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AUG 2017

Columbus Calling

- Gear Expo 2017 Preview
- Booth Previews, Part I

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features

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departments

Cover photo by David Ropinski

THE GEAR INDUSTRY'S INFORMATION SOURCE

www.geartechnology.com

GT Videos

We recently brought back Arrow Gear's video series on installing bevel gears. View these and other videos at the Gear Technology website: ***www.geartechnology.com/videos/***

E-News:

Each month, we'll bring you articles and information that's 100% relevant to gear manufacturers. The editors have scheduled a wide variety of gear related topics for our upcoming newsletters, and by subscribing you'll get articles that don't appear anywhere else, not even in the print version. *www.geartechnology.com/newsletter/*

Event Spotlight:

The 7th International Conference on Gears 2017 will be held in Garching near Munich at the Gear Research Centre (FZG) of the Technical University of Munich from September 13 to 15, 2017. Supported by national and international associations, the conference brings together over 600 leading experts from the international gear and transmission industry. Participating in the conference gives you the opportunity to take part in this leading international forum and learn about the latest developments and research results in the powertrain industry and academia.

www.geartechnology.com/news/8233/VDI_International_Conference_on_Gears_2017/

Gear Talk:

Our resident blogger Chuck Schultz discusses a variety of gear manufacturing topics including sharing stories with young engineers, recording your gear knowledge and observations on his recent move to Pennsylvania.

www.geartechnology.com/blog/

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Columbus Calling

Publisher & Editor-in-Chief
Michael Goldstein

Summer never lasts as long as you want it to. By the time you read this, you'll be well into the hazy, lazy days, and the season will be gone before you know it. That means you're running out of time to make plans to attend our industry's most important event. Of course, I'm talking about Gear Expo (October 24–26) and the AGMA Fall Technical Meeting (October 22–24), both of which will take place in Columbus, OH.

The Fall Technical Meeting (FTM) will include 27 presentations over three days, with a focus on some of the latest research and development related to gears, including topics such as efficiency, lubrication, noise, manufacturing, inspection, design, materials, heat treatment, gear wear and failure. More importantly, the FTM gives you the opportunity to meet and speak with the authors themselves, along with colleagues interested in the same subjects. Not only does this allow you to learn about the latest technologies, processes and techniques, but it also gives you the chance to ask questions and better determine how and why these presentation impact your own business and operations.

If the FTM were the only thing offered in Columbus in October, it would be well worth your time, and I'd urge you to go. But fortunately for us, the FTM precedes and overlaps with Gear Expo, making the trip to Columbus crucial for anyone who is serious about doing business in the gear industry.

Gear Expo is a unique biennial event, unlike anything offered or available anywhere. On the exhibition floor, you'll have access to all of the industry's important suppliers, including ourselves. If you're looking for a new hobbing machine, you'll find more than 15 suppliers to choose from. Looking for shaper cutters? More than a dozen suppliers are waiting for you. And the list goes on. In all, more than 225 exhibitors will occupy the Greater Columbus Convention Center. And if you happen to be a gear buyer instead of a gear manufacturer, I have even better news for you. More than 50 exhibitors are suppliers of gears and gear drives, ranging from suppliers of one-off commercial gears all the way up to high production automotive, aerospace and aircraft gearing.

Where else can you find this much gear-related knowledge and experience gathered under one roof? At Gear Expo, you have the opportunity to meet not only with your suppliers' salesmen, but also their manufacturing engineers, machine tool designers, service and installation engineers and many others, including experts in cutting tools, fixtures, grinding wheels, inspection and all other aspects of gear manufacturing.

Still not convinced? There's more. Gear Expo is also held in conjunction with the ASM Heat Treating Society Conference & Exhibition, which includes another 200 suppliers of furnaces, ovens, heat treating services and related equipment.

On top of all of that, we'll be hosting a live version of "Ask the Expert" in Booth #1022. Sessions will be held on Tuesday, October 24 and Wednesday, October 25, twice daily (at 10:30 a.m. and 2:30 p.m.). This is a unique opportunity for you to present your problems and questions to the leading experts in the world of gearing and to get the answers needed for your future success.

If you haven't been to a Gear Expo recently, you'll be surprised by how much it's grown and how much is available. And if you've never gone, you've been missing out. This year promises to be one of the best shows ever.

So no more excuses. You're going to the show. It's too important to miss.

Economic and Industrial Market Commentary — Gear Industry

Jim Meil, Principal, Industry Analyst, ACT Research

At the mid-year point of 2017, it appears that the U.S. economy, and the manufacturing sector in particular, are gradually accelerating, with most markets seeing an upside breakout from the flat or down conditions of 2015 and 2016.

This is good news for the gear industry — many companies are seeing the best top-line sales growth numbers in three years or longer. We see the growth trajectory for gears breaking away from the overall flat-line trend of the last two years, with some markets (and company sales reports) showing the potential to reach double-digit gains in the second half and momentum continuing into 2018.

While the improvement isn't as dramatic as way back in 2010, that was a year assisted by a bounce back from the trauma of the "Great Recession." Right now, we are eight years into the current economic expansion, so there isn't the same source of pent-up demand.

However, many of the constraints that held industrial growth in check during 2016 — such as excess inventory, a too-strong dollar, slack overseas demand for U.S. goods and reticence to invest when the view to Washington was perceived as antagonistic to business — have been reversed this year.

Inventories have been trimmed, the dollar has stabilized and in some cases weakened since late 2016, overseas economies (especially Europe) are rebounding and buying U.S. goods and while there is still ambivalence in regard to the Washington political scene, the perception that it is anti-business has been mitigated by last year's election results.

Logically enough, improving business conditions start with more positive attitudes. Starting in the fourth quarter last year, consumer confidence numbers from the Conference Board and University of Michigan, metrics such as the NFIB small business optimism survey and big business attitude readings (Business Roundtable outlook from Fortune 50 CEOs) took a major turn for the better. Some of these readings have reached levels that were the best in ten or more years.

That impression is confirmed by looking at the most important confidence measure of all — the stock market. Major stock market indices (Dow Jones Industrials, S&P 500, NASDAQ) are at or near record highs, and at mid-year, U.S Machinery stocks are up 13.7 percent from December 31, almost five percentage points ahead of the S&P 500's 8.9 percent gain. While security analysts can be wrong, their valuations seem to confirm that conditions have improved for the economy and for industrials and the machinery sector in the last six months.

Taking a look at more detailed sector performance, here is our current assessment of key industrial markets:

Passenger Car and Light Truck — After steady advances from the depths of the Great Recession into 2016, light vehicle sales and production are reaching a plateau and likely will decline from last year's levels. Auto inventories are too high, but even when they settle down, we are probably in a mode where light vehicle sales and production will be stable at high levels, not pushing into new record volume territory.

Commercial Vehicle — Medium duty trucks (Classes 5 to 7) are benefitting from a strong consumer sector, especially online retail and parcel delivery, in a market that should grow about 5 percent in 2017. Heavy duty trucks (Class 8) have had a surprising upside in 2017 with a positive acceleration in orders dating back to the Fourth Quarter of 2016. Class 8 production in 2017 may rise by as much as 5% from prior year, a big change from views that prevailed last December when a second year of production declines was anticipated.

Industrial Machinery — Shipments look to post a mid-single digit gain in 2017, as capacity utilization tightens, manufacturing activity increases, and export markets see a pickup in momentum.

Off-Highway Mobile Equipment — Mixed outlooks, depending on sector. Material handling has been consistently doing well, based in part on the warehouse boom supporting online retailing. Construction equipment is turning the corner after weak mid-decade years, in part on the prospects for a boost in publicly funded infrastructure. Farm machinery and oilfield/energy/mining equipment remained tied to the ups and down of commodity prices. This was a drag on 2015 and 2016 performance, though signs of stability (especially oil prices picking back up to the $45 to $50 per barrel level in the last 12 months from lows below $30/bbl) in energy and farm commodity prices have at least put a floor on production and offer some hope of a 2018 improvement.

Aerospace — 2017 is turning out strong, with an improving global economy driving increased air travel (critical for aftermarket) and accelerating deliveries of commercial aircraft. Some recovery in defense industry spending, mainly in the U.S. and Europe, will round out an improving across-the-board 2017 for aerospace.

No market review is complete without an assessment of risk. Short-term, downside risks are low and stem mainly from disappointed expectations if Washington fails to deliver on promises for business-friendly health-care law changes, tax reform, and infrastructure boosting programs.

Longer term, the Federal Reserve Board is on a quest to end its easy

For daily commentary, follow tweets *@jp_meil*

monetary policies and "normalize" interest rates. Its own statements and documents suggest that short-term interest rates, such as the Fed Funds rate and 90-Day Treasury yields, could reach as high as 3 percent by year-end 2019 from the 1 percent of June 2017. The combination of escalating rates and a shock could be fatal for the expansion. It has happened in the past, when rising rates and an exogenous negative (such as the oil price spike in 1980, the Persian Gulf War in 1990–91, the technology bubble bursting in 2001 and oil prices/housing collapse in 2007–2009) proved to be expansion-ending in earlier episodes. It will be important to keep a wary eye should the Federal Reserve raise rates to 2 percent or higher in 2018. If linked to a shock, it could set the stage for ending the current business expansion that dates back to 2009.

Jim Meil has been recognized as a leading industrial sector economist and planner for more than 30 years. As Principal Industry Analyst at ACT Research, he is responsible for forecasts and commentary on the North American economy, analyzing how goods-producing sectors are contributing to freight conditions and vocational activity. He is a contributor to Blue Chip Economic Indicators and The Wall Street Journal monthly U.S. economic forecast panels. Meil has received first-place recognition in the Wall Street Journal's survey of 50 forecasters and has been ranked among USA Today's "Top 50 Economic Forecasters" for accuracy. Prior to joining ACT Research, Meil spent 30 years in the planning department of Eaton Corporation, retiring from the position of Vice President and Chief Economist in April 2014. He previously served on the Board of Directors for the National Association for Business Economics, and he also worked for Chase Econometrics and Burroughs Corporation before joining Eaton. He holds an MBA degree in finance and a Bachelor of Arts in economics from the University of Chicago.

EMAG

VL 3 DUO OFFERS COMPACT PRODUCTION OF GEAR WHEELS

EMAG recently announced a direct development of its modular machines in combination with the TrackMotion automation system — the VL 3 DUO.

"We need just 13 m² (140 sq ft) to install the complete VL 3 DUO," explains Peter Loetzner, CEO at EMAG L.L.C. "For a twin-spindle vertical pick-up turning machine that is a fantastic size. Even if the machine is combined with a raw parts storage facility and the TrackMotion automation system, the dimensions for a complete manufacturing system for chucked parts up to 150 mm (2 in.) is almost laughably small. That makes the VL 3 DUO one of the most compact and efficient systems available from EMAG."

With its parts ranging up to 150 mm (2 in.) in diameter, the VL 3 DUO is ideal for the manufacturing of gearbox components, for example, machining blanks for gear wheel production. "Gearbox components such as gear wheels must be manufactured in very large quantities. The standard production process is always the same: in OP 10 and OP 20, both sides of the gear wheel blank are machined by a turning process and the surfaces are prepared; the gear cutting process follows in OP 30 and deburring takes place in OP 40," explains Loetzner. "The VL 3 DUO is, of course, primarily focused on the first process in this machining chain, in other words OP 10 and OP 20, which can be implemented perfectly with our system."

The VL 3 DUO can be fitted with EMAG's TrackMotion automation system as an option. The automation system consists of three central parts, the track (i.e. the rails) on which the TransLift NC gripper runs and the raw parts storage facility. The entire system is very compact and runs directly behind the machining areas of the VL 3 DUO. The TrackMotion always focuses on the individual component. Each transport process only moves a single component which allows for significant benefits for component management.

The increased mobility of the TransLift, including the Z-axis, means that stackable pallets can be used on the raw parts storage facility, making it possible for the raw and finished parts to be stacked with minimal space requirements. In addition, the TransLift is also used as a changer between the two machining operations. This means that the TrackMotion automation system provides everything required for compact manufacturing on the VL 3 DUO: an extensive parts storage area that accommodates up to 400 parts and a fast, flexible parts transport system between the various manufacturing stations.

Like every modular machine, the VL 3 DUO has its own parts buffer and a pick-up spindle in each machining area. The TrackMotion automation system loads the individual part pallets on the parts buffer as they shuttle between the loading position near the machining area and the rear section of the machine. From there, the working spindle takes the raw part, transports it into the relevant machining area and places the part back onto the appropriate pallet after it has been machined. Immediately next to it, the subsequent part is waiting to be picked up by the spindle, so that only a few seconds pass until the next part is being machined.

The machining areas are arranged in a mirror constellation and each has its own working spindle which, with a rating of up to 18.1 kW and torque of up to 142 Nm, has plenty of power for high speed, precision machining. In addition, each machining area has a tool turret with twelve tool positions which can be fitted with turning tools or driven tools. "The turrets can also be fitted with an additional Y-axis to extend the range of uses of the machine even further," explains Loetzner.

The VL 3 DUO adds a highly productive, compact manufacturing system for large-scale production to EMAG's modular machine family. "Its real strength can be seen when it is connected to other machines in the modular machine family," continues Loetzner. "Let's look at the example of gear wheel production mentioned above. If we supplement the VL 3 DUO with the VL 4 H, the modular gear hobbing machine from EMAG, and a VLC 100 CC or VLC 100 RC, the vertical chamfering and deburring machines, we create a manufacturing system for gear wheels which is completely linked using the TrackMotion automation system, with a very small footprint. The whole thing is made possible by the standard structure of the modular machines, the integrated automation system and the fact that the transfer height between the machines is always identical. In other words, almost as simple as using building blocks," Loetzner said.

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

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Emuge

INTRODUCES LINE OF END MILLS FOR TROCHOIDAL MILLING

Emuge Corp. recently announced the introduction of a new line of solid carbide end mills with unique geometry and chip breakers designed specifically for trochoidal milling. Emuge's new Trochoidal End Mills provide increased metal removal rates (MRR) of over 30 percent, fewer tool paths and longer tool life, while enabling a high axial depth of cut of up to 4XD. The Trochoidal End Mill series was developed specifically for advanced milling strategies available in modern CAM software to optimize the calculation of milling paths and avoid unproductive tool motion.

Trochoidal milling is a relatively new cutting strategy growing in use, that involves the overlapping of circular cutting paths with linear movement and is especially suitable for difficult to machine materials and thin-walled components. The small contact angle on the tool reduces heat generation during machining and promotes less thermal stress increasing tool life. The end mill is fully utilized over the entire flute length, resulting in wear that is evenly spaced over the full cutting edge, which also contributes to longer tool life. In addition, high MRR can be generated even on low-powered machines and wear is reduced during full slot milling.

Emuge Trochoidal End Mills feature low vibration characteristics such as variable spacing, variable helix angles and improved micro-geometries, along with new high performance coatings of TiN/TiALN or ALCR and a sub-micro grain carbide substrate. In addition, the newly developed chip breaker geometry reduces axial pull-out force and minimizes the risk of chip build up in pockets, since the resulting smaller chips can be easily removed with compressed air or coolant.

Emuge Trochoidal End Mills are available in two cutting geometries: *Jet-Cut* for both roughing and finishing in steel applications, and Coolant-Through *TiNox-Cut* for process-reliable roughing in tough materials such as Inconel, titanium and stainless steel. Standard and long-length rougher/finishers with flute length/diameter ratios of 2:1, 3:1 and 4:1 are available for applications in a wide range of materials.

For more information:
Emuge
Phone: (800) 323-3013
www.emuge.com/end-mills/Trochoidal

Ransohoff

WASHER OFFERS HIGH-VOLUME COLD FORMING SOLUTION

Ransohoff, a division of Cleaning Technologies Group LLC, has introduced its LeanDrum CF Washer. This new platform provides an energy efficient, reliable solution for your high-volume cleaning needs, along with an innovated design for cold forming applications.

The LeanDrum CF features a very robust, lower cost option utilizing stainless steel tanks, drum and housing, premium electrical components, a full immersion cleaning system and forced air dryer technology to produce consistently high quality cleaning results over an extended machine life. With this new design, you may recognize less chemical utilization and have better oil control resulting in a longer bath life. In this new design, you will have the ability to apply more aggressive chemicals without foaming. The new LeanDrum CF is designed for easy access that will allow easy drum removal for maintenance, with no crane required.

The new LeanDrum CF is a wash, rinse and blow-off machine in a small footprint of 5.3 ft. wide × 11 ft. deep × 5.3 ft. height. The part production rate is 12 CU FT/Hour at 2 rpm design drum speed, with a variable speed drive capable of 1–3 rpm's. This machine offers full immersion cleaning, eliminating any need for pumps and nozzles. The new LeanDrum CF comes standard with 3-2-1 warranty.

For more information:
Ransohoff
Phone: (877) 933-8278
www.ctgclean.com/ransohoff

Seco Tools

EXPANDS PCBN INSERT GRADE FAMILY

Seco Tools has expanded its family of PCBN insert grades to cover the entire spectrum of hard part turning applications. Using a new bimodal substrate and nanolaminate coating process, these new inserts extend tool life and increase productivity in a broader range of applications.

Seco's PCBN grade chain for materials ranging from ISO H05 to H35 consists of CH0550, CBN060K, CH2540 and CH3515 and is designed specifically for turning hardened steels. They incorporate advanced coatings and a bimodal substrate with coarser grain materials, along with optimized cutting edge profiles for long and predictable machining performance.

CH0550 provides prolonged wear resistance in high-speed continuous cut H05 operations. CBN060K excels in continuous to slight interrupted cuts in H15 applications.

CH2540 is designed to offer unparalleled performance in continuous and moderate interrupted cuts in the H25 area. CH3515 exhibits extreme toughness handling heavy interruptions in H35 operations.

Each of Seco's PCBN grades is available in common ISO insert geometries in both metric and imperial specifications. High feed wiper geometry options are available to further enhance performance.

For more information:
Seco Tools
Phone: (248) 528-5200
www.secotools.com

Solar Atmospheres

CONSTRUCTS CLIMATE-CONTROLLED VACUUM HEAT TREAT ENVIRONMENT

After surviving one of the hottest and most humid summer seasons on record, Solar Atmospheres of Western PA decided to construct a climate-controlled environment for the daily operation of its brand new all-metal hot zoned vacuum furnace. The critical climate within this room is controlled utilizing a high quality HVAC system and is equipped with dehumidifiers and customizable thermostats. A heavy duty insulation package was installed, which ultimately helps to manage and stabilize temperature and humidity around the clock. The space also was constructed to produce a slightly positive pressure environment, which will help eliminate dust and debris from entering the set-up and fixturing areas.

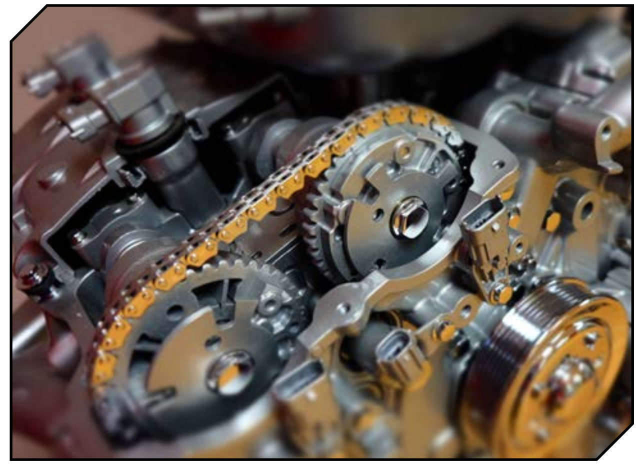
Kevin Bekelja, vice president of operations, states, "With the new third party accreditation programs such as MedAccred gaining momentum, and knowing how detrimental high levels of humidity can be in the vacuum thermal processing of certain critical materials, we believe this venture is well worth the investment."

Both medical and aerospace contractors are continuing to demand that environmental conditions be controlled, processes validated and the risk of foreign object debris (FOD) be totally eliminated. This newly constructed environmentally controlled room will enable Solar Atmospheres of Western PA to pristinely thermally process critical components, which in turn will add even more value to the customer's operations.

For more information:
Solar Atmospheres
Phone: (866) 982-0660
www.solaratm.com

Carbodeon

IMPROVES ABRASIVE WEAR RESISTANCE WITH COMPOSITE COATING



Nanodiamond material specialist Carbodeon of Finland has worked with metal finishing specialist CCT Plating of Germany, to develop a new electroless nickel, PTFE and nanodiamond composite coating.

Electroless nickel-PTFE (EN-PTFE) coatings provide excellent anti-adhesive and low friction properties but are traditionally soft and wear quickly in abrasive conditions. By adding NanoDiamond particles to the EN-PTFE coating, Carbodeon has been able to improve the abrasive wear resistance of these coatings without compromising the sliding or release properties.

Nanodiamond material consists of small, spherical diamond nanoparticles which are specially treated to make them disperse in coating liquids and carry a positive electrical charge on their surfaces. In the plating process, the diamond particles behave similarly to positively charged metal ions and together with the nickel and the PTFE material they co-deposit onto the component.

Key performance characteristics include resistance to adhesive and abrasive wear with a Taber Wear Index 30 percent better than the equivalent EN-PTFE coatings, coatings can also be heat treated, there is no increase in wear of the counterpart, the process contains no hexavalent chromium and so is environmentally friendly and free of complex regulations and the low diamond content makes these coatings affordable and easy to apply.

Carbodeon CTO Dr. Vesa Myllymaki said: "Customer applications have multiple requirements that are a challenge for existing coatings. Through a combination of these three materials, nickel, nanodiamond and PTFE, we produce coatings which are resistant to the multiple modes of wear and failure that components and systems are subject to, while keeping the low friction and release properties of the NE-PTFE surface."

For more information:
Carbodeon
Phone: (358) 5566 765
www.carbodeon.net

Makino

ENHANCES VMC OFFERING WITH THE D200Z

The Makino D200Z 5-axis vertical machining center answers machine challenges by combining the quickness of machine movements and accuracies with the latest software developments for high-precision, high-speed motion control. From roughing to high-speed finishing of multifaceted, contoured 3-D geometries, the D200Z boosts productivity with the most competitive processing capabilities for complex dies and molds typically found in the automotive, injection molding, packaging, medical and optical markets.

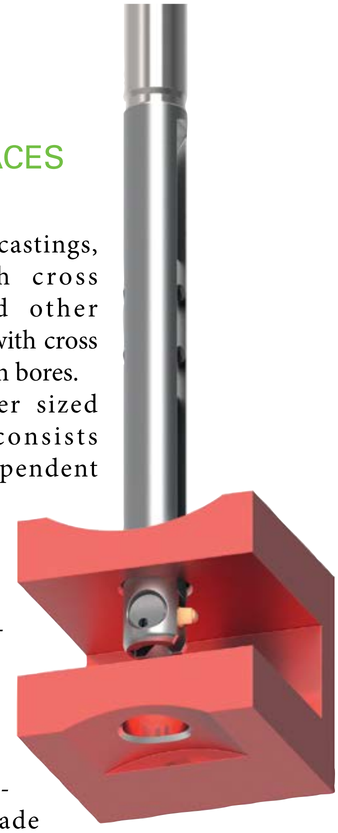
"With mold manufacturers strained for capacity and challenged to keep pace with new design changes, all while minimizing costs, the need for high-performance 5-axis machining has never been more critical," said William Howard, vertical product line manager at Makino. "The speed and precision of the D200Z supply a unique foundation for responsive high-speed cutting and outstanding surface finishes that reduce or eliminate handwork. Its 30,000-rpm spindle and integral direct-drive table provide quick, precise, full 5-axis machining. All of this capability is tied together with Makino's proprietary SGI.5 motion control software for the highest degree of accuracy and quality in the blends and matches of intricate surfaces and 3-D accuracy requirements typical of today's die, mold, medical and intricate-geometry components."

For more information:
Makino
Phone: (888) 625-4664
www.makino.com

Heule Tool Corp.

OFFERS TOOLING FOR DEBURRING ELLIPTICAL OR CONTOURED SURFACES IN LARGE DIAMETERS

Replaceable solid carbide coated blades for holes from 6–26 mm are available from stock, with various coatings providing longer tool life and optimum performance based on materials being machined. This proven technology provides different blade and spring options to create the most effective deburring tool for any application depending upon hole geometry and material being machined. The COFA-C series is designed for ID and OD elliptical deburring on even and uneven bore edges in a single operation. They are ideal for automotive and aerospace applications such as forks, yokes, common rails, castings, tubes with cross bores, and other workpieces with cross bores in main bores.



The larger sized C-series consists of an independent blade that is fit into a more rigidly guided blade holder. This increases the tool life and process capability. The blade itself requires less material and can be changed quickly. Different blade sizes are available for the same tool body, allowing different cutting diameters based on a specific application.

Controlled by a simple spring, the carbide cutting blade follows the contour of the holes' surface, removing all burrs while creating an even tapered corner break. The blade does not cut as it passes through the bore and will not damage the hole's surface. The edge break begins only at the point where the blade contacts the material and then tapers the hole's edge. This allows for faster feed rates since the tool slows itself down as it enters the through hole.

This simple concept has no adjusting screws or presetting requirements. The choice of spring is typically determined by the material being machined. Blades are available for cutting front and back or back cutting only. C-series tooling is available in common sizes from 6-26 mm (.236–1.024 inches).

For more information:
Heule Tool Corporation
Phone: (513) 860-9900
www.heuletool.com

Gear Expo 2017

AGMA Sets Up Shop in Living Laboratory of the Midwest

Matthew Jaster, Senior Editor

Columbus, Ohio recently surpassed Indianapolis as the second largest city in the Midwest behind Chicago, according to the United States Census Bureau. This could change come the 2020 census, but there's no denying Buckeye Nation is going places. Between 2011 and 2016, private employment in Ohio increased by 450,000 jobs, going above and beyond the regional average of 261,000.

With $40 million in funding from the U.S. Department of Transportation and $10 million from Vulcan Inc., (a private company founded by Microsoft philanthropist, Paul Allen), the city of Columbus is currently under construction to become America's first Smart City.

But what does that mean exactly?

It means a greater emphasis on urban planning, public transportation, parking and the introduction of more electric vehicles. It means putting sensors on everything so predictive analytics and data management become the norm. A Smart City works to eliminate traffic congestion, cut back on traffic accidents and provide a safer urban environment for families.

Follow the Technology

The Columbus Smart City is just one example of a project that will focus on fostering innovation here in the United States. You can add it to the growing list of initiatives designed to restore manufacturing and engineering knowledge, increase competitiveness and prepare our country for the digital future.

It's also a great way to keep the manufacturing discussion right here in the Midwest. Manufacturing USA is another example of this. Technology centers such as the Digital Manufacturing and Design Innovation Institute (Chicago, Illinois), Lightweight Innovations for Tomorrow (Detroit, Michigan), America Makes (Youngstown, Ohio) and Advanced Robotics Manufacturing (Pittsburgh, Pennsylvania), work toward securing the future of manufacturing through innovation, education and collaboration.

It's fitting — almost poetic in a way — that the same time Columbus is working to become a living laboratory for the future, AGMA is setting up shop to focus on the gear and power transmission industries. Coincidence? We think not!

While our cities are changing at a rapid pace, so too, is the manufacturing industry. The average shop floor will soon be collecting data, managing analytics and determining how to produce products faster and more efficiently than the competition. The decisions made today will certainly affect how our cities and factories are maintained and operated in the future.

Jenny Blackford, vice president, marketing at AGMA, and Matt Croson, president at AGMA, recently provided insight on the changes taking place in the gear industry, the importance of emerging technologies and the role AGMA will play in the future regarding gears and related power transmission components.

Jenny Blackford, Vice President Marketing, AGMA

How has the gear industry changed since closing the doors on the Detroit show in 2015? Explain.

Finally, we are beginning to see positive growth across the industry for the first time in six years. In 2015, many companies were still skittish from the losses of the last recession, but we are seeing positive signs that people are willing to invest in new equipment and new products. Since the 2015 show, there have been several mergers and acquisitions in the industry, and we will not be surprised if that continues for the second half of this year. All of these factors make Gear Expo perfectly timed as a great opportunity for companies to find new suppliers and business opportunities.

From a marketing perspective, what will Columbus, Ohio bring to Gear Expo's legacy?

Columbus is a great location and a short drive for many of the major manufacturing hubs. There are many restaurants and entertainment options close to the convention center, and I feel that the exhibitors and attendees will be pleasantly surprised by all that Columbus has to offer them.

What new topics and trends will be featured at the FTM and during the show?

We really wanted Gear Expo's focus to align with AGMA's strategic plan. One of the planks of the plan is emerging technologies. At the Fall Technical Meeting and the Gear Expo Solutions Center, we will have presentations on Industry 4.0, IoT and additive manufacturing to bring real world examples of how new technologies are being used in the gear and power transmission industries.

Explain the significance of the tagline to this year's Expo: What Drives You?

Historically, Gear Expo catered to suppliers selling to gear manufacturers. However the show is growing thanks to gear manufacturers who are exhibiting their products to the OEM and end user attendees to the show. In 2015, we added the tag line "the Drive Technology Show" to recognize that Gear Expo was a place that attendees could come to see the entire supply chain—from machine tools and materials to gears, bearings and full gear systems. This year's tag line, What Drives You, reiterates that focus on end users, and is being carried out through a large scale marketing campaign to a wide variety of OEMs and gear buyers in the automotive, off-highway and industrial markets, among others.

Will there be an international presence once again during Gear Expo 2017?

We have exhibitors coming from more than a dozen countries around the world. We are very excited at our international involvement, as creating strong relationships internationally in the industry is also one of AGMA's strategic goals.

How has AGMA's partnership with ASM evolved, and will the two shows continue to work together in the future?

This will be the fifth co-location with ASM and we couldn't be more pleased with the relationship. The co-location offers a better value to our attendees so that they receive a broader view of the supply chain and thus allows them to create better relationships for their businesses. We anticipate this partnership will continue to grow in the future.

What are you personally most excited about regarding the 2017 show and why?

I am most excited for the fact that Jay Rogers, co-founder of Local Motors is one of our keynote speakers at the Solutions Center this year. Local Motors is focused on open-source vehicle design and additive manufacturing—a completely new way of automotive design and manufacturing. Jay will add a new depth of knowledge to our emerging technologies focus, and I am interested to hear what he thinks about the future of automotive manufacturing.

What is AGMA doing to attract young, college graduates to consider engineering and manufacturing positions within the gear industry? Are there

plans to utilize Gear Expo as a forum to do this now or in the future?

The AGMA Foundation has invited the past and present scholarship recipients to attend the Show and the Fall Technical Meeting. Additionally, AGMA has been contacting many of the surrounding colleges, universities and technical schools to offer students a low-cost attendance option for the FTM and a free pass to the show. We see the need to have the next generation of engineers come be a part of Gear Expo so that they will grow with the show and take ownership over the future direction of the gear industry.

What can your members do to promote and market Gear Expo to the manufacturing community?

We are already seeing great traction from our members to promote Gear Expo on social media and hope they continue the conversation using AGMA's #GearExpo on Twitter. We encourage them to include the same information in their newsletter, E-mails and on their websites. In addition, members are able to give out free passes to the showroom floor for their guests, potential customers and current clients.

Matt Croson, AGMA President

You've done a fair bit of traveling and visiting key companies within the gear industry this year. What is the current pulse of our industry prior to this year's Gear Expo?

I've visited with almost 60 different companies in the past year, and I'd say the consensus is cautious optimism. There are clearly positive signs for members. We've seen month-to-month growth in the first half of the year—the first time this has happened in the past six years.

But members are still climbing from all-time lows, and it's my feeling companies are looking for a steadier market—something that is more of a strong pattern of purchasing.

How will the education portion of Gear Expo 2017 highlight your commitment to focus more on education and training within the gear industry?

Gear Expo is the world's largest gear school for attendees—they can learn all aspects of the industry by touring the floor, and looking for innovation. But we also have several classes being held in tandem with our partners at ABMA and ASM/Heat Treat, and our own Fall Technical Meeting. The

FTM, for example, has more than 25 peer-reviewed papers being shared. This event is a one-stop shop for all things tied to gears—from how to make them, to the systems themselves—and all of the education they need to ensure the innovation they are purchasing can be leveraged within their company.

What are you hoping attendees will take away from the show this year?

Our focus is on innovation. We want our attendees to walk away with the innovative solutions they need to produce the most efficient, cost effective power transmission system.

What have you learned from walking other manufacturing trade shows that you would like to apply or incorporate into a future Gear Expo?

Gear Expo is going to continue to expand to include all parts of the power transmission system. We are looking for partners, including members, other pieces of the system, including bearings, couplings, and motors—and supporting trade association partners who can help us create the leading power transmission and automation event in North America.

The power to deliver on this vision is with our members working together, and with other associations and their members working together, in order to come together and create something this industry needs: a focused power transmission and automation event that supports the innovation efforts of our customer community.

For more information:
AGMA
Phone: (703) 684-0211
www.agma.org

FTM and Gear Expo 2017 at a Glance

Fall Technical Meeting (Oct. 22–24)

Individual Sessions:

- Session I: Efficiency, Lubrication, Noise and Vibration Oct. 22 (1 pm to 5 pm)
- Session II: Manufacturing, Inspection & Quality Control Oct. 23 (8 am to 12 pm)
- Session III: Application, Design and Rating Oct. 23 (1:30 pm to 5 pm)
- Session IV: Materials & Heat Treat Oct. 24 (8 am to 12 pm)
- Session V: Gear Wear & Failure Oct. 24 (1 pm to 5 pm)

Education Courses:

- **Taming Tooth Deflections** – Oct. 24 (8 am to 5 pm)
- **Basics of Gearing** – Oct. 24 (8 am to 5 pm)
- **Why Bearings are Damaged?** – Oct. 24 (1 pm to 5 pm)
- **Gearbox Field Inspection** – Oct. 25 (8 am to 12 pm)
- **High Profile Contact Ratio Gearing** – Oct. 25 (8 am to 12 pm)
- **Reverse Gear System Engineering** – Oct. 25 (1 pm to 5 pm)
- **How to Read and Interpret a Gear Inspection Report** – Oct. 26 (8 am to 12 pm)
- **Gearbox Maintenance** – Oct. 26 (8 am to 12 pm)
- **Material Selection and Heat Treatment of Gears** – Oct. 26 (8 am to 5 pm)

Gear Expo (October 24–26)

Schedule:

Tuesday October 24
Exhibit Hall (9 am to 6 pm)
Solutions Center (9:30 am to 5 pm)

Wednesday October 25
Exhibit Hall (9 am to 5 pm)
Solutions Center (9:30 am to 4:30 pm)

Thursday October 26
Exhibit Hall (9 am to 4 pm)
Solutions Center (9:30 am to 3:00 pm)

Heat Treat 2017

The ASM Heat Treating Society Conference and Exposition is co-located with Gear Expo 2017. It features more than 125 technical sessions, a special symposium on induction heat treating, basics of heat treating short courses and a "Taste of Columbus" networking event at the historic Columbus North Market. For more information, visit *www.asminternational.org/web/heat-treat-2017/home.*

2017 Gear Expo: Gears, Machinery — and a Whole Lot More

Jack McGuinn, Senior Editor

"For the past six years, Gear Expo has been growing and expanding with more suppliers and attendees meeting to build new partnerships and explore the latest technology on the market."

AGMA Management

Perhaps since its inception in 1987, there has always been a bit of back-and-forth over just what kind of show Gear Expo is.

Is it a gear show? A machinery show? Does it matter?

Given how trade shows, along with the industries they promote, evolve over the years — always with the critical goal of maintaining technological relevance — the "Does it matter" question makes the most sense. As technologies and applications advance, trade shows mirror those two areas and, more importantly, provide a hands-on look at the technologies of tomorrow. Gear Expo 2017 is no different in this regard.

With that said, however, the bi-annual show remains known as *Gear* Expo — and not, say — Grinding Expo, CNC Expo or Work Holding Expo. At the end of the day, it's about the gears. Make no mistake — the machinery on display at Gear Expo 2017 is a huge draw for the show. And machinery makers get a second — or third — bite of the apple with mega-shows like IMTS and Hannover Messe. But other *gear-intensive* shows? Not so very much — which is partly why Gear Expo enjoys ongoing success.

And yet, aside from the gear vs. machinery dynamic, there is so much more to Gear Expo than gears *or* the machinery that makes them. That's because it takes much, much more to make a finished gear than even the most sophisticated machine. And it is exhibitors who are part of the "much, much, more" that is addressed in this article.

The Big Machinery entities still command the largest booths and choicest real estate on the show floor. But if attendees are sufficiently inquisitive and so inclined, they will also explore beyond "the Midway" with its bells-and-whistles hardware and walk some aisles less traveled.

That's where you'll find exhibitors that some attendees may mistakenly consider superfluous to the show. Make no mistake — these exhibitors are in their own way as important to the overall gear manufacturing process as any gear or machinery maker.

Let's consider, by way of examples, five companies — a mix of second- and first-

time Gear Expo exhibitors. These exhibitors help personify the gradual change in Gear Expo's mission over the years. With the advent of ultra-high-tech industrial automation, mechatronics, IIoT, 3-D printing, and robotics, AGMA continues to fulfill its mission by expanding Gear Expo's reach to best reflect today's real world of manufacturing. With the inexorable, production-driven advances in manufacturing and industrial automation, some believe we are in the midst of a second Industrial Revolution. To AGMA's credit, Gear Expo 2017's array of exhibitors is an excellent example of how the show — and the industry it serves — have changed since its debut in 1987.

Here are five Gear Expo 2017 exhibitors that reflect the show's diversity, followed by some Q & A with their representatives. Three exhibited at Gear Expo 2015 and two will exhibit for the first time. More to the point: these five companies all make and sell markedly different things. And yet every one of them is essential to gear making. There are many links in the gear manufacturing process chain — all intended to help produce the best gears possible — from commodity gears to custom. You can visit them all at Gear Expo 2017.

Acme Wire Products Co., Inc. (Booth 1049) specializes in precision fabrication of components, parts, and products; e.g., metal components for OEM equipment or industrial processes, or custom wire-formed parts for medical or HVAC equipment.

Third Wave Systems (Booth 538). Third Wave Systems is a provider of validated material, physics-based modeling solutions and services. Software suites *AdvantEdge* and *Production Module* are designed and built to improve manufacturers' current machining processes, providing engineers access to better information than trial-and-error tests.

Turnkey Design Services (TDS) (Booth 636). The company manufactures micro metering pumps while providing various other engineering services. Hardware produced includes motor- and gearbox-driven pumps; high-speed and power gearboxes; motor-driven actuators; brushless DC motor controllers; and DC motors. The company works to effectively shepherd customer products from concept to development.

Tekfor, Inc. (Booth 818) manufactures precision machine parts and weight-reduced, high-performance components. The company was incorporated in 1999 and is based in Wooster, Ohio. Tekfor, Inc. operates as a subsidiary of Neumayer Tekfor Holding GmbH.

RUF Briquetting Systems (Booth 700) is a North American provider of industrial briquetting systems. RUF's system allows companies to create valuable products for the generation of heat and secondary raw materials by making briquettes from production residues — thus leveraging smart technology to improve business operations and protect the natural environment.

They are: Mary Fitzgerald, president — **Acme Wire Products**; Jennifer

Holt, marketing and events manager — **Third Wave Systems**; Robert Kennedy, owner — **Turnkey Design Services (TDS)**; Kevin Weldi, managing director-Americas, assisted by Robin Martin and Steve Ruvalcaba, key account managers — **Tekfor**; and Joe Michalewicz, sales and marketing — **RUF-Briquetting Systems**.

Mary Fitzgerald, Acme Wire Products

Would you say there is a greater emphasis on automation (gear drives, etc.) at this year's Gear Expo?

We won't know the extent of the automation emphasis until we are at the show. [But] it is reasonable to say that improvements in gear processing through automation yield more consistent product and reduce overall costs of mass-producing gears. The automation companies work in tandem with the gear producers to improve the processes.

Have you exhibited at Gear Expo before? Why do you exhibit at Gear Expo?

Acme Wire Products provides precision wire baskets and other components for OEM manufacturers.

Yes. We exhibit at Gear Expo to support the automation companies we work with and to increase the awareness of automation companies about the myriad ways steel baskets and trays can be used in gear processing.

Are you rolling out anything new or updated?

Our investments in equipment enable Acme Wire Products to provide custom baskets with shorter lead times without sacrificing quality or dimensional accuracy. Acme Wire Products is the premier domestic source for precision wire baskets and trays.

We have developed unique insert and tray configurations for existing customers and develop parts that best meet each customer's specific needs. We don't have a "one-size-fits-all" mentality, but we do recognize that our experience in this marketplace can definitely benefit our existing and future customers.

Has the show been successful for you in the past?

Yes, and we anticipate another successful show in 2017.

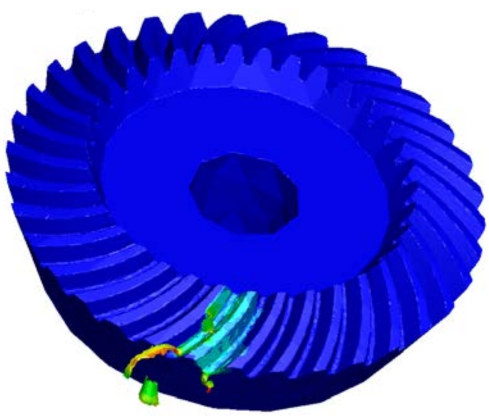
Jennifer Holt, Third Wave Systems

Why is Third Wave Systems exhibiting at Gear Expo?

"We exhibit at Gear Expo to gain exposure within the gear marketplace. For the most part we are new to this arena and we know it's a close-knit community. The more we can showcase our unique, one-of-a-kind software capability, the more the players in the gear industry can get to know us and become familiar with the software, evaluate the software and eventually implement the software into their gear machining processes."

(Holt explained that although this is the company's second Gear Expo, it represents a continuation of their efforts begun at the 2015 show.)

"[The 2015 show] was around the time when we started to transition our gear machining technology from the government project work we were doing to building a commercially available software package."



Is Third Wave Systems rolling out anything new or updated?

Yes. Earlier this year we released we *AdvantEdge Gear Machining v1.0* that featured capabilities for cylindrical hobbing. Then in June we released *AdvantEdge Gear Machining v1.1* that included capabilities for spiral bevel gear machining. In September we are planning another update that will speak to both features.

Has Gear Expo been successful for Third Wave in the past?

The 2015 show was successful for us in the sense that we met a lot of good people and were able to generate interest. We didn't necessarily come away with a lot of leads that turned into immediate sales, but we knew that was a possibility going into the show. We wanted to lay the groundwork in 2015 (since the show is every-other-year); so when we are back in 2017 we will have more robust gear machining capabilities to share with attendees—which we are very excited about!

Joe Michalewicz, RUF Briquetting Systems

As a former exhibitor, has the show been successful for you in the past?

Yes, we had several orders for both grinding sludge briquetters and for our metal briquetters from the last show.

Why exhibit at Gear Expo?

"There is a lot of grinding done during the process of manufacturing gears. RUF grinding sludge briquettes can eliminate the need to landfill the sludge and return valuable grinding fluid to be reused."

Are you rolling out anything new or updated?

Yes—the RUF 4/2300/60 grinding sludge briquetter.

Kevin Weldi, Tekfor

Would you say there is a greater emphasis on automation (gear drives, etc.) at this year's Gear Expo? And if so, do you see that trend continuing?

"Yes, there is a greater emphasis on automation which is one of the reasons that Tekfor has chosen to exhibit at this year's Gear Expo. "It is our belief that automation and integrated systems are a must to remain competitive in an automotive environment. Given the atmosphere in the automotive industry, we do see that emphasis continuing. Tekfor has embraced this trend and has been actively involved in improving automation and utilizing advanced technologies since 2012. And we only see the importance of this continuing to rise."

Has Tekfor exhibited at Gear Expo before?

No. While we've had attendees at the last several events, this will be The Tekfor Group's first time as an exhibitor at Gear Expo.

Why are you exhibiting at Gear Expo?

The Tekfor Group is a global partner for the automotive industry and a market leader in the creation, development and production of differentiated solutions for transmissions, engines, driveline, chassis, special applications and fasteners. With forging and machining in the U.S. and machining in Mexico, Tekfor has chosen to exhibit at Gear Expo 2017 because we feel this is a great opportunity to re-introduce our company to the North American market.

Are you rolling out anything new or updated?

Surprisingly, Tekfor's operations in the U.S. have been recognized as forge only. However Tekfor does offer a vast array of machining capabilities in North America and would like to share this with potential customers. Tekfor's

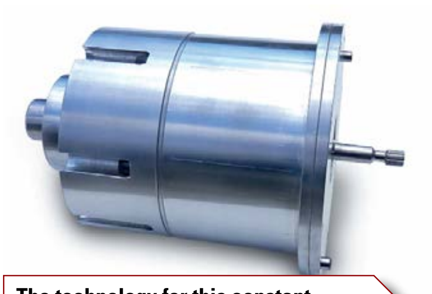
RUF-Briquetting systems will introduce the Ruf-2300 sludge machine at 2017 Gear Expo.

facilities in North America offer semi-finished and finished components ready for assembly. We also want to share knowledge of the global capabilities for cold, warm and hot forging and machining, with the option to localize in Mexico.

Having attended past Expos, what did Tekfor gain from that perspective?

It has been successful for us to better understand marketing and technology trends. But our goal now is to use Gear Expo for marketing and promoting The Tekfor Group's global brand as an innovative solution provider.

Robert Kennedy, Turnkey Design Services (TDS)



The technology for this constant-speed motor is demonstrated in a YouTube video at *https://youtu.be/QSVXYyHccs0*. The motor drives the VSD technology, whose output speed is electrically varied by a turning wheel.

Has TDS exhibited at Gear Expo before?

This will be the first time we will be exhibiting at the Gear Expo.

Why are you exhibiting at Gear Expo? Are you rolling out anything new or updated?

Turnkey Design Services is a full-service product development firm. We generate revenue by providing engineering services to companies, which includes gear design/gearboxes, and developing new technology for the military. The miniature pumps that we manufacture can be used for drones; the technology was developed for the Air Force. We will be displaying technology that we developed for the F-35 while under contract for the Navy. It is an electronically controlled gearbox that can change speed ratios across it on demand. This self-powering device consists of a planetary gear set coupled with a small generator. This

Mainshafts are a big part of automotive supplier Tekfor's product line.

technology allows a high-horsepower, gearbox-driven device to perform like a motor-driven device—without the weight penalty and associated reduction in reliability as with a high-power electric motor. The technology not only can change speed ratios on demand; it can also produce electrical power created by its self-contained generator.

For the F-35 application we are working with NAVAIR to control the main engine lubrication pump. By transforming the current gearbox-driven, fixed-displacement pump into a flow-on-demand pump, the aircraft's engine lubrication system temperature rise is reduced while reducing system weight and costs. This can generate a fuel savings of 4 to 5 gallons per day, per truck. Other applications include vehicle alternators, compressors and wind turbines.

For more information:
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Speed Matters – In Racing and in Hobbing

RCD Engineering's switch from manual to CNC hobbing operations breaks gear manufacturing lead time records with Bourn & Koch 100H in their gear production pit crew

Joe Goral Sr.

RCD Engineering (Race Car Dynamics) is a 50-year-old Northern California manufacturer of starters, blower drives, crankshafts, camshaft drives and other components used by National Hot Rod Association drag race teams and other racing circuits to move at speeds of 300+ mph.

For many years, RCD relied on an old manual Barber-Colman 6-series gear hobbing machine (built in the 1960s) to create idler gears used in their camshaft drives; but they were experiencing long lead times with their finish grinding operations and wanted to make a change. Jason Leach, Production Manager at RCD, explains the old process: "We cut blanks, machined the gear blank front and back, roughed the teeth in, milled the holes (they need to be clocked to the teeth), deburred manually, sent the gears out to heat treat (4 days shipping there and back), recut bore and faces of the gears to true up after heat treating, sent out for finish grinding (4 days shipping there and back), and finally applied finish coating."

This long, nine-step process took about eight weeks, but it could go even longer if their finish grinding source was backed up. After bringing the Bourn & Koch 100H gear hobbing machine on to their team in 2016, though, RCD has cut the process down to just four steps and has eliminated the need for finish grinding services altogether.

The key to changing the process was being able to cut heat-treated blanks (Rockwell 46-48) and clock the gear teeth to the timing marks or mounting holes on the new equipment while achieving the same AGMA 10+ quality as RCD's customers had come to expect.

"Since purchasing the 100H, we have changed our process," says Leach. "We now cut blanks, heat treat the blanks, machine gear blanks front and back on our turn mill complete with holes and timing dots, then rough and finish the teeth on our Bourn & Koch 100H. We have cut our lead time on these gears by 50%."

Standard Bourn & Koch sample hobbed on Barber-Colman 6-10.

50% Faster Overall Production AND 30% Faster Gear Cutting Cycle Times

"In addition to eliminating finish grinding operations," explains Leach, "we have noticed about a 33% faster run time on the hobbing operation alone versus our old mechanical hob." And because RCD tricked out their 100H with the optional deburring attachment, they found they could eliminate manual deburring operations as well. They were able to bring the deburring process inline on the 100H and complete it in one setup.

The 100H is part of Bourn & Koch's line of H-Series horizontal gear hobbers. H-Series machines are designed to produce AGMA Class 10+ quality external spur and helical gears in a compact footprint. The machines are manufactured and assembled in Bourn & Koch's Rockford, Illinois facility by precision machine tool builders with decades of experience.

Each machine is CNC-controlled with servo-motion on precision linear roller ways, hand-scraped bearing surfaces and accurate ball screws for easily achieving high tolerances. Bourn & Koch's conversational HMI with full touch-screen control panel guides the operator through the gear cutting process, reducing the need for specialized training to operate the machine. In fact, the HMI on the 100H allowed a new user with just one AGMA basic gear manufacturing training class and less than 40 hours of training and gear hobbing experience to cut a sample gear at least 25% faster than an operator with 40+ years of experience could cut the same gear on an old, manual Barber-Colman (see details of the time study in the sidebar).

Leach confirms that the transition

to the CNC machine was smooth. "We bought the 100H to replace our old Barber-Colman 6-10 mechanical hob, and the learning curve was not nearly as steep as I expected. The CNC control is very user friendly and easy to learn. The process for creating the programs is simple."

RCD enlisted Bourn & Koch's help to create the program that ensured the gear teeth were clocked to their mill work in the same place for each gear. This service got RCD's CNC program on the right track. But one of the biggest advantages for RCD of moving from Barber-Colman to Bourn & Koch was the compatibility of the tooling.

100% tooling compatibility between the old and new

Workholding can be very expensive to replace. So, the fact that Barber-Colman 6-10 model tooling is compatible with the new Bourn & Koch 100H means companies can benefit from a lower investment moving from manual to CNC operations.

One reason for the compatibility? In 1985, Bourn & Koch, Inc. acquired the machine tool division of Barber-Colman. And since then, Bourn & Koch have continued the tradition of manufacturing world-class gear manufacturing machines in Rockford, Illinois, just a few short miles from where Barber-Colman once did the same.

Another reason for the compatibility is that when approaching a new machine design, customization or re-engineering challenge, the Bourn & Koch team can draw from the years of time-tested engineering know-how available to them in their OEM archives. 125+ years of parallel OEM records (from 1889 to present day) are being carefully preserved in the climate-controlled Bourn & Koch facility.

The valuable archives consist of all original assembly drawings, bills of material, electrical diagrams, hydraulic schematics, detail prints, and spare parts inventories from over 30 American-made classic machine tool brands — including Fellows, Barber-Colman, Devlieg, Bullard, Motch, Jones & Lamson, Acme-Gridley, Blanchard, Brown & Sharpe and many more. Add up the number of years each machine tool company existed and you arrive at 2,500 years of combined engineering know-how.

In keeping with Bourn & Koch's philosophy of retaining the best features on legacy machine tools, the company had the foresight to retain compatibility with spindle bolt patterns so that customers would have an easier time making the transition to Bourn & Koch's 21st century machine tool offerings.

The same bolt pattern used on the spindle of the Barber-Colman 6-10 model gear hobbing machines is used on the new Bourn & Koch 100H hobbing machines. And the larger Barber-Colman 16-16 and 14-15 models are compatible with new Bourn & Koch 400H gear hobbing machines' bolt patterns as well. This compatibility allows RCD and other Bourn & Koch customers to use their existing collet chucks, face drivers, and other workholding devices on brand new equipment.

RCD is a Fan of Bourn & Koch's Adjustable Speeds and Feeds

"Our Barber-Colman was doing eight gears per hour... rough cut only," explains Leach. "On the Bourn & Koch 100H, we initially set up the machine to rough *and* finish cut one gear in four minutes (which is 15 gears per hour)." RCD was impressed with that speed, but also with the fact that they could use the "Speed and Feed Change" feature to tweak the speed-to-quality ratio. "We slowed the finish feed down a little to reduce the distance between scallops and improve the AGMA rating." They now run 10-11 gears per hour with rough and finish passes resulting in an AGMA 12-14. This was the perfect balance of speed and accuracy for the idler gears.

"The great thing about this machine," Leach concludes, "is the range you have to adjust feed and speeds easily to fit your needs." The 100H gear hobber with Bourn & Koch HMI is available with a standard Fanuc 0i-F CNC — other options for CNC controls are available as well. The control includes the Automatic Single- or Double-Cut Cycles (with speed and feed change between cuts) as well as Crown Hobbing or Taper Hobbing Cycles, Automatic Hob Shifter (with parts per shift counter), and Power-Programmable CNC Hob Swivel for accurate setting of hob slide.

Beyond the Machine — Custom Workholding, Cutters, and High Quality Service

"Having good fixtures is paramount in manufacturing quality gears," states Leach. "We purchased one workholding fixture from Bourn and Koch to elimi-

Photo of hobbed RCD Engineering 48T 10 D.P. 11 hole Vernier cam gear in Bourn & Koch engineered face clamping fixture.

nate any issues during the part run-off prior to machine delivery. We were provided a print with our fixture so that we were able to design and make our own work holding fixtures for our other gears."

"We also purchased all of our PM6 and carbide cutters from Star-SU," Leach adds. "And we use Star-SU's resharpening services. We have found them to be fairly priced with good return times." Star-SU has been Bourn & Koch's trusted partner in distributing their gear manufacturing machinery for over a decade. Star-SU also supplies the hobs and shaper cutters for all of Bourn & Koch's gear manufacturing machinery.

In addition to custom-designed workholding fixtures and cutters, the expert Bourn & Koch Customer Care and Field Service Groups can provide engineering support, custom-tailored preventive and predictive maintenance programs, operator training, and field services such as machine leveling/alignment; tool installation; recertification; rebuilds/retrofits; and diagnosis and repair of mechanical, electrical, hydraulic issues.

A few "Mods" take RCD from Classic to Modern Hobbing…and supercharge gear production

Bourn & Koch is proud to be able to have helped Race Car Dynamics (RCD) Engineering transition to a more accurate, modern 100H gear hobbing machine that had the ability to rough and finish cut heat-treated blanks for their crankshaft and camshaft gears; match the gear teeth to timing dots; and eliminate the need for finish grinding outsourcing. RCD is happy to have made the successful move from manual to CNC gear hobbing operations with AGMA 12-14 quality gears as the result. And RCD customers are cheering at the drastically reduced gear set lead times.

RCD plans to move other gear production tasks over to the Bourn & Koch 100H gear hobbing machine in the near future, including some gear sets for starter motor gear heads and helical bronze gears for their magneto drives. The Bourn & Koch crew say they will be ready to help RCD light 'em up!

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Joe Goral Sr. started working for Bourn & Koch in September of 2013, providing support service for Bullard & other vertical turning machines. Since then, he has moved into a technical support & applications role for Bourn & Koch, specializing in gear hobbing and vertical grinding applications. Joe attended the AGMA Basic Gear Training in April of 2017 to supplement the training he has received on the shop floor at Bourn & Koch.

Bourn & Koch Electrical Engineer Kenneth Braswell programming a Bourn & Koch 100H with full touch screen display.

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Gear Hobbing Time Study: Old vs. New

To test and validate the speed with which an inexperienced operator can cut a gear using the new HMI control on the 100H Gear Hobber, Bourn & Koch conducted a detailed time study in May 2017. The study compared the setup, workholding, programming/gear change, and cutting times required to cut a standard sample gear on a Barber-Colman 6-10 Gear Hobber (fully restored to OEM specs) and a brand-new Bourn & Koch 100H Gear Hobber. The gears from each machine were inspected, and detailed quality results are available by request.

The operator of the Barber-Colman had 40+ years of experience running Barber-Colman gear hobbers. The operator of the Bourn & Koch 100H had less than 40 *hours* of training and operating experience and had merely completed the AGMA Basic Training for Gear Manufacturing class in March 2017.

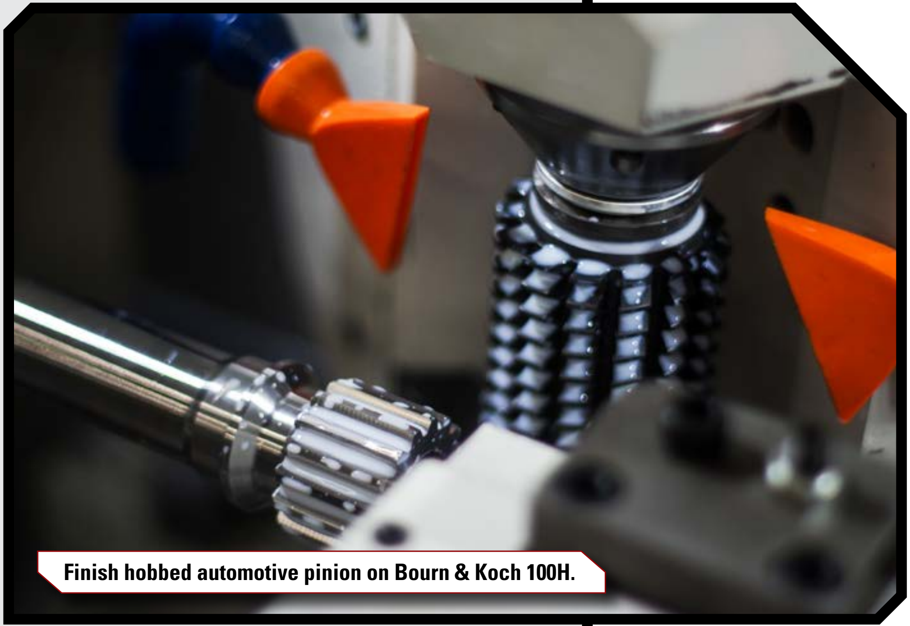
The sample gear was a 30-tooth helical with a 2-inch face width. The operator with 40+ years of experience cut the sample gear on the Barber-Colman 6-10 Gear Hobber in 34 minutes, 31 seconds total time to complete the first gear. The inexperienced operator cut the same sample gear on the Bourn & Koch 100H Gear Hobber in 25 minutes, 43 seconds total time to completion — a 25% time savings on the new machine vs. the old. The time savings was accumulated across all stages of the operation — from set up of the hob and workholding (10% faster on the Bourn & Koch 100H), programming/setting up and changing gears (50% faster on the Bourn & Koch), and cutting time (which was 25% faster on the Bourn & Koch).

The sample gear was hobbed using a single cut on the Barber-Colman and took 15 minutes, 39 seconds to complete. On the Bourn & Koch, a 2-cut cycle (climb & conventional) was used to achieve a speed of 11 minutes, 57 seconds total cut time. This shows the newer, Bourn & Koch machine to be approximately 25% faster than the old school hobber.

Surprisingly, the greatest time savings was in the CNC programming step of the test. The inexperienced operator with just one training class under his belt, was able to program the Bourn & Koch 100H machine to run the 2-cut cycle in just 4 minutes, 11 seconds. The experienced operator spent a total of 8 minutes and 20 seconds setting up change gears on the Barber-Colman. These results show the old Barber-Colman to be 50% slower in this phase of the time study.

The sample gear cut during this time study on the Bourn & Koch 100H was measured to AGMA Q-9 on the lead and involute, with an AGMA Q-11 on the index. Not bad for the inexperienced operator's first gear! The old Barber-Colman achieved quality scores of 7 for Index, 0 for lead, and 3 for involute. With a bit more training, the inexperienced operator could easily increase the quality of his results in subsequent tests, leaving the Barber-Colman even more solidly in the dust.

For the full report of this time study, please go to *www.bourn-koch.com/timestudy* or call 815-713-2367.



Finish hobbed automotive pinion on Bourn & Koch 100H.

The Right Tool for the Job

When a gearbox remanufacturer is trying to decide whether to regrind or replace a gear, any number of factors could be running through their head. Here are some remanufacturers' processes on how they reach the conclusions they do, and why you should listen to them.

Alex Cannella, Associate Editor

Any time a gearbox needs to be repaired, the question comes up: do you regrind or replace the damaged gears?

No gearbox remanufacturer answers the question quite the same way. For some, whether to regrind or replace a gear is a case by case problem based on a number of factors, while for others, it comes down to a few simple black and white questions. Some answers are about feasibility, while others look more at practicality. But one thing that did come across from each repair shop was that choosing the correct method to repair a gear is a matter of choosing the right tool for the job.

According to Circle Gear President, Mike McKernin, however, remanufacturers often have to back up a step before they can pick a tool. There are a wealth of considerations to make when deciding whether to regrind or replace, but the first that always needs to be looked at is money.

"It's economics, there's no question," McKernin said.

Repair guys like McKernin can study a gear to decide whether or not a regrind is feasible until the end of time, but it won't matter if the customer has monetary or time restrictions that force them towards one solution or another or, alternatively, their heart is already set on what they want.

Sometimes, a gearbox remanufacturer will look at a gear and decide it's safe to regrind, but a customer will accept nothing short of a full replacement with brand new gears. Or a gear might be so damaged that the only recourse is replacement, while the customer insists on getting the gear reground in the hopes of saving time or money. There could be any number of reasons behind it, but a disconnect between what a remanufacturer says can be done and what a customer is willing to purchase is not uncommon.

"I think that's your first consideration: would the customer consider a regrind rather than a replace? And then you start looking at the engineering parts of it," McKernin said.

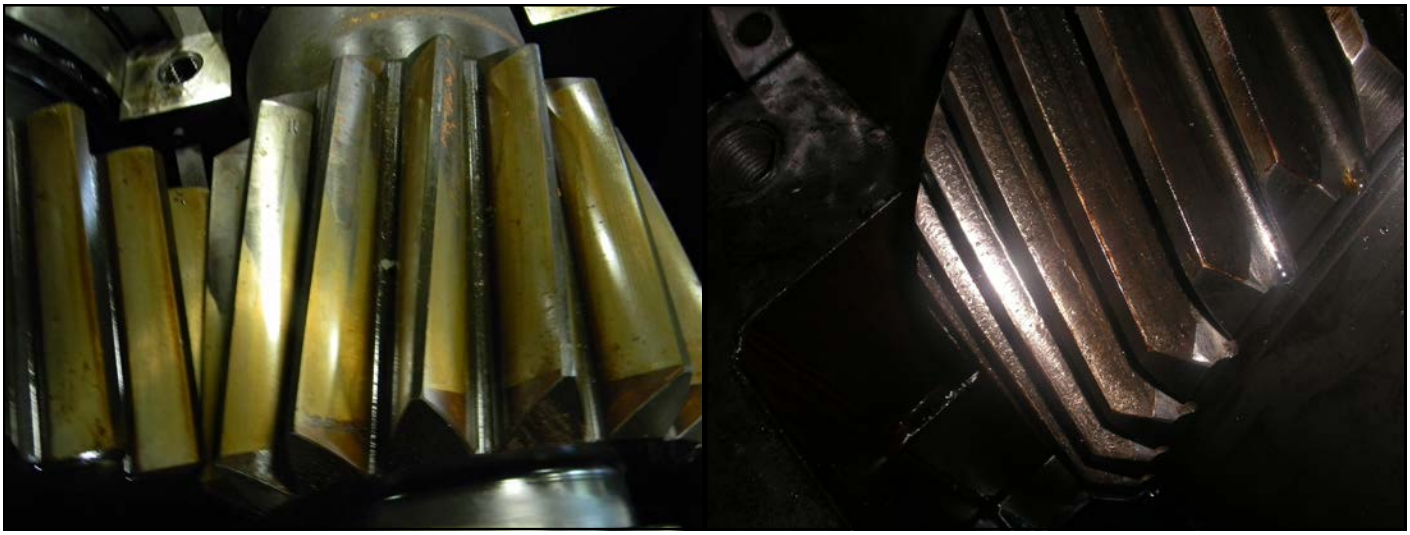
Dick Calvert, senior gear engineer at Chalmers & Kubeck, echoed McKernin's point. Calvert has regularly encountered customers who might benefit from a full replacement, but because of whatever economic or time factors involved, needed just a regrind.

"In the long run, you're going to give them what they want," Calvert said.

Economics are an active consideration beyond just the negotiating table. One thing McKernin looks at when deciding whether or not to regrind, for example, is the size of the part being considered. While regrinding is generally considered the "economic" option, McKernin has found that it can actually be cost prohibitive to regrind small gears as opposed to replacing them.

"If it's a little 2 inch diameter part, the cost of regrinding may not be economically sound," McKernin said. "You're just better off replacing a little component. Now if you're dealing with something that's 30 inches, that's a lot of material you're throwing away. So now you're looking at 'can we save some money by doing a regrind on the part?' And in some cases, saving the customer a fair amount of money."

Once it comes time to actually decide if regrinding is feasible, there are a wealth of new factors to consider,



Pictured: one gear that has suffered light wear and can be reground (left) and a gear that will need to be replaced (right).

and every gearbox that McKernin and Calvert look at needs to be judged on a case by case basis.

"I wish I had a real nice sweet little punch list that I could go through, but every situation is different, so you have to look at it based on its own merits," McKernin said.

The application the gearbox is being used for, which parts need repair, the gear's existing geometry, how hard the gear is, whether it needs to be recut or reground, the gear's case depth, the amount of wear already on the gear and how much stock would have to be removed to fix it, and whether the pinion can be replaced or not are all critical factors that McKernin looks at when deciding whether a regrind is possible.

One of the primary deciding factors for Calvert is how hard the gear is. For softer gears that may have only been hobbed, regrinding the gear is a relatively straightforward process: Grind down the OD surface of the gear to smooth out the imperfections, then make a mating oversized pinion to compensate for the lost material on the gear. Regrinding only becomes a questionable option if the gearbox already has an oversized pinion or the damage is truly severe.

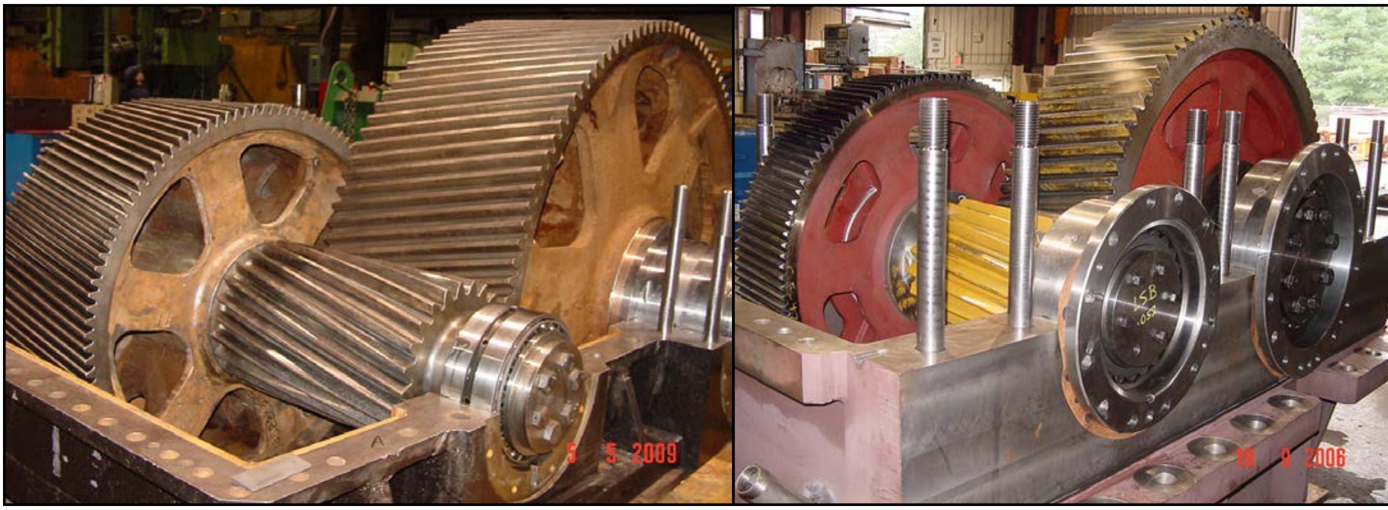
For harder, carburized or induction hardened gears, however, case depth becomes an obvious concern. Damage to a gear can often be bad enough that the gear needs to be ground down past its case depth, in which case the gear's hardness falls below acceptable levels. The only option in these situations is to replace the gear.

"If you've got wear that you're trying to clean up that exceeds the case depth, you're wasting your time," McKernin agreed. "It's not a good idea. Don't even consider it."

Calvert and McKernin have very similar processes when it comes to deciding whether to repair or replace a gear, but there is one point they disagree on: whether regrinding is better than replacement. While there are often cases where regrinding just isn't a feasible or safe option, McKernin prefers regrinding to save the customer money. He always likes to at least consider regrinding specifically because of how economic it is compared to the alternative, both in time and money.

"If it's feasible, I would definitely recommend it because you're saving the customer money," McKernin said. "I try to look at a project as if it was my own. If I was the one paying the bill, how would I want to work with it? And it's a matter of having a feasible economic solution. So if there's a way to save money and provide the correct quality, that makes perfect sense to me."

Calvert, on the other hand, prefers to suggest a full replacement to his customers when possible. Though Chalmers & Kubeck splits their work roughly half and half between replacing and regrinding, Calvert thinks there are more advantages to replacing a gear than just



A cutter drive before being upgraded by Chalmers & Kubeck (left) and one after repair work is complete (right).

repairing it.

Calvert is also such an advocate of replacement because of a value-added service Chalmers & Kubeck offers: If the job calls for gear replacement, the company can often improve a gear's capacity by 15 or 20 percent with small geometry changes at no additional cost while they're at it. When a gear is already in need of replacement, it's a valuable service that the customer loses nothing using, and Calvert urges them to take advantage of it.

"What we tell our customers is: 'listen, this is here because it's failed. If I replace it in kind, guess what's going to happen?'" Calvert said.

Outright replacement, however, isn't always an option. For Calvert, time is one of the strongest motivators to regrind instead of replace. Sometimes, the customer already has a replacement lined up, making the job less time sensitive, but when a production line is down, the repairs need to be as fast as possible, and replacement isn't always a speedy option.

"If it's a spare unit or a unit that's not used much, he can wait maybe a month or a month and a half to get the thing repaired. If it's part of a line, and the line is down, he wants you to do it by tomorrow!" Calvert said.

In general, Chalmers & Kubeck can replace a pinion in a week and a soft gear in three. Calvert refers to soft gear replacements as the company's "bread and butter." But for harder gears that require heat treatment, that number can turn to 8 to 10 weeks. That's understandably hard for a manufacturer with a downed line to swallow, and so it's in these situations that Chalmers & Kubeck turns to regrinding. In extremely rare and special cases, Chalmers & Kubeck will even make a soft gear to serve as a temporary replacement while a hardened gear is put through the longer carburizing process. While the temporary gear will likely only last a month or two before breaking, it can last long enough to get a proper replacement while maintaining profitability.

One method that Chalmers & Kubeck does not employ is to grind a little from both the gear and its matching pinion. Calvert strongly disagrees with this viewpoint because of the increased backlash it puts on the gear.

"Everybody will tell you that if the loading on the gears is not reversing, a little bit of extra backlash doesn't matter," Calvert said. "And sometimes that's right, but sometimes it's not right. In steel rolling applications, for instance, TAF [Torque Amplification Factor] is a big thing. The sudden impact that occurs when a slab or bar enters the rolls, creates very high dynamic loads, loads that can be many times normal running loads. All of this is aggravated by backlash, so you can't just go increasing backlash arbitrarily. If you know the application and the nature of the loading, you may be able to convince yourself that extra backlash will not be a problem. However, in most cases, we find that may not be the best solution…not because of what we know, but because of what we don't know."

Gearbox Express, on the other hand, takes an entirely different approach from Circle Gear and Chalmers & Kubeck. At Gearbox Express, replacement is almost always the option. According to CEO Bruce Neumiller, roughly 80 percent of the work they do is replacement. The company makes their decisions on the best way to repair a gearbox based on factors such as the type of gears that need to replaced and the quality of their material. And unlike other remanufacturers that might bend on whether a gear needs a full replacement, Gearbox Express's decisions are final and non-negotiable.

That all might sound like a hard-line stance to some, but according to Neumiller, Gearbox Express has good reason. They exclusively repair gearboxes for the wind power industry, and gearboxes for wind turbines have a lot less wiggle room than other industrial applications, which makes regrinding a more difficult option to recommend and leads to the company's skewed balance of replacement to regrind work.

"With an industrial gearbox, there is a lot more safety factor in the design, so you can get away with a lot more than you can in wind," Neumiller said.

The tight specifications of the wind industry aren't the only cause for Gearbox Express's disproportionate amount of replacements. Damaged gearboxes regularly come to the remanufacturer with gears made with poor materials, a problem Neumiller describes as "fairly prevalent" in the wind industry. Often, they're forced to throw out and replace gears because the base materials originally used to make them aren't up to the company's specifications.

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Express Gear (not to be confused with Gearbox Express) finds that on the opposite side of the spectrum, steel and sugar mills are the customers that often lean more towards regrinding. However, according to Sam King, CEO of Express Gear, the company still splits their regrind and replace work 50/50. Express Gear primarily decides between the two by looking at a gear's wall thickness. According to King, if damage has gone beyond a certain threshold, the company replaces, and if not, regrinds.

However, Express Gear adds an extra step to their regrinding process that sets them apart from their peers. After grinding down imperfections in the gear, the remanufacturer welds on new material to return the gear to its original dimensions. No need for oversize pinions or increased backlash. According to King, Express Gear can return these gears back to the customer "like they came from the OEM."

If there's one thing that's clear between each of these different companies' accounts, it's that no one remanufacturer's process or opinion is ever quite the same. One universal truth, however, is that these are professionals who have often been working in the field for decades, and they've each formed these opinions based on countless prior jobs and established best practices.

From the customer's standpoint, there's very little to be "done" in the remanufacturing process. The best thing they can do is find a remanufacturer they can trust and make sure they listen to them. Gearbox remanufacturers aren't the car repair shop technician that mysteriously finds three things wrong with your car when you bring it in for a routine oil change; when they give recommendations, it's after considering a broad range of factors often unique to that individual case and are giving their best advice on which solution they believe will make the longest lasting gears at the best price.

It may be painful to hear that you're going to have to wait a few weeks to get a gear replaced, or you may be dubious about the merits of regrinding to keep a gear from breaking back down in a year, but at the end of the day, these guys are the experts and they know best. The best advice the customer can take away is to listen to them and value their opinion.

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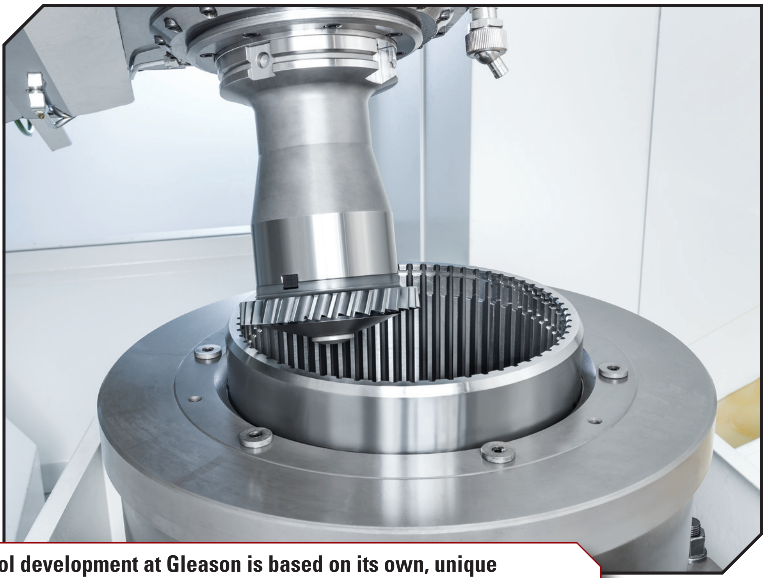
Skiving: A Manufacturing Renaissance

Matthew Jaster, Senior Editor

Skiving will be front and center when the gear industry comes together in Columbus this October. Attendees will find dedicated skiving equipment, multifunctional machines with skiving options and a slew of new cutting tools, machine designs and modifications to make the process more efficient and robust.

Although the skiving process has been around for a very long time, the industry continues to make adjustments where needed. Companies are reinvesting and reinventing how to present their customers with skiving capabilities. *Gear Technology* recently spoke with several companies to discuss where this highly productive process fits into gear manufacturing in 2017.



Tool development at Gleason is based on its own, unique simulation software and technology know-how.

Tool Technology

One area that has improved tremendously is the tools used for the skiving process. In the last few years, engineers from Gleason Cutting Tool Corporation in Rockford, Illinois and application engineering at Gleason-Pfauter operations in Germany and Switzerland have developed a new generation of power skiving tools that match the specific requirements of its customers.

"For soft machining, different substrates like G50 and G70 are used which, in combination with Gleason's AlCroNite Pro advanced coatings, deliver hardness and toughness characteristics needed for both productivity and optimum tool life during power skiving," said Udo Stolz, vice president worldwide sales and marketing at Gleason.

"Carbide tool development and execution are becoming more important today. Gleason has created capacities to design and manufacture these kinds of tools. For power skiving, we have a very special situation: The best design and execution is not worth much if you don't understand the process and its characteristics in every single cut. Tool development at Gleason is based on its own, unique simulation software and technology know-how," Stolz added.

The Gleason 100PS power skiving machine offers small to medium-sized workpieces in module range up to 2.0 mm.

Of course, better substrates and coatings helped to increase tool life, but the main step forward was the modern cutting strategy of the multi-cut-cycles with sometimes over a dozen cuts, according to Oliver Winkel, head of the application technology department at Liebherr. "This improves the cutting conditions a lot and gives the tool a chance," Winkel said.

In the beginning, Star SU/Samputensili used its knowledge of the shaping experience to make the choice of cutting material and coating combination. Early on, however, they realized, due to the special characteristics of the skiving process, extreme thermal and mechanical loads were occurring on the tool, which placed special demands on the tool's design and the choice of the material and coating combination.

"Today, with our experience, our designers choose the geometrical tool features like number of teeth, helix angle, clearance angle and profile corrections to offer our customers a high-performance skiving tool to achieve their process and quality demands. We are providing the market with skiving tools out of high speed steel and carbide. Together with our customers we develop custom fit material and coating combinations to have the best solution for each application," said Thomas Ware, product manager — gear tools at Star SU.

The tool team at MHI has developed three types of specialized skiving tools. First, the conventional pinion type cutter was introduced. All other suppliers of skiving tools

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are utilizing this type of tool. To greatly improve tool life, the tapered barrel helical cutter was developed.

"The most recent development is the three piece assembled cutter which was introduced to further advance tool life and metal removal rates," said Dwight Smith, vice president at Mitsubishi Heavy Industries America. "The patented Super Skiving tools have multiple cutting edges for creating the tooth space rather than just one cutting blade. By using a tapered roughing portion, three blades are involved in the cutting action."

While carbide cutting tools are preferred, Tim Sadek, engineering director—bevel gear division at Klingelnberg, believes the most critical tooling aspect is the design and the cutting strategy. "At this point in time, we focus on coated PM-HSS cylindrical Monobloc tools with dry cutting."

Liebherr's LK 500 opens a new chapter in gear skiving.

The Skiving Market Today

Attend any metalworking trade show and you'll hear a pitch or two about advancements to the skiving process. This includes new tooling, automated capabilities, deburring capabilities and partnerships that continue to help evolve gear skiving.

Introduced at JIMTOF 2016, the MHI MSS300 Super Skiving machine is the only system designed and built specifically to utilize the productivity of the new Super Skiving tools. These new tools require exceptional machine rigidity and stiff synchronization of the work table with the tool spindle. In the past, skiving was held back by machine tools that weren't rigid and stiff enough, and lacked robust spindle synchronization, according to Smith.

Winkel said that the Liebherr LK300 and LK500 for workpieces up to 500 mm diameter and module 5 mm will be presented at the upcoming EMO fair in Hannover, Germany and Gear Expo in Columbus, OH. The machine will have a tool changer and an integrated deburring device.

"Based on our decade-long experience in designing gear cutting machines, the machines are typically Liebherr-style, thus


Star-SU Scudding cutters.

Dedicated Versus Multifunctional

A debate that can be applied to many gear production processes is whether or not you should consider dedicated equipment or multifunctional machines for your gear shop needs. *(Ed's Note: See accompanying Toyoda article on page 56 for more on multifunctional capabilities).*

Most dedicated machines fulfill all the needs of the high-speed and high-dynamic skiving process. Winkel at Liebherr says that a customer can reach the best quality and lowest cycle times on serial production parts and believes programming with a dedicated HMI is easier and matches all the requirements of gear manufacturing.

"A general purpose machine has all necessary axes to do the movements, but will never reach the productivity of a dedicated gear cutting machine. And don't forget about the gearheads behind the machine," Winkel said. "Who do you call, if there is an issue? You need the necessary technology knowhow and the skilled application engineers to cover those questions and problems."

Smith at MHI says that for the mass production of internal ring gears using skiving, a dedicated machine offers the highest productivity and reliability because it has been designed specifically for this application.

"A general purpose machine is just that—designed for general machining. It may be able to skive, but compromises are inevitable if a specific machine is also expected to mill, drill, etc. As we have learned from 56 years of manufacturing gear equipment, the dynamics of the generating process are very demanding. If a company has occasional requirements and small lot sizes for skiving, a general purpose machine may serve this need."

very rigid and strong to handle the high dynamics of skiving. In combination with the Liebherr skiving tools and skiving technology, this will lead to a full package which we call Liebherr Skiving^3 (cubic skiving)," Winkel said.

Stolz at Gleason says that the latest technology developments take place in the field of hard power skiving. "Today, no efficient process for hard manufacturing of internal gears exists. As manufacturing solutions for hardened gears become increasingly important, especially in the context of electric mobility, Gleason is in the pole position related to hard power skiving developments on cylindrical as well as on bevel gear manufacturing machines," Stolz said.

Another important feature is the integration of deburring capabilities into power skiving tools for soft machining, where Gleason has developed and implemented a unique solution.

Gleason has successfully tested and installed highly productive power skiving machines for large workpieces up to 900 mm in diameter and module 9, certainly unique for dedicated skiving machines.

For several years StarSU/Samputensili and Profilator have been in an alliance to offer the market a tool and machine tool technology package *(Ed's Note: See article on page 54).* Profilator's Scudding process offers the market the possibility to use the skiving process as a soft as well as a hard machining process for internal and external gears. "Furthermore, together with Profilator we offer all customers the advantage to run a dry cutting process which avoids all the negative factors of a wet cutting operation," Ware said.

The MSS300 Super Skiving machine is designed specifically for the high-speed manufacturing of automotive internal ring gears.

The integration of power skiving on Klingelnberg's bevel gear cutting machines enables the customer to use the full capacity of the machine tool.

Dedicated skiving equipment — at least at Gleason — is designed to counteract torque and forces immanent to the power skiving process, resulting in higher productivity and cutter life on dedicated machines, according to Stolz.

He believes general-purpose machines are not designed for the power skiving process but for other processes like turning, milling, drilling etc. While power skiving as an add-on always asks for compromise, general-purpose machines have the benefit of combining different operations in a single production machine. "We recommend the use of dedicated power skiving machines for small/medium and in some cases even large lot sizes if the gear is the focus of the task," Stolz said.

Sari at Samputensili said that during skiving, the cutting speed results from the rotation speeds of tool and workpiece as well as the set cross-axis angle. Today the cutting speeds, now being implemented with modern machine and tool technology, are up to $v_c = 250$ m/min. These high spindle speeds produce high process dynamics. "To avoid the negative effects of the process dynamics on the process, it is necessary to use a dedicated skiving machine that is tailor-made to control the process," Sari said.

He continues, "This is the only way to ensure that vibrations are minimal and a rigid machine structure provides an optimal quality result. Most state of the art machining centers for standard milling or turning operations, do not have the stiffness and stability in the tool spindle, to meet our customer's requirements to produce high quality gears. This can only come from dedicated gear manufacturing machines."

Based on the company's experience in designing gear cutting machines, Liebherr's machines are very rigid and strong to handle the high dynamics of skiving.

Sadek at Klingelnberg believes that the integration of power skiving on bevel gear cutting machines enables the full capacity of the machine tool. The high stability of the bevel gear cutting machine C 30 gives significant advantages. "From our knowledge in bevel gear technology we work on the integration of the deburring process, automatically loading and closed loop," he added. "This will advance in the foreseeable future."

For Winkel at Liebherr, the future will be introducing carbide skiving cutters in the market as an option to PM-HSS as well as providing the skiving technology for bigger and smaller parts (meaning additional new skiving machine on other platforms).

Future Considerations

Gear Expo 2017 will give attendees the best industry preview of things to come regarding skiving technology. Many companies asked to participate in this article said they would have much more to discuss about the skiving process at the show. There is skiving technology today that is only scratching the surface, so to speak, of what machines will be capable of in the future.

"In the next three to five years, Gleason will stay focused on continuous improvement of the process and tool development. Related to the machines, the focus will be on faster changeover of tools and workpieces and integration of additional processes," Stolz said. "Even if significant progress has been made in the past years, hard Power Skiving is still in its initial development phase. Market penetration will increase and Gleason will stay in the forefront of this interesting development."

The gear and transmission industry continually asks for more weight reduction in transmission designs and this will become even more important in the future, according to Sari. This leads to more complex and integrated part designs. If the design is focusing on the objective of weight reduction, other requirements like machinability becoming secondary.

"In such cases, we as gear manufacturers must develop our processes in this direction to offer the market technologies which could reduce overrun lengths of the tool or combined machining steps to realize integrated transmission parts. Skiving offers us the possibility to machine highly integrated parts with different gearings (internal and external) in one machine using one clamping and less tool overrun space. Additionally, skiving machines with integrated technologies like turning or milling will become important," Sari said.

Skiving technology is always in flux. Winkel describes how Liebherr developed and offered skiving machines way back in the 1960s but with much different results. "We failed like all others due to insufficient tool life and gear quality," he said.

"In the beginning of this century Liebherr looked at reinventing or maybe re-investigating skiving again, with the aim to be faster than hobbing and replace shaping. Unfortunately, the research focused too much on tool improvement rather than on cutting strategies," Winkel said. "So, we did not succeed and postponed the technology. Several years later, we took a new attempt and this time, we did much better."

If at first you don't succeed…

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Hard Scudding: The Future Has Arrived

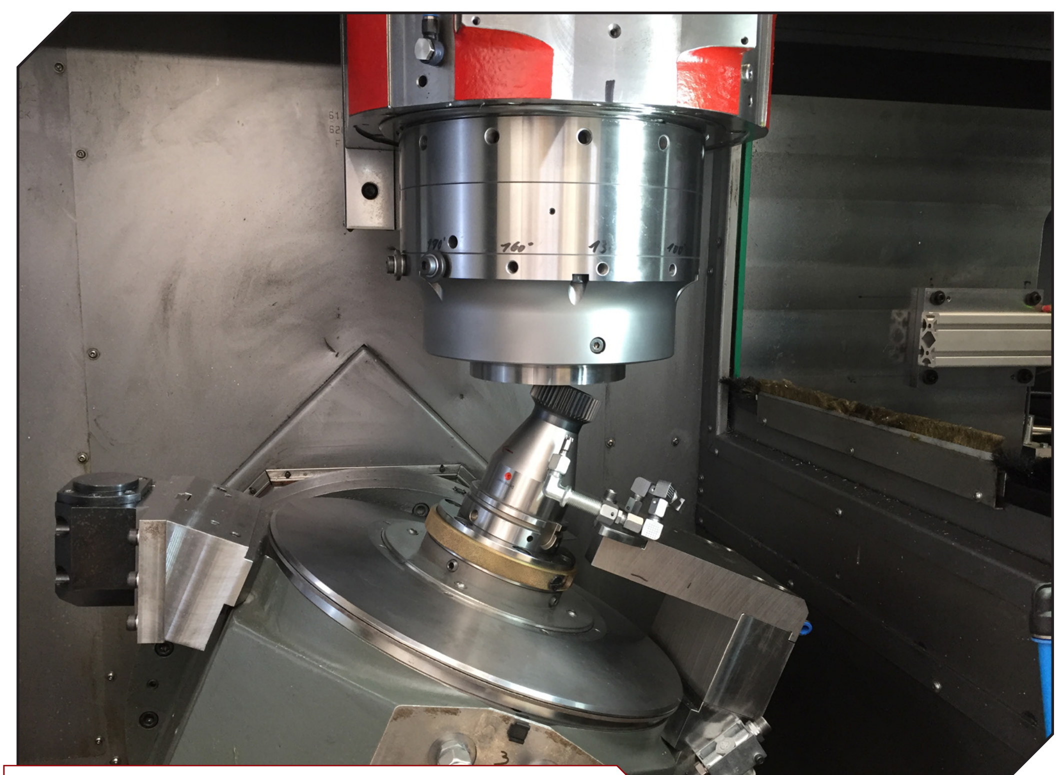
Scott Knoy, VP, GMTA

Just a few years ago, the concept of Scudding left the traditional skiving method in the dust, so to speak, for gear production used primarily in the powertrain buildup. This process, 5–10 times faster than gear shaping, formed the surface of the workpiece through several, small enveloping cuts, providing a surface finish and part quality level that was far superior to hobbing, shaping or broaching. Scudding is a continuous generating process, meaning no idle strokes on the machine tool, as when shaping gears.

Ring gears, sliding sleeves and annulus gearing, whether internal helical or spur, external helical or spur or blind spline, synchronizer parts with block tooth features and synchronizer hubs remain among the popular products in the market, made with Scudding technology. Today, this continuous gear cutting process is widely used in production environments for internal, external, helical and spur gears, as well as splines and other components in the powertrain world. The machining can be done without the need for an undercut or groove (clearance) and the lead of the gear can be manipulated via axial motions (crown/taper). It is a demonstrated superior technology and automotive suppliers have embraced its advantages for many years now.

As the science of Scudding has rapidly evolved, the interest in the more advanced process "Hard Scudding" is increasing at a feverish pitch. In 2015, Profilator in Germany introduced the concept of "Hard Scudding" to the market and began to run exhaustive testing on it. In order to have an optimum process, the parts being run had to be either heat-treated via carburization or through-hardened. This is due to the fact that a minimum of 60 microns/flank needed to be removed in the Hard Scudding process to be successful and guarantee clean-up, that is, no blank material remaining.

In order to control the initial testing, we and our German partners developed a process whereby the parts would first be subjected to Gear Scudding on a Profilator machine in the soft or green condition, then sent to a local heat-treat vendor for carburization and then returned to Profilator, where we would re-cut via Hard Scudding.



Today, Scudding is widely used in production environments for internal, external, helical and spur gears, as well as splines and other components in the powertrain world.

The results of the green Scudding produced parts that were in the DIN quality 6-7 range. As you see in Figure 1, this is a typical inspection chart of one of the ring gears. The profile appears to be within the DIN 6-7 range and the lead is also very good, showing DIN quality of 3-5. The characteristics of runout and index are also in better than acceptable ranges.

The cutting time for this part was 50 seconds and when load/unload time was added, the floor to floor cycle time was 60 seconds. As this test centered around the hard processing, we were not concerned with optimizing the green Scudding process, which we knew could be optimized to decrease the cutting cycle by at least 10%.

The parts were then loaded and transported to a local heat-treat vendor for carburization. When the parts were returned, they were measured to determine the loss of quality and roundness from the heat treat process. We found that the trend in the heat-treated parts indicated they were shrinking and losing their roundness, as a result of the carburization. A representative chart can be seen in Figure 2. Here, we see that the overall quality of the gear decreased 2-3 DIN quality levels.

Seeing the severe out-of-round condition, Profilator decided that they would either need to use a rounding machine to bring the parts back into a round shape or grind the outside diameter and datum face. Due to the limited availability of equipment, it was decided to grind the outside diameter to increase the roundness and also grind the datum face to insure flatness.

When the parts were introduced into the Hard Scudding process, the same machine was used for the testing, with the only difference being the addition of a contact stock division sensor, which is required for the Hard Scudding process. We targeted the Hard Scudding time at 45 seconds in order to remove the approximately 60 microns of hardened stock/flank. Together with the load/unload time, we achieved a total cycle time time of 55 seconds. The test ran 200 parts and the cutter was in excellent condition at the end of the test, with no visible wear.

Looking at the chart, we see that the quality coming from the Hard Scudding operation was quite good. The overall DIN Quality in the profile direction is Q6, with Q5 in the lead direction. The index error and the radial runout were also greatly improved and can be seen in Figure 3.

The surface finish of the parts was also quite remarkable, as seen in figure 4. The Ra/Rz measurements can be clearly seen, and in no case do we see any value over 0.46 Ra and 2.3 Rz. This is an impressive result, as it is in line with much more expensive abrasive gear finishing processes such as threaded wheel grinding, form grinding and gear honing.

All in all, it appears that the future of the Scudding and now Hard Scudding processes our company has pioneered is quite bright. Whether you are looking to process your parts in the green or finish hardened parts, Scudding can be a viable process for gear manufacturers of all shapes and sizes.

Obviously, there are limitations, but note that, not long ago, we told the market Scudding processes were useful in perhaps 10–20% of all gear applications. Today, that number has better than doubled and continues to grow, reaching into the much higher production ranges.

For more information:
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As the science of Scudding has rapidly evolved, the interest in the more advanced process "hard scudding" has increased.

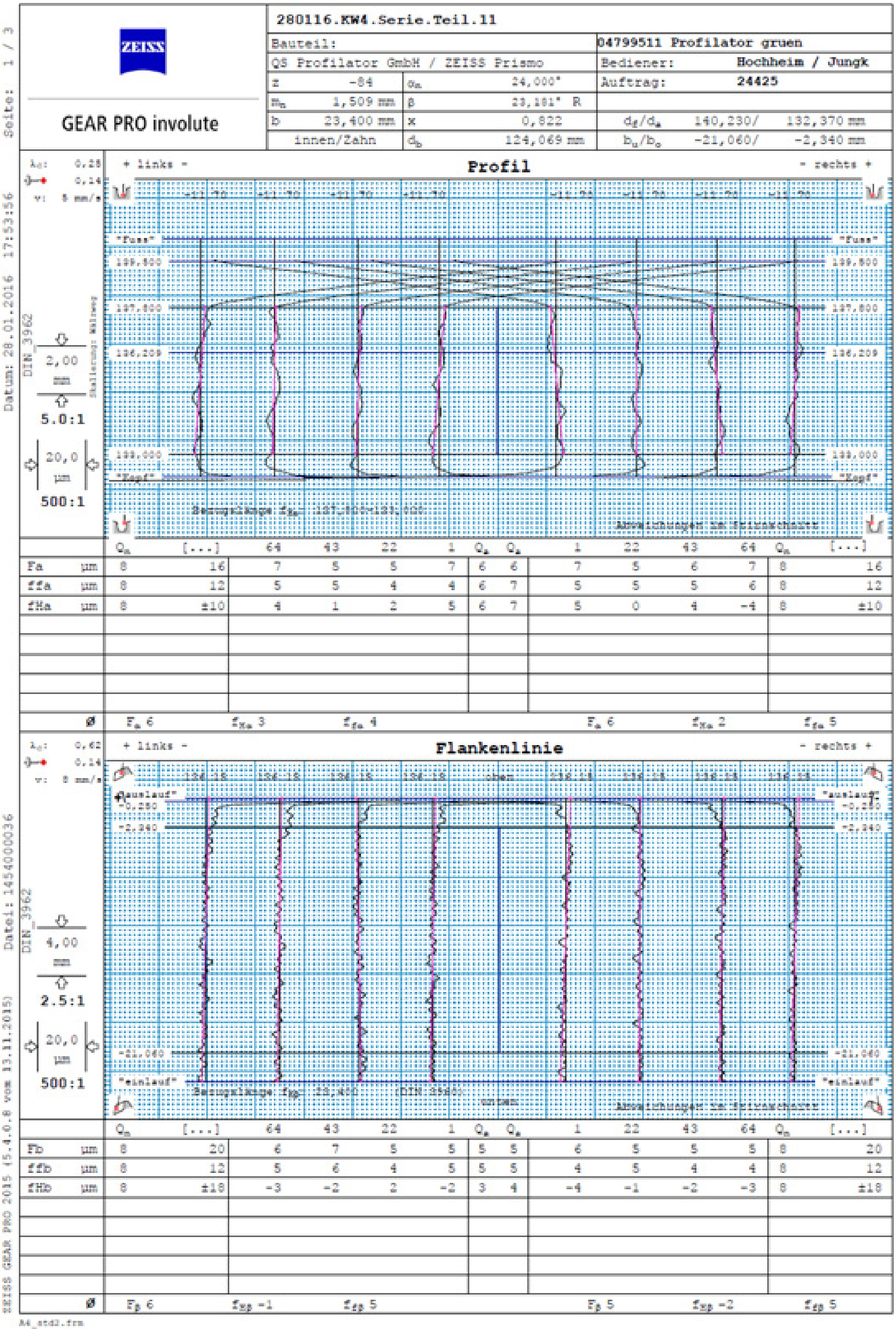


Figure 1a **Results after Green Scudding.**

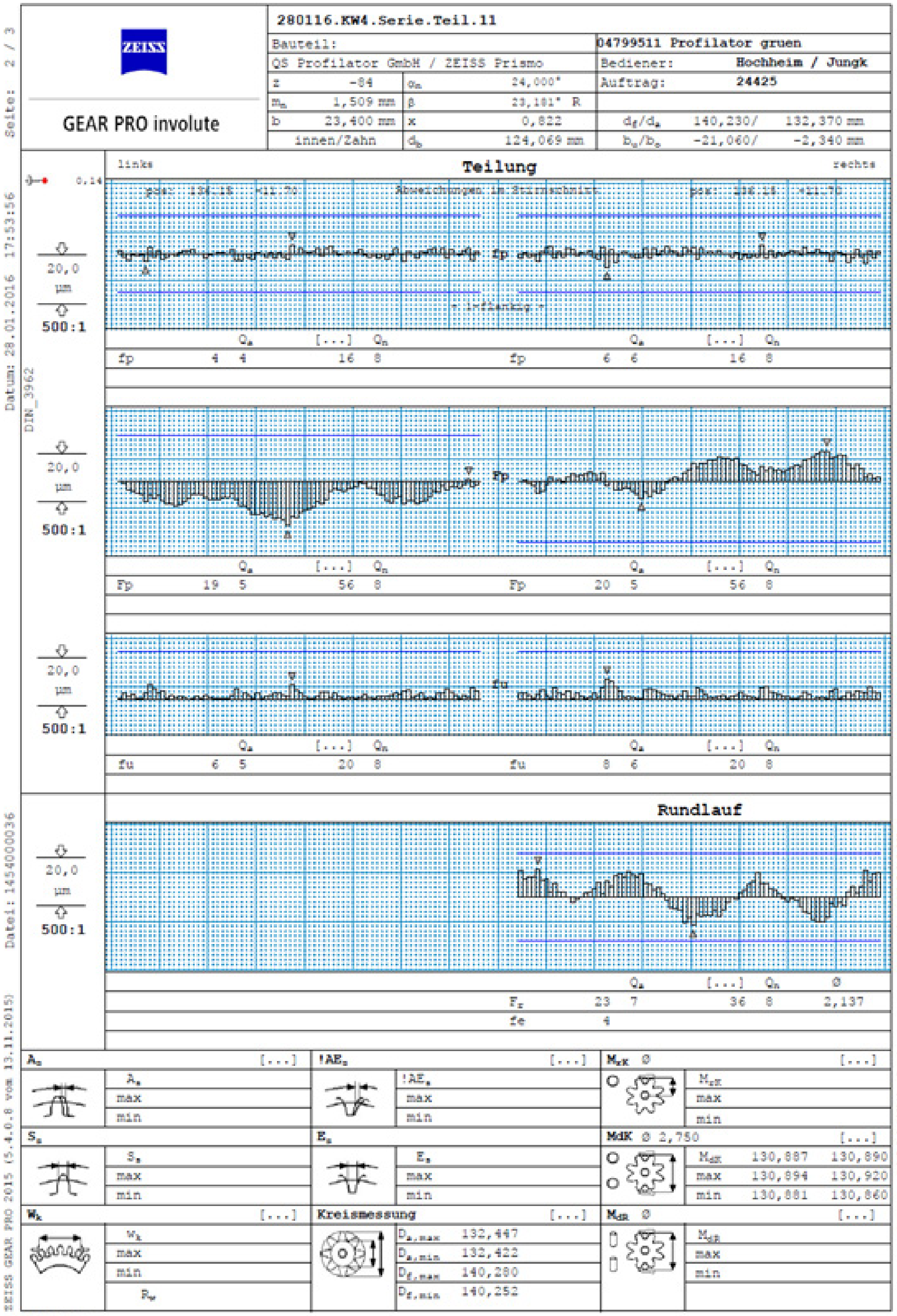


Figure 1b Results after Green Scudding.

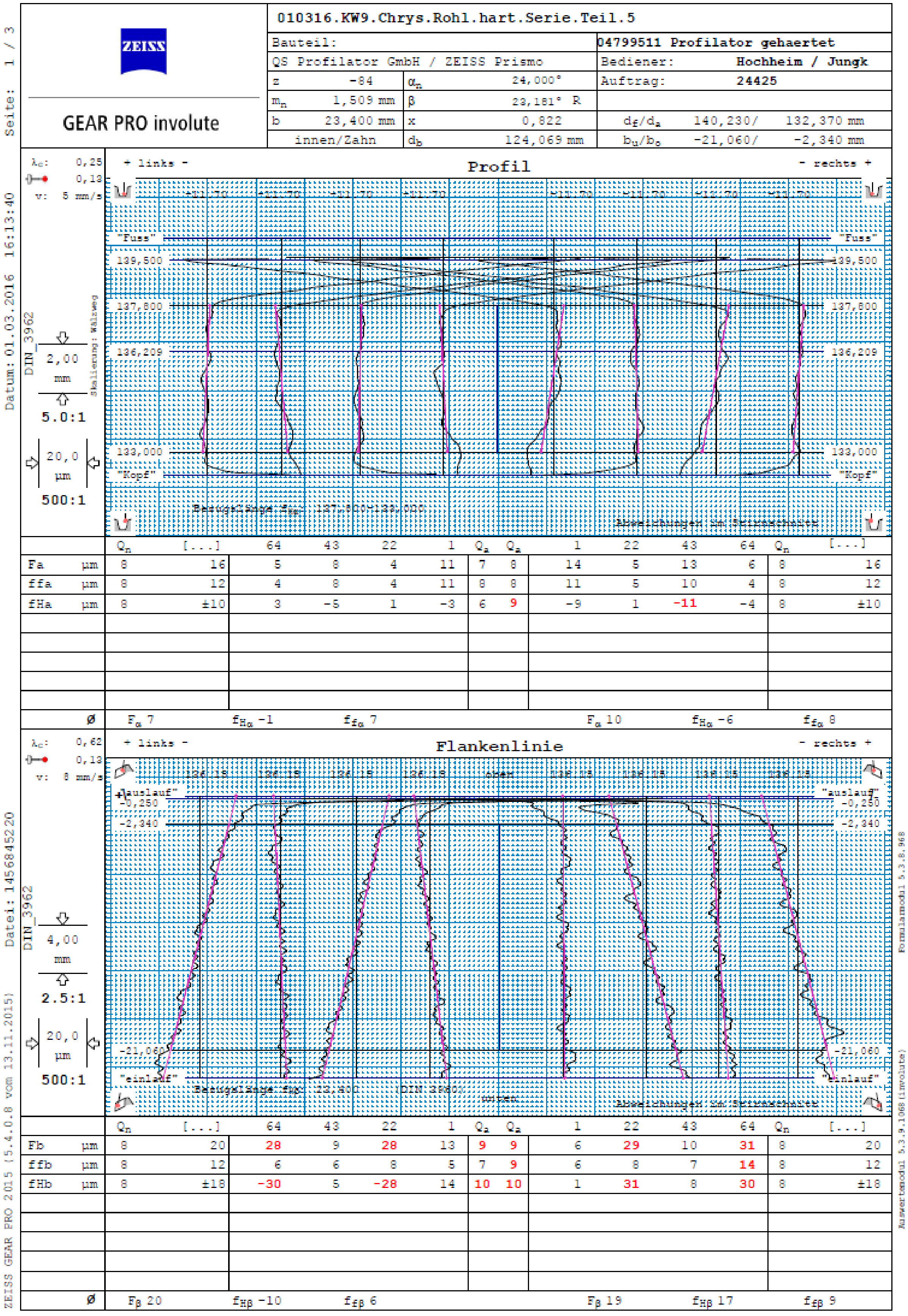


Figure 2a Post heat treatment via carburization.

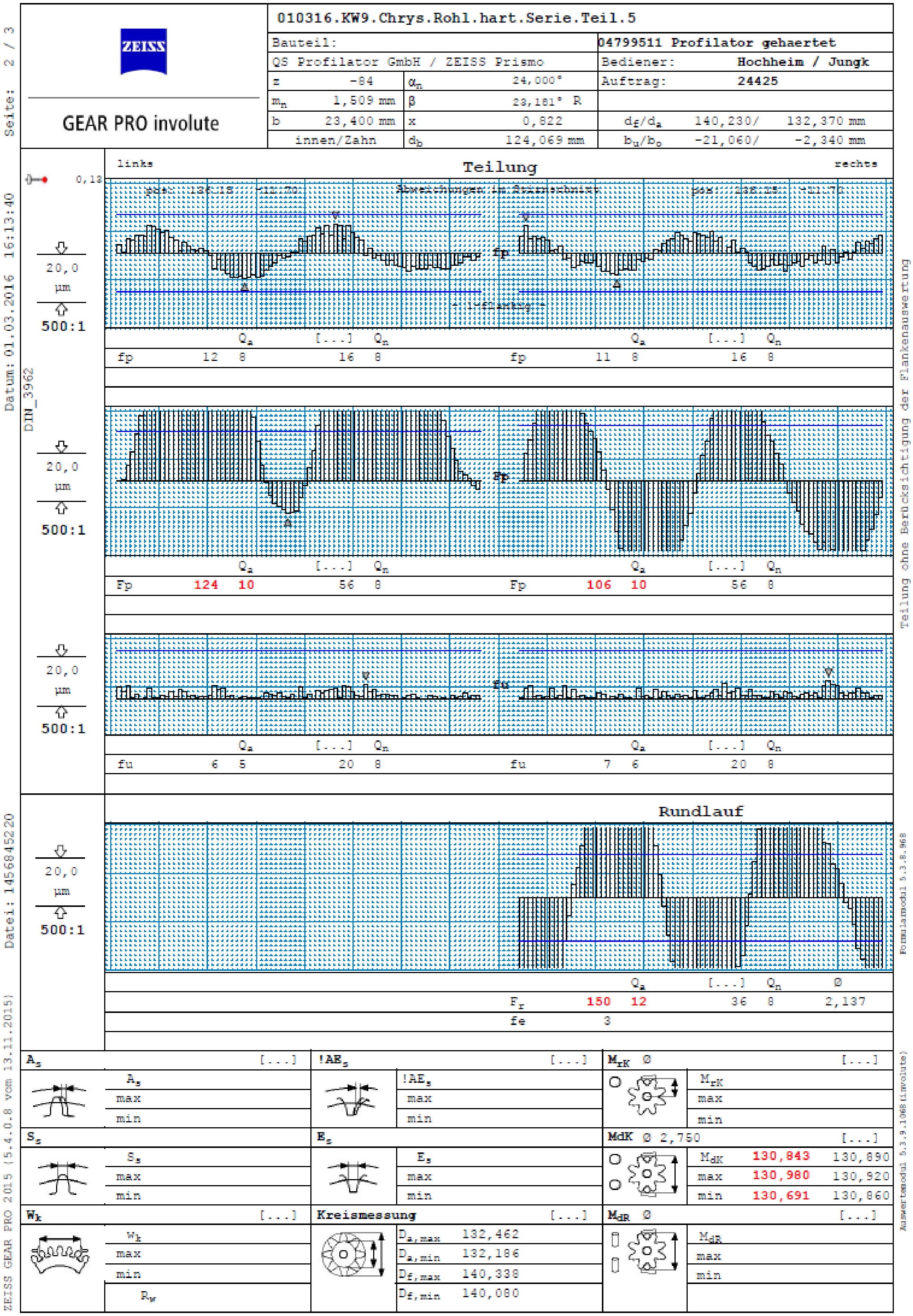


Figure 2b Post heat treatment via carburization.

Page: 1 / 3	08062016.KW23. E11			
ZEISS	Bauteil:		04799511 Profilator gehaertet	
	QS Profilator GmbH / ZEISS Prismo		Bediener:	Hochheim / Jungk
	z -84	α_n 20.500°	Auftrag:	24425
	m_n 1.467 mm	β 22.500° R		
GEAR PRO involute	b 23.400 mm	x 0.822	d_f/d_a	140.230/ 132.370 mm
	Internal/Tooth	d_b 123.640 mm	b_u/b_o	-21.060/ -2.340 mm

Date: 08.06.2016 13:51:52

DIN_3962

λ_c: 0.25 / 0.50 / v: 5 mm/s

Scaling: Roll distance 2.00 mm 5.0:1 / 20.0 µm 500:1

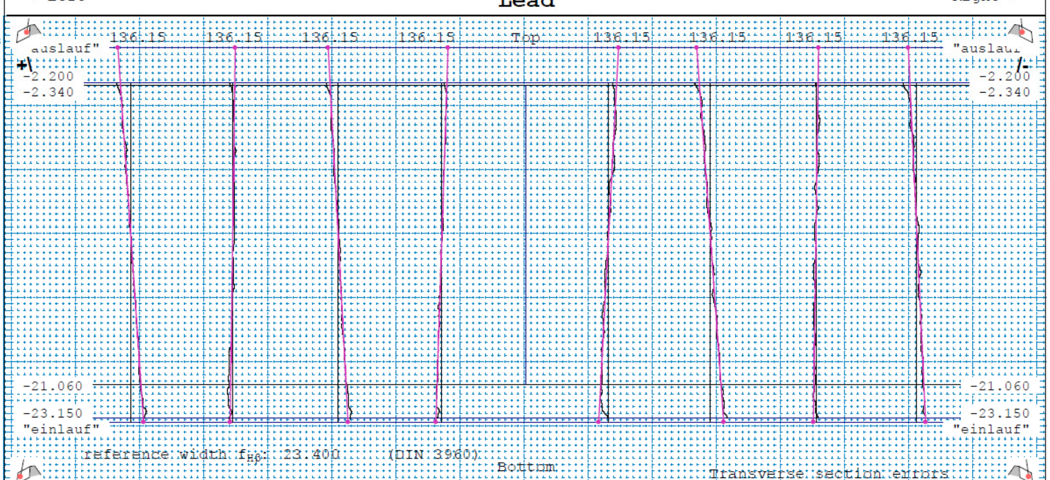
+ Left − **Profile** − Right +

		Q_n	[...]	64	43	22	1	Q_a	Q_a	1	22	43	64	Q_n	[...]
Fa	µm	8	16	4	5	4	7	6	6	7	7	6	6	8	16
ffa	µm	8	12	2	2	3	1	4	4	2	1	2	1	8	12
fHa	µm	8	±10	4	5	3	8	8	8	8	7	6	6	8	±10
	ø	F_α 5		$f_{H\alpha}$ 5		$f_{f\alpha}$ 2				F_α 6		$f_{H\alpha}$ 7		$f_{f\alpha}$ 2	

λ_c: 0.62 / 0.50 / v: 8 mm/s

DIN_3962 4.00 mm 2.5:1 / 20.0 µm 500:1

+ Left − **Lead** − Right +



		Q_n	[...]	64	43	22	1	Q_a	Q_a	1	22	43	64	Q_n	[...]
Fb	µm	8	20	7	2	6	3	5	6	5	8	2	6	8	20
ffb	µm	8	12	2	2	2	1	2	2	2	2	2	3	8	12
fHb	µm	8	±18	8	-2	6	-4	6	6	-6	8	-2	6	8	±18
	ø	F_β 5		$f_{H\beta}$ 2		$f_{f\beta}$ 2				F_β 5		$f_{H\beta}$ 1		$f_{f\beta}$ 2	

File: 1465386712

ZEISS GEAR PRO 2015 (5.4.0.8 vom 13.11.2015)

Form module 5.3.8.968

Evaluation module 5.3.9.1068(involute)

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Figure 3a After Hard Scudding.

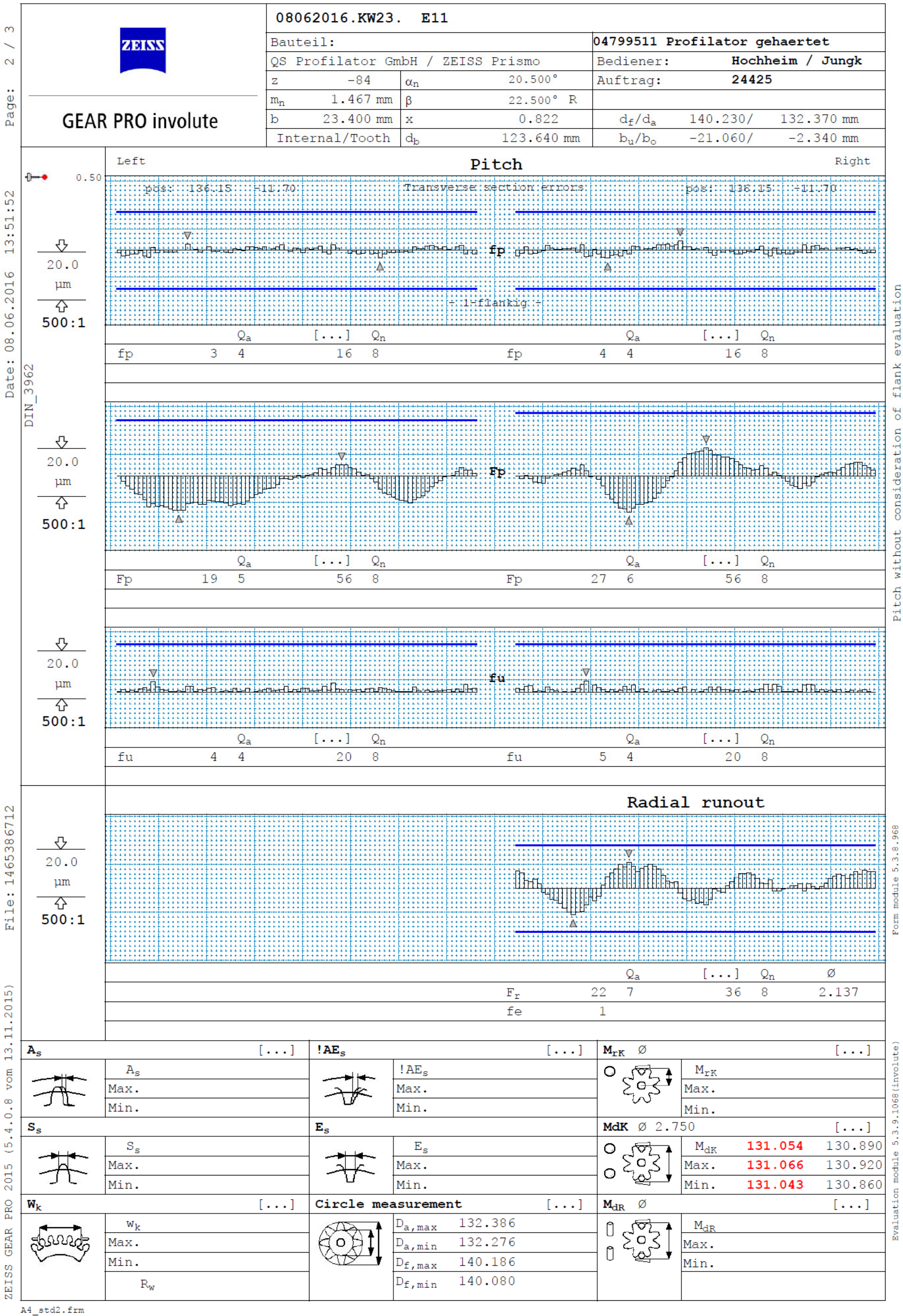


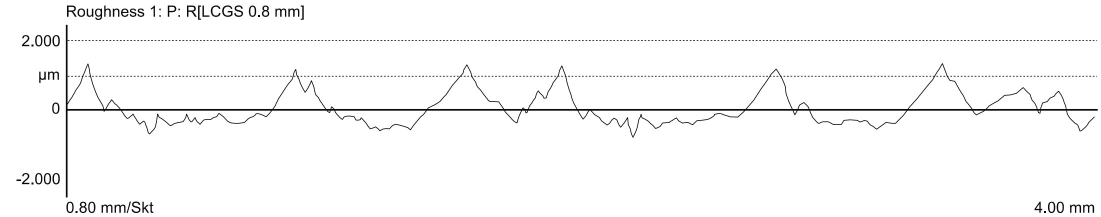
Figure 3b After Hard Scudding.

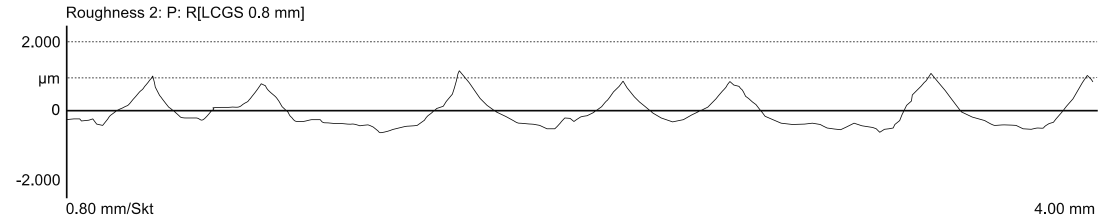
Mahr MarWin 8.00-28	Oerlikon Barmag Task: Roughness	08.08.2016 1 13:24:44 Auditor:
Part: **Ring Gear**	Drawing # Step: **327-16**	**Warzanowski** Signature:
Tooth 1	**Test:** Longitudinal Director-Lead	
Tooth Flank Left/Front	**Measurement:** 1 to 3*	

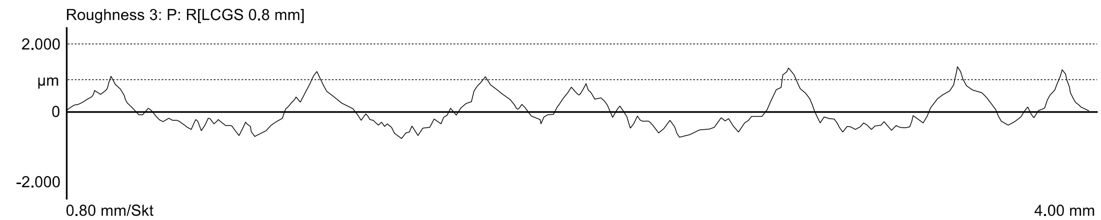
Comments:
*3 x je 0,25mm offset

Measuring Device:	MarTalk
Feed Unit:	DriveUnit.PGK 120
Tracer:	MFW-250:2 (#260) 1.8%:

Lt:	5.60 mm
Ls:	2.50 µm
VB:	+/-250.0 µm
Vt:	0.50 µm
Points:	11200







Roughness Values-Roughness 1: P: R[LC GS 0.8 mm];					
Ra	0,3820 µm	0,0000			0,0000
Rz	1,7479 µm	0,0000			0,0000
Roughness Values-Roughness 2: P: R[LC GS 0.8 mm];					
Ra	0,4519 µm	0,0000			0,0000
Rz	2,0842 µm	0,0000			0,0000
Roughness Values-Roughness 3: P: R[LC GS 0.8 mm];					
Ra	0,4522 µm	0,0000			0,0000
Rz	2,2829 µm	0,0000			0,0000

	Ra	**Rz**
	µm	µm
Mean Value	0.4287	2.0383

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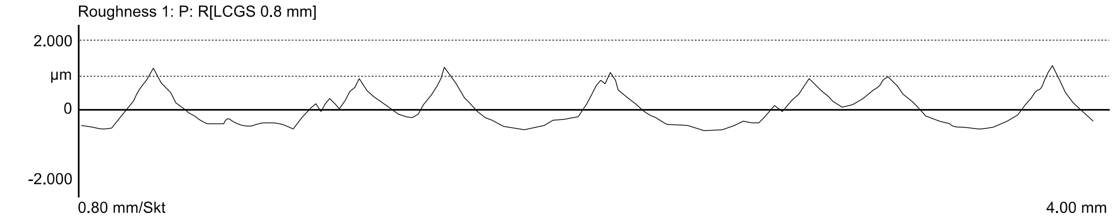
Figure 4a Surface finish charts.

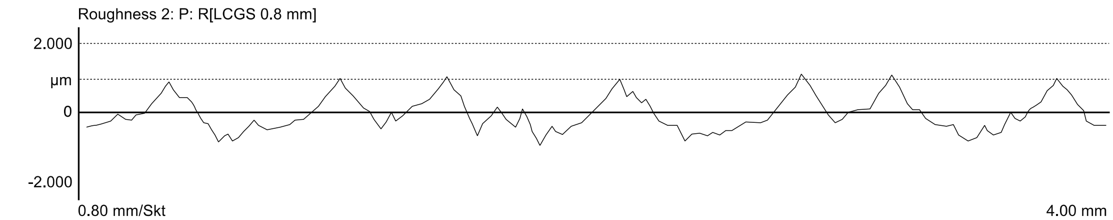
Mahr MarWin 8.00-28	**Oerlikon Barmag** **Task: Roughness**	**08.08.2016** **1** 13:20:51 Auditor:
Part: **Ring Gear**	Drawing #: Step: **327-16**	**Warzanowski** Signature:
Tooth 1	**Test:** Longitudinal Director-Lead	
Tooth Flank Left/Mid	**Measurement:** 1 to 3*	

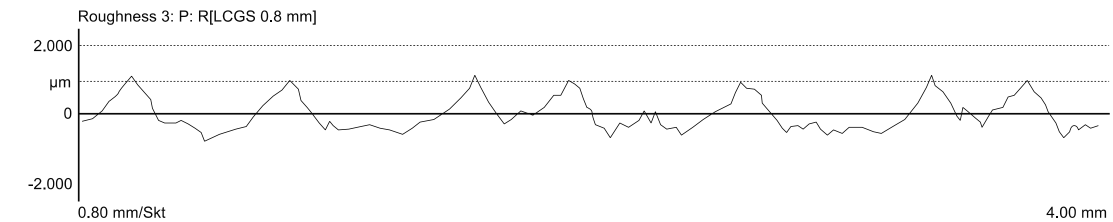
Comments:
*3 x je 0,25mm offset

Measuring Device:	MarTalk
Feed Unit:	DriveUnit.PGK 120
Tracer:	MFW-250:2 (#260) 1.8%:

Lt:	5.60 mm
Ls:	2.50 µm
VB:	+/-250.0 µm
Vt:	0.50 µm
Points:	11200







Roughness Values-Roughness 1: P: R[LC GS 0.8 mm];					
Ra	0,4133 µm	0,0000			0,0000
Rz	1,8070 µm	0,0000			0,0000
Roughness Values-Roughness 2: P: R[LC GS 0.8 mm];					
Ra	0,3924 µm	0,0000			0,0000
Rz	1,8721 µm	0,0000			0,0000
Roughness Values-Roughness 3: P: R[LC GS 0.8 mm];					
Ra	0,3884 µm	0,0000			0,0000
Rz	1,7651 µm	0,0000			0,0000

	Ra	**Rz**
	µm	µm
Mean Value	0.3980	1.8147

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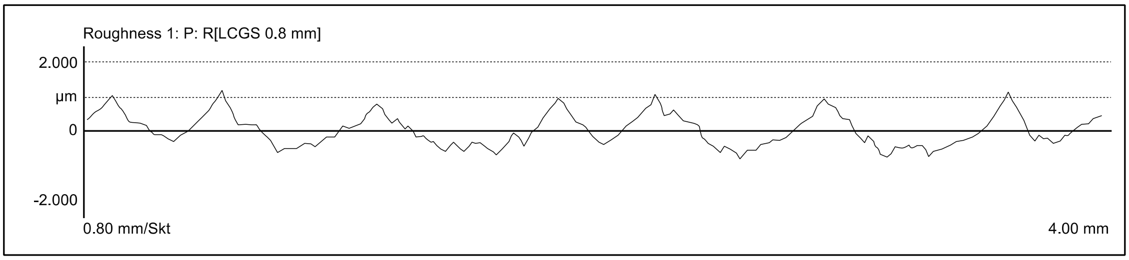
Figure 4b Surface finish charts.

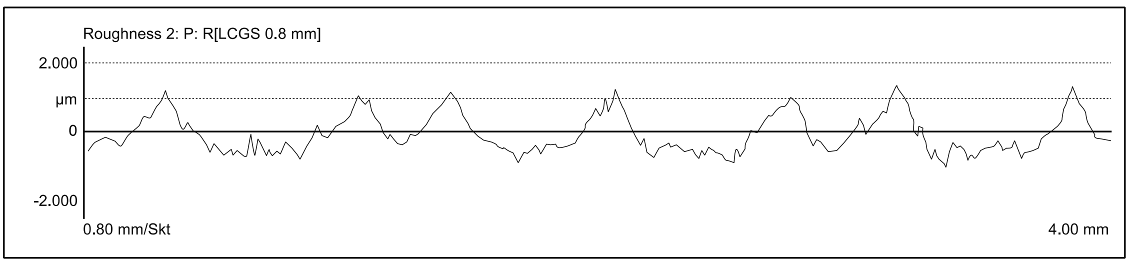
Mahr MarWin 8.00-28	Oerlikon Barmag Task: Roughness	08.08.2016 1 13:28:59 Auditor:
Part: Ring Gear	Drawing #	Step: 327-16
		Warzanowski Signature:
Tooth 1	Test: Longitudinal Director-Lead	
Tooth Flank Left/Rear	Measurement: 1 to 3*	

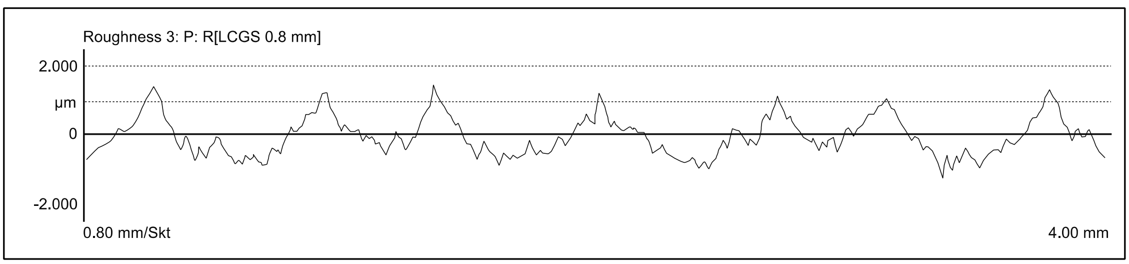
Comments:
*3 x je 0,25mm offset

Measuring Device:	MarTalk
Feed Unit:	DriveUnit.PGK 120
Tracer:	MFW-250:2 (#260) 1.8%:

Lt:	5.60 mm
Ls:	2.50 µm
VB:	+/-250.0 µm
Vt:	0.50 µm
Points:	11200







Roughness Values-Roughness 1: P: R[LC GS 0.8 mm];					
Ra	0,3932 µm	0,0000			0,0000
Rz	2,0027 µm	0,0000			0,0000
Roughness Values-Roughness 2: P: R[LC GS 0.8 mm];					
Ra	0,3544 µm	0,0000			0,0000
Rz	1,5925 µm	0,0000			0,0000
Roughness Values-Roughness 3: P: R[LC GS 0.8 mm];					
Ra	0,4041 µm	0,0000			0,0000
Rz	1,9023 µm	0,0000			0,0000

	Ra	Rz
	µm	µm
Mean Value	0.3839	1.8325

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Figure 4c Surface finish charts.

The Multifunctional Option

Toyoda's Gear Skiving Center Offers Skiving Alternative

Matthew Jaster and Randy Stott

Toyoda's new GS300H5 Gear Skiving Center is the first in the world to equip a skiving function to a general purpose horizontal machining center (HMC), through which mass production of gear parts is achieved. CNC controls and a high speed rotary table were developed specifically to achieve high-speed, multi-functional machining, as a compact and lightweight product, simple in programming functions. The single-chuck machining of the GS300H5 Gear Skiving Center integrates all gear part machining processes for a more functional and cost efficient shop floor.

Will Terry, product manager- special purpose machines at JTEKT Toyoda Americas Corporation, says this machine is designed to replace your turning operation, replace any kind of hobbing or shaping that you're doing and also replace any kind of milling.

"We're going to do this all in one setup," Terry said. "There's no longer a stack-up of errors from chucking and chucking and chucking and chucking. It's really what we had to bring to the table. Our high synchronization speed is what makes this all possible."

The GS300H4 and GS300H5 offers a range from 30 mm and 300 mm diameter, a huge window based on the industry research Terry has done in the field.

"Furthermore, we're synching the work axis and tool axis at 3,000 rpms and 6,000 rpms, it's not just spindle capability, it's not just how fast they can turn, we can actually synchronize the cutting action at those speeds and that's where the skiving comes in. It's also what gives us the capability to go as low as 40 mm on the internal diameter for skiving which is a lot smaller than a lot of the big players in the market," he added.

Machine experience and construction is at the center of this technology from JTEKT. The machine is built on the company's reliable 500J platform, an HMC that can be found in many shops across the country.

In recent years, the energy saving needs of vehicles has led to an increase in demand for gears to be compound and compact in accordance with hybrid vehicles and multistage automatic transmissions.

"You want a super rigid, proven technology to work with for skiving, and this machine is built on these concepts," Terry added. "We spent 10 years using this process internally at Torsen Traction before bringing it to market. These machines have seen a lifecycle of 10+ years in a high production environment before making their official debut at IMTS 2016."

These machines have been out in the field making gears in the United States as well as Japan during that timeframe. "The experience and success we've had internally gave us the green light to make the system available to the general public," Terry said.

They are currently working on some machines that will go up to 700 mm in diameter, specifically for the oil and gas and general energy market, attempting to develop the capability to make those bigger module gears.

Another selling point for the machine is for a manufacturing company that simply wants to test the waters in gear making or they have a ton of part families that are lower volume.

"Our customer can store programs like any other CNC machine tool, we could engineer up to 300 tools on this machine, we might have to change the fixturing, but we might not. So if a guy wants to get into gear-making, he doesn't have to go buy a lathe or a hobber or a shaper, I have one compact machine that will do all these things for you in a single machine footprint," Terry said.

Terry discusses a scenario where a manufacturer might be utilizing five pieces of equipment in a high-production environment. "You're going to have spare parts for each of these pieces of equipment. I only need spare parts for one machine! The spindles are all not going to go down at the same time. The hydraulic valves are not going to go down at the same time. I've possibly reduced your spare parts inventory by 80 percent," he said.

The other advantage is maintenance and training. If you're working with multiple pieces of equipment, you have to train employees on a lathe, milling machine, gear hobber, and so on. Here, a customer only has to train the maintenance personnel on a single machine tool. The same goes with operator training. They learn one machine and they know the whole line. According to Terry, this will likely result in fewer crashes and incidents.

Performance-wise how does this compare with dedicated skiving equipment? Terry said that the synchronization speed compares to most dedicated machines and the machine construction might give the GS300H4 and GS300H5 an edge.

"Some of the dedicated equipment seems pretty lightweight and delicate," Terry said. "We have a three point leveling system, Meehanite casting on this thing. We don't use the mineral epoxy some of the competition uses. My casting is strong enough to support it. It's a huge selling point if you have a foundation that settles."

As the gear industry evolves, Toyoda is striving to develop new processes and products that will enhance the manufacturing community. The gear skiving machine is just one example of this, and an example that Terry believes will help produce parts with more accuracy, less cost and less risk to the manufacturer.

For more information:

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Determination of Maximum Loads for Drivetrain Components in Thrusters Using Flexible Multibody-System Models

B. Schlecht, T. Rosenlöcher and C. Bauer

The usage of modern thrusters allows combining the functions of the drive and the ship rudder in one unit, which are separated in conventional ship propulsion systems. The horizontally oriented propeller is supported in a vertically rotatable nacelle that is mounted underneath the ship's hull. The propeller can directly or indirectly be driven by an electric motor or combustion engine. Direct drive requires the installation of a low-speed electric motor in the nacelle. This present paper concentrates on indirect drives where the driving torque is transferred by bevel gear stages and shafts from the motor to the propeller. Due to closed and inaccessible construction, high reliability has to be achieved. Especially for the design of the highly loaded bevel gear stages, accurate information of the occurring loads is required. The available experience of the operation of thrusters shows that, primarily, rarely occurring special load cases must be considered in the design process. Such operational conditions can only be determined by expensive, long-term measurements. By means of a detailed multi-body system simulation model of the thruster, it is already possible to develop a basic knowledge of the dynamic properties of the drivetrain and to determine design loads for drivetrain components.

Introduction

The different drivetrain and ship concepts, the complicated operational conditions, and the high demand on reliability lead to many different tasks and conditions that must be considered in the design process of thrusters. Therefore the occurring operational conditions are analyzed using simple, torsional oscillation models of the drivetrain as they exist today (Ref. 4). In addition to the typical concept where the fixed propeller is driven by a long shaft, water jet engines, thrusters and also special solutions like the Voith-Schneider drive are used. The thrusters are mounted underneath the ship hull and the thruster housing can rotate around the vertical axes so that they can be used as either pushing or pulling drive and also as ship rudder. The driving power can be directly supplied by an electrical motor, installed in the nacelle (ABB, Rolls-Royce).

Alternatively, the driving torque is transferred by gearboxes and long shafts from the driving unit in the ship hull to the propeller of the thruster (Schottel, Rolls-Royce, Wärtsilä). Thrusters driven by an electrical motor or combustion engine using a gearbox are able to operate with a constant driving speed if the provided thrust is adjustable by pitchable propeller blades. Due to their good maneuverability, thrusters are commonly used in ferries and tug boats. Thrusters are also often used if high demands are made upon the positioning accuracy required by ships for gas and oil production, as well as for scientific marine research.

In comparison to the typical driving concepts using a long shaft, changed design loads must be considered due to the combined function of driving and steering, as well as the paired arrangement on both sides of the ship (Fig. 1, left).

Also, the discontinuous operation and the area of application can influence the design process. Next to the occurring torques, bending moments around the vertical axes resulting from the steering movements of the thruster must also be taken into account for the different operational conditions. A relevant design load case results from the positioning of the thrusters on both sides of the rear. In high waves an emersion of propeller can occur so that during such immersion the

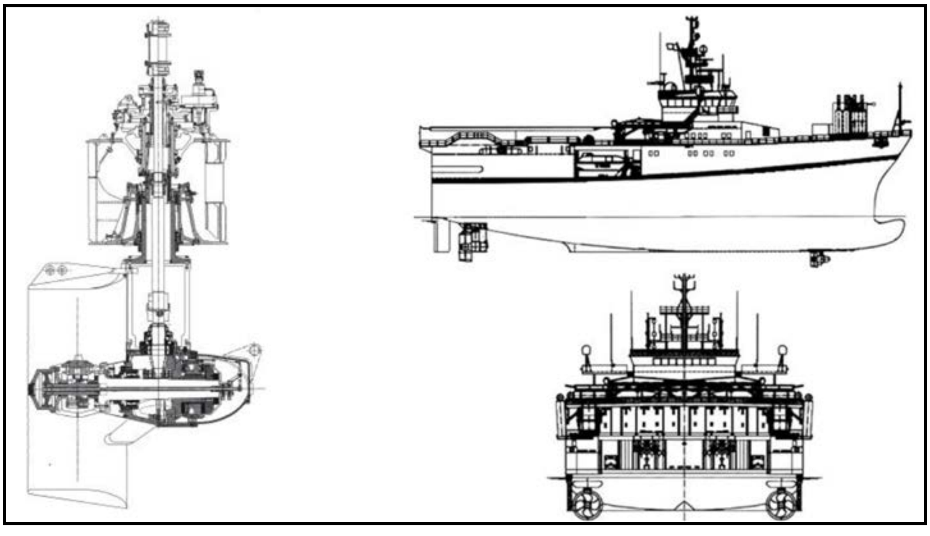

Figure 1 Positioning and design of the thruster (Ref. 16).

International Gear Conference 2014: 26th–28th August 2014, Lyon

blade tips are slamming on the water surface. This leads to short-time overloads that have to be transferred and supported by the drivetrain — without damage. The determination of occurring drivetrain components loads, and analysis of the dynamic behavior, can be achieved either by a complex measurement setup in the thruster nacelle or with the aid of detailed simulation models. The challenges of a measurement campaign are the difficult environmental conditions and missing accessibility to install sensors after the assembly of the thruster. Thus a measurement setup is time consuming and expensive. An availability of detailed measurement results for different drivetrain components will be an individual case and not applicable to design thrusters. The determination of the component loads using the simulation results of complex drivetrain models can already be performed during the product development process.

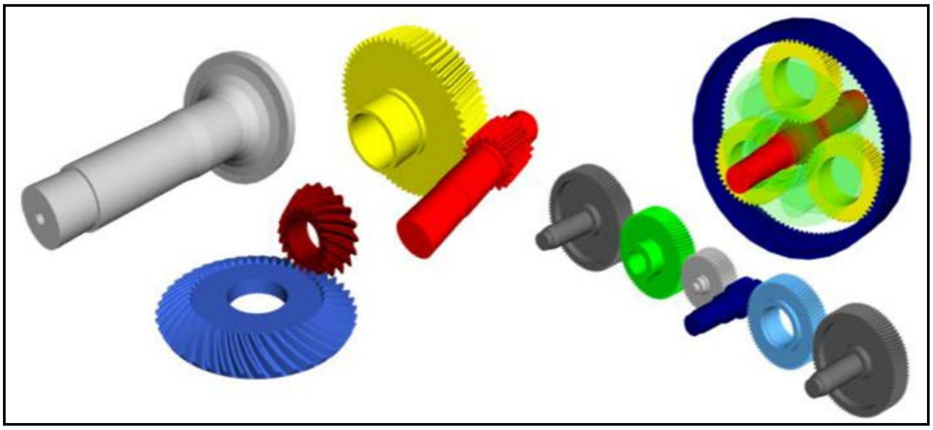

Figure 2 Different kinds of substructures.

Basics of Drivetrain Simulation

The analysis of drivetrains operating under high dynamic loads presupposes the assembly of a detailed simulation model that is able to represent the dynamic behavior of the drivetrain in the frequency and time domain. Even if high-performance computers are available, the level of detail of the simulation model has to correspond to the formulated question to ensure a feasible calculation effort. Despite the currently given possibilities of simulation software, the modeling process is very time-consuming; based on the present data to the drivetrain, a discrete simulation model must be assembled. A successive and modular assembly of fully parameterized simulation models allows a clear and reproducible modeling process, compared to the combination of all drivetrain components in one unstructured model.

The modular concept requires as a first step the decomposition of the drivetrain into its substructures. According to this approach a simulation model of a thruster consists of the following substructures: propeller; propeller shaft; coupling; motor; and an additional, subdivided gearbox. Further, the gearbox can be subdivided in different spur and helical gear stages, bevel gear stages, and planetary gear stages whereby in the analyzed thruster only bevel gear stages are used (Fig. 2). Each sub-structure consists of model components that can be subdivided into shafts, gear stages, bearings and supporting structures. The combination of single substructures leads to the final, complete simulation model of the thruster. Independent of the present requirements, an adjustment of the level of detail and the needed degrees of freedom for each sub-model can be performed. Compared to the work with one single simulation mode for the complete drivetrain, the usage of different sub-models enables an easy verification of the function and accuracy.

Assembly of Thruster Simulation Model

The assembly and functions of a thruster are shown (Fig. 1, right). The nacelle, with the function of the gearbox and cover of the drivetrain, is mounted rotatable around the vertical axes in the ship's hull, and can be turned by an additional drive. The main driving machine in the ship hull transfers the required torque for a horizontally positioned driving aggregate by an elastic coupling and a bevel gear stage. For a vertical-mounted driving machine the torque is transferred directly by a coupling to the vertical driveline in the nacelle. The segmented drive line is supported by several bearings in the housing. The shaft segments, as well as the pinion of the bevel gear stage, are connected by geared couplings. The wheel of the bevel gear stage is mounted on a carrier. The carrier is directly connected to the propeller shaft, which is supported by a roller and a sliding bearing. The axial-mounted hub is used to support the four pitchable propeller blades, which can be positioned by a hydraulically acting linkage.

The dynamic behavior of the drivetrain is mainly characterized by the large motor- and propeller-side mass moment of inertia, as well as the high flexibility. Depending on the required thrust, propeller diameters up to 5 meters are installed. The occurring torque and bending moment during operation presuppose a stiff design of the propeller shaft. By contrast, thin shafts are used in the vertical driveline because the gear stage ratio lowers the torque and the resulting stress. The lower torsional and bending stiffness of these shafts must be addressed; also, the motor is connected by an elastic coupling with the drivetrain. Simplified, the complete system can be

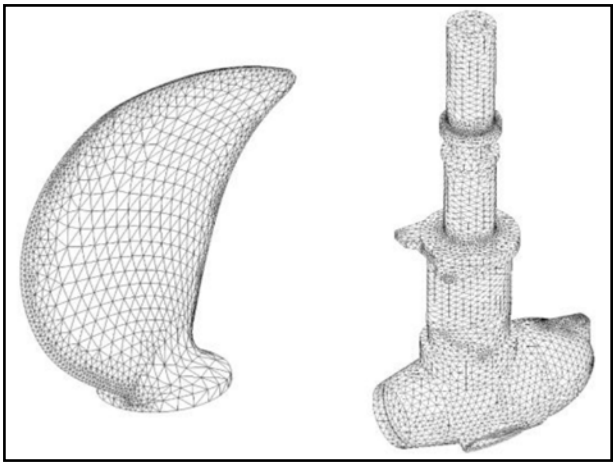

Figure 3 Finite-element model of the propeller blade (left) and the thruster housing (right).

described by two large masses of inertia, connected by a soft torsional stiffness.

Additionally, all drivetrain components are supported in the nacelle, which is also an elastic system and only connected at the top to the ship hull. Under consideration of the acting forces, torque, and bending moments, a simulation model representing the torsional degrees of freedom can be only used for a simplified, rough analysis of the dynamic behavior. A comprehensive investigation of the entire system requires a detailed modeling of all relevant degrees of freedom in a simulation model.

All shafts of the drivetrain have to be modeled with the information to the torsional and bending stiffness, the mass and mass moment of inertia, as well as with the rotatory and translator degrees of freedom. The determination of the mass parameters can be performed using common three-dimensional CAD software or by means of simple analytical approaches. A higher effort is demanded to calculate the stiffness of the components. The torsional stiffness of the drivetrain is mainly characterized by the flexibility of the shafts. Especially thin shafts have to be considered with their elastic properties. Additionally, the bending stiffness of such shafts can have major influence on the dynamic behavior and occurring displacements. A simulation model required to represent shafts can be assembled by means of the method of discretization, by the implementation of beam models, or by using modally reduced elastic structures (Refs. 2, 5, 17 and 25).

The consideration of axial and radial degrees of freedom supposes the modeling of the bearings. Essentially, the modeling of the bearings is realized by a force element that introduces the reaction forces in the axial and radial directions, as well as the reaction moments, if necessary. The bearing properties can be described by average bearing stiffness, characteristic curves or complex models imported as DLL's (Ref. 24).

To support the shafts in the thruster housing, the bearings are modeled as translatory spring-damper-elements, whereby the load-dependent bearing stiffness is implemented so that for all occurring load cases, this approach can be used. Also the properties of the elastically and geared couplings are described by spring-damper elements. For the motor side, coupling information of the stiffness characteristics is required and must be provided by the manufacturer. According to current knowledge, the stiffness of geared couplings can only be determined using analytical approaches (Refs. 1, 6 and 9). Information regarding radial stiffness and stiffness against inclination due to the comprehensive influence factors and uncertain calculation methods is not available. As a first approach, all possible degrees of freedom are locked by constraints or high stiffness, and the occurring influences on the dynamic behavior must be determined by sensitivity analysis. The model of the bevel gear stage between the vertical drive line and the propeller shaft must describe the transfer behavior for the torque, as well as for all force components, so that the dynamic properties of the complete drivetrain can be correctly represented. Next to the description of the non-linear characteristic of the stiffness resulting from the changing contact conditions, the backlash has to be considered during the calculation of the acting forces. For each step of the integration, the determination of the equilibrium between the acting forces, displacements, the inclination of the shafts and the inner gearing forces.must be ensured. The simulation software *Simpack* offers the toolboxes *Gearwheel* and *Gearpair* to model gearings and to describe the transfer behavior in detail.

An alternative modeling approach offers the mathematical description of the resulting forces in the gearing by means of user routines. Based on the calculation of the tooth normal force in the ideal pitch point, the complete tooth contact is simplified and described in one point. The tooth normal force consists of stiffness and damping-dependent parts. Information about the displacements and velocities in tangential, radial and axial directions resulting from the relative position of the gears can be determined by the joint states and the corresponding trigonometric relationships. The gearing stiffness can be considered as average contact stiffness according to DIN 3990 and variable gearing stiffness over the path of contact using Fourier coefficients.

The rigid modeled hub is mounted axially on the propeller shaft and supports the four pitchable propeller blades. To consider the flexibility and resulting deformations of the blades under the high loads, the material and shape-dependent elasticity has to be considered. Due to the complex geometry, the method of discretization or beam approaches cannot be used so that on the basis of a detailed finite element model and the dynamic reduction the propeller blades are represented by modal reduced elastic structures (Fig. 3, left). The implementation of a flexible structure in *Simpack* is based on a meshed finite element model of the component geometry and the definition of the material properties. Additionally, the modeling of the connection points between the elastic structure and the rigid bodies of the multi-body system model is required. The connection points to the supporting spring-damper elements that can be modeled by means of multipoint constraints (MPC). However, the resulting FE model is assembled by many shell or solid elements and has therefore much more degrees of freedom as necessary to describe the rigid body motions in the *MBS* model. Because such complex models cannot be handled by a classic *MBS* solver, the level of detail of the finite element model must be reduced to the transfer behavior between the connection points. Additional information on the displacement of nodes, which are not used as connection points in the *MBS* model, is not available in the reduced model of the structure. The application of the reduction approach according to Craig-Bampton requires the definition of the connection points between the flexible structure and the rigid bodies. The mode shapes of the reduced model are used to determine the deformation under load (Refs. 3 and 7). The number of natural frequencies chosen for the modal reduction defines the valid frequency range and the accuracy of the model, which is also influenced by the choice of frequency response modes in the *Simpack* add-on module *Fembs* (Ref. 8).

A comparable proceeding is performed to represent the elastic properties of the thruster housing. The large mass of the propeller and the propeller shaft with the bevel gear wheel as well the propeller side loads have to be supported by the structure of the thruster housing, and have to be transferred to the large bearing in the ship hull. The expected deformations under the load will have an influence on the dynamic behavior of the drivetrain. Based on the geometry of the thruster housing a finite element model can be assembled (Fig. 3, right). The connection points for the support in the ship hull and the positions of the bearings for the drivetrain components are linked by constraints to a number of surface nodes in the area of the bearing seats. After the implementation of the reduced finite element model, the spring-damper elements representing the bearings will be defined between these connection nodes and the body marker of the MBS model. So all introduced loads are directly transferred as torque or supported by the bearings in the thruster housing and the ship hull.

Analysis of the Thruster Drivetrain in the Frequency Domain

To realize the described modularization the simulation model of the thruster consists of the sub-models motor; coupling; vertical driveline; bevel gear stage; propeller shaft; and propeller. All components are assembled in a complete model of the thruster and supported in the modally reduced finite-element model of the thruster housing. The release of all degrees of freedom and consideration of all supporting and connecting spring-damper elements allows, by comparison of natural frequencies and excitation frequencies, the determination of critical operational speeds and the analysis of the dynamic behavior of drivetrain components and the supporting structure (Fig. 4). Possible excitations are the rotation frequency of all drivetrain components in the first and second order; the gear meshing frequency of the bevel gear stage with the first order and higher harmonics; the rotation frequency of the propeller with the first order and higher harmonics corresponding to the number of installed blades, and disturbance of the flow due to the nacelle design. The named sources can excite torsional, bending, radial and axial mode shapes that have to be analyzed for each determined, critical operational speed. Especially the propeller-side excitations have an important influence on the dynamic behavior of the complete system, because the torque as well as the acting forces can lead to resonances with different harmonics of the rotation frequency of the propeller shaft.

In Figure 5 the Campbell diagram for the thruster with all natural frequencies and the first (1p), second (2p), third (3p), fourth (4p), and eighth (8p) order excitation of the propeller rotation speed, as well as the first (1p) and second (2p) order excitation of the gear meshing frequency — with up to 140 Hz shown exemplarily. The first natural frequency of the complete system at 10 Hz is characterized by a bending mode shape of the thruster housing against the support in the ship hull. The fourth order of the propeller rotation frequency could cause a resonance with this mode shape at an operational speed of 635 rpm (Fig. 4, left). In addition to the stiffness of the housing, there exists the stiffness of the bearing that supports the thruster in the ship hull and has influence on the mode shape. The first torsional mode shape of the drivetrain at 11 Hz is super-posed by a second bending mode shape of the housing. This natural frequency can also be excited by the fourth order of the propeller rotation frequency at an operational speed of 720 rpm (Fig. 4, right). The mentioned excitation frequency is caused by flow disturbance that occurs if a blade passes the thruster housing. The changing torque, bending moments and forces can lead to an excitation of both mode shapes.

Also the higher natural frequencies of the drivetrain are characterized by the super-positioning of housing and drivetrain mode shapes, and can be excited by higher harmonics of the propeller rota-

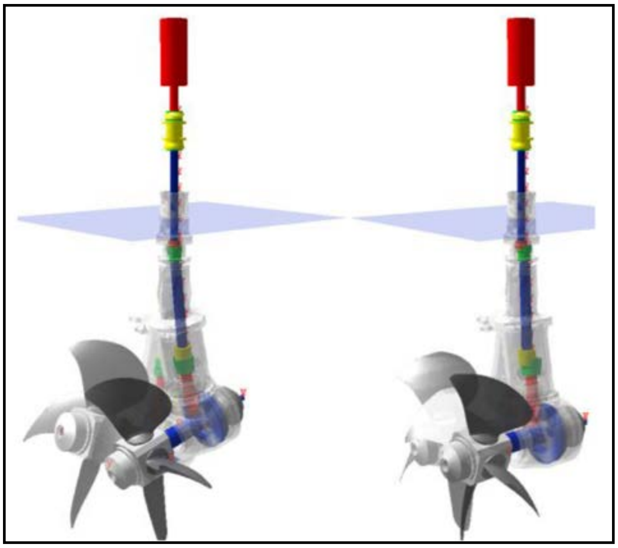

Figure 4 Mode shapes of the thruster (10 Hz, 11 Hz), (Ref. 16).

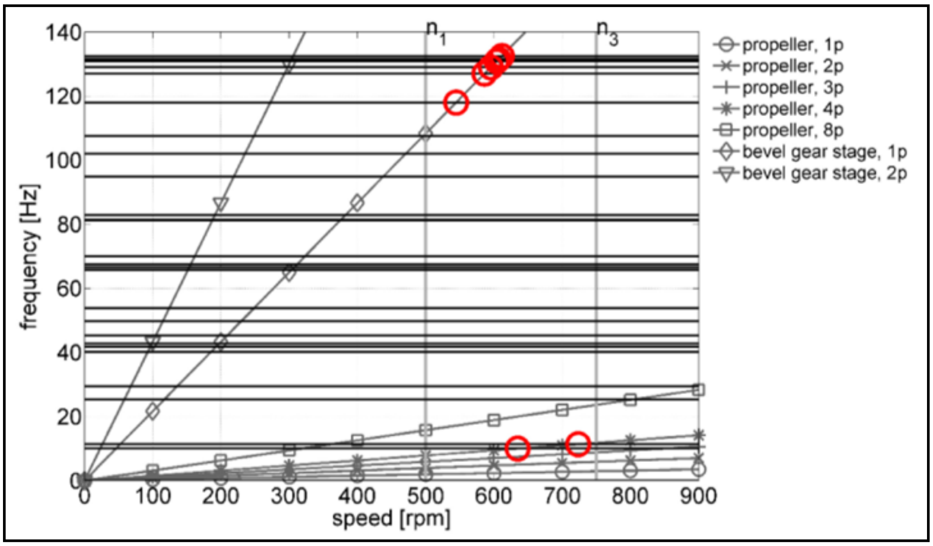

Figure 5 Campbell diagram for the flexible multi-body system model of the thruster.

tion frequency. For the analyzed drivetrain, only the fourth and eighth orders of the propeller rotation frequency are relevant. For future investigation, the interesting frequency/speed range is limited by the lower border of the operational speed and gear meshing frequency of the bevel gear stage at approximately 110 Hz. In the analysis of the higher frequency range, all possible intersections between the gear meshing frequencies and the determined mode shapes have to be taken into account. Due to the exciting gearing force components in tangential, radial, and axial direction, an excitation of torsional, axial and bending mode shapes, as well as mode shapes against the shaft support, are possible. In addition to the theoretical investigations using the Campbell diagram, a comprehensive evaluation of the excitability can only be performed by the simulation of a slow run-up and a detailed analysis of the simulated velocities, accelerations and torques.

Analysis of Thruster Drivetrain in Time Domain

Besides the analysis of possible excitations of natural frequencies in the range of the operational speed by means of the detailed simulation model, the occurring loads for all drivetrain components and different operational conditions can be analyzed. This requires an enlargement of the mechanical model to characterize the acting motor and propeller side loads in detail.

The description of the electric motor can be realized by modeling the different control loops in *Matlab/Simulink*. Important for a realistic motor model is the knowledge of all motor parameters. These parameters must be provided by the manufacturer of the electric motor. Regarding the presented thruster, only some rough information on the motor was available, so that by means of speed-torque characteristics a simplified model is used to describe motor behavior. The modeling of the propeller-side loads requires a comprehensive discussion on the proper modeling approach. To analyze a simple torsional vibration model, the information to the occurring torque is sufficient and already allows a first evaluation of the dynamic behavior and testing of the model. The simplified consideration of the torque neglects the important influences of the thrust forces and bending moments that are also applied at the propeller. These load components cause bending of the thruster housing, displacement of the propeller shaft, and also have an impact on the contact conditions in the bevel gear stage. Next to the analysis of operational states under full load for different flow angles, especially extreme load cases like the immersion of the propeller at maximum input power, can be seen as critical to the reliable operation of the thruster, and should be investigated with the model (Ref. 13). Until now, no comprehensive measurement results for such thrusters are available, so that the occurring loads during the immersion and emersion of the propeller were analyzed only with scaled models in water tanks. When the propeller approaches the water surface, the surrounding water is already mixed with air, so that the thrust and the acting torque decreases. The motor speed increases due to the lower-resisting torque. A further immersion of the propeller causes at first a water-free movement of the upper blade. At the moment of the blade immersion the resisting force suddenly increases, which leads to a short-time increase of the torque in the drivetrain (Refs. 10–12). To determine the occurring component loads during such load cases, a very detailed propeller force model is necessary. The introduction of the water-resisting forces is carried out by modeling a discrete load distribution over the blade length for the tangential and axial force component, separable for each blade. The calculation of the acting forces for each load introduction point occurs — independent of the rotation angle, the distance from the water surface, and measurement-based assumptions for the force progression by means of a *Matlab/Simulink* model. The introduction of the resulting forces on the propeller blades in the *MBS* model allows a first analysis of the occurring loads for shafts, bearings and gearings. Figure 6 shows the torque of the propeller shaft and the motor speed over the simulation time as a comparison between measured and simulation results.

Further possibilities for the description of the propeller-side loads are given by the computational fluid dynamics (CFD). The method is used to analyze the ship hull and interactions between ship hull and thruster during the design process. Because of the detailed, computational-intensive models, a CFD simulation can only be done for single revolutions of the propeller and defined environmental conditions. A combination of CFD and *MBS* simulation is due to long simulation time by using the currently available computer performance for the dynamic simulation not applicable. But the propeller forces and torques can be pre-calculated for defined quasi-static load cases and introduced in the *MBS* model using force elements (Ref. 15). To improve the

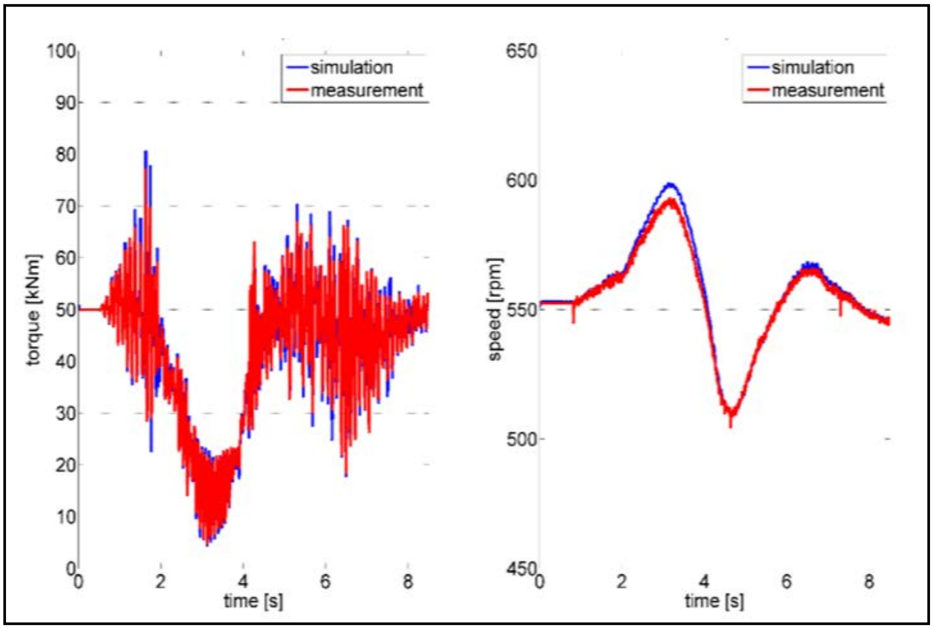

Figure 6 Time series for the immersion and emersion of the thruster.

propeller force models and to validate the mechanical simulation model, the measurement of the different real occurring operational loads by means of an extensive measurement setup over an extended period is mandatory.

Conclusion

The described methods can be used to model the mechanical components, as well as the acting propeller loads, so that basic observations of the dynamic behavior of the thruster drivetrain can be expressed. The comparatively simple constructive design of the drivetrain is characterized by the high flexibility of the driveline and the thruster housing. This leads in combination with the large propeller and motor inertias, as well as the acting forces, to high dynamic states in the drivetrain. If a sudden increase or decrease of the propeller-side torque occurs, first the twist of the drivetrain must be resolved before the backlash in the gearings or couplings can affect the dynamic drivetrain behavior. The occurrence of back flank contact in the bevel gear stage is possible if the propeller load changes with an amplitude and for the duration, so that a twist-free drivetrain exists. The motor-side coupling can reduce overloads at the motor. Damage to the drivetrain can only be avoided by an overload protection at the propeller shaft. The challenge is the design of an overload protection that can limit torque reliably and is small enough for installation in the available space in the thruster housing (Ref. 14).

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FE-Based Approaches for Tip Relief Design

Philip Konowalczyk, Christoph Löpenhaus and Christian Brecher

Introduction

The deformation of the gear teeth due to load conditions may cause premature tooth meshing. This irregular tooth contact causes increased stress on the tooth flank. These adverse effects can be avoided by using defined flank modifications, designed by means of FE-based tooth contact analysis.

The deformation of the gear teeth due to load conditions may cause premature tooth meshing. The purpose of a tip relief is to prevent premature tooth meshing and corresponding negative effects on the load distribution. The increase of tooth flank load carrying capacity by tip reliefs has been proven by Haslinger and is explained by an unloading of areas with high negative slip (Ref. 1). The pitting fatigue strength of profile-corrected gears differs depending on the design of the tip relief. Furthermore, the location of initial pitting damages depends on the design of tip reliefs. In this context, locally reduced radii of curvature in the transition region between the corrected and uncorrected involute have a major influence.

In order to achieve a lightweight design and, therefore, a high power density, the increase of load carrying capacity by means of pressure-optimized profile corrections has to be exhausted in the best possible way. For this purpose it is necessary to take the influence of the tip relief design on the tooth flank stress into account while designing the gears, including the local radii of curvature, the amount and the length of tip reliefs.

Therefore, this paper aims for the development of a FE-based method for designing pressure- optimized profile corrections for spur gears. By means of the existing FE-based tooth contact analysis, the load on the tooth surface is calculated in form of line loads. Following this, an analytical approach is presented to calculate the Hertzian pressure under consideration of the local radii of curvature. Using the developed method, a parameter study is performed to investigate the influence of different geometries of profile modifications on the Hertzian pressure distribution along the path of contact, and to derive a recommendation to determine a pressure-optimized geometry. Here the focus is on an objective method for evaluating the change of tooth flank stress, depending on the tip relief design. Furthermore, an FE-based approach for the definition of amount and length of a tip relief is presented in order to consider the influence of local stiffness, combined modifications, and their tolerances on the premature tooth meshing.

State of the Art

Manufacturing deviations, as well as deformation under load of teeth, gear body and other power transmitting parts of the gearbox affect the excitation behavior and the load carrying capacity of gears. The deformation of teeth under load can provoke a premature tooth meshing, which can have a negative effect on the tooth flank load capacity. Due to this, profile modifications — typically in the form of tip relief — are applied. In the following chapters the influence of tip reliefs on the running behavior of spur and helical gears and the approaches for the design of tip reliefs are discussed.

Influence of tip reliefs on the running behavior of spur and helical gears. The influence of tip reliefs on the running behavior of gears is has been under scientific investigation since the 1960s. The focus of the existing research is mostly on the acoustic behavior, dynamic tooth forces, and scuffing load capacity (Refs. 2–7).

Toppe (Ref. 2) shows in his work a generally positive influence of tip reliefs on the excitation behavior of gears. By calculation of the tooth under load within the single contact area, a tip relief can be derived and a premature tooth meshing can be avoided. According to Toppe, an especially long tip relief design according to Niemann/Winter (Ref. 8) can decrease the excitation of gears (Refs. 2 and 8). The following works of Tesch, Baethge and Knabel confirm the overall positive influence of tip reliefs on the excitation behavior (Refs. 3–5). Concerning the optimal length of a tip relief, there is no clear result. Tesch and Baethge indicate that the design of a tip relief is dependent on the gear geometry (Refs. 3–4).

The influence of the amount and length of a tip relief on the pitting load capacity is systematically investigated by Haslinger (Ref. 1). A positive influence of tip reliefs on the pitting load capacity is established and explained by an unload of the areas with high negative slip (Ref. 1). Further investigation shows an influence of the form of the tip relief and especially of the design of the transition area between modified and unmodified involute (Refs. 9–12).

Nazifi focuses on the influence of locally reduced radii of curvature on the Hertzian pressure during tooth flank contact. He compares gears with a linear and a parabolic tip relief. The Hertzian pressure within the transition area between modified and un-modified involute is increased by the linear tip relief by 110%, while the pressure is only increased by 8% for the parabolic tip relief. Nazifi concludes that the locally reduced radii of curvature in the transition area can reduce the pitting load capacity. Due to this, a parabolic tip relief should be preferred compared to a linear tip relief in order to achieve a maximum load capacity (Ref. 10).

The research of Luetzig also indicates a correlation between local radii of curvature and the tooth flank stress. He focuses

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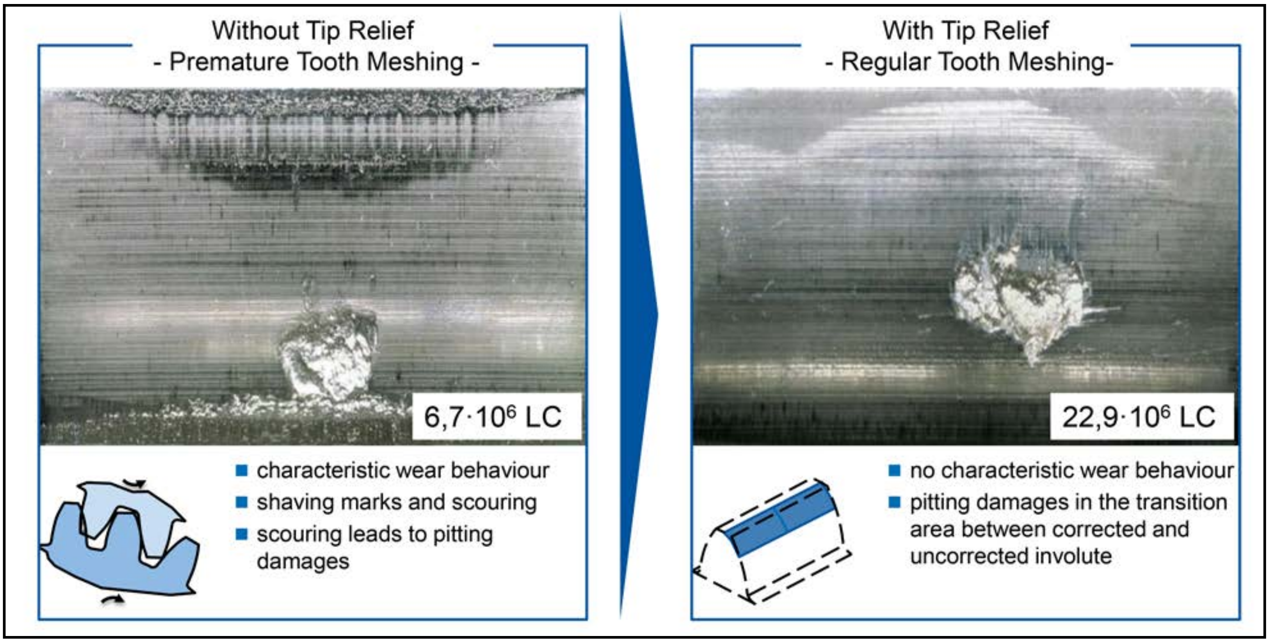

Figure 1 Influence of tip reliefs on the tooth flank load capacity.

on the wear in the tooth root flank area of modified and unmodified gears. For the modified gears a correlation between the location of maximum wear and minimum radii of curvature can be found (Ref. 9).

Brecher et al analyze the tooth flank stress of modified and unmodified spur gears by means of a high resolution FEM-simulation. At the same time experimental tests are performed by means of a back-to-back test rig. During the experimental tests modified and non-modified spur gears are compared concerning the resulting tooth flank load capacity. All in all, the modified gears show an increased load capacity. The increase of load capacity by the application of a tip relief is strongly dependent on the design of the tip relief. For the modified variants, pitting damages occur mostly in the transition area with locally reduced radii of curvature (Fig. 1). The FEM analysis confirms an increase of pressure in these regions (Ref. 11).

Approaches for tip relief design. The premature tooth meshing is caused by the deformation of teeth under load. The aim of a tip relief is compensation of the deformation (Refs. 3–4). Existing research has reached the conclusion that the amount and length of a tip relief should be derived by the analyzation of a theoretical penetration at the tooth, which comes into contact (Refs. 1, 3–4). This recommendation is derived by the analyzation of spur gears and has not been confirmed for helical gears.

The deformation of a tooth under load is dependent on applied load and tooth stiffness (Ref. 2). Therefore a tip relief can only be designed for a specific load torque (Ref. 8). A widely spread approach for the design of tip reliefs is the approach according to Niemann/Winter (Ref. 8); this approach separates short and long tip reliefs. The long tip relief starts/ends at the beginning/end of the single tooth contact area. For the short tip relief, the length of the unmodified part of the involute results in a profile contact ratio of $\varepsilon_\alpha = 1$. The amount of the tip relief is calculated according to Equation 1. A separation of spur and helical gears is mainly realized by use of different tooth stiffness.

$$C_{\alpha a} = \frac{F_{bt}}{c' \cdot b} + f_p \qquad (1)$$

b [mm] Tooth Width
$C_{\alpha a}$ [µm] Amount of Tip Relief
F_{bt} [N] Normal Force
c' [N/(mm · µm)] Maximum Tooth Stiffness
f_p [µm] Pitch Deviation

Although the Niemann/Winter approach is generally acknowledged, the results are often combined with experienced-based knowledge. Reasons for this proceeding are the missing consideration of local stiffness behavior and combined modifications. Furthermore, manufacturing-induced tolerance fields are not taken into account (Ref. 8).

An alternative approach for the design of tip relief is the FE-based, TCA approach; it is based on the substitutional spring model of Neupert (Ref. 13). This method is already used for designing modifications such as lead crowning under consideration of tolerance fields and load-induced deformations (Ref. 14). The FE-based TCA is used in the works of Wittke in order to estimate the theoretical penetration of the following tooth and its effects on the excitation behavior (Ref. 15). Wittke simply takes the influence of tip relief into account and does not consider other modifications or their tolerance fields.

Conclusion. The state of the art shows a principally positive influence of tip reliefs on the excitation behavior, as well as on the tooth flank load capacity of gears. For the design of the tip relief amount, it is recommended to estimate the theoretical penetration of the following tooth caused by the deformation under load. This recommendation is applied for both optimal excitation behavior and for optimal load capacity as well. The excitation behavior in particular is mainly influenced by the length of the tip relief, for which different recommendations exist. The research works of Tesch and Baethge show that optimal tip relief design depends on the geometry of the gear stage (Refs. 3–4). There exists no

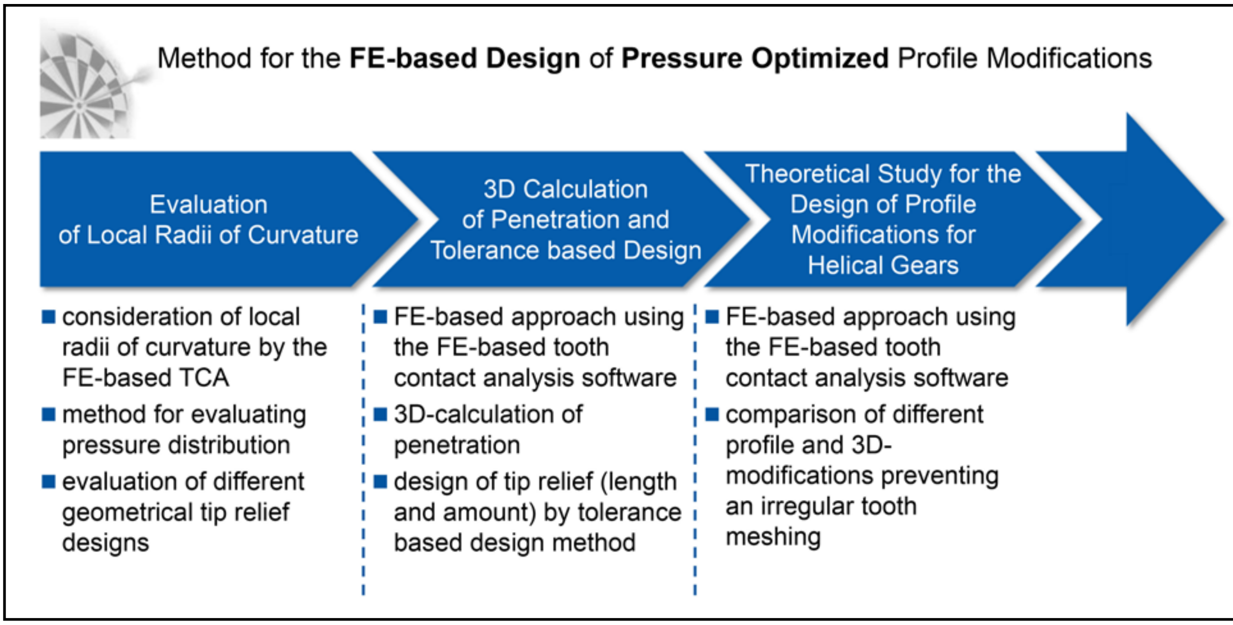

Figure 2 Objective and approach.

recommendation for estimation of tolerances for the tip relief design parameters.

The exact geometry of a gear and the resulting local stiffness is not considered by the methods usually used for the design of tip reliefs. This deficit is compensated by the experience and knowledge of the designer. Furthermore, the difference of spur and helical gears is only considered concerning the overall tooth stiffness. The different local contact characteristics are not taken into account. A promising alternative method is presented by the FE-based TCA. The approach of Wittke could be further developed in order to calculate the resulting theoretical penetration and by this design a tip relief. In addition, the FE-based TCA enables consideration of local radii of curvature and by this the evaluation of different tip relief geometries (Ref. 12). By implementing an approach for the consideration of local radii of curvature in the FE-based TCA, an integrated FE-based design of tip relief can be performed and the potential increase of the tooth flank load carrying capacity can be achieved.

Objective and Approach

Premature tooth meshing influences the tooth flank load carrying capacity and the excitation behavior of gears. In order to avoid the adverse effects of premature tooth meshing, tip reliefs are applied. The design of the tip relief concerning the amount, length and form of the modification, influences the increase of the tooth flank load carrying capacity and the excitation behavior of gears. Design methods used in practice do not consider local stiffness, influences of combined tooth flank modifications, tolerances and local radii of curvature. By using an alternative design approach, i.e. — FE-based TCA — these effects can be considered and the potential increase of tooth flank load carrying capacity and the potential enhancement of excitation behavior can be exploited.

Therefore this paper aims at an FE-based design method for pressure-optimized profile modifications. The objective and approach are depicted in Figure 2. Based on the FE-based TCA, a method for regarding the local radii of curvature is developed and a parameter study is performed in order to determine advantageous geometry forms for profile corrections concerning the tooth flank stress. Therefore an evaluation method is described to differentiate the different profile corrections. For the second step, the FE-based TCA is extended by a three-dimensional calculation of penetration. In this way the effectiveness of profile corrections concerning premature tooth meshing can be evaluated.

- Consideration of local radii of curvature by the FE-based TCA
- Method for evaluating pressure distribution
- Evaluation of different geometrical tip relief designs
- FE-based approach using FE-based tooth contact analysis software
- Comparison of different profile and 3-D modifications preventing an irregular tooth meshing
- FE-based approach using the FE-based tooth contact analysis software
- 3-D calculation of penetration
- Design of tip relief (length and amount) by tolerance-based design method

By an integration of the calculation of penetration in the variational calculus approach of the FE-based TCA, a tolerance based design is enabled. By means of a weighted grading algorithm, the tip relief design can be further adapted to the current case of application. The development and application of the FE-based design method for tip relief is demonstrated for an industrial use case. Finally, a study for an adapted design of profile modifications for helical gears is presented.

Influence of Profile Modification Form on the Tooth Flank Stress

Modification of the FE-based tooth contact analysis. The FE-based TCA enables the local calculation of stress and deformation with regard to micro geometrical modifications including different geometrical forms of profile corrections. However, regarding tip reliefs, only linear and circular forms can be analyzed. Other geometrical forms such as logarithmic, exponential or polynomial tip reliefs cannot be evaluated.

The micro-geometrical modifications are considered as a change of distance within the spring-based replacement system according to Neupert (Ref. 13). In this way the influence of the modifications on the distribution of normal forces is taken into account. Subsequently, the derived line loads and the radii of curvature of the uncorrected involute are used for the pressure calculation. Up to now, locally reduced radii of curvature in the transition area of uncorrected and corrected involute of profile-corrected gears are not considered.

Based upon these aspects, two modifications of the FE-based TCA must be implemented in order to evaluate the influence of different profile correction forms on the tooth flank stress. On one hand, the consideration of further tip relief forms has to be enabled. On the other hand, the local radii of curvature have to be taken into account for pressure calculation.

Regarding the various tip relief forms, the import function of the FE-based TCA for topography measurement files can be used. As all geometrical tip relief forms can be described through mathematic functions, synthetic topography measurement files can be calculated and subsequently imported into the FE-based TCA. For the consideration of local radii of curvature, an analytical calculation approach is used in combination with the FE-based TCA. While the line loads and the resulting distribution of normal forces are calculated by means of the FE-based TCA, the resulting pressure is calculated analytically according to Hertz. For this the geometry of the tooth flank is described by means of the involute function, and profile modifications are considered by means of mathematic formulas. Thus the geometry of the flank can be described analytically and the calculation of radii of curvature is not linked to the number of elements of the FE model. For the calculation of local radii of curvature, the circular function is used with the coordinates of three neighboring points of the tooth flank. The described calculation method is validated by comparing the calculated pressure with the results of a high-resolution, general FE- method calculation that shows good comparability.

Evaluation of different profile modification forms. The calculation method is also used for a parameter study, analyzing the influence of different profile modification forms on tooth flank stress. The study is performed for a test gear set with a number of teeth $z_{1/2} = 17/18$, and a normal module of $m_n = 5$ mm. The amount and length of the tip relief are calculated according to Niemann/Winter (Ref. 8) for a torque of $M_1 = 550$ Nm. To avoid effects of premature tooth meshing, the amount of the profile correction is defined as $C_a = 70$ µm. The tip reliefs are applied to pinion and gear. For every tip relief form, the short and the long length according to (Ref. 8) are considered. The parameter study includes linear, exponential, logarithmic and polynomial tip reliefs. In addition, a circular, symmetric profile crowning is regarded. For a valid comparison the profile crowning is applied only to the gear and an amount is chosen equal to the tip relief ($C_\alpha = C_a$); the parameters vary for each geometrical form of profile correction. Concerning the linear tip relief, the length of the transition area between the corrected and uncorrected involute Δl_{Ca} is varied. For the exponential forms, the base B, and for the polynomial form, the exponent *e* is modified. The logarithmic tip relief and the profile crowning are fully defined by the amount and length of the correction. In total, 58 variants are investigated.

For the evaluation of the tooth flank stress, the behavior of the calculated pressure along the path of contact is analyzed. In Figure 3 the calculated pressure for a linear tip relief with a transition length of $\Delta l_{Ca} = 200$ µm is depicted. Compared to the calculated pressure for an uncorrected gear set, the pressure calculated for the *corrected* gear set is continuously rising — from the beginning of contact (A) to the beginning of double tooth contact (B) — and continuously falling from the end of double tooth contact (D) to the end of contact (E). Hence, the areas of high slip are unloaded. Another difference between the uncorrected and the

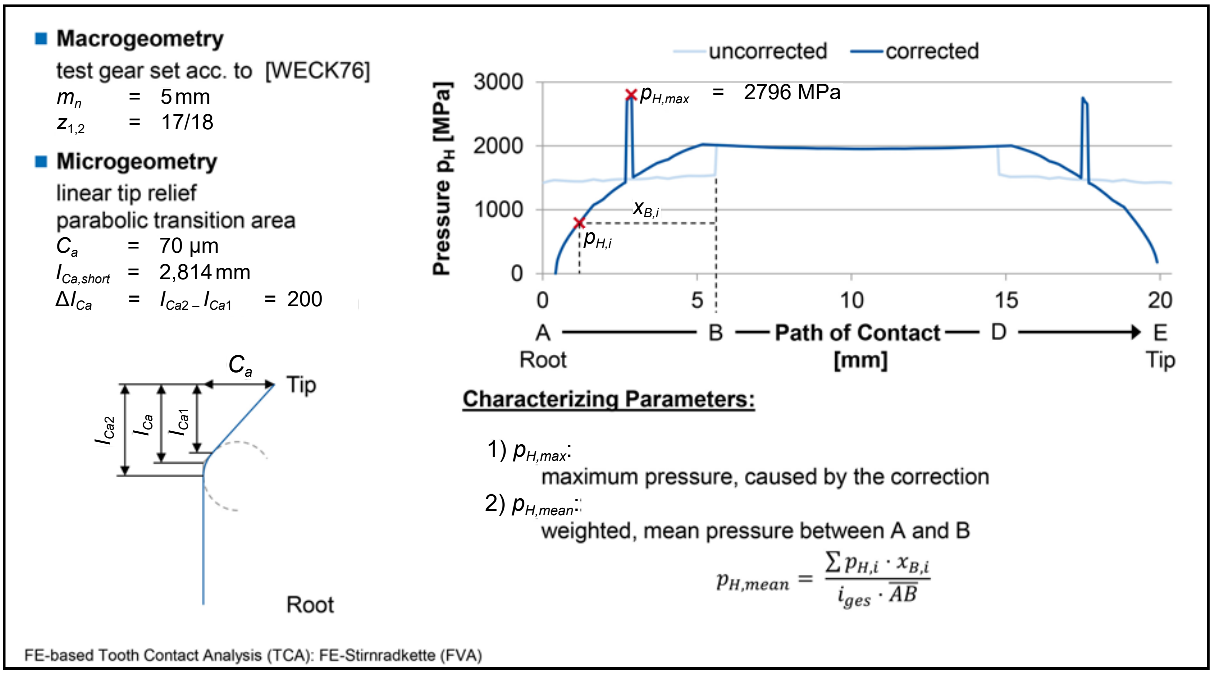

Figure 3 Characterizing parameters for the tooth flank stress.

corrected gear set are high pressures calculated for the transition area between uncorrected and corrected involute. This is caused by locally reduced radii of curvature, which can be reduced by up to 90% ($r_{uncorrected} = 31\,mm > r_{transition} = 3\,mm$). The amount of the increased pressure depends on the length of the transition area; for a longer transition area, the pressure is decreasing. But at the same time, the highly stressed volume is increasing. For evaluation of pressure behavior, more than maximum pressure must be considered — i.e., combination of pressure and *sliding speed* must be taken into account. And so, two characterizing parameters are derived for evaluating the potential increase of tooth flank load carrying capacity of each profile correction form (Fig. 3). Besides the maximum pressure caused by the profile correction $p_{H,max}$, a weighted, mean pressure in the area of high negative slip (A-B) $p_{H,mean}$ is introduced, as the high sliding speed in this area leads to high risk of pitting damages.

The described characterizing parameters are calculated for each variant of the parameter study. For an objective comparison of the variants, the two parameters are used as coordinates of each variant and plotted in a diagram (Fig. 4).

The linear tip reliefs mainly differ concerning the maximum pressure $p_{H,max}$. Due to the Hertzian model, the amount of $p_{H.max}$ is linked to the square root of the length of the transition area. Hence, the extension of the transition area only makes sense to a certain length.

For the focused test gear, a length of

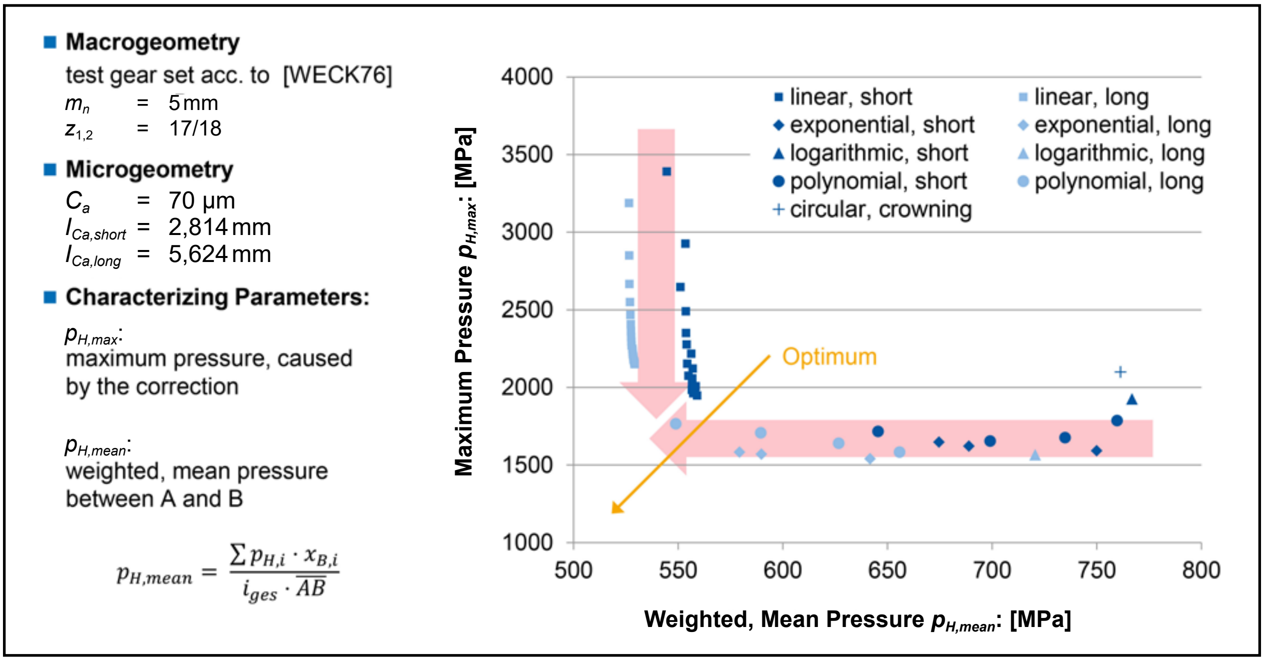

Figure 4 Result of tooth flank stress evaluation.

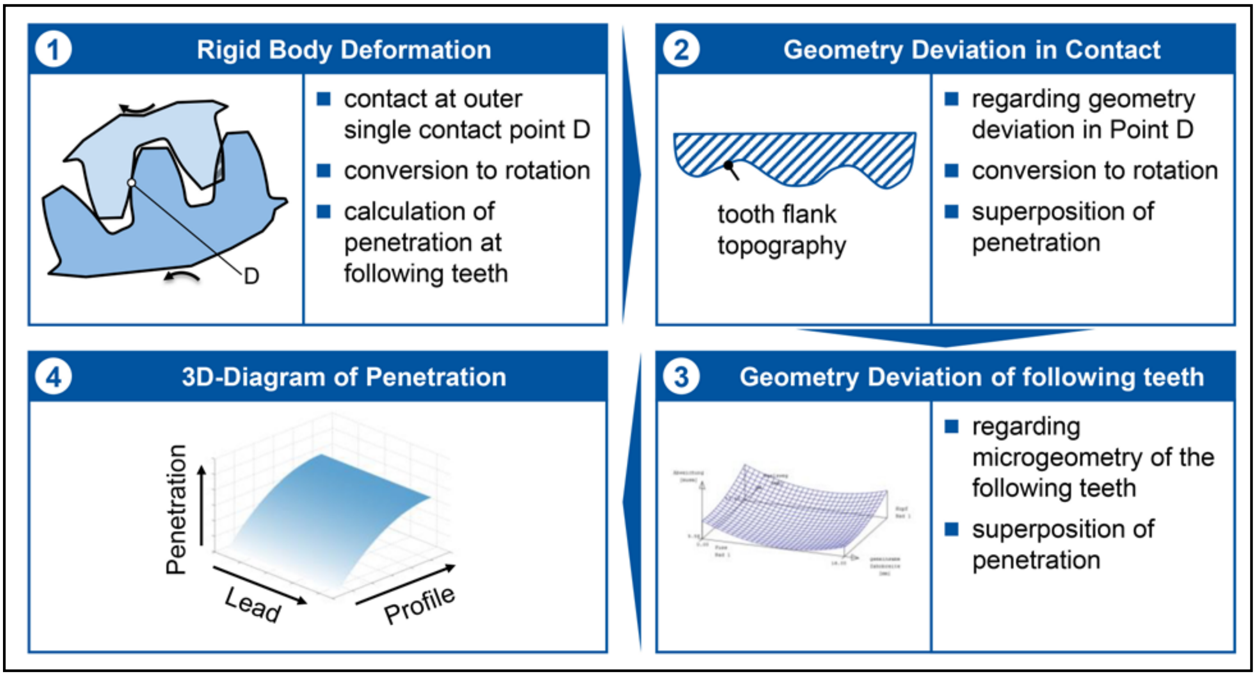

Figure 5 Approach for the calculation of penetration.

the transition area of 15% of the relief length is reasonable. The other tip relief forms mainly differ in the weighted, mean pressure $p_{H,mean}$. Especially the polynomial tip relief (2nd order, circular) shows a low tooth flank stress. The logarithmic tip relief and the profile crowning show the highest tooth flank stress. Based on these results — the linear tip relief, with a transition area length of 15%, and the circular tip relief — are the focus for future work.

Method for the Design of Tip Reliefs for Spur Gears

FE-based calculation of penetration. The concept and approach of the FE-based calculation of penetration is shown (Fig. 5). The calculation model can be divided into different parts that consider different influences on the penetration.

As a first step, the rigid body deformation is calculated for the point of contact, where the single tooth contact ends (D). This point of contact is the critical one for the theoretical penetration at the following pair of teeth. The calculated deformation is transformed in a relative rotation of the gears. Based on this, the theoretical penetration of the following tooth is calculated. In the following steps further influences on the penetration caused by geometrical deviations are considered. On the one hand, the geometry deviations at the point of contact (D) caused by desired modifications or undesired manufacturing tolerances lead to a further relative rotation of the gears. On the other hand, applied profile modifications at the following tooth have a direct influence on the calculated penetration. Finally, the resulting theoretical penetration at the following tooth can be calculated with regard to the local stiffness and the geometrical deviations caused by modifications and manufacturing tolerances.

The described calculation approach is further validated by means of contact patterns. For this a test gear set is used, which exists with two differently applied tip reliefs (Fig. 6).

In the upper part of the figure the calculated maximum penetration is shown. For the smaller tip relief ($C_a = 30$ µm), a penetration is avoided up to a torque of $M_1 = 1{,}000$ Nm. For the larger tip relief ($C_a = 75$ µm) the penetration is avoided up to a torque of $M_1 = 2{,}500$ Nm. For both gear sets ($C_a = 30/75$ µm), contact patterns are depicted in the lower part of the figure for differently applied torques. For the smaller tip relief ($C_a = 30$ µm) and an applied torque of $M_1 = 1{,}000$ Nm, there is still a small amount of contact compound left. For an applied torque of $M_1 = 1{,}250$ Nm, there is no compound left and the tooth is loaded along the complete height. Thus, for higher torques a premature tooth meshing and, therefore, a theoretical penetration, have to exist. This result shows good correlation with the calculated penetration. The larger tip reliefs avoid a premature tooth meshing up to a torque of $M_1 = 2{,}500$ Nm, according to the contact patterns. This result shows good correlation with the calculation results, as well.

Tolerance-based design of tip reliefs. The described calculation approach for the theoretical penetration is also used for a tolerance-based design of tip reliefs. By a full factorial variational calculus in the FE-based TCA, a significant number of possible tip relief lengths and tip relief amounts can be evaluated in a short time. By means of a weighted algorithm the possible variants can be evaluated; e.g., concerning tooth flank stress, excitation behavior and penetration. By means of weighting, important load cases and output parameter can be focused and the tip relief design can be optimized for each application. The results are further united in possible tolerance fields that can be described by a worst-case/best-case sce-

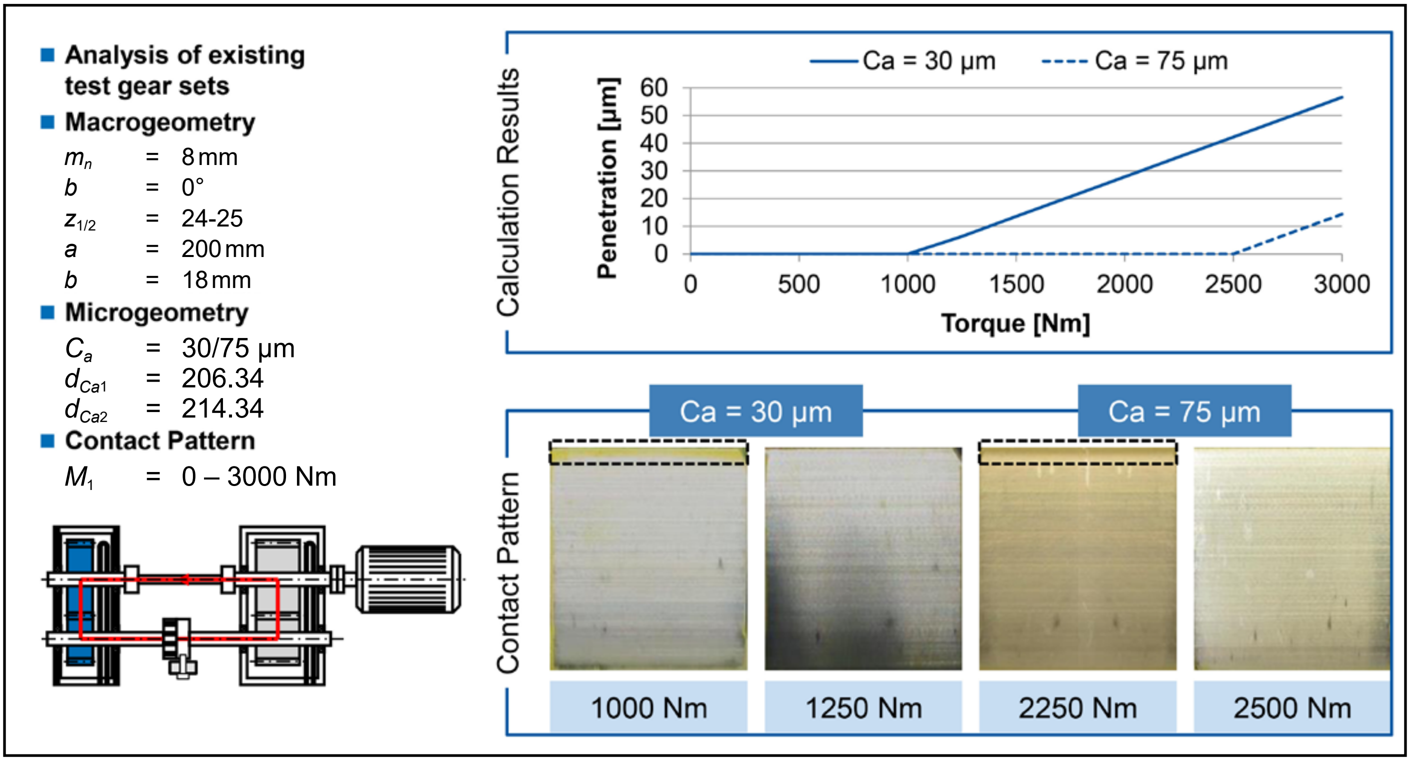

Figure 6 Validation of penetration calculation by means of contact pattern.

nario and target behavior.

Based on the results of the previous chapters, a linear and a circular tip relief are designed for an industrial gear set by means of the tolerance-based design method. The resulting tip reliefs are compared to analytically designed tip reliefs; the tip relief parameters are shown (Table 1).

For an objective comparison, characterizing parameters are needed. In Figure 7 (top), worst-case/best-case and target value of the penetration and the first gear mesh order of transmission error are shown, depending on the applied torque for the linear analytical design. For the comparison of the designed variants, the nominal torque of $M_1 = 18.5$ kNm is analyzed and the values of the worst-case/best-case and target behavior are derived (Fig. 7, bottom).

The described values are derived for each design variant so that an objective comparison is possible; the result of this approach is shown (Fig. 8, top).

The analytically designed tip reliefs, independent on the geometrical form, are not preventing a penetration, although the nominal torque of $M_1 = 18.5$ kNm has been used for the analytical design approach. In this connection the circular tip relief causes a higher penetration than the linear tip relief. The FE-based-and-designed variants are able to avoid a penetration, independent on the tip relief geometry. Therefore the FE-based design of the tip relief can efficiently prevent a premature tooth meshing and its consequences — such as higher tooth flank stress. In addition to that, the FE-based designed variants show an improved excitation behavior in comparison to the analytically designed tip reliefs. Compared to the analytical variants, the first gear mesh order is significantly lower for the FE-based variants. Comparing the tip relief geometry, the linear tip relief shows the most promising results.

Finally, the differently designed tip reliefs are compared concerning the caused tooth flank stress by means of the characterizing parameters introduced previously in this paper. Comparing the FE-based tip reliefs with the **analytically designed**, the weighted, mean pressure *pH,mean* is up to 35% lower for the FE-based variants. However, the above-described promising excitation behavior of the FE-based variants is realized by high lengths of the modifications. Thus the transition area and the locally reduced radii of curvature are nearer to the single tooth contact, which is connected to high normal forces. This is the reason for the higher maximum pressure *pH,max* of the FE-based variants. Nevertheless, the increase of the maximum pressure is not as high as the reduction of the weighted, mean pressure (19% increase of *pH,max* vs. 35% decrease of *pH,mean*). Also, the analytically designed tip reliefs do not prevent a premature tooth meshing, which increases the tooth flank stress further.

Theoretical Study for the Design of Profile Modifications for Helical Gears

Irregular tooth mesh of helical gears. The contact conditions during irregular tooth mesh of helical gears have not been analyzed in detail up to now. Occurring tooth flank damage — indicative of an irregular tooth mesh — has been encountered by tip reliefs. Such a damage pattern is presented (Fig. 9, top). The region of the tooth root flank shows strong material fatigue in form of a pitting line, similar to spur gears with a premature tooth mesh. However, the pitting line is orient-

Table 1 Parameters of designed tip reliefs

Approach	Analytical		FE-based	
Geometry	Linear	Circular	Linear	Circular
Amount Pinion	35 ± 5 µm		50 ± 5 µm	55 ± 5 µm
Diameter Pinion	223,95 ± 1 mm		221 ± 1 mm	221 ± 1 mm
Amount Gear	35 ± 5 µm		55 ± 5 µm	55 ± 5 µm
Diameter Gear	371,55 ± 1 mm		369 ± 1 mm	369 ± 1 mm
Transition Area	15% of Length	–	15% of Length	–

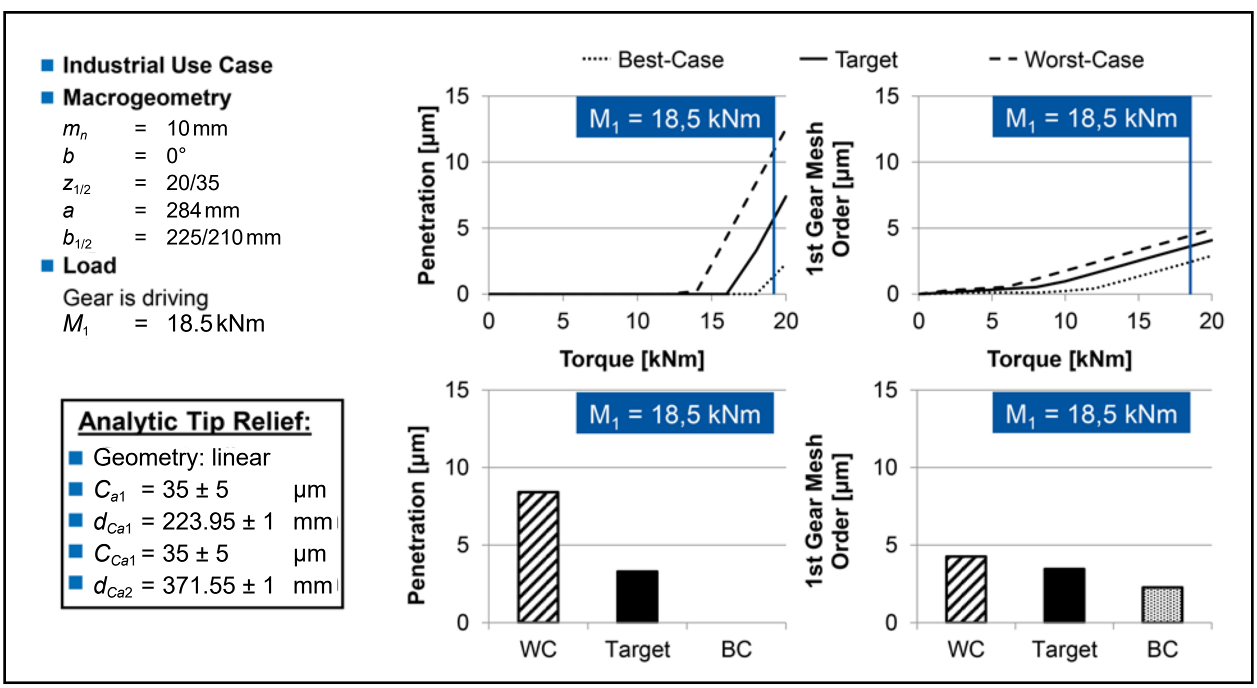

Figure 7 Approach for objective comparison of design variants.

ed in the direction of the flank lead — not along the path of contact. A premature tooth mesh of a helical gear can only take place at the start and end points of meshing — A and E (Fig. 9). As a result, there must be another reason for high tooth flank stress in the tooth root flank area of helical gears.

In order to explain the damage pattern (Fig. 9), a detailed FEM analysis is performed. In (Fig. 9, middle), it can be seen that the first point of contact is at the left side of the tooth root flank area of the driving gear. For this point of time, increased pressure is calculated and, against the theory of the gear contact, the point of contact first moves down in the direction of the tooth root. This behavior is similar to a premature tooth mesh of spur gears, but with the difference that it only takes place in a very small region of the flank of helical gears.

During further contact the line of contact moves across the driving flank from the left to the right side. It is noticeable that the maximum pressure of each contact line is at the point nearest to the tooth root. Furthermore, the maximum pressure decreases while the contact line moves from left to right. After crossing the middle of the tooth flank, the maximum pressure is at the tip region and increases from the left to the right.

A possible explanation for this behavior is the de-central application of force of helical gears. It is known for tooth root stress that the maximum is not middle-of-the-tooth width (Ref. 16). The reason for this is the inhomogeneous load along

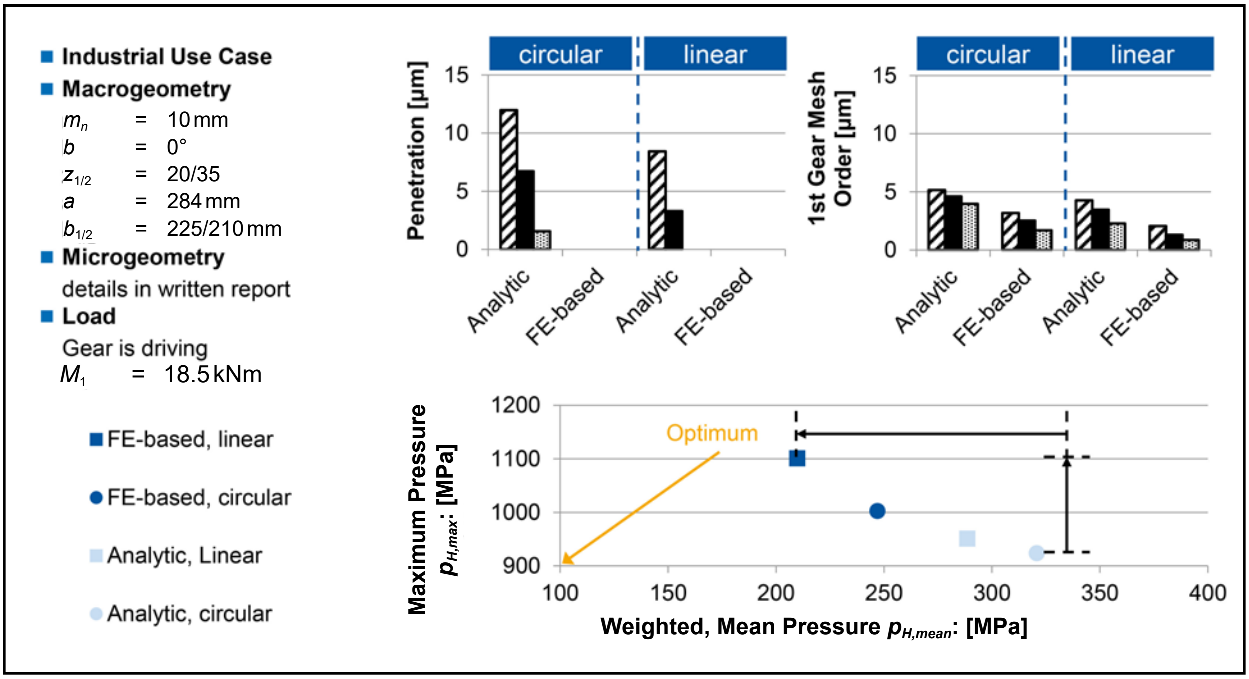

Figure 8 Comparison of design variants.

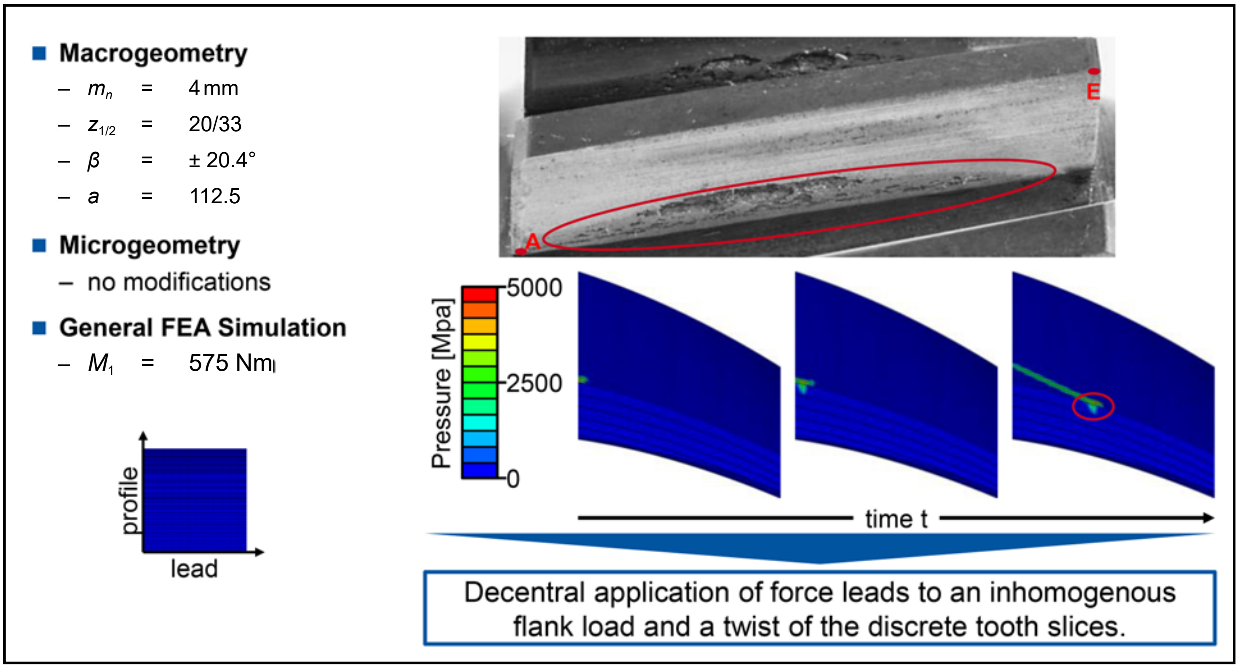

Figure 9 Damage pattern of helical gear with irregular tooth mesh.

the tooth width of helical gears. This inhomogeneous load application can lead to a twist of the flank, so that the effect of increased pressure in the tooth root and tooth tip region can be explained by a kind of premature tooth mesh of each tooth slide. As the increase of pressure is noticeable for almost every line of contact, and as its amount is dependent on the place of line of contact, it has to be investigated whether modifications other than a tip relief, e.g. — multi-dimensional modifications — are more efficient in order to decrease the overall flank stress.

Approach for design of tip reliefs for helical gears. The previously described effect, which leads to an increased pressure in the tooth root and tooth tip flank region of the driving gear, is caused by a twist of the loaded flank. The influence of this effect on the pressure distribution can be analyzed by means of the FE-based TCA. In this work the focus is on the suitability of different flank modifications concerning the prevention of pressure increase.

In a first step, the influence of tip reliefs on the pressure distribution is examined (Fig. 10). For the previously analyzed macro-geometry, different amounts of tip relief for the driving and driven gear are investigated. The length of the tip relief is always a long tip relief, according to NIEMANN/WINTER (Ref. 8). In Figure 10 (top) the resulting Ease-Off of the modifications is shown; below that is the resulting pressure distribution on the flank. For the unmodified gearset, the line of increased pressure, orientated in tooth width direction, can be seen in the tooth root flank region on the left side of the flank, and in the tooth tip flank region for the right side of the flank. By the application of a tip relief, the flank is unloaded in the tooth root and tooth tip flank region and along the complete tooth width. As the added pressure is decreasing from the face side to the middle of the flank, a constant unloading of the flank along the direction of the tooth width leads to an inhomogeneous pressure distribution. The flank regions at the upper left and lower right position are much lower loaded than the flank regions of the lower left and upper right. What's more, overdoing tip relief leads to a new line of increased pressure, which is then located more in the flank middle region. In terms of a high load capacity, this is not desirable.

As the increased pressure is dependent on the location along the tooth width, the influence of a specific flank twist on the pressure distribution of helical gears is examined. In order to simplify the interpretation, the twist is only applied for the driving gear (Fig. 11).

Choosing a twist with the wrong orientation leads to an amplification of the studied effect (Fig. 11, top-left). The flank regions with the higher flank load are loaded even higher, in turn leading to a worsening of the pressure distribution. A twist with the correct orientation decreases the load in these regions, and increases the load in the regions of the upper-left and lower-right flank. Thus a homogeneous pressure distribution along the tooth width can be realized. Nonetheless, the line of increased pressure caused by the effect previously addressed cannot be avoided. Therefore, a combination of flank twist and tip relief is analyzed. The twist leads to a homogeneous load distribution along the flank width; the tip relief prevents the pressure increase. And so a uniform load of the complete tooth flank is achieved, which is desirable for a high-load capacity.

Summary and Outlook

The purpose of tip relief is to prevent premature tooth meshing and corresponding, negative effects regarding load carrying capacity and excitation behavior. In existing research projects a positive influence of tip reliefs on the excitation behavior and the tooth flank load carrying capacity can be observed. This positive influence is dependent on the design of tip relief — especially the definition of geometry, amount, and length of tip reliefs. These design parameters are today calculated by means of analytical approximate formula. A disadvantage of this design method is the missing regard to local radii of curvature, local stiffness, and the influence of further tooth flank

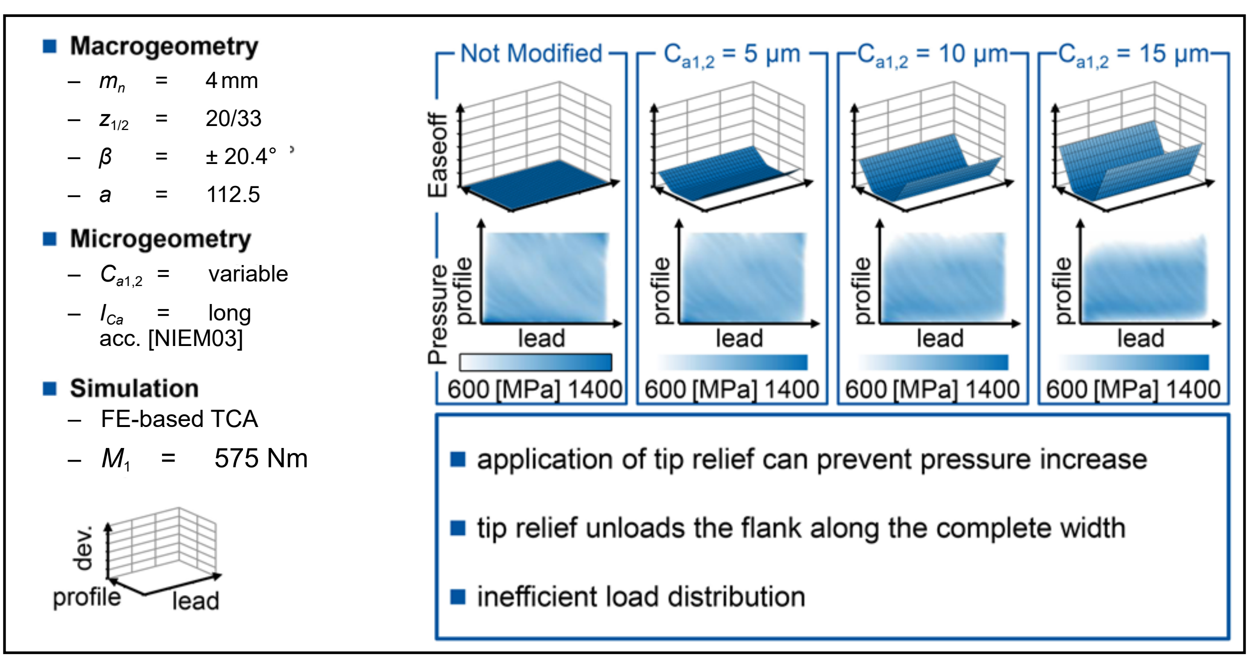

Figure 10 Influence of tip reliefs on the pressure distribution of helical gears.

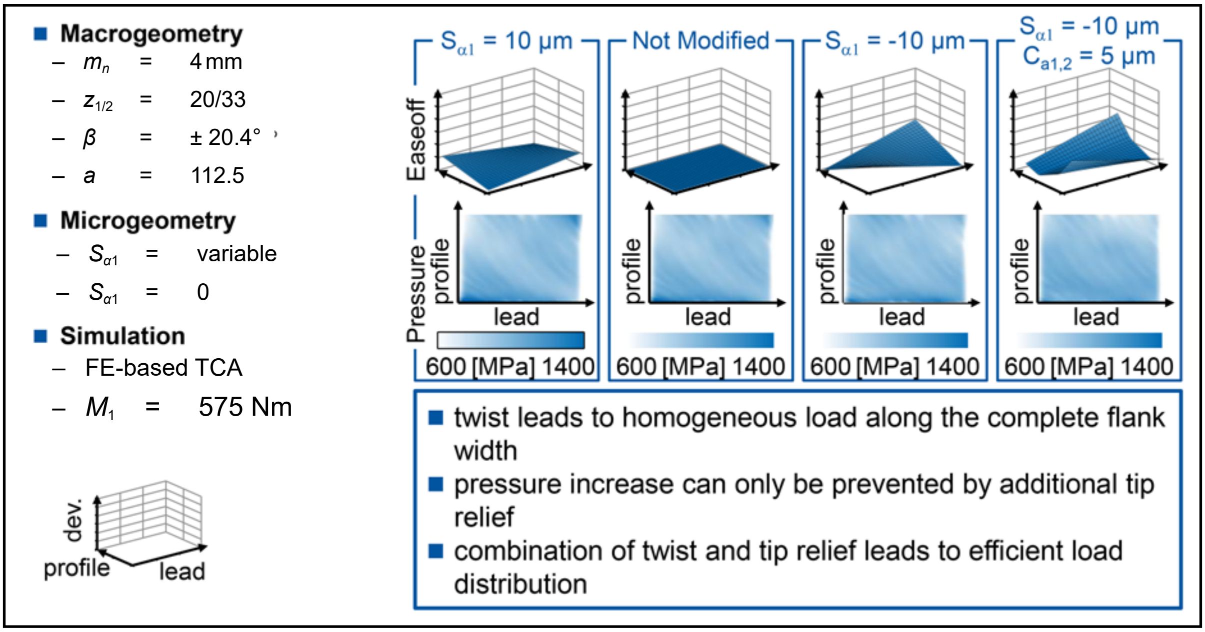

Figure 11 Influence of twist on the pressure distribution of helical gears.

modifications. Furthermore, a design method for appropriate tolerance fields is missing.

Therefore, this work focuses on the development of an FE-based method for the design of pressure optimized tip reliefs. For this purpose a method considering local radii of curvature in the pressure calculation, based on the existing FE-based tooth contact analysis, is presented and a parameter study is carried out to investigate the potential increase of tooth flank load carrying capacity by profile modifications. Furthermore, the theoretical penetration of the following teeth is calculated und used for the tolerance-based design of tip reliefs.

The FE-based designed tip relief is compared to an analytically designed tip relief concerning excitation behavior and tooth flank stress. Finally, a theoretical study focuses on the design of profile modifications for helical gears.

Due to the large number of design variants, two characteristics are used for an objective evaluation of the potential increase of tooth flank load carrying capacity. On the one hand, the maximum pressure caused by the profile modification is used. On the other hand, a weighted mean pressure is presented. In this way the location of the pressure is also considered, as well as its magnitude. The results of the parameter study reveal a different behavior of linear tip reliefs when compared to other relief geometries. What all variants of the linear relief have in common is that the weighted, mean pressure is on a comparable level. In general, a high increase of tooth flank load carrying capacity can be expected from linear and polynomial (2nd order, circular) tip reliefs. Based on these results the FE-based calculation of penetration developed in this paper is used for the design of the amount and length of tip reliefs, including appropriate tolerance fields. It can be shown that the analytical design approach is not suitable for preventing a premature tooth meshing. By using the FE-based design approach, a theoretical penetration and, by this, a premature tooth meshing is avoided. Along with the prevention of premature tooth meshing, the weighted, mean pressure and, by this, the pitting risk, can be reduced significantly for the FE-based variants. Furthermore, the excitation behavior, represented by the 1st gear mesh order, can be improved by the FE-based design. Summarizing, the FE-based design approach has a high potential for the improved, application-oriented design of tip reliefs.

By means of detailed FEM analysis, a premature tooth mesh is analyzed for helical gears. In contrast to spur gears, the premature tooth mesh for helical gears leads only for a small flank region to increased stress. The effect is limited to the points of the beginning and the end of the contact — A and E. In addition, another effect can be observed, i.e. — the decentral load application of helical gears — which is known from works focusing on tooth root stress — leads to a twist of the flank. In this way increased contact pressure occurs in the tooth flank root and tip area during the complete tooth contact. Further analyzation of damage pattern shows that this effect is even more critical, concerning the load capacity, than a premature tooth mesh. The effect is caused by the decentral load application and the local stiffness behavior that can be mapped by the FE-based TCA. Using the FE-based TCA, the influence of different flank modifications is discussed. For the focused test gear set, a tip relief combined with a specific flank twist shows the most promising results concerning a homogenous load distribution and, in turn, a high load capacity.

In the future the derived design method for tip reliefs has to be validated in further test rig investigations. Besides promising variants, unfavorable variants also must be tested by means of running tests to validate the design method presented in this paper.

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tip relief

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Efficient Hard Finishing of Asymmetric Tooth Profiles and Topological Modifications by Generating Grinding

Dr. Andreas E. Mehr and Scott Yoders

In order to improve load-carrying capacity and noise behavior, gears usually have profile and lead modifications. Furthermore, in gears where a specified tooth-flank load application direction (for drive and coast flanks) is a design enhancement, or even compulsory, the asymmetric tooth profile is a further solution. Nowadays, many gears need to be hard finished. Continuous generating grinding offers a very high process efficiency, but is this process able to grind all modifications, especially asymmetric gears? Yes, it is!

This technical paper will report about all new possibilities of modifications with the continuous generating grinding method, such as deviation-free topological grinding (DFT), generated end relief (GER), noise excitation optimized modification (NEO) and asymmetric gears

All of these modifications are indeed well-known in the gear industry, and tooth grinding methods are already established (namely profile grinding of asymmetric gears) to produce them. But now they can additionally be produced with, for certain parts, the faster—and therefore more economic—continuous generating grinding method.

Introduction

In the most modern transmission boxes, gears and shafts with profile and/or lead modifications can be found. With the help of these modifications, the efficiency and life time of the gears, and the transmission itself, can be increased. The running and noise behavior can also be improved.

Furthermore, the quality requirement of gears has been increased over the last 10 years. To fulfill the high-quality demands, it is necessary to hard finish the gears after their heat treatment. So nowadays, the hard finishing of gears is really established in a wide field of transmission applications like the automotive, truck, tractor and aerospace industries.

For these reasons, the gear production is always looking for a hard finishing method which is, on one hand, capable of creating all possible gear modifications, and on the other hand, as efficient as possible.

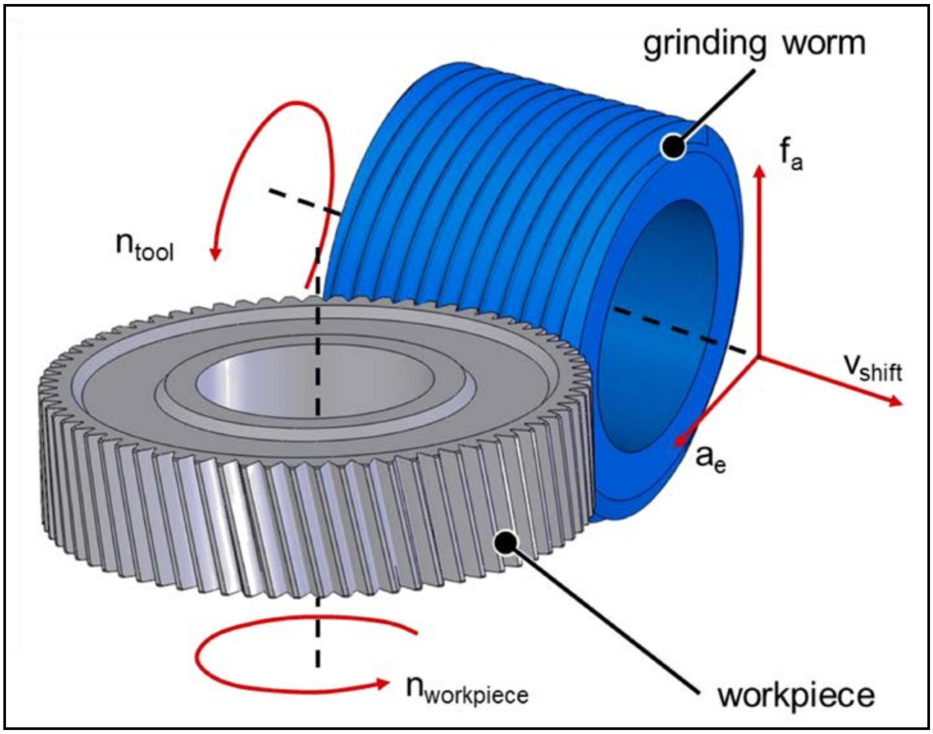


Figure 1 Kinematic principle of the continuous generating grinding (Ref. 1).

State of the Art

Generating Grinding. A very productive way to hard finish gears is the continuous generating grinding process. Its kinematic principle is shown (Fig. 1). The module range of external gears running in production is from 0.3 mm up to module 14 mm, and the latest developments of large gear generating grinding machines make it possible to grind gears with an outside diameter of 1,250 mm.

Due to the continuous rotary motion of the grinding worm (n_{tool}), which is always in a mating contact with the gear ($n_{workpiece}$), no time-consuming indexing from tooth to tooth appears. The grinding worm's high rotary speed leads to high cutting speed, and therefore also to a fast grinding time, so the stock removal rate on continuous generating grinding is sometimes higher than on other grinding processes.

Even with a high cutting speed of 80 to

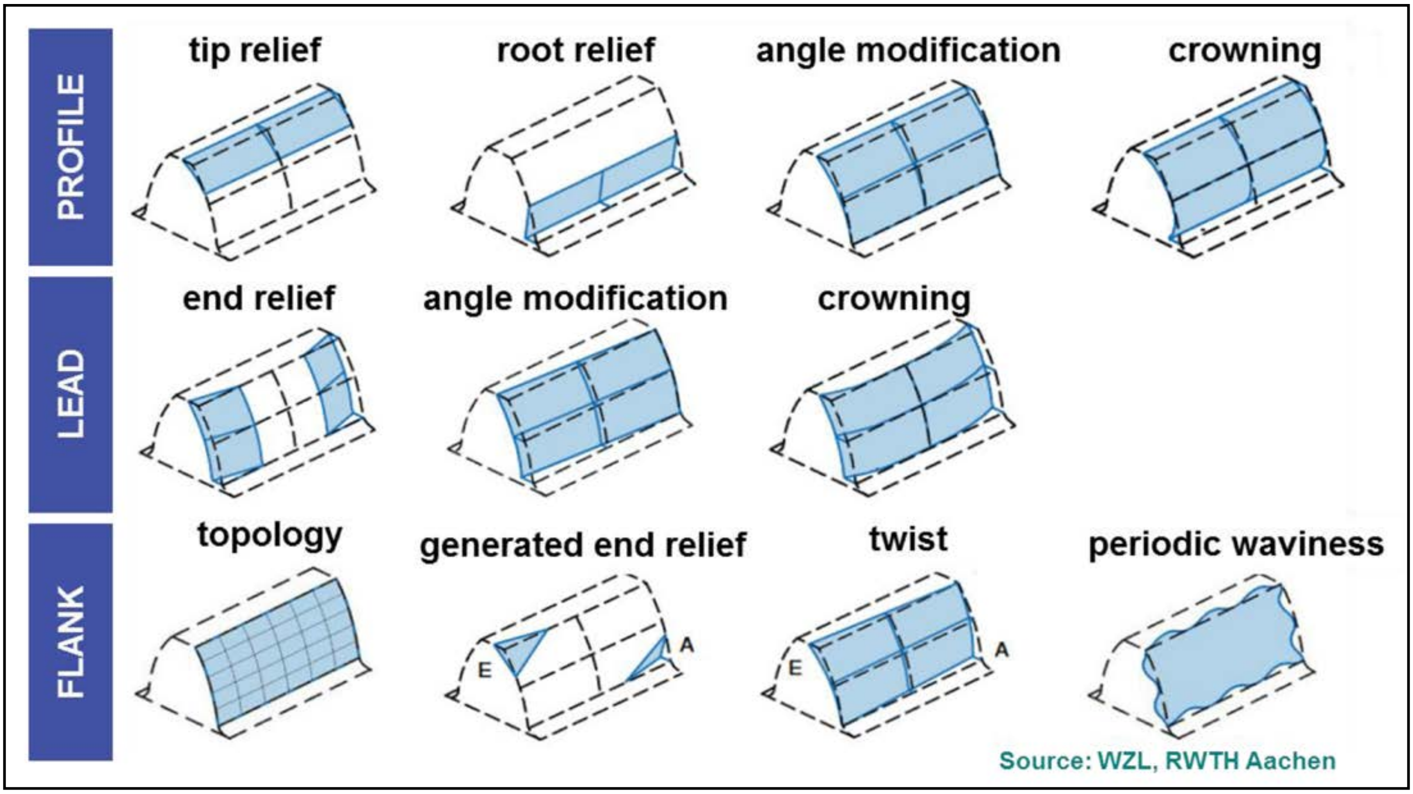


Figure 2 Overview of modifications (Ref. 6).

100 m/s — achievable with new types of abrasives and bonding systems — the risk for grinding burn is very low. The type of abrasive and the grinding technology have a big influence on thermal damage of the surface zone (Ref. 1), but recent studies show that these parameters can also have a positive influence on the load-carrying capacity on gear flanks (Ref. 2).

Modifications. Figure 2 shows all gear modifications possible on the profile, lead, and flank. This classification is based on DIN ISO 21771 (Ref. 3). All modifications have an influence on the tooth flank load-carrying capacity and the noise behavior (Refs. 4–5). The optimization of the gear design is always under the conflict of these two aims. This means that a modification which is useful for increasing the load-carrying capacity can have a more-or-less bad influence on the noise behavior.

Today the most commonly used are tip relief, profile and lead angle modifications in combination with crowning. In some special cases twist or twist-free grinding is applied. Recent scientific reports prove the optimization potential of topological modifications like twist (Ref. 6) and periodic waviness (Ref. 5) on a gear flank.

Twist-Free Grinding. Twist-free grinding with a profile angle-corrected worm used in a diagonal grinding method was invented in 1987 (Ref. 7). The aim of this method was to correct the natural twist that occurs during generating grinding of gear teeth featuring lead modifications, like lead crowning.

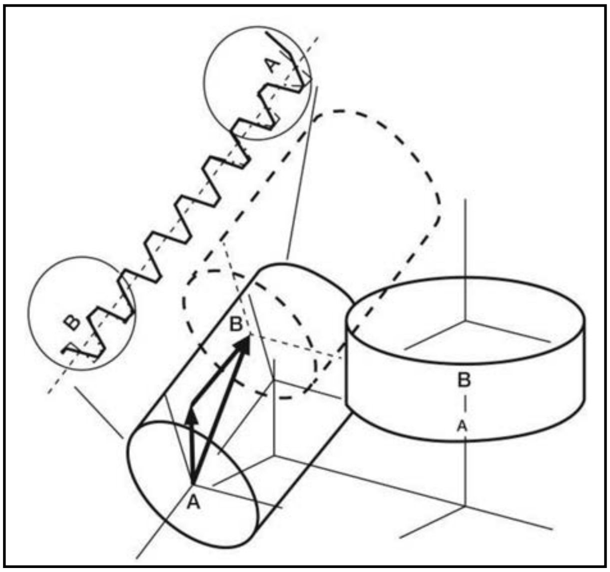


Figure 3 Principle of twist-free grinding (Ref. 7).

During the twist-free grinding process, the grinding worm moves diagonally; this means it is fed along the workpiece axis and at the same time, along its own axis from A to B (Fig. 3). This eliminates the twist or can be used to create a special twist. But this method does not eliminate geometrical errors over the total gear flank topology (Fig. 4). In Figure 4 (right) the twist has been corrected, but an unwanted concave crowning occurs in the profile.

Depending on the diagonal shift strategy, the number of parts-per-dressing cycle on the twist-free grinding is less in comparison to a conventional shift strategy. This reduced tool life affects the dressing time per part, which increases, and therefore the total cycle increases as well. The scientific report "Potential of Topological Grinding" (Ref. 6) investigated, besides the influence of the twist on the gear running behavior, also the hard finishing processes profile and generating grinding, with regard to productivity and costs. Here the result shows a cycle time increase of 20 to 25 percent for an automotive speed gear. Similar figures are known as a feedback from the industry. Optimization by using a two-sectioned

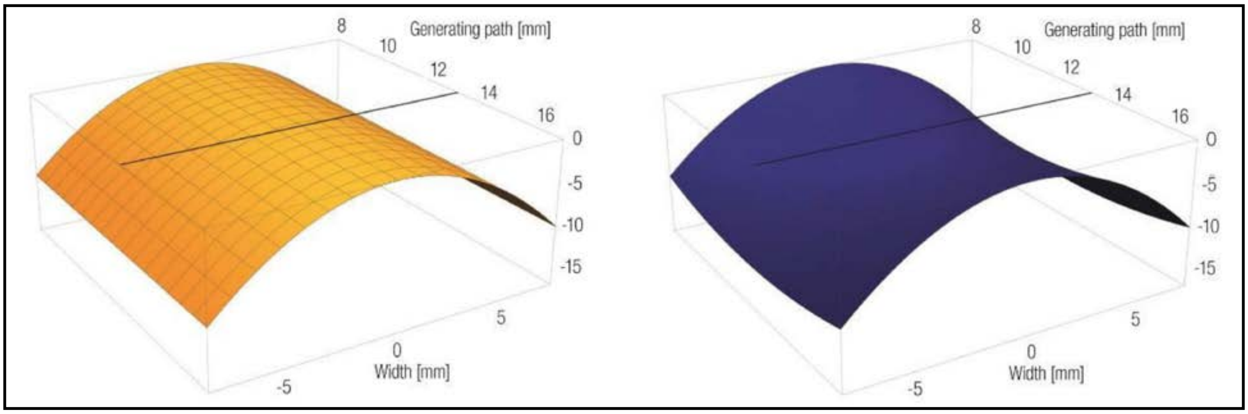


Figure 4 Twist-free nominal specification (left) and result (right).

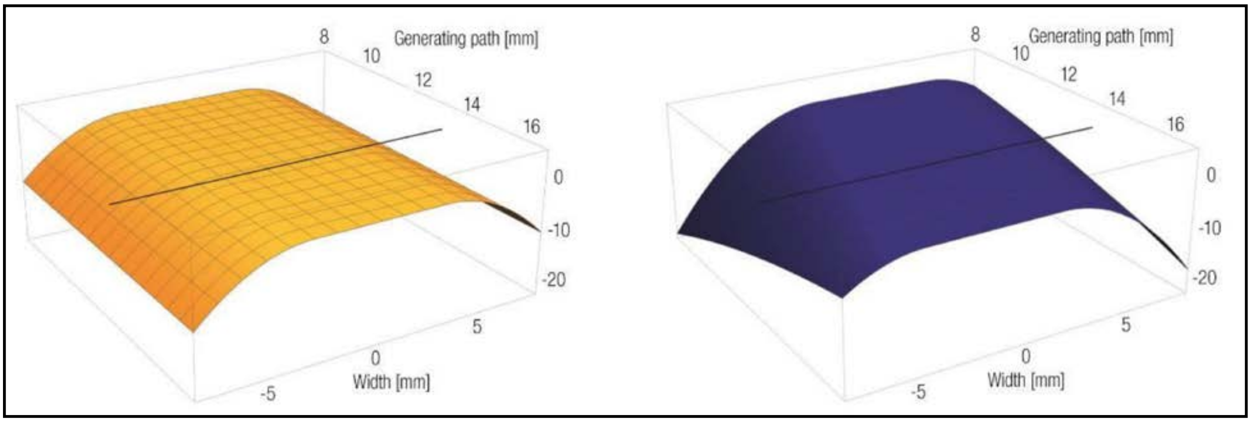


Figure 5 End relief nominal specification (left) and result (right).

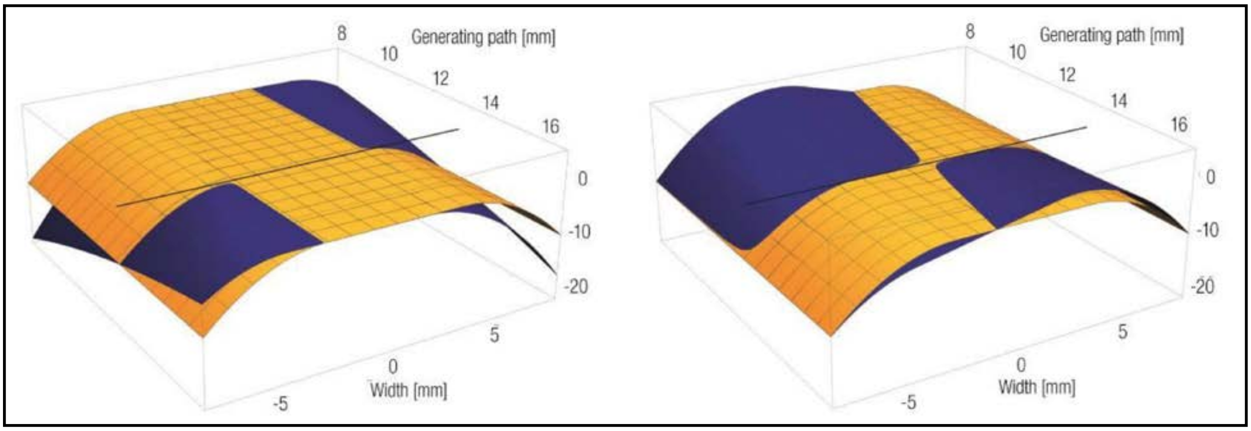


Figure 6 Illustration of the achieved end relief: conventional (left) and twist-free ground (right).

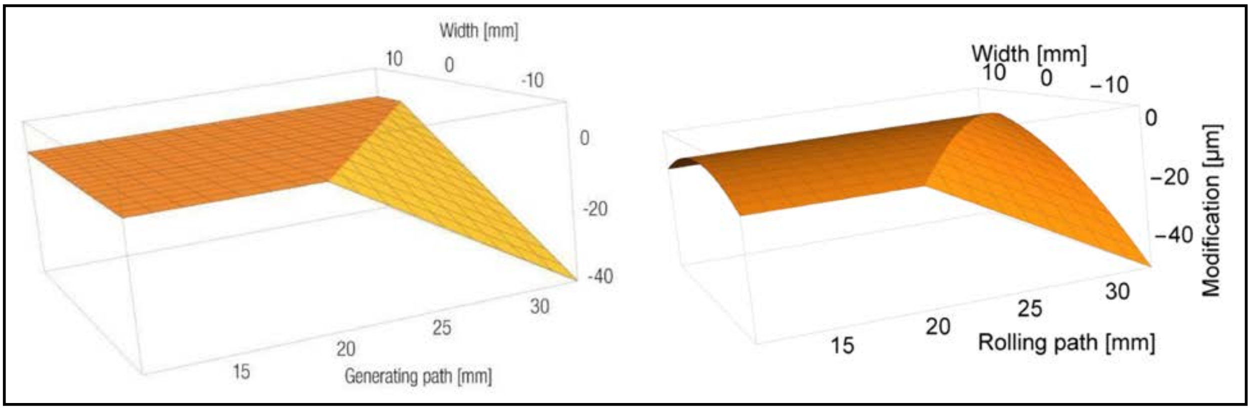


Figure 7 GER (left) and GER in combination with lead crowning (right).

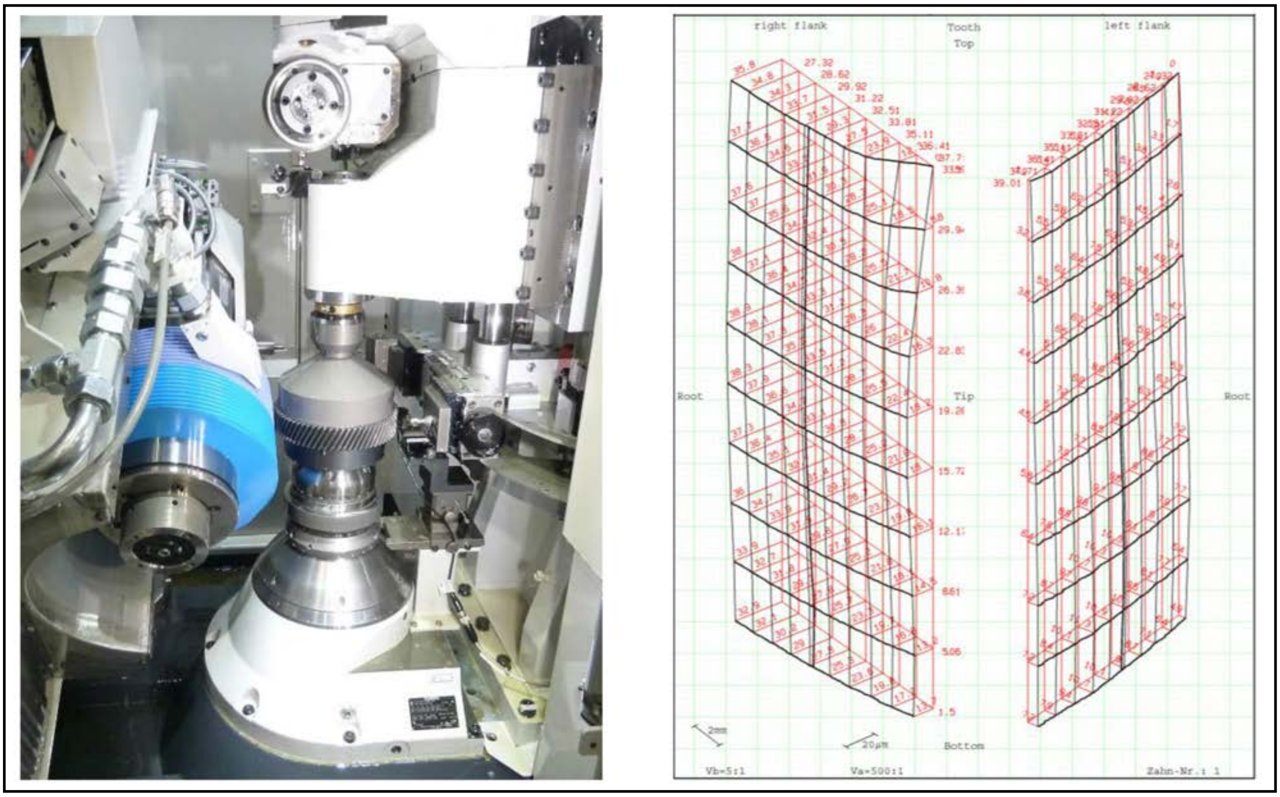


Figure 8 Grinding and polishing of a GER.

worm with a roughing and finishing zone improves the tool life, but still there is a small gap to the conventional grinding process.

Generating Grinding of an End Relief in the Lead. The generating grinding of an end relief in the lead is an established process (Ref. 8); but the conventional grinding shows that the nominal end relief is not achieved. There are distortions at the corners on the gear flank (Fig. 5, right) caused by the machine kinematics used for grinding. The root cause for this distortion is the same as that which creates the natural twist while grinding a lead crowing on helical gears, i.e. — the center distance and the corresponding generating point do not fit for all contact points.

Even using the twist-free grinding technology to compensate for the distortions at the gear tooth edges does not solve the problem completely. There are small discrepancies remaining and the modification is achieved correctly only on one diameter — the pitch diameter.

Deviation-Free Topological Grinding

The deviation free topological (DFT) grinding was developed exactly for this reason, to avoid the last unwanted distortions and geometrical errors on the gear flank.

Function Principle. Based on the old, but proven, twist-free grinding process, the deviation free topological (DFT) grinding was developed. The new grinding method (DFT) uses, during dressing and grinding, several CNC axes in addition to the profile angle-corrected grinding worm. A further advantage of DFT is working with standard dressing tools — no special or profile-corrected dressers are needed. Grinding and dressing time are equal to those occurring in twist-free grinding. For sure, the cycle time of the DFT is a little longer than a conventional grinding process, but it is still faster and more economic than the use of a topological, line-by-line dressed grinding worm.

Generated End Relief. In addition to grind and absolutely deviation-free lead modifications, the DFT grinding method can be adapted to enable generated end relief (GER) modifications as well. It is possible to superimpose the GER with all other modifications, such as lead crowning or twist.

Figure 8 shows an application example of the automotive industry. The differential gear with a module about 2.5 mm (DP 10) was ground and polished with a GER. Both the vitrified-bonded grinding and the elastic-bonded polishing worm section were dressed with the GER modification. And so it can be ensured that the triangular relief is also polished like the rest of the gear flank and the surface roughness is the same.

The benefits of such triangular end relief in terms of load capacity have been debated in the gear industry for many years. GER offers a targeted design of pressure distribution in meshing. This influences the maximum contact stress. Figure 9 shows an example of a truck speed gear under a constant torque. The gear width can be reduced by using a GER and adjusting the tip and root relief.

Noise Excitation Optimized Modification. Another application realizable with the DFT is excitation-enhanced modification. In the gear science the periodic waviness on gear flanks was investigated during the last few years. Time-variable gear tooth rigidity causes a periodic transmission error with amplitudes between two paired gears, which has a major impact on noise levels. To reduce the noise level a sinusoidal-shaped modification is ground on the gear flanks. The pos-

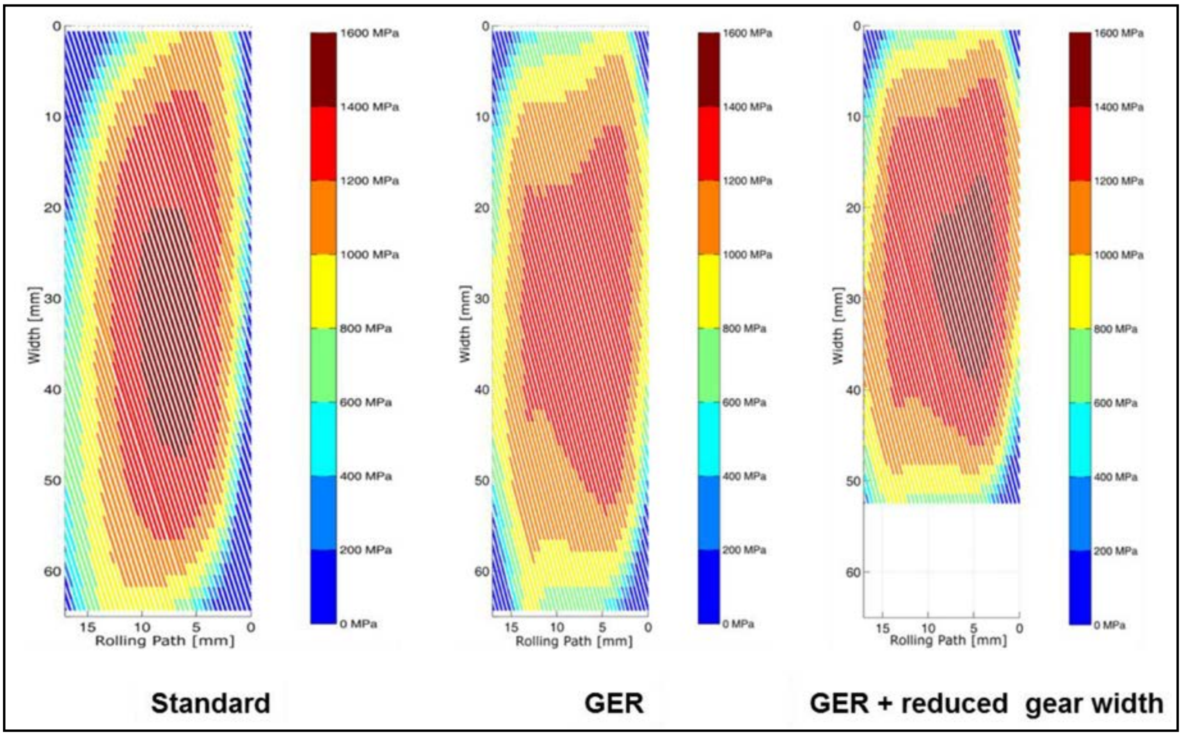


Figure 9 Reduced gear width by using a GER.

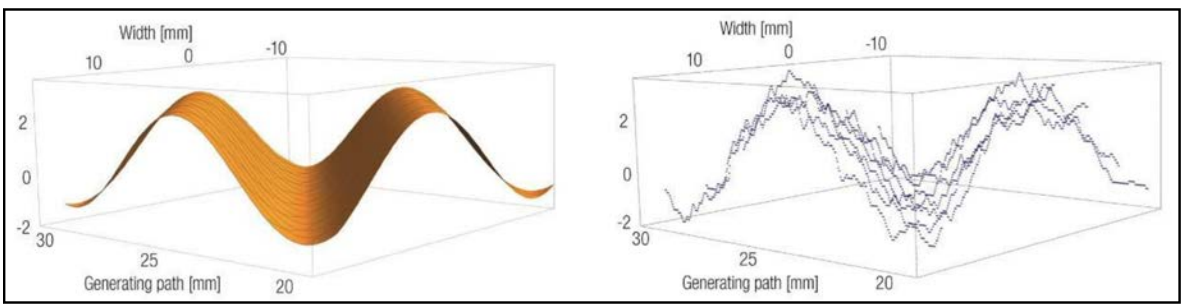


Figure 10 Sinusoidal-shaped modification: reference and DFT grinding result.

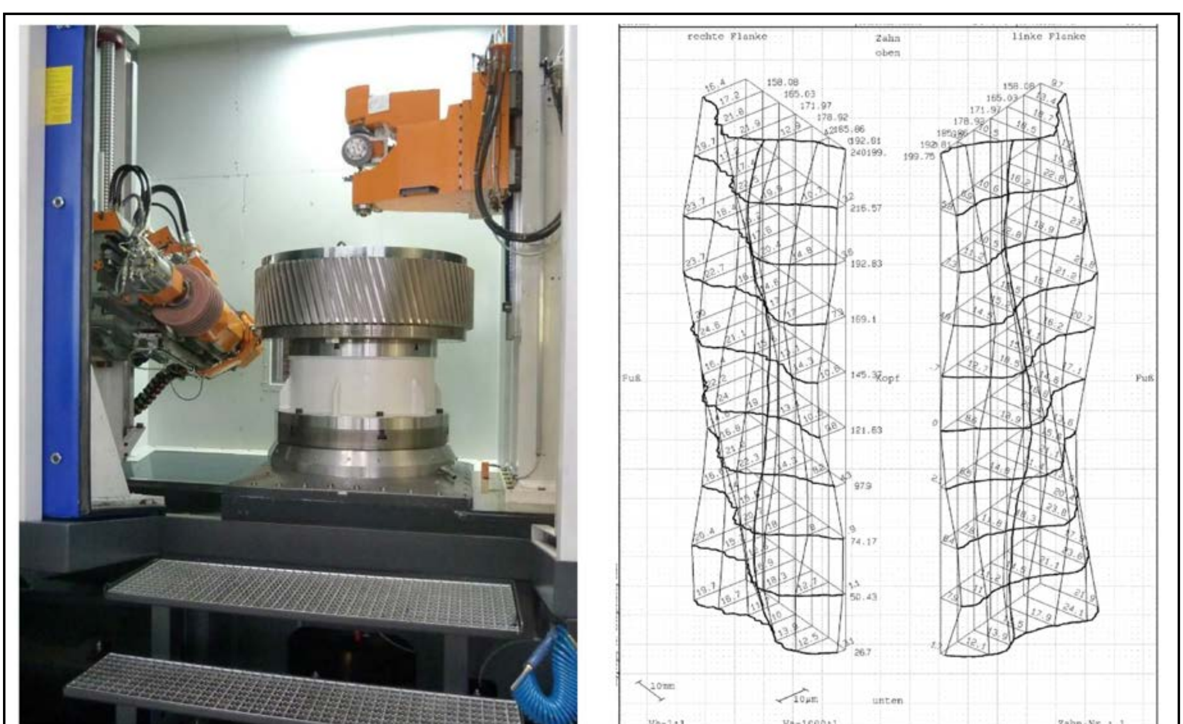


Figure 11 Grinding a NEO modification on a coarse module gear.

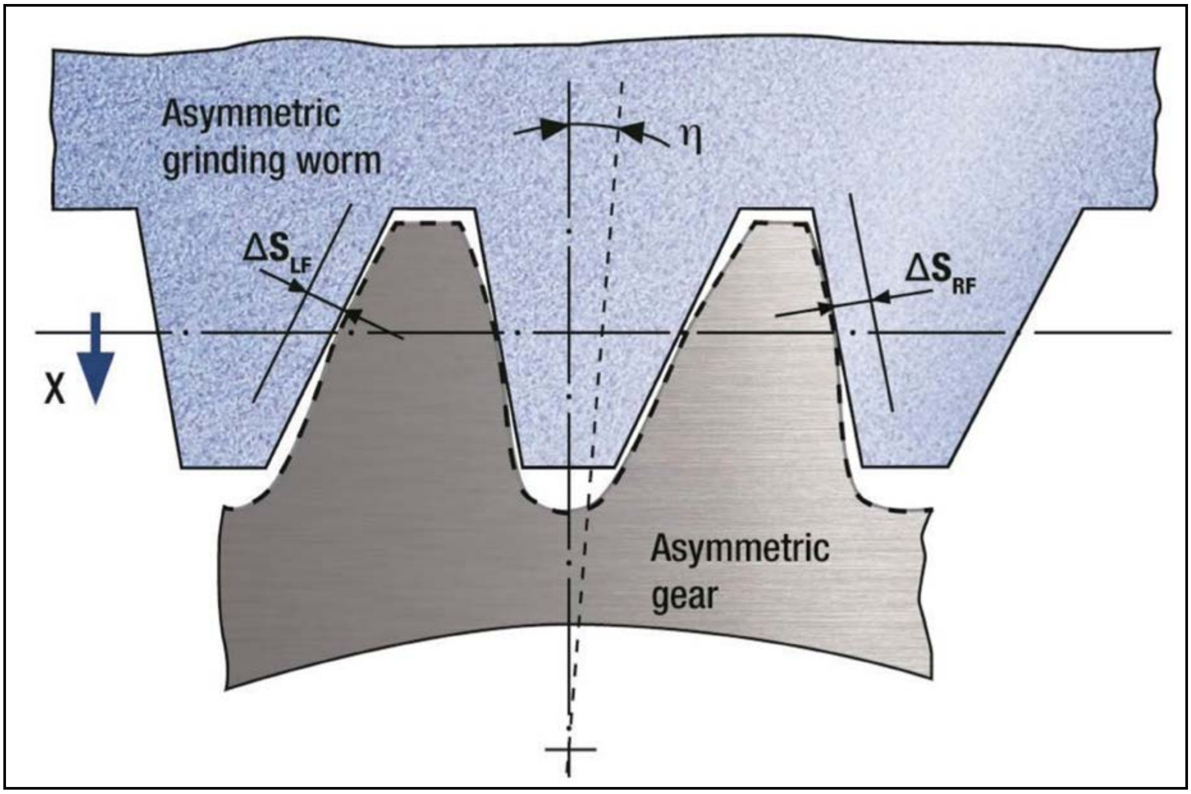


Figure 12 **Modified centering of an asymmetric gear and grinding worm.**

sible improvement has been conducted by the Gear Research Centre (FZG) at Munich Technical University's Institute for Machine Elements. This targeted degree of undulation, which typically has a µm-range amplitude, has no impact on load distribution.

This noise excitation-optimized (NEO) modification can be manufactured with the indexing generating grinding process as well, with a topological-dressed grinding worm used in the continuous generating grinding process. Both ways are very time-consuming and are therefore not economical enough for medium-to-mass production. Now with the new DFT grinding, a much faster and cost-effective production method is available. The method offers freedom in the design of the wave so the height of the amplitude, wave length, and orientation can be created on the demand of the application. Figure 11 shows a grinding result of a NEO modification on a gear with a module of 11 mm (DP 2.3). Due to the huge size of the gear, the amplitude of the wave should also have a higher amount. Therefore the periodic waviness is quite visible and gives a good impression as to what is really possible with this new grinding method.

Generating Grinding of Asymmetric Gears

The main advantage of asymmetric gears is contact stress reduction on the drive flanks. This results in higher torque density, i.e. — ratio of load capacity to gear size (Refs. 9–11). In the industry, hobbing, hardening and subsequent hard finishing (skive hobbing or profile grinding) have for years been a customary process chain for producing asymmetric gears. One important reason for the successful manufacture of asymmetric gears is the mathematical understanding of the gear size, as the machine operator must correct the measurement over balls and all cutting processes (Ref. 12).

Skive hobbing is effective, although it does not quite lead to maximum gear quality. Profile grinding achieves a significantly higher standard of quality than skive hobbing, but sometimes takes longer than a continuous generating method. Liebherr developed its asymmetric gear tooth generating grinding upon a customer request; this method combined high productivity with superior quality.

Technical Challenges and their Solutions. Asymmetric gear teeth, however, represent more of a challenge in terms of the generating grinding method and grinding and dressing tools than in terms of the grinding process itself. One key for success was to develop a dressing technology to produce an asymmetric grinding worm. For dressing purposes, the experts developed a software package that can work with asymmetric and symmetric dressing disks. The asymmetric dressing disk is ideal for a serial production. For prototype grinding, a symmetric dressing disc can be swiveled appropriately. A major challenge, as far as dressing, was to implement the complex mathematical calculations of the required swivel movement of the dressing unit. During the dressing process, the diameter of the grinding worm is reduced, which in turn necessitates a profile angle correction after each dressing sequence.

A quite different dynamic in respect of tooth-flank contact and contact order between the grinding worm and workpieces occurs during the grinding process itself, compared with conventional, symmetrical grinding processes (Ref. 13). Since stock removal on left and right tooth flank changes during the asymmetric grinding process, given differing pressure angles, an electronic correction is required. This degree of correction is determined by means of modified centering during the set-up procedure.

In the case of asymmetric gear teeth, this so called centering procedure, i.e. centered meshing of the grinding worm with the tooth gap, has to be slightly shifted by η during the radial feed *X* (Fig. 12) and maintained during the grinding process using precision monitoring and control technology. With this modified centering the different stock amount on the steep ΔS_{RF} and flat ΔS_{LF} gear flank can be nearly compensated. The cutting condition becomes more equal and now overloading the grinding worm with too high of a cutting removal rate on one flank can be avoided. This leads to a very low risk of grinding burn and no quality issues caused by tool wear.

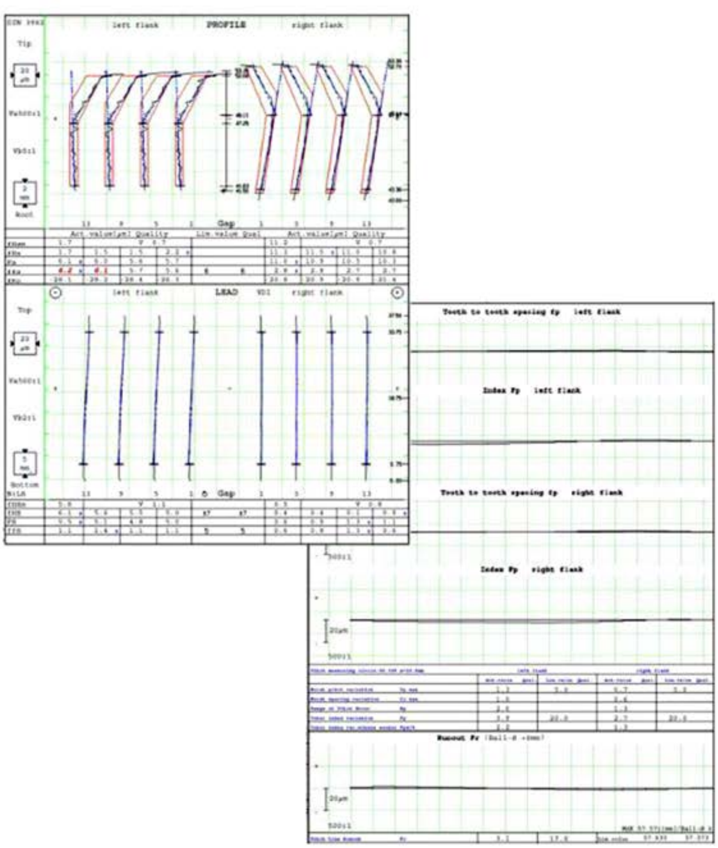
Application Example — Tractor Transmission. The generating grinding of asymmetric gears can now be reliably managed, and the first applications are running in series production. Figure 13 shows a drive shaft with four different gears. One of them has an asymmetric gear design. The challenge, beside the asymmetry, was that the grinding tool overrun was restricted. To grind the asymmetric gear, it was necessary to use a grinding worm with a maximum outside diameter of 75 mm. The achieved gear quality with the corresponding grinding technology is shown in Figure 14.

Gear Data and Tooling.

Workpiece:	
Module	2,5 mm
No. of teeth	17
Pressure angles	12° and 24°
Helix angle	25° (left hand)
Tip diameter	53 mm
Gear width	38 mm
Grinding worm:	
Dimension (D-L-B)	75-200-46
Type of abrasive	Cubitron II
Portion	30%
Grain size	+80
Grade	J
No. of starts	3

Figure 13 Drive shaft with asymmetric gear design.

Gear Quality, Grinding Technology, and Times.



Grinding technology:	
Cutting speed	25 m/s
Stock per flank	0.12 mm
Axial feed 1st cut	0.12 mm/tr
Axial feed 2nd cut	0.10 mm/tr
Axial feed 3rd cut	0.08 mm/tr
Times:	
Grinding time	95 s
Dressing time per part	12 s
Chip-to-chip time	18 s
Cycle time	125 s

Figure 14 Achieved gear quality by generating grinding

Summary

Nowadays with the continuous generating grinding method, there are increasingly more possibilities available to make even more complex tooth flank modifications. In this paper, it has been demonstrated that Liebherr has developed:

- Deviation-free topological grinding (DFT) to eliminate the minor distortions, which still can occur in end relief modification, and the twist-free grinding method. This has been solved by inducing multiple CNC-axes during grinding and has the further benefit of using standard dresser designs in twist-free grinding.
- Generated end relief (GER) is a further benefit of this DFT grinding, used to generate-grind a triangular shape end relief on helical gear applications, which can also be superimposed with profile- and lead-crowing shapes as well. GER enhances the designer's ability to increase load-carrying capacity by employing end-relief in the generating grinding applications.
- Noise excitation-optimized (NEO) modifications are also now possible in DFT grinding. In former times this type of sinusoidal flank modification was not possible with the continuous generating grinding method. This type of modification offers the designer the possibility to reduce noise emissions from time-variable tooth rigidity situations in a fast, economic gear grinding process.
- Asymmetric gears can also now be ground with the continuous generating method, thanks to software advancements in dressing and centering methods. The mathematics of differing pressure angles left to right flank, as well as pressure angle corrections necessitated in dressing as the tool diameter decreases, involves a complex technical challenge that has now been solved for industrial application.

Tooth flank modifications descried in this paper can now be produced with the established economic gear grinding process — the continuous generating grinding method.

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Scott Yoders graduated from The Pennsylvania State University (Penn State) in 1997 with a Bachelor of Science degree in Mechanical Engineering. He has been working in the gear industry for 20 years and holds two patents in gear manufacturing. His first 10 years in industry were spent in manufacturing engineering positions at both Eaton Corporation and General Motors, all in gear processing. In his tenth year at Liebherr, Yoders is currently VP Sales for Liebherr Gear Technology, Inc. in Saline, Michigan.

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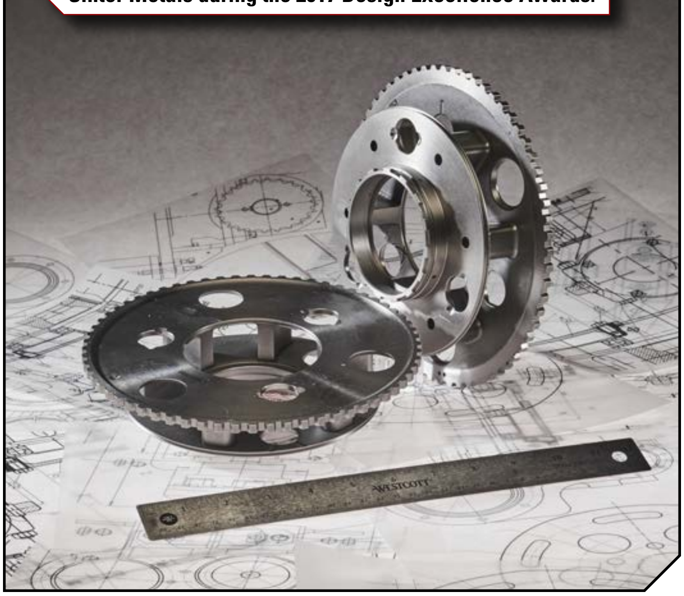
GRAND PRIZES

The Grand Prize in the Automotive—Transmission Category was awarded to GKN Sinter Metals, Auburn Hills, Michigan, for a planetary carrier assembly made for Ford Motor Company. The sinter-brazed copper-steel assembly, comprised of a cage and a flanged hub, goes into the all-new 10-speed transmission for the Ford F-150 pickup. The finished carrier assembly requires only simple milling and turning operations to hold the tight tolerances on the bearing bores, pinion pin shaft holes, and thrust faces.

The Grand Prize in the Automotive — Engine Category went to Phillips-Medisize, Menomonie, Wisconsin, for a four-slot fuel valve seat made for Delphi. The metal injection molded (MIM) part goes into the Multec3.5 compressed natural gas (CNG) fuel injector that satisfies the market's need for a low-cost, low-pressure port fuel injector. It is currently used by several small-engine and automotive applications, including after-market CNG conversions for trucks and cars, helping contribute to a reduction in greenhouse-gas emissions.

An Automotive-Transmission Grand Prize went to GKN Sinter Metals during the 2017 Design Excellence Awards.



The Grand Prize in the Automotive — Chassis Category was won by GKN Sinter Metals, Auburn Hills, Michigan, for a copper-steel output pulley made for Nidec Automotive Motor Americas. The part goes into an electric reclining mechanism in a minivan-rear-seat application. The part offers a lot of functionality in the small-footprint mechanism — the groove for cable retention, the cam for radial movement, and stops at both ends.

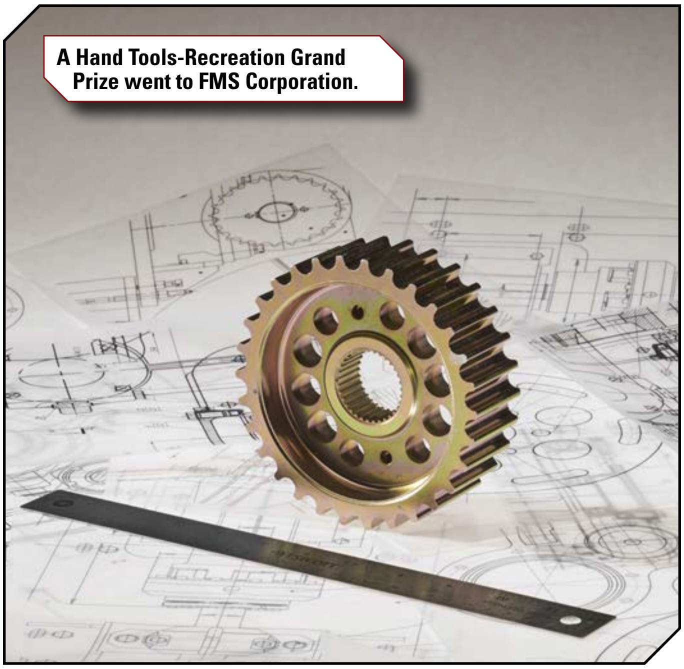
The Grand Prize in the Aerospace/Military Category was won by Dynacast Portland, Wilsonville, Oregon, for a MIM 17-4 PH canard made for UTC Aerospace Systems and Raytheon Company. The stainless steel part is used on the Talon, an add-on guidance and control package that transforms a legacy 2.75-inch Hydra-70 unguided rocket into a low-cost, precision-guided weapon. Three canards on each Talon act as the primary flight control surfaces. The MIM canard underwent a stringent qualification process.

The Grand Prize in the Hand Tools/Recreation Category went to FMS Corporation, Minneapolis, Minnesota, for a 30-tooth drive sprocket fabricated from sinter-hardened steel with a proprietary machining additive, made for Polaris Industries, Inc. The part goes into a motorcycle where it is driven by the output shaft of the transmission and in turn drives the rear wheel via a toothed pulley. Other than tapping, the part is formed completely net shape, which offered cost savings over the previously machined part.

The Grand Prize in the Hardware/Appliance Category was awarded to Indo-MIM Pvt. Ltd, India, for three MIM parts — upper stop ring, stop ring, and stop sleeve — made for Grohe, Germany. The parts go into the valve of a bath shower temperature controller unit. Made of MIM-316L stainless steel, all three complex parts are fabricated close to net shape, and special ceramic setters are employed for enhanced shape retention during sintering.

The Grand Prize in the Medical/Dental Category went to ARC Group Worldwide, Longmont, Colorado, for a MIM surgical keel punch made for Paragon Medical. The part functions as a broach to remove bone during knee surgery. Made from MIM 17-4 PH stainless steel, the part is molded and sintered to net shape with no additional coining, machining, or other post-processing to alter its shape.

The Grand Prize in the Industrial Motors/Controls & Hydraulics Category was won by FMS Corporation, Minneapolis, Minnesota, for a stainless steel fitting. The fitting provides a latching mechanism to easily move a safety pin on a hydraulic lever up and out of the way. An innovative ramp design acts as a cam surface to move the pin from one position to the other.



A Hand Tools-Recreation Grand Prize went to FMS Corporation.

AWARDS OF DISTINCTION

Winners included Stackpole International, Keystone Powdered Metal Co., Burgess-Norton Mfg. Co. Inc., NetShape Technologies, Indo-MIM Pvt. Ltd., FMS Corporation, ARC Group Worldwide, ASCO Sintering Co., and Capstan. (*www.mpif.org*)

Autodesk

ANNOUNCES NEW PRESIDENT AND CEO

Autodesk, Inc. recently announced that its board of directors has appointed **Andrew Anagnost,** current interim co-chief executive officer and chief marketing officer, as the company's new president and CEO, effective immediately. He will also join Autodesk's board of directors.

"The board and I are delighted that Andrew will lead Autodesk into its next stage of growth," said Crawford W. Beveridge, chairman of the board of Autodesk. "Andrew has been instrumental in the development and execution of Autodesk's successful business model transition, and with his leadership, we are confident that our move to the cloud and subscription will continue to be successful."

Anagnost, who holds a Ph.D. in aeronautical engineering and computer science from Stanford University, began his career at Lockheed Aeronautical Systems Company and as an NRC fellow at NASA Ames Research Center. After joining Autodesk in 1997, he held various technical and strategic roles.

He led engineering for Autodesk Inventor, the company's 3D model-based product design and engineering tool, growing revenue five-fold during his tenure. As senior vice president of business strategy and marketing, he led the company's successful transition to a subscription business model, and drove adoption of Autodesk's cloud technologies.

"This is an exciting time for Autodesk, and I am thrilled to be taking on the CEO role," said Anagnost. "Autodesk transformed the design industry by bringing CAD to the PC 35 years ago, and in the last 10 years became the clear technology leader. We were first to bring design to the cloud and mobile, and now we're bringing construction and manufacturing to the cloud as well. I can't wait to lead Autodesk into our next phase of growth, where we will combine business and product innovation to become an even more customer-focused company."

(*www.autodesk.com*)

Zeiss Industrial Metrology

HINTS AT MEASURING LAB OF THE FUTURE

At the Control 2017 trade fair, Zeiss discussed quality and inspection and how the measuring lab can be networked intelligently in the future.

"Networked intelligent systems that enable the results to be correlated in real time, calculated and visualized: these will become even more important in the Smart Factory," says Andrzej Grzesiak, senior director of metrology systems at ZEISS. CMMs provide 'a master plan' for the other measuring methods because of their extreme precision. Even small, networked solutions enable the metrology engineer to digitalize their day-to-day measuring jobs and network data to make analyses more reliable and efficient. The metrology engineer can then transfer comprehensive information derived from the quality data to the manufacturing and design departments.

At the heart of these networked solutions is the range of measuring systems available for capturing the surface shape of industrially manufactured products. In addition to traditional CMMs with contact and optical sensors, other systems are now being used successfully to perform measuring jobs. This is why the term "coordinate measuring system" is now being established in the relevant standards. Rather than being threatened with extinction, these systems will become more and more important in the manufacturing process.

All this will happen in spite of—or, better yet, because of—the increased use of other measuring techniques, such as at-line optical measurements. Increasingly the greatest challenge is being able to compare the results from these different technologies. If all the effects of these various technologies are considered, then comparability is possible. However, this requires considerable time and effort. Thus it is all the more important that today's software solutions, such as *Zeiss PiWeb*, correlate the results in real time and visualize these data.

With Zeiss solutions, the measurements in the entire product development process can be optimized, saving operators a significant amount of time when creating the necessary measurement plans with *Zeiss Calypso PMI* software. For the first time, it is possible to automatically combine the product and manufacturing information (PMI), which is increasingly standard in the CAD model, with the specified dimension, form and position tolerances in a single measurement plan. This drastically reduces the metrology engineer's workload, and these measuring experts can then invest this extra capacity in defect analysis and prevention, ultimately lowering the reject rate and increasing manufacturing efficiency. (*www.zeiss.com*)

Machine Tool Builders (MTB)

LAUNCHES DIABLO FURNACES HEAT TREATING COMPANY

Machine Tools Builders (MTB) has launched a spinoff company to build a new line of heat treating furnaces to better service their customers. The new operation, Diablo Furnaces, saved five employees from the unemployment lines and Diablo is looking to add more.

MTB was founded in 1995 to rebuild and re-control—add new controls to modernize machinery—large machines that make gears or work on gears. The company does this work for large national conglomerates such as Boeing and Caterpillar but also for local firms including Forest City Gear and Rockford Toolcraft.

Several years ago, MTB saw an opportunity to break into a related industry. When a gear is finished it has to be baked in a furnace to make it harder. Without the heat treating, the soft metal would wear down in a day.

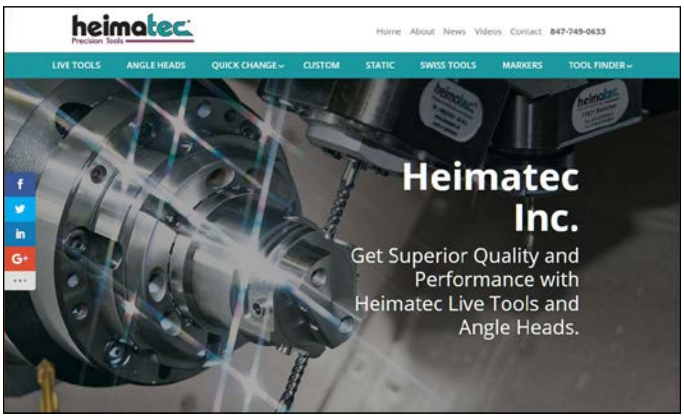
Machine Tool Builders began servicing and refurbishing heat treating furnaces. Many of those furnaces were built by a decades-old Rockford firm. When that company closed suddenly and its assets sold to a Michigan company, MTB added key personnel from that firm and began using that institutional knowledge to design and build new furnaces under the name Diablo Furnaces. Diablo builds internal quench, temper/draw, box and car bottom furnaces that are custom built for each customer, based on material, temperature range, volume and available floor space.

Diablo launched in February with five employees and a goal to do $6 million in sales this year. The company was 50 percent towards that goal by the end of April. Diablo now needs more workers to keep up with market demand.

(*www.machinetoolbuilders.com*)

Heimatec

INTRODUCES NEW WEBSITE



Heimatec recently announced the rollout of its new website.

The new site offers an in-depth look at the company's extensive lines of standard and machine brand tooling, including the new Tecnicrafts line of collets and guide bushings, specifically designed for the Swiss machine tool market.

The site includes dozens of downloadable PDF catalogs, as well as an online tool search feature and videos of various live tool demonstrations. A "Contact" page offers customers the option to inquire directly from the site, and easy access to local manufacturer's representative information. The site is easy-to-navigate and is mobile phone friendly.

Also included in the website is a dropdown section on custom designed tooling, which Heimatec offers in addition to its standard tooling and machine brand specific line. Tooling experts work directly with customers to design solutions to suit specific requirements for all CNC lathes, helping to solve the most challenging applications in multiple markets served by the company.

Heimatec tools offer the highest precision and most advanced technology available in the machine tool accessory market. The company is acknowledged as a world leader in live tools, angle heads and multi-spindle drill heads. With over 40,000 designs in its database, Heimatec offers the widest range of live tooling in the industry.

Heimatec North American distribution headquarters are located in Prospect Heights, Illinois (Chicagoland area) with world headquarters and all manufacturing based in Germany. A team of manufacturers' representatives covers the North American market for Heimatec.

(*www.heimatecinc.com*)

New Gear Technology at EMO Hannover 2017

Randy Stott, Managing Editor

EMO is arguably the most important trade show when it comes to the introduction of machine tool technology, and this year's show—taking place from September 18–23 in Hannover, Germany—promises not to disappoint. We've talked to a number of gear manufacturing technology providers to give you a sneak peak of what you can expect to see if you attend this year:

DVS Technology Group—Hall 17, Stand C46

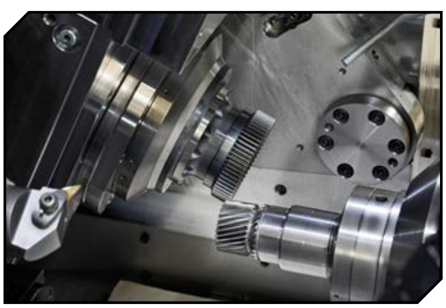
Pittler T&S GmbH will offer the first skiving center of its kind including automation cell for the complete machining of larger components (diameters up to 400 mm). The new platform is designed around the Pittler Power Skiving gearing technology, allowing for cutting of both internal and external gear components. The work chambers of up to two gear centers can be automatically supplied with tools via an innovative automation cell, minimizing space and investment requirements compared to robotic loading, allowing manufacturers to react economically to varying batch sizes.

PRÄWEMA internal honing - pioneering development for the surface quality of hardened internal gearings

Präwema will debut its SynchroSkiver machine, which combines the functions of hard skiving and internal honing for internal gears with significantly higher quality requirements. Präwema will also demonstrate VarioCrossHoning, a special oscillation method during honing which is deisgned to reduce surface roughness and improve surface quality for external gearing.

New for EMO17 - diamond dressing gear wheels from DVS Tooling

DVS Tooling will introduce the new VSD SF diamond dressing tool. The "SF" stands for "Super Finishing," and the tools allow for the manufacture of external gears with surfaces of Rz < 1 mm.

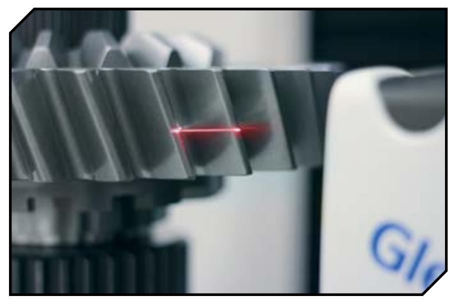


WMZ is demonstrating its Power Skiving gearing technology on an E-drive shaft.

Also at the booth, WMZ will demonstrate the complete manufacture of a motor shaft for an electric drive, including soft turning, milling, drilling and gear cutting via power skiving on its H200 machine.

Gleason—Hall 26, Stand D82

Gleason will highlight its 300GMSL Inspection System, which, in addition to conventional tactile probing, also offers non-contact laser sensor scanning of tooth flanks to support gear development. Complete topography data can be recorded far more rapidly than with conventional tactile probing with comparable results. In addition, its capabilities include surface finish measurement and Barkhausen noise analysis to inspect for grinding burn. The combination of functions make the system well suited for R&D applications for both prototype and production parts or when reverse engineering is required. It can accommodate spur, helical, straight bevel, spiral bevel and hypoid gears with diameters up to 300 mm.



Other significant new technologies on display will include the 100 HiC Horizontal Hobbing Machine with integrated chamfering/deburring unit and Gleason automation; the Gleason Genesis GX Series threaded wheel grinding machine with features like single-tool setup, twist-controlled grinding, integrated automation, and closed loop integration with Gleason GMS inspection machines; the 150SPH Spheric Power Honing machine; and the 500CB Cutter Build Inspection machine.

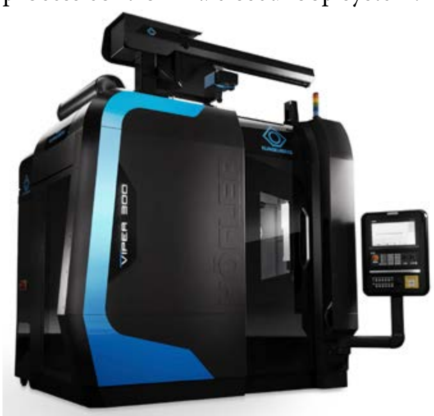
Gleason will also be emphasizing its advanced cutting tool solutions, such as the Pentac Plus-RT system, which is designed to be built faster and more precisely than stick blade cutter systems of the past. As in previous shows, Gleason will host its Quick-Flex Plus Challenge to demonstrate how easy it is to change the modular components of this technology.

Finally, visitors can expect to see the latest Gleason software solutions, including GEMS (Gleason Engineering and

Manufacturing System) as well as the latest release from KISSsoft of design software for gears and power transmission systems.

Klingelnberg — Hall 26, Stand B82

Klingelnberg will introduce the Höfler Speed Viper 180 and Speed Viper 300 generating grinding machines, which have been designed from the ground up for Industry 4.0, optimized ergonomics and user-friendly controls. The new *GearPro Operator* control system means that modifications and corrections no longer need to be entered manually, but are automatically loaded instead. The Speed Viper is designed for high productivity and robustness with short setup times, minimum cycle times and digital process control in a closed loop system.



Also on display will be the new Höfler TM 65 complete processing machining center, which can produce gear bodies and gearing systems of any complexity directly from rod material — regardless of whether it is bevel gears, cylindrical gears or internal gears.

Visitors can also see the P65 precision measuring, which has a new, ergonomically optimized design that allows for 3D coordinate measurement, form measurement and surface roughness measurement all on one machine, in one chucking. Klingelnberg also promises to introduce some new products in the field of optical measurement.

Finally, Klingelnberg will show its C 30 flexible production machine, which is capable of both bevel gear cutting and power skiving of cylindrical gears, as well as its SmartTooling system, which is a digital identification system for tools and chucking materials, which can be tied into the concept of Industry 4.0.

Liebherr Gear Technology — Hall 26, Stand A72

Liebherr will introduce gear skiving machines LK 300 and LK 500 based on the tried-and-tested components of the corresponding large hobbing machines but with greater rigidity and more powerful spindles. As skiving is a highly dynamic process, the machine is supplied on a "turnkey" basis with individual clamping fixtures for each workpiece, precise rigidity and contour accuracy. With its skiving^3 program, Liebherr provides not only the machine, but a whole process, including tools, technology and training.

The LK 300 is designed for maximum gearing diameter of 300 mm, but allows for workpiece diameters up to 500 mm. Maximum table speed is 3,000 rpm, while maximum tool speed is 2,700 rpm. The LK 500 can accommodate gearing diameters up to 500 mm and workpiece diameters up to 600 mm. The larger machine achieves a table speed up to 1,500 rpm, with the tool speed the same as the smaller model, at 2,700 rpm.

In addition to the skiving machines, Liebherr will introduce the LC 280 α gear hobbing machine, designed for maximum flexibility and productivity in a job-shop environment. The LC 280 can machine gears and shafts with a workpiece diameter up to 280 mm and a shaft length up to 500 mm with indexable carbide insert cutters. The hob head was designed for increased flexibility and productivity. "It is now possible to machine workpieces up to a module of five millimeters," says Dr.-Ing. Hansjörg Geiser, Manager Development and Design, Gear Cutting Machines. "The spindle speed was increased by 50% to 2,250 revolutions per minute compared with the previous model. At the same time, the shifting length increased to 200 mm and the maximum tool diameter increased to 150 mm."

Samputensili — Hall 26, Stand A56

The SAMP group will display the SG 160 Skygrind, the world's first dry gear grinding machine. The machine features two spindles: one for hobbing and one for generating grinding. The machine removes about 90 percent of the stock allowance with the first pass using dry hobbing. In the second pass, the remaining stock is removed via dry grinding. Moreover, the two-spindle structure, coupled with high-speed linear actuators, allows for chip-to-chip times of less than two seconds, ideal for applications in the automotive industry.

Also, the company will present the Samputensili G 160 dual-workspindle grinding machine for the first time in Europe. The G 160 is designed for highly productive grinding of gears up to 160 mm diameter, with chip-to-chip times as low as 1.6 seconds including meshing, synchronization and simultaneous repositioning of the tool. In addition, no additional axis is required to perform the dressing cycle. The dresser is mounted on the X1 axis slide next to the workpiece spindle. This enables topological modifications of the gear flank and makes the dressing cycle insensitive to thermal deviations.

An Event for All

WESTEC is positioning itself as an event for not only businesses of all sizes and interests, but also attendees of all ages.

Alex Cannella, News Editor

There are a lot of trade shows that vie for the manufacturing crowd's attention any given year, and even more conferences and educational seminars, but WESTEC is a rarer beast; it wants to be both. Alongside the usual trade show experience you might expect walking the floor, WESTEC is providing numerous educational offerings from their Machining Academy to even a seminar on how California businesses can take advantage of local skills gap funding.

With incentives for companies both new or old and local or distant, SME wants to give everyone a reason to attend WESTEC, but they seem to hold a special place for small and medium businesses. A number of the show's panel discussions are focused on giving small and medium businesses the know-how they need to thrive in the current changing industrial world.

"We tend to like to talk about the Northrop Grummans and the Boeings of the world, but really, the heart of manufacturing, the bulk of manufacturing in the United States is small- and medium-sized businesses," Debbie Holton, VP of events at SME, said. "And events like WESTEC are a great place for them to come, see technology in action, meet with people that have expertise, and then talk to their peers, make business connections, and get a lot done in a very short period of time."

One of the primary educational offerings that will interest small and medium businesses are WESTEC's various panels on the Industrial Internet of Things (IIoT) designed to get manufacturers up to speed about the topic. One such example will be the Smart Manufacturing Series workshop. The series will feature three seminars across the show's three days that will focus on different cornerstones of IIoT technology ranging from automation and robotics to additive manufacturing. Experts from companies ranging from IBM to Siemens will be sharing from their companies' well of knowledge on best practices, case studies and more.

"Part of the urgency in manufacturing right now in general is just that the technology is changing so fast…" Holton said. "Coming now and already here are the demands of the OEMs that people get in line and know how to use these advanced technologies. We definitely don't want people left behind. It's SME's responsibility to get out there and bring folks into the Fourth Industrial Revolution, and that's what we're doing with WESTEC and a lot of our programs out there right now."

According to Holton, SME is responding accordingly to many of the urgent changes in the industry by making sure attendees leave their IIoT seminars with somewhere to start, something actionable they can start doing now to make sure they don't fall behind.

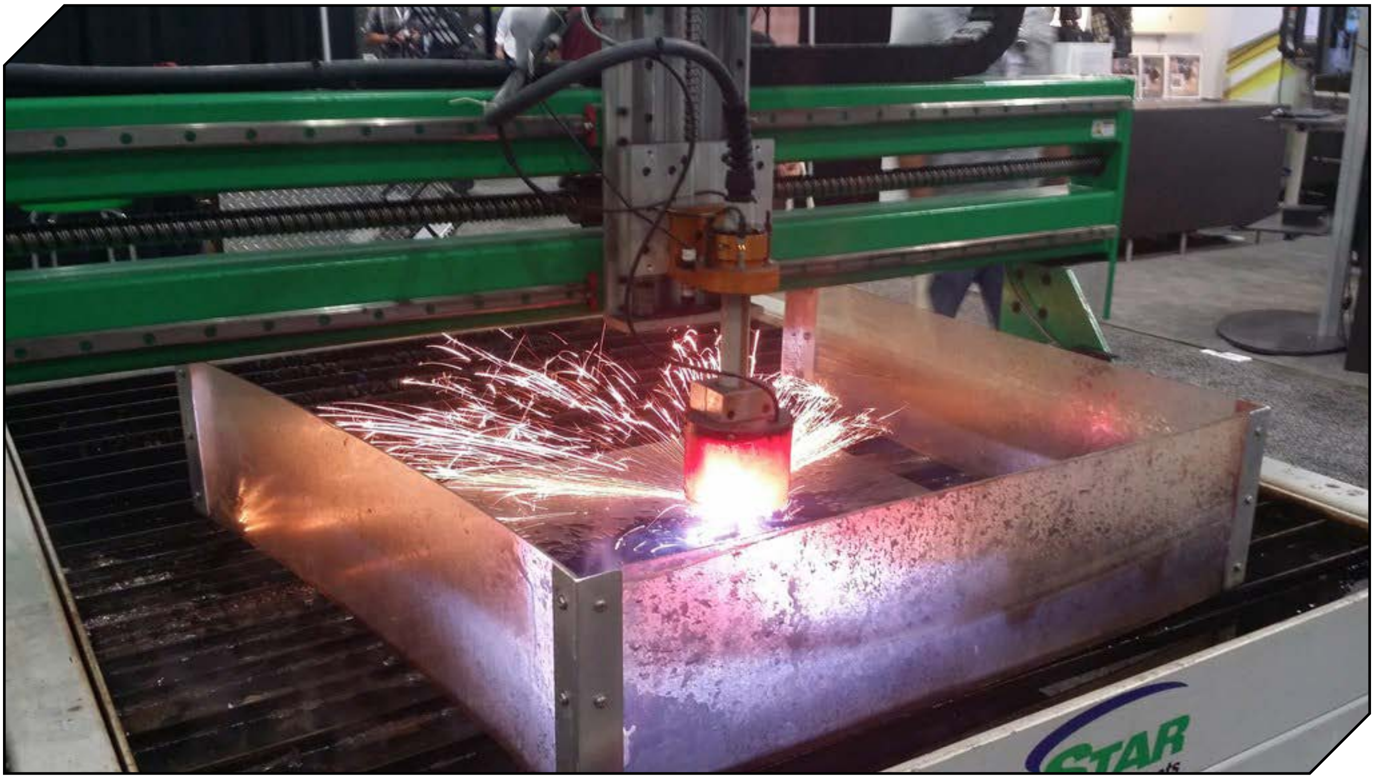
"We all like to sit in the brain calisthenics and think about 'wow, what can I do?' But to have something actionable going out is the best," Holton said.

WESTEC's panel topics won't be limited to just the Industrial Internet. Another hot button topic Holton expects will draw attention will be a seminar on how OEMs can break into the supplier business, which will be part of the larger Business of Manufacturing series of seminars. The Business of Manufacturing focuses specifically on small- to medium-sized businesses and the unique challenges associated with running one.

Running in parallel with WESTEC's panels will be SME's Machining Academy, a program designed to give attendees an opportunity to review, validate or brush up on their machining knowhow. Before coming to the show, attendees can take an assessment from SME to measure their machining skills, then go to the Machining Academy and engage in interactive training with live machinery on the trade show floor.

"What we were looking to do at WESTEC is to have some type of marriage between the live excitement of the trade show floor and all the equipment that's there and under power and the fact that we can provide training and online assessments to people in advance. So basically what we're planning to do is have people who sign up for this be able to take an assessment in advanceof their skills and knowledge in machining, and then come to the show and actually demonstrate that knowledge on machinery under power."

In addition to helping engineers review and validate the skills they've already obtained, the Machining Academy can also highlight areas they may need to brush up on. The academy is part of SME's larger efforts to address the skills gap in the industry, a problem only being exacerbated by the rapid changes the Industrial Internet is bringing to the industry, but Holton stressed that it isn't meant to train a fresh employee from start to finish in a single



week. However, many of the lessons and online assessments that are being used for the Machining Academy are part of SME's longer online courses on the topic.

Perhaps reflecting some of the changes the Industrial Internet is bringing to the industry as a whole, Holton has noted a surge of attention placed on automation on the trade show floor, as well. A number of new automation and robotics exhibitors have joined the show, and Holton thinks they'll be an important addition for attendees to look out for.

"I think it's important, especially in aerospace industries where a lot of that work is still done by hand, to look at ways we can utilize automation to both increase quality and productivity, but also reduce some of the repetitive stress injuries and things that happen in that field...And things that really were out of the reach of most manufacturers years ago are now at a price point on a capabilities side that makes sense for them to consider it in some way."

SME has even adjusted their educational offerings that cater to a younger audience, what they're calling the Student Innovation Tour. In the past, students that attended WESTEC were often placed in more traditional classrooms and given lectures by guest speakers, then cut loose to explore the trade show floor. However, according to Holton, SME is shifting away from the classic schoolroom approach and trying something different this year.

"We realized that they sit in classrooms all the time, and that might not be the best way for us to reach them and show them how fun and exciting manufacturing is," Holton said.

Instead, SME is attempting what Holton describes as a "Disney-world style orientation." Instead of a traditional classroom, students go through a special presentation area with interactive exhibits, including a "rocket challenge" that tasks students with determining the weight and trajectory of rockets and competing for both accuracy and longest distance. Afterwards, they're sent out to the trade show floor, but SME is also providing several student friendly booths for them to visit on their tour that will have presentations prepared for them.

Much like the rest of the industry, WESTEC is changing with the times to meet the new opportunities and demands of the Industrial Internet, and that means that like the rest of the industry, WESTEC is changing more from year to year than ever. SME is working hard to not just keep WESTEC up with the times, but also its attendees.

"When you have a long-running show like WESTEC, people think 'oh yeah, I've been there, I've seen that. It used to be this and it used to be that,'" Holton said. "But really I think it is a very pivotal event for people in this marketplace, and there's technology there that they're going to miss if they're not there. For folks that need to come and make the most of their time and they're looking at technology or they want to evaluate equipment for purchase, there's no better place than this event this year."

For more information:
WESTEC 2017
Phone: (800) 733-4763
www.westeconline.com

September 6–8—AGMA 2017 Bevel Gear System Design San Diego, CA. Learn how to design and apply bevel gears systems from the initial concept through manufacturing and quality control and on to assembly, installation and maintenance. Engage in a practical hands-on guide to the bevel gear design, manufacture, quality control, assembly, installation rating, lubrication and, most especially, application. Engineers, technicians, and others involved in the selection, application and/or design of bevel gear systems should attend. Ray Drago is the instructor. For more information, visit *www.agma.org*.

September 13–15—VDI International Conference on Gears 2017 Garching, Germany. Supported by national and international associations, the conference brings together over 600 leading experts from the international gear and transmission industry. The 2017 conference will be a unique meeting point for equipment manufacturers, producers and researchers of gear and transmission systems to present their new solutions, latest research results and technical ideas. There is still room for improvement in the field of gears and transmissions, how gears can contribute to increasing energy efficiency, reducing resource consumption and how new technologies will be incorporated in the powertrain. For more information, visit *www.vdi-wissensforum.de/en/event/international-conference-on-gears/*.

September 18–21—Gear Dynamics and Gear Noise Course Ohio State University, Columbus, Ohio. The purpose of this unique short course is to provide a better understanding of the mechanisms of gear noise generation, methods by which gear noise is measured and predicted and techniques employed in gear noise and vibration reduction. Over the past 38 years more than 2000 engineers and technicians from over 370 companies have attended the Gear Noise Short Course. The course is of particular interest to engineers and technicians involved in the analysis, manufacture, design specification or utilization of simple and complex gear systems. Industries that find this course helpful include the automotive, transportation, wind-energy, process machinery, aircraft, appliance, general manufacturing and all gear manufacturers. The course material is covered in such a way that the fundamentals of gearing, gear dynamics, noise analysis and measurements are covered first. This makes the course appropriate to the gear designer with minimal knowledge of noise and vibration analysis as well as to the noise specialist with little knowledge of gears. For more information, visit *www.nvhgear.org*.

September 18–22—AGMA Basic Training for Gear Manufacturers Hilton Oak Lawn, Illinois. Learn the fundamentals of gear manufacturing in this hands-on course. Gain an understanding of gearing and nomenclature, principles of inspection, gear manufacturing methods, and hobbing and shaping. Utilizing manual machines, develop a deeper breadth of perspective and understanding of the process and physics of making a gear as well as the ability to apply this knowledge in working with CNC equipment commonly in use. This course is taught at Daley College. A shuttle bus is available each day to transport students to and from the hotel. Although the Basic Course is designed primarily for newer employees with at least six months' experience in setup or machine operation, it has proved beneficial to quality control managers, sales representatives, management, and executives. Course instructors are Dwight Smith, Allen Bird and Peter Grossi. For more information, visit *www.agma.org*.

October 4–6—AGMA Steel for Gear Applications Alexandria, VA. This course provides detailed information to make use of steel properties in a system solution and understand the potential that different steel options can offer for various applications. Students will explore the how the production of the steel can affect the performance of the material and also the final component and system. The course will be facilitated by Lily Kamjou, a senior specialist in Ovako's Industry Solutions Development department. It is an advanced level course and qualifies for those individuals pursuing the Advanced Gear Engineering Certificate. For more information, visit *www.agma.org*.

October 24–26—Gear Expo 2017 Columbus, Ohio. For three days, the full range of drive technology experts—design, manufacturing, application engineering, gear buyers and manufacturers—network and build relationships that benefit their respective companies. For the past six years, AGMA's Gear Expo has been growing and expanding with more suppliers and attendees meeting to build new partnerships and explore the latest technology on the market. Attendees represent a variety of industries including off-highway, industrial applications, automotive, and oil and gas as well as aerospace, agriculture and construction. They come from around the United States, international manufacturing hubs, and emerging markets to conduct profitable business transactions and collaborate on the innovations that make their operations more streamlined. The show is co-located with the ASM Heat Treating Society Conference and Exposition. For more information, visit *www.gearexpo.com*.

October 24–26—2017 Quality Show Rosemont, Illinois. This event is the only tradeshow focused exclusively on quality manufacturing and will offer engineers and managers responsible for quality in the manufacturing process for automotive, aerospace, consumer products, electronics, medical devices, machinery, appliances and more two high-profile keynotes and an interactive tradeshow floor with dozens of education sessions and networking opportunities. Education will be another key component of The Quality Show, which is offering two high-profile keynotes by Matthew Napoli, VP of in-space operations for Made in Space, and Harry C. Moser, founder and president of Reshoring Initiative. In addition to the keynotes there will be a dozen free 30-minute education sessions in the Learning Theaters located in the exhibit hall by Coordinate Metrology Society (CMSC), DISCUS Software, Mahr, Zeiss Industrial Metrology, BSI and more. For more information, visit *www.qualityshow.com*.

October 24–26—South-Tec 2017 TD Convention Center, Greenville, S.C. South-Tec draws manufacturing suppliers, distributors and equipment builders from across North America and around the world - bringing them together in Greenville, South Carolina. With hundreds of exhibiting companies, attendees can find all the latest technologies and services - plus the experts who build them - ready to demonstrate solutions that can help them grow their business. Visitors can make side-by-side comparisons, discover integrated equipment, hear about industry trends and forecasts, and leverage their purchasing power. For more information, visit *www.southteconline.com*.

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gear TECHNOLOGY

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- ❑ Manufacturing Engineering Department (F)
- ❑ Product Design, R&D Management (H)
- ❑ Product Design, R&D Department (I)
- ❑ Purchasing (L)
- ❑ Marketing, Sales or Communications (M)
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- ❑ Quality Control Department (Q)
- ❑ Other (Please describe) (N) ________________

5 My company's principal product or service is:________________

6 How are YOU involved with gears (check all that apply)?

- ☐ My company MAKES gears (20)
- ☐ My company BUYS gears (22)
- ☐ I DESIGN gears (23)
- ☐ I am a SUPPLIER to the GEAR INDUSTRY (please specify product or service) (24) ________________

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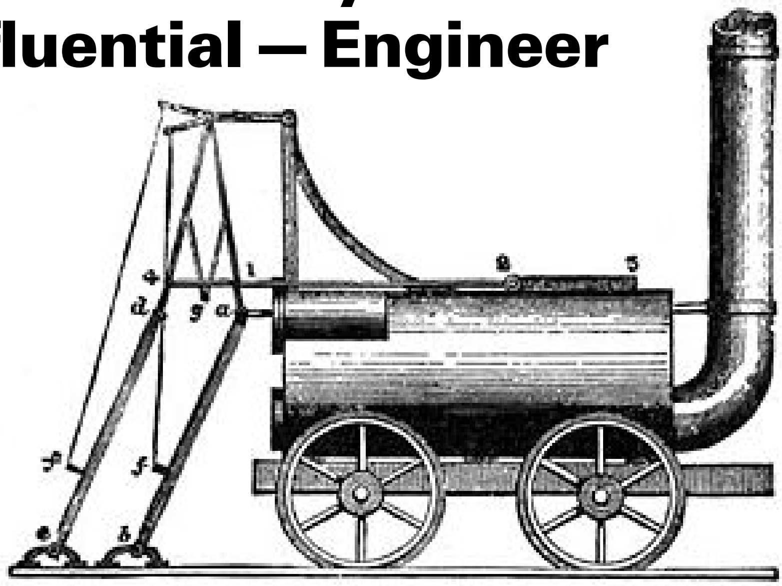
William Brunton: 19th Century Neglected — but Influential — Engineer

Jack McGuinn, Senior Editor



Brunton's Traveller (a.k.a. The Steam Horse), 1813.

Faithful readers of this space know we sometimes like to use Addendum to give relatively unknown 19th Century mechanical engineers/inventors their well-deserved props. Like, for example, William Brunton (1777–1851), who is credited — but generally unknown — with inventing the Steam Horse, also known as the Mechanical Traveler.

As a mechanical engineer his works were varied and important. Many of them were in the adaptation of original and ingenious modes of reducing and manufacturing metals and the improvement of the machinery that connected them.

In 1790 — at age 13 — he commenced work in the fitting shops of the cotton mills at New Lanark. In 1796 he migrated to Birmingham, finding employment at Soho's Boulton & Watt, where he remained until he was made foreman and superintendent of the engine manufactory. Still only twenty-one, he would be sent alone to troubleshoot and solve customer complaints. In 1808 he joined the Butterley Works, where, much like his previous position, he was entrusted with representing his employer on many important missions; in doing so he made the acquaintance of John Rennie, Thomas Telford, and other eminent engineers of the day. In 1815 he returned to Birmingham to become partner/mechanical manager of the Eagle Foundry, where he remained ten years and during which time he designed and executed a great variety of important work. Even more generally unknown is that with the Steam Horse, originally intended to facilitate coal mining, Brunton had sown the seeds for advancing the early technology of what we know today as railroading. Ironically, Steam Horse evokes echoes of what became commonly known midway through the century as the Iron Horse, i.e. — steam locomotive. The Brunton-designed Steam Horse was built in 1813 by the Butterley Company in Derbyshire for use on the company's mining conveyor at Crich. It sported a pair of mechanical legs with feet that gripped the rails at the rear of the engine to push it forward — at about three mph. A second one was built for the Newbottle colliery, which worked with a load up a gradient of 1 in 36 all through the winter of 1814.

Indeed, the Steam Horse was relatively pre-historic in its simplicity and capability. But it served its purpose. Until the Steam Horse, mining companies had long used nearby canals to ferry their ore, equipment, etc. back and forth between mine sites and towns. And, horse-drawn wagons were used to transport loads to the canals. Common wisdom had it that steam engines — too loud and dangerous — were inferior to the horse-drawn wagon model. Two things happened that changed this thinking. One — history tells us the Napoleonic Wars (1799–1815) generated significant price increases for livestock fodder, and two — some "railways" were now being constructed on increasingly steeper — and dangerous — embankments (gradients) within canals.

Initial skepticism over the Steam Horse derived from the general opinion that steel wheels running smoothly on steel rails was fantasy; a lack of sufficient adhesion was typically the reason given. But when in 1813 the Butterley Company was faced with a gradient of 1 in 50 between its Limestone quarry at Crich to the Cromford Canal at Amber Wharf — some 1.25 miles away — Brunton took out a patent for the locomotive. The Butterley locomotive cost a total of £240 (approx $313 U.S.).

The historical record is scanty but it seems that the *Steam Horse* operated successfully for an unknown period. In fact, a larger one with a 9ft boiler rather than the original 5ft, was built for the Newbottle Colliery, in County Durham. This locomotive cost £540 ($705 U.S.) and may have had two cylinders. During 1814 and 1815 it hauled loads up a 1-in-36 gradient at 3 miles per hour (4.8 km/h). But the colliery owners were not impressed. Exceedingly worse — during a demonstration on July 31, 1815, the iron boiler exploded, killing thirteen spectators and injuring several others. The apparent reason for the accident was due to the safety valves being screwed down too tightly, rendering them useless. Thus occurred what is considered to be the first recorded railway disaster.

After this experience Brunton was never again fully engaged in business. He was, however, a member of the Institution of Civil Engineers; but — typically for this neglected engineer — the date of his admission has not been determined.

Brunton died in 1851 at the residence of his son, William Brunton. Preceding him in death was wife of 41 years, Anne. The couple's four surviving sons — all respected engineers — were John, William, J. Dickinson and George. (Source: Wikipedia.)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