Cutting Tool Dynamics

Meeting Today's Requirements for High-Quality Gears

Matthew Jaster, Senior Editor

Changing manufacturing technologies usually trickle down the supply chain. Modern gear grinding machines, for example, support the manufacture of higher-quality gears and said gears are now being produced with a variety of exotic materials. In turn, cutting tool development needs to stay on par with this advanced machine tool technology. Representatives from companies like Gleason, Helios Gear Products, Klingelnberg, Liebherr and Star SU recently discussed some of the cutting tool technology that is keeping up with the machine tools.

Gleason Discusses Cutting Tool Evolution

Customers keep pushing the boundaries for cutting tool accuracies for finish hobbing and finish shaping. Fortunately, modern gear tool grinders support these higher accuracy requirements.

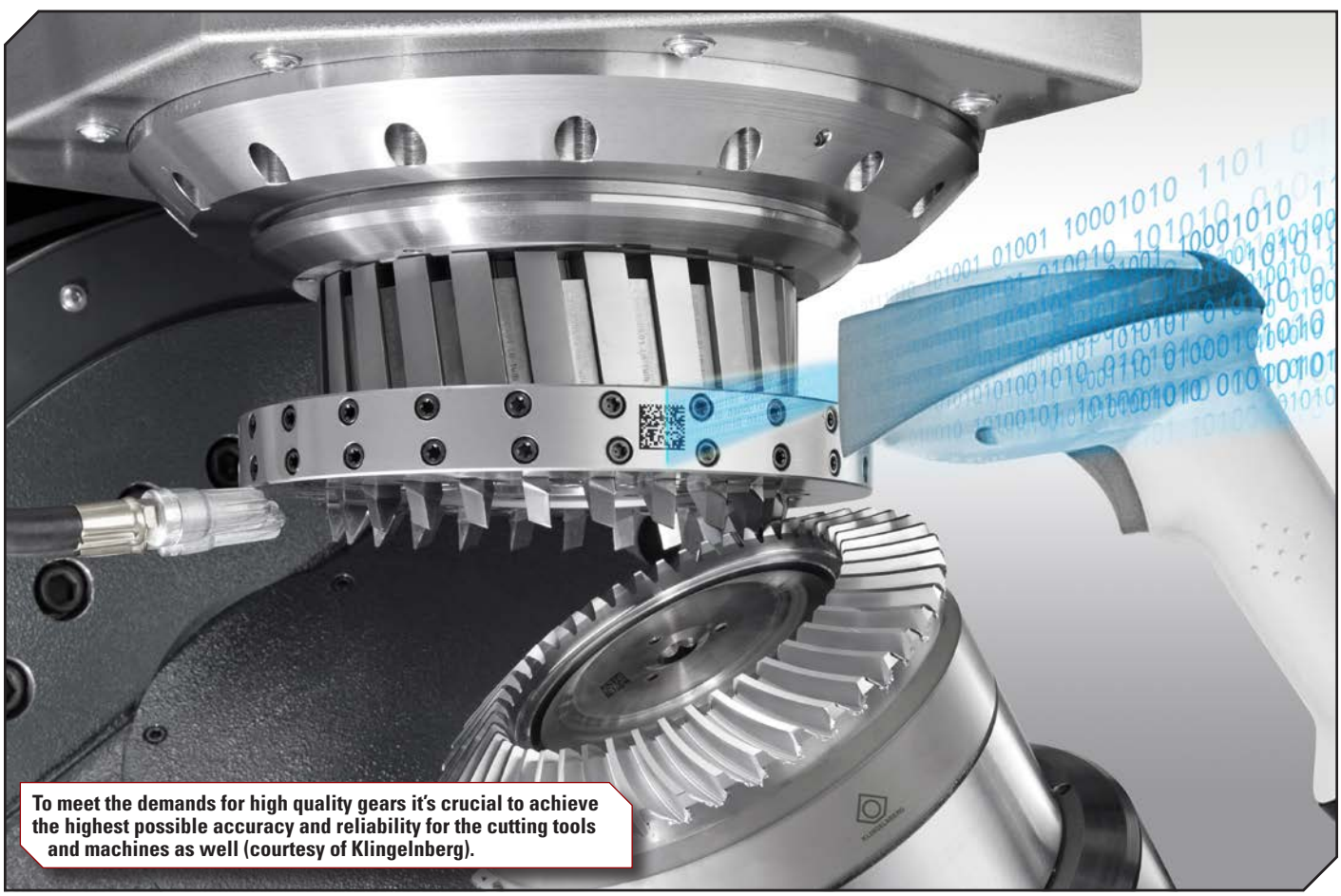
"More common however, is for our customers to utilize hard finishing processes such as grinding and honing to achieve their required accuracies. The cutting tools often require profile modifications such as protuberance to provide the required undercut clearances for these finishing operations. In spite of these hard finishing operations, high accuracy cutting tools are usually still requested for the pre-finish form to minimize the time for the finishing operation," said Keith Liston, vice president sales, Gleason Cutting Tools Corporation.

According to Liston, standard base material tools will not cut some of the exotic gear materials and still provide adequate tool life. Higher alloy base materials or even carbide are often needed to withstand the hardness or abrasive factors of the gear material. Choosing the correct coating for heat resistance is also paramount.

He also discussed the differences in requirements based on size.

Small and medium lot size customers are usually delivery sensitive, so quick delivery programs are usually of interest. Liston said that the use of lean manufacturing concepts help facilitate these quick delivery programs.

"For carbide tools, blanks can be stocked and tool designs can be tailored to the stock blank. From a process standpoint, power skiving for soft cutting and hard finishing of internal gears offers a great alternative to shaping or broaching. Power skiving is much faster than shaping and more cost effective than



To meet the demands for high quality gears it's crucial to achieve the highest possible accuracy and reliability for the cutting tools and machines as well (courtesy of Klingelnberg).

broaching for small to medium lot sizes. The short cycle time for power skiving, while longer than broaching, is much more cost effective for smaller lot sizes when considering the tool cost. In addition, power skiving allows for profile modifications unlike broaching. With hard power skiving, heat treat distortion can also be removed," Liston said.

And what about large batch size requirements?

Liston noted that large batch sizes require optimization of the cutting tools so they stay on the machine a long time. This requires premium high-speed steels and coatings for wear resistance. For hobs, a maximum shiftable length and higher number of gashes would also be desirable. For a shaper cutter, tool life can be increased using a larger diameter cutter as long as there are no interferences.

"The challenge with larger gears is with the removal of a large volume of material in a reasonable time period. To accomplish this, cutting tools using indexable carbide inserts (ICI) are often employed to rough out the material prior to a finishing or semi-finishing process. The carbide is heat tolerant and can be run at a high surface speed to allow for a relatively short cycle time. A subsequent finish hobbing, shaping or grinding operation is then required to achieve the finished part tolerances," Liston added.

In Liston's opinion, the biggest change has come with the power skiving process.

"Power skiving has grown dramatically in recent years. Primarily used for producing internal gears, power skiving is many times faster than shaping and much more flexible than broaching. This process is versatile enough to also cut external gears. Parts which require both an internal and external gear produced could potentially be done on one power skiving machine," he said.

As skiving gains popularity in the gear market, so too does the push for smart tooling and digital tool management.

"The Internet of Things is still developing for gear cutting tools, but is being used today in a number of facilities and offers real benefits, and much potential moving forward. With the use of chips or bar codes, important data used for tool setup can be transferred to the cutting machine. Tool identification and tool size is critical in determining the correct programs to run, the positioning of the cutting head and what cutting parameters to apply. Transferring this information through an electronic reader eliminates the possibility of inaccurate data entry. Tool/machine monitoring can also identify potential tool performance problems and stop a machine cycle before producing scrap parts and/or excessive tool wear. Tool performance, tool float, and remaining tool life can be captured and used to identify tool reorder points," Liston said.

We then asked Liston to expand on how other areas in cutting tools are evolving in 2019.

"The basic designs of gear cutting tools have been constant for decades. What has changed is the speed and rigidity of the cutting machines. These machine changes have resulted in the use of higher alloy high speed steels or even carbide to withstand the high machining speeds and the heat generated. Coatings

have been developed to further withstand the high temperatures," he added.

Liston said tool designers today utilize 3D modeling to further optimize the design of the tools. They not only optimize the tools static cutting clearances but are now able to also consider the dynamic cutting clearances which becomes relevant at higher feeds and speeds. This modeling can identify interference of the cutting tool with the workpiece and in the case of shaping, upstroke interference. When presented with an upstroke interference condition, offsets can be calculated to eliminate this interference. Modeling is also used to identify chip formation so cutting parameters can be specified to target specific chip thicknesses while allowing predictive wear analysis to be made.

And one last area that has gained more traction is chamfering.

"Chamfering of gear teeth has drawn a lot of attention in recent years. While this has always been an important process, more variations to this process have been introduced to manufacturing. Chamfer rolling has been around for many years and is a very quick and economical process. However, rolling is not suited for all applications so other methods using chamfer hobs, chamfer milling cutters, inserted carbide milling cutters and single point milling cutters have been introduced," Liston said.

Power skiving tools from Gleason.

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Klingelnberg Examines Cutting Tool Technology for Bevel Gears

Klingelnberg cutting tools have been developed and optimized for milling and hobbing under dry machining conditions with very sharp cutting edges. To meet the demands for high quality gears it's crucial to achieve the highest possible accuracy and reliability for the cutting tools and machines as well.

"Klingelnberg cutting tools have to be used on special high precision machines for gear manufacturing. For highest possible accuracy on the tool side, the body of the so-called cutter heads is manufactured out of one piece of high-strength material. The chambers for the stick blades are made with high precision EDM technology. The stick blades itself are out of carbide and coated for maximum wear resistance to get a stable gear quality. Cross section and profile of these blades are grinded on high precision machines, too. At last stick blades and the cutter head body have to be assembled which takes place on a special high precision mounting machine," said Philipp Becher, product management and sales gear tooling, at Klingelnberg GmbH.

Becher said that once the profile of the blades is worn a special regrinding

process ensures a like new condition after the preparation. These puzzle pieces ensures that the actual geometry of a machined gear hits except for a few microns, the calculated geometry. The use of highly wear resistant materials ensures the stability of the machined gear geometry within batches of several hundred parts without regrinding.

"Another quality affecting factor is the chip formation during machining. As the space for the chip removal within the gaps is limited through tooth root and the concave and convex flanks, chips can cause scratched surfaces or buildup welding on the teeth flanks, an issue which is handled through flexibility in the process design," Becher said.

Exotic materials walk along with other requirements on the stick blades. The strength and toughness of the material has a direct influence on forces and heat generation on the cutting edge of a blade. This requires a specific combination of carbide substrate and coating of the stick blades of a cutter head.

As far as IoT or Industry 4.0 being introduced to the cutting tools, Becher said that Klingelnberg's IoT solution is named SmartTooling by a digital twin, who is assigned via a DataMatrix Code tagged on each tool component.

"There are digital twins of machines, machining process and processes aside the machine involved as well. Through combining, recording and analyzing of the digital twins, it is possible to reduce setup time, to avoid crashes and to interlink tool parameters with recorded production data. With this extensive production data the customers are able to find interdependencies between gear quality, efficiency and tool parameters. Based on this identified interdependencies the optimization of quality and efficiency will reach a new level in the industrial evolution," he said.

Becher also discussed the different batch size requirements and the tools available.

"Smaller batches are usually accompanied with a higher variety of gear designs. A higher variety of gears causes a higher variety of necessary cutting tools. To keep tool variety under control and to reach maximum productivity Klingelnberg is offering universal carbide tools. For modules up to 10 we have established the ARCOFLEX process, which uses carbide stick blades with highly standardized blade profiles together with our high-precision monoblock cutter heads. With ARCOFLEX Klingelnberg transferred know-how from the high efficient mass production into the requirements for a small batch production. This solution reduces setup times and tooling expenses to a minimum, while increasing productivity and reliable gear quality strongly at the same time," Becher said.

Meanwhile, the greatest challenge of lager batch sizes is to keep quality stable over several hundreds of pieces without regrinding the stick blades. Once the regrinding is necessary, it's crucial to restore the quality which was achieved before the regrinding.

And what are the greatest challenges in cutting larger gears? A larger gear means in general longer contact time between cutting edge and gear. Becher said that this causes higher temperatures which require higher heat and

wear resistance of the cutting material of the blades. In other words it's a specific combination of substrate and coating you choose to counter these requirements. These tools are also confronted with higher forces. To counter this, Klingelnberg uses bigger cutter head bodies for more stable blades with bigger cross sections.

As today's tool technology is very mature, the focus for further development in recent years has been mainly on the cutting material side to increase wear resistance and tool life and/or productivity. Becher said that to really lift customer's shop floors to the next level Klingelnberg will focus on digital solutions.

"The digital twin of a tool can be used for tool management as well. SmartTooling allows visualizing inventory and the condition and status of it. Further on SmartTooling allows verifying tools when doing the setup of the machine. A simple scan is enough to ensure that the tool in front of the machine operator is the right one for the next job. During production or tool preparation incidents can be attached automatically or manually to a certain digital twin. For example: If there have been troubles with run-out adjustment or a crash happened, then this information will be attached to the involved digital twin so that anybody who handles this tool afterwards will be informed about that and can react accordingly," Becher said.

Understanding the variations in tool life and gear quality has been something which has been very difficult until today, as manual data collection is very complex and time consuming.

Becher believes that the maturity of the tooling is well-advanced and the reasons for these variations are coming typically from the environment of the cutting tool.

"Typical examples are variations in the batch quality of gear material, process parameters or used machines. SmartTooling uses digital twins of the complete environment, collects data automatically and helps with tailor made analyzes to understand the interdependencies between tool life and environment," Becher said.

A future where digital manufacturing will be the key to success.

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Helios Gear Products Looks to Bring Smart Tools to Gear Manufacturers

Coatings continue to drive innovations in cutting tools. For high-demand applications, such as dry hobbing and hard hobbing, the newest coatings such as BALINIT ALTENSA from Oerlikon Balzers Coating AG offer serious performance benefits that should be considered, according to Adam Gimpert, business manager, Helios Gear Products (formerly Koepfer America).

In addition, real-time spindle feedback can provide valuable insight to a cutting tool's degradation during production by accurately measuring load as a predictor of tool wear and gear quality. This can help manufacturers' better schedule and cost their jobs by more intelligently applying changeovers and resharpening efforts.

"Simply tracking cutting tools, applications, and performance can yield beneficial information," Gimpert said. "Helios Gear Products plans to launch a new tool in 2020 to make this collection of information easy for gear manufacturing personnel. Once this platform is ready, we can fully embrace IoT by automating the collection of this information via QR code readers, RFID chips, etc. and offer that anonymized and aggregated data back to customers for intelligent guidance on gear manufacturing applications."

On a personal note, Gimpert is excited to bring IoT solutions to gear manufacturers for something other than predictive maintenance.

One key area that continues to advance is production technologies for gear deburring and chamfering.

"The latest machine tool software packages offer the ability to use cutting tools for deburring. This could be burr-free hobbing with one or two hobs, or this could be proprietary systems that use unique cutting tools to accurately cut chamfers on hobbed gears," Gimpert said.

Skiving is another area of growing interest as well.

"Skiving tools are not technically new; the technology has been around for quite some time. However, the machine tools and CNC packages have advanced to

The image shows tandem skiving tools which makes it possible to machine two type of gears without using a tool changer (courtesy of Liebherr).

make this a highly productive operation for mass-produced parts over the past decade," Gimpert added.

Industry-standard coatings have been established and the recent newcomers have yet to find their position outside highly engineered applications.

"This leaves materials, such as MC90, which continue to carve an interesting space between traditional HSS applications and demanding (and costly) carbide applications. We still see MC90 offer measurable improvements to tool life and/or productivity for some manufacturers," Gimpert said.

And another high-demand area is tool management.

We're talking about solutions specific to gear manufacturers that do not deliver a heavy cost burden. These are in short supply," Gimpert said. "Hence, it is our goal to bring to market an affordable, intelligent, mobile solution to small and large manufacturers alike."

For more information:
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Liebherr Addresses Cutting Tool Needs with Latest Production and Measuring Technologies

Pierluigi Catellani, managing director, Liebherr Gear Cutting Tools, says gear tools are working more or less according to the imprint principle.

"The tooth gap on the tool gives the form of the tooth on the workpiece, the more accurate the tool, the more accurate the workpiece. There's a continuous shrinking of tolerances, so tool producers must use the latest technologies in production and measuring," he said. (Liebherr addresses this trend with its AAA quality shaping cutters and skiving cutters as well as high precision CBN profile grinding discs and worms.)

In order to support more exotic materials being used in gear manufacturing applications today, Catellani said you need better tool materials, better coatings and combination of both. "Some tools still in use are now no more up to date and the investment in (I admit: more expensive) high-performance substrates and coatings will definitely pay off when cutting such exotic materials."

He also agreed that smart manufacturing will be play a role in optimizing the cutting process.

"Even the best tool needs a good cutting process to reach the desired performance. For customers it's important to trace tool data for the whole life of it, resharpening after resharpening. QR or even bar codes in combination with according scanners help to identify tools and transfer the correct data directly into the machine. But, many customers today look more at the investment than the benefit. Therefore, IoT or Industry 4.0 is much less applied in industry than it should be," Catellani said.

He also said that the area that has experienced the most change in the industry in recent years is skiving tools, simply because they did not really exist 10 years ago.

"Their design and performance is a key for the success of modern gear skiving. In general, the developments in coatings and the surrounding processes like decoating, edge prep, etc. had the biggest impact on all kinds of tools, however," Catellani added.

Another key to success in gear manufacturing is tool management. For Catellani this means having "the right tool in the right place at the right time" and it includes the reconditioning (resharpening and recoating) according to quality standards.

While areas like skiving and smart manufacturing continue to expand gear manufacturers capabilities, the future of cutting tool design will include an emphasis on more additive manufacturing processes (see sidebar).

For more information:
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Star SU Looks at Accuracy and Tool Life

Some of the latest cutting tool technologies that are supporting higher quality gears today include the application of linear axis drives on tool grinding machines for improved tool accuracies. Jim Caldwell and Tom Ware, product managers for gear cutting tools, also reported that surface finish enhancement and prep deviation on the cutting edge is detrimental to tool life.

Changes that have been made in order to support more exotic materials in gear manufacturing include the increased development of higher alloyed grade high-speed-steels that allow for better productivity when cutting exotic materials.

"New coatings are also being developed and carbide has become a mainstream material for the gear manufacturing process," Ware added.

Smart manufacturing is able to provide benefits in cutting tool technology as well, particularly the use of RFID chips.

"These can be used to identify tool and size for accuracy and reduction of setup time. These chips are written or rewritten with each reconditioning of the hob. They contain key information about the hob such as: Tool Number and Serial Number, Outside Diameter at both ends of the hob, and Skip Zones or unusable portions of the hob due excess wear. The chip is mounting to the hob container," Ware said. "They cannot be mounted in the tool due to the temperature of the coating chamber. The hobbing machine has a reader wand and internal programing to read the chip data and adjust the machine settings to automatically make the necessary changes. This speeds up the changeover or tool change process and eliminates operator entry error. This reduces scrap gears cut during setup."

An RFID chip can be mounted to the hob container to adjust machine settings and read data (courtesy of Star SU).

"Through the use of real time in-process monitoring, machine tools are now making it possible for customers to reduce cost by optimizing tool life, using error detection to reduce the number of scrap parts, and by preventing catastrophic tool failure," Caldwell said.

Ware and Caldwell also discussed the areas of cutting tool technology that have recently had the greatest impact in the gear industry.

"Hobbing tools have gone through a significant technology change with integrated shanks and smaller diameters. Better materials and coatings allowing cutting speeds up to 500 m per minute," Caldwell said.

"Chamfer/deburring has gone back to cutting/generating chamfers on gears for improved control and tool wear," Ware added.

And another area gaining traction is technology advances in tool management.

"Onsite tool management provides the ability to assess tool wear from first use through end of life as well as reconditioning decoat/recoat for new tool conditioning," Ware said.

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A Hint at the Cutting Tool Technology to Come

GKN Cuts Tool Production Time with Additive Manufacturing

Many of the interviewees in this cutting tool article discussed the role additive manufacturing will play in the coming years regarding cutting tools. This is already well underway in some areas of manufacturing, particularly aerospace where designing complex tools with greater lead times is already a reality.

GKN Aerospace reported on their progress in this area at the end of 2018. GKN serves over 90 percent of the world's aircraft and engine manufacturers with aerostructures, engine systems and technologies.

According to Tim Hope, additive manufacturing center manager, at GKN Aerospace, the company decided to invest in the Stratasys F900 Production 3D Printer in a bid to cut lead times for production-line tools, and to create complex parts, impossible to make with traditional manufacturing methods.

"Since integrating the F900, we have dramatically reduced production-line downtime for certain teams and are enjoying a new found freedom to design complex tools," he said.

Traditionally, the lead-time required to produce a metal or plastic replacement tool is several weeks. Now, with the ability to use an in-house production 3D printer to do the same job, the replacement burden has been removed and the responsiveness to manufacturing requirements improved.

"We can now cost-effectively produce tools for our operators within three hours," Hope explained. "This saves critical production time, and by printing in engineering-grade thermoplastics, we can produce 3D printed tools with repeatable, predictable quality every time. All while matching the quality of a traditionally-produced tool, and reducing the costs and concessions compared to equivalent metallic tooling."

While GKN Aerospace is using a standard thermoplastic today, it is experimenting with Stratasys' high-strength, heat-resistant ULTEM 1010 Resin material for these applications.

In addition, GKN Aerospace is reporting unprecedented levels of design freedom since investing in the Stratasys F900 into its operations.

"One of the key benefits of additive manufacturing is the creative freedom this technology affords users," explained Hope. "The F900 offers the largest build-size of any FDM 3D printer enabling us to rapidly produce tools to meet any requirements. Most notably, complex geometries and cavities that would otherwise be problematic are now practical with the F900. We're utilizing it to design, and 3D print, previously inconceivable tools that enable us to manufacture complex parts that are uneconomical or just physically impossible by other methods."

In addition to design freedom benefits, GKN Aerospace has also seen a 40 percent decrease in material waste.

Hope anticipates a greater move towards the use of FDM additive manufacturing to produce high-value, flight-critical, end-use composite parts.

"GKN Aerospace's product range is vast, and we see large-scale FDM and carbon-reinforced parts as the future of additive manufacturing in aerospace. By using Stratasys additive manufacturing for tooling, we are harnessing a machine that offers us the freedom to produce unique and complex tools of any size, with the build quality to match any manufacturing requirement. All while simultaneously preparing ourselves for the future," he added.

Gear manufacturers take note as aerospace technologies eventually trickle down to other areas of manufacturing. The future for tool production looks faster, more affordable and much more versatile.

For more information:
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