

ALWAYS RELIABLE, EVEN WITH MINIMAL LUBRICATION – BEVEL GEAR SETS FOR HIGH-SPEED MACHINING PROCESSES



In the area of metal-cutting production, new cutting materials, combined with high-performance coatings, are making it possible to achieve outstanding rotation speeds of up to 20,000 rpm. High speeds of this magnitude impose special requirements on the "tool powertrain", which must be viewed as a complete system. The rolling contact of the bevel gearing must be designed so that it still functions reliably in application areas with only minimal lubrication or cooling, so that no tooth flank damage occurs.

High-speed machining processes result in high peripheral speeds at the outer diameter of the bevel gear and shafts. This happens even if the torque is low, i.e., when only minimal forces are exerted on the tool cutting face. When it comes to lubricating the gearing, oil sump lubrication must immediately be ruled out, if only because of the churning losses and the high centrifugal forces that drive the lubricant away from the point of rolling contact. It is for this reason that only oil mist can be injected into the transmission. The transmission housing can only be sealed with a labyrinth seal, but this allows the oil mist to escape again. Because the mixture is supposed to supply the entire system, i.e., the bevel gearing as well as the surrounding bearings, hydraulic oil is used instead of a specially enriched transmission oil. This arrangement results in a low level of lubrication, for which the gear sets must be specially designed.

In some machining tasks, such as those found within the aircraft construction industry, valuable workpieces are machined from the solid. This produces large chip volumes and means that the tool must remain engaged for long periods without any loss of operational reliability. Consequently, every single aspect (such as the high velocities, low torques, and the special lubrication conditions) must be covered by a well-thought-out holistic concept so that all the requirements are likewise accommodated. These are long service hours, operational reliability across the board, and the

avoidance of extreme heat build-up (which would otherwise subject the housing to thermal strain and change the mounting position of the bevel gear set).

Bevel Gear Beats Contrate Gear Hands Down

The first important decision is whether to opt for a bevel gear or a contrate gear. The bevel gear wins hands down because, even though the kinematic aspects are the same in both cases, it offers certain benefits: firstly, both the rolling contact and the requisite production quality can be perfectly tailored to the requirements and the general conditions. Secondly, this type of gearing plays a fundamental role in ensuring the transmission runs much more quietly overall. This is because, in the case of bevel gears, you can calculate and map the rotational error (i.e., a lack of precision during the transmission of motion) in a reliable manner.

Compact

Reliable Lubrication Even at High-Speed

High-speeds, low torques, and minimal lubrication must all be perfectly balanced so that the equipment can withstand long service hours and significant heat build-up. Klingelberg has developed innovative technologies and created new solutions in this area.

On machines that run at these high rotation speeds, the bevel gearing must be designed to work reliably, even with sub-optimal lubrication.



Grinding from the solid of a pinion



Grinding of a pinion

Design of High-Speed Bevel Gear Sets

The next problem associated with high rotation speeds is the correspondingly large influx of energy into the tooth flanks, which leads to flank damage. Consequently, there are three central objectives when designing high-speed bevel gear sets:

1. To maximize efficiency
2. To minimize power loss (which is closely related to the above point)
3. To avoid tooth flank damage by minimizing the detrimental effects of rolling contact (e.g. relative slip and heat input)

BASIC KNOWLEDGE AND EXPERIENCE GLEANED FROM MOTOR RACING

Intensive Research

Fundamental Experiments in the Area of Tooth Flank Damage

Klingelberg's practical approach to design and its consulting services are based on intensive research and development activities in this area. Our employees have carried out fundamental experiments in relation to tooth flank damage, design studies have been conducted at customer facilities, and empirical evidence has been gathered from designs for heavy-duty gear sets used in the motor racing industry.

Optimum Supply

The Study of Variants Using Design Programs

The high rotation speeds and high loads encountered in motor racing mean that additional oil has to be injected into the contact area to ensure an optimum supply of oil lubricant. The KIMoS and BECAL design programs used are industry-standard – both programs enable you to consider the contact area in a precise and realistic manner with a view to studying alternative designs as well.

Temperature Requirements

Optimization of the Transmission for Stringent Temperature Requirements

Another requirement that the transmission must meet concerns temperature: the transmission housing must not exceed a certain temperature on the outside, and for this reason the overall efficiency of the gearing and the rest of the transmission must be optimized. High-speed gear sets from Klingelberg help to ensure that the maximum temperature requirements of the transmission housing are met.

In order to achieve the required long operating times required and to safeguard operational reliability, the macro- and microgeometry of the tooth flanks, the machining processes, the material used, and the heat treatment method, must all be precisely coordinated with one another.

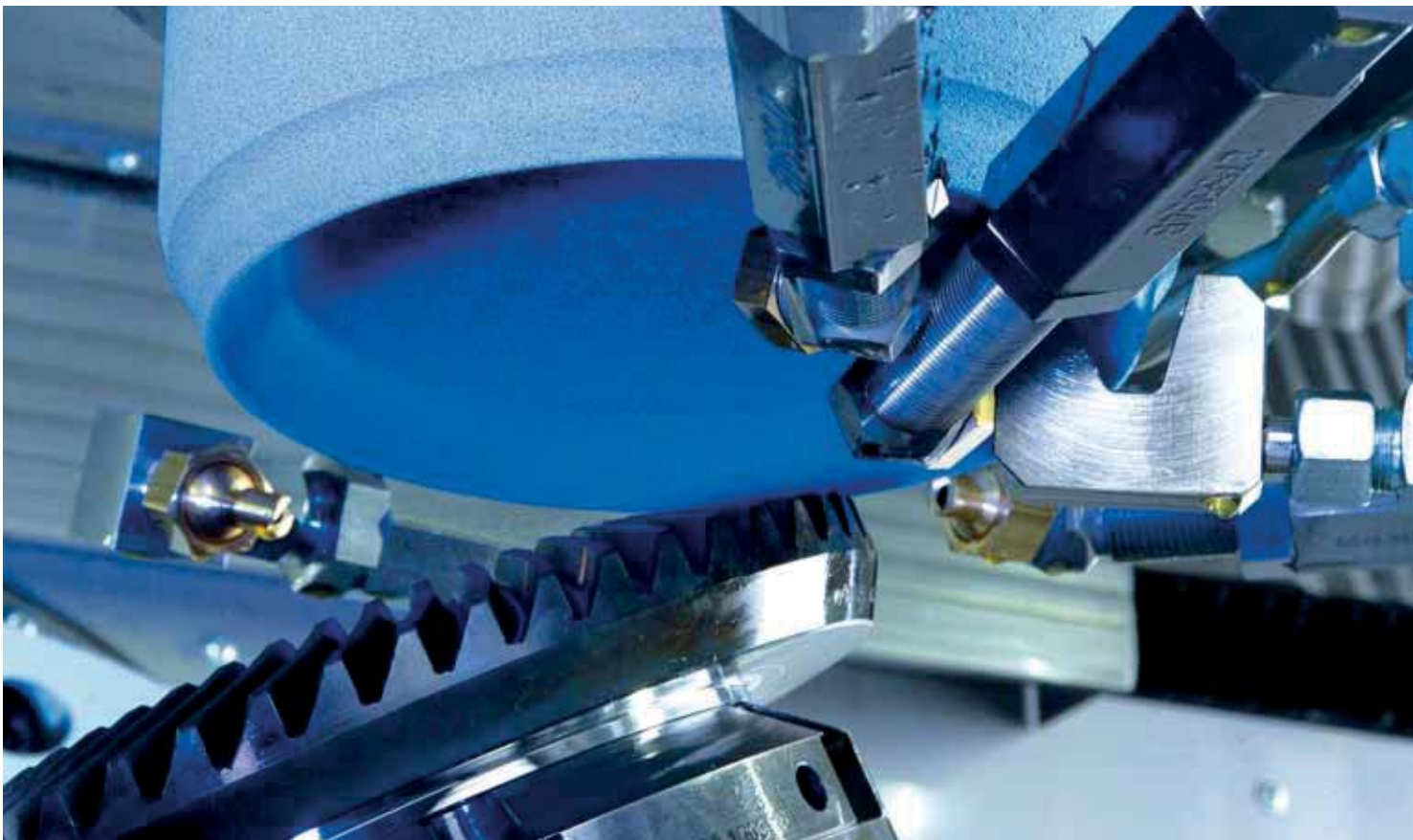
Optimizing efficiency also involves minimizing power losses, since these also lead to material stresses and material damage during rolling contact. By combining high speed and low pressure with minimal lubrication during rolling contact, Klingelnberg is entering new territory in bevel gear design.

In some respects, the potential design areas will affect the result in opposite ways. As a general rule, the tooth root load capacity is already assured due to the low loads involved. Thus, the entire focus needs to shift to what is happening at the tooth flank:

By combining high-speed and low pressure with minimal lubrication during rolling contact, Klingelnberg is entering new territory in bevel gear design.

here, there are also opportunities to follow unconventional design paths. For instance, it is possible to exploit degrees of freedom that would normally be ruled out in motor racing applications because of the high loads involved.

Powerful software tools are available in the form of KIMoS (Klingelnberg Integrated Manufacturing of Spiral Bevel Gears) and



Finish grinding of a ring gear (plunge grinding)

"Reduced airborne noise emissions and improved quality during cutting show that the gearing is interdependent with the powertrain right through to the cutting edge."

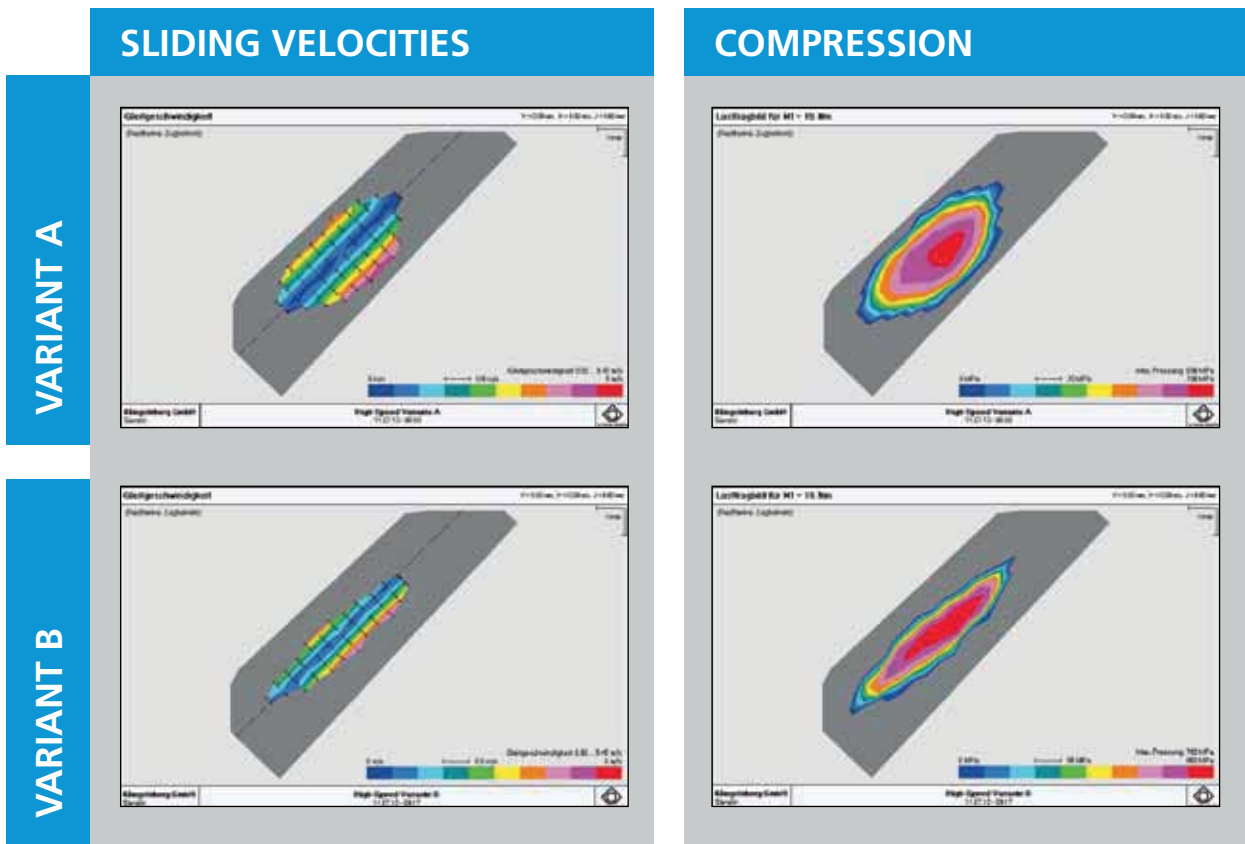
Thomas Serafin, Drive Technology/Calculation and Design
KLINGELNBERG GmbH

BECAL (Bevel Gear Calculation Program). These programs enable users to perform a full analysis of the rolling contact kinematics and to complete the associated kinematic design process. As a result, the "bevel gear" tribological system can be studied from the perspective of gear theory.

Minimized Power Loss

Power loss is caused – among other things – by high relative tooth flank speeds in the area of the contact patterns that are under load, and by excessive surface roughness. Therefore, both the macro- and microgeometry must be designed so that the rolling

Two ease-off variants with varied profile crowning



Although surface compression is diminished in the case of ease-off with a small degree of (top) profile crowning, the sliding velocities increase disproportionately and, along with them, the level of power loss.

Since the higher surface compression associated with a higher degree of (bottom) profile crowning is not critical for the material used, this variant was chosen. The change in profile crowning alone reduces the level of power loss due to rolling contact by 25%. This design has also proven to be less sensitive to displacement.



Bevel gears used in airplanes must meet the highest quality standards in terms of pitch and concentricity (DIN 1–3) and must also perform rotational movements with absolute reliability.

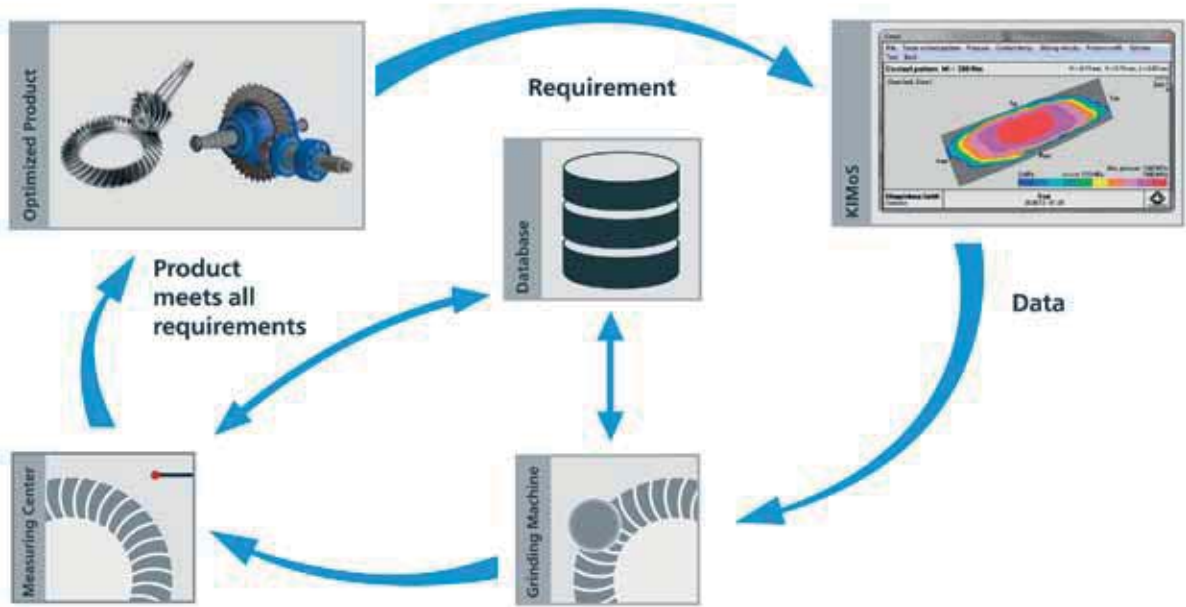
contact under load is concentrated in the area of the lowest sliding velocities. In bevel gears with no offset, this zone is located in the direct vicinity of the pitch cone. With this in mind, care is taken to ensure that this design approach is adopted right from the start when selecting the number of teeth (transmission ratio), the spiral angle, the addendum modification, the profile height factors, and the tool diameter for a given bevel gear size, i.e., by means of the macro-geometry parameters. A hypoid gear (with offset) is ruled out from the outset.

The choice of tool geometry must ensure that manufacturing the bevel gearing is actually feasible, particularly when grinding from the solid. The microgeometry of the tooth flanks (or ease-off) is then designed in such a way that the contact pattern is located on the pitch cone and is less

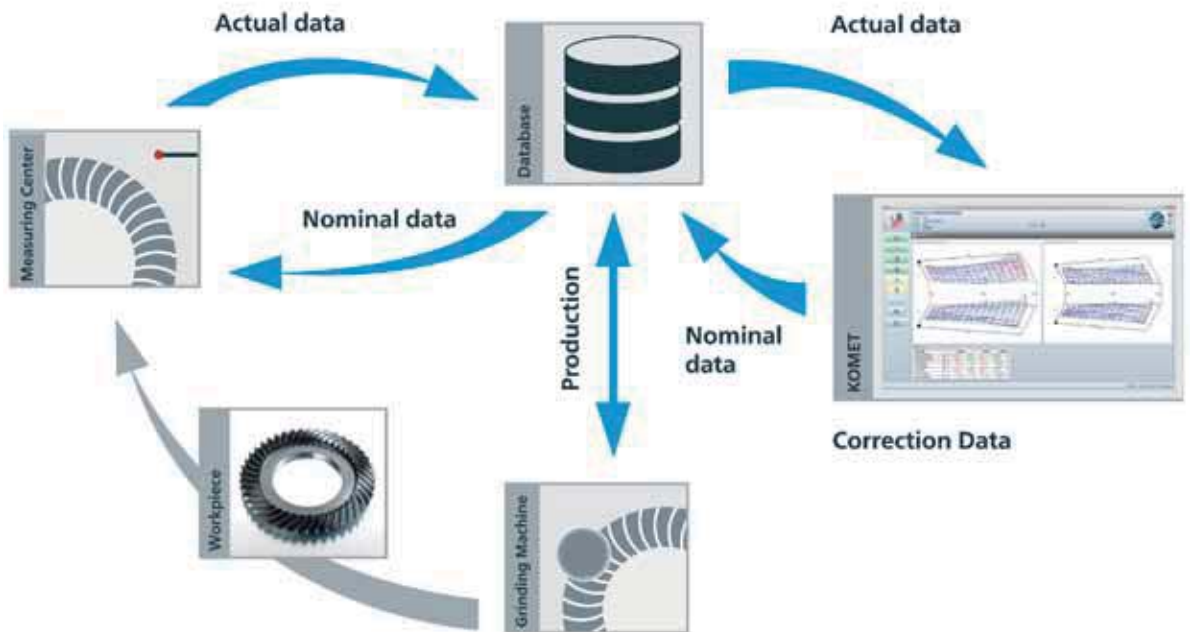
pronounced in the direction of tooth depth. Lengthwise crowning generally reduces the rotational error to an acceptable level. The shifting capability of the ease-off is sufficient, as displacements are likely to be small, due to the low loads associated with a rigid housing. Minimized power loss results in low heat input into the housing and, in turn, negligible thermal growth.

Quiet running behavior reduces airborne noise emissions, which are considerable at such high rotation speeds, and creates a more pleasant atmosphere for machine operators to work in. It also improves the quality of the surfaces machined by the cutter. This demonstrates the interdependency between the gearing and the entire powertrain, from the motor through to the cutting edge.

Closed-loop concept



KIMoS – for optimal design



KOMET – from design to optimal production result

Precise Production Methods and Optimum Process Reliability

To achieve the necessary topographical and surface quality, Klingelberg employs production methods that minimize deviations from the calculated contour of the tooth flanks. The bevel gear is ground from the solid with an allowance while soft, and is only finished after undergoing heat treatment. For small lot sizes, this method is an extremely economical alternative to cutting.

Because it uses the KOMET correction program to integrate the process into its closed-loop concept, Klingelberg can always be relied upon to achieve the highest possible quality: the gearing and locating distance are produced at "zero", which makes bevel gear installation considerably easier. Careful measurement of the housing, bearings, etc. generally leads to the correct contact pattern position.

As the surface quality has a major impact on the flash temperature, the tooth flanks also undergo a superfinishing process during production. To assist with this stage of the work, Klingelberg has managed to find a specialist so proficient in this technology that the entire tooth flank surface is ground right down to the tooth root using vibratory finishing, even in the case of small-module gear teeth.

To ensure that dry-running operation is possible if the lubricating film has not fully formed, due to an insufficient supply of oil, the material used must be hardenable and highly heat-resistant. For this reason, the gear sets are made from a type of steel that is also used elsewhere in the aircraft industry, and can either be case-hardened with carbon in the conventional manner or plasma-nitrided. By combining these two hardening processes, extremely hard surfaces are achieved, for optimal wear protection.

"Design calculations and contact patterns are the key to good gear sets."

Thomas Serafin, Drive Technology/Calculation and Design
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Guiding Customers Toward a Stable Process

To ensure its gear sets are perfectly tailored to individual requirements, Klingelberg takes precise customer specifications regarding speed, displacements, etc. into account when designing its high-speed gear sets. Klingelberg brings its many years of expertise to bear on the development and design phases, and provides customers with support from design through to installation: at the end of the planning and design phases, the finished gear sets are mounted and can be checked in situ, together with the customer, if required. In this way, machine manufacturers can be 100% confident that the contact patterns developed with the KIMoS design tool have been implemented perfectly. ◆

QUICK-REFERENCE INFO

- Transmission runs more quietly overall thanks to tailored kinematics
- Minimized power loss due to macro- and microgeometry
- High rotation speeds call for as little lubrication as possible, and so a labyrinth seal has to be used
- Reliable durability is achieved on the basis of topographical and surface quality, and through integration into a closed-loop concept
- Perfectly tailored to individual requirements



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