GEARS inline

KLINGELNBERG

The Trade Magazine for Gear Technology

07 | 2020

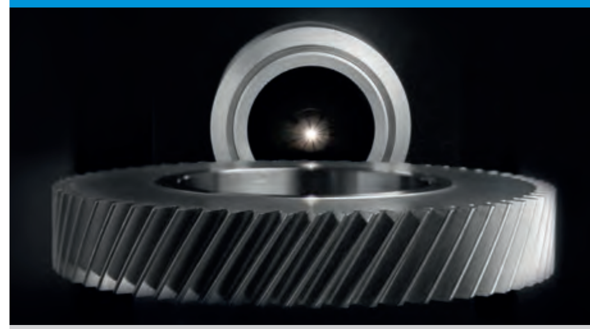
PRECISION MEASURING CENTERS

04

STANDARD MEASUREMENT WITH KLINGELNBERG OPTICAL METROLOGY

CONTENTS

TITLE TOPIC



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Phone: +49 2192 81-0
Fax: +49 2192 81-200
info@klingelnberg.com

Editor and editorial staff:
KLINGELNBERG GmbH:
Sandra Küster (Head of Marketing),
Dipl.-Ing. Georg Mies, Dr.-Ing. Christoph Kühlewein,
Stefan Staab, Dipl.-Ing. Frank Seibicke, Dr.-Ing. Rolf Schalaster,
Dr.-Ing. Florian Scheffler, Dipl.-Ing. (BA) Christian Brieden,
Dipl.-Ing. Karl-Martin Ribbeck, Dipl.-Ing. Daniel Meuris

public vision MEDIEN:
Stromstrasse 41 • D-40221 Düsseldorf
Phone: +49 211 416087-10 • abastian@public-vision.de
Aimée Bastian, Claudia Haese

Graphics and design:
public vision MEDIEN • Düsseldorf
Vanessa Peters

Photos:
KLINGELNBERG GmbH,
PhotographerEngineer/shutterstock.com (page 18)
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Dear Readers,

As the newest member of our Management team, I am delighted to present our latest issue of GEARS inline to you today. Our aim with this magazine is to share an optimistic look to the future with you.

We know that business leaders and decision-makers the world over are modifying their operational and strategic plans to cope with the short-term challenges of the Corona crisis while still adhering to their long-term objectives. Despite this – or perhaps because of this – we have decided to continue focusing on our innovative capacity and technological leadership. On the pages that follow, we present interesting articles illuminating these innovations in all our product ranges.

Our title story about optical pitch measurement thoroughly details our hybrid technology approach, which enables both tactile and optical measurement of gears on the same machine. Users benefit from this innovation, which reduces the time needed by up to 40 percent.

The growing global trend toward automation and electric drive concepts also calls for new technical solutions for torque transfer through transmission components. The Spiral Worm Drive (pages 16 and 20) offers tremendous potential in this regard and provides an exciting alternative to the worm gear.

To maximize the benefit for companies, high-quality production technologies should be combined with rock-solid digital solutions that are based on a reliable IT infrastructure. This is the only way to guarantee trouble-free production and strict adherence to quality requirements, even in uncertain and challenging times. In six fascinating articles, our experts give you a detailed overview of our established Closed Loop production system for cylindrical and bevel gears, the comprehensive performance benchmarks of the Speed Viper and VIPER 500 machines, as well as our optimally integrated digital solutions for the Industry 4.0 era.

Finally, I would like to thank you for the overwhelmingly positive response to our Klingelnberg webseminar series, which we launched in May 2020. The impressive number of registrations and the lively question-and-answer sessions made it clear that our product and technology innovations continue to be extremely important to you.

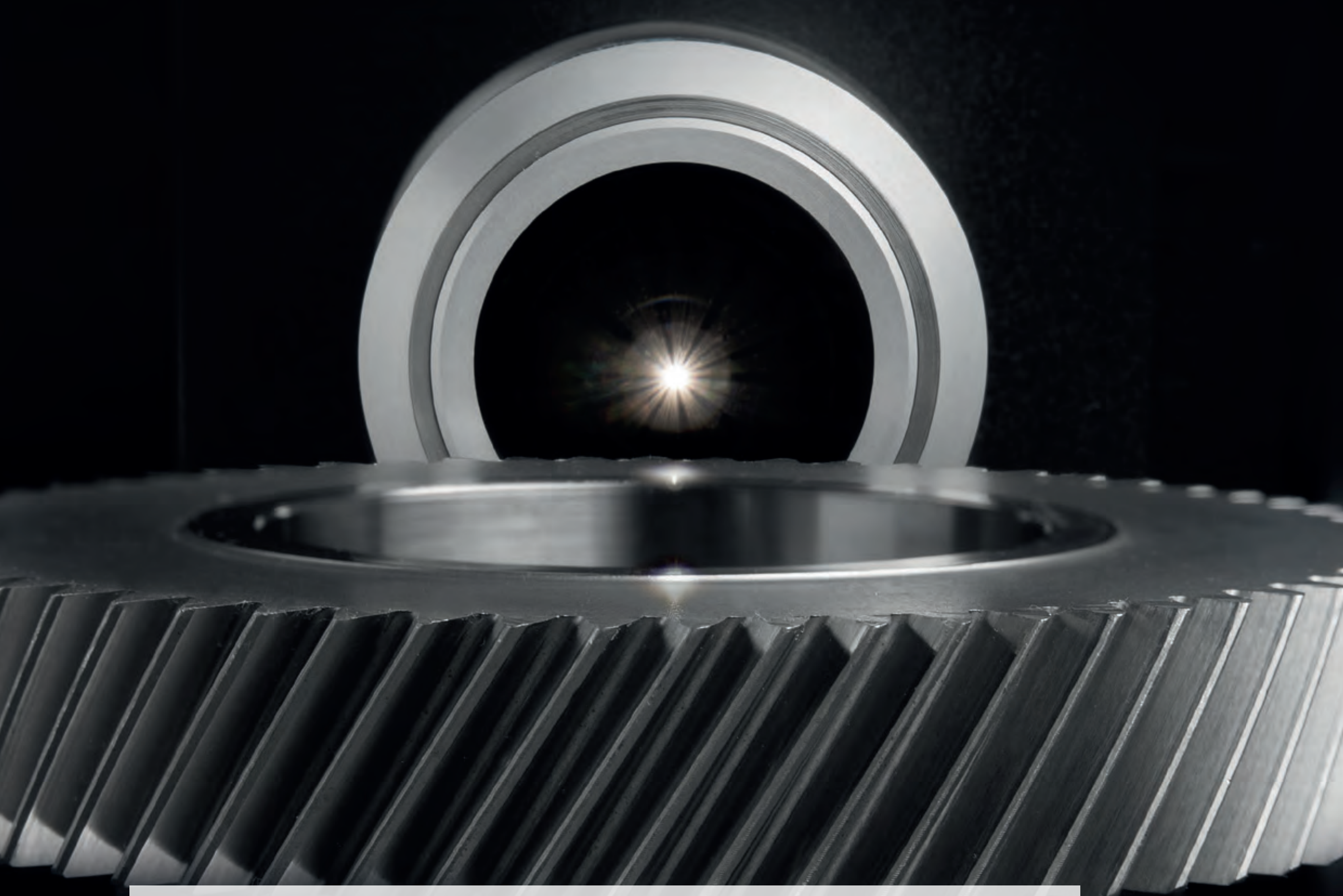
Please enjoy this issue. I am confident that it will make for interesting and informative reading.

Prasad Kizhakel

Prasad Kizhakel

CSO KLINGELNBERG Group

KLINGELNBERG OPTICAL METROLOGY: FROM LABORATORY APPLICATION TO STANDARD MEASUREMENT



Whereas the initial development stages of optical metrology were focused on applications used primarily in the lab, the solution now available is systematically oriented toward series application of cylindrical gear measurement. The primary advantage here is greater efficiency through a reduction in measurement times of up to 40 percent.

Klingelnberg first presented the initial development stage of the hybrid solution with optical metrology at the EMO Hannover exhibition back in 2017. The application at that time centered on digitization of axially symmetrical gear components. Components such as bevel gears and cylindrical gears, and other geometries as well, can thus be measured with an extremely high point density (digitized), followed by additional processing. This additional processing is extremely flexible. In addition to simply depicting the results as a 3D model, comparisons can be made against a CAD target geometry, or a geometrical evaluation can be conducted by creating sectional views. This application is used for reverse engineering, for example.

"In the last three years, we have significantly advanced our Klingelnberg Optical Metrology system," explains Markus Finkeldey, project manager of Optical Metrology at Klingelnberg. "Particularly in terms of sensor systems, measured data acquisition, and further processing, there has been significant progress."

High Accuracy in the Sub-Micrometer Range

In the first development stage, a high-precision laser triangulation sensor was used. This sensor technology is well suited to the digitization application described above. However, physical limits in laser triangulation restrict its use for measurements in the sub-micrometer range on gear components. "Because tactile gear metrology on the precision measuring centers over the years has achieved an extremely high level of maturity and thus also an impressive measuring accuracy, our customers' expectations for optical metrology on a Klingelnberg measuring machine are correspondingly high," notes Peter Mancasola, application engineer at Klingelnberg. "A restriction in accuracy that is accepted for digitization is not acceptable for other measurement tasks."

New White Light Measurement System

For this reason, Klingelnberg has been focusing its efforts on the entire signal chain in optical metrology and has joined forces with other development partners to develop a white light measurement system tailored specifically to the requirements of gear measurement. In this system, the active, current-carrying elements, such as a high-power light source, electronics and signal processing, are arranged separately from the sensor in the control cabinet. The distinct advantage of this is that it prevents thermal effects from occurring on the sensor itself as well as in the area surrounding the sensor – on the 3D tracer head, for example.

Compared to a laser sensor, this sensor has a significantly more favorable, compact design. In addition, in contrast to a laser sensor, this sensor works equally

Fig. 1: Pitch Measurement with HISPEED OPTOSCAN

Compact

Klingelnberg Optical Metrology: the Next Level

Klingelnberg has systematically advanced optical metrology and has introduced a new white light sensor technology that is ideally suited to measurements in the sub-micrometer range. This will allow the tactile pitch measurement to be replaced by optical measurement, significantly reducing measurement times in serial measurement applications.

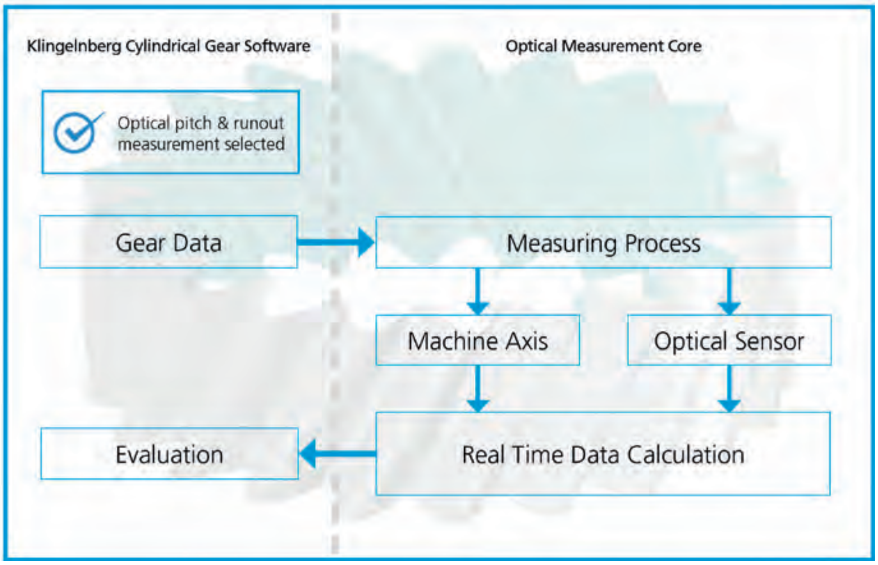


Fig. 2: Schematic diagram of a measuring run

Fig. 3: Optical sensor retracted

Fig. 4: Optical sensor extended

in all directions due to the coaxial light directed toward the component surface and back. The large lens aperture enables measurements with highly inclined surfaces, which are inevitable occurrences on gearings. Thanks to the system's high resolution, measurements in the sub-micrometer range are now ensured.

Reducing Measurement Times in Serial Measurement

Digitization of the entire component is an application for which optical metrology is ideally suited. For serial measurement of high-precision ground running gears, however, it is not necessary to measure the entire component geometry with a high point density. Instead, the focus is on high measuring accuracy at the level of the tactile measurement while also reducing the measurement time. For this reason, Klingelnberg has worked out a solution to this with its latest development stage in optical metrology.

In serial measurement of a cylindrical gear, the profile and lead are typically measured on three or four teeth, and pitch measurement is performed on all teeth. This tactile pitch measurement necessarily involves inserting the stylus into each tooth space. With optical measurement, by contrast, nothing is inserted into the tooth spaces. Accordingly, pitch measurement offers the greatest potential for reducing the measurement time. Through optical measurement of the pitch using one continuous, uninterrupted rotation of the component, the measurement time advantage increases with large numbers of teeth to up to 80 percent. It is not necessary to scan a large area of the gear with multiple revolutions.

This optical pitch measurement is combined with the tactile measurement of

Fig. 5: Component spectrum

the profile and lead. Overall, the total measurement time decreases by up to 40 percent. Thus in cases where there is a high utilization rate of the measuring machine, the costs for the optical metrology option are quickly recovered.

High-Precision Measuring Results

Decreased measurement time is not the only key factor, however. Just as important is a high achievable accuracy of the measuring results, even in the case of extremely complex gears with ground surfaces and steep profile angles. This is the result of intensive optimization of the sensor technology, the analysis algorithms, and the measurement strategy.

The only difference in operation is that optical pitch measurement must be selected in the same cylindrical gear measurement software customers are already familiar with. The measuring cycle is automatically modified accordingly, and the pitch measurement is performed

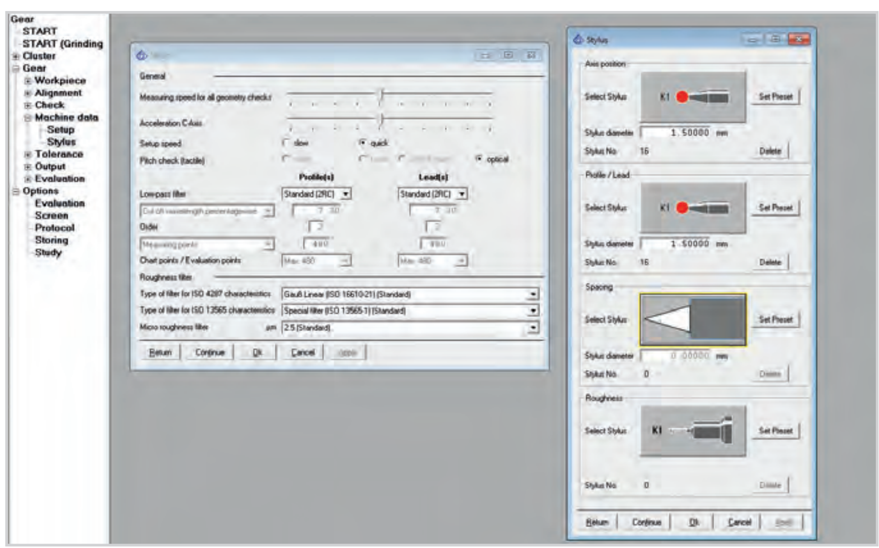


Fig. 6: Measurement software user interface, optical pitch measurement selected

By switching from tactile to optical pitch measurement, serial measurement time of cylindrical gears can be reduced by up to 40 percent.

OPTICAL METROLOGY – THE VIDEO

This video provides essential information about the latest generation of the Klingelnberg Optical Metrology system:

with the optical sensor. The changeover between the tactile 3D NANOSCAN probing system and the optical HISPEED OPTOSCAN sensor takes place automatically within approximately 1.5 seconds in conjunction with the entire measuring run.

During a series of internal analyses, Klingelnberg evaluated a typical component spectrum of cylindrical gears from the area of passenger car transmissions, electromobility and gauges. In a range of gear geometries with different reflection and absorption characteristics, as well as various gearing qualities, accuracies on par with tactile measurement were achieved. The system can be used even for gears with extremely fine surfaces and roughnesses of Rz = 1 µm.

"To determine without a doubt whether a component is suitable for optical measurement and whether a corresponding measurement time advantage can be achieved, we provide our customers with test measurements and demonstrations in our premises," says Holger Haybach, Head of Application Engineering at Klingelnberg.

The More, The Better

In terms of the measurement time advantage that can be achieved, one thing is true: The more teeth there are, the greater the advantage. However, even a component with 29 teeth benefits from a significant time advantage, as the examples in the table on the right show.

Next Development Stages

The system offers great potential for further applications. In particular, for measurement tasks consisting of tactile operations involving time-consuming individual touches and complex movement patterns, optical metrology is able to reduce measurement time. But optical measurement is also ideal for fast scanning sequences on complex geometries.

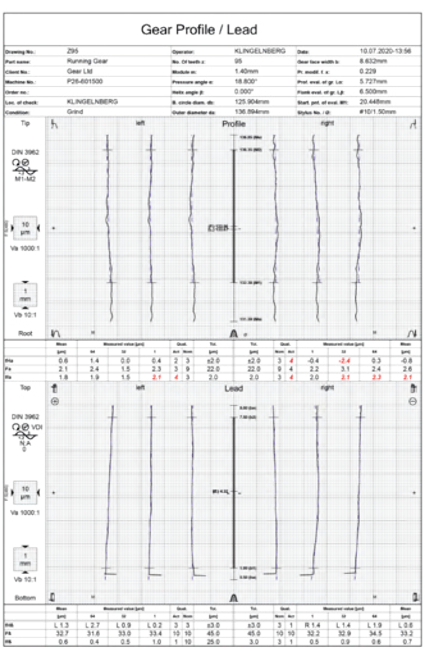


Fig. 7: Measuring results, profile and lead

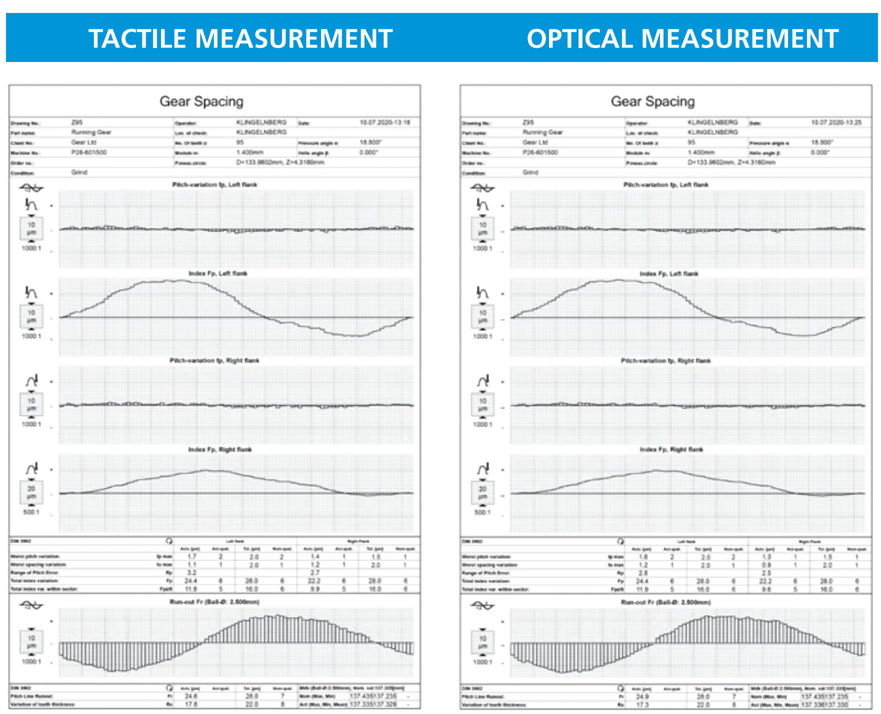


Fig. 8: Measuring results, pitch, comparison of tactile and optical

		
Toothed gear data	Z = 75; mn = 1.92 mm; β = 25.3 degrees; α = 18.7 degrees; da = 162 mm	Z = 29; mn = 2.2 mm; β = –31 degrees; α = 20 degrees; da = 79.5 mm; clamping between centers, measurement without axis position
Hybrid measurement, consisting of	axis position (tactile), pitch, gearing concentricity, tooth thickness variation (optical) axis position, profile and tooth trace on three teeth (tactile)	Pitch, gearing concentricity, tooth thickness variation (optical) profile and tooth trace on four teeth (tactile)
Total measurement time:	2 min 35 sec	1 min 50 sec
Conventional tactile measurement:	4 min 15 sec	2 min 45 sec

Fig. 9: Measuring example

Dr. Christof Gorgels, Director of Product Line Precision Measuring Centers at Klingelnberg, provides an outlook: "For the further development of the system, we already have a number of ideas, including tooth root and tip measurement, axis position, roundness and other form measurement tasks. And we would like to use our customers' feedback to set priorities. That is why we are delighted at the keen interest in Klingelnberg Optical Metrology and the conversations with users that we have had as a result." ◆

"We use optical metrology to reduce measurement times, thereby making a significant contribution to lowering quality costs."

Dr. Christof Gorgels, Director of Product Line Precision Measuring Centers

Dipl.-Ing. Georg Mies

Head of Development, Precision Measuring Centers, KLINGELNBERG GmbH

georg.mies@klingelnberg.com

CLOSED LOOP FOR CYLINDRICAL GEARS

Gear grinding is one of the most challenging processes in metalworking. Automated (corrective) procedures within a Closed Loop provide a major advantage in terms of safety and productivity. What is already state-of-the-art in bevel gears has now expanded to the world of cylindrical gears.

Compact

Closed Loop

In gear grinding, even the tiniest parameter variations in the grinding strategy can have a significant impact on the result. Conventional correction of deviations therefore not only requires considerable expertise; it also creates many opportunities for error. The Klingelnberg Closed Loop – already a technical standard in the area of cylindrical gears – provides support in this regard.

Industry 4.0 has gained a foothold in cylindrical drive component manufacturing as well. Here, the intuitive usability of the machines and a highly error-resistant support system (when making corrections, for example) lay the foundation for a safe and economically efficient production process. Klingelnberg is a single-source provider of machine tools and measuring machines – and the digital communication between the two machine types has been implemented fully in line with Industry 4.0.

Growing Demands – Met by Growing Solutions

Advances in research and development and a fundamental transformation in powertrains are reflected in manufacturers' workpieces. The trend is toward increasingly complex profile and lead geometries. Not only do the requirements for machining and quality assurance processes increase as a result, so also do the qualification requirements of the staff.

The processes involved in gear manufacturing generally call for an extremely high level of expertise. "Around the world, we observe various phenomena with our customers," explains Jonas Knop, application engineer in the Cylindrical Gear division at Klingelnberg. "In industrial countries with a highly qualified workforce, the organizational portion of the work accounts for an increasingly large share, alongside the activity to be carried out. And in the low-wage sector with a lesser-qualified workforce, economical production of extremely complex tooth geometries is often impossible to implement."

In both cases, customers benefit from the Klingelnberg Closed Loop: It offers reliable, user-friendly support and ensures the required workpiece quality at every moment, irrespective of the operator's skill level.

Because "Easy" Is Simply Better

Deviations between the actual and target geometry of a gear component can generally be attributed to a number of influences. Of these, the machine kinematics and the tools used are significant factors. The extent to which these influences impact the quality characteristics of the teeth on a workpiece varies greatly.

In real-world applications, therefore, conventional correction of deviations requires considerable expertise on the part of the machine operator – while at the same time creating many opportunities for error. Incorrect data input or mix-ups when allocating measured parameters are a recurring cause of quality problems and cost valuable time and money.

This is precisely where the Klingelnberg Closed Loop provides support. The process could hardly be easier: Geometrical deviations on the workpiece are measured in the usual way. The measurement information is sent directly and automatically to the machine tool. This information may comprise individual figures, such as angular deviations of the tooth trace for cylindrical gears. Or – as in the case of high-precision cycloid components – it may provide a comprehensive, point-by-point depiction of a tooth contour. The operator can decide how to respond to the information, regardless of the machine status. If the measured values fall outside the defined tolerance, various correction modes are available to choose from. The corrections are then completely traceable and documented using the available "Web Correction Loop" and "Data Manager" apps.

Optimizing the Grinding Process

In Closed Loop, the operator can choose from a number of correction modes on the Klingelnberg grinding machine. The deviations to be expected after the correction has been made are calculated and visualized in advance, depending on the mode. The operator can also determine the point in time at which the corrective measure will be applied, independently of events. With the appropriate profiling, the mode and time for executing a corrective measure determine to a large extent the tool service life, tool change intervals, and auxiliary times in the machining process. In short: The more efficiently any required corrections are applied, the more productive and cost-effective the grinding process is. Closed Loop provides tremendous assistance in this regard.

Proven by Experience

As Jonas Knop is pleased to note: "Customer feedback has proven us right." "Closed Loop has already met with acceptance in large-scale and mass production operations. Demand is also increasing on the part of our highly specialized customers, who use our tried-and-tested all-round machines. The major advantages here are the added safety and convenience, as well as the traceability."

The potential of Industry 4.0 solutions is gaining in importance. With the Closed Loop concept, Klingelnberg is setting standards in the manufacture of gear components and contributing significantly to optimizing customers' production structures. The innovative Speed Viper machines combine all these advantages, but customers also benefit from the convenient and safe functionality of Closed Loop with the tried-and-tested Höfler HELIX, RAPID, and VIPER 500 machines. ◆

Fig. 1: Closed Loop quality control in line with Industry 4.0

Dr.-Ing. Christoph Kühlewein

Head of Cylindrical Gear Application Engineering, KLINGELNBERG GmbH

christoph.kuehlewein@klingelnberg.com

THERE IS NO SUCH THING AS "NO CAN DO": PRECISION MEASURING CENTERS IN THE P-SERIES

The precision requirements for components and assemblies are steadily on the rise. To meet these demands, as many measurement tasks as possible should be combined into a single sequence – ideally directly on the shop floor rather than in the measuring room. The Precision Measuring Centers in the P-Series do just that. They integrate all coordinate and gear measurement tasks, as well as geometric and roughness measurement tasks, on one machine, which can be set up directly in the production environment. The results of these geometrical dimension and tolerancing (GD&T) measurements are absolute values, meaning they can be used for process control.

Combining different measurement tasks on one machine is a true leap forward in terms of quality assurance. It saves on tooling and setup times, eliminates the need for repeat alignments on the measuring machine and significantly reduces throughput times. Particularly for high-precision components produced in large quantities, this presents interesting potential. Due to their possible interchangeability, they must be determined with stable, high levels of precision.

The P-Series Precision Measuring Centers systematically follow the approach of processing as many measurement tasks as possible on one machine. They execute the entire process in a single automated sequence directly on the shop floor. Particularly when producing large series of axially symmetrical drive elements with their many GD&T features, it is important to monitor the process in real time and in the production environment, to the extent possible. The P-Series has proven itself in just such an environment. In the last ten years alone, over 500 configurations have been successfully installed. And Klingelnberg Precision Measuring Centers are used as a reference around the world, not just by countless customers, but also by renowned metrology institutes.

Complete End-of-Line Testing

Combining different measurement tasks from the areas of coordinate and gear measurement together with geometric and roughness measurement makes it possible to execute all tasks in one automated, process-integrated sequence, even for end-of-line testing of shaft-type components. In production-typical temperature ranges and ambient conditions, and with nearly unaltered precision, precision measuring centers are ideally suited to calculating absolute measuring results quickly and reliably between machining operations. The data are immediately available to monitoring and control tools, both visually and through various interfaces. Examples of this include results trends, dependent tool changes, tool corrections and clamping situation inspections. Thus the user can respond immediately to specific events, such as attainment of warning limits, and initiate appropriate measures.

Ambience Neutral Technology

For all Precision Measuring Centers in the P-Series, Klingelnberg offers its Ambience Neutral Technology, enabling the measuring centers to be integrated directly into production. In order to perform high precision measurement on the shop floor, the machine must be able to cope with the shop floor environment, which is influenced by temperature changes, dust and vibrations transmitted through the floor. Klingelnberg's Ambience Neutral Technology was specifically designed to withstand all these influences and ensure complete measuring accuracy. Here, Klingelnberg benefited from the wealth of experience it has in machine tool design and metrology.

Focus on Kinematics and Ergonomics

The special design with three high-precision linear axes and the precision rotary table provide ideal conditions for GD&T applications. The bearing arrangement of the precision rotary table has a maximum radial spindle deviation of 0.2 µm, thus providing suitable accuracy for geometric measurement. With this feature, P measuring devices offer absolutely reliable configurations in terms of geometric measurements, as well as the position measurements that are indispensable for manufacturing parts to be installed with

HIGHLIGHTS IN BRIEF

The P-Series is synonymous with multiplex measuring devices that handle complete GD&T measurement tasks in a single stage, right on the shop floor.

- G-variants: An attractive solution for measuring dimensional tolerances and geometric tolerances, and for dimensional measuring technology with standardized software in one clamping
- "Done-in-One" version: integrates surface measurement into the measurement process using the Klingelnberg roughness probe
- "Optical Measurement" version: Klingelnberg Precision Measuring Centers can also be equipped, or retrofitted, with an optical solution.

Fig. 1: The new machine generation

high levels of precision. In the new machine generation, the tried and tested technology was further developed specifically to meet the strict requirements for measuring accuracy in complete measurement of axially symmetrical precision components.

Beyond the technical functions, ease of operation and ergonomics are gaining importance, not only in processing machines but also in measuring machines. For this reason, Klingelnberg has thoroughly overhauled and standardized the design and ergonomics of its product range (see Figure 1).

Easy Operation – Made for the Real World

Another key factor is the operation of the measuring machine. In the production environment, there are generally no trained measuring technicians on site. In large-scale processing plants, only one to two plant operators per shift are available in many cases for several operations running in parallel. For this reason, the measuring machine must be extremely easy to operate in the real-world setting, and it must be easy to interpret the display of results and results trends.

WINNER OF THE BEST OF INDUSTRY AWARD

With the “Done-in-One” principle, complete measurement of axially symmetrical parts on one machine, the G-Variant of Klingelnberg Precision Measuring Centers won the Best of Industry Award 2020 (awarded by MM MaschinenMarkt) in the Measuring Technology category.

For programming, Klingelnberg offers easy-to-operate tools: In one simple, graphically assisted editor for parts measurement programming, the dimensions of the workpiece are specified one time. When determining the geometric tolerances, it helps that the standards applicable to the P-Series Precision Measuring Centers, such as ISO 1101/2768, ASME Y 14.5 and JIS B 0419, are generally implemented. The specifications and tolerances can thus be selected through simple dialogs, based on the dimensions and taking the references into account. The appropriate cases and tolerances are automatically used. When programming a precision measuring center, the user does not need to know a programming language and does not need to worry about collisions, use of inappropriate probe configurations or the feasibility of operations compared with standard specifications. A detailed plausibility check performed by the Klingelnberg software takes care of these tasks automatically.

Automatic Program Generator

An automatic program generator exists for scalable series (such as roller bearing elements) that differ in type and construction and the measurement tasks involved only because of their differing dimensions. Among other things, this makes it possible to generate additional variants for different dimensions and ranges of characteristics based on a complete program sequence. Thus a parts identification via a QR code allows the correct sequence that is appropriate for the operation. In specific terms, this means that a number of variants in the four-figure range can be processed with a program and the corresponding specifications.

With this in mind, Klingelnberg developed its "EasyStart" software, a system that effectively separates the creation of the measurement program from the measurement itself. The operator locates the measurement program on the start screen and launches it directly, with a click of the mouse. The process can be simplified even further by using a barcode scanner in conjunction with a barcode on the component (see Figure 2).

Tried and Tested Techniques on the Test Stand

Gauges (dimension and geometry) are currently used in many places to perform quality inspections of individual process steps directly in the production environment. There are also multiplex measurement devices that test position tolerances and other functional dimensions. Both solutions can be used without any restrictions directly on the production machine and both are characterized by extreme robustness and "built-in temperature compensation". If the gauge or multiplex device is made of a material with the same thermal expansion coefficients as the workpiece and both have the same temperature, any thermal influence on the test result can be reliably ruled out. In addition, this test is extremely simple and can be carried out directly by the machine tool operator.

The major disadvantages of gauges and multiplex devices are that they must be individually adapted to the component and test task, they are extremely expensive, and they require long delivery times. This poses a significant challenge for production managers, particularly when drawings are modified. In addition, documentation of the test result is merely qualitative in nature and cannot be used for process control purposes. Gauges are also subject to cyclical test equipment monitoring processes. With multiplex point installations, a master part, which is also subject to the monitoring process for its traceability, is generally needed for regular calibration.

Highly Flexible with Multiplex Measuring Devices

If you are looking for a measuring instrument that has the benefits of gauges without the drawbacks, you will find what you need in the P-Series. In general, all measurement tasks on axially symmetrical components can be performed on a Klingelnberg Precision Measuring Center. The P-Series is an extremely flexible solution for GD&T measurement tasks. On the one hand, it can be used with the same program for different processing steps; that is, parts can be used with the same configuration for hard and soft processing and for heat-treated states (see Figure 3). And on the other hand, the P-Series is able to respond quickly and cost-effectively to parts and drawing changes in contour tolerances and feature upgrades. This is accomplished by a simple program change and includes automatic plausibility checks for new specifications or changes. The P-Series is thus synonymous with multiplex measuring devices that handle complete GD&T measurement tasks in a single stage, right on the shop floor. ◆

Fig. 2: Incredibly easy operation with the intuitive EasyStart graphical user interface

Fig. 3: Gauges from the past – Precision Measuring Centers of today

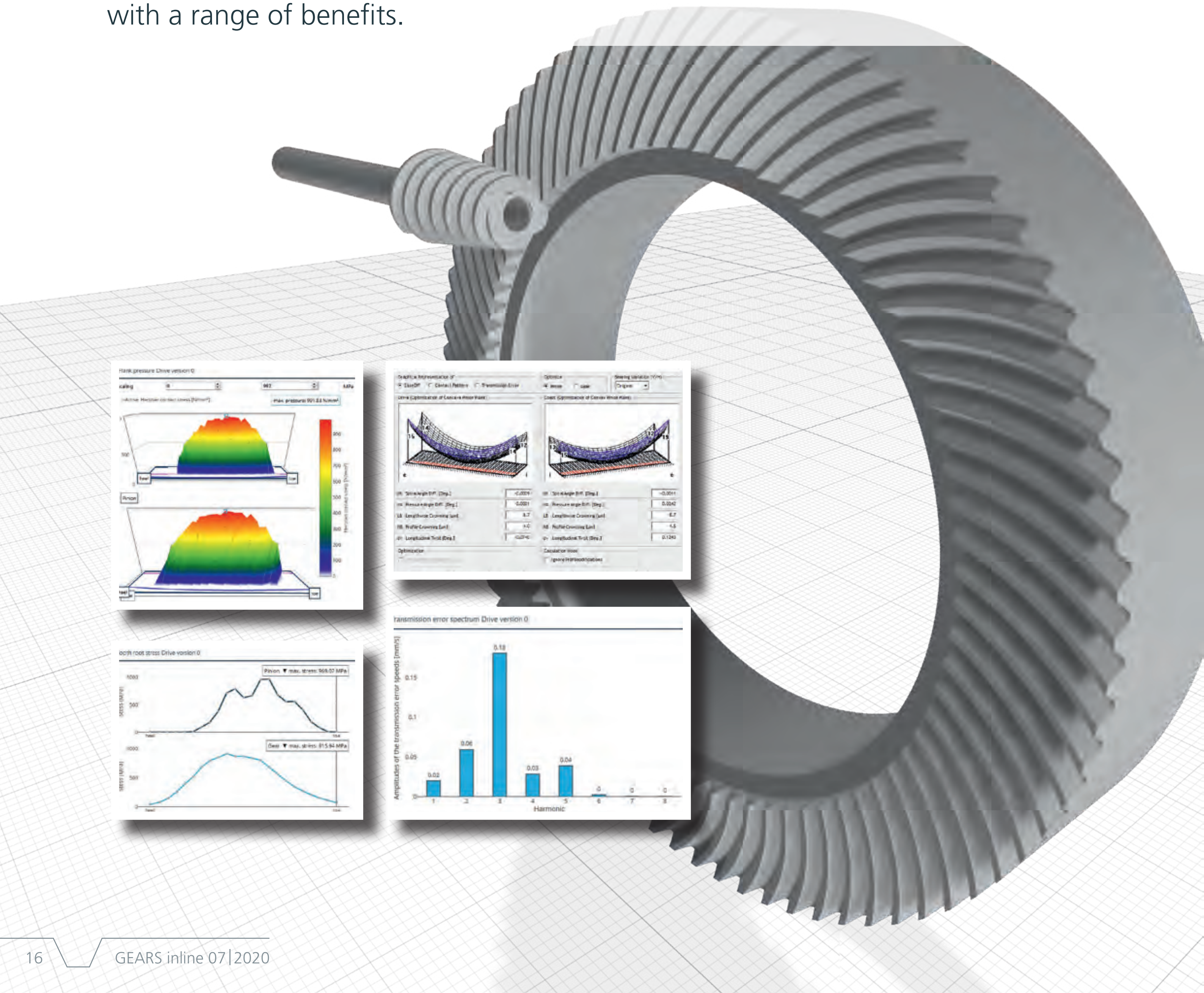
Stefan Staab

Business Development,
KLINGELNBERG GmbH

stefan.staab@klingelnberg.com

SPIRAL WORM DRIVE – INNOVATIONS IN BEVEL GEARS

Cost-effective worm gears in a compact format are widely used, but they are inefficient. The worldwide trend toward automation and electrical drive concepts therefore calls for new technical solutions for torque transmission by drive components. High ratio hypoid gears, so-called Spiral Worm Drives, offer exciting solutions in this regard – along with a range of benefits.



What exactly does the term "Spiral Worm Drive" mean? It refers to hypoid gears that have an extremely high transmission ratio. In order to realize this, it is common to use a very small number of teeth on the pinion along with a large offset – as compared with conventional hypoid gears. Common transmission ratios range from i = 40 to i = 90. The number of teeth on the pinion is between one and three, with a hypoid factor that is often greater than 0.5. At conventional hypoid gears, this value, which describes the ratio of the offset to the mean radius of reference circle of the ring gear, is between 0.1 and 0.3.

There are a number of design variations for transmissions with intersecting axes (see Figure 1). High ratio hypoid gears are comparable to gearings represented by the brand names SPIROID® Gear or HELICON® Gear.

Classification

Bevel gears (see Figure 2) do not have an axis offset. Balanced specific sliding can be achieved through targeted selection of the addendum modification coefficient. The efficiency of the gearing can be positively influenced in this way.

In **hypoid gears** (see Figure 3), the axis offset can be used for design reasons. Its primary use, however, is to increase the load capacity of the pinion. The offset is typically between 5 and 15 percent of the ring gear's pitch diameter. The sliding part in the contact is determined by the size of the offset, which in turn determines the achievable efficiency.

In **high ratio hypoid gears** (see Figure 4), the offset is between 20 and 32 percent of the ring gear's pitch diameter. The geometry of the pinion in particular approaches that of a cylindrical worm. Accordingly, the contact ratios and the achievable efficiency differ from those of classic hypoid gears.

The Worm Gear

In a worm gear (see Figure 5), the axis of the driving wheel does not intersect the driven wheel. Due to the high sliding part in contact, the efficiency in worm gears is significantly lower than in bevel gears or hypoid gears.

Spiral Worm Drive: Applications

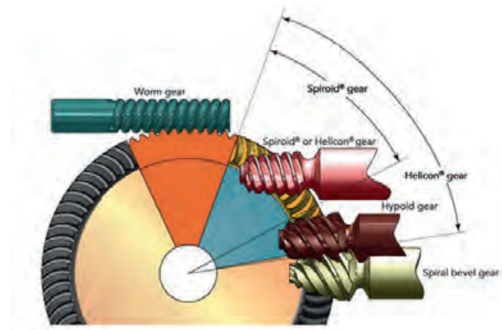
High ratio hypoid gears are used in applications in which a high overall ratio must be realized in one step, or in a few steps. This gives rise to a range of possibilities, particularly for electric drives, which are for efficiency reasons driven at higher rotation speeds. Their use as replacement solutions for worm gears is also advantageous to ...

- improve the efficiency of an existing solution.
- transmit higher powers.
- reduce space.
- save costs.
- reduce maintenance effort.
- eliminate the disadvantages of the different materials of the driving and driven wheel.
- make use of all the advantages of Closed Loop production for hypoid gears.

Special Features

The geometrical conditions described rise to a number of special features for high ratio hypoid gears:

- an extremely small number of teeth on the driving pinion
- a large contact ratio and multiple, simultaneous engagement of the individual pinion tooth
- The large transmission ratio results in an extremely small reference cone



Source: Evertz, F.; Gangireddy M.; Mork, B.; Porter, T.; Quist, A.: High Torque Skew Axis Gearing – Technical Primer. Spiroid High Torque Gearing (2019).

Fig. 1: Overview – design variations for transmissions with intersecting axes

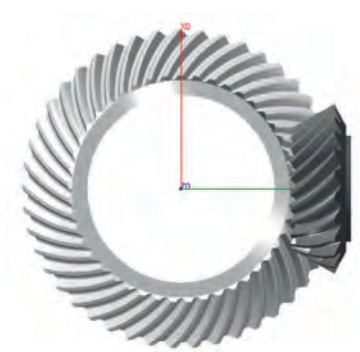


Fig. 2: Bevel gearing

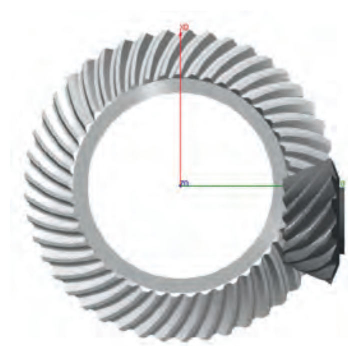


Fig. 3: Hypoid gearing

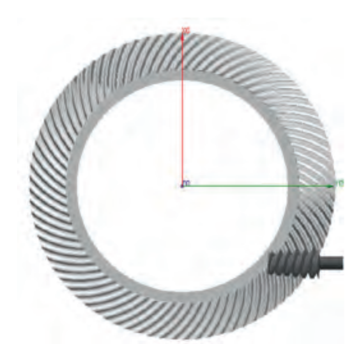


Fig. 4: Spiral Worm Drive

Fig. 5: Worm gear

angle on the pinion, and thus a small outside diameter.

- The contact conditions and thus the load capacity cannot be described in exact terms for high ratio hypoid gears using the familiar, proven calculation methods for hypoid gears.
- Consequently, specifications regarding load capacity and efficiency have only been possible to an extremely limited extent until now.
- The friction conditions cannot be clearly described, making a calculation of the efficiency according to the proven calculation methods impossible at present.

Design

Dimensioning: High ratio hypoid gears can be designed for both continuous and single indexing processes. In every case, they are designed for a forming method. The ring gear is made using the plunge-cutting method, whereas the pinion is produced by a generative process. Due to the high ratio and small number of teeth on the pinion, various boundary conditions must be taken into account when defining the macrogeometry. As is generally the case with hypoid gearings, the reference cone angles are obtained from the transmission ratio, shaft angle, outside diameter and face width of the ring gear, offset, tool diameter, and one of the two spiral angles. In practice, the first four parameters are design specifications and are therefore seldom variable. During the sizing calculation, the offset, tool diameter, and spiral angle of the ring gear are pre-defined based on the number of teeth so as to obtain an ideal spiral angle on the pinion. This ensures the largest possible outside diameter for the pinion. If the offset is changed to the design specification, the spiral angle on the ring gear and, if applicable, the tool diameter must be modified – if the suggested ideal spiral angle on the pinion is to be retained.

A new sizing module for circular arc gearing as a component of KIMoS takes into account the geometrical features of Spiral Worm Drives and can be used to design high ratio hypoid gears.

Feasible contact ratios in practice are best obtained when high ratio hypoid gears are designed with a comparatively small tool diameter (small cutter design). This produces tooth forms with extremely small addendum and dedendum angles. Other parameters that are defining for the macrogeometry are modified according to the selected base data.

A new dimensioning module for Face Milling as a component of KIMoS (Klingelnberg Integrated Manufacturing of Spiral Bevel Gears) takes these geometrical features into account and can be used to design high ratio hypoid gears. The dimensioning calculation with KIMoS Designer delivers practicable gearings that can be analyzed and improved using the familiar means of EaseOff development (see Figures 6 and 7).

Calculation of load capacity: The usual methods and existing programs for calculating load capacity to standard or for tooth contact analysis under load have until now been only of limited suitability for re-calculation of high ratio hypoid gears.

Calculation of load capacity to standard: The efficiency calculation is performed according to the Wech model. To calculate the load capacity to standard, the hypoid geometry is converted to an equivalent cylindrical gear geometry. At very high ratios, this conversion provides unrealistic equivalent cylindrical gear geometries. Due to the large contact ratio, the calculated safeties are significantly excessive.

Tooth contact analysis under load: Due to the large lead on the pinion, an improved calculation of the compensating surfaces is required. The results of the calculation of local safeties against micropitting are questionable because the tribological conditions in the calculation model are not simulated properly. To calculate efficiency, the coefficient of friction is used. Due to the longitudinal sliding typical for high ratio hypoid gears, reliable calculation of the coefficient of friction is not currently possible.

Future-Proof Solution? A Prospective View

To ensure that the programs for calculating load capacity also provide reliable, robust results for high ratio hypoid gears, Klingelnberg analyzes the following questions in partnership with the institutes involved through the German Research Association for Power Transmission Engineering (FVA):

- How well do the mathematical models used simulate the real contact conditions of high ratio hypoid gears?
- To what extent are the test methods used to validate calculation methods meaningful for this type of gearing?

Depending on the results of these studies, the contracting parties will modify the calculation algorithms and, if necessary, the discussed test methods in a timely manner.

Designs for high ratio hypoid gears normally have comparatively large lengthwise and profile crowning, and consequently a high contact stress. It can therefore be assumed that high ratio hypoid gearings have a particularly high risk of damage due to pitting under real loads. This is confirmed by calculations of load capacity to standard and via tooth contact analysis under load performed to date. The results of both calculation methods correlate well here. New designs are therefore focused on achieving an EaseOff with less lengthwise and profile crowning. ◆

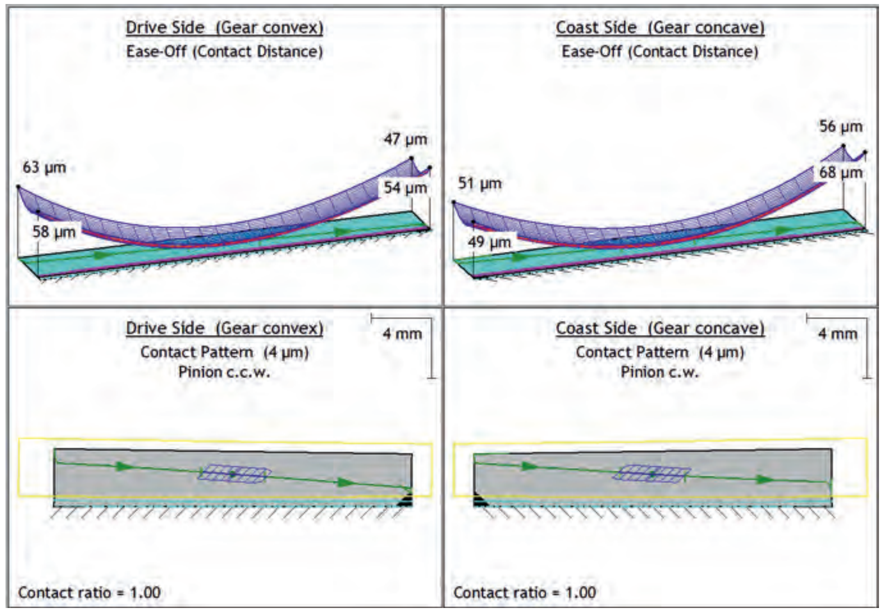


Fig. 6: Result of a sizing calculation

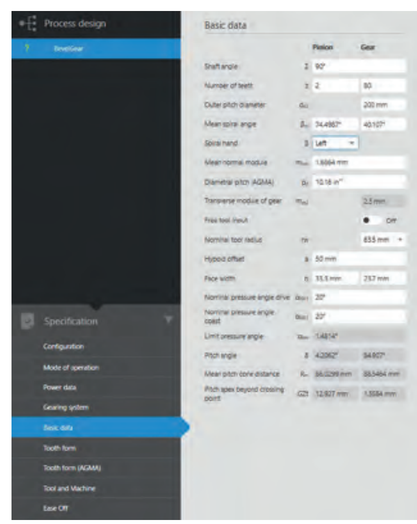
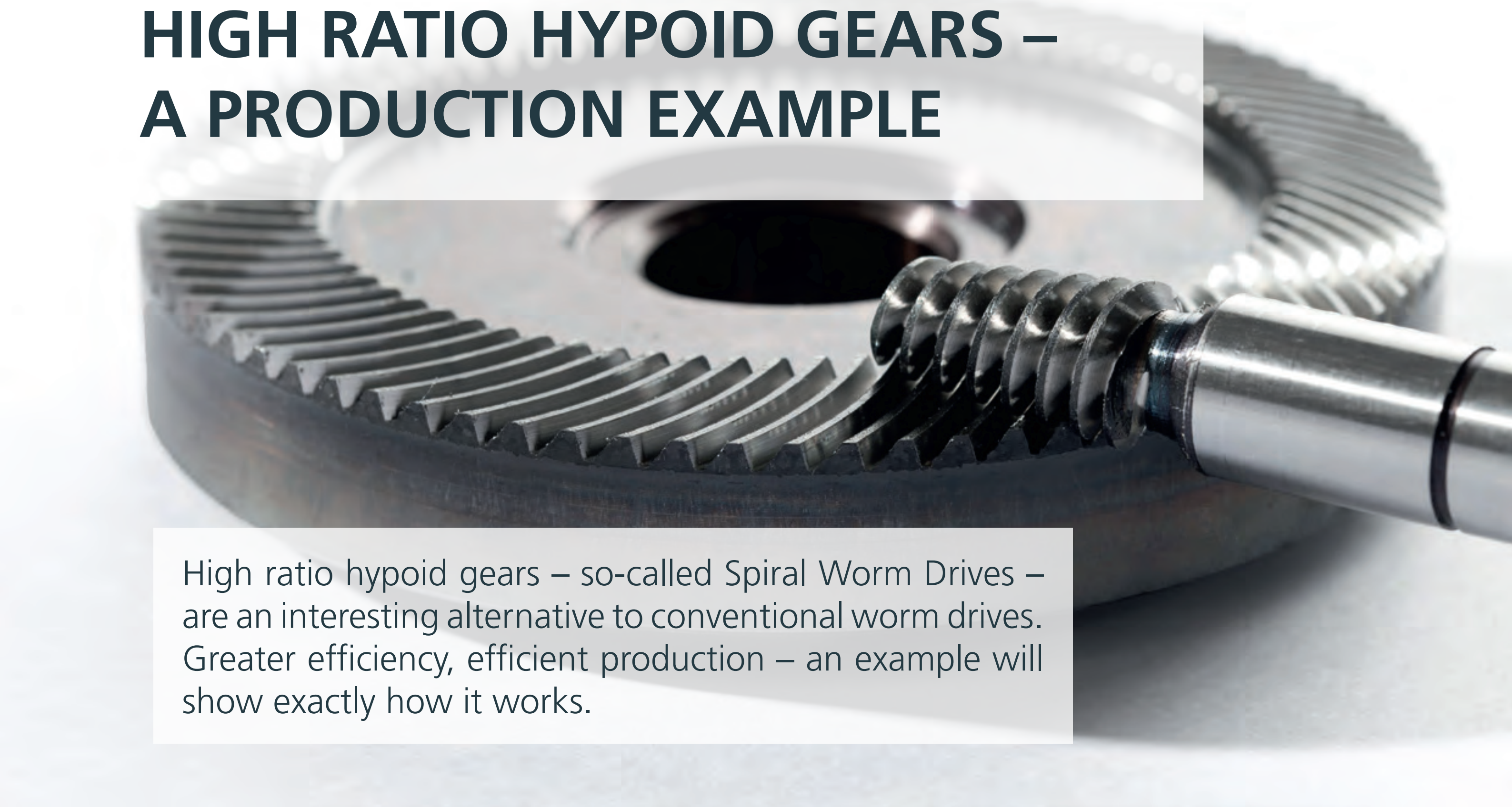


Fig. 7: KIMoS Designer

Dipl.-Ing. Frank Seibicke

Head of CA Tools,
KLINGELNBERG GmbH

frank.seibicke@klingelnberg.com



HIGH RATIO HYPOID GEARS – A PRODUCTION EXAMPLE

High ratio hypoid gears – so-called Spiral Worm Drives – are an interesting alternative to conventional worm drives. Greater efficiency, efficient production – an example will show exactly how it works.

Fig. 1: High ratio hypoid gear set

Fig. 2: Dressing the grinding wheel

If you ask the experts how to design high ratio miter gears, the answer will typically be worm drives. Compared with worm drives, however, high ratio hypoid drives offer many advantages: Both the pinion and the ring gear can be made of steel, greatly reducing material costs. Run-in and the continual wear on the worm wheel that goes along with an increased backlash are also eliminated. In the workshop, greater efficiency can generally be achieved with high ratio hypoid drives. Like the production of typical bevel gears, production of high ratio hypoid drives takes place completely in Closed Loop. Details on the design of high ratio hypoid drives have already been described in the preceding article (page 16 to 19). How this may actually look in practice will be shown in the following using the production of the first speed step of a gear motor as an example.

Example: Gear Motor

The transmission ratio of the example gear set is 2:78 with a gear diameter of 76 mm and 21 mm offset. Due to the small module (m_{nm} = 0.68 mm) and the expected distortions on the pinion due to case hardening, deep grinding (grinding from the solid) – but in the hardened state – was chosen as the gear machining process. Thanks to the high performance of current grinding tools and the possibility of generating any desired tool profile immediately during machining, the aforementioned deep grinding is very popular for manufacturing prototypes and small to medium volumes.

Grinding

The grinding process takes place on an Oerlikon G 30 bevel gear grinding machine. Thanks to a grinding spindle speed of up to 12,000 rpm, this machine is capable of achieving an adequate cutting speed of 20 m/s, even at the minimum possible tool diameter of 1.25". When deep grinding small modules, the most critical point is typically the stability of the tip of the tool profile. The tip width of less than 0.4 mm in this example poses a challenge for the grinding wheel.

Thanks to the Duplex-Formate design, the ring gear is produced using the plunge-cutting method. Because these are prototype transmissions, it is essential to prevent thermal damage to the hardened material. Even with the selected process, which comprises three passes and eight dressing cycles in total, the 78 tooth spaces can be ground in the solid material in less than seven minutes. The measured individual pitch variation f_p here is always significantly less than 2 µm.

The two tooth gaps of the pinion – which can also be referred to as a bevel worm – are machined alternately in four passes in total. As a result, the grinding forces and the temperature loading into the delicate component are minimal. The grinding wheel is always plunged at the heel and generates toward the toe. Because the gap volume decreases toward the toe, the generating speed can be increased over the generating path. The workpiece nevertheless makes four complete rotations when machining a gap in contrast to a conventional bevel pinion. The processing time for the bevel worm is 4.5 minutes in this example. Thus 450 components can be cut with one grinding wheel.

Quality Assessment

Whereas the geometrical measurement of the ring gear corresponds to that of a normal bevel gear, the measurement report of the pinion provides a special phenomenon for bevel worm novices: With a sufficient grid resolution (e.g., 25 × 15 points), the concentricity error of the gearing with respect to the reference surfaces in the topography deviation of the individual tooth measurement is visible as a sinusoidal wave (see Figure 5 above). This is due to the four revolutions of the tooth space around the pinion tip. If a lower grid resolution is chosen (e.g., 7 × 5 points), this can give the impression of stochastic topography deviations. Because this is a concentricity error that affects all of the tooth spaces in an axial section of the gearing, a rotational error corresponding to the concentricity error results from the waviness, but the contact pattern and load capacity remain virtually unaffected by the measured deviation in form. The diagram of the averaged topography deviations (see Figure 5 below) shows a wave-free grid, as usual.

Conclusion

High ratio hypoid gears are a design and production alternative to conventional worm drives. Based on the production and geometry data provided by KIMoS, Closed Loop enables maximum component precision on par with that of bevel gear production. ◆

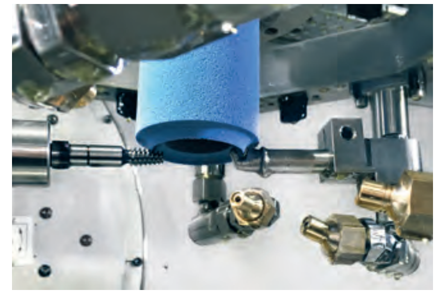


Fig. 3: Grinding of the bevel pinion

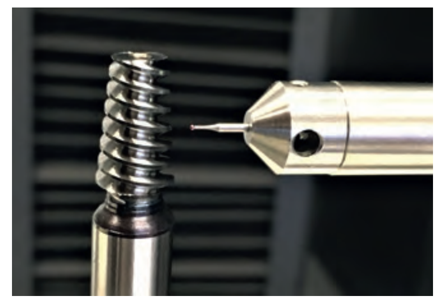


Fig. 4: Geometrical measurement of the bevel pinion

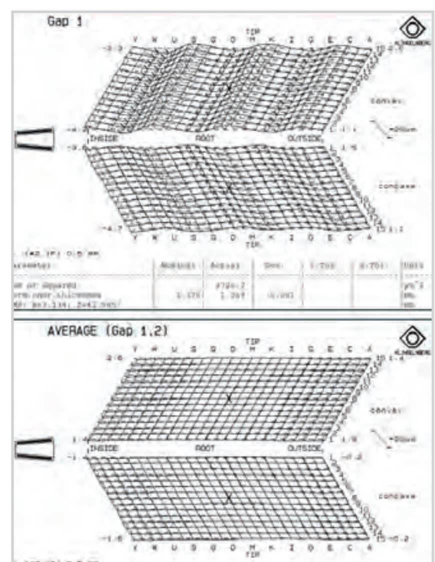


Fig. 5: Topography deviations with concentricity errors of the gearing

Dr.-Ing. Rolf Schalaster

Head of the Competence Center
for Bevel Gear Grinding,
KLINGELNBERG GmbH

rolf.schalaster@klingelnberg.com

SPEED VIPER – STABLE QUALITY IN GENERATING GRINDING

Since it was introduced in 2017, the Speed Viper family has become firmly established in a challenging market environment. One fundamental secret to its success is that it has grown along with the customers' demands regarding the quality characteristics of the machine itself and the accompanying features. In the age of Industry 4.0, this means integrating more and more digital options, and for individual automation requirements, various alternatives are now also available.

Three years ago, it celebrated its grand debut in front of an international audience at EMO Hannover: the Speed Viper product series of the Höfler Cylindrical Gear Generating Grinding Machine. Then, in summer of 2018, the first Speed Viper went into operation and has been on the shop floor ever since. The customer base now ranges from renowned automotive suppliers from Asia and North America to mid-sized contract manufacturers in Europe, who are up against a continually changing product portfolio and small lot sizes. Accordingly, the Speed Viper machines must be capable of handling a wide-ranging component spectrum for contract manufacturers and the automotive industry, as well as delivering maximum productivity, machining quality, and process stability without compromise.

Speed Viper Proves Itself in Real-World Applications

Since its introduction in 2017, the Klingelnberg team – consisting of experts in Application Engineering and Technology Development – have conducted a number of acceptance tests, with components from customers in nearly all cases. This continually provided new challenges for development. The range of acceptance components covered the entire bandwidth of everything that matches the Speed Viper series specification. This included bore components, which are clamped with collets or hydraulic expansion chucks, as well as gear shafts. Some of these were clamped with hydraulic chucks, or friction tapers if interference contours made extremely slim arbor assembly necessary.

Through the use of suitable clamping equipment and machining strategies, a broad product spectrum can be processed by generating grinding: from delicate components with an extremely small gearing width, to weight-optimized toothed gears with numerous material cut-outs and thin walls, to heavy components with a high intrinsic weight. The automation of the Speed Viper 180 and Speed Viper 300 has loaded and unloaded even veritable "chunks" of components both reliably and quickly. The automation successfully handled even large shaft components measuring up to 500 mm with ease – the large stroke travel of the Speed Viper really pays off in such cases. Altogether, the Klingelnberg team has successfully validated the Speed Viper machines over the entire standard module range of 1.3 mm to 5 mm.

Different Variants of Full Automation

Of course, the machine acceptance tests were conducted with full automation (see Figure 1). In addition to the one- or two-arm CompactLoader concept introduced on the world stage in 2017, customer-specific solutions were also used. But the high-end model still remains the CompactLoader, which can be combined with all Speed Vipers as well as with all VIPER 500 machines. The loader is char-

	CompactLoader	BasicLoader	Conveyor Belt with Lifting Station
Speed Viper^2 (dual spindle concept)	✓	✓	
Speed Viper (single spindle concept)	✓		✓

Fig. 1: Speed Viper loading concepts: single and dual spindle machines

Compact

Validated for All Standard Modules

The component spectrum of the Speed Viper machines has now been successfully validated over the entire standard module range of 1.3 mm to 5 mm. The automation easily handles it all – from delicate components with an extremely small gearing width, to weight-optimized toothed gears with numerous material cut-outs and thin walls, to heavy components with a high intrinsic weight.

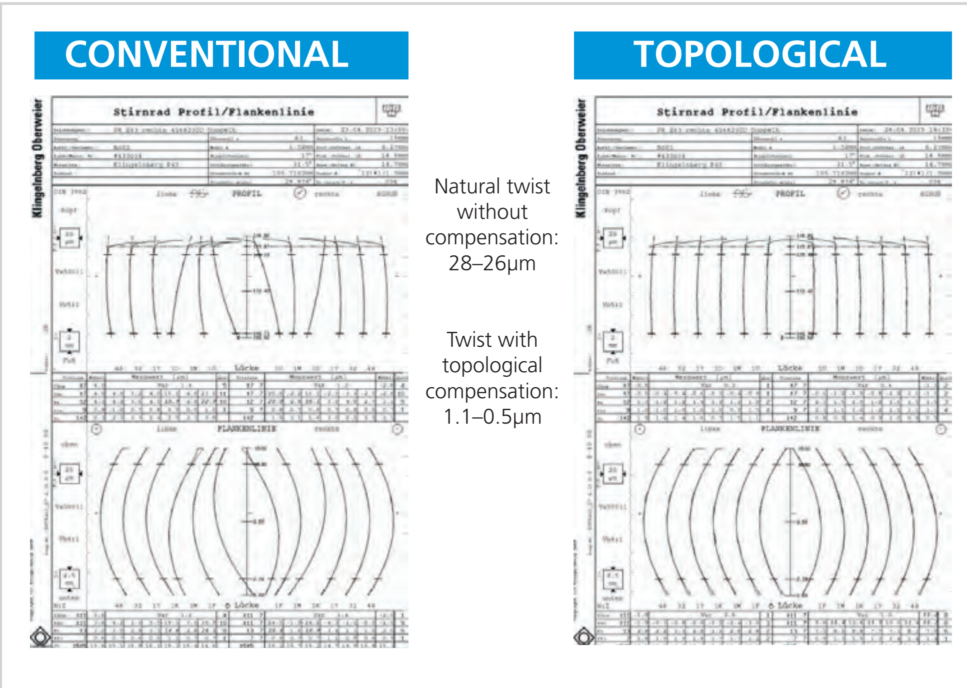


Fig. 2: Comparison of conventional and topologically ground gearing

acterized by ultra-short changeover times of just six seconds, a centrifuge station, SPC and NOK station, and a stacking palettes inside the loader.

For the single-spindle variant of the Speed Viper machines, a loading conveyor belt with a lifting station is available as a cost-effective alternative. Via the lifting station, a component is supplied to the internal loading arm – without an additional gripper. The loading arm then places the component on the workpiece spindle or picks it up from the workpiece spindle. The conveyor can be equipped with an optional centrifuge station, so that components come out of the machine "dry," to satisfy a clean factory concept.

More flexible automation possibilities, additional digital interfaces and connections: The potential of the Speed Viper machines is continually growing.

The BasicLoader was developed as an alternative cost-effective automation system for the dual-spindle machines as well. Instead of a multi-axis robot arm, the BasicLoader uses a simple swivel arm to pick and place the components. The lower costs of this simpler automation system go hand in hand with component changeover times, which are approximately 20 seconds longer than those of the fast CompactLoader.

Leveraging Potential with Gear Designer

Numerous advances have been achieved, not just in automation. In process development, considerable potential has been leveraged in the Speed Viper machines. Certain applications place extremely high demands on surface qualities or reliable geometrical deviations. By separating design from production, the cyberphysical system of the digital twin shows its strengths in this regard: With Klingelnberg's Gear Designer, the expected geometrical deviations between a purely function-oriented tooth flank form and the manufacturable tooth flank form can be visualized in the design stage. If twists must be minimized or precisely adjusted, topological grinding is used (see Figure 2). All of this takes place in advance in Gear Designer – without having to grind a toothed gear, on which the effects on the tooth flank are measured. In the acceptance tests and demonstrations performed, the twist was reduced by up to 96 percent, with only a 15 percent increase in cycle time.

A combined grinding and polishing process can be created in Gear Designer. For this purpose, a two-part cylindrical worm is used, which has a grinding area with a conventional ceramic bond and a polish area with a synthetic resin bond. The required technology parameters are defined in Gear Designer. Depending on

Fig. 3: Web application for visualizing the performed measurements (pink dots) and corrections (green triangles)

the technology used and the grinding wheel specification, it was possible to reduce the roughness to $R_a < 0.1$ µm and $R_z < 0.8$ µm. This grinding and polishing process also allows topological tooth flank modifications.

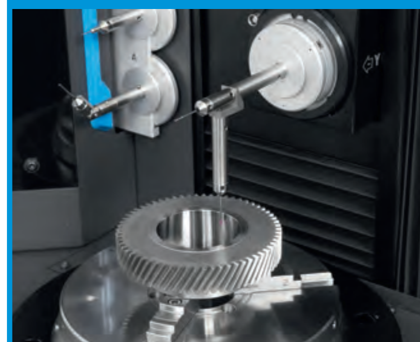
Integration into GearEngine®

Another important step is the integration of the Speed Viper machines into Klingelnberg's GearEngine®. In addition to the basic function of the same Closed Loop used in the bevel gear area – i.e., automatic transfer of measured deviations to the machine along with suggested corrections – the GearEngine® platform makes additional tools available to the machine operator and design engineer. The design engineer can access the complete database of orders in the company and can thus compare different designs quickly and in a detailed manner. In addition, every component measured in Closed Loop is assigned a tag containing information about the machine, the order, and the time and content of the correction. Using an intuitive web application (see Figure 3), a complete history of all ground and measured components can be generated.

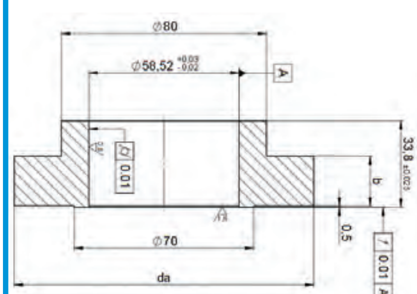
But not every correction needs to be made via the Closed Loop system. Many users have also requested direct intervention by the operator, in other words, manual corrections more or less alongside Closed Loop. The digital documentation of the production history in GearEngine® records and distinguishes between manual and automatic correction. This assures complete transparency with the greatest possible flexibility. In addition, the history contains not only individual figures, but also the complete measuring diagram, enabling the identification of outliers or measurement errors due to dirt on the tooth flank, for example.

The next logical step is to plot machine data and integrate the SmartTooling concept used with bevel gears for additional, maximum transparency and traceability.

TOOTHING DATA FOR AN AUTOMOBILE GEAR



Parameters	Symbol	Unit	Value
Number of teeth	z	–	63
Pressure angle	α_n	°	17
Normal module	m_n	mm	1.69
Helix angle	β	°	31.5
Gearing width	b	mm	19
Tip circle diameter	d_a	mm	116.8
Root circle diameter	d_f	mm	107.625

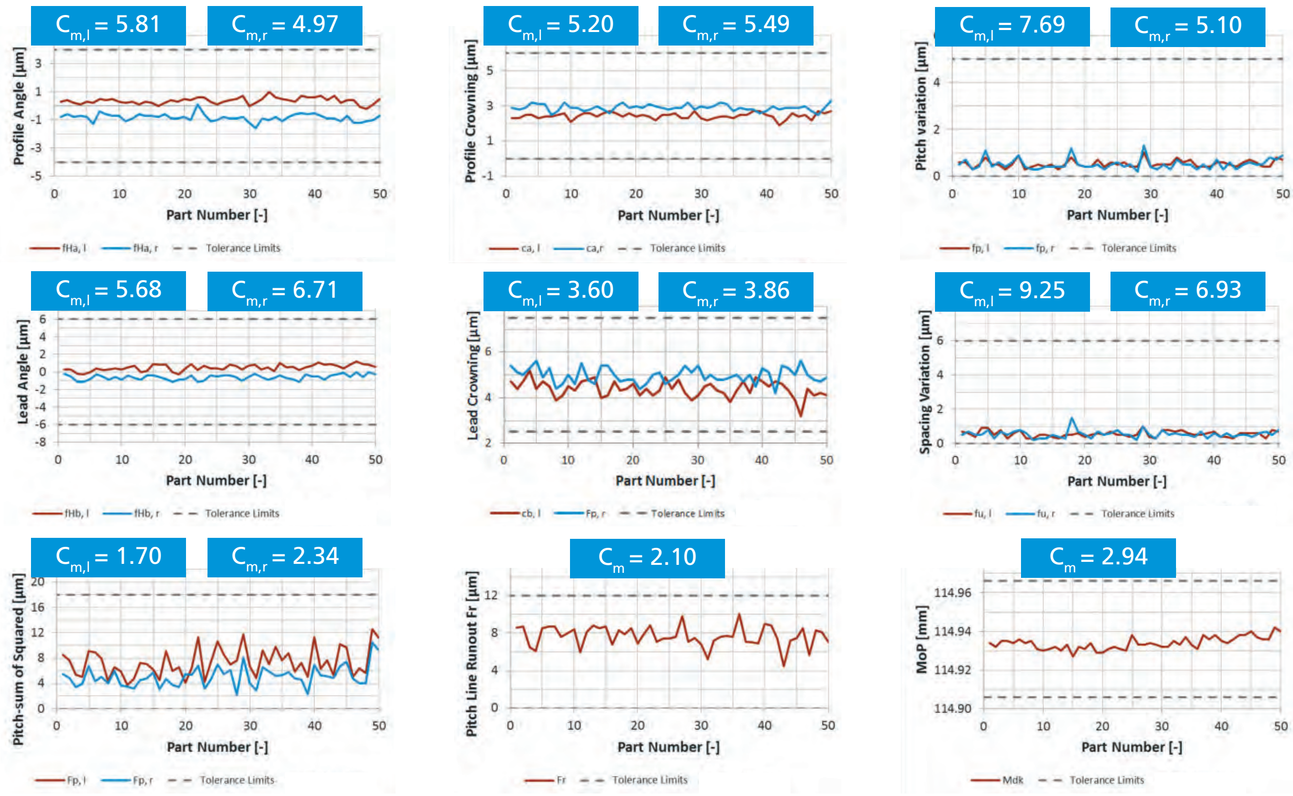


Toothing Data for an Automobile Gear: Process Data and Times

Dressing	Unit	Roughing	Finishing
Number of strokes		3	3
Radial infeed per stroke	mm	0.03	0.3
Rotation speed	1/mm	4000	4000
Speed ratio		15	18
Time	Sec.	102.4	
Grinding	**Unit**	**Stroke 1**	**Stroke 2**
Infeed	mm	0.075	0.025
Feed per workpiece revolution	mm	0.5	0.22
Cutting speed	m/s	80	80
Stroke direction		Synchronism	Counterrotation
Shift jump	mm	–9	7.8
Shift distance	mm/mm	0.04	0.04
Components per dressing cycle		86	
Time	Sec.	11.1	22.7
			33.8

Cycle time: 34 sec.

Results of a Machine Capability Analysis



Made for High Quality Classes

All of this progress goes along with a machine quality that meets extremely high requirements. For evaluation purposes, the generally accepted machine capability parameters used in quality management, c_m/c_{mk}, are applied. The machine capability index c_m is a measure for the spread of a parameter within previously defined tolerances. If the average value, that is, the position within the tolerance, is taken into account in addition to the spread, the critical machine capability c_{mk} is evaluated. In general, 50 components plus a few startup parts are ground, and the described parameters c_m/c_{mk} are calculated. The machine is considered capable if all these values are above 1.67 for all characteristics. The capability value indicates how many components, out of a quantity of ten million, for example, will be defined as rejects. At a c_{mk} of 1.67, this is only six components.

In the previous acceptance tests and demonstrations, the Speed Viper has impressively proven its performance capacity. Based on a gear quality of DIN 5, the machine achieves reliable capability values of 2.5 for the pressure angle at a point, 4.1 for the profile crowning, 5.0 for the flank angle, 3.2 for the helix crowning, and extremely stable indexing values of 8.0 in the single pitch and 3.0 in the cumulative pitch. The machine is also characterized by its extremely high stability in the dimension over balls and base tangent length with a capability value of 3.1. These results show that the Speed Viper machine series has the potential to achieve even higher quality classes.

Of course, cycle time is always a core focus in design. Cutting speeds of up to 100 m/s and grinding spindle speeds of up to 7,200 rpm allow for ultra-short cycle times. An obligatory grinding burn test with nital etching is performed on each ground series in regular intervals. Through the systematic use of 3M™ Cubitron™ II grinding wheels and in close coordination with the specialists at 3M™, the gears ground on the Speed Viper are generally free of grinding burn.

Speed Viper Grows With Requirements

The Speed Viper product family has had an extremely successful market introduction in a challenging market environment. The customer feedback following the conducted final acceptance tests has been positive. As a result, various customers are currently examining further investments. Based on the feedback and experience of each individual machine acceptance test, Klingelnberg is continually improving the Speed Viper along with its GearEngine® environment and is regularly incorporating customers' suggestions and requirements into further development efforts. In this way, the high machine quality will continue to be ensured in the long term. ◆

Compact

Speed Viper – a Fixture in the World of Cylindrical Gears

In numerous acceptance tests and demonstrations since its introduction in 2017, the Speed Viper has impressively proven its performance capacity. Based on a DIN 5 gear quality, the machine reliably achieves capability values that prove it has the potential to attain even higher quality classes.

Dr.-Ing. Florian Scheffler

Head of Cylindrical Gear
Technology Development
KLINGELNBERG GmbH

florian.scheffler@klingelnberg.com

VIPER 500: THE ALL-ROUNDER AMONG CYLINDRICAL GEAR GRINDING MACHINES

The family of VIPER 500 Cylindrical Gear Grinding Machines is now quite large. With its four versions, the VIPER 500, VIPER 500 W, VIPER 500 K and – the most recent of the bunch – the VIPER 500 KW, it offers the solution for flexible, highly efficient production – while satisfying a broad range of requirement profiles.

	VIPER 500	VIPER 500 K	VIPER 500 W	VIPER 500 KW
Workpiece diameter (max.)	Ø 500 mm			
Grinding stroke (max.)	500 mm	430 mm	500 mm	430 mm
Working range over table (min. – max.)	300 – 800 mm	370 – 800 mm	300 – 800 mm	370 – 800 mm
Distance between centers over table (min. – max.)	442 – 1,042 mm			
Module	0.5 – 22*		0.5 – 13*	
Swivel angle	-180° / +45°			
Grinding wheel diameter (min. – max.)	Ø 206 – 400 mm	Ø 25 – 300 mm	Ø 221 – 350 mm (Ø 221 – 350 mm)	Ø 25 – 300 mm (Ø 111 – 200 mm)
Grinding wheel width (max.)	75 mm	60 mm	75 mm (150 mm)	60 mm (80 mm)
Grinding spindle	24 kW	35 kW	37 kW	35 kW
Grinding wheel rotation speed (max.)	5,000 rpm	17,000 rpm	6,000 rpm	17,000 rpm
Table diameter	Ø 400 mm			
Table load (max.)	500 kg			
Table hole (diameter x depth)	Ø 100 × 500 mm			
Table rotation (max.)	120 rpm		1,000 rpm	

* depends on gear geometry

Fig. 1: Technical data

Quality, cost, and time are classic target variables in production processes. Due to their mutually exclusive interdependencies, the term "magical triangle of production technology" is often used to refer to these variables. If the goal is to optimize one target variable, this generally has a negative impact on another variable. Operating resource requirements stem from this magical triangle. Quality, cost, and time can be directly measured and tracked. Their values can be further abstracted and incorporated into important parameters such as productivity, cost-effectiveness, profitability, and flexibility. A modern machine tool should embody all these characteristics.

Flexibility and productivity, in particular, do not normally work as a pair and are rarely encountered together. Flexible production equipment is characterized by its broad range of possibilities, which by the very concept always come at the expense of high productivity. In high-productivity machines, by contrast, changing over to other components is often a lengthy and tedious undertaking. With the Höfler Flexible Gear Grinding Machine VIPER 500, however, Klingelnberg has found a way to keep productivity high while developing a versatile, extremely flexible grinding machine. The VIPER 500 has already been successfully launched on the market, with over 100 machines in operation worldwide.

One Machine Does It All

If the throughput time of an order is extremely important for very small production lots, productivity becomes even more important as the lot size increases. And in cylindrical gear grinding, productivity is determined not only by the cutting speed and axis speed of the machine, but also by the selected grinding technique. Thus generating grinding is significantly faster than profile grinding – but not all toothed gears can undergo generating grinding. Often, in addition to external gearing, internal gearing is also required and must also have a place in the machine fleet's production spectrum.

With the VIPER 500, Klingelnberg has combined these disparate requirements without making any compromises. The machine handles both generating grinding and profile grinding of external and internal gearings. Thus the user can choose the technique best suited for each production order.

The VIPER Family: Something for Everyone

The VIPER 500 machines are available in four different grinding spindle versions. For pure profile grinding with the VIPER 500 and VIPER 500 W, the spin-

Compact

VIPER 500: Highlights at a Glance

- Well over 100 machines successfully installed worldwide
- Internal and external gearing – faster changes thanks to easy setup
- Gear Production machine operating software with Closed Loop functionality
- Generating grinding of beveloid gearings with and without topological modifications

dle can hold grinding wheels between 206 and 400 mm. This makes it possible to cover a large module range up to 22 mm, while ensuring high productivity. For many gearings, a very small tool is required to avoid collisions. The K-Version of the VIPER was developed for this very purpose. Targeting small tools, this grinding spindle provides speeds of up to 17,000 rpm, whereby grinding wheels cover the extremely broad range of 25 to 300 mm with a respectable width of up to 60 mm. This added flexibility was achieved without compromising productivity.

Fig. 2: Machine configuration variants 500 and 500 K

Fig. 3: Machine configuration variants 500 W and 500 KW

If larger production lots or smaller quantities of prototypes for large-volume applications are planned, generating grinding is obligatory. The VIPER 500 delivers maximum flexibility here, too. The VIPER 500 W handles both profile and generating grinding. The grinding worm can have a maximum diameter of 350 mm at a width of 150 mm, and the smallest diameter is 221 mm.

Version Four: VIPER 500 KW

The trend is moving toward compact components with an increased power density. And Klingelnberg's strengths, in turn, lie in special applications, across all cylindrical gear machine series. The K variant, for example, specializes in processing components with limited scope for tool withdrawal. Accordingly, requests were made for a variant of the VIPER 500 that combines both profile grinding and generating grinding with small tools. Klingelnberg listened to this feedback from the market and developed the fourth version of the VIPER, namely the VIPER 500 KW. This machine combines all the options for gear grinding: profile grinding with tools ranging in diameter from 25 to 300 mm and up to 60 mm wide, as well as generating grinding with a grinding worm in the diameter range between 111 and 200 mm and 80 mm wide.

Tremendous Flexibility without Changing Tools

The VIPER 500 K provides another option for grinding several different gearings in one clamping. As shown in Figure 2, several grinding wheels can be mounted on the spindle arbor. This allows different gearings on a shaft to be ground in one clamping, precisely oriented to one another, without requiring a tool change. In addition to high productivity, this also provides a significant advantage in terms of the quality of the gearing.

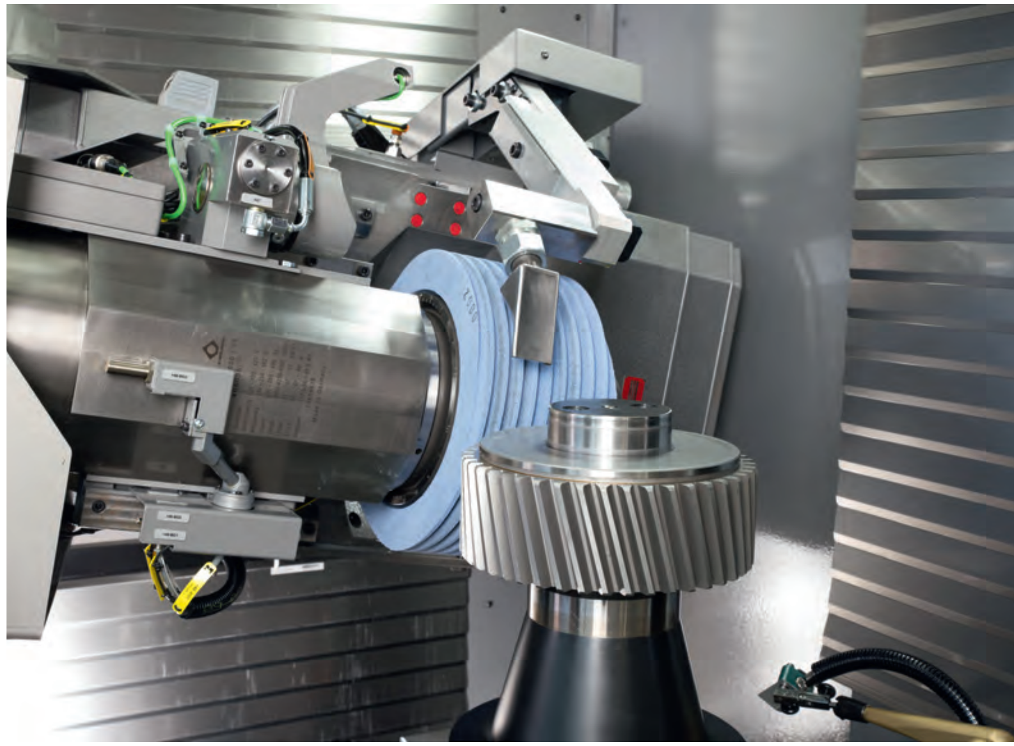


Fig. 4: Swivel axis for ergonomic mounting of the grinding wheel and internal grinding arms

This principle can also be implemented with non-dressable CBN grinding wheels. At 17,000 rpm, the high rotation speed of the K-spindle allows a cutting speed of over 20 m/s even with the smallest grinding wheel, measuring 25 mm in diameter.

High Productivity Without Compromise

Spreading out the requirement profile during development typically leads to compromises. But not with the VIPER 500, where engineers were able to successfully bypass such compromises using technically sophisticated solutions.

In doing so, the focus was on minimizing setup effort and achieving a favorable ergonomic design. Grinding worms may well weigh 30 kg, and mounting this tool on the grinding spindle is tricky business, even with optimized lifting gear tools. The solution to this challenge was to expand the traversing range of the swivel axis. Using the swivel axis (see Figure 4), the grinding spindle can be swiveled directly toward the operator during setup. Thanks to the angled arrangement of the working chamber doors, the operator can change the tool practically "at nose level" without having to crouch down in the machine's working chamber. For grinding, this axis swivels the grinding spindle to the other side. In this way, it was possible to realize a machine that is able to move the tool toward the operator as well as toward the workpiece, without requiring even the slightest compromise in terms of rigidity. Of course, the same also applies to setting up for internal grinding, which a trained operator can accomplish in 15 minutes.

It goes without saying that all versions of the VIPER 500 machines can also grind internal gearings. Depending on the application, different internal grinding arms are used. The VIPER 500 follows a special concept in this regard: An internal grinding arm is placed via an adapter onto the grinding spindle, which drives the machine. This eliminates any electrical connections and complicated setup operations when converting to internal grinding. In addition, it allows internal arms to be compact in design, which in turn leads to a high degree of flexibility of the collision contour during operation.

The flexibility of the different grinding wheels continues with the internal grinding arms. For the VIPER 500 machines, there are three different internal grinding arms. The grinding spindle mo-

VIPER 500 – THE VIDEO

Easy, quick access to all machine components – this and other highlights of the VIPER 500 are featured in this video:

Today, over 100 VIPER 500 machines worldwide are successfully in operation.

	V5	V7	V8
Grinding wheel diameter (max.)	Ø 120 mm	Ø 80 mm	Ø 44 mm
Grinding wheel width	15 mm	6.8 mm	3.4 mm
Insertion depth	180 mm	190 mm	69 mm
Flange diameter	Ø 54 mm	Ø 34 mm	–
Profile height	15 mm	10.5 mm	–
Shoulder diameter (min.)	Ø 65 mm	Ø 38 mm	–
Ring thickness (max.)	200 mm	200 mm	200 mm
Inside diameter (min.)	Ø 95 mm	Ø 57 mm	28 mm
X-distance	10 mm	1.4 mm	5.5 mm
Y-distance	389.5 mm	397.7 mm	401.5 mm

Fig. 5: Technical data and application options for the VIPER 500 internal grinding arms

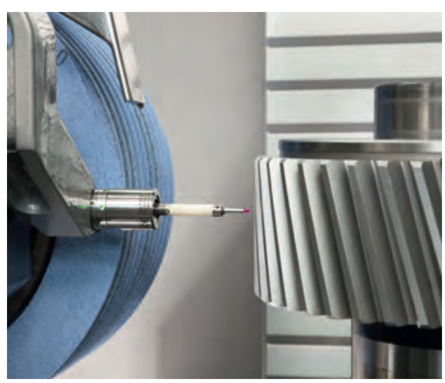


Fig. 6: On-board measurement on the VIPER 500

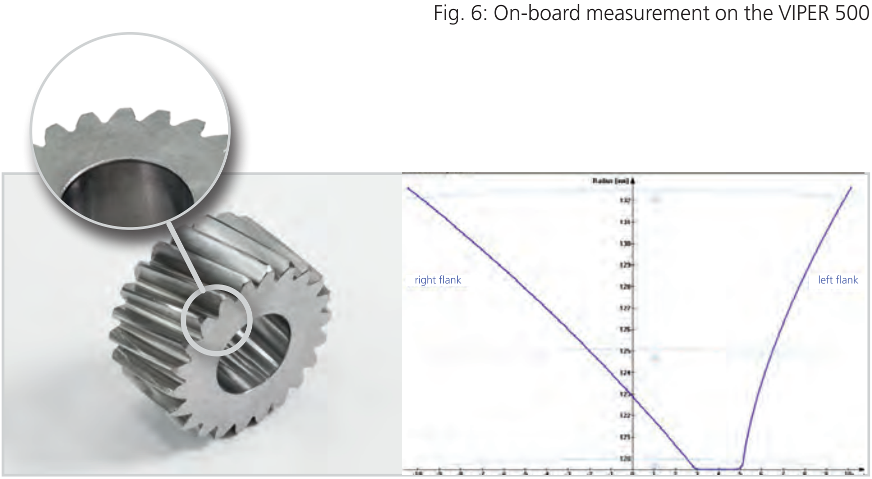


Fig. 7: Asymmetrical involute gearing

tor always provides the driving power. Internal grinding arms can therefore be both compact and sturdy – and this in turn translates to maximum flexibility at the same time as optimal performance capability, and hence high productivity in production.

On-Board Measurement for Fast Production Startup

Following the setup itself, the next question is how long it will take until the first workpiece is produced on the machine. This applies to production of minimal quantities and series grinding processes. The on-board measuring device on the VIPER 500 helps answer this question. With this tactile measurement system, the profile and tooth trace, as well as the pitch and tooth thickness, can be measured on the machine in the same workpiece fixture as in the grinding process and subsequently evaluated. Instead of running to the measuring room with the first workpiece and waiting for the results, the integrated toothed gear measurement allows for significant gains in productivity. After the first component has been measured, production can begin immediately via automatic correction of the machine setting values. Although it may take 45 minutes for the results to come back from the measuring room, it takes only a few minutes with the on-board measuring device on the VIPER 500 to process the production lot following machine setup.

Special Gearing? No Problem!

As an additional special feature, the VIPER 500 software provides numerous options for grinding special gearings. These can be asymmetrical involute gearings, beveloid gearings, cycloid gearings, or free form profiles.

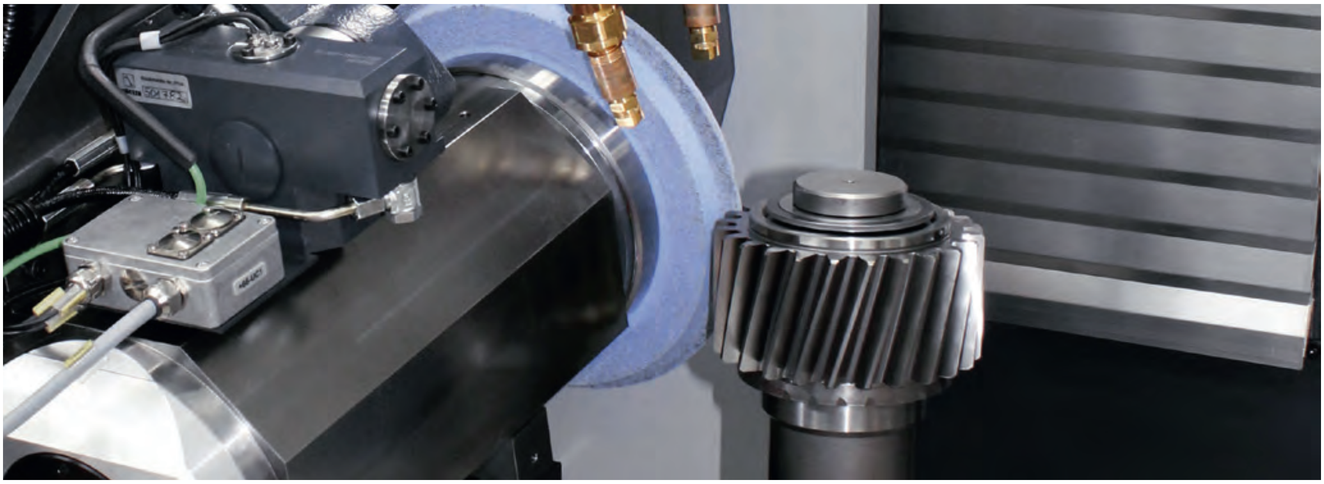


Fig. 8: Maximum production technology, minimal footprint

With asymmetrical involute gearings, the pressure angles are different on the left and right tooth flank. Designs of this type are preferably used when a transmission is essentially operated in only one direction of rotation. Merely making it possible to enter the different tooth trace angles is not sufficient. Rather, the base circles and the fillet radii for the left and right tooth flanks must also be processed in the software independently of one another.

Cycloid gearing is another special case. The gearing on cycloid discs can undergo either profile grinding or generating grinding on the VIPER 500, whereas the associated cycloid cases are produced with an internal grinding arm using the profile grinding method.

For profile grinding of special profiles, the software provides the option of entering the profile point-by-point. This allows just about any free form profile to be ground on the VIPER 500. Of course, all special forms can also be inspected with the on-board measurement system.

Innovative Solutions with a Minimal Footprint

The VIPER 500 truly is an all-rounder, with which Klingelnberg has filled a gap in the market. The secret to success is that only the best characteristics of the tried-and-tested Höfler machine series were retained, innovative solutions were incorporated, and all of this was combined with a minimal footprint. The result is a machine that offers maximum productivity and flexibility. In addition, it is extremely rigid and heat-stable, thus fulfilling the prerequisites for short processing times and consistent workpiece quality at the highest level. Maximum process efficiency and numerous application possibilities are also hallmark features of the Gear Production machine operating software. What's more, the convenient, intuitive operation of the machine has already acquired a devoted fan base around the world. ◆

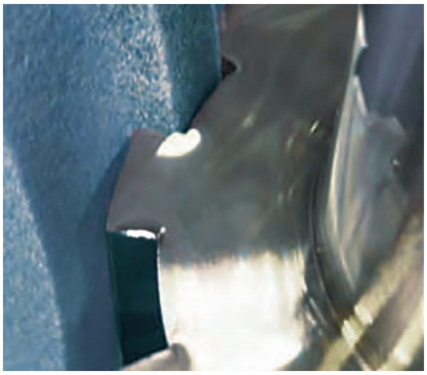


Fig. 9: Special profile on the VIPER 500

Dr.-Ing. Christoph Kühlewein

Head of Cylindrical Gear
Application Engineering
KLINGELNBERG GmbH

christoph.kuehlewein@klingelnberg.com

SMART TOOLING – VALUABLE ON ITS OWN MERITS

With SmartTooling, a system that enables a comprehensive view of all key production parameters is ready for use. After all, machine data are not the only critical data for a highly efficient production process. Data from the tools and clamping devices can also be used for extensive analyses, opening up new ways to leverage optimization potential.

Acceptance testing of a machine tool by the customer is always an exciting moment. "Even if we at Klingelnberg are convinced of our processes and products, we must always put this to the test every time we conduct a preliminary acceptance test in-house," explains Philipp Becher, Product Manager of Tool Sales at Klingelnberg. There are numerous conditions that influence the successful outcome of a machine acceptance test. On the one hand, the machine itself must be fully installed and put into service. On the other hand, the equipment used also plays a key role. Only with impeccable clamping equipment and tools can the machine prove its full performance capability. To achieve this, Klingelnberg relies on SmartTooling, the digital tracking system for production equipment. Because SmartTooling provides a reliable overview of both the machine acceptance tests and the status of the tools and clamping devices, it is consequently used for every internal acceptance and preliminary customer acceptance. Data for the equipment used are automatically generated and collected in a central database. Data from the machining process are also logged, with no extra effort required. This creates the basis for later analyses or optimizations.

The remainder of this article will show how the system is used and what benefits it brings to the machine acceptance process. Prior to machine acceptance, there are various questions that are answered with the help of SmartTooling:

- What clamping equipment is right for machining the workpiece?
- What cutter head should be used in the cutting machine?
- Do the stick blades mounted in the cutter head have the correct profile?

Without digital tracking, it can quickly become quite laborious and complicated to answer these supposedly simple questions. But even subsequently, SmartTooling provides answers to important questions through the intelligent acquisition of product data:

- How many workpieces have already been clamped in the collet?
- What is the condition of the cutter head?
- How exactly was the cutter head configured?
- How many workpieces have already been machined by the cutter head?

Advantages at a Glance

SmartTooling, Klingelnberg's solution for digital tracking of clamping devices and tools, has three main objectives:

1. Operator support
Errors during tooling and machine setup are effectively avoided; scrap and crashes are reliably prevented.
2. Optimized tool management
Access to a tool's useful data is enabled as early as the production planning stage. SmartTooling allows a comprehensive look at all relevant information relating to the tool or clamping equipment at any time.
3. Database creation
By linking the components involved in production to the process parameters, the database is generated for subsequent analysis and optimization of the production process.

Simple and Flexible Layout

The design of SmartTooling has intentionally been kept simple. All collected data are stored in a central database, i.e. GearEngine®, and are made available to all participants from there. For identification purposes, each Klingelnberg component used is marked in-house with a unique, standardized data matrix code. This code can be quickly read by the handscanner before each work step. The relevant work steps in soft cutting of bevel gears include the setup and measurement of the tool, as well as equipping and production on the Oerlikon Bevel Gear Machine. The machine's graphical user interface guides the operator through the individual work steps and provides further useful information. Moreover, these data are accessible from anywhere via the SmartTooling app.

Runs on all Bevel Gear Machines

All new Oerlikon Bevel Gear Machines are already equipped with the software and a handscanner for SmartTooling. Likewise, all equipment is marked with a data matrix code. Through the internal networking of the ERP system with the cutter head and device production, new components are created in the SmartTooling database immediately after the order is received. In the production process, additional information can be added, so that at the end, the data required to use the component in the machine can be assigned to each data matrix code. These data are also made available in digital format to all customers, if they want to use SmartTooling themselves. Klingelnberg's database is so flexible that the customers' own part numbers and characteristics can be added based on the previously defined data. This makes SmartTooling the ideal entry point into Industry 4.0, particularly for customers

Compact

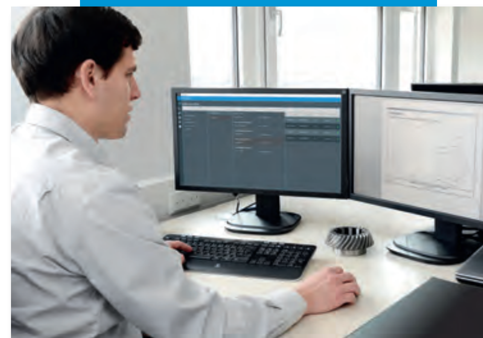
360° View of Production with SmartTooling

SmartTooling is an Industry 4.0 product with three main objectives:

- Reduction of errors in the equipping process
- Optimized tool management
- Comprehensive documentation and database for thorough process analyses

All new Oerlikon Bevel Gear Machines are equipped with the appropriate software and a handscanner for SmartTooling. Older machines can be easily upgraded at any time.

1
EQUIPMENT SELECTION IN THE SMART TOOLING APP



2
SETTING THE CUTTER HEAD ON THE OERLIKON CUTTER HEAD SETTING DEVICE CS 200

3
EQUIPPING THE MACHINE

4
SMART TOOLING IN THE MACHINING PROCESS

5
EQUIPMENT REMOVAL AND RELEASE

who already use or plan to use Klingelnberg tools. Figures 1 to 5 show how to practically use SmartTooling, using the Oerlikon Bevel Gear Cutting Machine C 30 as an example.

Component Selection

For every machine acceptance test, a defined scope of tools and clamping equipment is required, and is identified with the SmartTooling app. Each component number and machine is assigned to the equipment to be used, such as collets, centering bushings, and cutter heads. After selecting the appropriate machine, an overview of the available components is immediately displayed.

Tool Preparation

After the equipment has been identified and defined, the cutter head is prepared on an Oerlikon Cutter Head Setting Device CS 200. To this end, the stick blade set is set up with the required accuracy and confirmed by scanning the code on the stick blade set and cutter head. The measuring results are then uploaded directly from the cutter head setting device to GearEngine®. Additional data, up to and including even the stick blade coating, can be saved as required.

Equipping the Machine

Once the cutter head has been set up, it arrives at the bevel gear cutting machine, which is prepared for the tasks ahead. SmartTooling elegantly assists with the equipping process. SmartTooling is directly integrated into the machine's operating software, thereby ensuring minimal interactions and maximum efficiency during equipping. The same applies for the cutter head. Here, the software checks to make sure the correct composition of cutter head and stick blades is used. The machine setup technician always receives immediate feedback and can be sure at all times that the correct components have been equipped.

SmartTooling in the Machining Process

Everything is now prepared, and components can be produced during the machine acceptance test. At this point, all process parameters and the number of produced workpieces are saved to the digital twin of the cutter head and the clamping device. This provides the database needed to identify possible errors and any additional optimization when working with the machine. The clear overview also makes it easy to evaluate the service life of tools and wear parts in the clamping devices. Additional acceptance tests on other machines but using the same equipment, for example, can therefore be planned in an efficient manner. Whereas before there were data sheets that had to be filled in by hand, today there is SmartTooling. For process reliability, guaranteed.

Equipment Removal and Release

After the acceptance test is completed, the cutter head and clamping device are scanned again and removed from the machine. The equipment is now available for new tasks. The SmartTooling app provides access to the entire range of tool and clamping equipment, any time and anywhere. Questions about the current use of components or their condition can be answered in an instant. In terms of benefits, SmartTooling speaks for itself and Klingelnberg is pleased to demonstrate it during acceptance test. ◆

Dipl.-Ing. (BA) Christian Brieden

Head of the Technology Center,
KLINGELNBERG GmbH

christian.brieden@klingelnberg.com

SMART PROCESS CONTROL – A GEARENGINE® MODULE

Total integration of all machines and application software is a prerequisite for comprehensive process documentation and analysis of the many factors influencing production. With total integration, a targeted search for potential optimizations becomes possible.

Compact

More Data, More Transparency

In line with Industry 4.0, Klingelnberg is continually expanding its modules and their ability to communicate with each other. The symbiosis between the Smart Process Control and SmartTooling software applications provides access to a wealth of additional information, which can then be used to easily identify the impact of a broad range of factors on production.

Recognizing optimization potential among the many different influences in production is not just a question of expertise. Rather, the major challenge lies in obtaining an overview of the entire process chain and its potential, from the material, to tool preparation and the cutting process. In the past, it was also extremely difficult to track and analyze influences and their changes due to the interactions. Compact digital data analysis tools did not exist.

In the overall context of Industry 4.0, Klingelnberg is expanding its modules and the intensity of the communication capability among the modules. Users therefore benefit from extensive integration of Klingelnberg machines and application software, such as Smart Process Control and SmartTooling. A symbiosis of these two applications gives Smart Process Control access to a wealth of additional information to identify the impact of various factors, such as material batch, tool preparations, and clamping device wear. After all, production is influenced by a broad range of production processes, tools, and accessories, but also by such things as the material.

The Three Tasks of Smart Process Control

With the Smart Process Control software, users have a comprehensive process documentation tool at their disposal. As one of the elements of GearEngine® specifically designed for the production process, the software provides deep insights into production.

Smart Process Control performs three significant tasks. The first consists in optimizing machining processes, linked with long-term logging of information about the optimization level to be analyzed. As the core module of Smart Process Control, the database created from these logs then enables an analysis of the data – the second key function of the software application. The analysis focuses on the relationship between process design and tool wear and thus directly on the cost-effectiveness. A further analysis option targets the detection of anomalies in the data acquired during series production. In this way, anomalies that could jeopardize statistical precision in production can be traced. This third major function of Smart Process Control therefore has an immediate impact on production quality.

One Software for Everything – Machines and PCs

Because Smart Process Control encompasses various functions, it is used accordingly at different points. One component of Smart Process Control runs on the machine tool and communicates directly with the machine software; another component is installed on the PC in the office or in the production control center and communicates with a central database.

The application running on the machine is tasked with collecting performance data from the tool spindle and assigning these data to the precise process position or process time, then storing the data as a packet. These performance data are visualized directly on the machine, and changes to the cutting process can be graphically displayed on the operating unit, compared side-by-side, and evaluated. These performance data can be determined and stored for a freely definable number of components with the same or different geometry. This can take place for the same process (i.e. a process already optimized for production) or for a process still in the analysis stage.

The process parameters used are also stored along with these performance and position data. Accordingly, any changes to the data can be easily identified in the analysis. Thus it is possible to perform an analysis and comparisons up to an explicit, local position within the process itself.

SmartTooling

All data generated by Smart Process Control are logically stored in a database. This database is preferably created using the SmartTooling application, which, like the Smart Process Control module, is part of Klingelnberg GearEngine®. SmartTooling makes it possible to collect a broad range of information about the tools and clamping devices used on the shop floor. This tool information allows even the coating of an individual stick blade to be tracked, for example. The clamping device information, e.g. the number of clamping cycles of a collet, is also always available for queries. In principle, the database can be expanded to

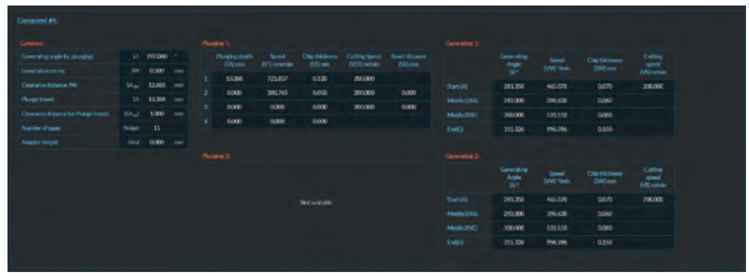
GEARENGINE® IN PRACTICE

GearEngine® with the Smart Process Control module requires three software components, which must be installed on the machine or in the production network.

- The first component is the GearEngine® platform, which is installed on a server. This platform enables communication between the components that generate information and those that save information.
- The second component is the Smart Process Control database associated with GearEngine®. This is the data pool and source for applications that are specialized in analysis.
- The third component is the Smart Process Control app, which is part of GearEngine®. It is the system's "clever brain" for tracking special characteristics.

SMART PROCESS CONTROL IN PRACTICE

The information content of the data saved by Smart Process Control is extensive. Every process parameter used can be accessed for every component produced. Even changes made by mistake are easily identified, thereby preventing false conclusions during analyses and evaluations.



For every process sequence, the loads attributable to the machining position can be graphically displayed. Significant changes to the process are readily evident in a direct comparison due to the changes in the machine load, as the following example shows:

The next example shows that even small variations in the machine load can be visualized directly. If no variations were made in the process, the factors that influence this effect can be investigated.

include much more information, such as material batches.

Simple Solutions for Complex Processes

Even today, many parameters are measured at different production positions in a modern factory, and are available for evaluation. An entire production chain is extremely complex, which is why it is essential for an accurate view to be able to take as much additional information into account simultaneously. This plethora of information does not make it easier to evaluate the data. This is where the Analysis component of Smart Process Control comes into play. With its graphical support, Analysis allows for straightforward data management and analysis of a wealth of information.

Additional complexity results from the reuse of components, as many tools and production accessories are frequently used for different components on the shop floor. Changes resulting from the use of these peripheral elements quickly influence the quality of the manufactured components, but this causality is often underestimated or goes undetected. Such uncertainty is undesirable, particularly for components that attain their final component quality through a specific process. Here again, SmartTooling supports the evaluation options.

With Smart Process Control, users can access a large amount of information in a complex context and thereby quickly search for clues. Even small changes in the recordings make the critical observer aware of the need to closely analyze the available graphical information, draw meaningful conclusions with regard to influencing factors, and implement optimizing measures.

The possibilities now available provide the basis for an even more extensive use of a cutting machine's load data.

Outlook

The possibilities described in this article provide the basis for an even more extensive use of a cutting machine's load data. Simulation programs enable the machining-specific parameters to be generated for a specific position in the cutting process. The information recorded by Smart Process Control can be standardized with these machining-specific parameters. Thus for the first time, it is possible to generate information on a realistic view of the local tool load down to the level of the currently engaged tool blade. ◆

Dipl.-Ing. Karl-Martin Ribbeck

Head of the Competence Center
Bevel Gear Technology,
KLINGELNBERG GmbH

karlmartin.ribbeck@klingelnberg.com

KLINGELNBERG GOES SINUMERIK EDGE

One-stop source: Klingelnberg joins Siemens SINUMERIK Edge with its own GearEngine®. Customers now benefit from the combination of the two systems. Whereas GearEngine® measures toothing data, SINUMERIK Edge analyzes the data directly at their point of origin, i.e. the machining process. Working together, they produce a detailed overall picture of all machine data.

Compact

Edge Computing

Data interfaces are the fundamental basis of advanced Industry 4.0 applications and their integrated systems. They are the necessary condition, enabling continuous acquisition and analysis of data. There are no out-of-the-box solutions here. By combining GearEngine® with SINUMERIK Edge from Siemens, Klingelnberg has taken an important step, signaling its commitment to Edge Computing – distributed data processing at the edge of the network.

Production data increasingly form the basis for economic decisions. The promise here, in particular, is an increase in the efficiency of production plants through simple data analysis functions across all processing steps. As we all know, many challenges must be overcome as we move toward such advanced Industry 4.0 applications as preventive maintenance. One of the more challenging tasks is to continuously acquire and analyze data taken from the machining process of the machine tool. Did you know that a Klingelnberg machine tool generates up to 1.5 GB of data per hour? This is roughly equivalent to two tons of printed paper. In addition to these IT challenges, detailed knowledge of the design and control-related conditions of the Klingelnberg machine tool and the specific toothed gear machining process is required. Otherwise, the data analysis will only reveal banal correlations and no valuable causations. Indeed, added value can only be generated through a combination of IT technology, control engineering, and the cutting process. We cannot expect out-of-the box solutions here.

Data Analysis at the Point of Origin

Given these requirements, Klingelnberg now offers a solution that paves the way to data-driven analyses for machine tools in a simple manner. It involves merging two products – Siemens SINUMERIK Edge and Klingelnberg GearEngine® – in a new way. The SINUMERIK Edge platform is a combined hardware and software solution for machine tools with a Siemens control unit. It enables data analysis directly at the point of origin, the machining process of the machine tool. SINUMERIK Edge collects continuous data and subsequently processes these data with integrated software modules, the so-called Edge apps. Via a special interface, numerous signals can be recorded in parallel – a unique feature of this technology. Special applications on the Edge hardware can then pre-process and analyze these data. This reduces the network load, i.e.

the data transfer from the machine to the local network, to a necessary minimum. Before the Edge hardware is installed in the machine, the management, system administration, and configuration of the data analysis functions takes place via MindSphere, the Siemens Cloud solution. Once installed in the machine's control cabinet, SINUMERIK Edge can do its job of recording and pre-processing data, without an active Internet connection.

Strong Together: SINUMERIK Edge and GearEngine®

The advantages of the Siemens hardware can only be fully realized, however, if SINUMERIK Edge is ideally integrated into the Klingelnberg production system. Edge works by acquiring data based on individual NC sets. For every NC set executed, all associated sensor data are recorded. SINUMERIK Edge cannot "see" beyond this initially. This is because conventional NC programs only account for part of the world of production. For example, they do not include any information regarding toothing data specifications or measuring results for a specific component, which are typically managed with Klingelnberg systems. Thus a number of detours are required to relate the data to a specific toothed gear. Valuable knowledge remains hidden. This is where Klingelnberg's GearEngine® comes into play as a platform for toothing data. GearEngine® brings these two worlds together. The extremely precise, but non-process-specific, Edge data are integrated into the specific toothing data, giving the user a comprehensive overall picture for improved decision-making processes. Here, GearEngine® serves as a data platform and makes the key applications available. These include applications for storing measuring results (Gear Tracer), the evaluation software for servotraces (Machine State Analyzer), the apps for digital tracking of production equipment (SmartTooling), and finally, the load analysis of tool data (Smart Process Control). By linking the Siemens production data, the following strategies can be successfully implemented:

- Transparent machine operation
- Optimized cycle times
- Reduced waste
- Preventive maintenance

The advantages of integrating Siemens SINUMERIK Edge and GearEngine® from Klingelnberg are therefore obvious.

Step by step, Klingelnberg is moving toward providing new, digital solutions that are easily integrated into customers' production processes. The goal is to ensure that no one will have to deal with complex commissioning procedures and cloud connections in the future. Klingelnberg is a one-stop source for it all. ◆

Dipl.-Ing. Daniel Meuris

Head of Digitization and Virtualization,
KLINGELNBERG GmbH

daniel.meuris@klingelnberg.com

FOLLOW US AND STAY UP TO DATE:

WWW.KLINGELNBERG.COM • INFO@KLINGELNBERG.COM

KLINGELNBERG AG
Binzmühlestrasse 171
8050 Zurich, Switzerland
Phone: +41 44 278 7979
Fax: +41 44 273 1594

KLINGELNBERG GMBH
Peterstrasse 45
42499 Hückeswagen, Germany
Phone: +49 2192 81-0
Fax: +49 2192 81-200

KLINGELNBERG GMBH
Industriestrasse 19
76275 Ettlingen, Germany
Phone: +49 7243 599-0
Fax: +49 7243 599-165