the company grew steadily to become a global supplier of heat processing equipment for virtually every industry in every industrialized country in the world. (*www.grievecorp.com*)

Klingelnberg

WINS TWO IF DESIGN AWARDS

The Höfler Speed Viper cylindrical gear generating grinding machine and the Klingelnberg P 65 precision measuring center are the first machines in which Klingelnberg has implemented and launched its newly developed design concept. Both were honored at this year's iF Design Award with a distinction in the "Product" category.

The iF Design Award is given out once a year by the world's oldest independent design institution, iF International Forum Design GmbH in Hanover/Germany. The competition attracted a large number of entries again this year, with 6,400 submissions from 54 countries vying for the internationally acclaimed seal of quality. It wasn't an easy choice for the 63-member jury of experts, who recognized not one, but two, of the machines submitted by Klingelnberg with an award in the "Product" category. Martin Boelter, chief operating officer at Klingelnberg, accepted the Design Award for the Speed Viper cylindrical gear generating grinding machine and the precision measuring center on Mar. 9, 2018, during the iF design award night at BMW Welt in Munich/Germany. "We are extremely pleased that our new design language has received such immediate confirmation!" exclaimed Boelter at the awards ceremony, which was attended by some 2,000 guests from 36 countries.

The Speed Viper cylindrical gear generating grinding machine and the P 65 precision measuring center were designed in line with Klingelnberg's new brand and design principle: "The new precision is black." The machine builder launched the design project in February 2016, as the design concept for the new Speed Viper 300 was evolving. Working together with product design specialist, The Kaikai Company, Klingelnberg developed a new look that will extend to the company's product portfolio. The P 65 precision measuring center was designed from the ground up based on these new standards, which feature a longlife color concept focused on dark gray hues. The color scheme ensures that machines used directly on the shop floor are less prone to showing dirt. Klingelnberg's signature blue color comes into play as an eye-catcher in selected design elements, which are coordinated with every product group and product; together, these elements form a central, unifying moment that promotes a consistent brand image. The machine's haptic interfaces were a major consideration in the ergonomically optimized design, since this is where the user "gets a feel" for the machine's quality in the truest sense of the word.

This overall concept, which can be applied to the entire machine lineup, immediately received accolades in its first practical implementation in the Speed Viper and the P 65. More information on the Speed Viper cylindrical gear generating grinding machine and the P 65 precision measuring center can be found under "Design Excellence" in the iF World Design Guide. (*www.klingelnberg.com*)

Amarillo Gear Company

CELEBRATES 100 YEARS OF INNOVATION

Amarillo Gear Company, located in Amarillo, Texas is celebrating 100 years of innovation. Amarillo Gear is one of the largest manufacturers of top-quality right-angle spiral bevel gear drives in the world. Originally founded to produce gear drives for the agricultural industry, the company has expanded over the years to make gears for fire protection, marine, power generation, petrochemical and HVAC industries. The following is an excerpt from the company's news page on Industry in 2018:

Manufacturing is a cut and dry industry. The premium placed on production times and automation only help to affirm

the impersonal nature. But the paradox that's easy to miss is that purpose of manufacturing is to meet the needs of a community.

Amarillo started out in a railroad town sprawled out on a windswept plateau and an infinite horizon. It was a place where the quality of life depended on how well you worked with members of community and how stubborn you could be. These are traits of resilience and reliance. In the panhandle those traits are valued and upheld to a high degree because they mean survival. Understanding the meaning of the traits most valued by a community is critical to any manufacturing company's bottom line.

Initially, the Amarillo Gear Company production was central to the farming. The company's emphasis was on manufacturing the machines and parts that used by farmers in growing their crops. Water sources were flung far and few in-between and mandated the use of irrigation systems in cultivation. This created a niche in the market, which Amarillo Gear quickly filled.

The company knew the farmers by name, the models they purchased and what tools to take out for service calls. Eventually, they built the right-angle drives that allowed for an expansion of the crops that fed and sustained the growing city population. The food they put on the plates of their neighbors was also the food they put on their own plates. They were totally invested in the success of their drives because it benefited the organization directly as a local company.

This is something that more consumers need to see. To manufacture, there must be a need and to have needs is to be human. By promoting a desire to help raise the quality of life by creating the products that allow for it, Amarillo unveils the humanity within machinery.

It's the key to how a company can survive the changes brought by the years. Technology changes at the speed of light, so do regulations and trade agreements and the free market is an eternal gamble. But the importance of knowing what the purpose of a manufacturer is and fulfilling that purpose is where a company can grow. (*www.amarillogear.com*)

Heat Exchange Institute

LAUNCHES ONLINE WEBSTORE FOR SALE OF STANDARDS

The Heat Exchange Institute (HEI) announced the launch of an online webstore, powered by Techstreet, for the sale of all HEI standards. HEI tech sheets are also available on the webstore for download at no charge. As a trade association committed to the technical advancement, promotion, and understanding of a broad range of utility and industrial-scale heat exchange and vacuum apparatus, HEI's online publication store allows users from across the globe to immediately access all HEI standards in a secure and convenient manner. The Institute is pleased to offer two new discount bundle packs with a number of relevant standards included in each bundle.

Coinciding with the release of the 12th edition of *Standards for Steam Surface Condensers,* the new webstore will provide secure PDF downloads, the opportunity to purchase hard copies of standards, and a smooth user experience to ensure customers have access to the latest from the Heat Exchange Institute.

Heat Exchange Institute secretary/treasurer Craig Addington noted, "Through our partnership with Techstreet, we expect our members and customers to more quickly and seamlessly access these standards which are used throughout the world for the design, manufacture, and operation of heat exchange and vacuum equipment."

(*www.techstreet.com/hei*)

Holroyd Precision Apprentice

RECEIVES ADVANCED ENGINEERING AWARD

Rochdale-based Holroyd Precision Rotors had cause to celebrate when one of its apprentices secured a top honor at Rochdale Training's 48th Annual Awards Evening.

Holroyd's Joe Butler, 20, from Milnrow, was presented with Rochdale Training's coveted Advanced Engineering Apprentice of the Year (Level 3) award at the event, which took place at Rochdale Town Hall on Jan. 25, 2018.

Butler, who began his apprenticeship with Holroyd in 2013, also received a certificate to mark his successful completion of an Advanced Modern Apprenticeship in Mechanical Manufacturing Engineering. Other Holroyd apprentices to be recognized for their achievements included: Matthew Lockyer (who also completed a HNC course), David Wall, Matthew Humphries and business administration apprentice, Jordan Gray. All have now commenced full time employment with either Holroyd Precision or Holroyd Precision Rotors.

Holroyd's Joe Butler, 20, from Milnrow, was presented this year with Rochdale Training's coveted Advanced Engineering Apprentice of the Year (Level 3).

Apprentices from a number of organizations attended the event, as did local employers; the MP for Rochdale, Tony Lloyd; the Mayor of Rochdale, Councillor Ian Duckworth, and Mayoress Christine Duckworth. The guest speaker was David Bottomley, director of Rochdale AFC.

Rochdale Training Chief Executive, Jill Nagy, said: "Well done to our learners for your hard work. We are proud of your achievements and congratulations to you all. Thank you to the parents, carers and families for your support of the learners. But most of all I'd like to thank the employers - our customers - thank you for using us, as without you, we don't exist. It is much appreciated."

"I am delighted to congratulate Joe and our other apprentices on their achievements," commented Holroyd Precision's HR Manager, Mary Mcgrath. "They have all worked extremely hard. For almost 30 years, we have invested in recruiting and training young people as part of our apprenticeship and graduate training programs. With expert support from Rochdale Training, we are seeing our young apprentices mature and, in many cases, take on senior roles within our organization."

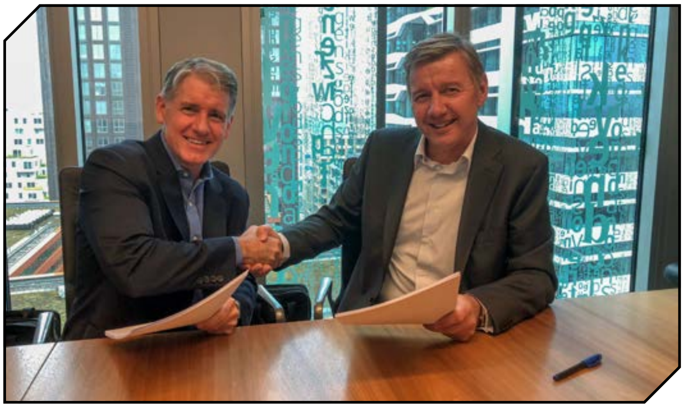
(*www.holroyd.com*)

Des-Case Corporation

ACQUIRES RMF SYSTEMS

Des-Case Corporation, a provider of desiccant breathers and manufacturer of specialty products that improve process equipment reliability and extend lubricant life for companies around the world, today recently announced its acquisition of RMF Systems, an experienced specialist in desiccant breathers, filtration systems, analysis and monitoring solutions to maintain hydraulic oil and lubricant cleanliness. With the addition of RMF, Des-Case will provide a broader range of solutions, greater customer convenience, and deeper professional expertise.

Des-Case holds a leading position in the North American breather market and also provides world-class filtration and transfer systems of all shapes and sizes, while RMF is a major player in the European filtration market with particular focus on hydraulic solutions. Together, Des-Case and RMF will help companies make their equipment investments last longer through an extensive combined product line that will provide solutions of breadth and depth for any contamination problem. (*decase.com*)



Frank Robben, CEO of Doedijns Group International (right) and Brian Gleason, CEO of Des-Case (left) moments after the acquisition was official.

Team Penske

FORMS TECHNICAL PARTNERSHIP WITH SIEMENS

Team Penske and Siemens, a leading global provider of product lifecycle management (PLM) software and services, have entered into a new technical partnership. Under the multi-year agreement, Siemens will help enhance Team Penske's performance with full access to a wide variety of software products to enable advanced digital design and simulations. Team Penske race teams will utilize Siemens' software across their computer-aided design (CAD), engineering, simulation and machining platforms. Utilizing this software, Team Penske can create a digital twin of their race cars, which can help engineers simulate engine configurations, innovate new parts and predict race results in real-time.

"Team Penske is excited to welcome Siemens as a key technical partner, beginning with the 2018 season," said Roger Penske. "Siemens is a company and a brand that is known worldwide for its superior technology and engineering. Our teams will benefit from Siemens' expertise and support and we look forward to helping grow the Siemens footprint in the world of motorsports."

Team Penske is partnering with Siemens PLM Software to adopt an integrated virtual environment for digital modeling and simulation. Siemens' PLM tools allow Team Penske to keep large amounts of data well organized and accessible for review by anyone within the team, and also enables engineers to quickly iterate through design concepts with the digital twin to arrive at near-optimum solutions within a high-intensity, short timeframe environment. The digital twin is the key to making effective, data-driven design changes at a very rapid pace, and thus, helping improve the results at the racetrack every week.

"We are proud to team up with Team Penske, an American icon in motorsports. As a racing team with extremely challenging requirements on development time and accuracy, Team Penske will be able to fully leverage the unique capabilities of our software solutions," said Lisa Davis, Managing Board member of Siemens and CEO of Siemens USA. "Our integrated industry solutions, combined with the expertise of the entire design and racing team from Team Penske, will help create world-class vehicles."

Utilizing Siemens' PLM tools allows Team Penske to quickly analyze thousands of electronic data streams full of critical on-track performance information, and apply changes to the race car's digital twin. These changes are then reviewed for performance and durability in a virtual environment, which allows low-cost, high fidelity simulation of the results. With Siemens' technology, Team Penske is able to capitalize on this streamlined digital process and quickly transition to the physical stages of manufacturing, quality assurance, installation onto the race car, and validate performance in the physical environment. This entire process can be completed with high-impact components in as little as a few hours.

"We are excited to partner with Team Penske and be a part of their strong legacy of championship racing," said Tony Hemmelgarn, president and CEO, Siemens PLM Software. "We look forward to supporting Team Penske with our software to help streamline designs, speed results, and deliver the most successful racing teams yet."

The partnership will also include Siemens as an associate sponsor on the Team Penske cars competing in the Monster Energy NASCAR Cup Series, the NASCAR XFINITY Series, the Verizon IndyCar Series and the Virgin Australia Supercars Championship. Siemens branding will be featured on all Team Penske Indy cars and on the uniforms worn by Team Penske drivers and teams competing in NASCAR. (*www.siemens.com/plm*)

Seco Tools

RELEASES MACHINING NAVIGATOR

With intelligent interactivity, the Machining Navigator pages look just like those in a standard interactive PDF or flip book but provide several useful capabilities. Users can quickly access the catalog page for a specific product range by clicking on the name of the product from the list on the contents pages. Instead of searching through multiple catalogs, brochures and website pages, just a few clicks take users directly to the product's interactive catalog page for detailed information and helpful links.

Included in the Machining Navigator PDF pages are links to secotools.com for a more in-depth presentation of each Seco product and support that will help users to find and order the best tool to meet a particular need.

Seco's interactive functionality also allows users to build their own flipbook by selecting pages to compose a customized "summary" of products. This flipbook can be emailed, printed or downloaded for future reference. (*www.secotools.com*)

Romax Technology

COLLABORATES ON AEROSPACE PROJECT WITH CRANFIELD UNIVERSITY

Cranfield University and Romax Technology have forged a collaboration to support an aerospace Ph.D. project investigating an open rotor and pitch control mechanism. Within this partnership agreement, alongside licences of their flagship software product, Romax will also provide technical support for both software usage and practical application for the duration of the project. This will include workshop activity to specifically focus on developing deeper understanding where necessary.

Romax's Partnership Management Specialist, Sam Wade, comments: "Our academic program aims to collaborate with universities from all around the world and has more than 50 partners. We provide students with state-of-the-art software, access to world-leading experts, and the most up-to-date methods and tools, in order to support world-leading research and help to develop excellence in the next generation of engineers. We are thrilled to invite Cranfield University to join our academic program and for the opportunity to provide support for some very exciting research within the aerospace industry."

Dr. Bobby Sethi, Leader of Cranfield University's "Technoconomic Environmental Risk Assessment (TERA)" for Civil Aviation comments: "We believe joining Romax's partner program will be very beneficial for us. Our collaboration with Romax will enable our Ph.D. students to use the latest simulation tools on their research projects. Knowing that the software is backed up by experts with experience from a range of projects within the aerospace sector, who can provide technical support and training where necessary, is very reassuring."

The project will use Romax's flagship product, *RomaxDesigner*, a complete simulation platform for end-to-end integrated whole system design and analysis. With a strong client base in the automotive sector, *RomaxDesigner* is being used more and more by the aerospace industry, to investigate novel design concepts and make optimizations regarding noise and efficiency. (*www.romaxtech.com*)

Hannover Messe 2018

FOCUSES ON ROBOTICS, AUTOMATION AND SMART MANUFACTURING

Robotics and automation continue to take center stage at manufacturing trade shows around the world and Hannover Messe 2018 was no exception.

"Technology is not about competing with us humans; it's about assisting us. That is the core message conveyed by this trade fair, which has again underscored Hannover's reputation as a global hotspot for the digital transformation of industry," said Dr. Jochen Köckler, chairman of the managing board at Deutsche Messe, at the close of Hannover 2018 and CeMAT. "The focus here has clearly been on the human element: We're the ones making the decisions and setting the course. The interaction of humans with machines and IT adds up to a huge competitive gain across manufacturing, logistics and the energy industry."

Under the motto of "Integrated Industry – Connect & Collaborate", a total of 210,000 visitors seized the opportunity to explore the innovations on display. A total of 5,800 exhibitors were present at Hannover Messe & CeMAT. Topics like machine learning, artificial intelligence, industrial IT platforms, the expansion of power grids for eMobility, the use of robots and autonomous systems in production and intralogistics, and the role of workers in the integrated factory were the subject of intense debate at the stands of exhibitors at the event. As the official Partner Country, Mexico profiled itself as an innovative business partner and industrial location.

"Businesses have successfully negotiated the first steps on the path towards digitized, connected production and are now firing up for the second stage of the journey," reported Thilo Brodtmann, executive director of the German Engineering Federation (VDMA). "New platform-based business models, the use of digital twins and initial experiences with machine learning – all of this is set to play an increasingly important role in the mechanical engineering sector. Hannover Messe is a place where people present and discuss the shape of things to come, and we are once again highly satisfied with the outcome of the show," he continued.

Out of a total of 210,000 visitors at the fair, more than 70,000 of them came from abroad, for an international share of 30 percent. China headed the foreign visitor statistics with a total of 6,500, followed by the Netherlands (5,300), Poland (2,700) and the United States (1,700). A total of 1,400 visitors attended from Mexico.

The next Hannover Messe will be staged from April 1-5 2019, with Sweden as the official Partner Country. The next CeMAT will run parallel to Hannover Messe in April 2020. (*www.hannovermesse.de*)

June 5–6–KISSsoft Special Training: Precision Mechanics Bubikon,Switzerland. The specific differences compared to gears in steel and their calculation methods will be explained and several exercises will be carried out to see the problems and the possible solutions in practical cases. An overview of the material properties with advantages and limitations as well as the measuring techniques will be explained. The choice of the material and the calculation of the tooth form specialties will be treated. The basic issues involved in the theory of worm wheels and crossed helical gears are summarized. The differences between worm wheels with and without globoid form are illustrated. For more information, visit *www.kisssoft.ag*.

June 5–7–Ipsen U 2018 Cherry Valley, Illinois. Throughout the course, attendees are able to learn about an extensive range of topics - from an introduction to vacuum and atmosphere furnaces to heat treating, furnace controls, subsystems, maintenance and more. They will also be able to view the different furnace components firsthand while learning how they affect other parts of the furnace and/or specific processes, take part in one-on-one discussions with Ipsen experts, participate in a leak detection demonstration, and tour Ipsen's facility. A forum where all levels of experience are welcome, Ipsen U instructors believe in using the participants' specific questions and interests to shape the hands-on class. Past attendees have appreciated the instructors' "incredible amount of knowledge, hints, tips and real-world advice." The Ipsen U classroom features comfortable seating for up to 36 attendees, as well as integrated technology with a large smartboard and two additional monitors for interactive presentations and demonstrations. For more information, visit *www.ipsenusa.com*.

June 6–7–EMAG Technology Days 2018 Farmington Hills, Michigan. The EMAG event will include a variety of machine tools under power for live demonstrations, plus a series of technical and market presentations by industry experts from the company. Topics will cover all the machining and joining technologies EMAG currently brings to the market, including vertical milling, ECM, laser and induction hardening. The keynote presentations will be a discussion of innovative propulsion systems on June 6 and E-mobility trends and their impact on the traditional manufacturing landscape in the automotive supply chain on June 7. The event will be led by CEO of EMAG L.L.C. for North America, Peter Loetzner. Other featured speakers will be Michael Robinet from HIS Markit and Brett Smith from the Center for Automotive Research. For more information, visit *techdays.emag.com*.

June 12–15–HxGN Live 2018 Las Vegas, Nevada. HxGN LIVE is for manufacturers seeking to learn more about process automation, closed-loop manufacturing, and connecting CAE, CAD, CAM and metrology technology via the digital thread. The conference stages more than 120,000 sq. ft. of Hexagon technologies, nearly 500 sessions and 60+ exhibiting sponsors. The Zone technology expo features the digital thread at work as a common communication framework with feedback loops that embed continuous improvement into the product lifecycle. HxGN SMART Quality, Hexagon's online quality data and measurement resource management platform, is one of the prime tech highlights in The Zone. The innovative solution delivers information automation to quality management, so manufacturers and quality control professionals can shape smarter workflows and actively improve efficiency and productivity. For more information, visit *hexagonMI.com*.

June 17–20–PowderMet 2018 San Antonio, Texas. PowderMet2018 is the International Conference on Powder Metallurgy & Particulate Materials. The conference will feature over 200 worldwide PM industry experts presenting on PM, particulate materials, and metal additive manufacturing. The event includes extended exhibit hall hours, student poster sessions, evening networking events and the return of the co-located program AMPM2018, featuring worldwide industry experts presenting on the latest developments in the fast-growing field of metal additive manufacturing. AMPM2018 also hosts a 100+ exhibitor trade show in conjunction with PowderMet2018. "Metal AM is a natural fit for MPIF as we have supported the PM industry for nearly 75 years. We're excited to offer an expanded AMPM conference that allows for more time for the transfer of technology, and to expose the metal AM sector to the greater PM industry through access to both AMPM and PowderMet conferences," said James P. Adams, executive director/CEO of the MPIF. For more information, visit *AMPM2018.org* and *PowderMet2018.org*.

June 27–28–Dritev 2018 Bonn, Germany. Increased CO2 discussions, sustainable mobility and electrified drives: The automotive transmission world is changing. Why the understanding of the transmission changes, how it is to be understood as part of the overall powertrain and why cross-component know-how becomes more and more important are the subjects of the Dritev in Bonn. Attendees can expect more than 1,500 developers, around 100 international exhibitors and 80 specialist lectures on one of the world's largest networking platforms for powertrain and transmission development. Thus, Dritev seamlessly connects to the long-standing tradition of the VDI Congress "Drivetrain for Vehicles." At the heart of the event is its selected technical program, which reflects the current challenges and developments in the transmission world. The program includes subjects such as the transmission topology for electrified powertrains and current concepts for automatic transmissions and e-axes. In these, the individual components motor, axle and gear are integrated in one element. For more information, visit *www.dritev.com*.

July 23-27–2018 Coordinate Metrology Society Conference Reno, Nevada. Designed to empower a rapidly evolving profession, the CMSC attracts metrology practitioners, quality control managers, manufacturing executives, scientists, students and educators. Attendees will find enriching, informative opportunities to learn about technology achievements, network with high-level master users, and get an overall picture of the state of the metrology industry. The conference is renowned for its original, expert-level technical papers and presentations covering the successful use of measurement and inspection technologies, industry best practices, new applications and innovations emerging in the field. The CMS Executive Board peer reviews all technical papers and publishes top selections in its prestigious, high-impact Journal of the CMSC. For more information, visit *www.cmsc.org*.

Little-Known Horologist Made Waves with His Revolutionary Chronometer

Jack McGuinn, Senior Editor

Faithful followers of this space are aware that we sometimes like to spotlight important—but virtually unknown or remembered—historical figures that have made a significant contribution to society or everyday commerce with mechanical engineering breakthroughs.

Next up—John Harrison (1693–1776)—a British clockmaker (and carpenter) whose extremely precise chronometer enabled seafarers to calculate longitude (also known as east-west axis) with a degree of accuracy that until then was unheard of. A marine chronometer is defined as a timepiece that is precise and accurate enough to be used as a portable time standard; it can therefore be used to determine longitude by means of celestial navigation. When first developed in the 18th century, it was a major technical achievement. Continuously improving his creation became Harrison's raison d'etre—spanning more than 30 years of persistent experimentation and testing that revolutionized naval (and later aerial) navigation, and served to facilitate the emergence of the Age of Discovery—a good thing—and colonialism—a not-so-good-thing—to accelerate.

For many years navigators used the positioning of the sun or North Star to calculate *latitude*—that is, the distance from the equator in the north-south direction (The Conversation). But calculating *longitude* was extremely more complicated and therefore often far off the mark. For example, there were many instances where explorers "discovered" the same island multiple times, particularly in the Pacific region, where 18th century navigators were obsessed with plotting the islands reliably.

Getting this right was vitally important, given that miscalculating longitude could spell economic—and often —fatal disaster. Consider just one example: In 1707 a five-vessel "pile-up" near the Cornish coast led to the deaths of *1,400* people. This was merely one of numerous maritime incidents involving navigational failure and resultant loss of life. Meanwhile, the British Navy finally was stepping up its efforts to determine a reliable method of calculating longitude. But it was not until 1714 that the British Board of Longitude (no, it's not a Monty Python creation) announced a competition by which £20,000 ($2,039,850 U.S. dollars today) would be awarded to whoever developed the most practically accurate method to calculate longitude.

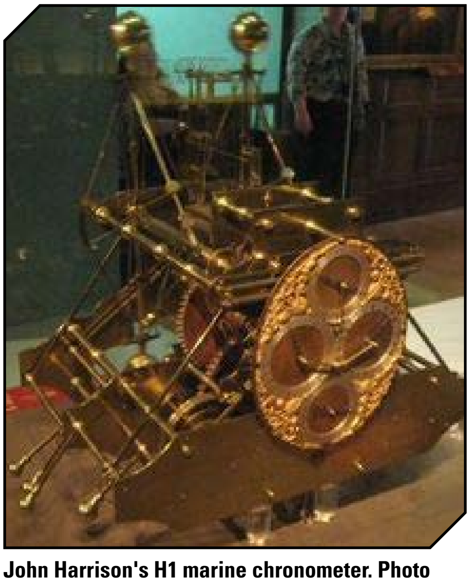
So Harrison entered the competition with a hand-crafted clock that could keep precise time—even at sea. (How the contest played out is a story in itself. The Board arbitrarily decided to award Harrison a partial prize—£10,000. He later received the balance of the award upon the insistence of King George III. There was a later competition as well, in 1761, also not without controversy.)

Harrison's approach to the challenge was to design a highly reliable clock that could keep the time-of-reference place. The difficulties involved included: producing a clock that was impervious to the often wild variations in temperature, pressure, or humidity; maintaining accuracy over long time intervals; resisting corrosion in salt air; and being able to function despite a seagoing vessel's constant movement.

It took Harrison five years to build his first (of five—H1-H5) sea clock. He demonstrated it to members of the Royal Society who spoke on his behalf to the Board of Longitude. The clock was the first proposal that the Board considered to be worthy of a sea trial. In 1736, Harrison sailed to Lisbon on HMS *Centurion* under the command of Captain George Proctor and returned on HMS *Orford* after Proctor died at Lisbon in 1736. The clock lost time on the outward voyage. However, it performed well on the return trip: both the captain and the sailing master of the *Orford* praised the design. The master noted that his own calculations had placed the ship sixty miles east of its true landfall, which had been correctly predicted by Harrison.

In 1730, Harrison designed a marine clock to compete for the Longitude Prize and travelled to London, seeking financial assistance. He presented his ideas to Edmond Halley, the Astronomer Royal, who in turn referred him to George Graham, the country's foremost clockmaker. Graham must have been impressed by Harrison's ideas, for he loaned him money to build a model of his "Sea clock." As the clock was an attempt to make a seagoing version of his wooden pendulum clocks, which performed exceptionally well, he used wooden wheels, roller pinions and a version of the 'grasshopper' escapement. But instead of a pendulum, he opted for two dumbbell balances, linked together.

Today it is accepted wisdom that Harrison's device revolutionized navigation accuracy and enhanced the safety of long-distance sea travel. Harrison was 39th in the BBC's 2002 public poll of the 100 Greatest Britons. Indeed, time has looked kindly on Harrison's inventions. In 2015, the Guinness World Records association declared one of his clocks to be the most accurate swinging pendulum clock in the world. (*Sources: theconversation.com and online article by Rachel Becker at theverge.com.)*



John Harrison's H1 marine chronometer. Photo by Phantom Photographer (CC BY-SA 3.0).

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"Initially, what appealed to us about this Ipsen equipment was its general purposefulness ... We wanted a low-cost, off-the-shelf-type solution that would allow us the flexibility we required – which is what the ATLAS and TITAN® delivered. Now after having performed some pre-training, I would say what stands out the most for both are the ease of use and control of the equipment."

– Continuous Improvement Manager

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Challenge:
The customer was seeing an increase in production demands and volume of parts. While they were relocating their existing facility to a new location, they also needed to find an equipment solution that would help them keep up with the recent influx.

Action:
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