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THRUSTERS SESSION

High Torque Gear (HTG)- the new premium class in azimuth thruster gear technology

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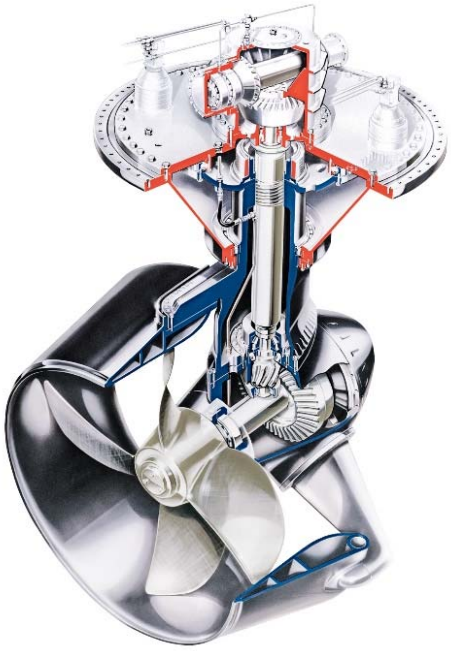
Abstract

Under the project title “high-torque-gear (HTG)” SCHOTTEL´s mechanical development team together with Dresden university´s institute for machine elements (IMM, TU Dresden) has developed fundamentally new kind of bevel gears specially optimized for the azimuth thruster application.
The whole project, consisting of several sub-projects covers a development period of almost exactly 10 years.
The idea of the HTG came up around 2005 in a period of significant growth of the offshore market and a resulting lack of large bevel gear sets for offshore thrusters. This bottleneck even limited the business for SCHOTTEL and there seemed to be no way out of the dilemma due to the very limited number of large specialized bevel gear production machines worldwide. In this situation SCHOTTEL teamed up with Dutch gear manufacturer BIERENS who had already started to copy standard spiral bevel gear shapes of Klingelnberg type using more or less standard 5-axis milling centers.
In the following years SCHOTTEL made production tests and manufacturing accuracy surveys and even tested such new gears under load to bring this production method into safe application for azimuth thrusters. The final results in accuracy of the new production method were so promising that several innovative ideas for macro geometry and flank topography of the bevel gear sets came up. This was possible using the almost unlimited kinematic freedom of the 5-axis machines.
Ideas were further worked out around 2008-2011 within a governmentally founded research project, which leads to several international patent applications.
The project was completed by a software development, which allows modeling, and calculating the HTG gears under consideration of displacements and elastic deformations of the underwater gear system of the azimuth thruster, which transmits all thrust and steering forces and is further exposed to dynamic sea loads and thermal expansions.
As a result a full design package with locally calculated stress and safety values at each individual point of the gear flank contact under any load situation is generated ready to be transmitted to the CNC 5-axis machine; even the reverse calculation of measurement values of machined gear sets is possible.
It can be proven that a significant safety increase of all relevant design criteria such as pitting and micropitting safety, sub-surface fatigue safety, scuffing safety and tooth breakage safety can be reached at once. This was proven both in simulation with the new software and by extensive series tests on independent test benches at SCHOTTEL R&D and Dresden university and meanwhile also in multiple applications of different thruster sizes. Safety increases of approximately 20% have been demonstrated by tests.
As a conclusion SCHOTTEL can offer a complete closed-loop system of design and production of significantly improved thruster gear technology which is also used as standard in the recently released Ecopeller thruster series (SRE) which actually was awarded the Fuel Efficiency Award of the European Marine Engineering Conference.

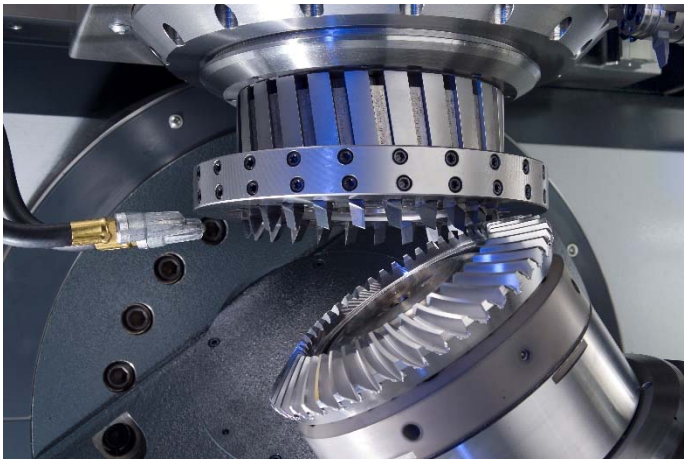
Chapter 1: 5-axis-milled bevel gears / development and usage at SCHOTTEL

In a more than 10 years extensive gradual development process SCHOTTEL has fundamentally improved the expertise and the processes involved in the development and manufacturing of high-performance bevel gearboxes and thus offers its customers today another component with a plus on performance compared to the competition.
The new technology, named HTG (high torque gear), is today already used in several new products of the company and has proven over years of operation in hard usage.
The starting point of the development was the year 2005. The shipbuilding market was moving with great momentum into a sustainable growth phase; this development clearly overwhelmed the procurement processes also for suppliers of propulsion systems and therefore also at SCHOTTEL.

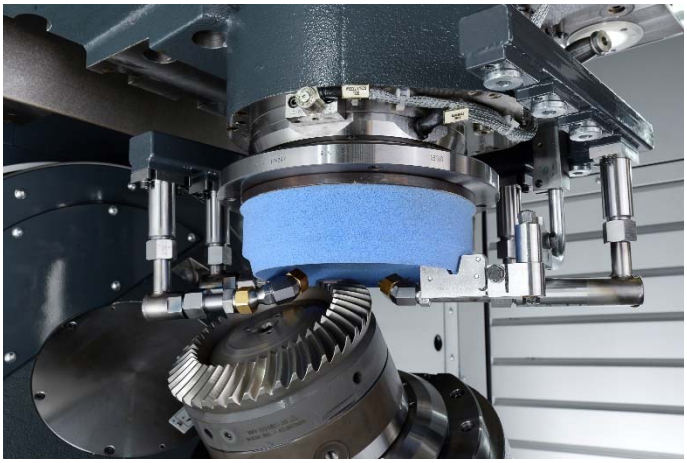


Pic. 1a left - rudderpropeller with bevel gear sets [SCHOTTEL]
Pic. 1b right – bevel gear set from the underwater gear of a large azimuth thruster [SCHOTTEL]

A major bottleneck was the availability of gear sets for the bevel gears of large rudderpropellers in particular in the megawatt range. Thus, the core component of the drive system was affected which had a severe impact to the business development.
Because the bevel gears are required at an early time in the assembly process of the rudderpropeller this scarcity began to limit the sales development of the company.
Furthermore these bevel gear sets are individually developed to the structural and geometrical constraints of the thruster, which applies for all makers, and manufacturing of such specialized gears was only offered by a handful of gear set makers worldwide that time.
Under this pressure to act a task force was formed to search for alternative procurement channels and finally SCHOTTEL chose the company BIERENS B.V. in the Netherlands to team up.
Being a medium-sized company with a wide general experience in gear design and manufacturing BIERENS was on the way to produce large bevel gear sets in the diameter range of 1.000..2.000mm using more or less standard 5-axis milling machines.
Some essential modifications of the standard machines and the milling strategy parameters generated by a self-developed software were the key knowledge that allowed BIERENS to produce in a superior quality and within the tolerances that SCHOTTEL requires for their gears.



Pic. 2a - conventional machining with cutter head [KLINGELNBERG]



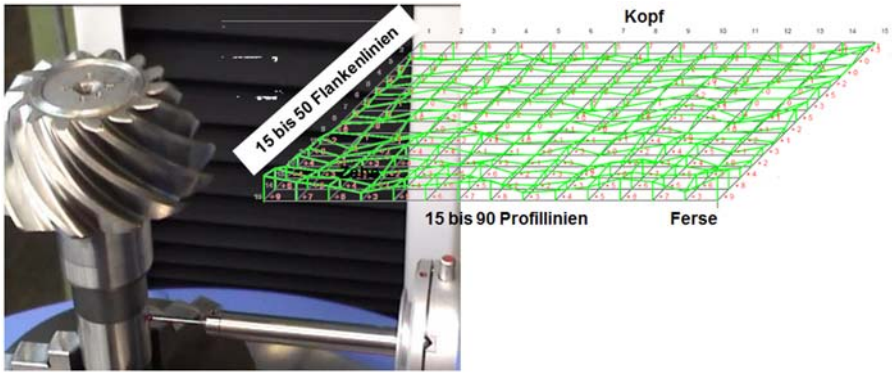
Pic. 2b - conventional machining using a bevel gear grinding machine [KLINGELNBERG]

Pic. 2c - alternative machining using the 5-axis milling process [ATA GEARS]

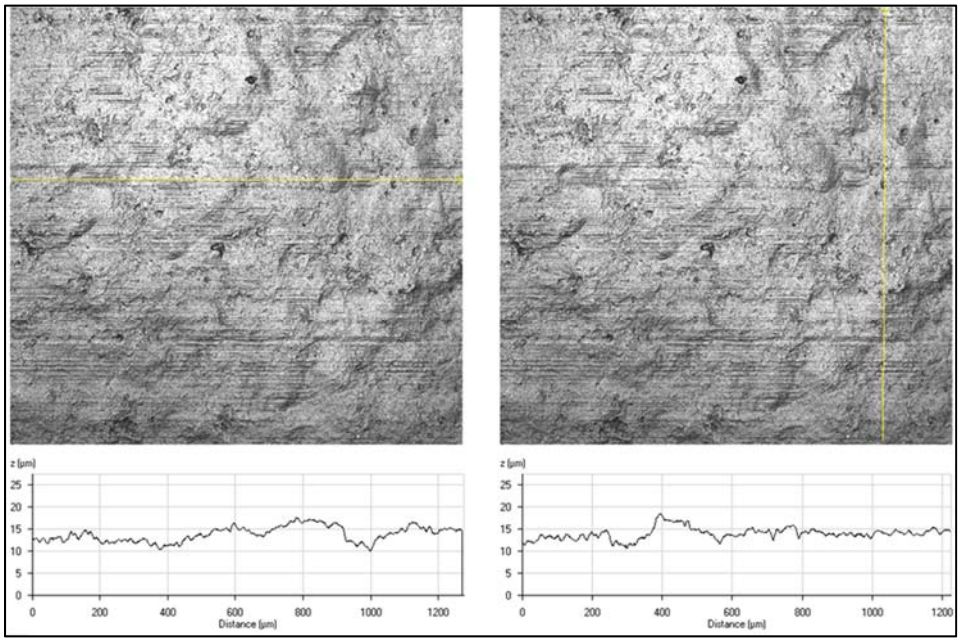
To further develop this new production method for use in SCHOTTEL thrusters an extensive know-how regarding accuracy optimization, usage of tools and cutting strategy for very large bevel gears had to be built up and BIERENS together with SCHOTTEL managed this challenge.

While the established manufacturers of such gear sets were bound to their rather large and cost extensive machine and tool equipment the new production method with its flexibility could quickly catch up and optimize.
Step-by-step over test machining, extensive measurement and both experimental and numerical tooth contact simulation the alternative machining solution was improved and brought to market fitness.
Finally, in cooperation of the companies SCHOTTEL and BIERENS and the technical university of Dresden (TU Dresden) a fully compatible "copy" of the conventionally produced large thruster gear sets could be achieved. This breakthrough was reached after only abt. two years of intensive development action and was consolidated by several subsequential research projects such as

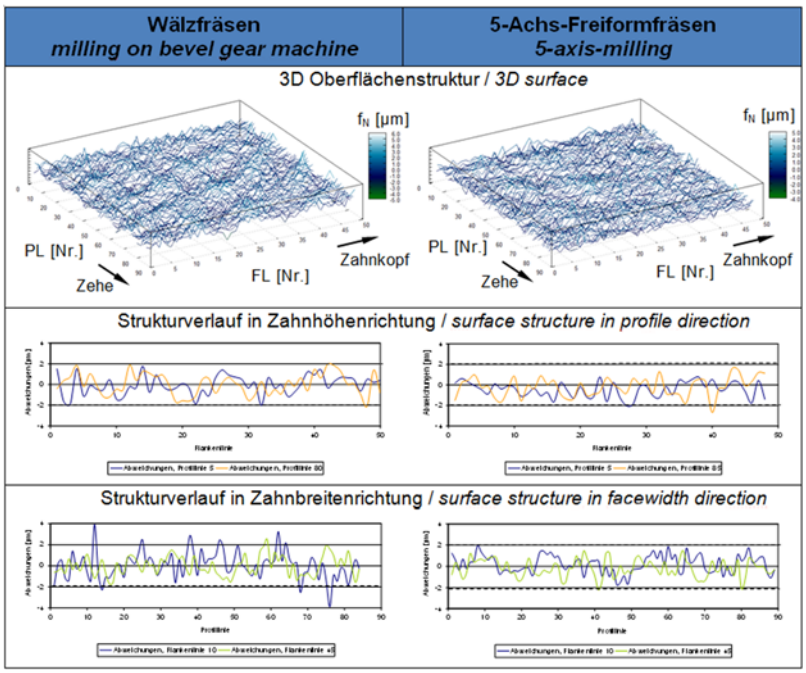
- metrological quality assurance / gear calculation with actual data
- surface measurement technology
- comparison of production accuracy data of conventional versus 5-axis machined gear sets
- software developments for tooth contact analysis
- testing technology / large bevel gear test benches



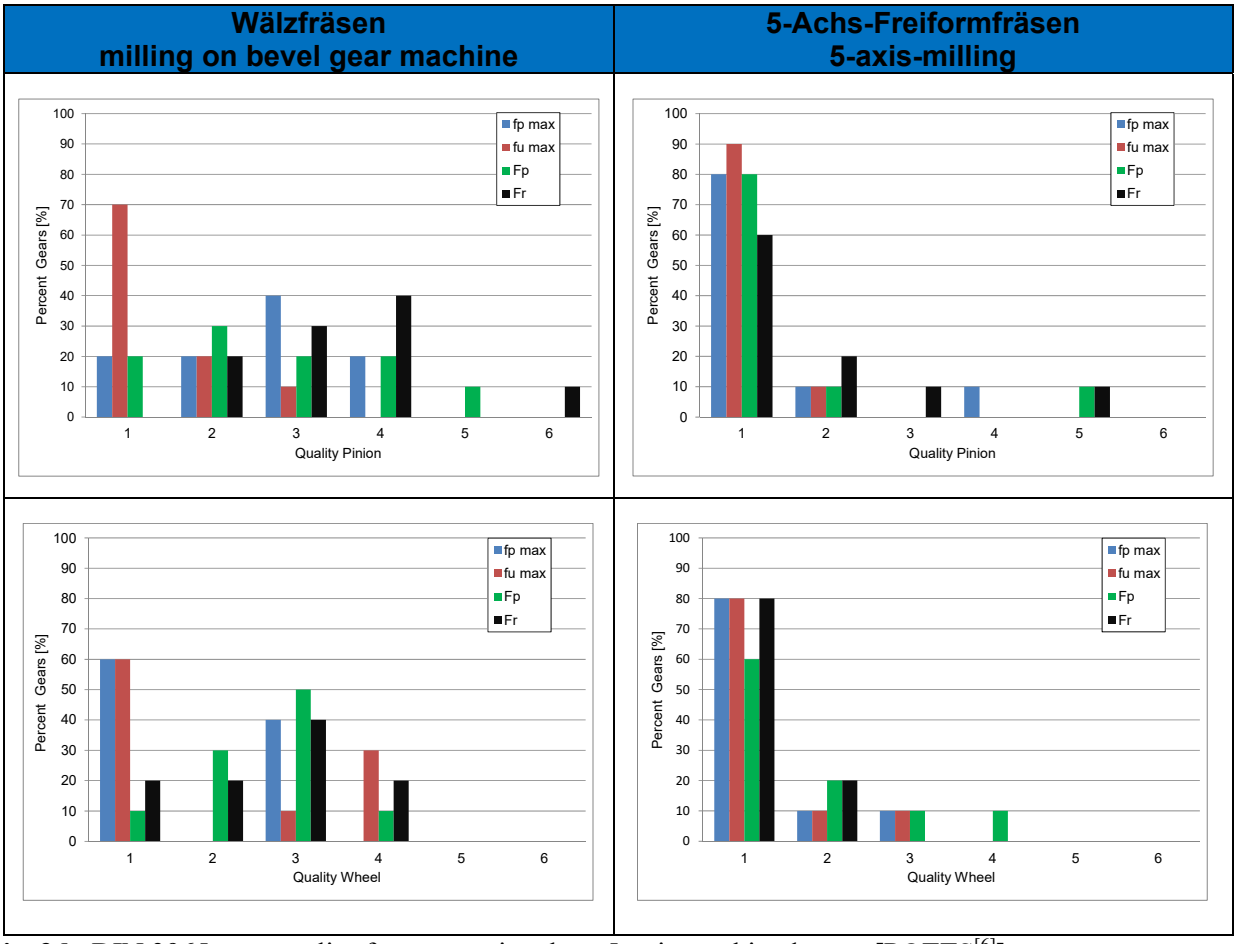
Pic. 3a – measurement grid [KLINGELNBERG]



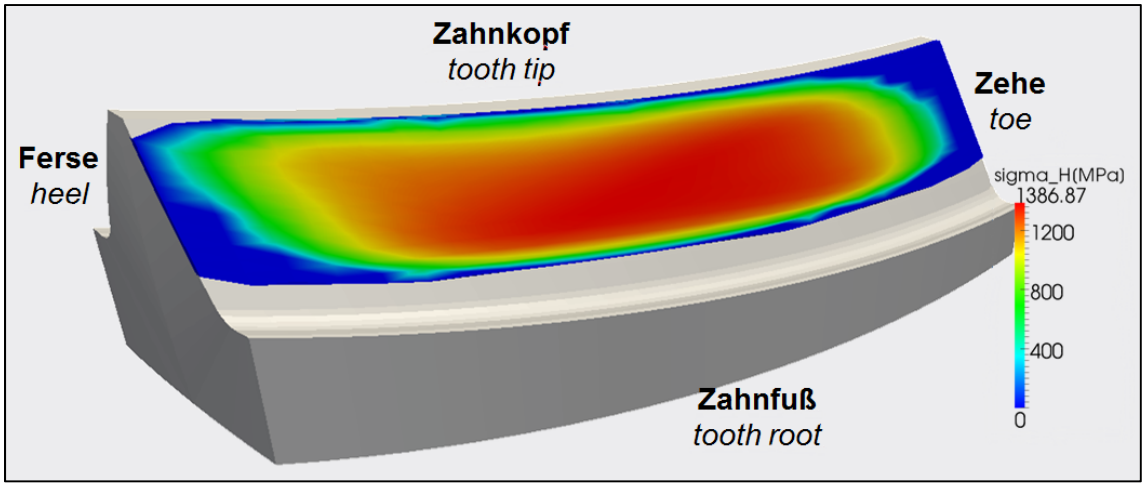
Pic. 3b - confocal laser scanning microscopy [CHEMNITZER WERKSTOFFMECHANIK]



Pic. 3c – comparison of the surface structure of conventional vs. 5-axis machined tooth flanks [POTTS[6], WOLFIEN[7]]

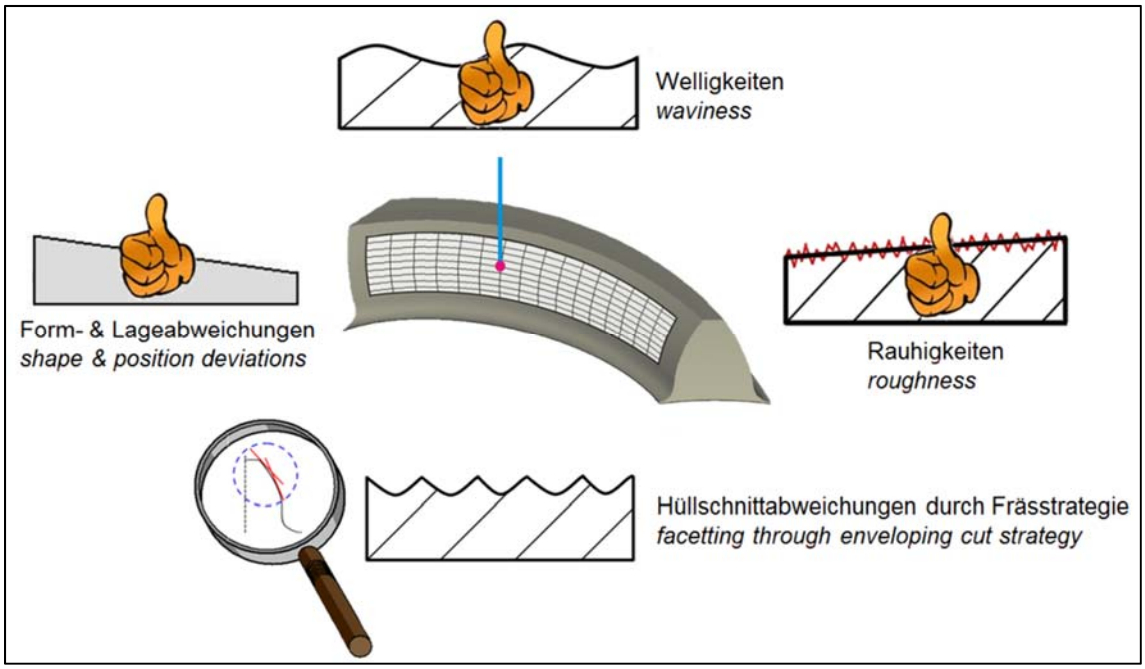


Pic. 3d –DIN 3965 gear quality for conventional vs. 5-axis machined gears [POTTS[6]]



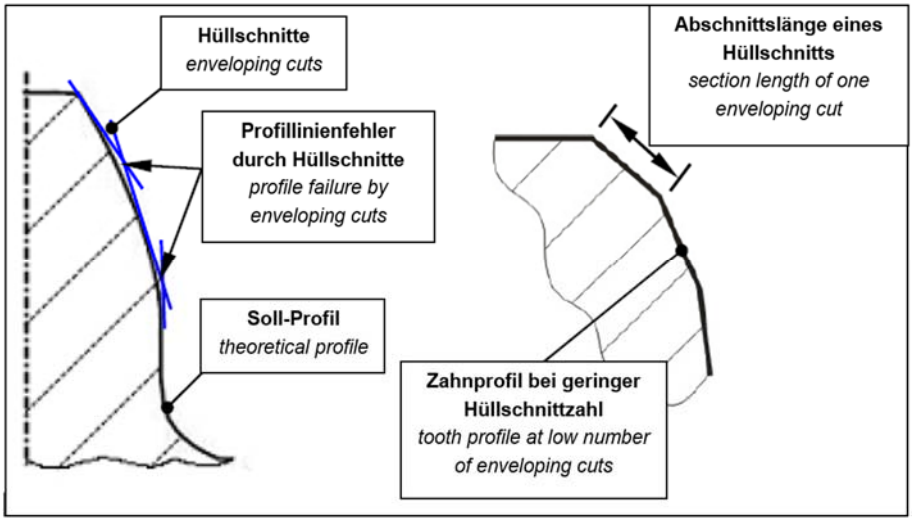
Pic. 3e – tooth contact analysis using the *GearDesigner* Software [SCHOTTEL, TU DRESDEN]

By these measures the new process was scaled and tested to fulfill the SCHOTTEL quality standards for bevel gear sets in main propulsion azimuth thrusters.
In detail almost every single step in the design and production process was touched and improved; this also includes the conventionally machined bevel gear sets which are still used in a huge number of product variants and which can now be either machined in the conventional or the 5-axis method.
Many of the findings of the 5-axis machining project could be usefully transferred to the conventional machining process.



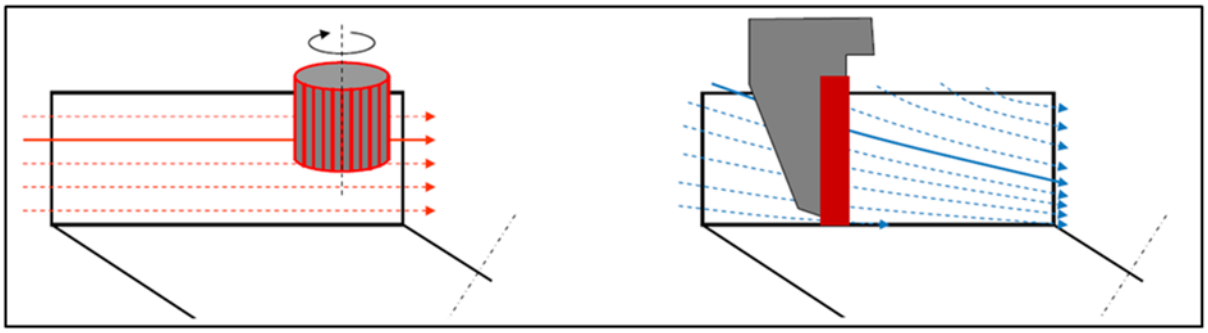
Pic. 4a – verified flank characteristics [SCHOTTEL]

Beyond the a.m. properties especially the controversially discussed influence of the enveloping cut failure was carefully examined and optimized.[9]
While the conventional "continuously dividing" processes usually deliver a high number of enveloping cuts (cutter head method) or virtually no enveloping cut failure (grinding process) the finger cutter in the 5-axis process works along the flank height "row-by-row" and such generates as many facets with determinable height (failure) as rows are chosen by the machining strategy.

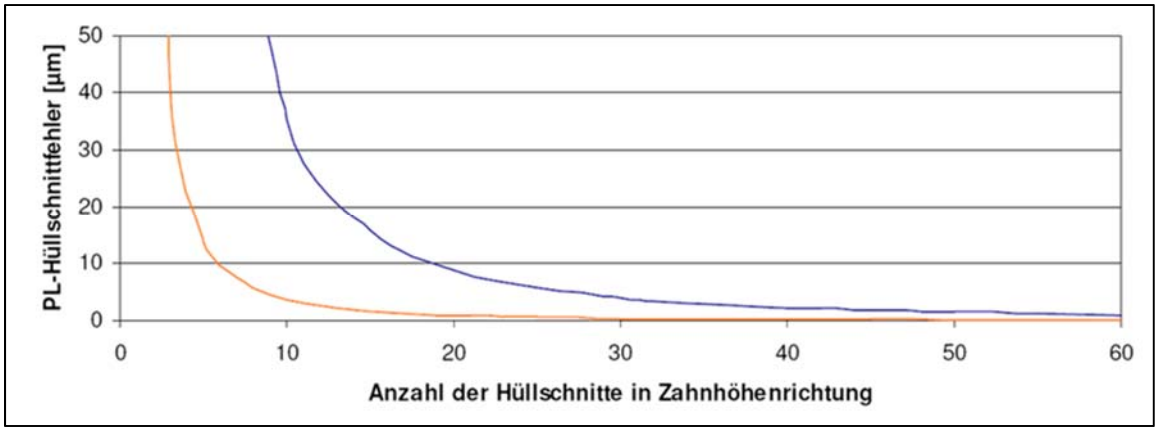


Pic. 4b – enveloping cut failure („faceting“) by tangential operation of the finger cutter [SCHOTTEL]

Because the milling cutter has a significant smaller chip performance than the structurally larger cutter head, the processing time at the 5-axis milling is generally significantly longer than on specialized gear cutting machines. In contrast the much lower machine-hour rate of the universal 5-axis machine reduces manufacturing costs; this concerns both the cost of the machine and the cost of tools.
The number of enveloping cuts executed in 5-axis milling is directly proportional to the main time of machining; this means minimizing the number of enveloping cuts increases directly the economy. Too low number of enveloping cuts leads to faceting in the vertical section of the tooth and thus in the direction of sliding movement of the engaged tooth flanks, whereby the capacity of the gearing is limited in terms of surface damage resistance.
Through extensive theoretical calculations with simulated surfaces and test runs on a tension tester in accordance with DIN 51354 optimal feasible facet altitudes could be identified which in turn allows calculating the required number of enveloping cuts for each gear taking into account the respective flank curvatures.
Considering bevel gear sets with greater translation (in rudderpropeller gearboxes typically i=2,5..4) the more curved pinion flank requires several times more cuts than the much straighter gear wheel flank.
Ultimately, this point of the critics of the new method could be dispelled through careful analysis, calculation and testing and is today automatically considered in the company´s design software for the 5-axis machining strategy.

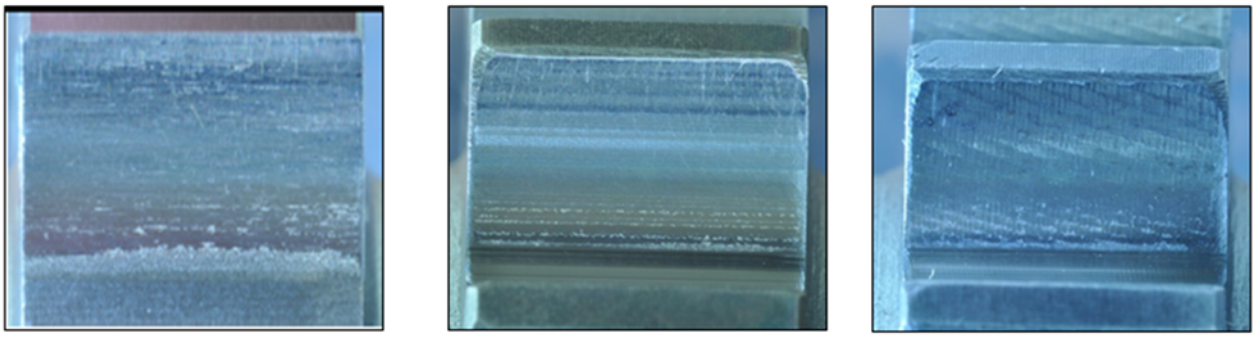


Pic. 4c – enveloping cuts 5-axis-milling / enveloping cuts conventional machine [KLINGELNBERG]



Pic. 4d – exemplary graph for the determination of required enveloping cuts (abscissa) to reach a specific facet failure (ordinate) for a bevel gear set of reduction ab. 1:3 [SCHOTTEL]

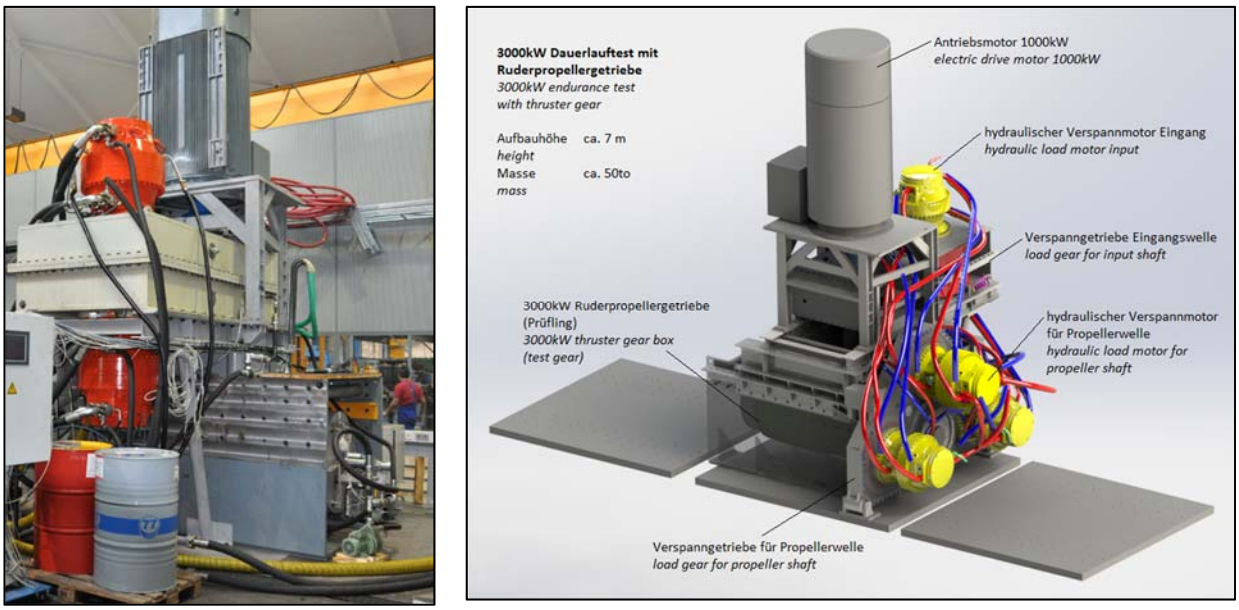
Due to the reduction ratio of the gear stage in the above example (**pic. 4d**), the pinion (drive) diameter is much smaller than the gear wheel diameter (output) and thus the flanks of the pinion are much more curved than that of the ring gear. Thus, for example, with 10 enveloping cuts on the pinion flank (blue graph) a facet failure of almost 40 microns occurs while with the same number of enveloping cuts a failure of only 4 microns can be achieved for the gear wheel flank (orange graph).
Knowing these facts to achieve an optimized processing time and thus to increase the profitability of the process is of fundamental importance. Impermissible large enveloping cut failures express themselves e.g. in increased gray staining damage risk (micro pitting of the tooth flank).
By extensive studies the permissible envelope cut deviation to achieve the standard required micro pitting safety could be theoretically found by calculation and proven in respective tests.
From the stifling shortage of large bevel gears an increased supply source with high quality potential could be generated just in the continued sustained growth phase.



Pic. 4e – micro pitting test of conventionally ground gear sets in comparison to milled gear sets with different machining direction [TU DRESDEN, POTTS[6]]

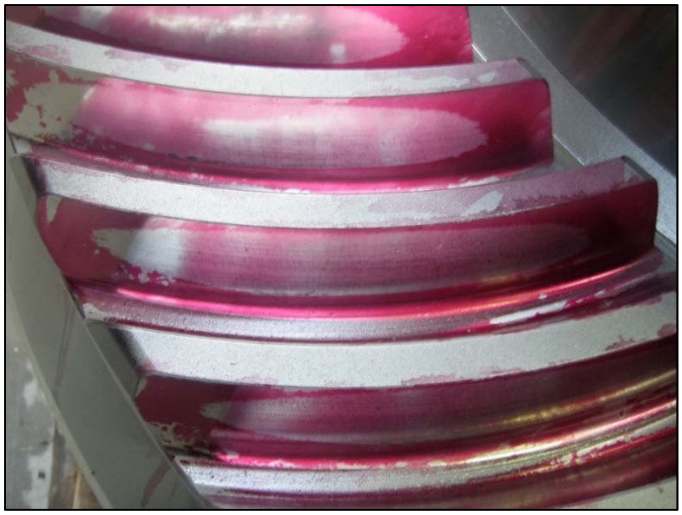
Chapter 2: Success makes hunger for more success – development of the HTG gear technology

From 2007 SCHOTTEL steamed ahead with increased dynamics. Taking the lead of the company management Prof. Dr. Gerhard Jensen gave more weight to the success factor „technology“ also expressed by the new company slogan „*Your experts in propulsion technology*!“.
An example for this new corporate slogan´s attitude was applying for a comprehensive funding project entitled "High torque gear for rudderpropellers." which was promoted in the period 2008-2011 by the Investment and Economic Development Bank of Rhineland-Palatinate (ISB) and was very successfully performed by the company´s development team together with further partners.
In the course of this project, and also during the subsequent further cooperation with the Technical University of Dresden, based on the outset production optimized 5-axis bevel gears with conventional macro and micro geometry new tooth geometries and studied topographies were developed and ultimately tested in the scale of a 3500kW offshore thruster gear.
A major objective of this development project was to increase the operational reliability of large rudderpropeller gearboxes, which are increasingly being used with extraordinary high annual operating hours and extended service intervals.
Therefore, already at an early stage in the project, tests with rather large test gears whose production and testing was associated with enormous effort were carried out.



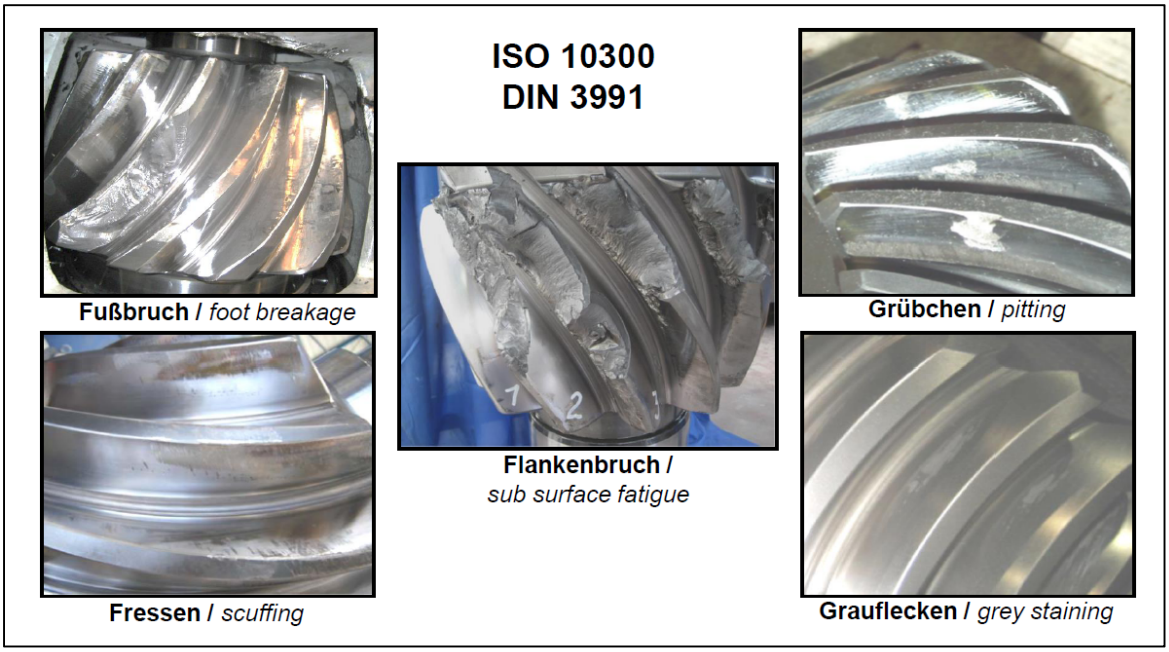
Pic. 5a - test setup of a 3500kW full power test bench [SCHOTTEL]

The results of this research were so promising that further co-operation projects have been initiated with the participation of development engineers of the SCHOTTEL locations Spay and Wismar and the “Institute for Machine Elements and Machine Design” at the TU Dresden under the direction of Prof. Dr. Berthold Schlecht.
Based on the meanwhile reached excellent performance in production of standard bevel gears, with a very high manufacturing quality of typically DIN3965 Q4, several new gearing characteristics have been conceived and studied mathematically in the period up to ab. 2011. These new features were specially tailored to the requirements of power transmission in the rudderpropeller.



Pic. 5b – loaded contact pattern of a 3500kW thruster gear; the relatively low contact width is exceptionally intended for this application [SCHOTTEL, ISB Fördervorhaben „Hochdrehmoment-Ruderpropeller“, 2011]

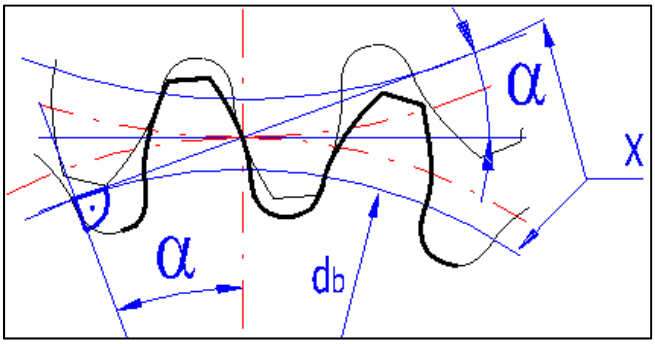
Under the company's internal identifier **HTG** (high-torque gear) further features of the thruster gear sets of the future were developed taking advantage of the virtually unlimited design possibilities of the 5-axis milling process which aimed for significant performance improvements and for increased safety gains. So, a total of 7 independent beneficial gearing characteristics were defined and analyzed.
Therein the main objectives were the optimization of the production quality, the reduction of production cost, increasing the load capacity and the targeted increase of individual safety values of the teeth against the failure modes of foot fracture, pitting, sub surface fatigue, scuffing and micro pitting (grey staining). On the next pages some of these new features shall be exemplary explained.



Pic. 6 – typical types of gear damage of a bevel gear set [SCHOTTEL]

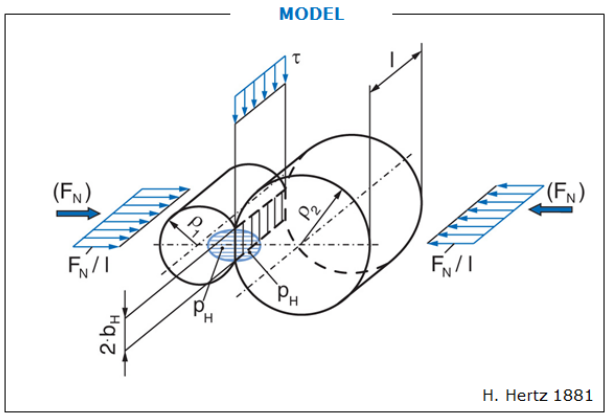
Chapter 3: Feature „asymmetric pressure angle“

In the conventional production of bevel gears on special machines with cutter head or grinding cup tools usually standardized symmetrical pressure angles are applied, normally the load flank and coast flank have the same pressure angle. The pressure angle indicates the steepness of the flank of the bevel gear.



Pic. 7a – pressure angle α [MITCALC]

A certain standardization (typically α = 20°) is required to limit the number of different tools and hence to guarantee the economic production of these manufacturing processes.
By varying the angle α towards larger pressure angles, so increases the active flank area.This positive effect of a gain in flank surface is lessened by the negative effect of an increased normal tooth force resulting from the unchanged transmitted torque.
Mathematically an optimal pressure angle could be found at 45° using the formula below (Hertzian Pressure). [9],[10],[11]



Hertzian Pressure

$$p_H = \sqrt{\frac{F_N \cdot E}{2\pi \cdot (1-\nu^2) \cdot l} \cdot \left(\frac{1}{\rho_1} + \frac{1}{\rho_2}\right)}$$

$$\rho_i = r_{wi} \cdot \sin(\alpha_w) \Rightarrow \left(\frac{1}{\rho_1} + \frac{1}{\rho_2}\right) = \frac{r_{w1} + r_{w2}}{r_{w1} \cdot r_{w2} \cdot \sin(\alpha_w)} \sim \frac{1}{\sin(\alpha_w)}$$

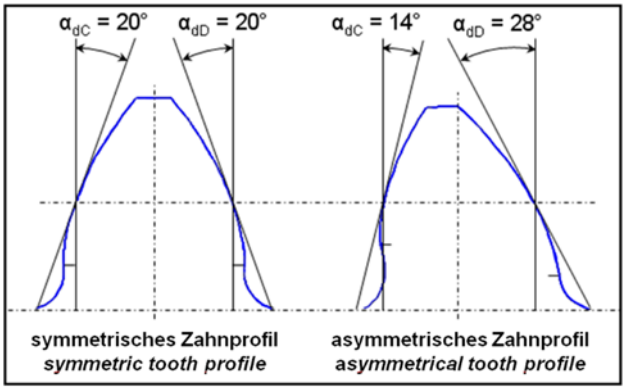
$$F_N = \frac{F_{wt}}{\cos(\alpha_w)} \sim \frac{1}{\cos(\alpha_w)}$$

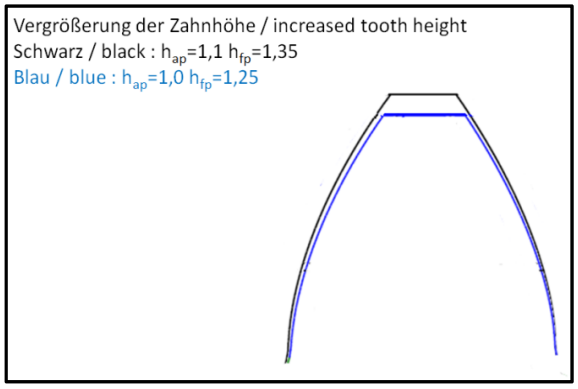
$$p_H = C \cdot \sqrt{\frac{1}{\cos(\alpha_w) \cdot \sin(\alpha_w)}} = C \cdot \sqrt{\frac{2}{\sin(2 \cdot \alpha_w)}}$$

$$p_H(\alpha_w = 45°) \rightarrow \text{minimal}$$

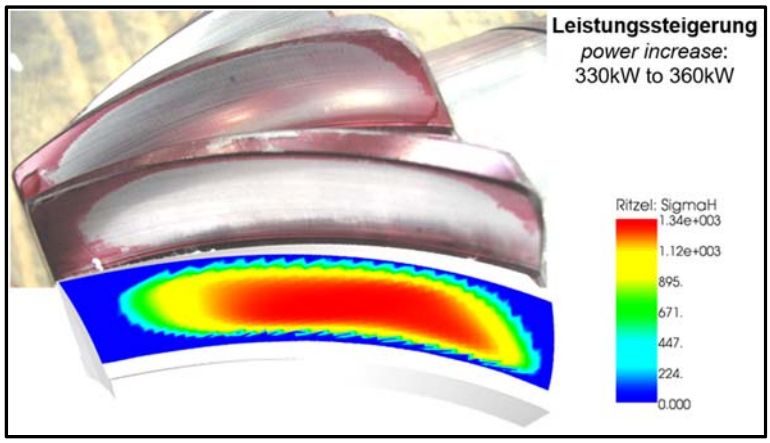
Here F_{wt} is the tangential torque-forming force, l is the tooth width, α is the pressure angle to be optimized, ρ are the equivalent radii of curvature of the engaged tooth flanks.
However, taking into account all relevant parameters of the tooth contact simulation of the real thruster gear a practical optimum can be found more in the range of 28..32°.
These parameters include primarily the dimension determining parameters for sub surface fatigue, pitting, scuffing and micro pitting (grey staining).
With the kinematic freedom of the 5-axis milling any pressure angle of the load flank and even varying pressure angles over the tooth width can be machined.
Thus the feature asymmetrical tooth flank increases the load capacity of the gear set without increasing the external dimensions of the gears.
Another positive effect is the reduction in the global surface sliding speed at the beginning and end of the tooth engagement. The increased pressure angle changes the tooth engagement "from sliding more toward rolling" and this has a positive effect e.g. on the scuffing safety.

The effect of reduced surface sliding speeds is so serious (e.g.: approximately 20% reduced sliding speeds) that the tooth height can also be increased without risk of excessive friction load. This additional area then gains even more torque capacity and/or safety can be further increased.





Pic. 7b left – comparison of symmetrical and asymmetrical tooth [SCHOTTEL, POTTS/SCHAEFER[9]]
Pic. 7c right – increased tooth height [SCHOTTEL]



Pic. 7d – comparison of real and simulated contact pattern of asymmetrical HTG-toothing [SCHOTTEL, POTTS/SCHAEFER[9]]

The performance increase achieved in practical applications of asymmetric thruster bevel gears amounts to approximately 15% at constant safety factors!
The clear asymmetric tooth shape results from the combination of an increased pressure angle of the load flank and a reduced pressure angle of the coast flank.
The latter is necessary because at constant diameters of meshing gears a flatter load flank cannot be achieved without an equally steeper coast flank, otherwise the teeth would not fit around the pitch circle circumference.
In the rudderpropeller application this restriction, however, is of no importance; the rudder propeller as 360° controllable drive unit (azimuth drive) may steer its thrust in any direction without reversing the propeller turning direction.
So the thruster always uses the right and thrust optimized direction of rotation of the propeller and now also the load optimized direction of rotation of the bevel gear.
Provided that the utility of the HTG technique is converted into a reduction in diameter of the gears, in addition, a slimmer gearbox nacelle can be realized with further hydrodynamic advantages.

Chapter 4: Feature „free flank modification“ (logarithmic crowning)

The above-mentioned asymmetry is a macro geometric feature of the teeth. A much more complex approach was to design and implement a further idea of the SCHOTTEL engineers. The "free flank topography modification" with the aim of optimizing pressure distribution on the tooth surface with reduced maxima. [9],[11]

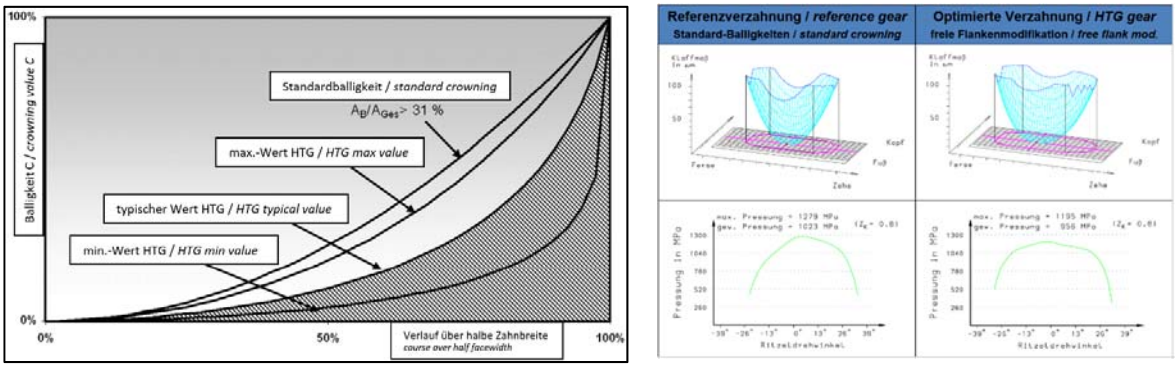
Principally it should be noted that the gear bodies, in particular in the thruster application, remain in no way fixed on their axes of rotation. The underwater gear transmission of an azimuthing propulsor is a supporting component and has to carry the mighty ship propulsion and steering forces.

Consequently, it is subject to considerable deformations and displacements of the elastic steel structure, which have an adverse effect on the tooth contact.

Therefore calculation possibilities were created in software development that capture the tooth contact analysis of micron exactly mathematically defined tooth flanks taking into account the deformation of the shaft-bearing-system and the housing.

By means of parametric studies typical operating conditions were analyzed and appropriate flank topographies were developed and described mathematically.

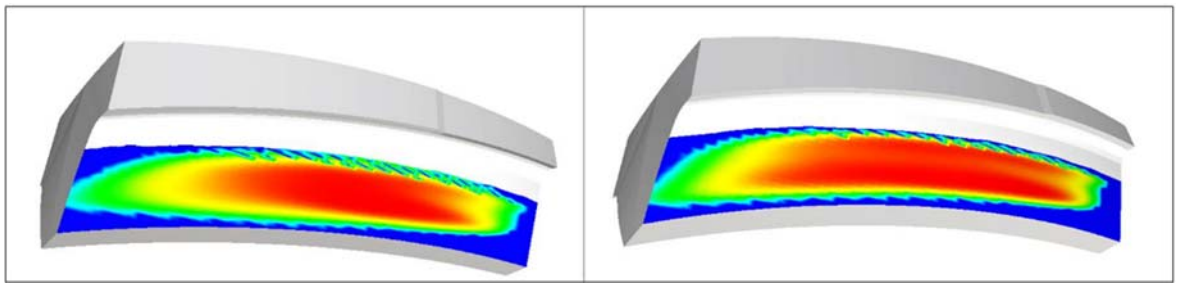
The resulting “3D point cloud”, a micron precisely defined grid describing the real tooth flanks, is the output of the software and is also the direct CNC manufacturing specification to the 5-axis milling machine; there the designed tooth topography is precisely cut into the 700HV hard tooth surface.



Pic. 8a – qualitative comparison of the flank modifications of standard vs. HTG gear [SCHOTTEL]
Pic. 8b – flank topography „ease-off“ of the standard vs. HTG toothing [SCHOTTEL]

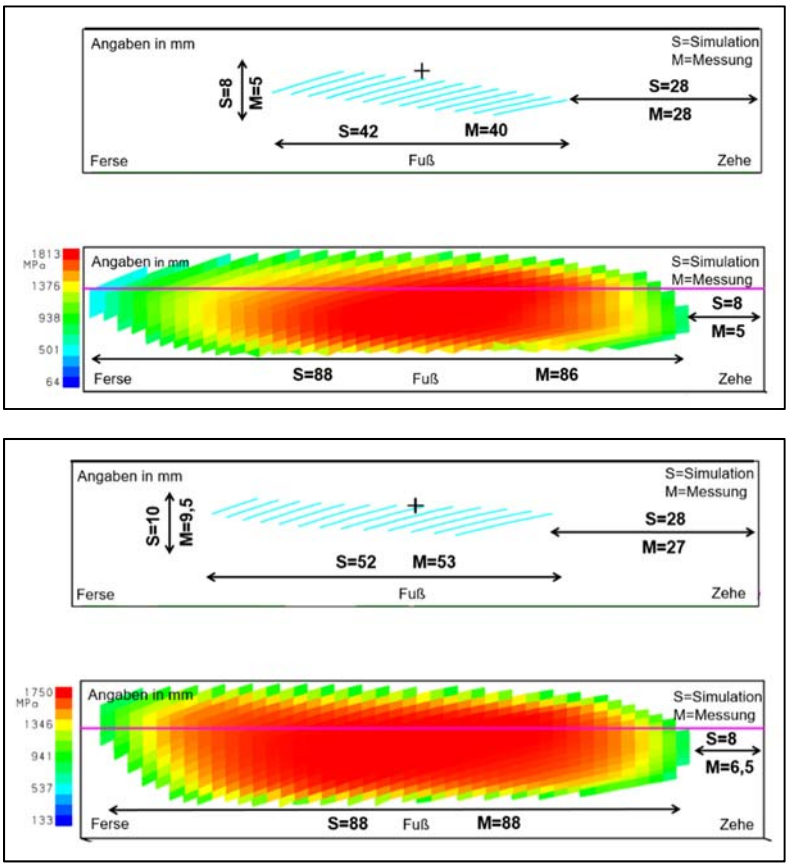
In combination with an asymmetric base shape of the bevel gear toothing a theoretical performance improvement in torque load capacity of up to 30% can be proven!

In practical terms, a combination of performance and safety enhancement is normally chosen. Therefore, performance increases of 5..15% were realized in the previous applications but even stronger gears will follow in the near future.



Pic. 8c – comparison of pressure distribution achieved by free flank modifications left standard toothing / right HTG toothing [SCHOTTEL,TU DRESDEN[12]]

Using the *GearDesigner* software developed in cooperation with the TU Dresden the gear design engineer receives a powerful evaluation tool which allows targeted modification and optimization in a balanced security for all of the above shown damage characteristics.
The software supports the developer by recommending proven parameter combinations. The tooth surface can be modified using given stored supporting curves (in particular logarithmic & elliptical curvatures) which form the flank specifically in width and height direction. By suitable modifications the highly-loaded center of the flank is relieved and the zone of high pressure falls more flat in direction of the flank edges. Pictorially speaking the standard flank topography is flattened like a cushion.



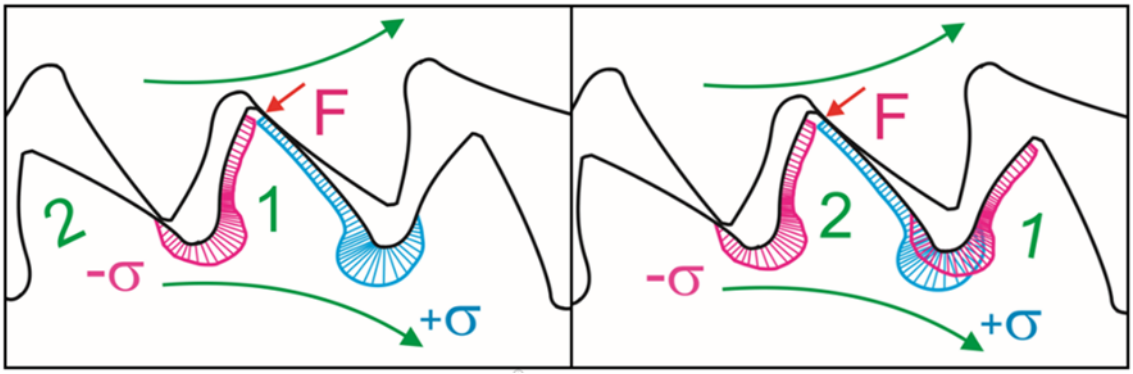
Pic. 9 – contact pattern development, comparison of load free and loaded patterns
standard crowning (top) vs. log. crowning (bottom) [SCHOTTEL, POTTS[6]]

For bevel gear sets of transverse thrusters with monoblock propellers (molded from a single piece propeller) the feature of the free flank topography modification is of particular importance.
With these drive systems the thrust direction can only be changed from starboard to port side and vice versa by changing the direction of rotation of the propeller.
This means the bevel gear is operated with both directions of rotation and, consequently, on both flanks of each tooth.
Therefore an asymmetrical toothing is not possible and the free flank topography modification remains as the relevant performance and safety enhancement measure possibly even combined with an increase in the tooth height. Here another advantage of the 5-axis milling can be used; both flanks can be individually designed because the machine shapes the flank topographies independent from each other, different from the standard bevel gear milling machine.

Chapter 5: Feature „adapted foot curvature, e.g. elliptical foot curve“

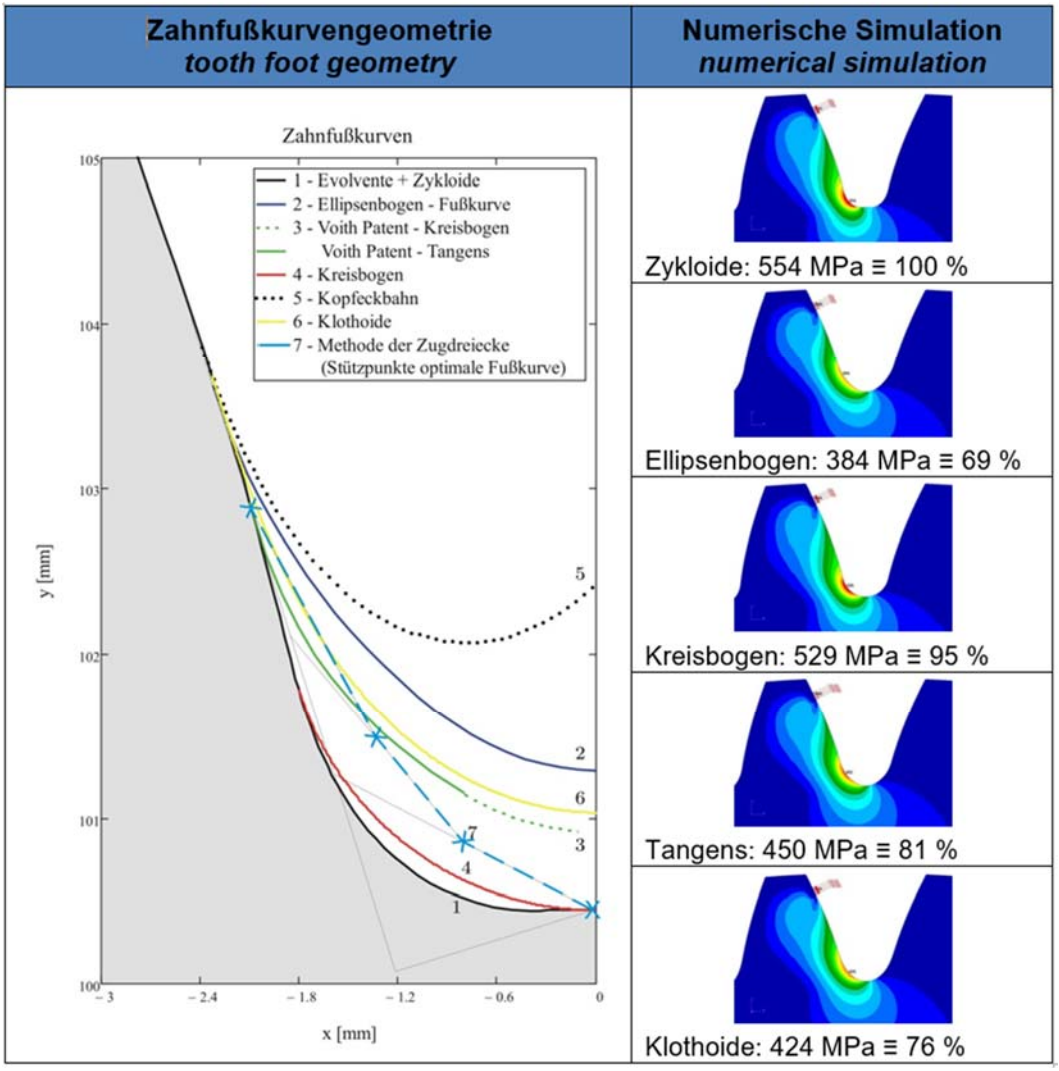
As already shown the aforementioned damage risks of sub surface fatigue, pitting, scuffing and grey staining can be reduced and aligned through targeted design strategies using asymmetry and the free flank modification. However the so far uncritical criterion of foot breakage is negatively affected by the asymmetric tooth design with its sharper tooth ground and its wider pressure distribution which is the design result of the overall higher tooth force of the HTG gear set. So the higher load on the flank area may cause problems in the notch of the foot radius.

Pic. 10a – foot breakage of a bevel gear toothing [SCHOTTEL]



Pic. 10b – increased alternate bending stress in the foot ground of the asymmetrical toothing [SCHOTTEL,POTTS/SCHÄFER[9]]

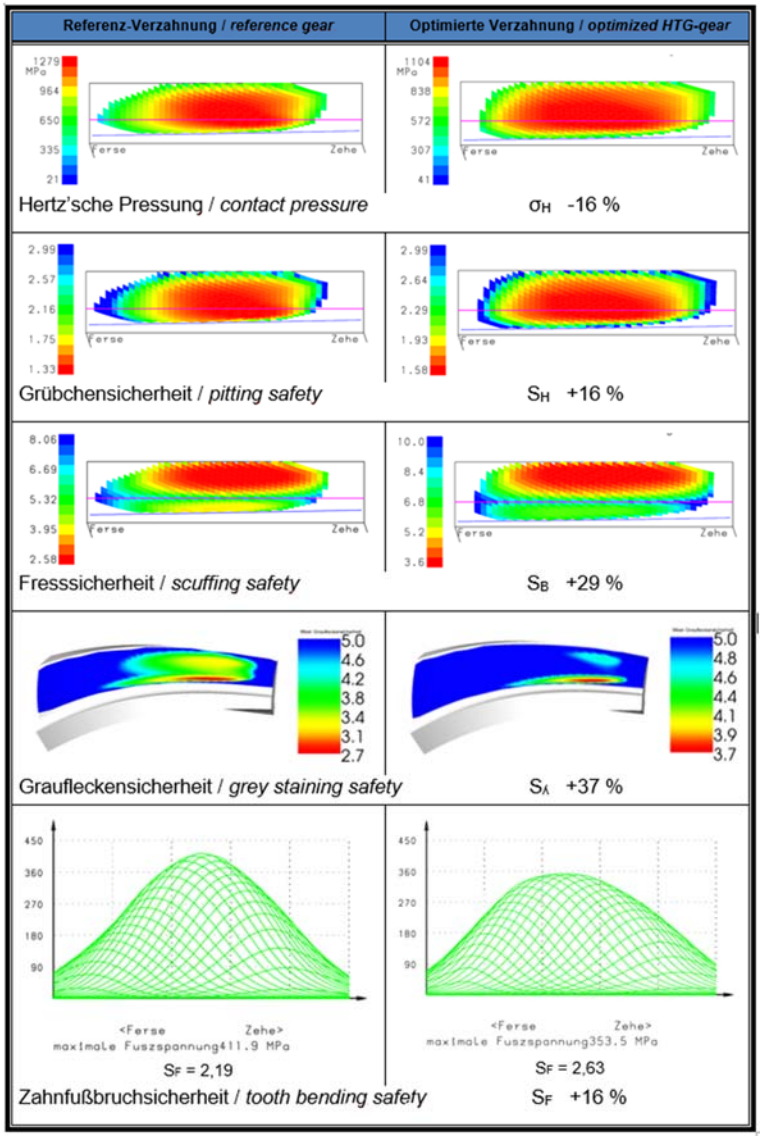
The measure against this higher alternating stress load is however simple using the geometric freedoms of 5-axis gear milling.
The given standard tooth foot radius, which is inevitably formed by the cutter head radius of the generating standard tools, can be replaced by suitable tooth foot curves of any shape with lower notch effect because in the 5-axis process even the foot curve consists of multiple cutting movements of a finger cutter or ball shaped cutter. [9]
In earlier studies, especially for standard cylindrical gears, means to increase the load capacity of the tooth foot were already examined.
Corresponding publications give recommendations for appropriate foot curves. These include for example tangent or elliptical foot curves which are known from the literature (e.g. Mattheck, VOITH, Linke, etc.) [1],[2],[3].
In principle all these three named foot curvatures offer sufficient stress reduction potential to compensate the notch effect in the tighter foot ground of the asymmetrical HTG toothing.[9]
So, using one of these favorable shapes makes the tooth foot totally uncritical again.
In the *GearDesigner* software, after final design of the macro and micro geometry of the teeth, the calculation engineer can check for the tooth foot stress load and safeties and then simply applies an appropriate size of foot curvature; in most cases an elliptical shape is chosen.
The following comparison shows the stress reduction potential of the various possible foot curvatures of similar dimension.



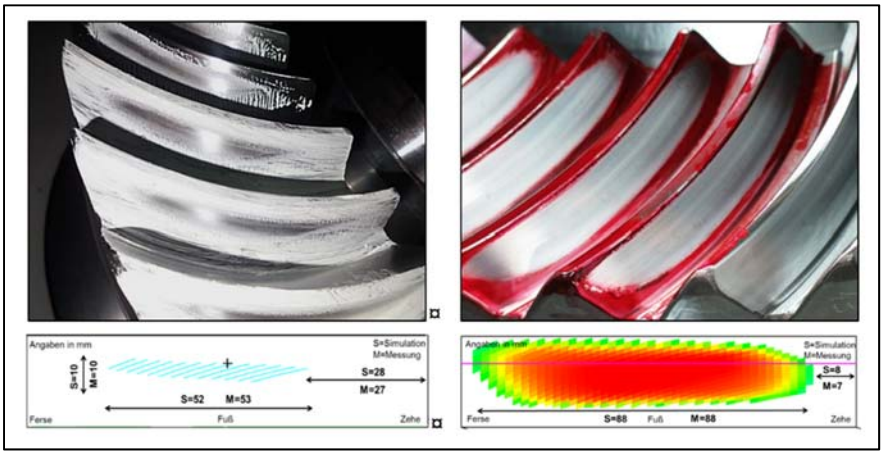
Pic. 10c – stress reduction potential by the elliptic foot curve of the HTG toothing [SCHOTTEL, TU DRESDEN]

Further to the a.m. three features of asymmetrical tooting, free flank modification and alternative foot curves several other unique modifications can be used thanks to the new machining method. SCHOTTEL uses these various modification features of the HTG gear technology in different ways. Depending on the objectives in the product development or product improvement process selectively targeted modifications are applied. Safeties can be increased, higher powers can be achieved or gear dimension can be reduced to reach hydrodynamically favorable forms.
Also other known beneficial technologies such as the shot peening of the tooth root and the vibratory grinding of the tooth flanks are often used in combination.
But ultimately all these efforts serve one purpose; to increase the customer benefit of the SCHOTTEL product and to strengthen the value of SCHOTTEL´s claim to be:

“Your propulsion experts!”



Pic. 11a – load and safety parameters of an optimized rudderpropeller gear stage [SCHOTTEL, POTTS[6]]



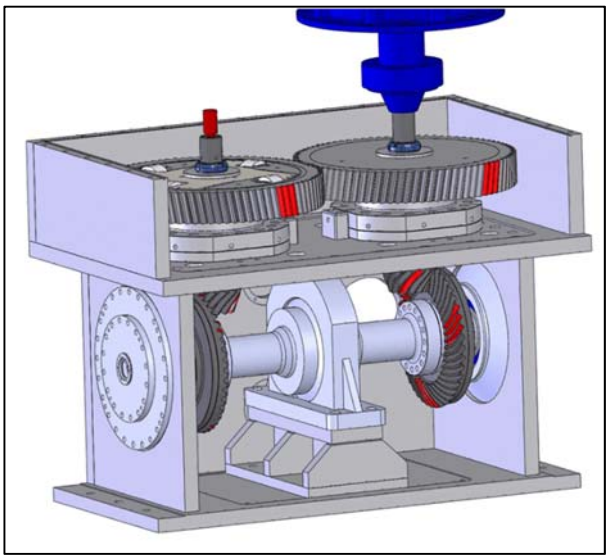
Pic. 11b – typical no-load and loaded contact pattern of a HTG flank at high load [SCHOTTEL]

Patent rights achievements

This article describes some of the many novel features of the innovative HTG toothing technology. However, in particular the combination of asymmetry and defined free flank topography modifications of the tooth flanks offers such a huge increase in performance that patent applications have been made for these and other features worldwide.
Today the HTG toothing enjoys patent legal protection in many countries around the globe. Patents have already been granted for Europe, Japan, USA, China, Korea, etc. Other national applications are in the verification process or close to be issued. [4]

Practical experiences

From the beginning of the project it was clear, that such a high increase in performance could not be placed in the market without extensive testing to verify the theoretical studies.
In addition to various tests on standard gear testing machines the new gears were in parallel tested in different sizes since 2011.
In a common action of the R&D department at SCHOTTEL, Spay and at TU Dresden, tests were carried out on different own-developed test machines in the power range up to about 2000kW.
Here, all essential test parameters such as torque, speed, oil temperature and purity, vibrations (online-FFT) are permanently monitored and recorded for later evaluation.



Pic. 12a & b – gear tester „Hellbox“ / section through computer model and real machine [SCHOTTEL]

Pic. 12c – test setup of closed loop tension test at TU Dresden [TU DRESDEN]

In many years of test series with specifically modified gear set batches all the essential characteristics of damage could be checked and comparatively tested with standard gears under controlled conditions. The main testing phase lasted from ab 2011 to 2015.
The parallel test program with structurally different test setups and in different scale in Spay and Dresden allows an independent assessment of the achieved performance increases.

Pic. 13 – intentionally produced sub surface fatigue damages (SCHOTTEL *hellbox*)
[SCHOTTEL, POTTS[6]]

Based on these experimental findings technically safe pilot series of HTG-equipped thrusters were put into use from 2013 onwards. These were brought into deliberately selected harsh applications where conventional bevel gears were used to their performance limit.
Today HTG bevel gears can be found in a variety of SCHOTTEL products, both in new developments and in proven products which have been upgraded in the wake of ongoing product maintenance. HTG is a registered trademark and the unique characteristics of HTG technology are protected by international patents.
A current focus of development is also that HTG technology can be produced on conventional bevel gear machines (cutter head and cup grinding wheel machines) of the actual machine generation.
For this first successful productions have been performed. It is foreseeable that by the end of 2016 an overall production possibility for such gear sets over the entire size range is available and thus the performance of the new toothing will be combined with the productivity of the most modern specialized gear production machines. Through this development step, the HTG technique will be generally useable.

„HTG = more power at higher safeties“

The HTG technology carries the unstoppable success of the SCHOTTEL rudderpropeller also in the Offshore propulsion market. More intensive use of the propulsion systems close to a 24/7 operation, harder because more precise DP applications (dynamic positioning), more global mission profiles of the ships and at the same time the demand for extended servicing intervals required measures at the core component of the azimuth thruster.

HTG technology is the answer to these requirements and so it is logical that the latest product development of the SCHOTTEL Group, the Ecopeller series, is equipped with the current state of the art design of HTG gear technology. In addition to the HTG technology this new rudderpropeller series combines all the essential technical product innovations in recent years in a premium product:

- the **HTG** gear technology
- the **Combidrive** e-motor-concept in which a water jacket-cooled, extremely silent and efficient induction motor is very compactly integrated into the rudderpropeller drive
- the latest generation of sealing technology for propeller shaft and azimuth shaft with sealing solutions for bio-oils and alternatively controlled leakage discharge systems
- etc.

SRE s*ilent.robust.efficient.*

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EP 2 545 299 B1 Optimierte Balligkeiten bei Kegelradzahnrädern eines Kegelradgetriebes

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