# State of the Gear Industry Special Edition

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*.

For this issue's Ask the Expert installment, we contacted nine individuals and their respective companies or organizations, here and abroad, with the simple question, i.e.—simple to ask, not to answer —

**What are the most important trends affecting the gear industry today?**

**Matthew Croson,** *President, AGMA*

The single largest issue facing AGMA members—and the industry at large—is finding and retaining talent.

AGMA conducted an industry survey to guide our long range planning process and we received more than 460 responses from members, non-members, suppliers, customers—really, the entire supply chain provided input. And it didn't matter whether you were part of a large, small or medium-sized company; whether you were part of management, engineering or R&D; whether you were a customer, machine tool supplier or gear cutter; finding people was the primary challenge facing industry. Whether you talked about it as "grayhairs ready to retire," as one respondent put it, or "it's harder to attract millennials to manufacturing," as another put it—people was the challenge.

The AGMA Foundation responded by launching its "Get in to Gears" program. We have developed a full suite of marketing materials to promote the industry to potential employees. We want every company that produces gears, or is part of the gear manufacturing process, to leverage the free tools we have made available to industry. The beauty of the program is that the AGMA Foundation leveraged its assets to develop these free tools, essentially saving thousands of dollars in design work alone. The materials can also be tailored to each company; e.g., you can place your own logo, website and information about your company on the brochure, Power Point, posters or handouts that we put together. The details are at *https://agmafoundation.org/getintogears*.

AGMA and the AGMA Foundation listen to its members, and respond to current trends impacting the industry today—just as our members must do for their ever-changing customer needs. In this case, we are responding in a new way to essentially innovating how the Foundation delivers value to the industry it serves, and helping ensure that our industry gets its fair share of the most valuable resource a company can have—its people.

**John J. Perrotti,** *CEO/President, Gleason Corp*

The expectations for gears continue to become more stringent in terms of efficiency, duty-cycle and, importantly, noise characteristics. Particularly with the future growth of electric drives, including in automotive, the quality requirements for gearing continue to increase. To meet these challenges requires a systems-based approach from design through manufacturing.

There are many major transformations occurring in the design and manufacturing of gearing; to reach the next level of performance requires intelligent systems. These systems begin with creating a digital twin so that complex processes can be modeled and become highly predictable. At Gleason, we focus on gear driveline systems design and building manufacturing intelligence into our design and analysis software so you just don't have a theoretical solution, but one that can be realized in practice with defined production processes and known data—including costs and quality. This capability—complemented by advanced simulation tools—provides the ability to modify variables and consider a range of possible solutions.

Once a gear enters the manufacturing stage, the development and optimization process continues as information is captured about the production process and the part quality which can be used either in a real-time mode—to quickly send corrective settings back to the machines—or to send information to a cloud-based environment where it can be stored and analyzed over longer periods of time. For example, Gleason has developed in-process inspection capabilities with its GRSL laser-based inspection that can measure most gear features in a matter of seconds and present this information for closed loop corrections. In addition, the experiential learning captured from the data can also be used to further refine design parameters.

These knowledge-based solutions are becoming part of broader manufacturing systems, including advanced automation where multiple tasks are combined and connected as part of the information loop. It is no longer separate islands for design, machines, tooling and inspection, but highly integrated solutions with data applied to customized algorithms which over time can support machine (systems) in learning to continually optimize your results.

Finally, watching how quickly gear producers and consumers are able to adapt to the digital transformation needed for long-term success against the near-term backdrop of an uncertain global marketplace with trade issues and other geo-political challenges, will make 2019 an interesting time for all involved.

**Prof. Dr. Karsten Stahl,** *Chair, Institute of Machine Elements, Gear Research Center (FZG), Technical University Munich*

Within an estimated global production of about $10^8$ gear transmissions per year, automotive powertrains certainly play a decisive role. During the next years we will see a significant increase of vehicles with electrified powertrain. In such New Energy Vehicles — like BEV — the total number of required gears will be drastically reduced compared to conventional vehicles. Additionally, the transmission in an electric powertrain is more compact and seems less complex. These changes present the question about the future of gears in automotive applications.

But despite of the assumed simplicity of the powertrain of New Energy Vehicles, their requirements are becoming more demanding compared to conventional cars with internal combustion engines. Since the combination of a high-speed electric motor with a gearbox shows significant advantages in terms of costs and weight in contrast to direct drive topologies, an elimination of the transmission is not expected in the future. Although the total number of necessary gears in electrified transmissions is reduced, the requirements in terms of power density, efficiency and NVH are becoming much more ambitious. To meet the increased requirements many research projects are being carried out worldwide, focusing on both component-level and overall system-level optimization. For continuous adaption of the powertrain to the increasing demands of electrified vehicles, ongoing research activities on transmission and gears will be necessary.

Against this background, research, development and the production of high-end gears for the automotive industry will have a promising future.

**Dwight Smith,** *Vice President, Mitsubishi Heavy Industries America, Inc., Machine Tool Division*

It is useful to look at three large segments of the overall gear industry, i.e. — automotive, industrial and aerospace. The Machine Tool Division of Mitsubishi Heavy Industries America, Inc. is fortunate to have deep involvement in all three sectors.

It appears that the automotive sector will begin a cooling trend. With the evolution away from conventional sedans to crossovers, SUVs and pickup trucks, car transmission production is turning down, and in some cases (e.g., GM's Warren Transmission Operation and Baltimore plant) — ceasing production. Although 2018 production topped 17 million vehicles overall, this may represent the peak, and softer sales volumes in the next several years are expected. In addition, the increase in electric and hybrid vehicles, as well as future autonomous vehicles, will require gear grinding and, in some cases, improved surface finish via gear tooth polishing, as available on the newly introduced ZE16C/ZE26C machines from Mitsubishi.

From a process perspective, hard gear finishing — primarily gear grinding — will continue to grow. In particular, grinding of internal gears with the Mitsubishi ZI20A will be of great interest, as it is the best technology to reduce noise and improve final accuracy after heat treatment. Helical internal planetary ring gear production will continue to shift to the skiving process due to flexibility and cost.

The industrial sector — especially robotics and automation — is expected to increasingly incorporate gear grinding for both internal and external gears. For gear cutting, the greatly increased throughput and accuracy of modern CNC hobbers, such as Mitsubishi's GE series and electronic guide shapers (ST series), will make it imperative for job shops and other gear producers to replace older mechanical machines. The need for companies to get machines on the floor quickly and into profitable production will make our quick delivery and stock machine program very useful.

In the aerospace sector, civil aircraft orders remain strong for at least the next several years. The need to improve productivity should drive machine purchases in both the green cutting side as well as for gear grinding. There is a large fleet of old and obsolete gear machines that should be replaced as suppliers work to improve productivity and reduce labor cost.

**Dr.-Ing. Oliver Winkel,** *Head of Technology Application, Liebherr-Verzahntechnik GmbH, Kempten/ Germany*

1. We see several trends that are coming up more and more nowadays:
2. Handling and use of data (IoT, Industry 4.0, exchange formats, …)
3. High flexibility of the gear cutting machines (job shops, sub-suppliers, TIER1, …)
4. Reduction of setup and change-over time (maximizing uptime of the machine)
5. Precision grinding and noise reduction (quieter gears, E-Motive)
6. Chamfering and deburring (higher quality and lower costs)
7. Gear skiving (relatively new technology)
8. Hiring of qualified skilled workers

Some comments on the above points and how Liebherr is addressing them:

***1. Handling and use of data.*** It is common that a worker programs the machine by having a printed part and hob drawing, and uses a hand calculator to calculate missing values. The future is that all of these values are transferred electronically into the machine by using standard exchange formats like GDE, DIN 4000, REXS or others. Missing values are calculated by the machine control.With the new Liebherr LH Geartec HMI, we are already making a big step in this direction.Some call it IoT or Industry 4.0, but in general it is all about handling, collecting and using data. It is important to not only collect terabytes of data — which is very easy with the dozens of sensors in the machine — but to use the data reasonably.

One example would be the process monitoring (e.g., in gear hobbing) to detect tool wear and especially unexpected tool failure. Another is the so-called Liebherr kilometer-0-cycle, where we can compare with a standard cycle the actual status of the machine or all axes with the originally delivered condition. This enables the customer to find worn components or to initiate preventive maintenance.

2. ***High flexibility of the gear cutting machines.*** Many of our customers request more and more flexible machines that are not optimized to a specific part but rather are able to machine a huge variety of parts as productively as possible. This means that regardless of shaft or disc-type gear, small or bigger module, small or large diameter, etc. — the machine should be able to cut the part.
   The reason is that the job shop and sub-supplier business increases, and more and more parts are outsourced, so you never know what kind of parts are requested from your customers over the lifetime of a machine, which can be easily be 10-20 years.
3. ***Reduction of setup and change-over time.*** The higher the variety of parts, the more often you have to change-over or make a new setup. Even in typical mass production — as in the car or truck industry — the variants increase. A typical speed gear can have maybe 7 variants, a differential gear maybe 15. To maintain high uptime of the machine, the setup and change-over times have to be reduced to a minimum. On Liebherr machines, quick-change grippers, fixtures and pallets are steps in this direction; a guided setup via the CNC control is another.
4. ***Precision grinding and noise reduction.*** The trend to higher power density and less noise is ongoing; both lead to the clear trend of hard-finishing gears worldwide — especially gear grinding and generating grinding. This usually offers the highest productivity and leads to excellent gear quality — even on medium batch sizes. But sometimes just grinding is not enough. For cars — and especially electrical cars due to the missing masking noise of the combustion engine — the need for very silent gearboxes is increasing. Besides high-precision machine and drive technology in gear grinders, Liebherr approaches this topic with additional features like silent shift grinding (SSG), deviation-free topological grinding (DFT) or noise excitation optimization grinding (NEO) to offer new potentials to improve the NVH performance of gears.
5. ***Chamfering and deburring.*** The higher power density also leads to a more effective use of the tooth width, so the contact pattern comes closer to the faces. Therefore, the chamfering of the teeth becomes more and more important. At the same time, the quality regarding shape and consistency should improve. On the other hand, the chamfering cost should be very small and setup should be very easy and fast (see above). In recent years the ChamferCut-technology (invented by LMT-FETTE) was successfully introduced and established by Liebherr in the gear industry. And the cooperation continues as we just recently introduced the new opportunity of using ChamferCut, despite interference contours.
6. ***Gear skiving.*** An old process is suddenly brand new. Being an option to gear shaping or, in some cases, even broaching or hobbing, the gear skiving process offers new perspectives to increase productivity or reduce cost-per-piece. While many different machine suppliers (gear cutting machines as well as machining centers) offer this feature, every gear producing company should make themselves familiar with the skiving process and find out whether it is applicable or feasible for them or not. While having introduced its skiving[3] (cubic skiving) technology in combination with the new LK 300/500 gear skiving machine in 2017, Liebherr will be pleased to consult with customers on their way to evaluating or maybe establishing this new process in their process.
7. ***Hiring or qualifying skilled workers.*** Finally, gear making is not easy. It is not part of any standard education — whether it is mechanical engineering or manufacturing or anything else. Therefore, it was, is and will always be difficult to find experienced or skilled workers or gear specialists all over the world. The only way seems to be to train them on our own. A first step might be to support schools or universities to get kids and young engineers in contact with gears and to start their fascination on their abilities and challenges. In the end, this will never be enough, so we all have to add on our own company knowledge. In this way, Liebherr supports its customers with regular basic gear technology seminars plus customer-specific, advanced seminars and — most importantly — technology application support when necessary.

## **John Winzeler,** *President, Winzeler Gear*

We continue to be challenged to design and produce gears that meet higher standards for sound quality. From automobiles to appliances, sound is a reflection of quality. Hence we must continue to work towards producing higher-accuracy gears with reduced variability throughout production.

Reducing gear product development time continues to be a challenge. Metal-to-plastic gear conversions to improve sound quality, and reduce weight and cost require extensive material technical data that may not be available for appropriate gear design calculations. Future solutions require expanding the dynamic testing of plastic gears — especially at elevated temperatures.

There is a continued focus on collaboration with clients and suppliers to develop innovative gear products. Engineering is a "team sport," yet few companies approach it in a real-time, collaborative manner. Gear manufacturing capabilities must be considered from the concept phase of a new product design.

We all must focus on the concept of Industry 4.0 and utilizing big data to drive inefficiencies and waste from our gear manufacturing. Developing a strategy to gather and analyze data for continued incremental improvement is critical to remaining competitive.

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**Aaron Isaacson,** *Managing Director, Gear Research Institute*

In my opinion the AGMA Emerging Technologies Committee (ETC) has done a great job selecting topics likely to affect the gear industry in the next few years. If you haven't heard about the ETC, I highly encourage you to take a look at the information compiled on their website (*www.agma.org/emerging-technology*). I've been personally involved with several R&D programs in two of the identified areas, specifically 3-D Printing / Additive Manufacturing (AM) and New Materials. Progress is being made faster than you probably realize.

Most people imagine crude plastic trinkets with rough surfaces and poor dimensional accuracy when they hear that something was 3-D printed. However, dramatic progress has been made in the world of AM in recent years. Metal parts (yes even gears!) can be produced with very little porosity and reasonable accuracy. There have been two projects in the past year come through the Gear Research Institute's (GRI) test lab to characterize the bending fatigue performance of metal gear teeth fabricated using additive processes. Sure there is still work to do before you can print a replacement transmission gear for your old John Deere tractor, but in both instances the fatigue performance greatly exceeded my expectations.

This semester at Penn State, I am advising a multi-disciplinary team of senior undergraduate engineering students to produce 3-D-printed plastic gears for use as replacement parts in their senior capstone design project. This is an exciting opportunity to investigate a wide variety of materials and fabrication techniques for gear applications and, hopefully, teach a few students a thing of two about gears along the way.

New materials and the advancement of existing materials and processing technologies are areas where there is likely to be continued improvement in 2019.Cleaner gear steels, lightweight hybrid gears and the expanded use of polymers for gear applications are examples of current research efforts that could transition to commercial applications in the coming year or two.

The GRI Aerospace Bloc research consortium has been investigating triple vacuum melt steel for gear applications. During the steel making process, each vacuum melting operation removes a significant number of impurities (non-metallic inclusions) in the steel. The inclusions create stress risers in the material and lead to premature crack formation. The ultimate goal is to dramatically improve the fatigue life of the gears. Early results are promising — stay tuned!

Hybrid gears use a lightweight material like titanium or carbon fiber for the hub and body of the gear, but have hardened-steel teeth. The gears have similar load carrying capacity to gears made completely from steel, but are significantly lighter; therefore they have lower inertia and reduced losses in high-speed applications. They offer tremendous potential for weight savings in a rotorcraft gearbox.

Lastly, several polymer manufacturers have introduced high-strength plastics with much higher glass transition temperatures compared to what was previously available for gear applications. These materials can be reinforced with various filler materials to get higher strength than typical plastic gears, opening up a range of new application possibilities. These materials have led to a dramatic increase in R&D ideas applicable to polymer gears. In fact, we are exploring the formation of a polymer gear research consortium. If your company is interested, please don't hesitate to contact me for further information.

**David Goodfellow,** *President, Star SU*

The gear industry is facing its greatest challenge since the recession in 2008-2009. We've enjoyed ten years of overall market expansion — especially in the automotive industry — where we had programs every year for 6-, 8-, 9- and 10-speed transmission projects. There is also a significant process change from hob shave to hob grind. With these automotive projects maturing, we are now faced with a customer demand of increased quality requirements and ways to decrease the cost-per-piece of production — especially as it relates to tool cost-per-piece. This has manifested itself in improvements of substrate material such as carbide and MC90, and wear resistant coatings such as ALTENSA.

So the biggest challenge today, especially in automotive, is to find ways to increase tool performance for the cutting tools throughout their entire usable life. At Star SU, we are investing not only in new tool production, but in the total life cycle management of the tool — from the new tool through the last regrind and coating.

The main activities are focused around increasing tool performance while decreasing tool cost-per-piece with proper applications of substrate material, high performance wear-resistant coatings, enhanced tool surface conditioning, and edge prepping. These activities require a lot of research and development, as well as investment in new capital equipment to improve the process of re-sharpening and coating.

While we are working on the cost reduction measures, we are also faced with significant challenges of tariffs, as well as significant material price increases. We've also seen a substantial increase in the utilization of power skiving and Scudding globally, and a challenge in keeping up with the high demand for these cutters, both new and refurbished.

We will now be faced with even greater challenges with the impact of the development of the electric vehicle, where there are indications that by 2025 35-38% of global automobile production will be electric vehicles (or roughly 6 million vehicles). This could have a significant impact on the number of gears being produced in the automotive industry and industry as a whole.

**Dr.-Ing. Dipl.-Wirt.-Ing. Christoph Löpenhaus,** *Laboratory of Machine Tools (WZL) of RWTH Aachen*

***New materials and treatments.*** Developments in E-Mobility and jet engine design show a clear trend to high-speed transmissions with speeds >15.000 rpm. In these applications a high number of load cycles are transferred via a single gear set. The expected lifetime-per-gear-set is much higher than in conventional applications today. Consequently, new methods in lifetime prediction (ultra-high cycle fatigue range), as well as countermeasures for late fatigue failures, have to be developed. In our expectation the meaning of clean steels will rise, as late failures often originate in inclusions or comparable weakest links in the material matrix. In high-cost applications, steel grades with higher amounts of alloys are currently being developed and tested in WZL's aerospace-approved lab. Furthermore, alternative material structure compositions obtained in alternative heat treatment procedures show a high potential for strength increase. Besides the potential in fatigue life, the influence on machinability/grindability needs to be analyzed.

***Noise reduction.*** Especially in E-Mobility, the masking noise of the combustion engine is missing; this leads to a more pronounced perception of gear noise.

Additionally, the large speed range in these applications shows the importance of control on all three scales: gear (runout, pitch), tooth flank (modifications), and surface (waviness). A strong trend in consideration of all three aspects in gear design is visible making use of powerful tooth contact analysis, e.g. — developed at WZL. Especially runout and pitch need to be addressed, as the shaft rotational frequency is in the range of human hearing at high gearbox speed. Therefore, WZL works on tolerances for pitch and runout in high-speed applications. Furthermore, results at WZL show that a controlled disturbance of regularity of the gear mesh, e.g. — by changing flank corrections from tooth to tooth — shows impressive results in the decrease of tonality and could build up a new era of gear design regarding noise excitation.

***Internal gears.*** Power density optimization puts planetary gear stages on the table. The high noise and strength demands require heat treatments and hard finishing of the surfaces. This poses multiple challenges to gear manufacturing of internal gears, i.e. — what is a suitable finishing technology with high productivity compared to discontinuous profile grinding. Multiple technologies show potential, including: honing of internal gears, internal generating gear grinding, or hard skiving. Furthermore, the ring thickness of internal gears decreases more and more. On one hand, multiple manufacturing steps in a single clamping setup via process integration help optimizing the quality; on the other, intelligent ways for clamping of gears in the machine are necessary to allow for process integration.

Additionally — and especially for internal gears — flank deviations due to deformation in the clamping device must be avoided; otherwise, a polygonal geometric error over the circumference results.

**Editors' Note:** Have questions or comments regarding the above? We'd love to hear from you. Simply contact Managing Editor & Publisher Randy Stott (*wrs@geartechnology.com*) or Senior Editor Jack McGuinn (*jmcguinn@geartechnology.com*).