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JAN/FEB 2018

2018 STATE OF THE GEAR INDUSTRY

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2018 STATE of the GEAR INDUSTRY SURVEY

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Vol. 35, No. 1

departments

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THE GEAR INDUSTRY'S INFORMATION SOURCE

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Gear Technology TV

Browse our webpage dedicated to original content prepared by our editors, along with the help of gear industry experts from around the world. (*www.geartechnology.com/tv/*)

Gearbox Test Center

British engine manufacturer Rolls-Royce inaugurated its new test center for power gearboxes. Rolls-Royce is working in partnership with Liebherr-Aerospace through their Aerospace Transmission Technologies joint venture to develop manufacturing capability and capacity for a new power gearbox. (*www.geartechnology.com/videos/Liebherr---Rolls-Royce-Power-Gearbox-Test-Center-/*)

Zeiss Industrial Metrology

At the Quality Show in Chicago, Zeiss had two technology areas to show visitors how the measuring lab can be networked intelligently in the future. One booth featured Zeiss CMMs, optical machines, and surface and form measurement systems. The second booth illustrated the importance of in-line inspection and process control. (*www.geartechnology.com/videos/Zeiss-Industrial-Metrology/*)

Gear Talk

Gear Technology technical editor and resident blogger Chuck Schultz weighs in on some important gear topics on the homepage:

In *Brushing up on Fundamentals*, Chuck discusses the importance of basic articles on gear design and gear making. These will be featured regularly in the blog this year.

In *The Importance of Scut Work*, Chuck describes why knowing the ins and outs of your product on every level makes you a better engineer.

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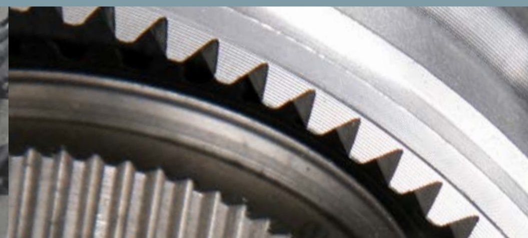
The all new MSS300 brings flexible, high-volume internal gear skiving to internal gear manufacturing. With revolutionary Multi-Blade skiving tools, it produces three to five times more parts than conventional tools. Additionally, the MSS300 offers greater flexibility by cutting restrictive geometries and even allowing parts previously manufactured in two parts to be cut in one Super Skiving process. To learn more about how the MSS300 is ready cut up your competition visit **www.mitsubishigearcenter.com** or contact sales at **248-669-6136**.





We'd Grow Faster If We Could

Publisher & Editor-in-Chief
Michael Goldstein

It's probably no surprise to anyone that the majority of the gear industry had a pretty good year in 2017, and that most gear manufacturers are expecting a pretty good 2018 as well. After all, most major economic indicators — including the ones that focus on the manufacturing sector — have been positive for some time.

For example, according to the Institute for Supply Management, the Purchasing Managers Index (PMI) registered at 59.7% in December 2017, the 16th consecutive month the index has indicated growth in the manufacturing industry. According to the Association for Manufacturing Technology (AMT), manufacturing technology orders were up 9.4% through the first 11 months of 2017.

But it's nice to have reassurance that comes from closer to home, especially when we operate in such a specialized industry. That's why *Gear Technology*'s annual State-of-the-Gear-Industry survey is so important. And the survey confirms what most of us have been feeling—that the world still needs gears.

The full results of our survey are presented in the article beginning on page 30 of this issue. If you study the results, you'll see that 70% of gear manufacturers saw production volume increase in 2017, and even more (77%) expect production to increase further in 2018. The same is true of sales, with 68.6% reporting an increase in 2017, and 73.5% expecting an increase in 2018.

From these numbers, it seems like 2017 was a strong year for the gear industry, and 2018 looks to be even stronger.

Unfortunately, all of that projected growth is not a guaranteed result. You need people to make it happen. And not just any people: You need skilled labor.

And that's the problem. You get the sense that the gear industry could show even more impressive gains if it could grow its skilled workforce. We've been talking about this for more than a decade. I don't want to be an alarmist, but every year, we seem to get closer and closer to a state of crisis.

In this year's survey, nearly 80% of respondents say their companies are currently experiencing a shortage of skilled labor. In the open-ended responses, which you can read on page 31, finding skilled labor was by far the most commonly cited challenge. Clearly, this is the No. 1 issue facing our industry today by a wide margin.

So what should we do about it?

Many of you are already working on solutions. Two-thirds of your companies are already working with local educational institutions to help develop or train employees. Over half have mentoring programs in place for new hires. But according to the survey, only about 45% of you work for companies that regularly send employees to gear-related training seminars or courses.

Shouldn't that number be much closer to 100%?

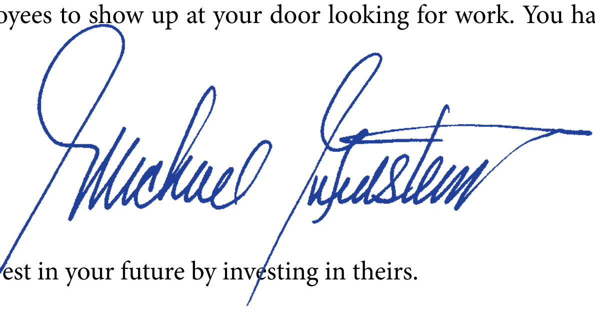
After all, there are plenty of opportunities available, starting with the AGMA, which has expanded its educational offerings considerably over the past couple of years. Their *Basic Training for Gear Manufacturing* course is a hands-on, face-to-face class that combines classroom instruction with shop floor time using manual machines to better demonstrate the fundamentals. The next session is in April. You can sign up at *www.agma.org*. AGMA also offers a wide variety of in-person and online courses to meet a wide variety of skill levels and needs, including gear design, metallurgy, inspection, failure analysis and more. Go to their website and click on "Education." If you haven't been there in a while, you'll probably be surprised by how much is offered.

Besides AGMA, there are plenty of other options as well. Most of the major gear machine tool manufacturers offer webinars and seminars throughout the year, as well as in-person training. Considering that "Machining Best Practices" is the type of training most needed by the gear industry (according to the survey), it makes sense to learn from the people who design the technology and have the broadest exposure to what your competitors and colleagues are doing around the world.

Finally, over the past year, Arvin Global Solutions has developed an extensive series of seminars for gear manufacturing training, utilizing a team of industry veterans who've been there, done that. You can see their schedule of upcoming seminars in their ad on page 55.

There are always lots of educational opportunities in our printed calendar each issue (see page 79), and even more posted on our website (*www.geartechnology.com/events.htm)*.

Whatever you do, it's time to stop waiting for new, qualified employees to show up at your door looking for work. You have to invest in your future by investing in theirs.



There's a Story Here

Lewis A. Weiss

As the founder, president and co-host of *Manufacturing Talk Radio*, as well as publisher of *Metals & Manufacturing Outlook* eZine, I am excited to report that the economic outlook for 2018 is just too good not to tout. Whatever 'final GDP number' the government divines for 2017, the year will finish above 3% for the first time in a decade. While that is great news, the real excitement is that we have a pretty good handle of 2018 with the expectation that the year will run above 3% or better month-by-month, quarter-by-quarter, and may just have a shot at 4% for the entire year for the first time in decades.

What that means is that machines will be selling well, and inside many of those machines are the magical gears that covert energy and power to increase speed, increase force or change direction. And some gears do a combination of those things. Those components move the modern world, even more so than the lever and fulcrum. And the incredible brilliance of the engineers who design gears, and the machinists who make gears, and the mechanics who install gears is truly remarkable when you look beyond what a machine does to how it has the ability to do it at all.

For a decade, America has waited for the recovery from The Great Recession. No one expected it to drag on this long or be this tepid, but the water in the kettle is boiling now and the gear industry will be cooking in 2018, with some early inklings that 2019 might just be another strong year of economic growth. There will be great excitement in the gear industry, from new gears for new machines to replacement gears for maintenance and repair being in high demand.

At *Manufacturing Talk Radio*, we're looking for stories in manufacturing. Somewhere in the gear industry, perhaps as hidden as gears in the gearbox, are amazing stories of 'how things work' or a new gear design that has never been created before for a use no one imagined just five years ago. We want to hear those stories. We want to highlight them "on the air." Tell the world just how cool gears are and the astonishing things these unsung components do deep inside a manufacturing marvel. We want gear manufacturers or industry associations to bring their story to us so we can tell it, so we can interview the mavens and gurus behind what is so often taken for granted or simply unsung. And in that telling, we hope to touch the minds of the next generation so they take a deeper look into an industry that is at the forefront of innovation and change, especially the change of speed, force or direction.

> ***"Somewhere in the gear industry, perhaps as hidden as gears in the gearbox, are amazing stories of 'how things work' or a new gear design that has never been created before for a use no one imagined just five years ago. We want to hear those stories."***

As you work through 2018, bring a story to the forefront of a segment of a remarkable industry that has transformed the world many times since the invention of the wheel.

Lewis A. Weiss is the president of All Metals & Forge Group, a manufacturer of open die forgings and seamless rolled rings, who has continuously published *Metals & Manufacturing Outlook* and its predecessor, *MetalsWatch*, since 1987, and launched *Manufacturing Talk Radio* in 2013 to promote manufacturing to the next generation.

What's Your Story?

If you have something to say to the gear industry, this is the place to do it. Send your letters to the editor, opinion pieces and other short columns to Managing Editor Randy Stott at *wrs@geartechnology.com*.

Praewema Antriebstechnik

DEVELOPS PRECISE MACHINING SOLUTIONS FOR PLANETARY GEARING

The DVS gearing specialist Praewema Antriebstechnik continues to expand its technological expertise in order to keep pace with the growing significance of planetary geartrains for automatic and particularly electric vehicles, with the associated need for even higher-precision production of toothed gear components. The company now offers holistic machining solutions for µm-precise production and optimization of both external and internal gearings. Here is a detailed look at the market and technology leader's extensive expertise when it comes to the complex production of inner-toothed ring gears for planetary geartrains.

Planetary geartrains are predestined for installation in the powertrains of automatic and particularly electric vehicles. Compared to conventional spur gear stages, the planetary geartrain makes it possible to divide the power flow into three or more strands. This permits higher transmission and reduction ratios to achieve greater performance density, while reducing weight and package aspects and improving running smoothness. As a result, they fulfill the existing need for higher torques with reduced package and weight for electric drives that stand out with higher motor speeds of up to 17,000 rpm.

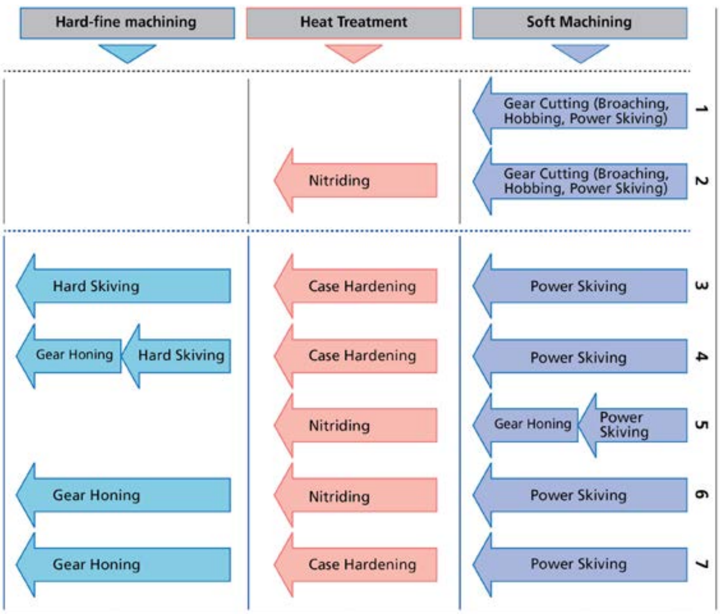


Figure 1 Possible process sequence for the production of ring gears.

In terms of production, these factors lead to narrower geometrical tolerances and thus the complex demand for even higher precision NVH-optimized machining of corresponding planetary geartrain parts, referring particularly to the quality of necessary gearings. Praewema Antriebstechnik fulfills these requirements with tailor-made technology, machinery and tool solutions for high-precision gear manufacturing and optimization.

Based on a wealth of comprehensive expertise with Praewema gear honing for external gearing surfaces, the DVS gearing specialist has now refined this technology even further for the hard-fine machining of internal gearings. Supplemented by the use of the highly productive power skiving technology together with the possible integration of additional machining steps such as deburring, Praewema now offers an integrated package for high-precision soft and hard-fine machining of the simple planetary set — in other words, now also for inner-toothed ring gears as well as outer-toothed planetary and sun gears.

While in the past inner-toothed ring gears were not expected to reach the same high quality standards as outer-toothed planetary and sun gears, things have changed as a result of current powertrain developments. There were two reasons for the lower quality standards in the past. Tooth root bearing capacity is less critical than in planetary and sun gears due to more favorable geometrical conditions, and until recently, suitable highly developed machining technologies were simply not available due to comparatively small batch sizes of rings gears.

Up to now, manufacturers have enhanced the performance and NVH behavior of planetary geartrains almost exclusively through continuous improvements to the machining quality of planetary and sun gears with a sequence of both soft and hard-fine machining processes. These parts therefore offer high gearing qualities and strength values and allow for a large number of toothing corrections. By contrast, the inner toothing of ring gears typically made of tempering steel is usually just soft machined with no additional heat treatment as a rule after the gearing is finished. The result: limited correction possibilities and average strength values and toothing qualities, with a negative impact on wear and noise behavior and thus on the functional efficiency of the powertrain.

Praewema has identified possibilities for optimizing the production of ring gears. This demanded expertise, not just in machining toothings but indeed in all process steps, and opened up scope both enhance the load rating through case hardening and to use precise, economically efficient hard-fine machining procedures after the heat treatment phase. To this end, the company developed and optimized corresponding soft and hard-fine machining methods together with a suitable machine concept.

Depending on the user's quality demands for the resulting ring gear, Figure 1 shows possible process sequences for the production of ring gears listed from top to bottom in seven variants. Variants 1 and 2 show the conventional manufacturing process described above; the nitriding heat treatment option in Variant 2 improves the load rating but has a negative impact on toothing quality. Variants 3, 4 and 7 show process sequences that optimize both load rating and toothing quality. In each case, soft machining is followed by case hardening heat treatment. This hardening method, implemented, for example, by mandrel hardening or low pressure carburizing followed by high-pressure quenching, may improve material strength but results in hardening distortion such as shrinking, ovality and ship-form (Fig. 3). Hardening then has to be followed by corrective hard-fine machining for important functional parts of the gear wheels, particularly the running gears and bearing seats.

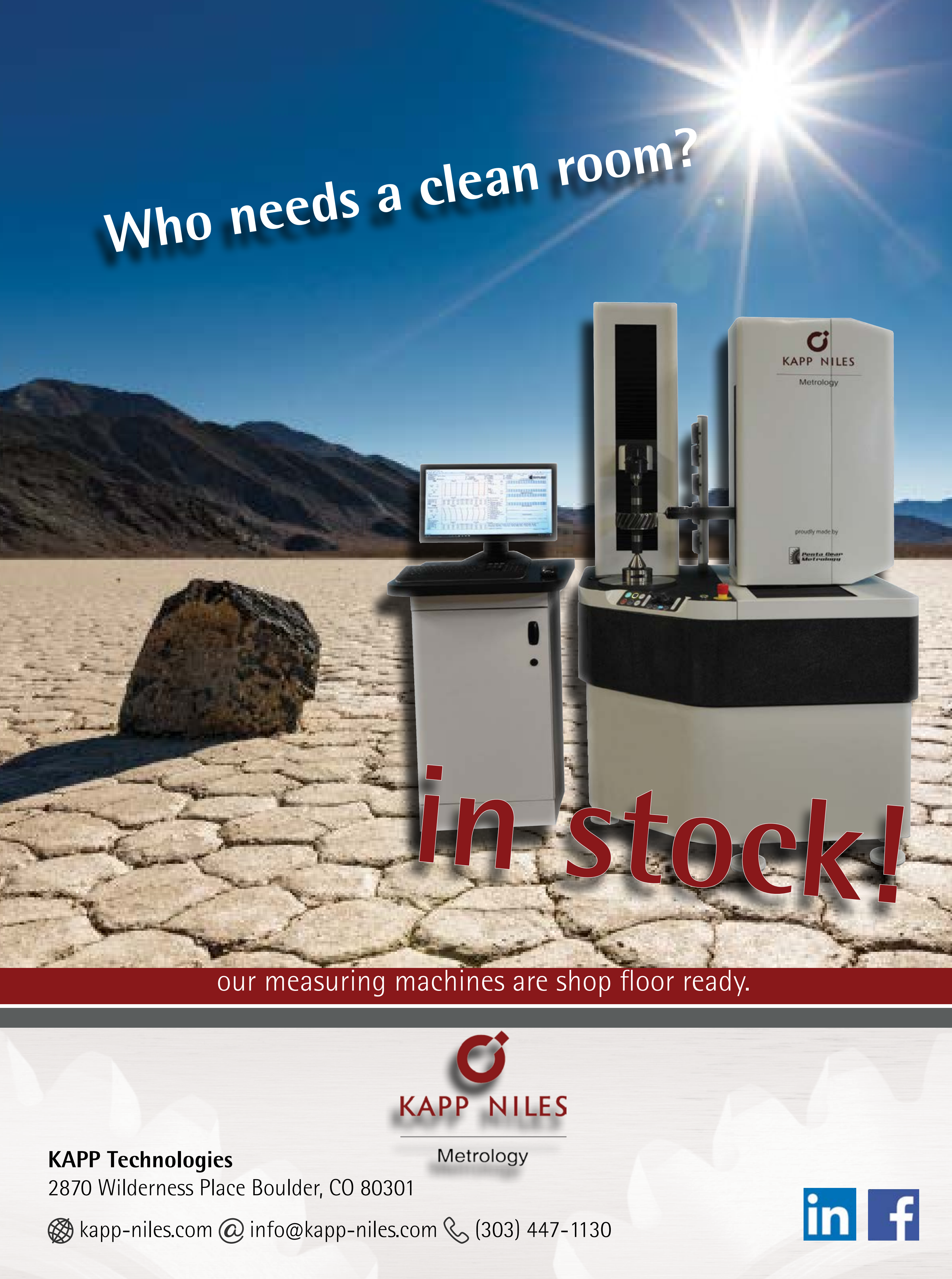

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Figure 3 shows a typical ring gear geometry for an automatic car transmission where the roundness and smoothness distortions were almost halved by specific process control of the hardening phase. Here due consideration must be given to the fact that a certain protuberance allowance has to be heeded during soft machining to prevent notches in the finished gearing. The quality requirements for soft machining can also be reduced within narrow limits due to the subsequent hard-fine machining. The same also applies to the possibility of toothing corrections. Variant 5 constitutes a stand-alone special case: here a pre-skiving process is followed by honing as part of soft machining in order to improve the surface quality. This process sequence deliberately tolerates the hardness distortion resulting from subsequent nitriding.

When it comes to hard-fine machining, Praewema opts for highly productive power skiving, specifically their gear honing that has been specially refined for inner gearing applications. Hard skiving permits effective correction of hardening distortions without the characteristic feed marks. It is therefore suitable for the mass production of ring gears with slightly lower quality standards (Variant 3) as well as a pre-machining for gear honing, as only very limited further material removals are necessary to minimize form deviations and pitch errors, thus achieving very high gearing qualities (Variant 4). In Variants 6 and 7, soft machining using power skiving and heat treatment with nitriding or case hardening is followed by hard-fine machining using inner honing of the soft machined gearing. The latter variant is given preference for ultra-high stressed parts in view of the better load rating properties.

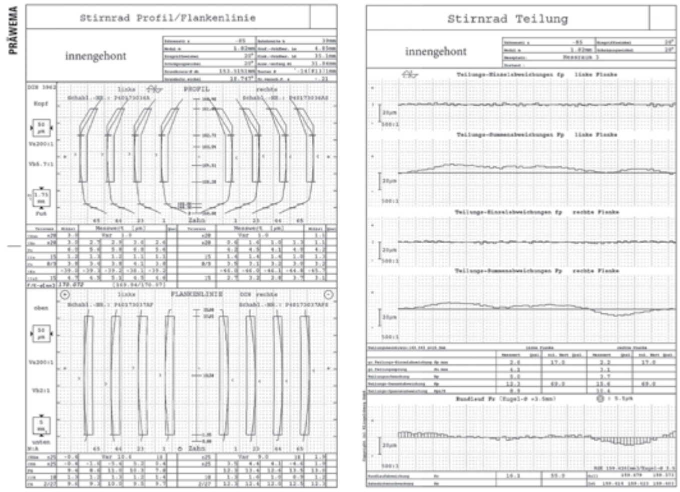

Figure 2 This chart shows the minimizing effect on both surface structure and the parameters influencing noise and wear development.

Just like the proven honing for external gearings, Praewema's refined gear honing for internal gearings fulfils the highest standards for surface and profile quality of toothed parts so that ring gears can now be machined in hitherto unequalled productivity and manufacturing quality. The typical gear honing structure has a positive impact on the excitation characteristics of the gearing. Figure 2 clearly shows the minimizing effect on both surface structure and the parameters influencing noise and wear development, respectively pitch deviations. Powertrain manufacturers can therefore produce wear- and noise-reducing planetary geartrains with higher transmissible torques, exactly in line with the demands made for application in the powertrains of automatic and particularly electric vehicles.

Economically efficient and precisely fitting original tool solutions for this process are available from the DVS affiliate DVS tooling, whose range covers the entire scope of tools needed for Praewema gear honing. This includes the completely new development of inner-toothed VarioSpeedDresser tools and outer-toothed honing wheels. As with the honing of external gearings, the VarioSpeedDresser also permits precise dressing of the honing tool, or in this specific case the honing wheel, with a defined cutting edge and flexible definition of the tooth geometry. In combination with Praewema gear honing, it is thus possible to make geometric adjustments respectively flank line corrections while at the same time applying exact finishing to the gearing surfaces. As such, it comprises a milestone in the field of hard fine-machining of hardened internal gearings of gear components.

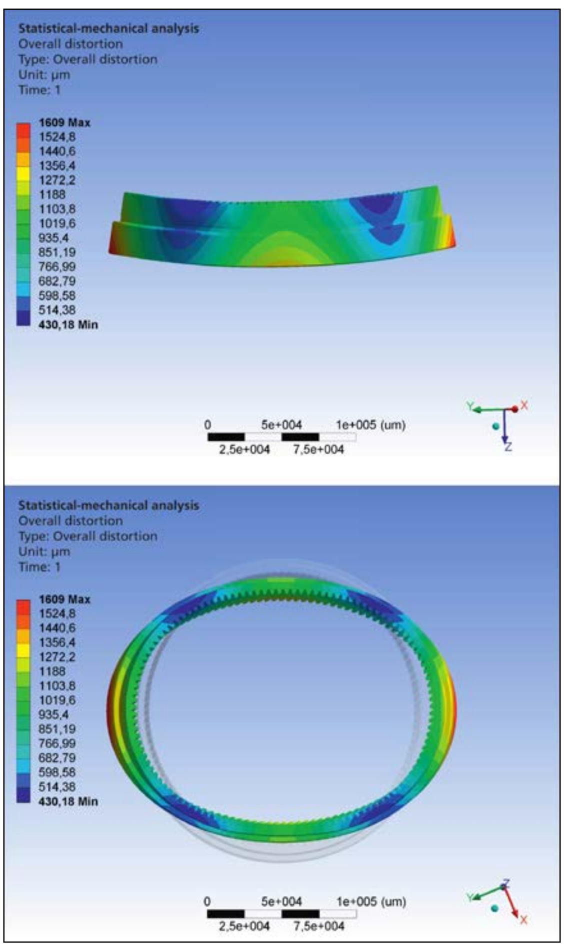

Figure 3 This hardening method, implemented, for example, by mandrel hardening or low pressure carburizing followed by high pressure quenching, may improve material strength but results in hardening distortion such as shrinking, ovality and shipform.

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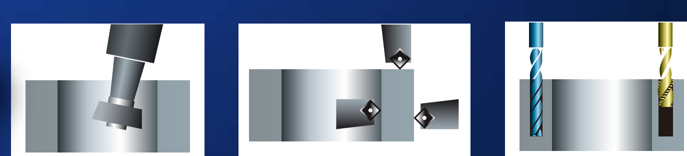

- High Efficiency Gear Skiving Reduces Work Time up to 1/5 (compared to gear shaping)
- Proprietary Technologies Used
- High Precision Machining of Hardened Gears
- Easy to Control Tooth Profile
- Compact, yet can Machine up to 450mm Diameter Part

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Kadia Inc.

INTRODUCES COST-EFFECTIVE, ECO-HONING MACHINE

Manufacturing companies that produce highly precise bores in small to medium batch sizes often hesitate to invest in their own precision honing machine. The rate of utilization is simply too low. Such manufacturers might use a simpler machine that is less costly but often does not work precisely enough.

With a new single-spindle Eco Honing Machine, Kadia now seeks to meet the needs of exactly these and similar user groups. The E line, as it is called, is the ideal solution for entry into high-precision honing. And in the event that production quantities rise — no problem, as the machine concept offers options for series production.

In view of rising quality requirements, every µ matters when honing is used for finishing of precision bores. The edge of what is technically possible is becoming the norm. High-end machining equipment and highly developed technology are the prerequisites to even be considered as a supplier. Working productively and precisely to the last µ is Kadia's specialty. The honing specialists from Nürtingen have positioned themselves for years in the area of professional users, with the focus on small to medium diameters.

"The new single-spindle E line is a cost-effective, productive honing solution for the highest precision. With this machine we are rounding off our spectrum in the smaller range," said Kadia's Executive Director Henning Klein. The machine is also ultra-compact and requires just 2.5 m² of floor space. The control cabinet is integrated into the side and all the components that require regular maintenance are easily accessible. Potential users who also have the area of their production space in mind will be glad to learn that installation close to the wall is possible.

Until recently, the company has developed mostly multi-spindle machines for use in large series production, especially by automotive manufacturers and large suppliers. "The E line is aimed, on one hand, at these current customers, especially at prototype developers," Klein said. "We see the second user group as manufacturing companies that want to

either produce small volumes especially flexibly or produce in series economically, all in the high-precision range.

Such companies then have two options: They either handle the honing themselves or they hand off the demanding precision work to external service providers. The latter lends itself well when the company does not view honing as one of its own core competencies but would still like to accept orders from customers with highly precise requirements for boring quality.

Professional honing providers can carry out such tasks quickly and reliably. The new E line is the ideal alternative, especially when honing is a central part of the company's manufacturing competence and highly economical and precise work is important. In this case, the special entry-level features and the quality of output are not mutually exclusive, since the same components that Kadia uses in other types of machines ensure that the end quality is correct down to the µ: a highly dynamic lean high-speed honing spindle and intuitive high-performance control.

For more information:
Kadia Inc.
Phone: (734) 277-4060
www.kadia.com

Forest City Gear

EXPANDS SMALL DIAMETER ID/OD GRINDING CAPABILITY

Forest City Gear has expanded its capabilities for the hard finishing of smaller diameter gears with particularly tight ID and length tolerances with the addition of a Usach 100-T4 ID/OD Grinder with 4-station turret.

While the new Usach can accommodate parts with diameters as large as 450 mm (17.71"), its ability to deliver exceptional grinding performance for gears with smaller diameters made from difficult-to-machine hard materials made it ideal for the types of projects Forest City Gear specializes in, according to Forest City Gear Director of Operations Jared Lyford. "Where in the past we might have outsourced this work, we're now able to take on even the most challenging ID grinding configurations in-house and maintain tighter control of the process," says Lyford. "It's an amazingly versatile, highly productive machine."

The Usach features a 4-station turret to speed changeover between three ID grinding spindles, an OD grinding spindle and a probe unit for in-process inspection of axial length, roundness, feature size and other critical part characteristics. An on-board rotary diamond dresser enables Forest City Gear to use dressable CBN grinding wheels for profile grinding of radius angles and other special features.

For more information:
Forest City Gear
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www.forestcitygear.com

VBN Components

LAUNCHES VIBENITE 290 WEAR RESISTANT STEEL

VBN Components is launching the world's hardest near-net-shape steel; Vibenite 290. The hardness of the alloy, plus its high carbide content, make it a realistic alternative to cemented carbides for numerous applications that demand high resistance to both wear and heat. The additive technology of Vibenite 290 enables complex and smart shapes.

"We interact daily with customers who have very specific requirements regarding materials performance concerning wear and heat resistance. To meet their needs, we have developed a material with excellent qualities, and which can be ordered in near-net-shape," says Martin Nilsson, CEO of VBN Components.

A replacement for cemented carbides

Vibenite 290 alloy is highly wear and heat-resistant and contains a high proportion of carbides; around 25 volume percent in fully-hardened condition. This high carbide content makes the material a strong candidate for replacing cemented carbides in many

Liebherr Automation Systems

OFFERS FLEXIBLE PRODUCTION WITH PHS ALLROUND PALLET HANDLING SYSTEM

Liebherr Automation Systems introduced its new PHS Allround pallet handling system, designed to enable a broad range of shops to engage in flexible production in combination with 4- and 5-axis machining centers, at EMO 2017. The new modular concept, available in three capacities, can handle loads up to three tons, is extremely flexible and can be individually configured and expanded. This corresponds to pallet sizes of 500 × 500 mm to 1000 × 1000 mm. Users can introduce flexible production systems with manageable investment and expand them when necessary.

The customer is able to combine preconfigured modules as needed to match production handling needs: the storage locations can be arranged in a circular pattern, with one or more machines, or in a line.

For more information:
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situations, especially for larger details with complex designs. Furthermore, the alloy's unique properties make it suitable for any type of application where erosion and abrasion are present, especially when adapted to metal cutting tools, for example.

Typical users come up against numerous obstacles to finding the ideal material for their tools and components. They traditionally face the need to first forge and roll metal bars that, following heavy logistics, are finally drilled, milled and turned. With additive technology, VBN makes this whole process obsolete. The result is higher efficiency for the user and, thanks to the material's greater wear resistance, substantially increased product efficiency and life-span.

For more information:
VBN Components AB
Phone: +46 (0) 18-24 07 60
www.vbncomponents.com

Holding Fast, Bouncing Back

Business is finally starting to get back to usual in the big gear world, which offers us a chance to look back at the greatest lesson on how to survive an economic downturn.

Alex Cannella, Associate Editor


A Hofmann Engineering forged steel gear being installed in a gold mine in Asia.

Like the rest of the world, big gear manufacturers are finally seeing signs of business returning to "normal." Thoughts about recessions and survival strategies are starting to fade into memories, and as customers in the mining and marine markets are starting to look at expanding their equipment, big gear manufacturers, in turn, are starting to see improving fortunes on the horizon. That said, as we move forward to brighter times, it doesn't hurt to glance back at how we made it this far.

So let me tell you the parable of Hofmann Engineering's Mill Gearing Department. It's a story that affirms some of the most common advice you'll hear during an economic downturn Advice that, heck, I've written multiple times in this magazine myself. Advice that should be taken to heart and not forgotten while we let the good times roll.

When economic downturns happen and times turn tough, the most common advice you'll hear is that you need to scale back and cut costs to keep yourself financially solvent, but you also need to make sure you maintain your core competencies for when the market inevitably starts going back up. A whole hog fire sale might keep your company alive, but doing so also leaves it gutted and left behind when better times come, which can be just as damaging as stubbornly powering through a recession like nothing's wrong. The crucial advice is to make sure you balance it and don't lay off your entire sales force when you're going to need them again in two years.

In Holger Fritz, Hofmann Engineering's manager of mill gearing and site services, own words: "You have to make it through the low times...and then when the high times are coming, then you already have to look the next five years ahead."

For Hofmann Engineering, however, making it through the low times was easier said than done. They're a company that prides itself primarily on exceptional quality and its custom manufacturing jobs, and when the economic downturn came, those were the two things the market immediately threw out the window.

When times were good, the Mill Gearing Department was what the market wanted. But in a recession, they were a department geared to the exact opposite sensibilities of what market conditions demanded. Nobody had the funds to pay for a high end, quality product. But even with the deck stacked against them, they still managed to come out the other side of the recession intact.

But to understand how Hofmann Engineering got there, we need to start almost 20 years ago, when the department's pursuit of quality included a shift to focusing on steel forging. The casting techniques they were already using were cheaper, but according to Fritz, the department was running into regular issues with their cast gears. Often, Hofmann's engineers would put in weeks of work, only to find errors such as small gas holes that only became noticeable in the final stages of machining and reduced the quality of the gear such as small gas holes, and whenever this occurred, Hofmann and their customers were always left with two unfortunate choices: ship the gear as is, warts and all, or start over and spend another 20 weeks making a new gear. For the customer, that meant waiting for parts they might not have had the luxury of waiting for. For Hofmann Engineering, it meant additional overhead costs and reduced profits. It's a situation that nobody benefits from. Eventually, the department had

had enough of being put in that position, and so they turned to steel forging for their gears instead.

Focusing on forged steel turned out to be the right choice. Even if the process was a little more expensive, Hofmann Engineering saw an overall leap of quality in their products and could design higher AGMA-rated gears. For a decade and a half, the manufacturer saw positive returns for the shift in strategy and continued to pursue quality first.

Then what Fritz has dubbed as "the mining crisis" hit roughly five years ago. Business dried up. Customers went into survival mode as the mining market, a primary source of business for Hofmann Engineering, receded. The influx of new projects halted. Suddenly, all the mining industry wanted were replacement gears, the bare minimum they needed to keep their existing equipment functioning and survive until the market turned back upwards, and they wanted them cheap.

"So the focus changed completely in development and so on," Fritz said. "Five years ago, quality, quality, quality, and now it's more cheap, cheap, cheap. This is what the customer wants and you have to trust the market."

Suddenly, the market was favoring cheaper methods like casting that Hofmann Engineering had left on the wayside, and they had to find a way to make up for the higher cost of forging. But the manufacturer had no choice but to follow the market and pivot their business model to meet its new demands. They shifted to manufacturing spare and replacement gears.

It rapidly became apparent, however, that much of how they did business before hadn't prepared them for the aftermarket space. The department had always manufactured batches of spare gears, but they had specialized for some time in doing one-off custom gear manufacturing jobs. During the recession, their projects became predominantly for replacement gears instead, while the custom projects became less prevalent.

When taking on custom gears, every assignment was a unique challenge with its own set of requirements that Hofmann's engineers needed to meet. That meant a lot of time tweaking and optimizing gear designs to make the highest quality workpiece they could. None of that expertise could be utilized when Hofmann had to switch to manufacturing standardized gears, which not only meant they couldn't leverage one of the department's greatest strengths, but also failed to satiate the engineers' desire for design work.

"On spare gears now, it's a design schism," Fritz said. "You can't optimize. You can't do anything. It has to be interchangeable."

Faced with a market that was rapidly drying up and ran counter to everything their department's culture espoused, switching over to manufacturing spare gears was going to be easier said than done for Hofmann. It was going to take changes in how the department functioned.

The first thing they did was narrow their profit margins to make their forged gears competitive with cheaper manufacturing processes. To reach competitiveness, however, they had to narrow that margin to a razor thin line, and part of that included buying less material for each gear with the idea that they could save money if they machined with narrower allowances. The next natural step was to focus on ensuring accuracy and consistency in manufacturing. Errors meant having to recut or restart manufacturing a gear, and with such thin profits, there wasn't any room for mistakes.

But even with a focus on stringent quality control, margins were still narrow. Everything Hofmann Engineering had done so far was just to keep them competitive in this new market. If they wanted a profit, they needed something more.

It was at this point that management called on the entire department to come together in one meeting. Every employee, not just the engineers, was encouraged to think on where the department could save money or optimize their processes and come up with ideas on how to improve their profit margins.

"This made a big difference for us, to involve everyone," Fritz said. "Not only say 'here, engineers, figure something out [about] what to do.' Get everyone involved. And you would be surprised what good ideas come from the workshop floor."

That difference showed in the department's bottom line, as well. By bringing the heads of everyone in the department together and implementing the suggestions they came up with, the Mill Gearing Department's profit margin went up by 10 percent over the next two years. They had stabilized, and even if perhaps they weren't making money hand over fist, they had successfully hunkered down for the winter, so to speak.

Fast forward to today, and the snow has started to thaw, to be sure, but winter still isn't quite over for Hofmann Engineering Mill Gearing Department yet. Business is heading in the right direction, and those custom orders are starting to trickle back in. According to Fritz, South America and Africa in particular are becoming noticeably active markets again. But business has yet to recover to where it was before the downturn. The manufacturer's home market of Australia remains slow to recover, and they continue to look for ways to make their manufacturing pipeline more efficient and push that margin up a little bit more.

However, Fritz says that the department has a lot of plans "in the pipeline," though nothing is ready to be talked about yet. And arguably, the department is stronger than ever. They held out without losing any of their core competencies while also innovating their manufacturing process. The lessons they learned fighting through the past few years will serve them well in both good and bad times to come, and they're already positioned to take advantage of returning demand for custom projects. It's a parable with a happy ending on the horizon.

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Brass Tacks with Klingelnberg

Looking on the more practical application side of big gear manufacturing, Klingelnberg's Drive Technology Division has innovated its way past a few challenges a bit more technical in nature while wrestling with the economics of an entire market.

One challenge that the Drive Technology Division ran into was finding alternative markets and applications for their products and innovations. One primary selling point for the division was their core competence in heat treatment and having furnaces large enough to treat their products. Heat treatment is a critical, arguably non-negotiable, part of the gear manufacturing process; you just can't make the same quality of gears without it.

"Especially when it comes to durability, heat treatment is a very important factor that makes a big portion of the final quality of the gearset," Michael Mohr, sales manager of Klingelnberg's Drive Technology Division, said.

This made Klingelnberg appealing for big gear manufacturers, but it was a challenge to find markets outside of their established customer base.

The solution was simple in an "easier said than done" sort of way. The Drive Technology Division managed to enlarge their global business in the mining industry by offering case hardened and hard finished gears in dimensions and qualities that have never been manufactured before. In addition, the interchangeability with existing gear designs can be guaranteed, which is an important factor especially for the aftermarket business. Klingelnberg took the challenge to apply their experience from the marine industry's applications to even bigger dimensions within the mining industry.

"[Case hardening] allows our customers to downsize their equipment, which is a very important factor, of course," Mohr said.

According to Klingelnberg's Drive Technology Division's Head of Calculation and Design, Rudolf Houben, power density is a common consideration, especially in the marine sector, which accounts for a large segment of the division's customers. In applications that include a propeller, gearbox size, and by extension, power density, becomes an important factor.

"The bigger your gearbox is, the less of the surface of the propeller can be active," Houben said. "So if you have a big gear in the final stage, then you have a big shadow effect coming from the gearbox, reducing the efficiency of the propeller."

According to Houben, the division has achieved a higher power density in their products by utilizing Klingelnberg's well-known simulation software to produce more detailed information on how the gear would perform during operation. By taking this information and implementing it into the design of their gears to optimize their behavior under load, they've managed to either reduce the size of their gears while maintaining quality or increasing the rated power for a given size of gears.

Everything on the factory floor is Klingelnberg-built. Design software, gear cutting, grinding machines, precision measuring centers, tooling, workholding, and more; the Drive Technology Division works with a single, comprehensive suite composed entirely of Klingelnberg products from start to finish.

And at the center of the division's operation is the C300, a cutting machine capable of working with spiral bevel gears up to 120 inches in diameter. The machines also allow the Drive Technology Division to soft and hard cut gears at both a faster pace and a higher quality than they could previously thanks to the numerical controlled machine tools and its additional degrees of freedom it's capable of performing.

One addition to Klingelnberg's suite of products is the introduction of a Virtual Master, a sort of digital twin version of a test prototype. The Virtual Master is an entirely digitized copy of a gear primarily used for designing and testing gears before their manufacture. By utilizing a wide swath of data from tests conducted across several universities, it can accurately simulate the performance of a gear just as well as a physical prototype would in the actual field, and by its digital nature, can shave off weeks, if not months, of back and forth and shipping costs that would normally be required to test that prototype.

In addition, it can also be utilized to get rid of physical master gear sets for contact testing in order to proof interchangeability of each individually produced pinion or ring gear. While the Virtual Master was first introduced for smaller gears, Klingelnberg also utilizes it for larger applications in the marine industry, and they keep on working to further implement the technology in even more mining applications.

Klingelnberg's C300 is at the heart of the Drive Technology Division's operations.

There are a whole host of new technologies alongside the Virtual Master that the Drive Technology Division are investigating currently: full digital twins all along the process chain, additional cutting processes, condition monitoring and superfinishing, to name a few. Many of these concepts are still experimental and used only on a case-by-case basis, but we'll no doubt be hearing back from Klingelnberg about in the future as they become more standardized.

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Pardon the Disruption

Emerging technologies such as robotics/automation, new materials, additive manufacturing and IIoT can and will change the course of gear manufacturing for the foreseeable future.

Matthew Jaster, Senior Editor

Photo courtesy of German Aerospace Center (DLR).

Early last year Matt Croson, AGMA president, spoke with *Gear Technology* about the emerging technologies and trends in gear manufacturing he believed would play a significant role in the coming years. These megatrends included additive manufacturing (3D-printing), the Industrial Internet of Things (IIoT), robotics/automation and emerging alloys and new materials. The conversation carried on throughout 2017 in the pages of this magazine, during AGMA meetings and on the exhibition floor at Gear Expo. As optimism grows for 2018, we continue to explore how these technologies can potentially increase productivity and efficiency in gear manufacturing.

NASA Discusses Bulk Metallic Glass Gears & Additive Manufacturing

First, let's look at the science. Metallic glass is a mysterious material that offers a unique atomic structure, according to Douglas Hofmann, technologist for the Materials Development and Manufacturing Technology Group at NASA's Jet Propulsion Laboratory at Caltech.

"Metallic glasses are non-crystalline metal alloys and they are not transparent. The fact they are called glass just means that they are cooled so rapidly that the atoms are completely random as opposed to being located in a crystal (where all the atoms are in a well-defined location)," Hofmann said.

It was first developed at Caltech back in the late 1950s, early 1960s. "The first paper was published by my advisor's advisor (basically my grand advisor)," Hofmann added. "Some of the big innovations regarding this technology occurred in the early 1990s when it was discovered that a few metallic glass compositions (mostly based in the element zirconium) could be cast into parts thicker than one millimeter."

Those parts became known as Bulk Metallic Glass (BMG) and those parts were able to be cast into thick components yet still retained their glassy or amorphous microstructure.

An interesting side note about BMG: If you Google the terms "bulk metallic glass," "liquid metal," and "amorphous metals," you'll get thousands of different entries for each term. None of these web searches will overlap despite the fact that all three search words are the exact same material.

"So, the most confusing aspect of BMG might simply be what exactly we should call it!" Hofmann said.

The development of thick alloys in the 1990s opened up the door to be able to make net-shaped parts through casting. The company Liquidmetal Technologies was founded at Caltech in the 1990s and they went off and made cell phone cases, golf clubs and watches, taking advantage of the fact you could cast metallic glass that had exceptional metallic properties—they we particularly scratch resistant and very flexible.

For NASA, BMG has the necessary properties to handle hostile environments that often don't have an Earth

Bulk metallic glass, a metal alloy, doesn't get brittle in extreme cold. That makes the material perfect for robotics operated in space or on icy planets. Image Credit: NASA/JPL-Caltech equivalent. It is perfect for spacecrafts that will go to the Moon, Mars, land on asteroids or comets or conduct research on the moons of Saturn (Titan) and Jupiter (Europa).

BMGs have properties other materials don't for specific applications, Hofmann said. "For example, they operate at low temperatures very well. They don't become particularly brittle. They also have very good wear resistance if you design the alloys correctly so you can make gearboxes that don't require lubricants. This was one of the big reasons why we started getting interested in metallic glass gears for our Mars Rover as well as some future planned rovers to other very cold planets and moons," Hofmann added.

While the Mars Rover Curiosity uses steel gears, the gearboxes need cartridge heaters to heat the lubricant to work effectively. Without the cartridge heaters, Hofmann said the lubricant would become sticky at those extreme temperatures and the gears wouldn't turn.

An example of a strain wave gear, also known as a harmonic drive — one of the most expensive types of gears used in high-precision robotics. As the gear turns, the flexible ring inside it squeezes, becoming an oval shape. Image Credit: NASA/JPL-Caltech

"If those cartridge heaters ever broke, the Rover would no longer operate. So there was a huge motivation to be able to make gears that could run without lubricant," Hofmann said. "The natural alternative is making ceramic gears because they would definitely run without lubricant, but the fracture toughness is really low so we fear a gear fracture on landing."

Scientists and engineers began discussing how they could make gears that were 10 times tougher than ceramics, but were much more wear resistant than steel and could run without any lubrication.

This was simply necessary to make the appropriate engineering workarounds for future spacecraft missions beyond Mars.

"When you start looking at landing a spacecraft on Europa, for example, you realize that cartridge heaters need cabling, they need a controller and they need power," Hofmann said. "You're going to want to get rid of as many things as possible on this spacecraft that aren't pivotal to the mission at hand."

So how did bulk metallic glass gears come into play?

The commercially available metallic glass alloy has been used widely in industry, but it's not a great gear material. Generally speaking, it has pretty poor wear resistance compared to steel. Also, manufacturing gears is not trivial—you need specialty gear equipment to make great gears. This challenge was solved by bringing the Materials Development and Manufacturing Technology Group together with JPL's Robotics and Gear Groups to collaborate on possible solutions.

"We came up with a strategy to make gears cheaply and easily and test them in hundreds of different alloy iterations to arrive at the alloys that had superior wear performance," Hofmann said. "We were able to balance the wear resistance and the toughness so that the gears worked effectively. Manufacturing was by far the greatest hurdle we had. This is what prevented people from making metallic gears in the past. The collaboration between divisions was vital to our success. The end result was metallic glass gears that can be utilized for future space missions."

During the development of this technology, Hofmann said JPL filed several patents and began exploring the potential commercialization of metallic glass gears. One of the things that conspired against bringing new materials into gear applications is that lubricant basically works at any temperature on Earth. You're not mass-constrained in any gearbox application and steel is cheap and easy to machine. So, there's not a lot of motivation in many gear applications to try new materials.

"That being said, there are all kinds of specialty applications where you're mass–constrained or temperature-constrained or working in a hostile environment where there's contamination, debris, and corrosion. These are the types of applications where lubricants might not work," Hofmann said. "We're looking into niche applications where metallic glass gears might compete with steel or ceramic gears."

Hofmann said that metallic glass can be injection molded into gears and the result is a gear that out behaves steel in many applications. "This is pretty innovative. There is no other metal that can be injection molded like plastic into molds that has wear performance characteristics like BMGs. We can net-shape cast our gears without having to machine or hob them," he added. "That means we can get surface finishes that can't be replicated without having to go to micro-grinding or chemical-etching. That's a really big selling point, the mass production through standard injection molding capabilities. "

If BMG gears weren't innovative enough, Hofmann's group at JPL is also hard at work at some innovative additive manufacturing projects.

"There's interest in developing extremely customized gears that would be impossible to machine," Hofmann said. "We're also examining functionally-graded metals with a 3D-printer here at JPL. This can print up to four metals on a single print so we can blend from one metal to another metal."

This is the kind of technology the industry hoped to hear about when they first started discussing the potential for additive manufacturing. (*Editor's note: Look to a future issue of Gear Technology to read more about JPL's additive manufacturing technologies.*)

"As applied to gears, this is fascinating because we can make the interior of the gear out of something tough and lightweight like titanium and then you can blend the gear into something much more wear resistant at the teeth like titanium carbide. You can make a single gear that satisfies multiple requirements. Extreme hardness and wear resistance on the teeth, but toughness and low density on the interior, so I think functionally graded metals is really an exciting area."

But in all this research and testing, additive manufacturing will first and foremost be a priority for NASA's exploration of the galaxy.

"We're creating gear technologies for 3D-printing in space, customized excavating tools, for example, that can cut through rock and ice," Hofmann said. "When these prototypes work well, we will increase the readiness level so they can be utilized on upcoming space missions."

Thoughts on the Automated Gear Shop

Quality and productivity come into play each and every day on the shop floor. How fast can we produce this gear? What tools will make us better, more efficient and more flexible for future projects? The answer might be hidden away in that robotic arm being utilized for deburring in the corner of the factory.

"We all know the skills gap is coming, we've been talking about it for some time," said Geoff Dawson, director, FANUC America. "There's a shift in the paradigm of the types of jobs people want coming out of college today. The emphasis is on building a smarter workforce. This can be accomplished with the right personnel working hand-in-hand with robotic and automation solutions on the shop floor."

Dawson believes the focus should be on using the new labor force *smarter* not *harder*. "Just look at our smartphones. Look at how this technology has evolved since these products were first released and how the users have adapted to the technology over time. Robotics and automation can play a similar role in the future of manufacturing."

OEMs know this and have known it for some time. For years, the automotive and aerospace industries have incorporated robotics and automation for assembly, motion control, complex machining, material removal, part transfer, picking/packaging and more.

But look at general manufacturing and North America lags behind its counterparts in Japan and Europe in large numbers. The good news is that FANUC and other system integrators are starting to help other areas in manufacturing pick up the pace.

"As robotic systems become more intelligent through increased vision and force sensing capabilities, manufacturers will be able to broaden the areas where these systems can be applied," Dawson said. "We have all this automotive experience, particularly the focus on the powertrain—engine, transmission and drivetrain. The push is to take these technologies and make them simpler for everyone across the board."

This FANUC M-20iB-35S robot has been utilized to deburr components (courtesy of FANUC).

Force-sensing robots, for example, give manufacturers the ability to deburr gears on the shop floor. "We have collaborated with many gear companies on force-sensing robots that take care of burrs and are also used in assembly to mesh gears," Dawson said.

Another gear application is looking at gear blanks. FANUC offers 3D vision systems where the robots pick parts directly out of a bin and can save a gear operation on expensive fixturing on conveyors.

Dawson believes the challenge in robotics and automation specifically for gear applications involves the high product mix and the existing machine layouts. There are opportunities to take advantage of automation that can work with multiple machines, but you're constrained by current layouts or manufacturing methods that weren't made to be automated.

Adapting to certain products can also be challenging.

"Gears are nice, round parts because the center of the circle is always the center of the circle. When you're handling gears, your data points typically are the same and the point that you're loading is pretty straightforward," Dawson said. "Complex gears, however, may have an array of tooling to handle an array of sizes and this can be a significant challenge for gear shops."

There's also the perception that a job shop simply won't be able to afford the kind of automation and robotic upgrades you might find within OEMs.

"Return of investment (ROI) is so important to consider when discussing these upgrades. Several of our integrators start with an entry-level system—maybe a robot, a feeding device and a fixture table. There are cost-effective ways to make these shop floor upgrades feasible," Dawson said. "At the end of the day, you want a system that will be able to support *your* products and equipment."

In order to better prepare the next generation of manufacturers for robotics and automation, FANUC continues to emphasize training and educational programs. The company works with community colleges, trade schools and universities on programs where they receive robots for their labs and a curriculum that FANUC provides. This allows these institutions to better prepare the next workforce.

"Some still say that robots take jobs, but there's some pretty good data out there that suggests robots sustain jobs and make companies more competitive. Instead of going offshore, many organizations have invested in automation and robotics to remain competitive which allows them to keep a facility open, having the solid, well-rounded, qualified employees in place to accomplish what they need," Dawson said.

Information is key to one of FANUC's pioneer programs with the automotive industry known as its Zero Down Time (ZDT) Application. This analytics system (in collaboration with Cisco) identifies potential failures so that manufacturing equipment can be maintained and repaired in scheduled downtime rather than breakdown during critical production. The application was recognized with a GM Innovation Award in 2016.

"General industrial is part of this initiative (including gear manufacturing) where we'll be able to work with our customers and provide services so they don't lose production time due to maintenance issues. It's about being proactive instead of reactive," Dawson said.

Intelligent technologies will be the crux of FANUC's focus for the foreseeable future. "Our servomotors are at the heart of everything we do," Dawson said. "Whether it's a CNC or a robot, our goal is to continue to develop solutions for the next generation of users."

IIoT: The Promise of Big Data

What does Industry 4.0 or the Industrial Internet of Things (IIoT) really mean to gear manufacturing? The whole concept, according to Marco Kampka, program manager at the Gear and Transmission Technology Group, Fraunhofer CMI, is based on the availability of information.

"This means that every element along the process chain has the right information to complete the given task in the most economical way. It may be a machine tool having the tool and workpiece data to machine the next part, or a human, who needs additional information to make the best decision, solving a given problem," Kampka said.

The main difference from the past is that this is supposed to happen in real time, and in a way that every piece of information is available to everyone from a single source. Kampka said that in this framework, it is important to differentiate between information and data.

"Information is formatted and often filtered data to be easily understood by either machine or human. The transfer of data to information can either happen using very generic approaches of analyzing data, which would make it a big data problem, or by using sophisticated models or rule sets," Kampka said. "Gathering data is easy. Producing information can be difficult."

This FANUC R-1000iA robot can handle magnetic bin picking operations (courtesy of FANUC).

Essentially, every piece of information gathered along the process chain is a first step to Industry 4.0/IIoT. In reality, Kampka said there are currently not many *real solutions* in our field yet. "Those big terms like 'Industry 4.0' or 'IIoT' are often widely used without reaching the level of a true solution. Even though, a lot of products show promising approaches," Kampka added. One of the challenges is to collect the right data and derive the most important information from it. Modern machine tools and the controls create much more data than gets used or collected on an average basis.

"Blindly adding more and more sensors into the machine tools will create more data, but not necessarily more information. The challenge right now is identifying the right data to collect and the right analytics to turn that data into information. But time can't be turned back and all the data not collected may be a drawback later on. So it is kind of a guessing game at the moment," Kampka added.

Obviously, conversations need to continue between the manufacturing industry and academia to discuss how to make the most out of these strategies.

"I suggest contacting the universities who do research in gear manufacturing, get involved in discussions on how these solutions might assist your organization and try the software solutions that are available," Kampka said. "Most of those solutions are not perfect, but they improve much less than they could, because of little feedback provided from the gear industry. The machine tool manufacturers should do their part, and participate in finding a common data standard to simplify communication and data management."

The right simulations and software tools can help a job shop employee to set up a process by proposing tools and the necessary parameters. This could shorten setup times and increase the process knowledge of the employee. This is a great way for new employees to gain experience on the shop floor, but you'll still need skilled workers on hand that know the ins and outs of every machine they operate which enables them to optimize the output.

"With our partners at WZL and IPT in Germany, we constantly try to improve manufacturing simulation capabilities to be able to offer digital shadows and digital twins of the most common gear manufacturing processes in the future," Kampka said. "Besides that, we will be happy to help establish these solutions by offering consultant and training services."

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Grinding It Out

C&B Machinery Meets Rigorous Demands with Installation of Manufacturing Cell

Matthew Jaster, Senior Editor

As a customer-driven organization, C&B Machinery's clients come with various production requirements and challenges. This might simply be an error-proofed part changeover without the use of hand tools, avoiding part-to-part contact so gear teeth are not damaged and a design that will provide low costs and short downtime to retool for a different product. Flexibility is of the upmost importance when products and volumes change as rapidly as they do in gear manufacturing.

"We design, manufacture and completely integrate our machines with the required automation and robotics to produce a 100-percent turnkey manufacturing cell," said Fabrizio Tarara, vice president at C&B Machinery, headquartered in Brighton, Michigan.

A History in Double Disc Grinding&Retooling

C&B Machinery was founded in 1980 by the current owner and CEO Joe Parker. The company started off specializing in the maintenance, rebuilding, and re-engineering of all types of grinding machines. Over time, C&B Machinery became well known for its double disc grinding machine offerings. They also work with brands such as Besly, Gardner, Mattison and Blanchard. In 2017, C&B celebrated the 10th anniversary of their DG-2H series of double disc grinding machines. The machines are completely designed, manufactured and assembled right here in the United States.

In addition, C&B has completed hundreds of retools in its 35+ year history on all types of grinding machines. A retool offers customers a way to utilize their existing capital to run a new line of parts. C&B can also complete upgrades to the grinder that will lessen machine wear over time and increase uptime.

The Automated Advantage

According to Tarara, the recent integration of robotics and automation into C&B's machine tools has improved the precision, accuracy and quality of various components.

"The integration of robotics has been a game changer. They offer the flexibility demanded by our customers to be able to not just handle one part type, but a family of part types in one system. Our manufacturing customers have learned that future flexibility is the competitive advantage they need," Tarara said. "These machines can be upgraded and retooled to process additional part types at a fraction of the cost as our competitors."

The entire manufacturing cell is meeting the rigorous demands of C&B's end customers for their automotive production rates. It also maintains the strict requirements for a 15-minute or less changeover from good part to good part.

"The overall design of this cell has made this requirement easily attainable and eliminated old processing designs where gear teeth were touching each other on the old conventional handling systems," Tarara said.

And the only hiccup during the process was aligning the machine with the customer-supplied automation. "This was a minor challenge that was overcome rather quickly," Tarara said. "Once the machine was properly aligned the design, engineering and manufacturing work shined."

Tarara and the staff at C&B Machinery were surprised at just how robust the automation and overall machine design was once these manufacturing cells were up and running. The combination of the basket/tray automation systems with the company's indexing staging table easily met customers cycle time requirements.

"The precision and accuracy that these robots can load our machines at is incredible. The true success is attained in the part quality. C&B Machinery continues to be a market leader in face grinding of transmission gears. We continue to manufacture the most robust machine in the market with an easy to use interface and overall design. This certainly helps the process," Tarara added.

The particular end customer that received this manufacturing cell has been extremely excited about the direction C&B has taken its machines regarding robotics and automation. One of C&B's largest customers is extremely eager to startup five identical

C & B's integration of robotics and automation has improved the precision, accuracy and quality of various components (photo courtesy of C & B Machinery).

manufacturing cells in Sharonville, Ohio. This plays an added role in C&B's drive to keep manufacturing strong in the Midwest and the United States.

Keeping an Eye on Automation

Tarara believes the company will continue to do research and development and monitor the latest trends in automation design.

"In a matter of just a few years, our cells have changed dramatically, so we can provide our customers the best end product that is continually improved. We will continue to make improvements and invest in R&D to ensure that C&B Machinery continues to be a global leader in the high production and precision grinding machine market," he said.

The plan for the future is to continue to be a market leader in the face grinding of gears. C&B would also like to enhance its vertical (clamp bore) microfinishing grinding machines to serve a broader customer base. Tarara notes that the company offers many different configurations to meet various customer requirements for this equipment.

With the potential slowdown in new transmission gear manufacturing programs, C&B hopes to continue to grow in different market sectors like hand tools, aerospace, heavy equipment, knife, connecting rods and bearings industries to name a few.

Overall, they are extremely optimistic heading into 2018.

"We have just road the wave of 8-speed, 9-speed & 10-speed transmission programs with many large automotive manufacturers. You could say we're currently 'cautious' in the automotive sector, but very optimistic in all others as we have seen these markets work in tandem with each other. When one is down, we see an uptick in the others which keeps things well balanced for C&B Machinery. Since C&B Machinery is a dynamic company we can meet the demands and requirements of many different markets and customers."

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2018 State of the Gear Industry

Reader Survey Results

***Gear Technology's* annual State-of-the-Gear-Industry survey polls gear manufacturers about the latest trends and opinions relating to the overall health of the gear industry.**

As in years past, the survey was conducted anonymously, with invitations sent by e-mail to gear manufacturing companies – primarily in North America, but also including gear manufacturers around the world.

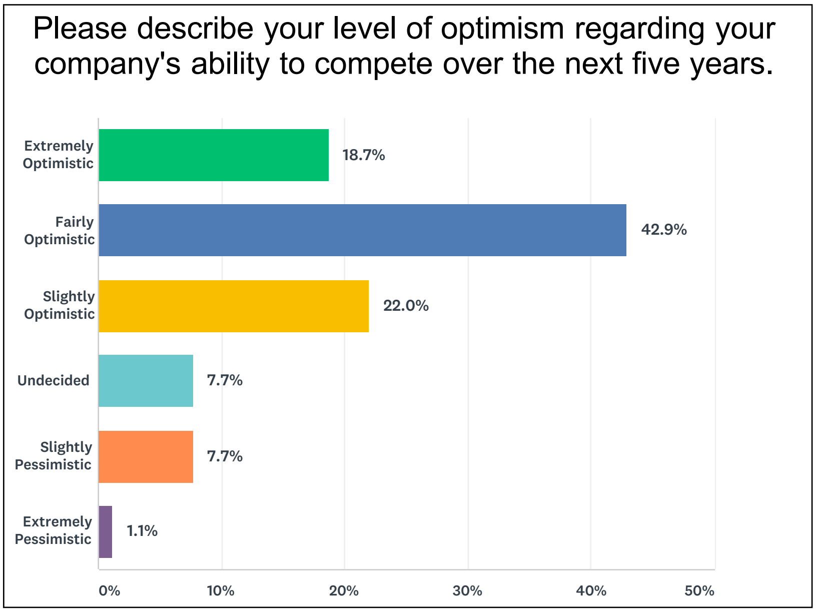
All of the responses included in these results come from individuals who work at locations where gears, splines, sprockets, worms and similar components are manufactured. They work at gear manufacturing job shops as well as captive shops at OEMs. A full breakdown of the respondent demographics can be found at the end of this article.

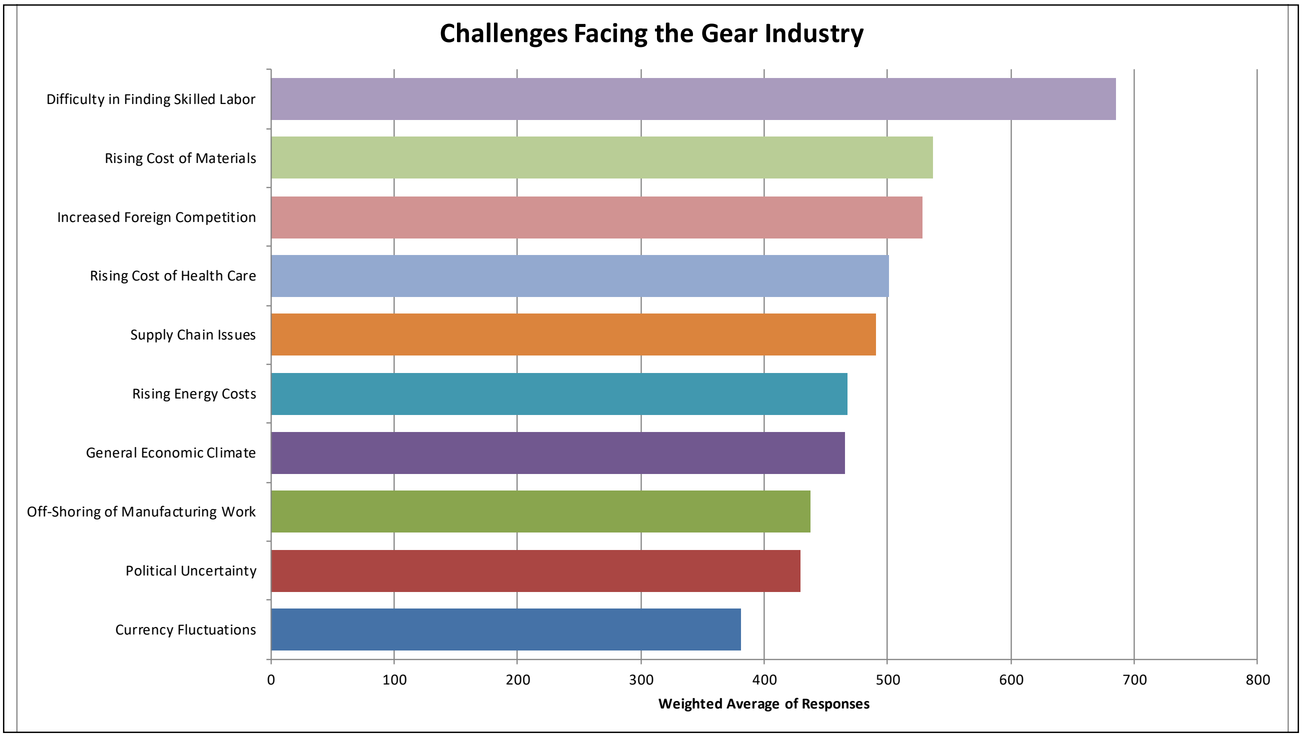
Gear Industry Optimism

As usual, the gear industry is mostly optimistic about its ability to compete over the near future, with 82.9% showing some level of optimism. This is about the same as the industry's mood at the beginning of 2017, when our survey revealed an 83.4% optimism level.

Significant Business Challenges

Once again, our industry is struggling with the difficulty of finding skilled labor, far outstripping any other concerns in our survey responses. Last year, respondents were almost equally concerned with finding skilled labor and the general economic climate. But a year of solid growth seems to have done wonders for that concern. The general economic climate doesn't even rank in the top 5 concerns this year.





Significant Business Challenges

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

"Production."

"Finding workers, not even skilled. We will train them, just need people who will come to work that can learn."

"Whatever trade stunts the oval office will pull."

"Labor."

"Finding new avenues for our product."

"To find out clients from international market."

"Rising cost of materials."

"Expansion plans for facilities."

"Workforce skill/training and maintaining quality throughout the process of growth."

"Finding enough skilled, reliable employees to meet demand."

"Finding new customers."

"Trained personnel."

"Improving productivity."

"Increasing sales."

"Replacing an aging work force."

"Meeting customer demand with limited talent pool."

"Machinists – talent."

"Set up operators vs. parts catchers."

"Finding skilled labor."

"Supply chain issues and rising cost of steel."

"Keeping Sales UP."

"Qualified help."

"Customer schedule fluctuations."

"Manufacturing automation and efficiency."

"Manpower retention and uncertain political climate."

"1. Material cost. 2. Labor policy."

"Qualified personnel and supply chain disruptions."

"Capacity."

"I am just trying to increase sales volume."

"To meet the various product mix challenges."

"Selling the business."

"Finding good help."

"China."

"Delivery on time."

"Training younger people."

"Labor and its happiness index, efficiency of cashflow/ working capital."

"Employees ."

"Meeting production numbers after eliminating a facility."

"On time delivery, efficiency, doing more with less in a cautiously optimistic economic landscape."

"Orders from new customers."

"Keeping up with orders."

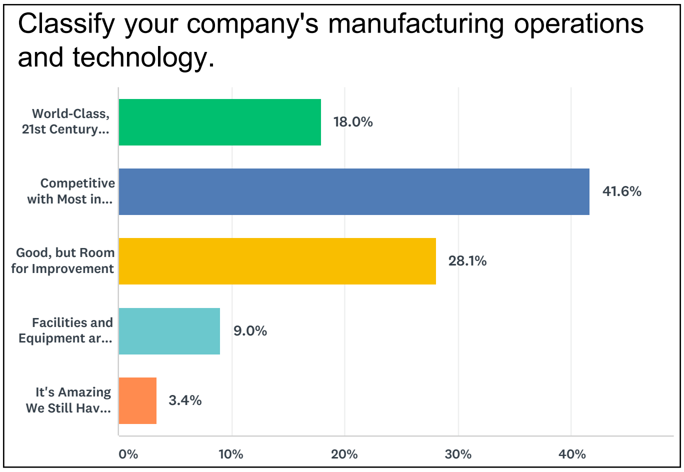
"Skilled labor."

"Health care costs."

"Selling new product value in a mature market."

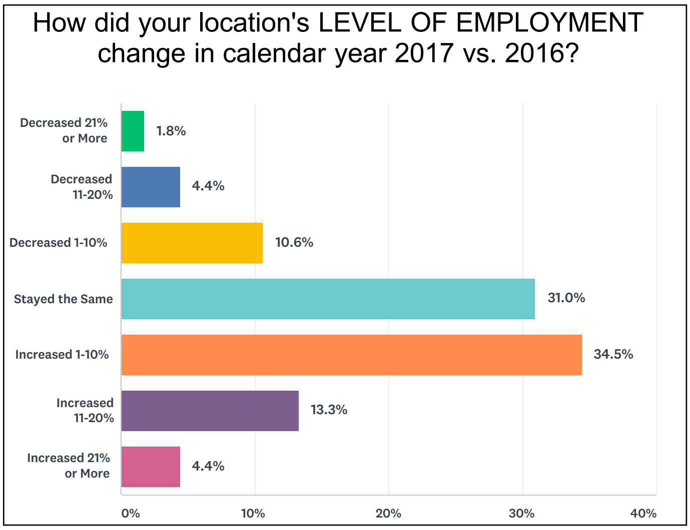
"Transition from diesel engines to EV."

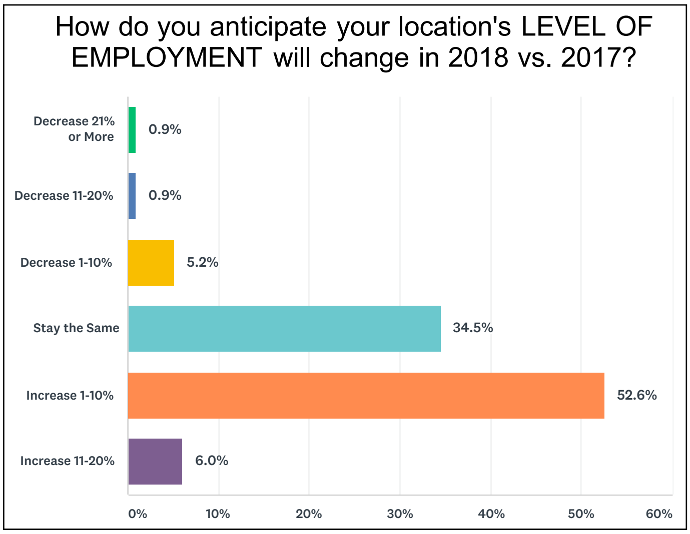
"Acquiring new business to return the company to previous sales levels in 2014."

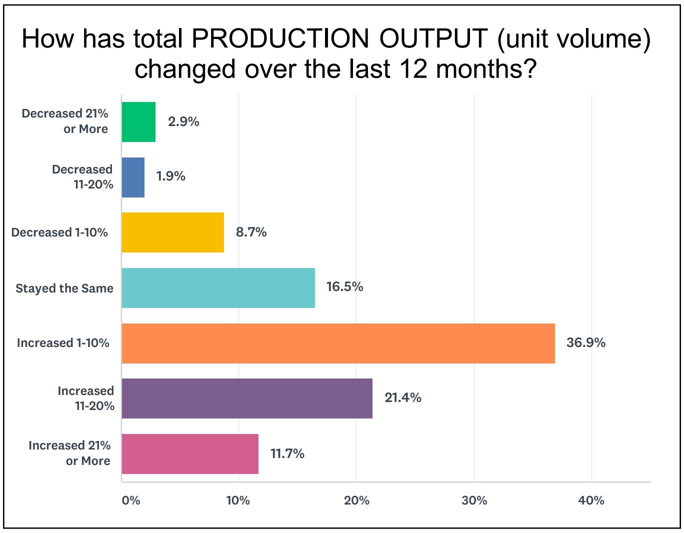


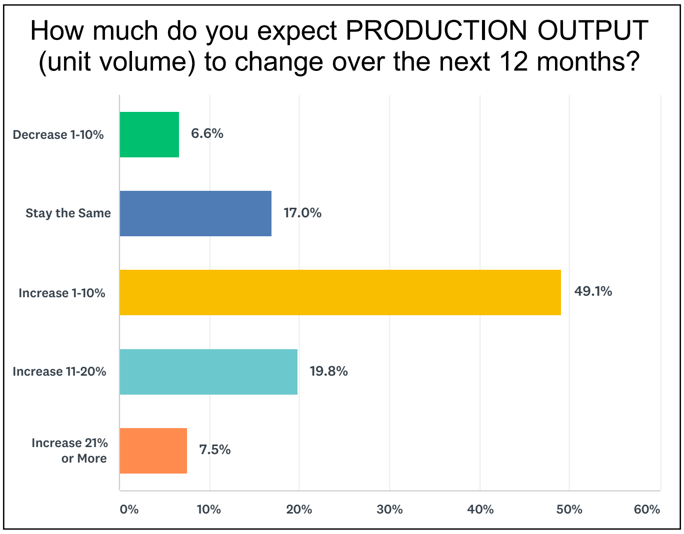
Employment

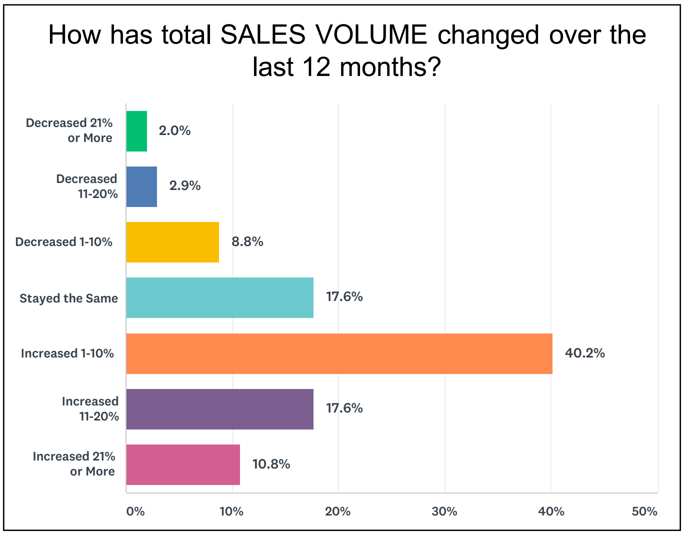
The gear industry seems to have rebounded from a tough 2016, with more than half of respondent seeing an increase in employment in 2017. Nearly 60% expect employment to continue to increase in 2018.

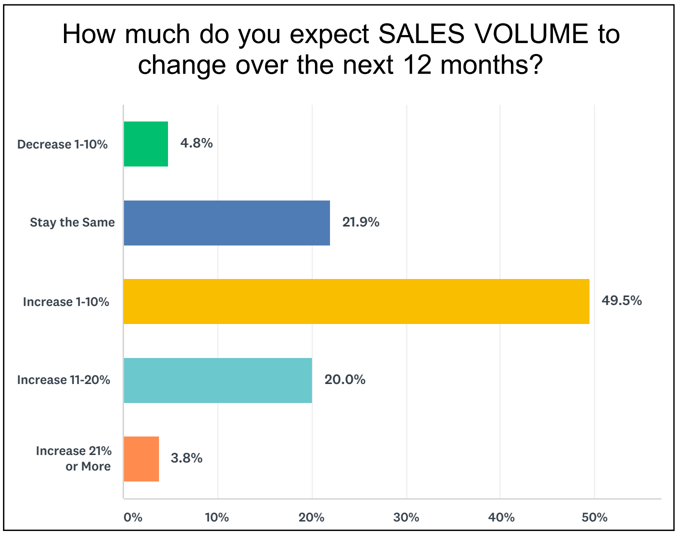


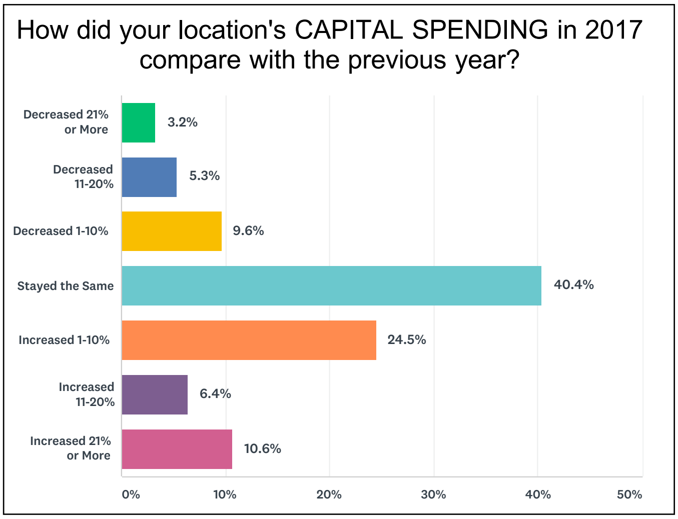


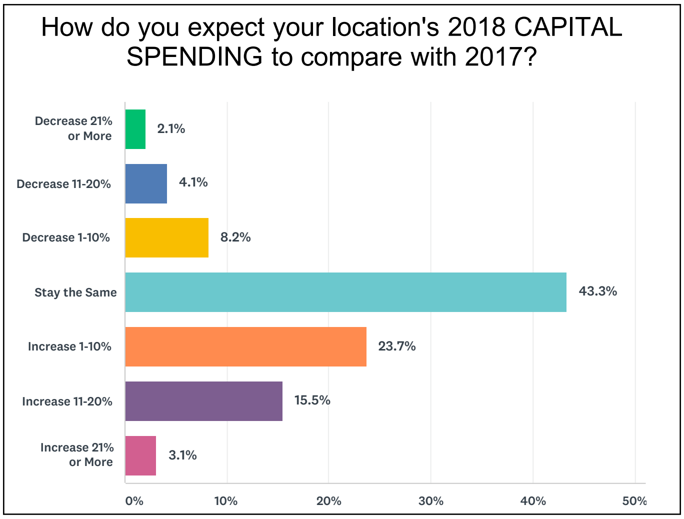

How has total PRODUCTION OUTPUT (unit volume) changed over the last 12 months?
Decreased 21% or More 2.9%
Decreased 11-20% 1.9%
Decreased 1-10% 8.7%
Stayed the Same 16.5%
Increased 1-10% 36.9%
Increased 11-20% 21.4%
Increased 21% or More 11.7%
0% 10% 20% 30% 40%


How much do you expect PRODUCTION OUTPUT (unit volume) to change over the next 12 months?
Decrease 1-10% 6.6%
Stay the Same 17.0%
Increase 1-10% 49.1%
Increase 11-20% 19.8%
Increase 21% or More 7.5%
0% 10% 20% 30% 40% 50% 60%


How has total SALES VOLUME changed over the last 12 months?
Decreased 21% or More 2.0%
Decreased 11-20% 2.9%
Decreased 1-10% 8.8%
Stayed the Same 17.6%
Increased 1-10% 40.2%
Increased 11-20% 17.6%
Increased 21% or More 10.8%
0% 10% 20% 30% 40% 50%


How much do you expect SALES VOLUME to change over the next 12 months?
Decrease 1-10% 4.8%
Stay the Same 21.9%
Increase 1-10% 49.5%
Increase 11-20% 20.0%
Increase 21% or More 3.8%
0% 10% 20% 30% 40% 50%


How did your location's CAPITAL SPENDING in 2017 compare with the previous year?
Decreased 21% or More 3.2%
Decreased 11-20% 5.3%
Decreased 1-10% 9.6%
Stayed the Same 40.4%
Increased 1-10% 24.5%
Increased 11-20% 6.4%
Increased 21% or More 10.6%
0% 10% 20% 30% 40% 50%


How do you expect your location's 2018 CAPITAL SPENDING to compare with 2017?
Decrease 21% or More 2.1%
Decrease 11-20% 4.1%
Decrease 1-10% 8.2%
Stay the Same 43.3%
Increase 1-10% 23.7%
Increase 11-20% 15.5%
Increase 21% or More 3.1%
0% 10% 20% 30% 40% 50%

Capital Spending

42% of respondents work at locations where capital spending increased in 2017. The same percentage expect another increase in 2018. Both of these numbers are significantly higher than last year.

The hottest ticket items for gear manufacturers in 2018 will be gear grinding and inspection equipment.

Capital Spending

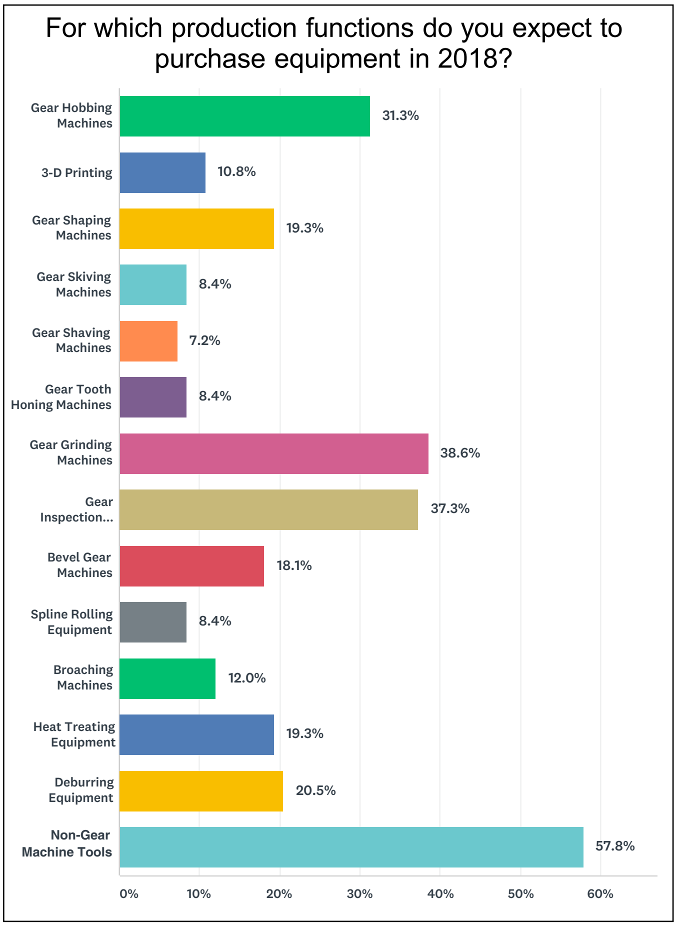
81% of respondents work at locations that spent more than $100,000 on capital equipment in 2017.

40% work at locations that spent more than $1,000,000.

18% of respondents' companies spent less than last year.

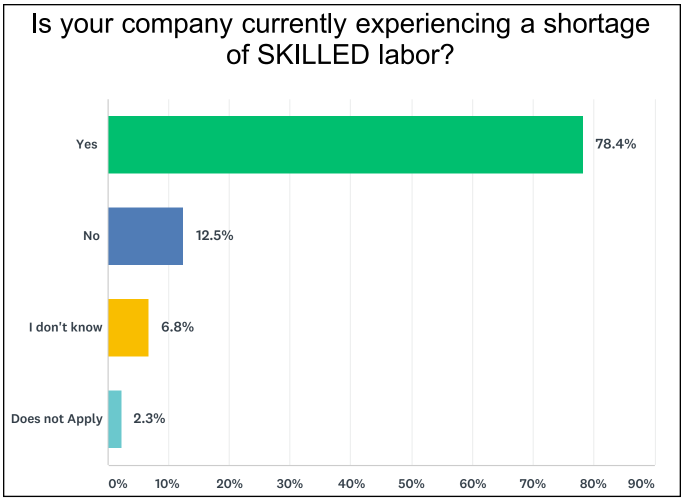
42% of respondents' companies spent more

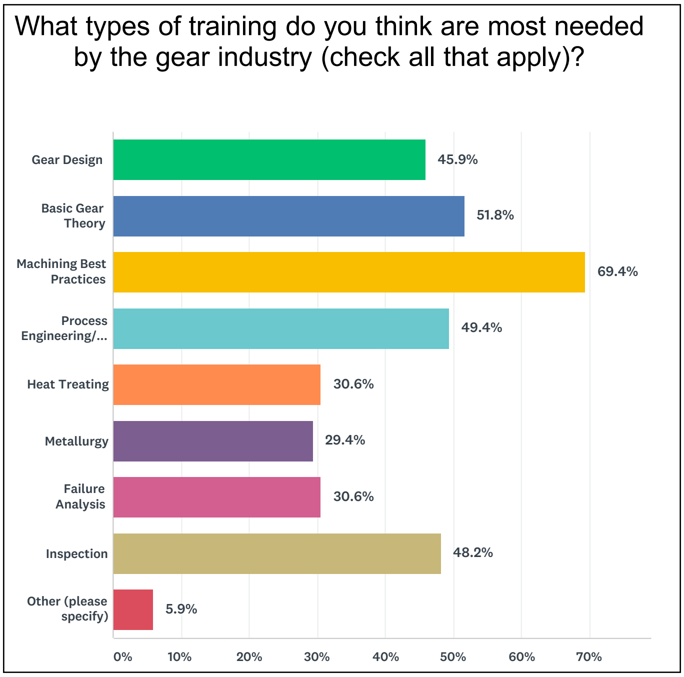
82% of respondents expect to spend the same as 2017 or more in 2018.



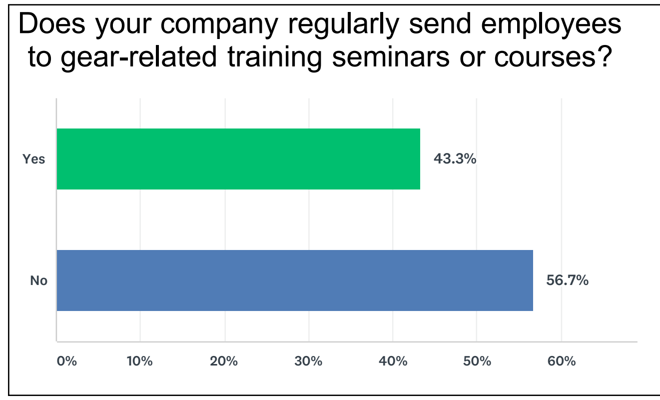
Skilled Labor

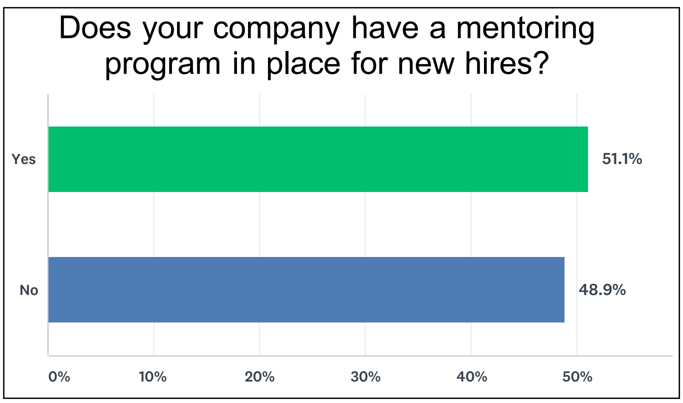
A whopping 78% of respondents report that their companies are experiencing a shortage of skilled labor. This is much larger than either of the previous two years (53% in 2017 and 64% in 2016).





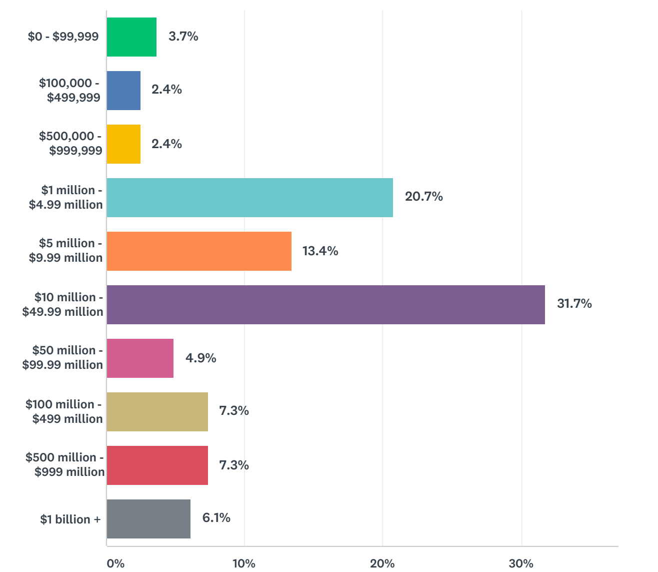

Does your company work with (assist, contribute, etc) local educational venues to help develop new trained employees (or training for employees)?
Yes
65.5%
No
34.5%
0%
10%
20%
30%
40%
50%
60%
70%


Does your company regularly send employees to gear-related training seminars or courses?
Yes
43.3%
No
56.7%
0%
10%
20%
30%
40%
50%
60%

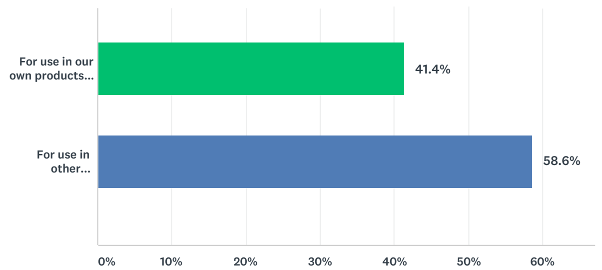

Does your company have a mentoring program in place for new hires?
Yes
51.1%
No
48.9%
0%
10%
20%
30%
40%
50%

Demographics

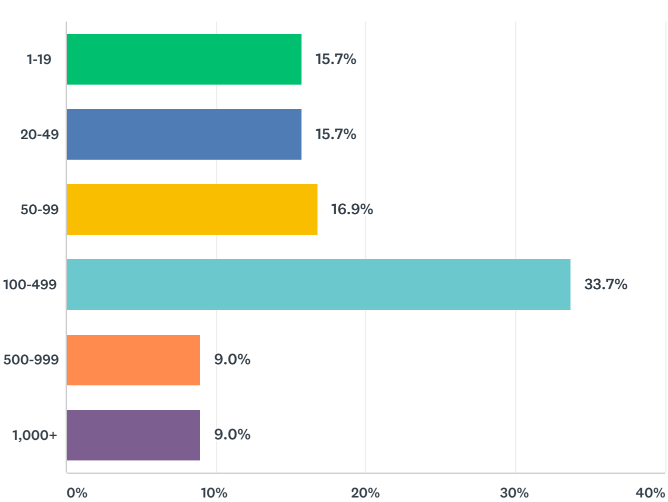
What is the approximate annual revenue for your company? (If this location is owned by another company, please use figures from the corporate parent)



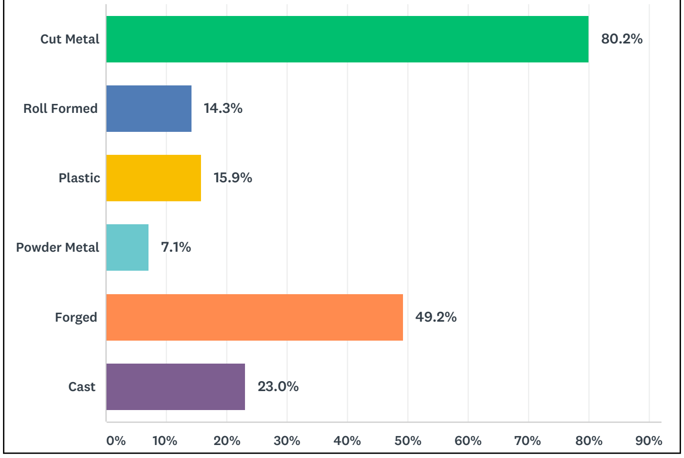
Gears (including splines, sprockets, worms and similar components) are manufactured at this location:



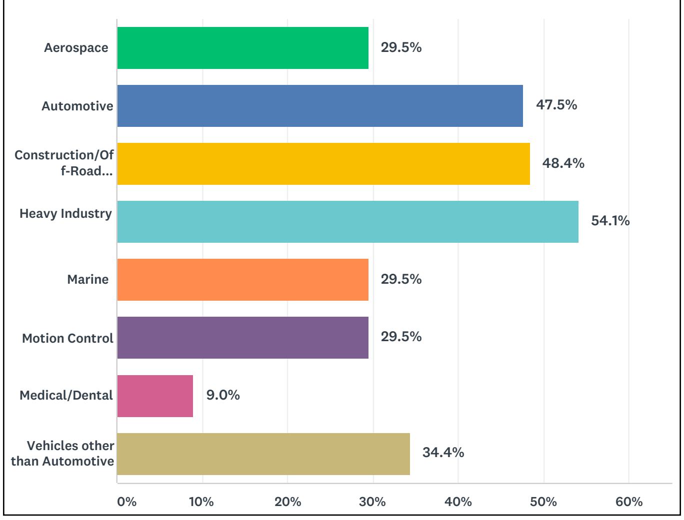
How many employees work at your location?



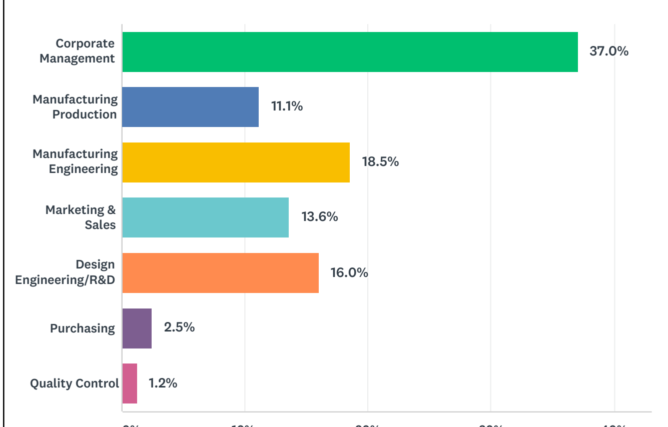
The gears manufactured at this location are (Check all that apply):



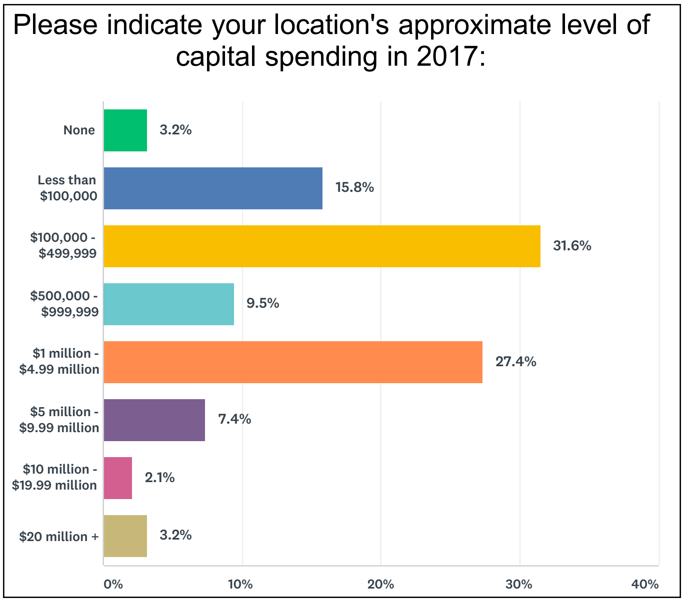
The gears (including sprockets, splines, worms and similar components) made at this facility are used for (check all that apply):

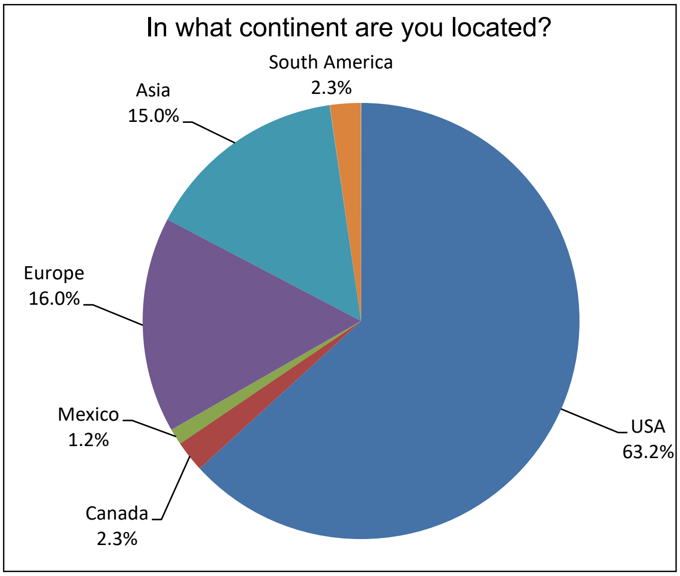


Which category best describes your job title/function?



Demographics





Thank you to all of our 2018 survey participants!

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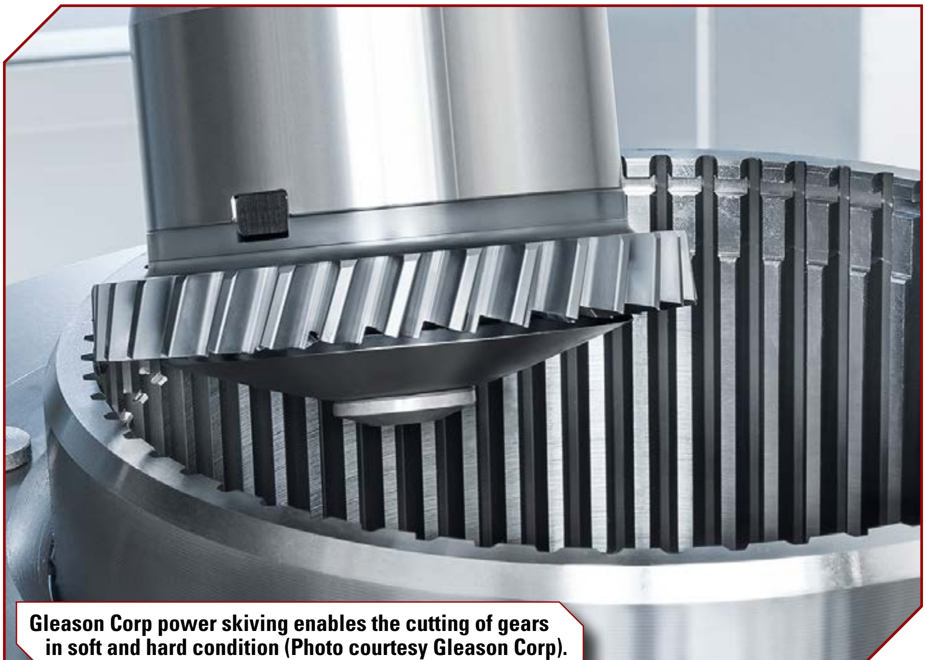
Skiving Is Thriving on a Global Scale

Skiving Gears is a Win-Win for Gear Makers and Buyers

Jack McGuinn, Senior Editor



Gleason Corp power skiving enables the cutting of gears in soft and hard condition (Photo courtesy Gleason Corp).

Call it new wine in old bottles, or old wine in new bottles, but gear skiving has certainly aged well over time. Gear skiving's evolution, perhaps gaining momentum most dramatically since around 2004, has ultimately led to rather dramatic technological advancement and cost saving in the manufacture of certain gears.

But before we get too far along, it's important to make sure everyone knows what we're talking about. The term "skiving" has been used to describe a wide variety of processes in a wide variety of industries over the years. Twenty or thirty years ago, if you said you were skiving gears, most people would assume you were talking about skive hobbing or hard hobbing, which is a completely different process.

When we talk about gear skiving today, we're referring to modern derivations of the process originally invented by Julius Wilhem von Pittler, way back in 1910. The process uses a disc- or gear-shaped cutter (often very similar in appearance to a gear shaping tool) and employs synchronized tool and workpiece motions, with the cutting motion generated by intersecting tool and workpiece axes.

Among its attractions, the gear skiving process is considerably faster than shaping, for example, while boasting enhanced chip removal, and is demonstrably more cost-effective. Major, relatively recent breakthroughs in areas such as intelligent software, machinery and tooling stiffness, amped up speeds and feeds, and tool coatings has positioned gear skiving as the go-to, most productive process for the manufacture of many types of internal gears, and even some external gears as well. As you read the following Q&A with industry experts, you will notice that gear skiving has many variations, along with many different names, including "power skiving," "hard skiving," "Super Skiving," "hard power skiving" and, as Profilator calls it — "Scudding" or "hard Scudding."

And so from this point forward, we'll use "gear skiving" as the generic term for all of the above.

Participating in this Q&A are:

Vincent Affolter, general manager Affolter Technologies SA; **Dr. Nicklas Bylund**, Sandvik Coromant director, customized automotive solutions; **Scott Knoy,** GMTA vice president; **Dr. Patrick Labenda**, Klingelnberg head of application engineering, bevel gears; ; **Phillip Ruckwied**, EMAG manager of cutting technology; **Dwight Smith**, vice president, Mitsubishi Heavy Industries America, Inc., machine tool division; **Udo Stolz**, Gleason vice president of worldwide sales and marketing; **Tom Ware**, Star SU LLC product manager, gear cutting tools; **Dr. Oliver Winkel**, Liebherr head of technology development; and **John Lange,** longtime gear professional. (*In the spirit of full disclosure, Lange is a Gear Technology Technical Editor and former longtime Gleason-Pfauter gear specialist. Thinking it would be helpful to add an independent view, we invited him to the discussion.*

Please describe the newest gear/skiving-related tools and how they enhance gear skiving.

BYLUND. Power skiving tools exist both as solid tools in high-speed steel and carbide. For machines with the capability of synchronization at high speed, solid carbide tools are definitely preferred (due to) better tool life and productivity at the same time. From modules 2.5/DP10 tools with carbide inserts are a good alternative.

WARE. The use of solid carbide tools has increased cutting speeds and extended tool life.

WINKEL. Dominant are actually modern PM-HSS tools with the newest AlCrN-coatings to enhance tool life. But essential is the mathematically correct profile design, so that the first part is a good part. This was in the past not the case, because some assumed that a skiving cutter is the same as a shaping cutter. Indeed, it looks similar, but the profile is very much different, so several loops of profile optimization were necessary. Liebherr did its homework to develop the necessary mathematics to ensure the correct skiving cutter profile.

SMITH. The newest tool development is MHI's three-piece assembled cutter which was engineered to further advance tool life and metal removal rates. The patented Super Skiving tools have multiple cutting edges for creating the tooth space rather than the single cutting blade of conventional pinion type cutters.

KNOY. The newest application of the Scudding technology is the "hard Scudding" process. In "hard Scudding" we finish a gear in the hardened state as an alternative process to grinding or honing. We use Star-SU solid carbide Scudding tools along with the best coating available on the market, which is currently the Balinit Altensa coating provided by Oerlikon Balzers. Additionally, the use of indexable roughing tools in Scudding coarse-pitch gear applications has proven to be an excellent way to control tool cost.

STOLZ. For larger modules, a combination of cutters with inserted carbide blades for roughing and PM or solid carbide cutters for finishing seems to be the best option; of course depending on the lot size. For hard finishing, carbide cutters are a must.

It is not so much the tool material which makes the difference, it is the understanding of the process in detail, in combination with the ability to design and manufacture the right cutter based on the application.

Please describe the latest updates relative to gear skiving machinery and how it enhances gear manufacturing.

KNOY. Profilator has made dedicated Scudding machines since 2005. We offer horizontal and vertical machines and that allows us to offer the machine that best fits the application. In many cases our competition has started their machine developments by using a hobbing platform, but using a repurposed machine platform has not been a long-term solution for any of the people in this market. Several 5-axis milling machine manufacturers have tried to include gear skiving in their machinery with limited success. These machines lack synchronized drive packages that do not allow them to produce a high quality gear.

LABENDA. We have the gear cutting machine C30 with universal application for bevel gears and power skiving for internal and external gears.

WINKEL. Very important is the direct drive technology for high spindle and table rpm, and high gear accuracy while assuring optimal synchronization between workpiece and tool spindle. In addition, the high dynamics of the skiving process requires a high machine rigidity and stiffness to get reliable and robust process settings. The automatic choice of optimal drive control parameters on Liebherr skiving machines is an important feature to support stable cutting processes from the beginning.

To achieve a high process capability, especially on internal gears regarding surface quality and to avoid chip weldings, the precise and constant positioning of the coolant nozzle is quite important. Liebherr has here besides a manual setup solution a quick-change option to easily change over from one gear to the other and keep the proven setup.

SMITH. The MSS300 from MHI fulfills the machine tool requirements with massive guideways and a rigid tool spindle and column. Two servo drives operate the vertical axis for power and control. Long-term process stability is assured by the special design of the machine base to minimize or eliminate thermal distortion.

RUCKWIED. Advances in machine technology with the electronic gear train have resulted in a more precise maintaining of the transmission ratio between tool and workpiece, while the speeds in the generating train could be increased. Another advantage of power skiving machines from EMAG is the fact that both rough-machining (turning) and finish-machining can be done in one clamping operation. Including the turning process in the same clamping operation prevents re-clamping errors, and is an effective way to eliminate radial deviations.

STOLZ. Key for a successful power skiving process is the stiffness of the system, where the stability of the machine plays an important role; especially also for hard power skiving.

In addition, the flexibility of the machine is very important. Features like stock dividing, automatic tool changer, automatic loading/unloading and integrated deburring are enhancing the process. With the same power skiving system we have the possibility to cut gears in a soft and hard condition. In many cases we are eliminating an additional manufacturing step by integrating the deburring capability into the power skiving tool for internal gears or adding a rotary chamfering unit for shafts on our horizontal machine.

The MSS300 from MHI fulfills the machine tool requirements with massive guideways and a rigid tool spindle and column (Photo courtesy MHI).

Are there any anticipated or pending technology gains that would further the benefits of gear skiving?

STOLZ. Today, power skiving materials in the soft condition is state of the art. An interesting application with significant potential is hard power skiving. Today there is no efficient process in place to fine finish small-to-medium internal gears in the hardened condition. Power skiving has the potential to be a game changer.

WINKEL. Liebherr just recently introduced its newest gear skiving machine with the option of a tool changer. This enables the customer to either run the machine longer without any operator or to cut multiple gears in one setup without compromises to the tool design. Also the changeover to other parts is simplified by a tool changer.

The other new technology is hard skiving. This enables the customer to machine the parts soft and hard on the same machine. This lowers investments for additional machines. Furthermore, there is an additional option for hard finishing — especially of internal gears, which regarding its productivity is much faster than e.g. internal profile grinding but not as accurate.

Regarding Liebherr, we think it is also very helpful to support the operator with an MC control that is gear technology-driven and especially dedicated to gear skiving. So programming and machine corrections for lead, profile and MOB are easily possible.

RUCKWIED. Compared to gear shaping, the power skiving method provides 2 to 6 times more productivity and tool life.

What Took So Long?

Just for some perspective, what do you think prevented skiving for gear production from being developed sooner?

STOLZ. Power skiving is a high-frequency process. In the past, the missing stiffness in the axis drive systems made it difficult to prevent vibrations.

Due to the cross-axis angle necessary for power skiving, the process is much more complex compared to shaping. There was no technology software available to help understand the process in detail and to design the cutter and the process very precisely.

In the meantime, substrates and coatings for cutters have evolved and are contributing significantly to the success of the process.

In the past it was more a trial-and-error approach.

LANGE. High power and speed for the two rotational axes (tool and work spindle) and cutting tool design parameters once you had a machine that could handle the cutting forces, so the results of the tool design were not clouded by machine weaknesses. The cutter design is extremely important for this process to work!

AFFOLTER. There were probably two aspects. First, the existing processes (hobbing, shaping, broaching) are well-known, widespread and in some applications better suited. Second, the power skiving needs high rotating speed and high torque and precise interpolation; not anyone can reliably manufacture such CNC machines.

LABENDA. The reason is that power skiving is a very dynamic process and requires very stable machines and high accuracy for the coupling of the axes.

WINKEL. Regarding the machine, the drive technology was a key factor. High rpm and perfect synchronization plus high rigidity are essential.

Regarding tools, tool life was and is the main topic in gear skiving. But new substrates and coatings as well as better technology understanding helped to improve tool design and performance.

Regarding the technology, the introduction of the multi-pass-cutting-strategy to reduce negative rake angles was a big step forward to get more reliable processes and tool life.

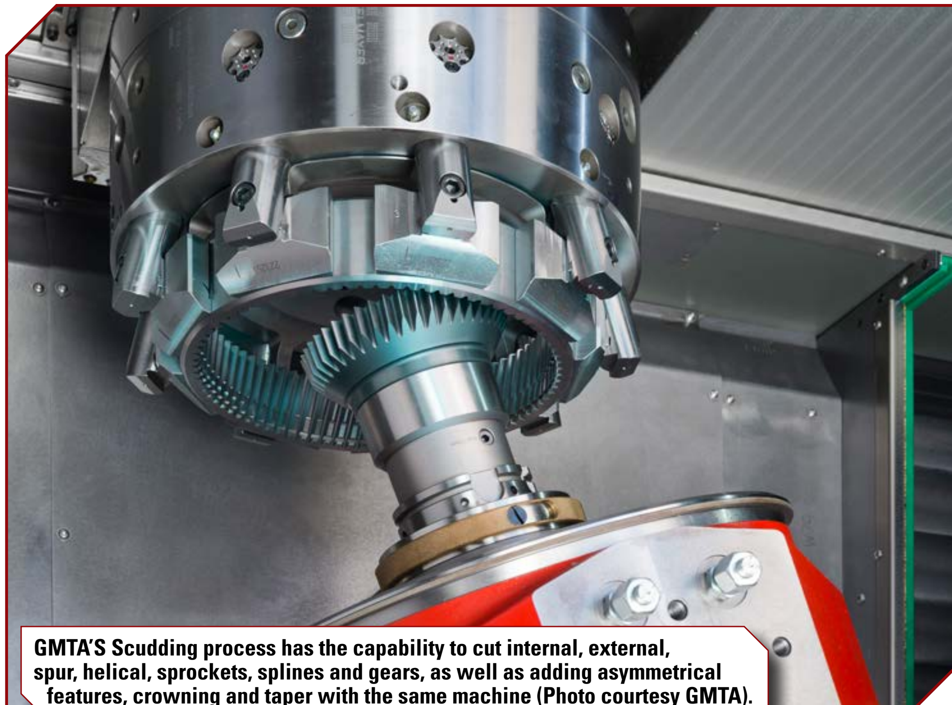
Finally, the development of the mathematical basics and high-sophisticated simulation software used on modern computers set the basis to avoid bad process and tool designs.

SMITH. Skiving was held back by machine tools that weren't rigid and stiff enough, and lacked robust spindle synchronization.

Affordability

Is gear skiving an expensive startup? If so, please elaborate, e.g.—is it tooling? coatings? software? Can we assume that gear skiving tooling is more expensive than conventional tooling? If so, why is that?

AFFOLTER. For our worm screw power skiving process, the machine can be the same as the one use for standard hobbing, because the spindles driving



GMTA'S Scudding process has the capability to cut internal, external, spur, helical, sprockets, splines and gears, as well as adding asymmetrical features, crowning and taper with the same machine (Photo courtesy GMTA).

the parts can reach high speeds (higher than 10,000 rpm). However the tool for power skiving is about 30-50% more expensive than a standard hob. But the life time of such a tool is quite high, especially cutting brass (between 30,000 and 40,000 parts between each re-sharpening). The software used is our standard *Affolter Gear* (same as for hobbing).

KNOY. The tooling is generally the same cost as a gear shaper cutter. The materials and coatings are the same and the size and geometry are similar. As it is newer technology, the tool may cost nominally more as the manufacturing process to make these tools is not as developed as the process to make the shaping tools.

STOLZ. Depending on the individual situation, for the customer in most cases it is a tremendous cost reduction opportunity. On one hand, a power skiving machine can replace several shaping machines. On the other hand, for small-to-medium lot sizes, power skiving can be a very efficient alternative to broaching, as it offers a much higher flexibility. Large inventory in broaching tools and long delivery times can be avoided. Modifications in profile and lead direction can easily be accomplished.

WINKEL. In skiving, the clamping fixtures for the workpieces are more sophisticated than in shaping, due to the higher process dynamics. It has to be considered that typically the skiving cutters are workpiece specific while in shaping different number of teeth or profile shift coefficients can be produced with the same shaping cutter (e.g, splines). Compared to broaching, the skiving machine is much cheaper and also the tools as well as the reconditioning. But again, the fixtures are the driving cost factor in skiving regarding investment, since there are more or less no fixtures in broaching.

SMITH. Gear skiving, or Super Skiving as MHI refers to it, is on par with other gear cutting processes in regards to startup costs, slotting in between shaping and broaching. Due to their superior tool life, the Super Skiving tools from MHI deliver a lower-cost-per-unit than ordinary pinion type cutters.

WARE. The overall manufacturing cost is lower with power skiving since the cycle time is much lower than with shaping technology. Less work in progress (= less cost) is possible if CNC machines are able to do the whole component, including the teeth. As in all machining the workpiece-tool-machine analysis (in that order) must be made.

New Applications?

Is gear skiving equally effective for both internal and external gear cutting? Or one more than the other?

STOLZ. We see the highest benefits for internal gears and external gears with shoulders, which cannot be hobbed. If hobbing is possible, it is in most cases the more efficient process. Just imagine the number of teeth on a hob and on a power skiving cutter. If you assume the same length-per-tooth, you will find the lifetime of the hob between re-sharpenings to be much higher.

In some cases there is not enough clearance between the gear and a shoulder even for power skiving. In these cases, the cross-axis angle needs to be reduced, which impacts the efficiency of the process. In these cases, shaping may be the better option.

WARE. Power skiving is an alternative process to shaping, so hobbing is still the most efficient process for external gears. Like shaping, it can generate both internal and external gear teeth. The cross axis angle between the cutter and the workpiece does limit some applications.

LANGE. Some external cutting of shaft parts requires shaping, so a win-win for power skiving over shaping — assuming the power skiving process can be applied. However, if it can be hobbed, I think I would stick with hobbing — especially if a pre-finishing process where a multi-thread hob can be used. Hobbing should be faster and tooling cost less. I would say the cost for shaping larger internal gears was the most significant driver for the development of power skiving. Add to that better quality and, I believe, similar or less tooling cost. The machine cost is more than a shaper but not four times more expensive since cycle times are many times four times faster! What are plant floor space and less machine operators worth? I believe the (greatest) impact of this process appears in the construction machine industry and larger, internal gears previously being shaped.

KNOY. When you are using the Scudding process you are able to cut internal, external, spur, helical, sprockets, splines and gears, as well as adding asymmetrical features, crowning and taper with the same machine. As noted above, the software provides the direction for the machine. The flexibility of the process is one of its best features. Most people see Scudding as a good process for internal gears, which it is. However, the scudding of external gears can provide a better quality part in less time than you can make by the hobbing process.

WINKEL. Skiving is applicable for external and internal gears, but if there are no other advantages or restrictions to the external gears (like interference, or positioning to other skived gears) hobbing is always more cost-effective and productive.

SMITH. The greatest advantage is in the volume production of internal ring gears, both spur and helical. For external gears, hobbing will be used except in cases with interfering part geometry. For many applications with recessed gear or spline features, shaping is the preferred process since skiving has limitations due to the crossed axis needed.

BYLUND. For internal it is especially effective since the alternatives such as shaping (slow) and reaming (very inflexible and cumbersome) are not so good. For externals, power skiving is a good alternative for a shop that is investing in new technology since if using a multi-axis CNC, both internals, externals and other parts can be made.

RUCKWIED. Internal gear cutting is more effective because of competition from the technologies of broaching and shaping. External gear cutting with gear hobbing technology is often more effective with the use of two or more hobs on the tool. If machining is next to a face, external gear hobbing is not possible. Therefore gear skiving is an effective solution.

EMAG power skiving machines enable both rough-machining (turning) and finish-machining in one clamping operation (Photo courtesy EMAG).

Skiving Gearbox Components

Gear skiving has been touted as a process for producing "cost-saving gearbox components," and that workpieces with constraining contours can be produced efficiently using this method."

LABENDA. With our software we can manufacture gears with modifications. That means time saving when modifying internal gears instead of planetary gears.

STOLZ. When designing a gearbox, there are two main targets. The gearbox should be as compact as possible and cost competitive. Compactness means sometimes very small clearances between the gear and a shoulder or another contour, which require shaping as a manufacturing process. Gleason can tell customers upfront precisely what clearance is necessary as a minimum to be able to use the extremely productive power skiving process. If it can be accomplished without major compromises, especially in a high-volume production, the savings can be significant.

Related to "workpieces with constraining contours," take for example an input or output shaft. For shaping a spur gear or a spline, the shaping head being in the same plane with the tailstock has a high risk of collision, if the cutter diameter is not large enough. Power skiving, due to the cross axis angle, can be less critical as you are moving the power skiving spindle interference contour away from the tailstock.

KNOY. The size of the gears is getting smaller, but the loads and torques are increasing. Scudding can assist in this move as it does not require clearance to evacuate the chips, as gear shaping does. This means as the clearance grooves are eliminated as a function of the scudding process, the "weak point" in the gear is also eliminated. This allows that the entire gear can be reduced in mass — but still provide the same strength. Smaller components mean smaller, more efficient transmissions. This is also evident to the extent that speed enters the equation. The possibility to complete all geometries desired has existed for some time — just not economically.

WINKEL. (Designers) are actually checking in many cases if they can change the shaping design to a "skiving design." This focuses especially on the higher necessary overrun of the skiving cutter compared to the shaping cutter, which is caused by the cross-axis angle.

RUCKWIED. There are solutions where two parts were machined and combined can be designed and machined as one part with the technology of power skiving. Gear shaping on one part was (more) expensive than machining two parts with gear broaching and welding them together.

Gear designs against faces needed to be machined with gear shaping that was very often (non-productive) for series solutions. The power skiving technology with its productivity gives the designers of parts and planners of machining operations a new flexibility and productive option.

LABENDA. With our software we can manufacture gears with modifications. That means time saving when modifying internal gears instead of planetary gears.

BYLUND. As with all manufacturing technology requirements on workpieces change. Power skiving does not work if there are shoulders close to the gears or splines, or when the teeth are very deep into the part. "Parts designed for power skiving can be efficiently power skived."

RUCKWIED. There are solutions where two parts were machined and combined can be designed and machined as one part with the technology of power skiving. Gear shaping on one part was too expensive than machining two parts with gear broaching and welding them together.

Gear designs against faces needed to be machined with gear shaping what was very often too low productive for series solutions. The power skiving technology with its productivity gives the designers of parts and planers of machining operations a new flexibility and productive option.

Liebherr's skiving process includes direct drive technology for high spindle and table rpm, and high gear accuracy, while assuring optimal synchronization between workpiece and tool spindle. (Photo courtesy Liebherr).

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Solutions for Your Process Engineer Shortage

Joe Arvin

As you might imagine, I talk to many gear industry people through the course of my day-to-day activities. And there is one question that I hear over and over again. "Joe, we need an experienced gear process engineer. Do you know anyone who's available?"

Unfortunately, my response is usually, "I'm very sorry, but no."

The role of the gear process engineer is critical to the success of a gear manufacturing company. And having an experienced engineer who can develop an efficient process often means the difference between profit and loss on a job.

If you are like most gear companies, qualified people for this role probably aren't trying to knock your door down looking for a job. So, what do you do to fill this role when no one is responding to your recruitment efforts? You basically have two options. You can either find an experienced engineer you can lure away from a competitor, or you can develop someone internally. More often than not, the latter will need to be your course of action. For this reason, I wanted to share a few ideas on how you can internally develop a process engineer in the most effective way.

Accept the Investment Right Up Front

When choosing the option of developing a process engineer internally, you're going to have to understand that this will be a long-term project — one that comes with a significant price tag. But remember, this is an investment in the future of the organization.

Finding the Right Trainee

For the most part, there are two types of people who will be likely candidates for the process engineer training — a recent graduate with an engineering degree, or a person from the shop floor with machining experience. When making the decision between these two options, consider these points.

A newly degreed engineer will most likely not have any experience in gear manufacturing, and he or she will require a lot of information to get up to speed. But on the other hand, don't forget that these individuals do have the traditional training as engineers, and this will often help in their transition to becoming productive members of your engineering team.

As for developing people from the shop floor, the benefit here is that they will likely have a wider knowledge of general gear manufacturing principles. And the deeper their machining experience, the better off they will be. Obviously, a tooth grinder will have more developed experience than someone in turning. But keep in mind that the transition to the role of engineer will require a lot of new information, and you need to allow time for this.

Here is another thing to consider in the comparisons between a newly degreed engineer and someone from the shop floor. Generally, it is not feasible for this person to be in training eight hours per day every week. People can only take in so much new information effectively. If the trainee was an operator, they can spend their off-training time working with the person who replaced them and sharing their machining knowledge. For a trainee who is a degreed engineer, in their off-training time, consider assigning other engineering tasks like designing tooling or fixtures so that they can be as productive as possible.

The bottom line here is that you will need to carefully evaluate each of these two options in the context of your organization and your needs. However, in either case, it's best to explain clearly to the trainee that this will be a long process that will cost the company a significant amount of investment. Make sure that they are willing to make a personal commitment to you to complete the training and continue contributing to the company after their training is completed. Obviously, you can't make the trainee an indentured servant, but it is important that this expectation is communicated.

Assigning a Mentor for Guidance

For ensuring the best results, it is advisable that you select an experienced engineer in your department to act as the primary mentor for the new engineer. This individual will be tasked not only with sharing information, but to also with guiding the trainee through the trajectory of his or her training program. The mentors will be the ones to give and review assignments, and gauge when the trainee is ready for the next level.

But you might be thinking, "Joe, come on, the reason we need another process engineer is because our guys are swamped. We don't have time to pull our experienced guys off of their projects." If this is the case, you might consider engaging the services of a consultant or recent retiree for this role. By having them in your plant several hours per week, or available for email and phone communication, you can avoid putting additional responsibilities on your existing engineers.

Again, as I said before, it will be a long road to transform a trainee to an experienced process engineer. For this reason, it's best to work a well thought-out plan for how the engineer's training will progress. Consider these steps in that sequence.

The Course of Study

To begin, have the trainee spend time in all of your departments. Have them speak with the operators for insights about how and why certain things are done. It has been my experience that trainee engineers are often dropped into the engineering department to absorb information. Don't overlook this valuable introductory learning opportunity to have the trainee really get to know

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each area of your manufacturing operation. Perhaps this time in the shop can take place for half of the day, with the other half spent in your engineering department learning from the mentor or other engineers.

Provide the trainee with a capabilities spreadsheet for all of your operations so that they know the scope of your capabilities and the tolerances that are possible.

Have the trainee tour the facilities of your vendors that perform outside services. They need to understand these operations as well as those performed in-house.

Seek out opportunities for outside training courses, such as community colleges or industry seminars that provide insights to your specific manufacturing process. The American Gear Manufacturers Association (AGMA) is a valuable resource for this type of training. Also, be sure the trainee is receiving key publications for the industry like *Gear Technology* magazine, and encourage them to carefully read all of the technical articles.

Have the trainee learn the CAD/CAM software used by your company. This should include both formal training as well as the opportunity for self-paced experimentation.

Provide the trainee with existing processes for proven methods of manufacturing on past jobs. Have them start with a study of the blueprint, and then have them study the actual process.

Have the trainee study various specifications required by your customers so they know how to read these and what to look for as a process engineer.

Using blueprints from past jobs, have the trainee develop his or her own process, and then compare those to the proven methods developed for those jobs.

Have the trainee begin processing simple jobs for your customers.

Finally, begin assigning processing assignments for more detailed and complex jobs for active orders.

In time, if you picked the right candidate, this person will have a good knowledge of your capabilities and will be able to take part in this valuable role for your company and contribute to your profitability.

A Final Word

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

Also, if you missed any of my previous articles in 2017, here is a list of them by issue number and page. If you'd like for me to send you a copy, please send me an email or give me a call.

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

Cyber Physical Gear Production System: A Vision of Industry 4.0 Gear Production

Markus Brumm and Hartmuth Müller

Introduction

The engineering design print remains the dominating data storage medium for gear production. This is related to the genius Leonhard Euler, who invented the involute as an optimal gear profile. Involute gears can be accurately described using figures copied from drawings. During manufacturing, operators need to keyboard these figures several times into the machine controls. This is made possible by a bundled software system consisting of gear design and machine operation software, and quality inspection systems. But there as yet exist only a few interfaces for data exchange, and so the printed page continues as the primary data carrier on shop floors.

This report describes Klingelnberg's vision of Industry 4.0 gear production. It describes a concept for a gear production system called *GearEngine* that is fundamental to data collection during gear manufacturing. The system can be used to derive information from the data for process optimization and operator support. The main goal of the new system is quality optimization and cost reduction. The whole concept is based on Klingelnberg's philosophy that only an open system will be successful in the future. This means *GearEngine* is not limited solely to Klingelnberg products; it is also for machine tools from other machine tool manufacturers.

Figure 1 Leonhard Euler on the former 10 CHF bill.

The manufacturing principle of involute gears is based on a rack profile with straight flanks in mesh with a cylindrical gear. The rack profile is standardized according to DIN 867 (Ref. 1). The origin of this principle is Euler's (Fig. 1) invention of using the mathematical involute as a gear profile. The geometry of an unmodified involute gear is described explicitly if rack profile, dimension over teeth, helix angle, tooth width and tip diameter are known. Using involute gears as a standard gear profile does indeed have its advantages; however, that in fact is the reason why cylindrical gear manufacturing processes are so far removed from the principles of industry 4.0.

While the unmodified involute gear can be clearly described by some figures on a drawing, the descriptions of gears with lead and profile modifications are

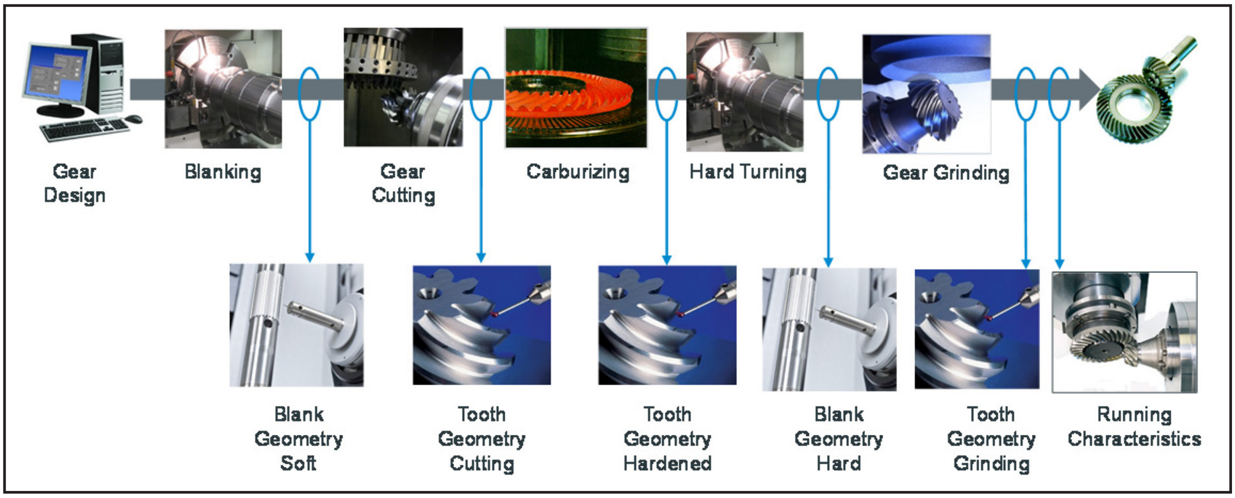

Figure 2 Creation of a digital twin in bevel gear production.

This paper was first presented at the 2017 VDI Conference on Gears, Munich.

Figure 3 Klingelnberg Closed Loop 1.0.

more complicated. Taking a lead crowning as an example, its value depends not only on the crowning—but also upon the length of the path taken for its evaluation (Ref. 2). This description of the cylindrical gear geometry via a few figures is not sufficient. An approach to make it more fail-safe is found in the standardized *Gear Data Exchange* (*GDE*) format.

But even with *GDE* the manufacturing of cylindrical gears remains far away from attaining the requirements of Industry 4.0. Industry 4.0 is linked to some buzzwords like "internet of things," "cyber physical systems" and "co-existence of virtual and real production systems;" they are just a brief example list of all terms mentioned in relation to Industry 4.0. Given its higher degree of complexity, Klingelnberg's bevel gear production system features digital twins and process models, i.e.—years closer to the requirements of industry 4.0 than the cylindrical production system. For Klingelnberg, the bevel gear production system is an example of the cylindrical production system of the future.

The design of bevel gears is based on material models that describe the load-carrying capacity of the basic material. The strength of the material was determined by standard tests on standard reference gear geometry. Thus the strength of the material must be adapted to the geometry of the individual gear. Therefore a standardized calculation model is available that is described in detail in Reference 3. The ISO standard is a virtual model that enables one to determine the running behavior of a virtual twin of the final part.

Industry 4.0 requires one single source of truth, which means information must be unique and have a direct link between sender and receiver; therefore Klingelnberg introduced one database for manufacturing. This database is installed at customer sites and all machines for gear manufacturing and quality inspection are linked to it. The design software is also linked to the database. For customers manufacturing gears at different plants, the database can be consolidated into one common database for all Klingelnberg machines at all affected sites.

The closed loop has been a part of bevel gear manufacturing systems for years. The actual gear geometry is calculated based on the virtual flank form description. Deviations from the target geometry can be traced back to machine settings that deviate from optimal machine settings. If the bevel gear production system is considered as an example for the cylindrical gear production system of the future, the implementation of a closed loop is the first step.

Implementation of Closed Loop for Cylindrical Gears

The first step in modernizing a bevel gear production system is to implement a digital data transfer between measuring center and gear grinding machines. This means that information described by figures must be transferred digitally to the operator software of the gear grinding machine. The implemented interface is based on the *GDE* format to enable an open interface that is not limited to Klingelnberg's *Gear Production* software.

The interface is available for involute gears of any type; thus internal and external gears can be evaluated and described by *GDE*. Important to consider is that gear quality can be evaluated according to different standards, but the geometrical deviation to the target is independent from this evaluation. This means the interpretation of the gear geometry must consider this; thus *Gear Production* deletes the *GDE* protocol (evaluation method) that was used during gear inspection—which prevents misinterpretation by the machine operator.

Who decides when a correction has to be calculated and the settings of the process must be changed? This question was also asked during the development of Closed Loop 1.0. Typically, it is the responsibility of the operator. But is it possible to provide some guidance? Can a company define general rules? Klingelnberg thinks it is necessary to define general rules and displays measuring results in *Gear Production* within tolerance fields (Fig. 4).

The customer can define green, yellow and red ranges for the tolerance field. The green area means the operator does not need to correct the process. The yellow fields display ranges where a correction is recommended. Red informs that the measured part was out of specification.

Closed Loop 1.0 is an active system, meaning that *Gear Production* alerts the operator if a new measurement for the running process becomes available. The operator acknowledges the alert and he is forwarded to the correction menu.

Calculation of Digital Twin

Closed Loop 1.0 is only one first approach to optimize cylindrical gear production. It is still not failure-safe because the operator might yet make mistakes by ignoring relevant measuring data. It is also not clear that the geometry that was considered in the gear design is really manufactured on the machine. In contrast to bevel gear

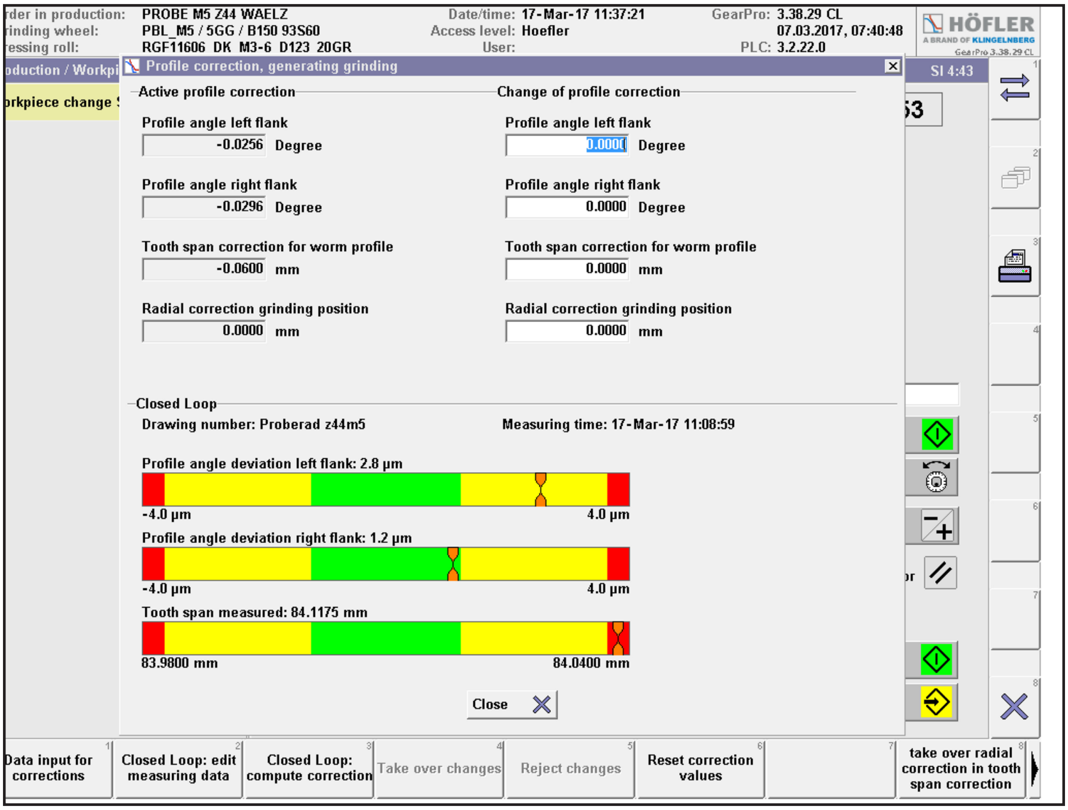

Figure 4 Illustration of measuring results in *Gear Production*.

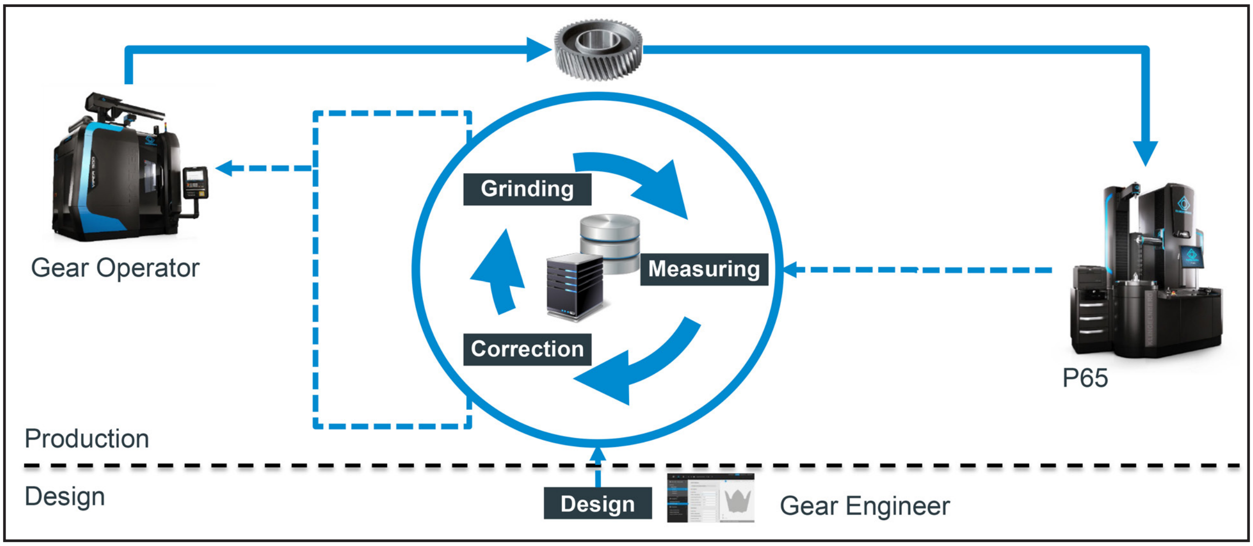

Figure 5 The new Klingelnberg Closed Loop.

production, the process simulation is not considered in the design phase. This may lead to different running behavior of the virtual twin and the manufactured gear. It also incurs higher costs in series production because tolerances are minimized in that the relevant deviation causing the different running behavior is not caused by the stability of the machine tool; it is related only to the process kinematics.

Klingelnberg decided to implement a quality gate in the gear design step, i.e. — to link gear design and gear manufacturing. The result is a software system called *Gear Designer*. As its name implies, the aim of this software is process design. It creates a virtual twin by process simulation. This geometry can be exported to the tooth contact analysis (TCA) software to determine whether the process-related deviation is acceptable or not. The designer also receives feedback to check how topological modifications affect productivity. This quality gate can be considered as a closed loop for the gear design phase. If prototypes are manufactured and tested as being good, the process can be frozen and passes the quality gate for serial production (Fig. 5).

Figure 5 describes a new closed loop with advanced functionality. The main difference to Closed Loop 1.0 is that the closed loop in series production is based on an approved geometry derived from a manufacturing simulation. This means the target geometry used for the correction is a real virtual twin — comparable to the target geometry used for bevel gear manufacturing. Should deviations from the target design be detected, they can be completely compensated for by the process.

Virtual Process Design is an Enabler of Silent Gears

Gear design has three main targets — the gear set must fulfil requirements on load-carrying capacity, efficiency, and low noise; the last requirement is checked by subjective noise evaluation. The driver of the car evaluates the noise by NVH rating. Generally there is no sophisticated calculation model available that synthesizes the final noise based on the gear set excitation.

In future, the requirements of noise quality will increase. Urbanization, demographic change and climate change will lead to a rising demand for gears in noise-critical applications. Electric-driven cars are one of the most sensitive applications for gear noise. The input speed of the transmission can exceed 30,000 rpm and the masking noise from the combustion engine is missing. But also e-bikes, trains, etc., are noise-critical applications.

If the gear process is simulated in the gear design phase, the designer can then use the real geometry for TCA. Christian Carl presented at the International Conference on Gears in 2013 (Refs. 4–5) an approach for gear noise synthesis based on a dynamic gear mesh simulation model. He demonstrated that there is good correlation between tooth contact analysis and gear noise. As long as the real tooth geometry is considered during gear design, a comparison between different gear designs is possible. Also, if the effort for simulation is reduced by testing gears in situ, a good gear design can be determined. As long as the manufacturing can ensure that the geometry is equal to the approved geometry, the risk of unforeseen gear noise will be reduced.

A Vision of Industry 4.0 Gear Production

What gear manufacturers gain from series production is information that results in realistic tolerances for gear design. This information is also needed for later failure analysis if problems occur in the field. Data collection and analysis are also needed for quality improvements,

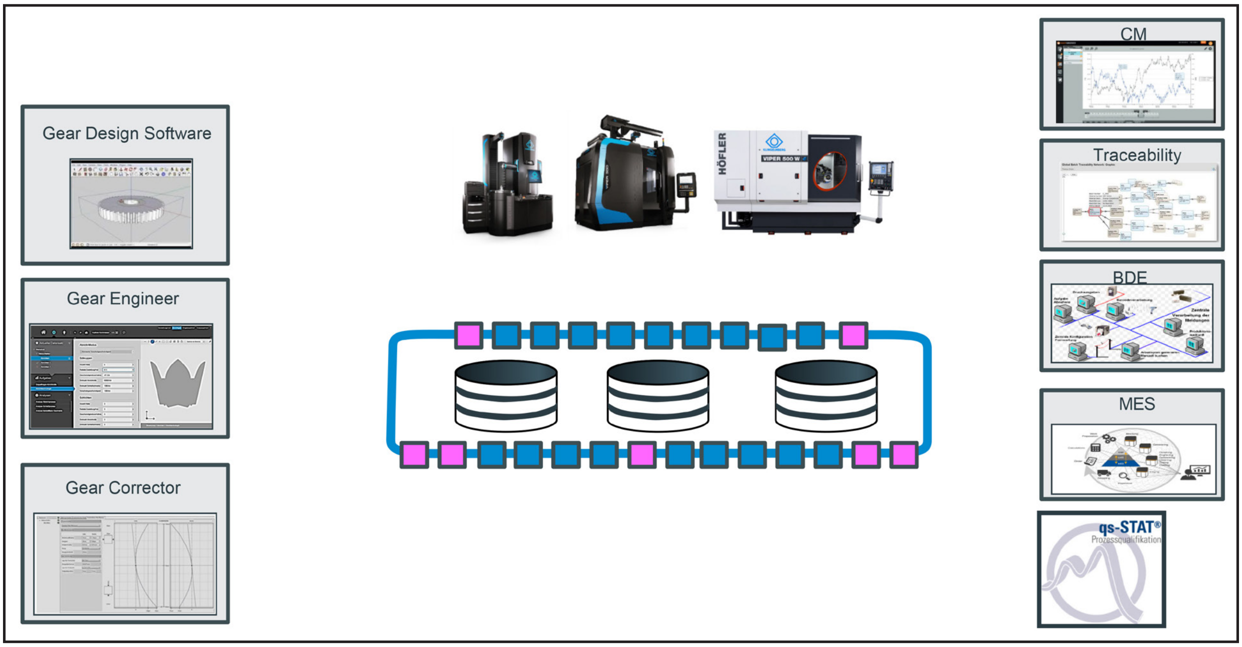

Figure 6 Klingelnberg *GearEngine*.

process optimization, tool life analysis and continuous improvement processes. Gear manufacturers continue to use disparate software solutions and enterprise resource planning (ERP) systems to collect data from production. Machine tool manufacturers must create individual interfaces for every type of machine in the field. All interfaces must be updated continuously and this need expands with every sold machine.

Klingelnberg has created the concept of a new production system for gears — *GearEngine*. The heart of *GearEngine* is a database for gear data, tool data and production data. The platform has interfaces to design software for gear and process design (e.g., *Gear Designer*). Every machine in the production network is connected to *GearEngine* and is reading and writing data. This means that data is not stored locally on machining centers — it is *centrally* stored in *GearEngine*.

GearEngine is an open system; new applications can be programmed not only by Klingelnberg but also by customers and partners. The stored data in the system can be used to improve the set up process, to create new knowledge for the gear design, or for predictive maintenance. It is not limited to cylindrical gear production. In future all Klingelnberg products will be integrated into *GearEngine*.

Summary

Klingelnberg's new *GearEngine* is the consequent follow-up to Klingelnberg's Closed Loop 1.0. It contains functionality like the new Closed Loop for cylindrical gears. Software products like *Gear Designer* and *Gear Operator* are integrated, as are Klingelnberg measuring centers. The heart of the system is a database for data storage. Open interfaces to other applications are needed to add continuously new functionality to it. *GearEngine* is a platform that readies gear production for Industry 4.0.

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Dr.-Ing. Hartmuth Müller is Head of Technology and Innovation for Klingelnberg GmbH. He has been with the company since 1990 (as a software developer) before assuming in 2016 his current position.

Analysis of the Influence of the Working Angles on the Tool Wear in Gear Hobbing

Felix Kühn, Christoph Löpenhaus and Fritz Klocke

Gear hobbing is one of the most productive manufacturing processes for cylindrical gears. The macro geometry of the cutting edge of a hob is decisively designed on the tool angle. The tool angles are defined as rake angle, wedge angle and clearance angle. In the process, the tool angles change to the working angles as a result of the resulting velocity. The goal of this report is to calculate and optimize the working angles at the hob. First, the tool angles and the working angles along the cutting edge at the hob are explained in detail. A calculation method is developed with the support of the production simulation *SPARTApro*. As the free choice of tool angles is especially possible for hobs with indexable inserts, the simulation of indexable inserts in gear hobbing is presented, as well. The method can be used to calculate the working angles in the hobbing process. Subsequently, the calculation method is applied, a simulation plan is set up, and the working angles are calculated for all variants. With the aid of the calculated working angles, an estimation of the tool wear can be given.

Introduction and Motivation

One of the most productive processes for the manufacturing of external gears is gear hobbing (Refs. 1–4). The simplest design of a hob is the conventional hob, where the body is made from a single piece of cutting material. The shape of a conventional hob is defined by two categories: macro and micro geometry (Ref. 3). Parameters such as external diameter, tool length, chip flanks, chip gashes and the tool angles belong to the macro geometry category. The tool angles are defined as rake angle, wedge angle and clearance angle.

Until today, there are few scientific investigations regarding the free modification of the tool angles in the gear hobbing process. Only Joppa (Ref. 5) investigated the influence of rake and clearance angles on tool wear in 1977 (Fig. 1; Ref. 5). He varied the angles for HSS-tools in wet processing. As the results show, the tool angles have a significant influence on the wear behavior and the life time of the hob. Since (Ref. 5), coatings and alternative cutting materials such as cemented carbide tools have changed the wear behavior of hobs. In the field of bevel gears, several studies have shown that specific modifications in the tool angles can lead to an extension in tool life of cemented carbide tools (Refs. 6–7). This potential is also expected for gear hobs. However, the transfer of the research results from bevel gear to spur gears is not directly possible. This is due to the fundamental differences of kinematics between both processes. In gear hobbing each tooth experiences a load spectrum resulting from the different tool positions, the same does not occur in bevel gear plunging. Due to the indicated potential shown by manufacturing of bevel gears, a specific

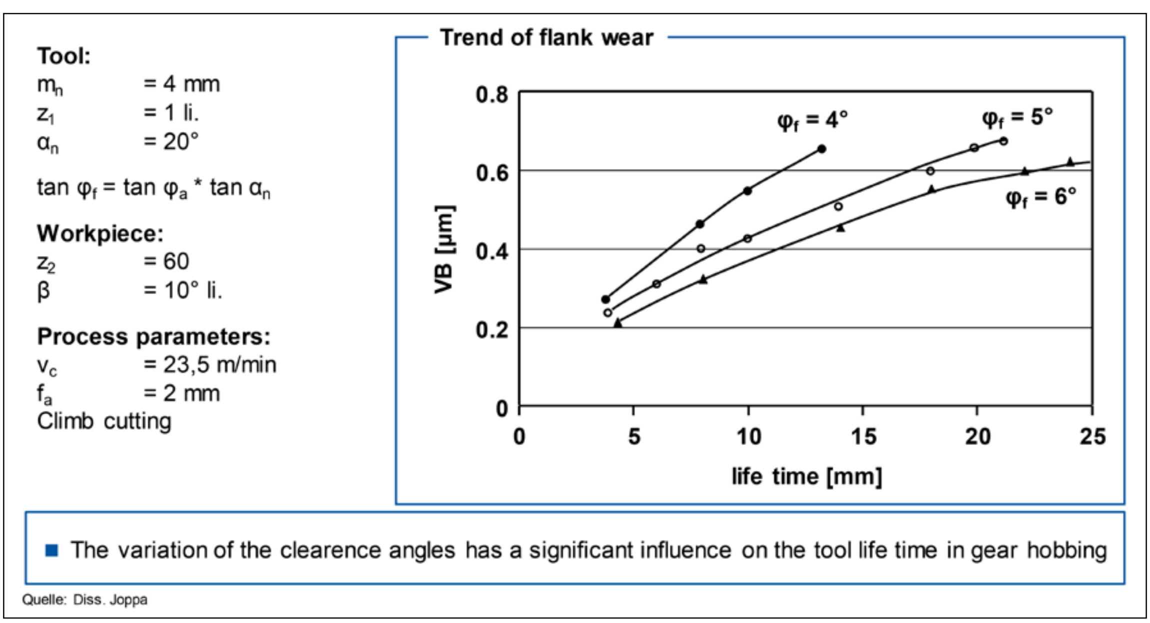

Figure 1 Varied clearance angle (Ref. 5).

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modification in the tool angles for the hobbing process is promising. Thus, this report will analyze the influence of the tool angles in gear hobbing process.

Objective and Approach

In the hobbing process, critical wear can occur on the tool due to the resulting load spectrum at the cutting edge. Basic investigations must be conducted in order to explain basic causes of tool wear and make correlations to specific variables.

The objective of this report is to analyze the hob macro geometry regarding the working angles (Fig. 2). The basis for this is a geometrical penetration calculation taking the clearance and rake angles during machining into account. For this purpose, the method of penetration calculation developed at WZL, which is integrated in the software *SPARTApro*, will be further developed in order to enable the calculation of working angles during the entire machining process. In addition, the penetration calculation for application of indexable insert has to be developed because the tool angles can be varied by application of indexable inserts. The originality of the work lies in the complete consideration of the influence of the defined tool angles as well as the working tool angles, set during the process, on the tool wear behavior. Previous wear tests of hobbing processes proved the significant influence of the working clearance and rake angles at the tool cutting edge (Ref. 5). These changes, however, are not only caused by kinematics, but also a function of the generating position. In order to provide a complete understanding of the process and a scientifically and comprehensible analysis of the machining process, the knowledge of the effects of these angles on tool wear is imperative. The scientific contribution of this research is the fundamental investigation of the cutting mechanisms and their effect on the wear behavior. Based on the results obtained, the objective is to achieve an improvement in the machining conditions by

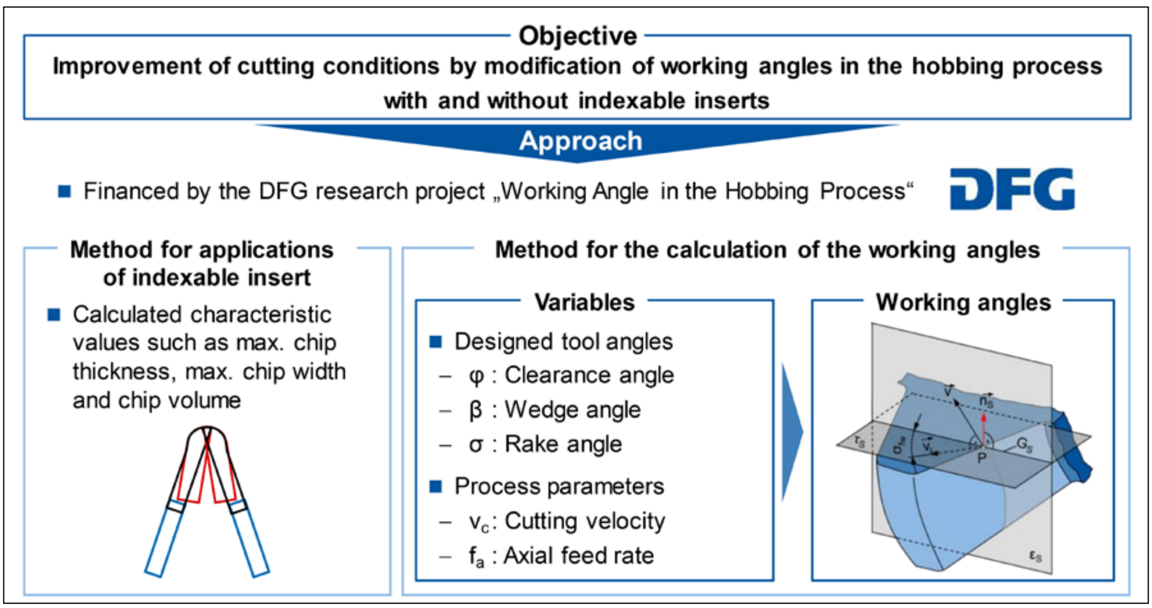

Figure 2 Objective and approach.

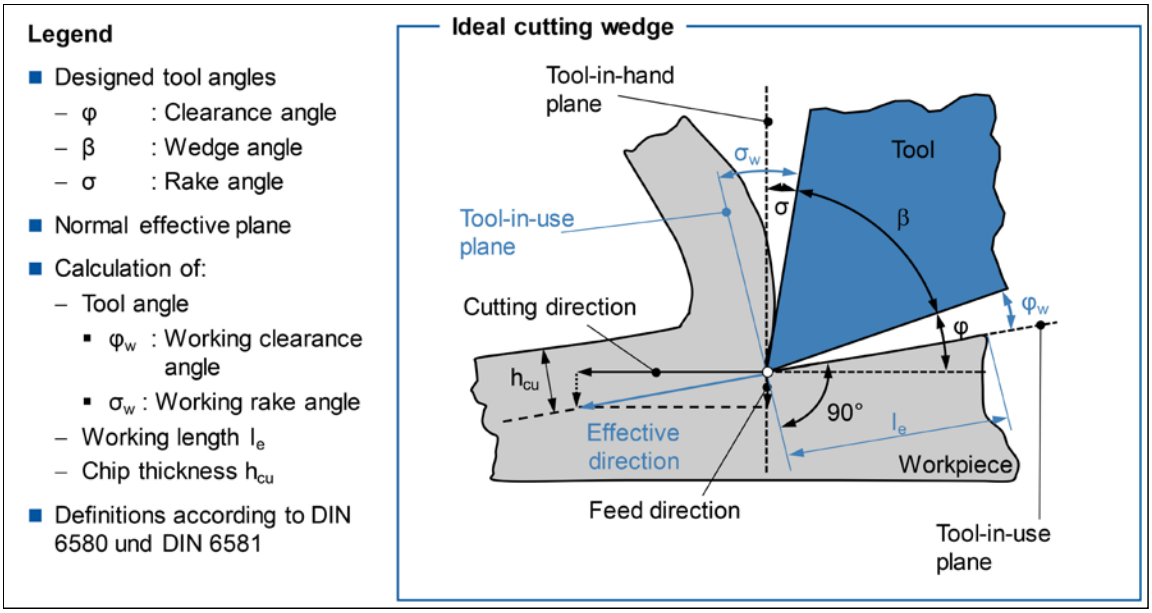

Figure 3 Process kinematics at the idealized cutting wedge.

modifying the working tool angles in the hobbing process.

Process Kinematics at the Idealized Cutting Wedge

Definitions, nomenclatures and descriptions for the geometry of a tool cutting wedge are specified in the DIN 6581 (Ref. 8). The ideal cutting wedge is represented in Figure 3, which is composed of tool clearance angle φ, wedge angle β and rake angle σ. The correlation between the clearance, tool and rake angles is described in Equation 1.

$$\varphi + \beta + \sigma = 90° \quad (1)$$

φ [°] Clearance angle

σ [°] Rake Angle

β [°] Wedge angle

The clearance angle influences crucially the heat input into the tool. The larger the clearance angle, the smaller is the wedge angle, which leads to a reduction of the tool tip's stability. If the clearance angle is too large, the input of heat can be too great, increasing the tool temperature and leading to a disturbance or loss of the tool hardness (Ref. 9). A small clearance angle improves the heat transfer through the tool. However, if the angle is too small, the contact between the tool clearance surface and the workpiece surface increases. The friction from this contact leads to abrasive wear with negative effect on the tool life (Refs. 6–7).

The rake angle influences the material forming, which occurs during the cutting process (Ref. 6). The larger the rake angle, the smaller is the chip deformation during cutting. On the other hand, the increase of the rake angle reduces the tool stability. The smaller the rake angle, the larger is the chip deformation. In this case, the chip experiences a larger curvature than usual. It is for this reason that the rake angle influences the resulting cutting forces as well as the temperature along the cutting edge and the rake surface (Ref. 7).

In order to have a clear description of location, position and movement direction of a cutting wedge, a reference system is used, where characteristic planes are defined and applied to all process variants. The two reference systems used are the tool-in-hand system and the tool-in-use system. The tool-in-hand system is used for tool design, as well as for the manufacturing and testing of cutting tools. In this system, the tool angles are measured without considering the process kinematics. During the machining process, the working clearance and rake angles may differ from the designed angles due to the process kinematics. The tool angle remains unmodified. For this reason, the tool-in-use system was created (Ref. 9).

Figure 3 presents the tool-in-use system defined by the effective velocity, which is the result of the vectorial summation of the cutting velocity and the feed rate velocity. The working clearance angle φ_w calculated in the tool-in-use system is smaller than the tool clearance angle φ. The wedge angle β remains unmodified. Since the relationship stipulated (Eq. 1) is also valid for the tool-in-use system, the variation between the designed rake angle σ and the working rake angle σ_w is the same amount as the variation of the clearance angle — but in a positive direction. In this case, the working rake angle σ_w is larger than the designed rake angle σ.

Tool Angles in Gear Hobbing in the Tool-In-Hand System

The magnitude of the tool angles of a hob has a direct influence on the chip formation, the cutting force and the tool wear. Partly they have a connection to vibrations and chattering during the process (Ref. 1). For the hob, the designed angles follow the same rules described in the ideal cutting wedge regarding clearance, wedge and rake angles. The designed tool angles are altered along the cutting edge of the hob. This leads to a distinction between the designed angles in the tip and flank of the tool (Fig. 4), which are described with the symbols φ_a for designed tip clearance angle and φ_f for designed flank clearance angle. The designed clearance angle for a specific point *P* of the cutting edge is defined as the angle between the plane tangential to the hob clearance surface and the plane tangential to the hob thread, in the same

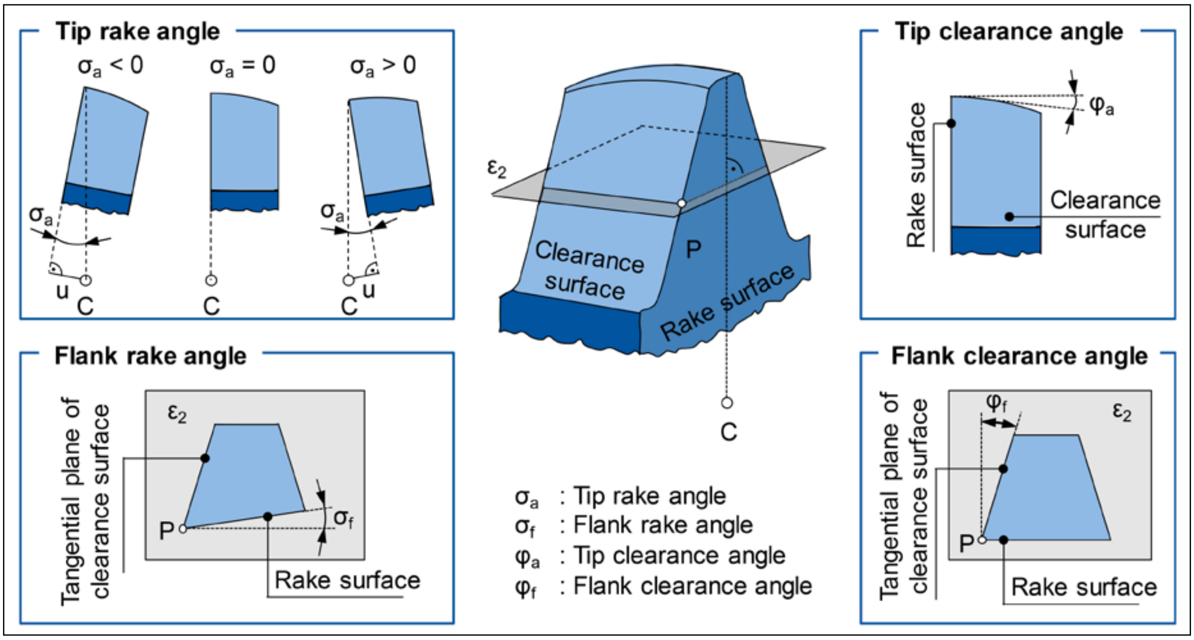

Figure 4 Process kinematics at the idealized cutting edge.

point P (Ref. 1).

The designed clearance angle is manufactured along the tool cutting edge in circumferential direction according to a logarithmic spiral (Refs. 1, 10). As a result, the designed clearance angle is manufactured. In the case of a conventional hob, there is a relation between the tip clearance angle φ_a and the flank clearance angle φ_f, stated by Equation 2:

$$\tan\varphi_f = \tan\varphi_a \cdot \tan \cdot \alpha_0 \tag{2}$$

φ_f [°] Flank clearance angle
φ_a [°] Clearance angle
α_0 [°] Clearance angle

Equation 2 contains the tool profile angle α_0 (Ref. 11). This relation must exist in order to avoid that a re-grinding process in tool modifies the clearance angle along the tool flank as well as the tool profile (Ref. 12). The state of the art for hobs defines tip clearance angle values between $8° \leq \varphi_a \leq 12°$, and in special occasions the value can vary between $12° \leq \varphi_a \leq 20°$. In case of indexable inserts that are changed after reaching the wear criterion this dependency can be neglected. The geometry of different inserts along the profile can be chosen independently.

For designed rake angles there is also a distinction between the designed tip rake angle σ_a and the designed flank rake angle σ_f. The designed rake angle for a specific point P localized on the cutting edge is defined as the angle between the plane tangential to the hob rake surface and the plane through point P which contains the hob axis (Ref. 1). The rake angle is positive when the plane containing the hob axis touches the cutting wedge in P. The angle is negative when the plane intersects the cutting wedge.

The designed flank rake angle can be realized by modifying the tool gash angle. For the case of tools gashed parallel to the hob axis (gash angle of $\gamma_N = 0°$), the designed flank rake angle is $\sigma_f = 0°$. If the gash angle is $\gamma_N > 0°$, a negative flank rake angle σ_f on the right cutting edge is obtained while a positive flank rake angle is obtained on the opposite edge. If $\gamma_N < 0°$, the sign of the angles would be inverse.

$$\varphi_a = \arctan\left(\frac{2 \cdot u}{d_a}\right) \tag{3}$$

σ_a [°] Tip rak angle
d_a [mm] Tool external diameter
u [mm] Rake surface offset

The designed tip rake angle can be obtained by a face offset "u" in the rake surface position. If the rake surface offset is shifted toward its original position with respect to the hob axis, the tip rake angle σ_a is positive. If the offset is performed in the opposite direction, the tip rake angle is negative. From the amount of offset of the rake surface, the tip rake angle is determined, according to Equation 3.

Working clearance angle at the hob in the tool-in-use system. Due to the resulting velocity on the hob blade in the cutting process, the working clearance angle differs from the designed clearance angle. This modified clearance angle is referred to as working clearance angle φ_{fW}. The direction and magnitude of the difference between designed and working clearance angle is particularly interesting on the flank cutting edges. The clearance angles in the flank cutting edges are smaller compared to the angle in the tip cutting edge. Under inconvenient circumstances, the working clearance angle at the flank edges can reach values close to below 0°. The definition of the working flank clearance angle φ_{fW} is shown (Fig. 5). The center of Figure 5 highlights one tooth of a hob. A random point P on the cutting edge of the tooth is selected. From the point P, a normal vector n_F is drawn, perpendicular to the tangential surface τ_F of the flank surface. The vector V represents the velocity in the point P, combining three velocity components V_{r0}, V_{r2} and V_S, (Eq. 4). The velocity component V_{r0} represents the tool rotation around the hob axis, while V_{r2} represents the component for the workpiece rotation. The third component V_S represents the feed motion of the hob relative to the workpiece. The individual components of velocity V take different positions from each other for different angular positions of the hob. This causes the resultant vector V to change its position with respect to the hob according to the angular position of

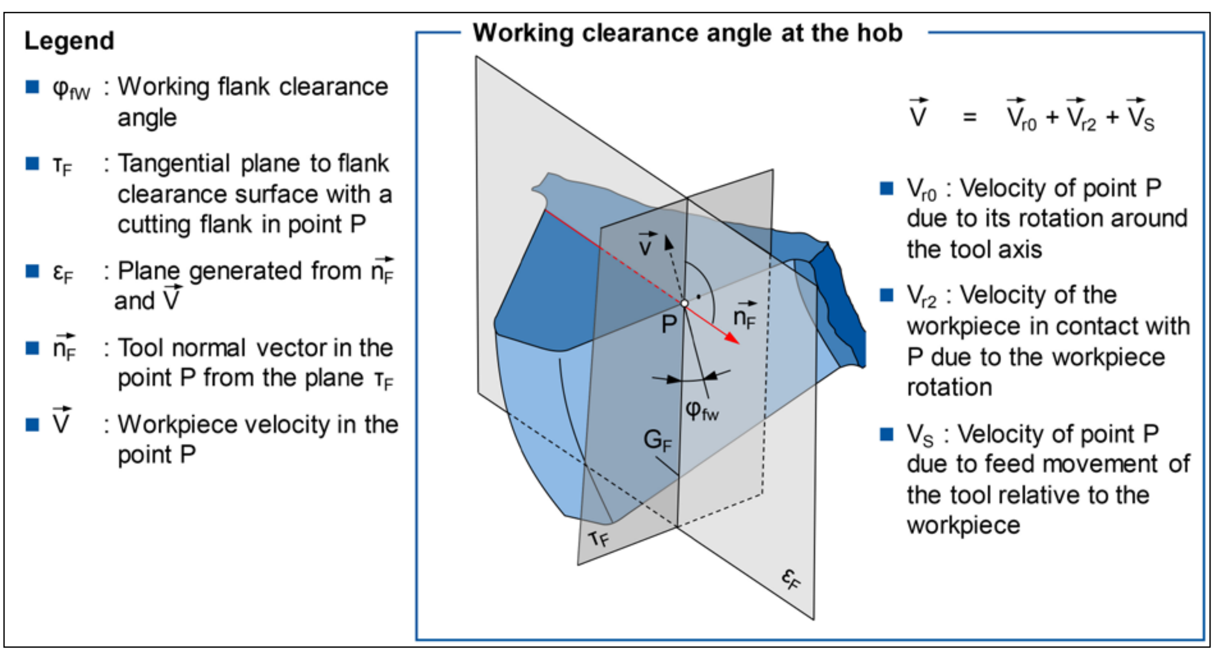

Figure 5 Working clearance angle in gear hobbing.

this same hob.

$$\vec{V} = \vec{V}_{r0} + \vec{V}_{r2} + \vec{V}_s \qquad (4)$$

$\vec{V}$ [m/s] Relative velocity

$\vec{V}_{r2}$ [m/s] Velocity component resulting from work piece rotation

$\vec{V}_{r0}$ [m/s] Velocity component resulting from rotation around the hob axis

$\vec{V}_s$ [m/s] Velocity component resulting from tool feed motion

The vectors V and n_F build the plane ε_F. The intersecting line between the planes ε_F and τ_F is called G_F. The working clearance angle φ_{fW} in the point P is defined as the angle between vector V from the relative velocity and the intersecting line G_F. The working flank clearance angle depends on the process operating conditions. The velocity component V_{r0} depends on the distance to the hob axis, which means that V_{r0} changes for different points on the tool cutting edge.

Working rake angle at the hob in the tool-in-use system. The working rake angle mainly depends on two factors: 1) the designed angles and 2) the relative velocity in the considered point. Figure 6 shows a single blade of the hob, where the working rake angle is illustrated. The working rake angle is not constant along the cutting edge. The relative velocity changes through the different velocity components along the cutting edge, as shown Eq. (4). Figure 6 examines point P in more detail. The velocity in point P is indicated by the vector V, and τ_S is the plane tangential to the rake surface. The normal vector n_s is perpendicular to the tangential plane τ_S. The velocity V and the normal vector n_s build the plane ε_S. Vector V^* has the same module of vector V, but it is rotated by 90° to the vector V in the plane ε_S. The plane ε_S is perpendicular to plane τ_S, and the intersecting line between both planes is called G_S. The working flank rake angle σ_{fw} is measured between the vector V^* and the cutting line G_S.

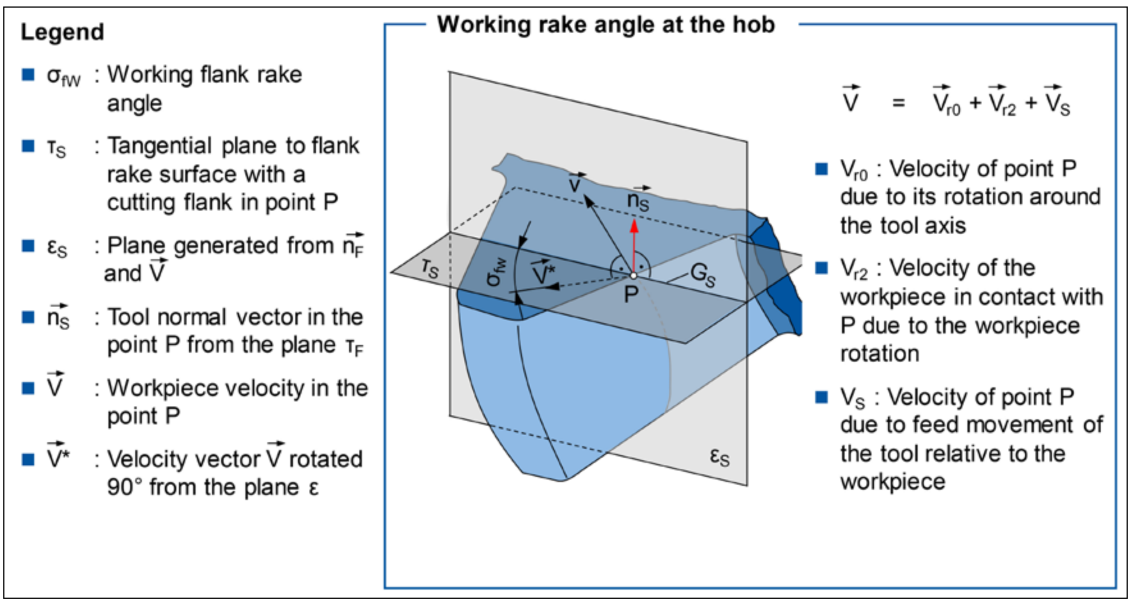

Figure 6 Working rake angle in gear hobbing.

Figure 7 Manufacturing simulation software *SPARTApro*.

Further Development of the Penetration Calculation *SPARTApro*

The Laboratory for Machine Tools and Production Engineering in Aachen (WZL) developed specific software to simulate the process of gear hobbing, i.e. — *SPARTApro* (Fig. 7; Refs. 13–15). Based on the input information regarding tool geometry, workpiece geometry and process parameters the tooth gap is generated with the assistance of a numerical penetration calculation. During simulation, the final chip geometry is determined. With the chip geometry characteristic values such as maximum chip thickness $h_{cu,max}$, maximum chip length l_{max} and machined volume V' can be calculated. These characteristic values are important for the determination of mechanical and thermal loads at the cutting edge of the tool.

Applications of indexable inserts. The difference between indexable insert tools and conventional tools exists in the division of the tool profile into different cutting sections. Each cutting section consists of one indexable insert; the number of cutting sections increases according to the module of the tool. For small-module hobs the profile is divided into two sections — each with one indexable insert. One indexable insert cuts the left side of the gap and one indexable insert cuts the right side of the gap. For large-module hobs the profile is divided into more than two sections. Especially the tip area of the tool can consist of several indexable inserts as this area shows the maximum chip thickness that can be reduced by an overlap.

In addition to the distribution of the profile, the cutting sections are also distributed along the tool circumference in order to create cutting edges for all hob gashes. In most cases, the angles between the individual cutting sections are constant. This results in equal loads for all indexable inserts. But also changing angles between the cutting sections are used to distribute the load on different cutting sections and, therefore, on the different indexable inserts. This can be taken into account in the extended model (Fig. 8).

The tool profile is divided into several cutting sections. The individual indexable inserts successively penetrate the workpiece body and, therefore, it is possible to calculate the formation of non-deformed chip geometries for each indexable insert. In order to define the cutting sections the position with its upper and lower geometrical limitations needs to be known. The position of each cutting section along the tool circumference can be described by the angle $\delta_{\varphi i}$. By this parameter also different angular positon of the cutting sections can be considered.

For a better understanding of the tool concept, a hobbing process with an indexable insert tool typically used in the wind power industry is considered. The tool has a tip diameter of $d_{a,0} = 300$ mm (Fig. 9). The tool profile is represented by six cutting sections. The division of the cutting sections is symmetrical to the profile center line. The tip area of the tool profile is represented by one left and one right tip indexable insert, as well as by one left and one right indexable insert at the flank. In the lower area of the profile, straight-sided indexable inserts are located. The combination of one right and one left tip indexable insert results in an effective number of tip cutting edges Z_{eff}. Therefore the flank's indexable inserts are not considered in the definition of the effective tip cutting edges. The cutting loads in the flank area are significantly lower than at the tooth tip. The tool has in total 8.5 groups of indexable inserts along the tool circumference, therefore, $Z_{eff} = 17$ effective tip cutting edges. The tool profile contains a protuberance that creates a clearance in the tooth root area.

The test gear is a planetary gear with a module of $m_n = 16$ mm; a pressure angle of $\alpha_n = 20°$; a helix angle of $\beta = 7.5°$; and a tip diameter of $d_{a,2} = 615$ mm. The gear is made of the steel alloy 18CrNiMo7-6 and has $z = 35$ teeth and, therefore, for this gear size both hobbing and form milling processes are efficiently used.

With the geometry data from the tool and the workpiece as well as process parameters like axial feed rate, the model calculates the non-deformed geometry

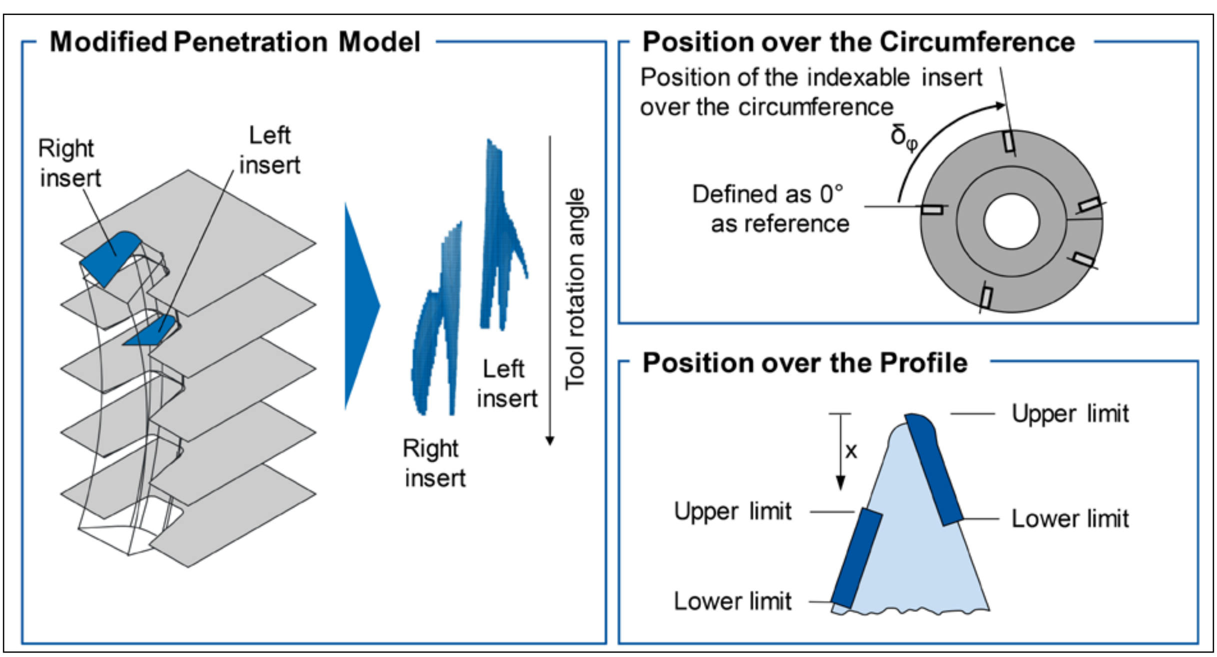

Figure 8: Further development of penetration calculation for application of indexable inserts.

of the intermittent chips. Through the evaluation of the chip geometry, different characteristic values, such as intermittent loads during the process, can be calculated. Currently, the model is able to provide the maximum $h_{cu,max}$ and average chip thickness $h_{cu,mit}$, the related chip volume V' and the maximum and average cutting length, l_{max} and l_{mit}, during the process. These characteristic values are output parameters for the entire process as well as individually for each indexable insert over the unrolled tool profile. Hence, the loads at each point of the cutting edge can be determined and evaluated. For the process described above, examples of maximum chip thickness $h_{cu,max}$, maximum cutting length l_{max} and related volume V' for individual indexable insert over the unrolled tool profile are presented in Figure 10. The course of the maximum chip thickness is divided onto the different indexable inserts. The lower flank indexable inserts Nos. 3 and 6 cut the material with a maximum chip thickness of $h_{cu,max} = 0.14$ mm. The course of the upper flank indexable inserts Nos. 1 and 4 can be divided into two sections. The first section has a linear increase that occurs during the flank machining; the second section has a parabolic increase that occurs during the tip machining. The maximum chip thickness is obtained at the upper flank indexable inserts in the tip area of the tool with a value of $h_{cu,max} = 0.34$ mm. The tip indexable insert Nos. 2 and 5 cut exclusively in the tip area of the tool. The progress of the maximum chip thickness is similar to that of the upper flank indexable inserts in the tip area. The parabolic profile increases to a maximum value of $h_{cu,max} = 0.34$ mm. With the additional application of the tip indexable inserts, the loads in the tip area are distributed over the upper flank and tip indexable inserts. The indexable inserts allocated in the tip area of the tool are evenly distributed over the tool circumference. Because of this, uniform distribution and the same value for the maximum chip thickness of $h_{cu,max} = 0.34$ mm can be found at all tip indexable inserts.

Method of the calculation of the

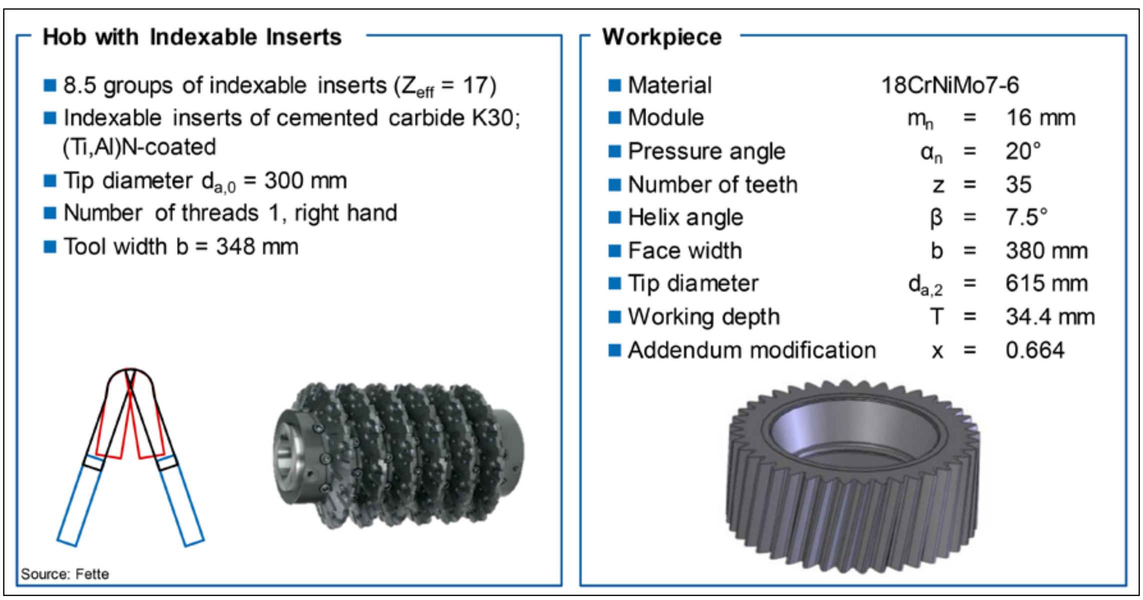

Figure 9 **Tool and gear parameters for indexable insert hobbing.**

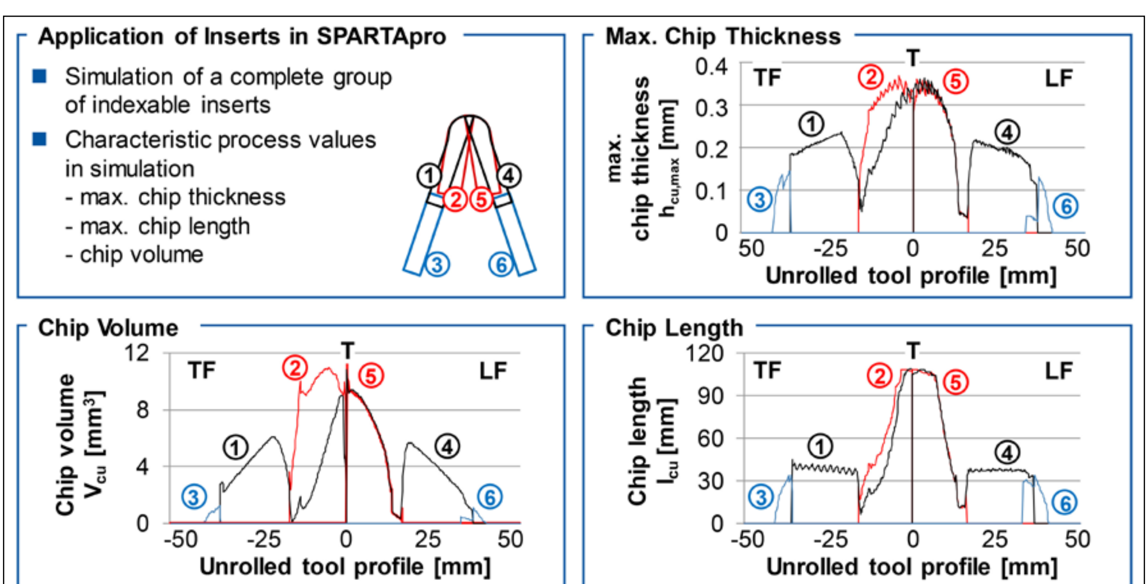

Figure 10 **Calculated characteristics values.**

working angles. The working angles occurring during the process through the variable velocity components along the cutting edge and the rotation angles of the hob can only be reasonably calculated by means of computer support. *SPARTApro* was further developed in order to calculate the working angles along the cutting edge. In the software, the cutting edge is defined by individual points and the number of these points is specified in the *SPARTApro* interface. For each point at the cutting edge, the resultant velocity vector *V*, the normal vector *N* and the clearance normal vector *KN* are calculated (Fig. 11). The velocity vector gives the information regarding the direction of the motion of the point. The normal vector is localized perpendicular to the cutting edge, in the plane of the rake surface. The clearance normal vector is perpendicular to the clearance surface. From the cross product of the normal vector and the clearance normal vector, the *Pne* plane is calculated. The *Pne* plane is the plane where the working clearance angle is measured. The vector *Pne* is perpendicular to the *Pne* plane, in the direction of the cutting edge. The cross product between *Pne* vector and velocity vector generates a plane called *Pse*. The *Pse* plane is tangential to the cutting edge, in the direction of the resultant velocity. With the cross product between *Pse* vector, the vector perpendicular to the *Pse* plane, and the clearance normal vector, the *Aα* plane is generated. The plane *Aα* and the clearance surface are localized in the same plane. The working clearance angle φ_{fw} is the angle measured between the *Pse* and the *Aα* plane in the *Pne* plane.

Analysis of the Working Tool Angle in Machining

The following section about the analysis of working angles during machining includes the description of these angles for each individual test point. The simulation with the software *SPARTApro* (Refs. 14–15) gives an estimation of the influence of the working angles on tool wear behavior. In addition, also presened is the scheduled simulation plan for further KL500/134-1 project developments.

Design of experiments. In order to investigate the influence of the working angles on the tool wear during hobbing, the simulation plan is shown (Fig. 12). The adjustment of the tool angles is performed through the relative velocity, shown in Equation 4 and the designed tool angles; the latter can be held in the tool. In order to cover a wide range of parameters it is necessary to vary the designed tool angles. At the starting point of the experimental plan the flank rake angle is $\sigma_f = 0°$, the clearance angle of $\varphi_f = 6°$ and a maximal chip thickness of $h_{cu,max} = 0.25$ mm. The values established in the experimental plan correspond to the current state of the art. From the base point the designed flank clearance angle φ_f is varied to 2°, 10° and 15°. The designed flank rake angle is varied in the range of -15°, -5°, 0°, 5°, 15°. The chip thickness plays a decisive role on the wear behavior of the hob (Refs. 16–18) and, therefore, a variation of the chip thickness is taken into consideration in the experimental plan. The values extend from the base point ($h_{cu,max} = 0.25$ mm) upwards to a maximum of $h_{cu,max} = 0.35$ mm and downwards to a minimum of $h_{cu,max} = 0.15$ mm. The gear considered for this experimental plan is a large gear with a module of $m_n = 10$ mm, number of teeth $z = 53$, helix angle $\beta = 10°$ and a pressure angle of $\alpha = 20°$.

In order to characterize the tests variants, characteristic values such as maximum chip thickness $h_{cu,max}$, average chip thickness $h_{cu,max}$, number of cuts and chip length are calculated with *SPARTApro*. These characteristic values are presented (Fig. 13) as a function of the unrolled tool profile. The curves of the maximum chip thickness have a peak beginning on the tip left flank of the tool. The maximum values are detected in the tip area of the blade for the respective values $h_{cu,max} = 0.15$ mm, $h_{cu,max} = 0.25$ mm and $h_{cu,max} = 0.35$ mm. In the right flank, the curve also drops from tip to root. In the curve for maximum chip thickness, the values of the left flank are smaller than the values of the right flank. It is expected that the variant with the maximum chip thickness of $h_{cu,max} = 0.35$ mm generates the most wear. The cutting forces increase with the increase of the chip thickness, inducing higher loads at the cutting edge.

The curves of the number of cuts

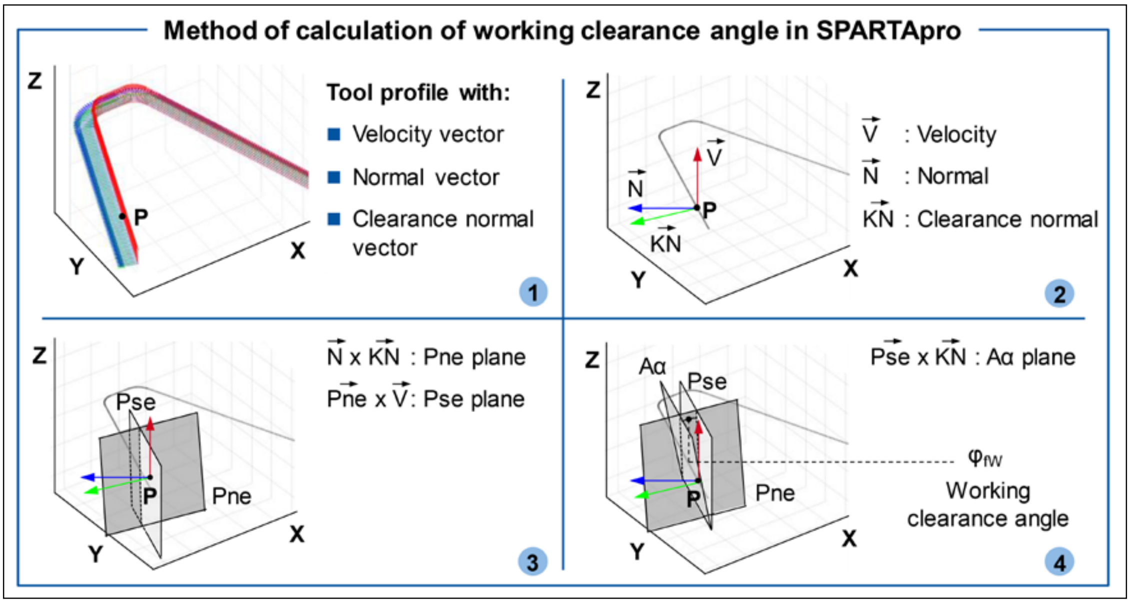

Figure 11 Calculation method of the working clearance angle in *SPARTApro*.

rise on the flank towards the tip. The maximum values are found in the transition area between the left flank and the tip, reaching the value of 27 cuts. In the tip area, the curves drop again, reaching values from 12 to 15 cuts. In the transition area between tip and right flank, the curves rise again.

Analysis of the working clearance angles. According to the experimental plan presented, the clearance angle is varied between the values $\varphi_f = 2°$, 6°, 10° and 15°. The designed clearance angle and the maximum working clearance angle calculated by the simulation are shown (Fig. 14). The clearance angle calculated for each case is plotted over the unrolled tool profile. The process parameters remain the same for all cases, such as a cutting velocity of $v_c = 120$ m/min, a maximum chip thickness of $h_{cu,max} = 0.25$ mm and designed tip rake angle of $\sigma_a = 0°$. In Figure 14 the designed clearance angle is represented by a dashed line while the working clearance angle is designated by a solid line. For the case with a designed clearance angle of $\varphi_f = 2°$ the working clearance angle on the left flank reaches the value $\varphi_{fw} = -3°$. In the tip area the curve for the working clearance angle reaches its maximum, which is identical to the designed clearance angle $\varphi_f = \varphi_{fw} = 20°$. In the right flank the working clearance angle is established in $\varphi_{fw} = 7°$. Thus, the maximum working clearance angle alteration for both left and right flank is the same — only in different directions. The negative value of the working clearance angle on the left flank causes the contact between the left clearance surface and the workpiece tooth flank surface. The resulting mechanical and thermal stresses generated in the tool clearance surface cause an increase of the tool wear.

The curves for the working clearance angle variation of $\varphi_f = 6°$, 10° and 15° are similar to the variation of the $\varphi_f = 2°$, but with a shift upwards according to the respective angle variation amount. The case of $\varphi_f = 6°$ shows a working clearance

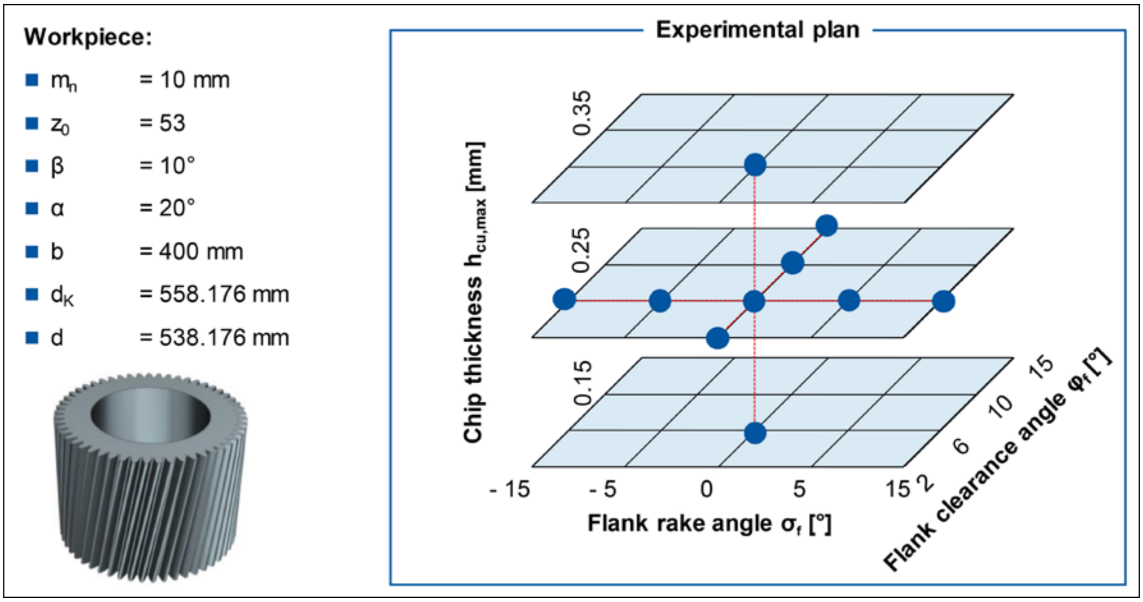

Figure 12 Workpiece and design of experiments.

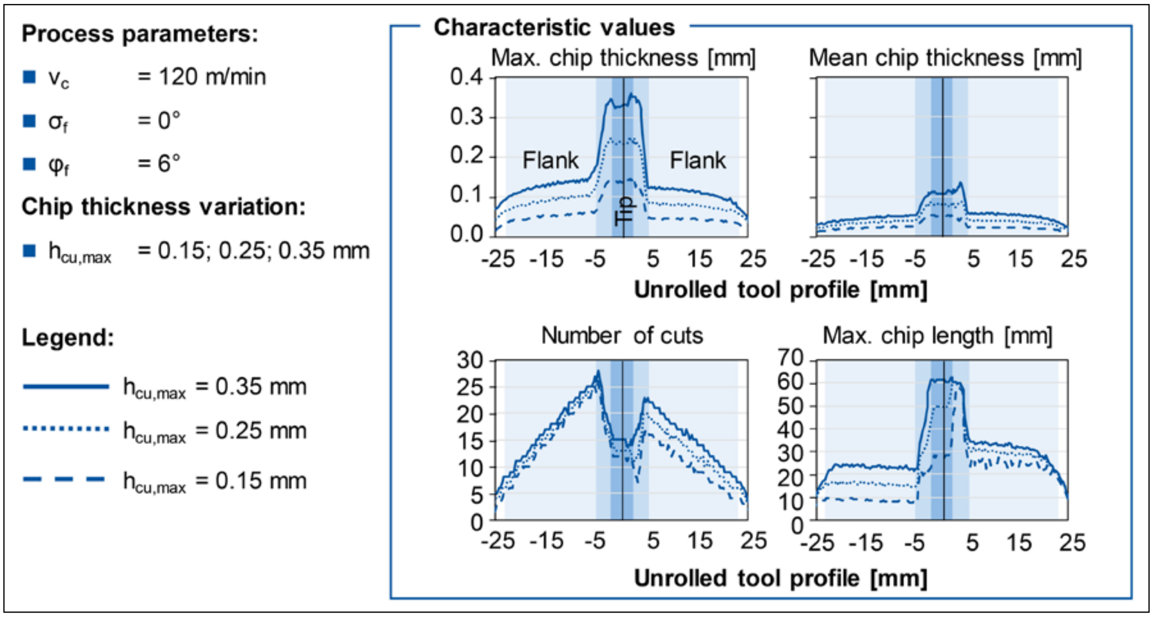

Figure 13 Calculated characteristic values with *SPARTApro*.

angle of $\varphi_{fw} = 1°$ on the left flank. A small clearance angle leads to a larger contact area and, therefore, an increase the heat flow to the tool substrate. The increase of temperature in the cutting process causes a progressive increase of wear (Ref. 3).

Analysis of the working rake angles. Figure 15 shows the designed and working rake angles for each case presented in the experimental plan for the rake angles. As already established in early diagrams, the designed rake angle is represented by a dashed line, while the working rake angle is a solid line. The process parameters used for the tests are the same used in the tests with the clearance angle. The designed rake angles vary between the values $\sigma_f = -15°$, $-5°$, $5°$ and $15°$. For all four variants, the designed flank clearance angle is established with $\varphi_f = 6°$ and the designed tip rake angle with $\sigma_a = 0°$. During the cutting process, the tool rake angles of the left flank are different from the rake angles of the right flank. The magnitude of the angles in both flanks are the same, but with an opposite sign. This characteristic is shown in the curve of the designed rake flank angle in Figure 15. For the variant $\sigma_f = -15°$, a minimum working flank rake angle of $\sigma_{fw} = -19°$ is established on the left flank during the process. The large negative rake angles lead to a skive during the cutting process. In addition, the cutting forces will increase and the following chip will be in contact with the rake surface, causing friction. Due to the large wedge angle of $\beta = 99°$, the cutting edge is strengthened.

The working rake angle in the tip area of the tool is $\sigma_{fw} = 0°$. In the transition areas between left flank and tip and between tip and right flank the working flank rake angle increases. The right flank exhibits a maximum working flank rake angle of $\sigma_{fw} = 22°$, which decreases the cutting forces. In this case, the cutting is sharper and the chip can flow away better from the tool. However, in the same time the wedge angle is reduced to $\beta = 69°$. Small wedge angles decrease the tool stability and can cause cutting edge breakage.

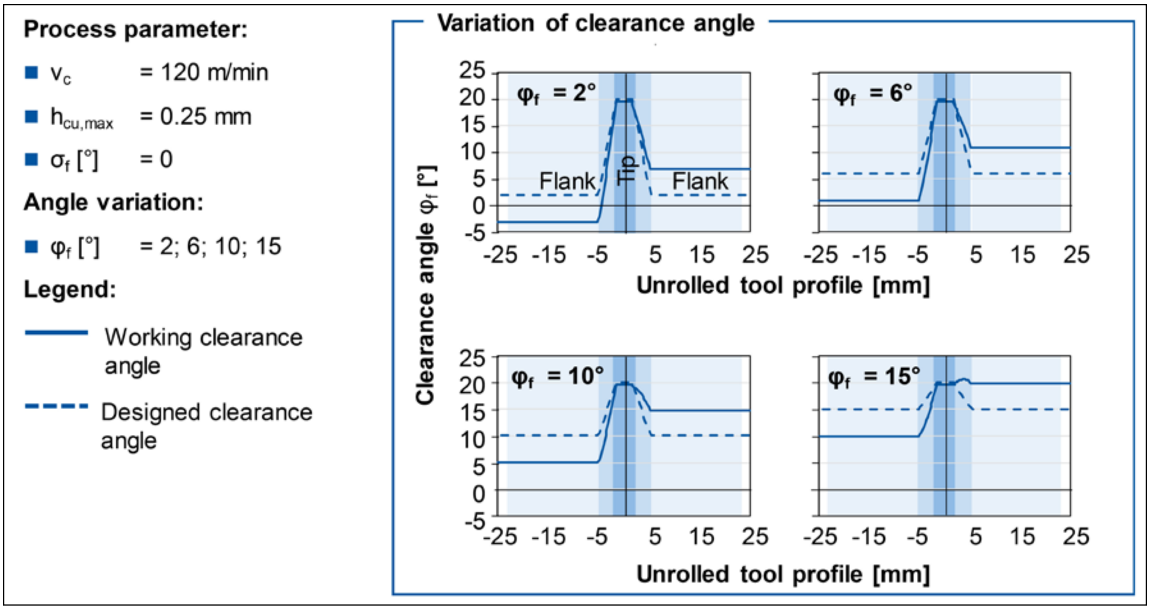

Figure 14 **Calculated working clearance angle.**

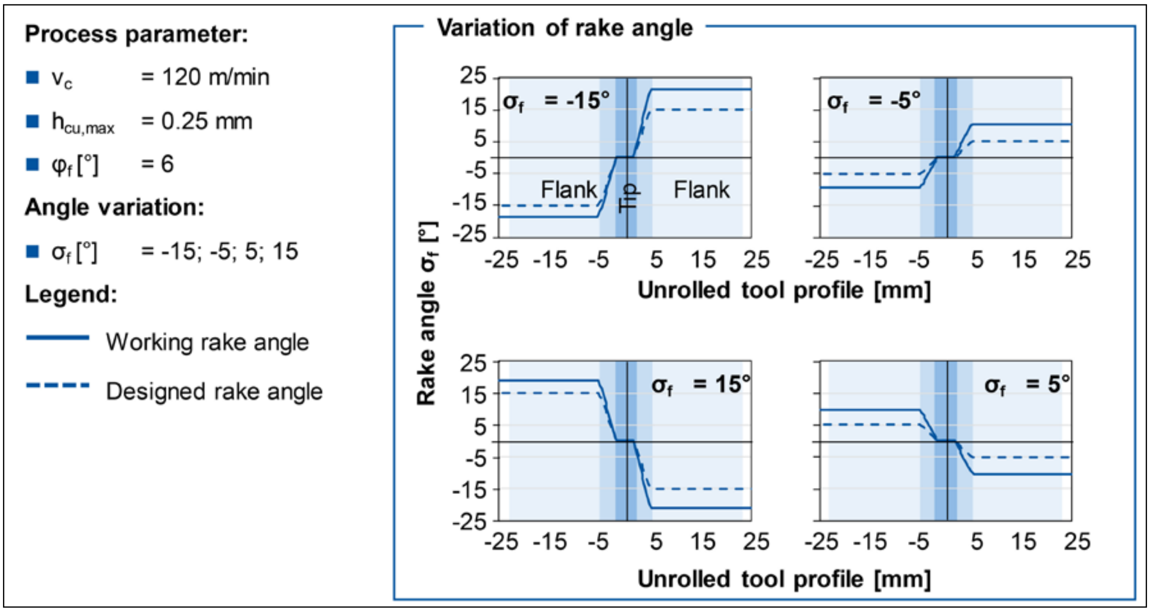

Figure 15 **Calculated working rake angle.**

For the case where $\sigma_f = -5°$, the maximum working rake angle on the left flank is $\sigma_{fw} = -10°$ and on the right flank the same angle is $\sigma_{fw} = 10°$. In order to be able to analyze the effect of the angle on both leading and trailing flank of the tool, the working rake angle is mirrored in the center of the tooth tip, as shown in the diagrams of $\sigma_f = 5°$ and 15°.

Summary and Outlook

In this report the working tool angles for an ideal cutting edge and a hob cutting edge were described and analyzed. For optimized hob design, the influence on the tool wear by means of working tool angles is important. Due to the variation of the velocity at the cutting edge and the tool rotation, the working tool angles can be determined only by computer-based calculations. For this purpose *SPARTApro* was further developed, now including a method that can calculate the working tool angles along the cutting edge. A test model was designed for the case of a large gear with a module of $m_n = 10$ mm. For the test model, an experimental setup was defined, in which the designed rake and clearance angles as well as the chip thickness were varied. The working tool angles were calculated for each point in the experimental setup and an estimation of the influence on the tool wear was given. As the design of tool angles has the highest degree of freedom for hobs with indexable inserts, *SPARTApro* furthermore was enhanced by a method for consideration of split tool profiles with overlap sections.

For further steps experimental tool wear investigations based on the test model are planned. Tools with the angles from the experimental setup will be used, and wear measurements will be performed in constant intervals. From these tests the influence of the working tool angles on the tool wear can be determined more precisely. The developed calculation method can be applied in the wear tests and can give a better understanding for wear phenomena.

Acknowledgement. The authors gratefully acknowledge financial support by the German Research Foundation (DFG) [KL 500/134-1] for the achievement of the project results. The authors gratefully acknowledge financial support by the WZL Gear Research Circle for the achievement of the project results with regards to the enhancement of *SPARTApro*.

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Prof. Dr.-Ing. Dr.-Ing. E.h. Dr. h.c. Dr. h.c. Fritz Klocke began his distinguished career (1970–1973) as an apprenticed toolmaker while at the same time pursuing his production engineering studies at Lemgo/Lippe Polytechnic, and later (1973–1976) at Technical University Berlin. He then (1977–1981) went on to serve as Assistant at the Institute for Machine Tools and Production Engineering, Technical University Berlin. Starting in 1981, Klocke achieved or received the following academic credentials and awards: Chief Engineer; (1982) Doctorate in engineering; (1984–1994)employed at Ernst Winter & Sohn GmbH & Co., Norderstedt; (1984) Head of Process Monitoring; (1985) Technical Director, Mechanical Engineering Department; (1985) Awarded Otto Kienzle Medal by the Universities Production Engineering Group; (1995) Director of the Chair of Manufacturing Technology at the Institute for Machine Tools and Production Engineering (WZL) of the RWTH Aachen, and director of the Fraunhofer Institute for Production Technology, Aachen; (2001–2002) Dean of the Faculty for Mechanical Engineering; (2006) Honorary Ph.D. by the University of Hannover; (2007–2008) President of the International Academy for Production Engineering (CIRP); (2009) Honorary Ph.D. by the University of Thessaloniki; (2010) Honorary Ph.D. by the Keio University; Award of Fraunhofer Medal; (2012) Fellow of the Society of Manufacturing Engineers (SME); (2014) Eli Whitney Productivity Award (SME); and (2014) Fellow of RWTH Aachen University.

Globalization's Effect Upon Gear Steel Quality

Background on development of high-speed, automatic hardness tester

Aizoh Kubo

Introduction

Globalization continues driving the world economy — with deterioration of gear steel quality as one of its ramifications.

In this presentation, examples of gear failure are shown and gear material problems are introduced.

For example — it is difficult today for companies to confirm the real quality of purchased gear steels because their gear engineers are not metallurgists and therefore do not have the time — nor money — for that inspection. To address the quality issue regarding purchased steel, we have developed a new tester for measuring thousand-points hardness — automatically — and in quick order. Examples of quality evaluation of some steels with this tester are introduced here.

As a gearing troubleshooter, I feel that the probability of material problems causing gear failure have increased since globalization of the world economy. The deterioration of gear steel quality is the rational result of globalization because purchasing departments of machine companies typically look for the cheapest choice among the same mill-certified steels around the world. The usual question from the purchasing department regarding gear material is, "Why do we pay so much money for the same steel? There is much cheaper steel of the same kind in the world."

Gear steel prices enter the market today amid fierce competition between industrialized countries and other emerging players. Similar to gear engineers not being metallurgists, purchasing agents are typically not mechanical engineers. Nor, for that matter, is a company's top management, who severely cut production costs. As opposed to obtaining available steel of top quality, the nominal-quality steel is received by the standardized steel name and bearing a mill test report (mill inspection certificate). In today's competitive atmosphere "expensive" — but high-quality — steel can barely make it to market. There are also some cases where steel quality somehow changes for the worse after the purchasing contract was signed. The reliable checking of steel quality requires solid metallurgical knowledge, time, and money, rendering users' prompt checking of gear steel quality difficult. In Japan we have created a new-concept apparatus for quality evaluation of gear steels, for which some information is here introduced. I also intend with this presentation to help people understand that good quality costs money is why "it takes money to make money" — a universal fact.

High-Strength Gear Steel

In machine design textbooks the definite values of strength and endurance limits are always written for steel material to be used as machine parts, which imparts incorrect information to the green machine designer, i.e. — that the steel material is "homogeneous." An so there is nothing gained by informing them that steel is *heterogeneous* and thus contains a considerable amount of inclusions and foreign objects.

Figure 1 is an example of typical gear steel — a big naval bevel gear made from 18CrNiMo67 steel that incurred some mild scuffing, and the matrix material on the surface is slightly removed while inclusions appear on the tooth flank. Today, high-strength steel for gear manufacture is designed to disturb the movement of dislocation inside the steel matrix by distributing solid solution

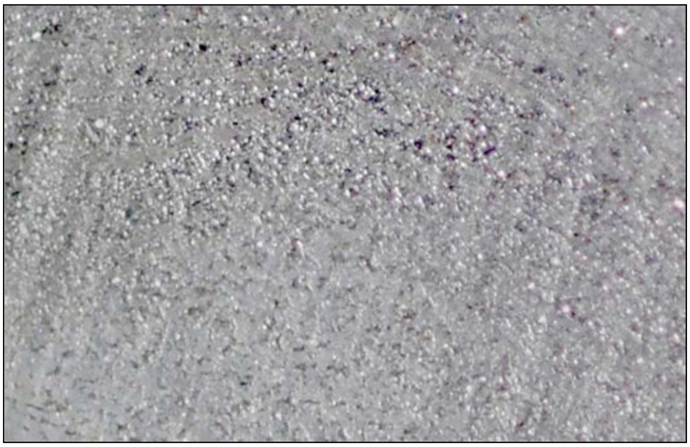

Figure 1 **Inclusions that appear on the gear tooth.**

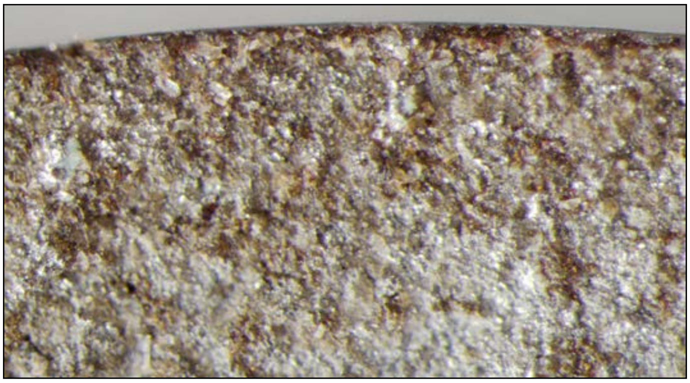

Figure 2 **Fracture section of case hardened CrMo steel bar specimen, after endurance test.**

This paper waqs first presented at the 2017 VDI Conference on Gears, Munich.

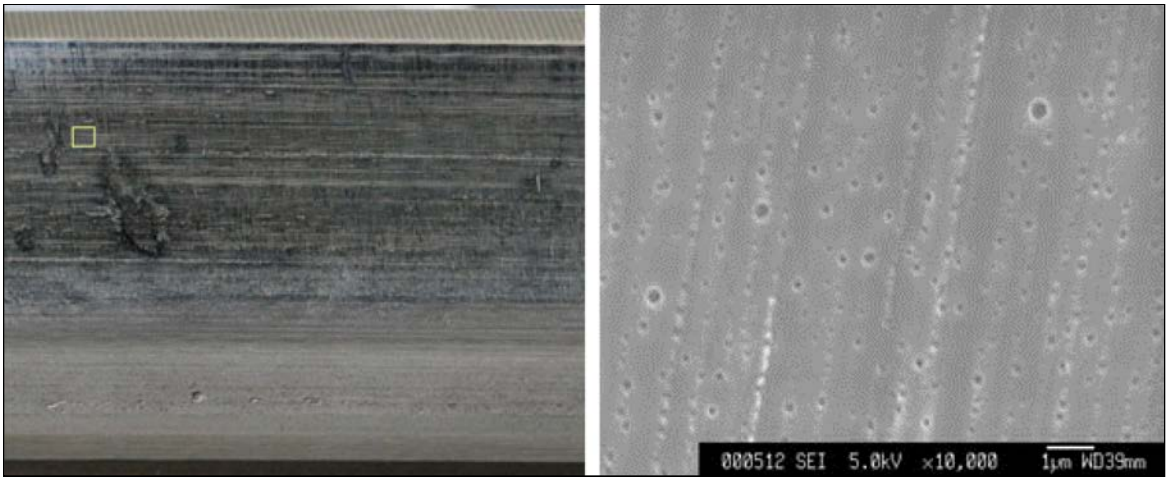

Figure 3 **Tooth flank after long heavy usage (left) and the observed SEM picture.**

and/or precipitating articles properly into the matrix. It is as if gear steel were a mixture of small stones in mud; thus it is never homogeneous, and stones in mud carry the load and resist wear.

Figure 2 shows another example — a fractured surface of a case-hardened steel specimen made from JIS SCN420H after bending-rotating endurance testing. You can see many black balls; those are precipitating particles to carry load. One common problem is that those particles are barely detected by conventional testing methods of steel quality before endurance testing.

Figure 3 (left) shows a failed tooth flank of a case-hardened, ground helical gear made from JIS SCM835 steel after long, heavy usage. (In Fig. 3, right) is the SEM picture of a still-healthy part of that tooth flank shown with rectangle frame in (Fig. 3, left). The SEM picture was made with replica and the dark spots are surely particles in the steel matrix. It is very strange that those particles align in lines of sliding direction between contacting tooth flanks. There are only two probable reasons for this: 1) the particles align by the plastic deformation of the steel matrix through strong frictional force due to slipping tooth flank contact; or 2) they were created during the gear operation by strong frictional heating. This shows that those hard particles in the matrix of high-strength gear steel carry considerable stress.

Production of Gear Blank

Today, most steel is produced via electric heating converter. Melted steel material is processed with continuous casting into a bloom bar. The sampling for elements-check for the mill certificate of this steel is usually taken from the melted steel in the upper stage of the production. During cooling, steel congeals and crystalizes. Crystal formation proceeds differently from part to part of the bloom material. Impurities in the melted steel gather more thickly at the center of the cross-section.

Figure 4 shows a macro-etched cross-section of a steel bloom obtained by cutting the bloom just after its congealed state in continuous casting production. There are many impurities, voids, etc. in the central part of the bloom. The steel bar that we usually use for gear production is made from such a bloom via the press-rolling process, which means that the steel texture remains almost the same as that of Figure 4. When the amount of discarded steel reduces to help offset economical steel production cost, some amount of agents for refining — like Al, Si etc. — remain in final-state steel bar available on the market. Figure 5 shows a cross-section of a CrMo steel blank of 800 mm

Figure 4 **Cross-section of steel bloom just after congealed state in CC production.**

Figure 5 **Macro-etched figure of a cross-section of CrMo steel bar of 800 mm diameter.**

diameter for gears. Around the center of the blank, segregated impurity and voids are distributed in circular fashion. Each part of the segregation has considerable length in the axial direction of the blank. Figure 6 shows a macro-etched figure of rectangular CrMo steel slab of 500 mm side length. The left edge is the surface of the rectangle slab, and ca.⅛ from the right edge is the center of the slab. It is clear that the state of crystallization and impurity distribution at both the periphery and center of the slab are different. Surely the strength or the durability of the material is considerably different at the peripheral or middle of the cross-section and at the central part. But the gear designer calculates the load-carrying capacity of gears using the same value for the material strength that is typically indicated by the specification of the steel.

The gear blank of an internal gear has more serious problems because the gear blank takes ring form, which means that the internal gear teeth are made at the central part of the original steel slab, where much segregation, etc., exists. Figure 7 (left) shows a cross-section of a blank piece for a large internal gear; this figure is digitally treated to increase the contrast. The upper side of (Fig. 7) corresponds to the central part of the slab, i.e. — the part to be toothed. To ring form the gear blank the central part of the original slab is punched to create a hole from both front and reverse sides. You can see the state of plastic flow of the material: the twisted figure of segregation curves. The internal gear made from this gear blank operated for several years before suffering from a strange surface failure (Fig. 7, right). This gear was not case-hardened; it was a so-called "soft" gear. But the cracks observed on the tooth flank look very brittle. The run of cracks corresponds to the plastic deformation flow curves inside the gear blank, along which the material contains much segregation. Surely the cause of this surface failure has a strong correlation with the steel quality.

Figure 8 (left) shows the fracture surface of a case-hardened SCM420H steel bar specimen; a test was conducted (Ref. 1). In the cross-section a great deal of hard-to-explain segregation is observed. The test piece was cut at 2 mm; a partial specimen from this fractured section was polished and nital-etched; the (Fig. 8, right) figure shows the result. The figure appears here in the same angular position as the (Fig. 8, left) figure. In observing this etched surface it is difficult to determine that this specimen contains such a robust segregation

Figure 6 **Macro-etched figure of 500 mm rectangular CrMo steel slab made by rolling.**

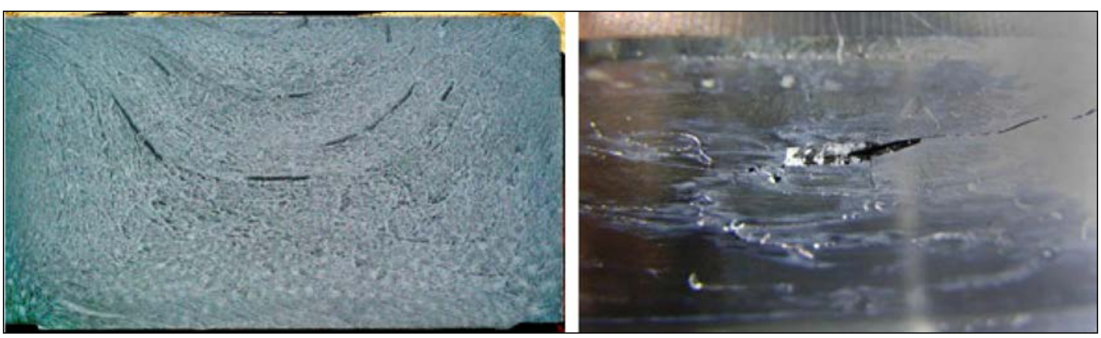

Figure 7 **Plastic flow and segregation remained in the cross-section of a blank for big internal gear.** **Induced tooth flank failure.**

Figure 8 **Segregation found in fatigue fracture surface and the polished and etched figure.**

Figure 9 Cluster forming of impurity particles in gear steel.

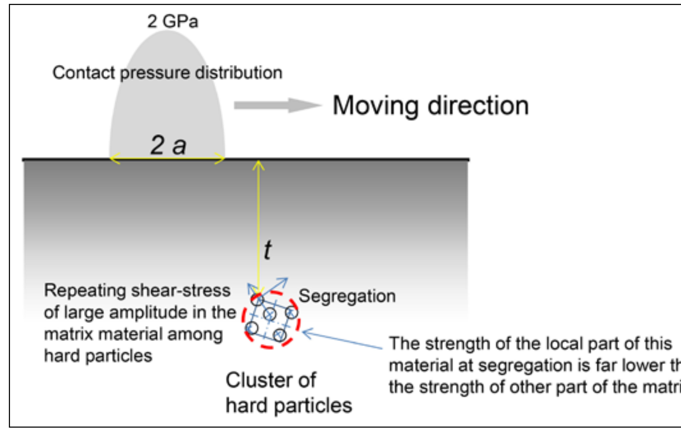

Figure 10 Possible micro crack initiation in a cluster of inclusion.

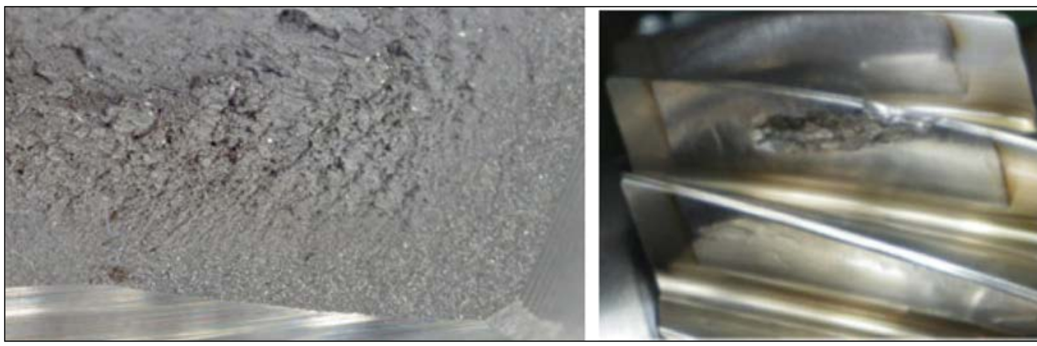

Figure 11 Cluster of impurity particles just under the tooth flank. Sudden spalling of tooth flank.

in material texture. This is a very serious problem in that qualified mechanical engineers could not determine steel quality via accepted etching methods.

Material-Induced Gear Failure

As previously mentioned, the steel material is *designed* as homogeneous — but is actually heterogeneous and contains a considerable amount of inclusions. Foreign objects — small, hard particles in the steel matrix — work in part to strengthen the material. To do so the foreign objects must be small and distributed uniformly within the material. In actual steel material, however, it is not easy to realize such a homogeneous state.

Figure 9 shows an example of an undesirable state of existence of impurities in steel matrix, i.e. — they gather and form a cluster. Also in this material some thin layers of MnS exist (Fig. 9, lower right). You can see the oblique ridges of material in the fractured section. When a cluster of hard particles exists in the material, just beneath the surface, and the surface is loaded with heavy contact, the state of shearing stress induced between the particles in the cluster differs from that of homogeneous material. The shearing stress between hard particles in the cluster becomes higher than normally induced stress value (Fig. 10), and micro-crack can initiate there rather easily. Such micro-cracks are thought to be a trigger for the development of *macro*-crack, which leads to the fracture of, for example, gear teeth. Figure 11 (left) shows a fractured surface of gear tooth broken in the endurance test. In (Fig. 11, lower left) a cluster of impurity particles is found just under the tooth flank. A helical gear was made from the same material, of the same lot, and an endurance test was conducted under the maximum contact pressure of 2.3 GPa. Until 3×10^7 loading cycles, all tooth flanks showed no sign of failure initiation. At 3.7×10^7 loading cycles, there appeared suddenly a big and deep spalling of tooth flank. On the bottom of the crack cavity a cluster of foreign objects was observed. Other tooth flanks of this gear are all OK and look quite healthy. There is no sign of surface failure (Fig. 11, right).

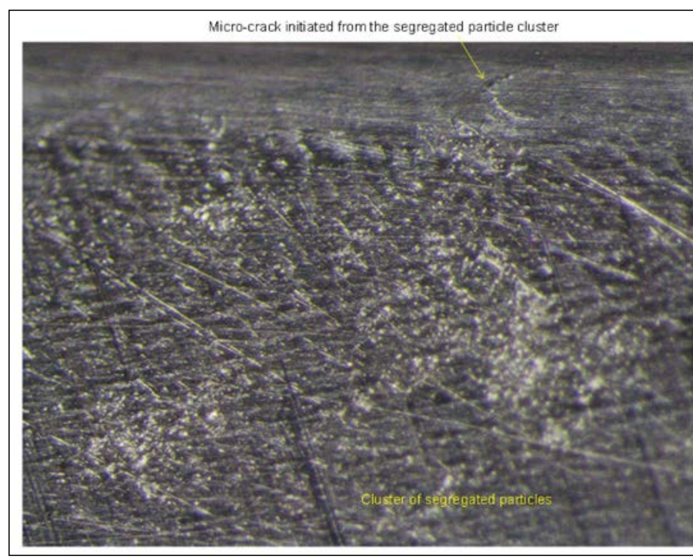

Figure 12 Cluster of impurity particles appeared on tooth flank from which a fatigue crack initiated.

On another tooth flank of the same gear, a cluster of impurity particles was found on the surface of the tooth flank (Fig. 12); a fatigue micro-crack initiated from that impurity cluster.

Summing up the above — the existence of impurity clusters can be a cause of serious tooth flank failure that can lead to tooth breakage. To evaluate gear steel quality, we should pay much more attention to checking for the existence of impurity clusters.

Detailed Measurement of Steel Hardness

We know of course that the hardness of steel is synonymous with strength. We usually use hardness measurement to evaluate heat treatment to find whether the process is carried out properly or not. At measurement when light loading is used, the scattering of measured data becomes extensive. To obtain a stable result, rather larger loading is typically used. When considering the nature of steel texture — consisting of crystals and some inclusions — it is heterogeneous. Then the scattering of measured hardness values must have some meaning, when the measurement is carried out accurately. To address this issue a high-speed, automatic hardness tester has been developed as a joint project of JGMA (Japan Gear Manufacturers Association) and RIAS (Research Institute for Applied Sciences), with the financial support of the Japanese Ministry for Economy, Technology and Industry. In Figure 13 we see a test piece for the measurement. The material is annealed carbon steel JIS SK4, and the surface is mirror-like-polished with a roughness of Rz = 0.07 µm. The surface to be measured cannot reflect light into camera; the lighting is peripheral and the surface looks black. The entire surface looks uniform and the steel quality looks perfect. The dotted horizontal band in the diagonal position of the specimen is the trace of 1,200 points of Hv measurement. With 50g loading and each 3 seconds steady loading time, the measurement took 86 minutes (Fig. 14). In the region near the center of the specimen, an abnormal situation is clearly observed that must be material-related, but its indication has never been found.

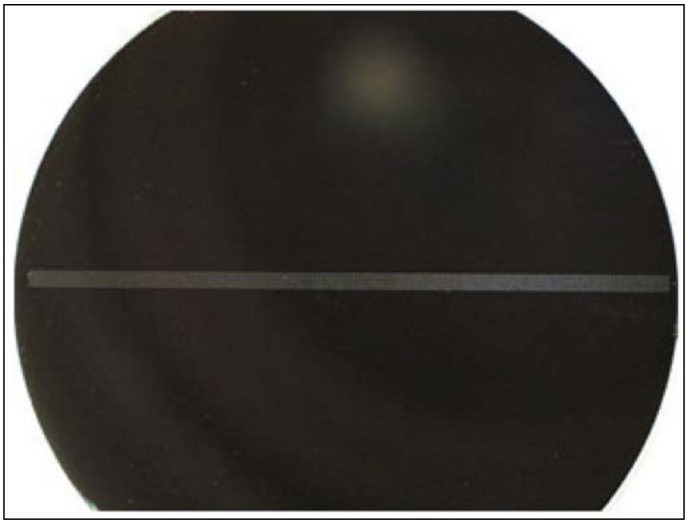

Figure 13 Specimen for hardness measurement.

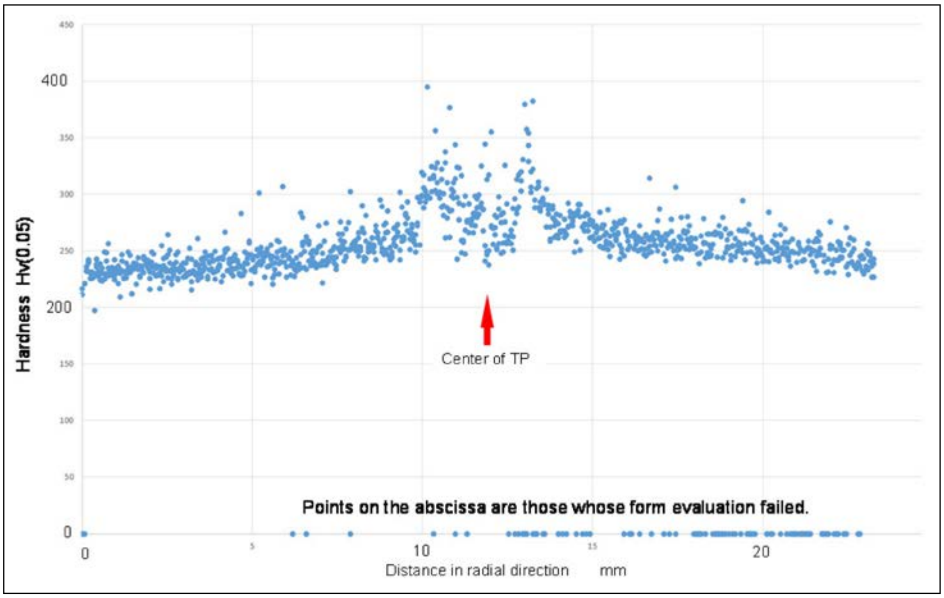

Figure 14 Measured Vickers' hardness value distribution.

To determine the cause of this measured result of probable material problems, the specimen was aggressively macro-nital-etched. The roughness of the etched surface becomes Rz = ca. 4 µm. Near the center of the specimen a dim, circle-like figure appears. This position corresponds well with the state of hardness distribution in Figure 17. This indicates the probable existence of segregation in this bar steel material. The large number of hardness tests with rather smaller loading appears to be a good method for identifying material quality problems.

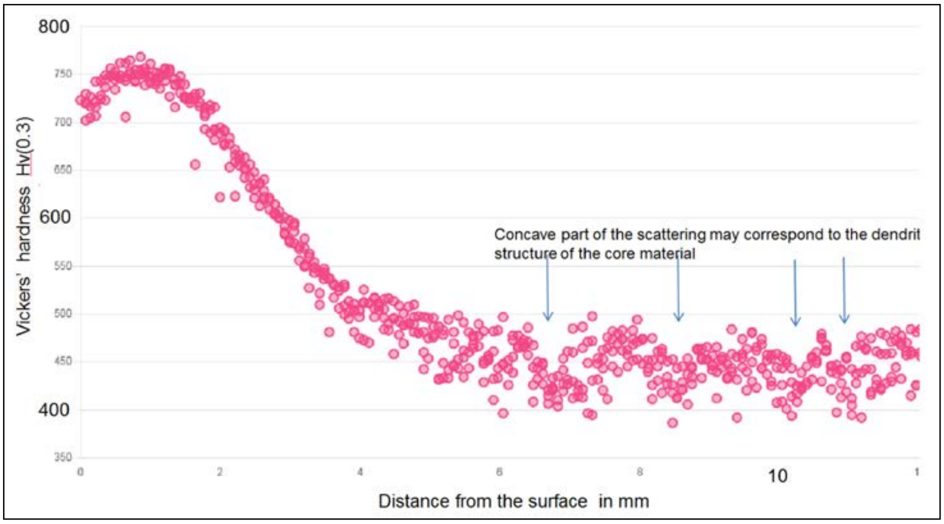

Figure 15 Case hardness of carburized gear tooth.

Figure 15 shows a measured hardness of a case-hardened, big bevel wheel tooth at 600 points. It is clearly observed from the rather wide scattering band of hardness in the right part of the figure that the texture of the core is constructed with different kinds of steel crystals. But in the hardened case the scattering band becomes narrow,

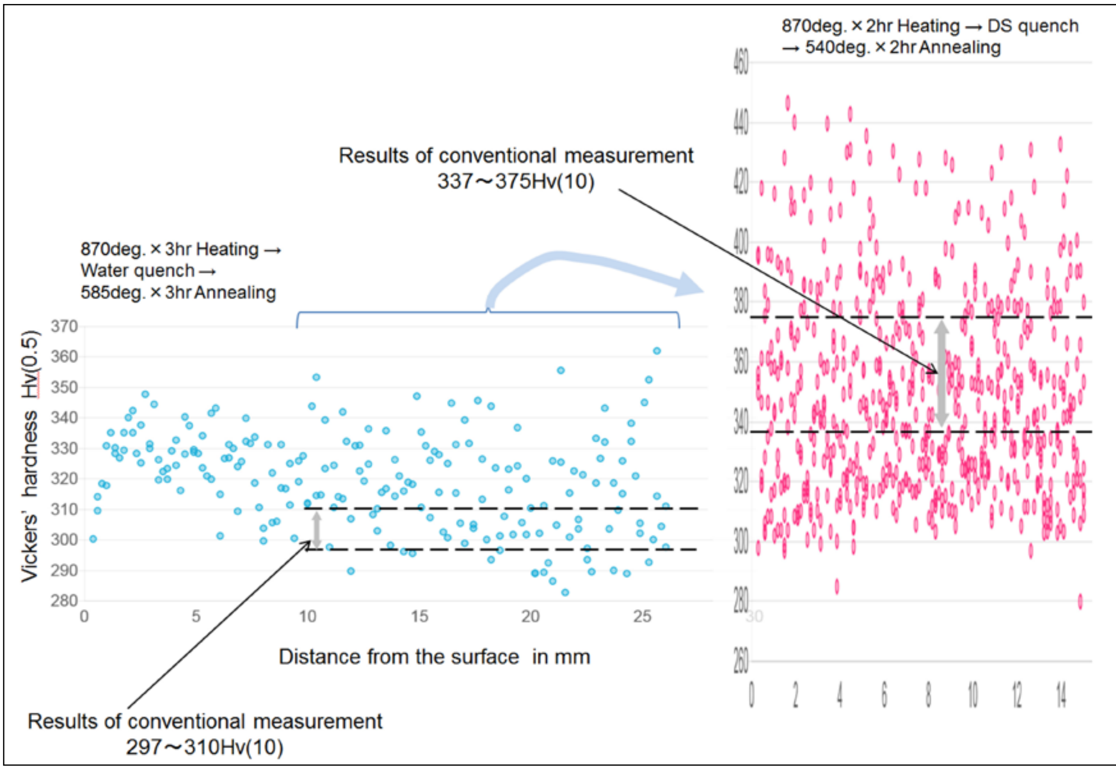

Figure 16 Difference of hardness as function of the loading value at measurement.

indicating that the kind of constructing crystals is focused. Near the tooth flank surface the hardness drops — perhaps due to the escape of carbon.

Figure 16 shows the hardness of JIS SCM435 steel after two different quench and tempering processes; both test pieces were made from the corresponding position of the same steel block. The hardness was measured with the conventional method using constant load 10kg. The hardness of the 2-hour-processed specimen is Hv337-375, and that of the 3-hour-processed is Hv297-310, where the kind of cooling media was different. The test surface was then hand-lapped carefully for smoothness and the hardness was measured with 500g loading at many points over the same part of the specimen. It clearly shows that the hardness measured with light loading has wide scattering. We can see that this wide scattering band of hardness values is compressed to narrow band, when large loading is incorporated; very local high hardness values cannot be measured and vanish. It is important to find the high-hardness inclusion and its state of distribution in the matrix because local hard material in the texture could induce very local initiation of micro-crack in the neighboring, soft part of the texture.

Such important information concerning steel quality is lost when we incorporate large loading at hardness measurement. It is perhaps better to measure the hardness at as many points as possible using rather light loading, and to evaluate the scattering distribution of the hardness. Such a method can produce a lot of information about steel quality, in comparison with the evaluation based on a rather small sample size of hardness values under heavy loading. Incorporation of heavy loading at hardness measurement means that the operator puts a high-cut mechanical filter on that measurement.

Conclusions

With globalization of the world's economic structure, gear steel quality can no longer be guaranteed using last-century testing methods. The result is "garbage in — garbage out."

Segregation, impurities, etc. remain in the material and do not disperse well in the material; they often gather together and cluster; and the crystal structure of the material becomes lamellar. All of which impacts steel quality.

Hardness tests using heavy loading elicit high-cut-filtered information, including regarding material quality.

Hardness testing at many points using rather light loading and evaluating the bandwidth of the scattering distribution of measured data produces critical information about the steel quality. It is a proven method for identifying inferior-quality steel.

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Prof.hc.Dr.-Ing. Aizoh Kubo earned his degrees, including his 1971 Ph.D. (research on the dynamics of high-speed gearing), from Kyoto University. He subsequently served as guest researcher at the University of Stutgart (1972) and at FZG, T.U. Muenchen (1973). Kubo's professional/academic career began (1971–1979) as a research associate at the Kyoto Institute of Technology, followed by fifteen years (1979–1994) as associate professor at Kyoto University's precision mechanics department. From 1994–2007 he was a full professor in the university's department of mechanical engineering. Since 2007, Kubo began Gear Technologies Company (owner and president), was general manager of the Research Institute for Applied Sciences EV, and since 2009 has been president of Alchemica Co. Ltd.

Fraunhofer CMI Center for Manufacturing Innovation

FOCUSES ON NEW U.S. GEAR AND TRANSMISSION TECHNOLOGIES GROUP

MATTHEW JASTER, SENIOR EDITOR

Collaboration between the United States and Germany's gear industries has provided a wealth of knowledge, technology and gear research. For years there have been U.S. members in the WZL's Gear Research Circle or partnerships between Fraunhofer IPT with Fraunhofer Center for Manufacturing Innovation (CMI) in Boston. But geographic obstacles prevented WZL from providing the same quality of service to the U.S. market compared to its many partners in Europe.

"This led us to the decision to create a new gear and transmission technologies group in the U.S. at Fraunhofer CMI," said Marco Kampka, program manager at the Gear and Transmission Technology Group, Fraunhofer CMI. "This brings us closer to our U.S. customers, and also enables us to learn more about the challenges and needs of the U.S. gear industry. We strongly believe that this can be a mutually beneficial undertaking."

This group brings together Fraunhofer CMI with German partners from Aachen, Fraunhofer IPT and WZL. Kampka sees all the organizations as one unit in this venture with Fraunhofer CMI being the key interface and gateway to the U.S. gear industry.

"This enables us to operate in the U.S. market without dealing with the spatial distance, the time difference or currency fluctuations. We will be offering all of our well-known services relating to gear design, analysis, simulation, consulting and education directly in the U.S. and execute all the projects with the support of our experienced partners WZL and IPT in Germany," Kampka said.

This new venture began with the first training course "Fundamentals of Gear and Transmission Technology" in December 2017—a course that will also be offered in 2018. This compact training course gives an overview that examines gear manufacturing, gear design and running behavior. Kampka says that the group is currently developing an extended version of this course going further into detail and being more beneficial for experienced engineers.

"If a company is looking for a custom training solution, we are open to discuss options as well. Additionally, we already started cooperating with U.S. companies on different topics in gear technology to improve their gear designs and manufacturing processes. We have a lot more in the making and it will be an exciting year in 2018," Kampka said.

During the first months of this venture, the Gear and Transmission Technology Group entered into dialog with as many companies as possible to assess the needs of the U.S. gear industry on the one hand and to get feedback regarding the group's U.S. expansion on the other hand.

"The feedback we received so far was without exception extremely positive," Kampka said. "I would like to invite all U.S. gear manufacturers to contact us when facing new challenges, and we will do our very best to assist them and provide the quality of service that we've been providing our European customers for many years."

Kampka's journey to the United States began with one of the most common career paths at WZL in Germany. "As an undergraduate studying mechanical engineering at RWTH University Aachen, I came in contact with WZL in 2008 and started working as a student worker at the WZL gear department. From that point on gears became my passion. After receiving my engineering diploma in 2012, I became a research assistant at WZL focusing on hard machining and surface integrity of gears. In July of 2017, I defended my Ph.D. dissertation 'Locally Resolved Cutting Forces in Gear Honing' and two days later I got on a plane to the United States. The timeline of this project matched perfectly and was in part a lucky coincidence for me personally," Kampka said.

Coming from WZL and Fraunhofer IPT, both world-leading institutes in academic research in their fields, Kampka feels the group has a responsibility and duty to perform up to the high standards they are known for. The group's mission is to become the number one provider of the latest and most innovative gear related content available both in bilateral research services as well as in education.

For 2018 and beyond, the Gear and Transmission Technology Group will examine many of the new technologies that the gear industry has been discussing in recent years.

One of the topics already being addressed is E-Mobility. Due to the elimination of the masking sound emitted by the combustion engine, noise behavior of high speed transmissions is one major research topic. This is challenging for both, design and production.

Another topic on the agenda is Industry 4.0 or Industrial Internet of Things (IoT). "The concept behind that is still a little bit too obscure for a lot of people, but in the long run it will be an enabler for productivity increase in any high wage country and industry. This is one of the reasons why we are constantly improving the capabilities of our virtual process chain, which is one of the keystones of Industry 4.0," Kampka added.

3D-printing and other near net shape processes like powder metallurgy are also of interest for the Gear and Transmission Technology Group. Both will bring new materials and the gear industry will not be constrained to the same geometries as in conventional process chains. This will open a much wider playground for gear research, according to Kampka.

"There are enough interesting challenges to overcome for both the U.S. gear industry and the rest of the gear world in the future," Kampka added. (*www.cmi.fraunhofer.org*)

Diablo Furnace

APPOINTS COO

Sue Harrod was recently appointed to C.O.O. of Diablo Furnaces LLC, a company manufacturing, refurbishing, upgrading, servicing and supplying parts for atmospheric heat treating equipment. Harrod has worked within the thermal processing industry for 25 years in supporting and leading roles at BeaverMatic, Ipsen International, and Diablo Furnaces. With her passion and exemplary leadership capabilities, Ken Flowers and Ron Peiffer, owners of Diablo Furnaces LLC and Machine Tool Builders (MTB) have appointed Harrod to this position. Please congratulate and support Harrod in this expanded role in the heat treating industry. (*www.diablofurnaces.com*)

Forest City Gear

EARNS WOMEN'S BUSINESS ENTERPRISE CERTIFICATION

Forest City Gear has successfully met the Women's Business Enterprise National Council's standards for certification as a Women's Business Enterprise.

WBENC National WBE Certification validates that the business is owned, controlled, operated, and managed by a woman or women. To achieve WBE Certification, women owned businesses complete a rigorous documentation and site visit process. WBE Certification is an important accreditation recognized by hundreds of WBENC Corporate Members and government agencies, including most major US corporations and federal, state and local government entities.

"Supplier diversity is an increasingly important aspect of the procurement process that Forest City Gear is involved with in the industries we serve, and the WBE Certification gives us critical recognition," says Forest City Gear President and CEO **Wendy Young**. (*www.forestcitygear.com*)

Gear Motions

ANNOUNCES RETIREMENT OF SAM HAINES

Samuel R. Haines has retired from his position as CFO of Gear Motions, Inc. effective at the end of 2017, following 44 years of service.

In 1973 Haines was in graduate school and in search of a thesis topic to complete his MBA at Babson College in Wellesley, MA. As fate would have it, his father was in need of business plan for a bank loan for a small gear manufacturing company that he had acquired a few years earlier. Thus, as they say, was the trap set.

Following graduation and in the midst of the `73 "oil recession" Haines signed on (temporarily) to help work through the newly formed Gear Motions' first acquisition of Oliver Gear in Buffalo, NY.

Still on "temporary assignment" in 1980, Haines and his family moved to Syracuse, and he assumed the management of the recently acquired Nixon Gear as VP/GM. Shortly thereafter he was named president of Gear Motions in 1985 when his father was diagnosed with pancreatic cancer.

In 2005, in anticipation of his eventual retirement, he began the sale of the company through the establishment of an Employee Stock Ownership Plan (ESOP) and became chairman and CFO. This created a 10 year financial plan for transferring 100% ownership of the company to its employees, assured that the company would remain at its current location and viable for many years to come, and created a phased financial transition for the owners.

Under Haines leadership, the company won numerous awards including the 1999 Donlon Award for Employee Centered Practices and many customer awards for outstanding performance, among them the UTC Supplier Gold Award, Carrier Q+ Certified Supplier Award and Eaton Certificate of Excellence.

He has always been active in the community and industry. He served on the American Gear Manufacturers Association (AGMA) board of directors from 1988-2000, and was chairman of the board from 1998-1999. He was a member of the AGMA Foundation Board from 1999-2006. In 1993 he received the AGMA's highest honor, the E.P. Connell Award, and in 1997 The Board of Directors Award.

Locally, Haines has served on the board of directors of the Manufacturers Association of Central New York (MACNY) since 1989, Chaired the Factory Managers Council from 1985-1988 and was Chairman of the Board from 1995-1997. In 2006, he was recognized for his distinguished service to manufacturing in Central NY and named to the MACNY Wall of Fame. He plans to continue in his role as chairman of the board of directors for Gear Motions, until at least the end of 2018. (*www.gearmotions.com*)

Kapp

ANNOUNCES SERVICE MANAGER PROMOTION

Kapp Technologies recently announced the promotion of **Johannes Hoehn** to service manager. In his new role, Hoehn will lead service and parts efforts to ensure and maintain customer satisfaction.

He joined the Kapp Niles group in 2000 as an industrial technician in Coburg, Germany. In 2012, he relocated to Kapp Technologies in Boulder, Colorado together with his family. Since relocation, Hoehn has been supporting the Kapp Technologies team as a service technician. This position allowed Hoehn to strengthen his subject-specific knowledge while deepening the relationships to customers.

"Close contact with our customers paired with high-quality technical support was my philosophy as a service technician. I'm excited to bring in these aspects among others in my new role as service manager," said Hoehn.

The service manager role has been handed over to Johannes by Michael Kapp, who pursues new challenges together with his brother, Matthias Kapp, both filling the position as management assistant with Kapp Niles in Coburg, Germany.

Kapp Technologies would like to thank Michael Kapp for his support as service manager and wish him all the best in his new position. (*www.kapp-niles.com/usa*)

March 6 — Lean Six Sigma Strategies for the Job Shop Environment Naperville, Illinois. Lean Six Sigma has become a widely used methodology in manufacturing for reducing waste without sacrificing productivity. But for job shops, with their unique characteristics and needs, special considerations and strategies must be taken into account for optimal implementation of Lean Six Sigma in these environments. When considering the implementation of Lean Six Sigma in a job shop environment, the use of several key strategies is critical. Failing to utilize these strategies can result in less than ideal outcomes. This one day seminar from Arvin Global Solutions will examine the strategies for implementation of Lean Six Sigma in the job shop – featuring case studies and methods for success. Those that will benefit from this seminar include company owners and executives, managers and supervisors and members of an organization's improvement team. By learning about strategies for effective implementation specific to the job shop, attendees will be provided with methods to improve the Lean Six Sigma efforts in their facility, meaning less waste and improved productivity and profitability. For more information, visit *www.arvinglobalsolutions.com*.

March 7–10 — The Manufacturing Meeting 2018 Miami, Florida. Hosted by two major manufacturing trade associations, AMT—The Association For Manufacturing Technology and National Tooling and Machining Association (NTMA), The MFG Meeting brings together the complete manufacturing chain for a unique conference experience. This event provides unparalleled opportunities to network with industry leaders and the agenda topics are designed to address key business challenges and provide actionable solutions. The event is intended for senior leadership, executives, vice presidents, senior sales directors, manufacturing technology's builders, distributors and end users. Learn about the future challenges and opportunities facing the American manufacturing industry, discover new ideas and participate in interactive discussions. For more information, visit *http://mfgmeeting.org/*.

March 12–15 — PCI Powder Coating 2018 Indianapolis, Indiana. This four-day event will kick off with the Technical Conference and Tabletop Exhibition on Monday & Tuesday, March 12 & 13, closing on the morning of March 14. Complete with general sessions and concurrent technical programs, attendees will have access to a variety of powder coating information as well as personal interaction with suppliers. The tabletop display area will feature powder coating manufacturers, powder coating application equipment, system houses, chemical suppliers and various services that support the powder coating industry. For more information, visit *www.powdercoating.org*.

March 14–15 — Innovations in Bevel Gear Technology Aachen, Germany. This WZL Aachen event will examine topics and trends in bevel gear technology that are presented and discussed in this special-interest seminar which is well established among the international technical community. Nowadays customers require high performance bevel gears. Within this seminar current developments of design and calculation processes are introduced. Furthermore the new inventions in bevel gear production and quality inspection will be presented. The seminar gives an overview about the state of the art. Current problems in bevel gear production will be discussed in preparation for future research and developments. This conference will be offered with simultaneous translation into English. Instructors include Christian Brecher, Fritz Klocke and Christoph Lopenhaus. Contact WZLforum for additional information at *https://wzlforum.de*.

March 20–21 — Fundamentals of Gear and Transmission Technology Brookline, MA. This two-day course located at Franhofer USA CMI will examine the basic properties of gears as machine elements, gear manufacturing technologies, methods for quality control, as well as testing and analysis of load carrying capacity and running behavior. The course focuses on methods of interpretation, analysis and solving challenges in the design, manufacturing and application of gears. This course is "geared" towards designers and manufacturing engineers working in gear and transmission technologies, as well as for shop floor and department managers involved with the production and sale of gears and gearboxes. The $1,495 fee includes all seminar materials, lunches and dinners. The U.S. Gear and Transmission Technologies Group brings together Fraunhofer CMI with German partners from Aachen, Fraunhofer IPT and WZL. For more information, visit *www.cmi.fraunhofer.org*.

March 20–22 — Gearbox CSI Concordville, PA. Gain a better understanding of various types of gears and bearings. Learn about the limitation and capabilities of rolling element bearings and the gears that they support. Grasp an understanding of how to properly apply the best gear-bearing combination to any gearbox from simple to complex. Gear design engineers, management involved with design, maintenance, customer service and sales should consider attending. Upon completion, attendees will be able to apply an undrestanding of forensic analysis of gearbox failures in future gearbox designs. Instructors scheduled include Raymond Drago and Joseph Lenski, Jr. For more information, visit *www.agma.org*.

March 20–21 — AWEA Wind Project Siting and Environmental Compliance Conference 2018 Memphis, Tennessee. The AWEA Wind Project Siting and Environmental Compliance Conference is where leaders from the wind industry, environmental permitting and compliance sector, the scientific community and regulatory officials come together for a robust discussion about the current state of siting and environmental compliance, and network. Take away key insights within wind energy development, operations, evolving trends, and strategies for improving the project permitting process and maximizing the output of operating assets while increasing regulatory and legal certainty. For more information, visit *www.awea.org*.

March 22 — A Study of Non-Destructive Testing, Surface Temper Inspection, and Barkhausen for Manufacturing Naperville, Illinois. Key inspections in the manufacturing process are essential for ensuring quality, meeting customer requirements, as well as regulatory compliance such as Nadcap. Having a solid understanding of these processes is essential for a number of roles in manufacturing – from inspectors and engineers to supervisors and operators. This AGS training course will provide an introductory overview of the common inspection procedures including, magnetic particle inspection, dye penetrant inspection, radiographic inspection, ultrasonic inspection and surface temper etch. The causes of the quality problems these inspections are used to identify will also be addressed. This course will also provide an opportunity to learn about the Barkhausen Noise Analysis Method for detecting surface defects in parts. With a better understanding of these processes, the attendee will be better equipped to understand the critical role of these inspection procedures and their impact on providing quality products. For more information, visit *www.arvinglobalsolutions.com*.

TEACHING TECHNICALITIES

40 years later, people are still learning basic gearing principles from Legos, and the internet is making the hobby community tighter and bigger than ever.

Alex Cannella, Associate Editor

Lego Technic isn't exactly new. The line of products actually just turned 40 last year. Technic kits have always differentiated themselves from their blocky contemporaries with a focus on additional parts such as gears, motors and axles to facilitate motion, and while the window dressing has changed over the years from the bulldozers and helicopters of yesteryear to the newest, coolest sports cars today, that core premise hasn't. For four decades, kids have been able to put together gear trains to operate cranes, cars, tow trucks and more.

And they've only gotten more complex over time, introducing pneumatics, programming and ever-increasingly powerful engines based on real brands of vehicles. But a Lego kit doesn't quite teach you the basics of gearing. Anyone can follow a guide to assemble a kit, but someone at Lego already did the work of measuring ratios, pairing gears, knowing the difference between a bevel and a clutch gear, etc. Lego Technic teaches the what, but not necessarily the how.

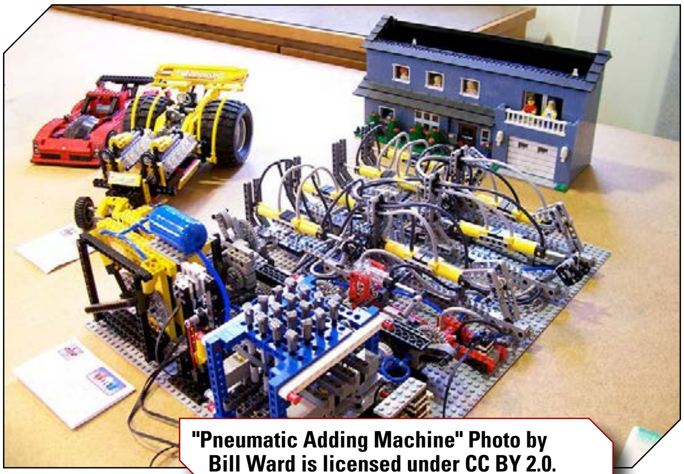
Luckily, the real fun with Legos is when you don't follow the script and build your own little creations with whatever parts are on hand. And when Technic gears get added to the mix, terms like torque you don't hear much outside the industry suddenly become a commonplace part of your kid's Lego lexicon.

It's a dialogue that's only grown over the years, what with the advent of the internet and, in the past few years, the solidification of YouTube and Facebook in the public consciousness. On YouTube, especially, dozens of tutorials explaining basic concepts like gear ratios sit side by side with compilations of fully functional, multi-cylinder engines designed from scratch.

And then, occasionally, you get a video like one in which Adam Savage of MythBusters fame assembles a custom, fan-made Lego kit and gets 4.5 million views.

That particular kit, an automata of Sisyphus rolling a boulder designed by Jason Allemann, is only a small portion of the custom creations community, where some of the creations get very, very involved. The Sisyphus automata, for example, features 1,350 pieces and is designed based on principles in a video put out by the Disney Research Hub about real life automata design called "Computational Design of Mechanical Characters."

Other designs that you can find online include fully functional versions of cars both real and fictional, a functional orrery, fully automated assembly lines and massive Rube Goldberg machines commonly referred to as "great ball contraptions," the longest of which takes 50 minutes to transport a ball across a room through a gauntlet of automated mechanical contraptions. The engineering complexity of some of these custom designs is only limited by one's creativity.


"Pneumatic Adding Machine" Photo by Bill Ward is licensed under CC BY 2.0.

Many of these creations are centered around a large fan community at rebrickable.com, a website that not only is having designs regularly added to by the community, but also allows other enthusiasts to easily replicate those designs by keeping track of what pieces they already own from Lego's standard Technic sets, what they still need, and even find stores selling the pieces they're lacking.

Most notable, however, is many of the community members' ages. It's not much of a surprise that Legos are predominantly enjoyed by younger crowds, but what is more surprising is just how far the younger generations' interest is taking them when they start engineering their own Technic creations. More often than not, the aforementioned YouTube tutorials are put together by young teens to educate their peers on when and why you would want to use a worm gear or which gear ratios work best and why. These are the people that may very well enter manufacturing themselves eventually.

And more than anything, that's the coolest part about the community surrounding Lego Technic models: it's inspiring tomorrow's manufacturers to learn the very basics of their crafts, and maybe for a few, even introducing them to a career path that might make them our peers one day. 40 years of that is something the gear industry can raise a glass to and celebrate.

For more information:
Lego Technic
www.lego.com/en-us/technic