# Good Things Need Some Time

Content:



It began more than 100 years ago: The story of skiving. On March 1st, 1910, Wilhelm von Pittler registered a patent which was to revolutionize the manufacture of internal gears.

KAISERLICHES PATENTAMT.

AUSGEGEBEN DEN 16. FEBRUAR 1912.

PATENTSCHRIFT

— № 243514 —

KLASSE 49 *a*. GRUPPE 51.

GEORGE ADAMS IN LONDON UND DIE RECHTSNACHFOLGER DES IN LONDON VERSTORBENEN WILHELM VON PITTLER.

Verfahren zum Schneiden von Zahnrädern mittels eines zahnradartigen, an den Stirnflächen der Zähne mit Schneidkanten versehenen Schneidwerkzeuges.

Patentiert im Deutschen Reiche vom 1. März 1910 ab.

KLINGELNBERG

His patent for skiving with the title "Procedure for the cutting of internal gears by means of a internal gear-like cutting tool on which the faces of the teeth are provided with cutting edges" was initially reminiscent of the method for shaping internal gears that was already known at the time. The truly revolutionary aspect of this idea required a second look.

**Differentiation from shaping and hobbing**

With shaping, the cutting movement is generated by means of the stroke of the shaper cutter in an axial direction, which rotates the workpiece and the tool somewhat further in accordance with the number of their teeth during the oscillating stroke movements. The tool is pulled back from the workpiece in a radial direction to an extent sufficient to ensure a collision-free return stroke. All in all, this results in an interrupted cutting movement of the shaper cutter. Because of the return stroke, during which no cutting takes place, this shaping of cylindrical gears always involves a time loss.

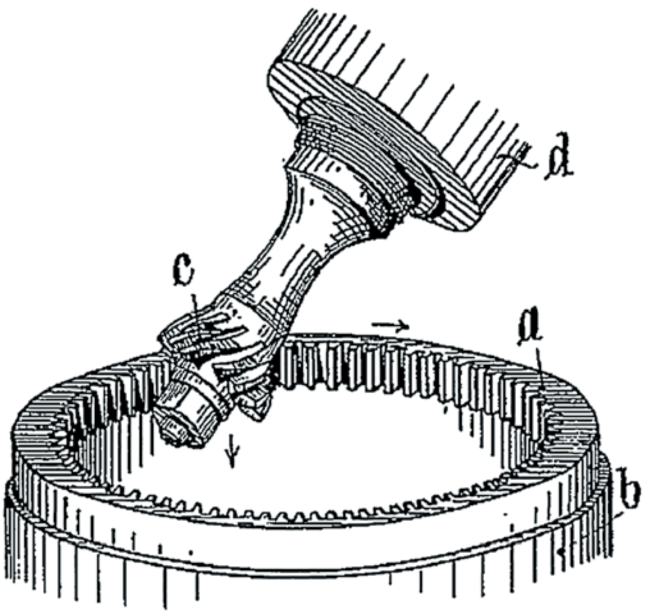



*Fig. 1: Patent application of Wilhelm von Pittler and sketsch, 1910*

Approximately 50 years prior to the invention of skiving, Christian Schiele obtained a patent for a screw-shaped hob for the manufacture of cylindrical gears, the predecessor of the hob. The advantage of this procedure lays in its enormous productivity. Even though the manufacture of such tools was not simple, the short processing times and the high quality of the gears manufactured in this fashion were convincing enough to ensure that hobbing became the established standard toothing procedure for cylindrical gears.

Unfortunately, hobbing can only be applied to external cylindrical gears. In order to produce rings with internal gearing, even today one is still forced to rely on broaching, form cutting or shaping. It is precisely at this point that skiving opens up new opportunities. An internal gear with cutting on the abutting face is used as the tool. In contrast with shaping, however, the cutting movement is not generated by an oscillating stroke movement. It is far more the case that the intersecting axis alignment of the tool and workpiece creates an axial relative speed which makes the cutting movement possible. During the rotation of the tool, each cutting edge cuts through different tooth depths on the workpiece – a movement which is required for the cutting process. The intersection of the axes accounts for the fact that the helix angle of the tool and the helix angle of the internal gear to be manufactured differ by the amount of the axis intersection angle (see Fig. 1 sketch). Von Pittler thus developed a continuously revolving toothing process which can drastically increase productivity for internal gearing. As a basic rule, skiving makes it possible to generate any kind of periodic structures on axially symmetrical lateral areas.

Fig. 2 shows the degrees of freedom of the kinematics of skiving. In addition to this gradient for the axis intersection angle, there is also a tilting angle, the gradient of which proceeds perpendicular to the axis of rotation of the tool and perpendicular to the gradient for the axis intersection angle. With this tilting, a relief angle is achieved between the tooth flanks of the tool and the tooth flanks of the workpiece, which can also be referred to as the kinematic relief angle. In addition, two linear offsets are required. On the one hand, the distance between the workpiece axis and the tool axis must be adjusted, and on the other hand, the tool must be traversed along the workpiece axis. This traversing of the tool along the workpiece axis requires a rotation which overlaps the tool rotation or the workpiece rotation which is dependent on the axis intersection angle. It is usually referred to as differential speed.

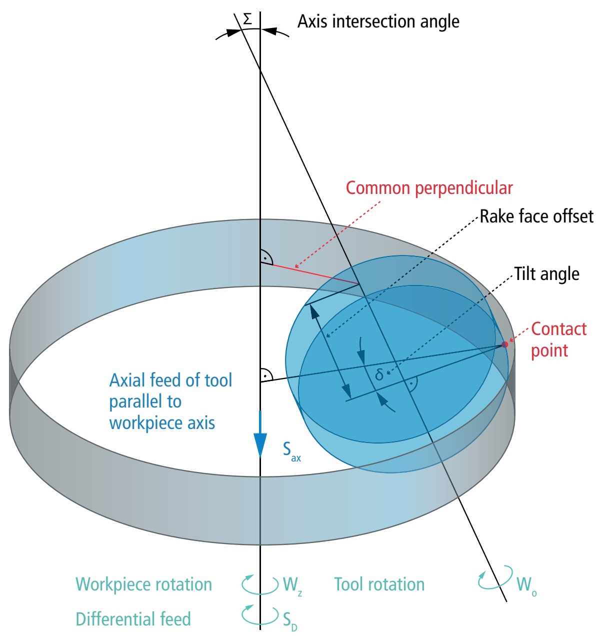



*Fig. 2: Kinematics of the skiving process: The intersecting axis arrangement is achieved by a tilting around the distance of closest approach and base points of the perpendicular of the axes of tool and workpiece.*

**Classic tools for skiving**

In accordance with the idea contained in Pittler's patent, shaping cutters have been used for skiving in the past. This becomes particularly evident when the tool is a straight-toothed cylindrical cutting wheel. The axis intersection angle must then correspond precisely to the helix angle of the internal gear to be manufactured. Such tools can therefore only be utilized if the helix angle of the internal gear to be manufactured is sufficiently large. The cutting profile must be adjusted in accordance with the helix angle. Because of the cylindrical contour of the cutting wheel, it is mandatory to set a suitable tilting angle in order for a usable relief angle to result from the process. This tilting angle requires a renewed adjustment in the tooth profile of the cutting wheel (for an example of such tools, see Fig. 3 above). The immediately recognizable advantage of such tools is the simple resharpening. It is sufficient to resharpen after the stripping of the rake face and to apply a new coating to the tool. The geometry does not change, which means that after each resharpening with the original kinematics, the same tooth form is generated. The longer the cutting wheel is, the more often resharpening can be applied to it and the lower the associated tool costs becomes.

The decisive disadvantage to such tools lies with the relief angle, which is always way too small. The smaller the relief angle, the higher the thermal load on the cutting edge and the shorter the tool life of the tool. The wearing characteristics with cylindrical cutting wheels are always exposed surface wear and cracks. The problem of a relief angle which is too small can be avoided through the utilization of conical tools.

Furthermore, Fig. 3 shows a conical cutting wheel. The relief angle is integrated here in the tool. If the helix angle and the axis intersection angle are different, then one will obtain extremely different rake angles for the leading and trailing flank of the cutters. In such cases, a step cut must be carried out on the rake faces. It is only that a similar rake angle can be achieved for the leading and tailing flanks of the cutters. This makes resharpening a difficult process. In addition to that, a somewhat different profile is obtained after each time the tool is resharpened. In order to produce the same exact tooth space, adjustments to the kinematics are necessary. Experience has shown that conical tools can be resharpened only a very few times.

Here the first dilemma becomes evident: A cylindrical tool requires little effort for resharpening, but always exhibits an inferior behavior with respect to wearing. A conical tool has a significantly better wearing behavior, but it can be resharpened only a very few times and this resharpening is a very difficult process.

*Fig. 3: Classic tools for skiving: Cylindrical (above) and conical*
*(Source: Bechle, A.: Beitrag zur prozesssicheren Bearbeitung beim Hochleistungsfertigungsverfahren Wälzschälen, Dissertation WBK, University Karlsruhe, 2006)*

**Why has skiving been unsuccessful to date?**

The productivity of a machining process depends essentially on thickness and on the number of cuts per time unit. The great potential of skiving is evident in the number of cuts per time unit. The required cutting speed can be achieved by means of suitable tool and workpiece rotation speeds and through the suitable choice of the axis intersection angle. For a dry cutting procedure with a carbide tool, cutting speeds of 150 to 250 meters per minute are beneficial. Simple approximate calculations make this difference clear: With an assumed rotation speed of 2,000 rotations per minute, which leads to 200 meters per minute of cutting speed, and with a tool with 25 teeth, 50,000 cuts are obtained per minute. A hob with 8 studs and two gears, which requires only 1,200 rotations per minute of tool rotations for the same cutting speed, provides by contrast only 19,200 cuts per minute.

Naturally the question comes up of why, given this potential, skiving has had a completely unsuccessful existence to the present day. It is certainly not for lack of scientific interest. For more than 20 years, many investigations have been carried out in this area, all of which are in agreement on one point: skiving is a high-performance procedure, the success of which cannot take hold because of the limited tool lives, excessive machinery vibrations and critical chip removal.

The previously mentioned parameters of chip thickness and cuts per time unit do indeed define the essence of productivity, but it is the cost-effectiveness of a procedure which is of decisive importance for success in everyday practice. Short processing times alone are not sufficient if the tool life is unsatisfactory.

In order to understand why the tools fail so rapidly, one must analyze the chip formation in detail. Even though the kinematics of skiving can be described in very simple terms, the relation between the cutting edge and workpiece is a complicated movement for which suitable simulation tools are required (Fig. 4). In this example, the workpiece has 48 teeth and the tool 17. After every 17 teeth, this cutter machines the next tooth space of the workpiece. Because the number of teeth is rela-

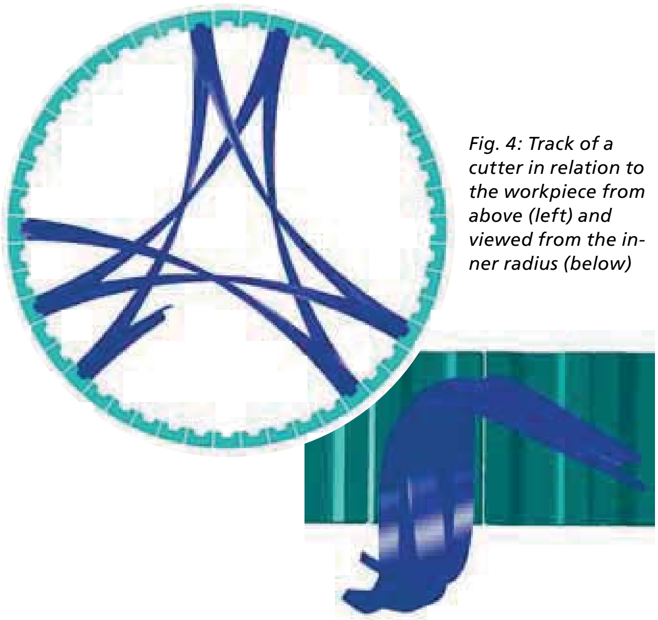


*Fig. 4: Track of a cutter in relation to the workpiece from above (left) and viewed from the inner radius (below)*

tively prime, all of the tooth spaces of the workpiece will actually be machined. If one numbers the tooth spaces sequentially and counts them in counterclockwise order starting with the tooth space at 9 o'clock, then the cutter depicted will machine the tooth spaces in the sequence 1-18-35-4-21-38-7 etc., or to formulate this precisely ix17mod48+1.

In the right-hand side of the image, one sees the movement of the cutter within a tooth space. The cutter plunges into the tooth space from the upper right. The radial movement advances as far as the bottom of the tooth space and then back again out of the tooth space. During the radial plunging and emergence, the cutter moves axially along the facewidth of the workpiece. The curved course of the track is significant. From it one can recognize that the tip rake angle is continuously changing during the cutting in a tooth space and can even take on a negative value at the end.

Starting results are obtained when simulation tools are used for precise analysis of the dimensions relevant to the rake and relief angles for chip formation. The rake angle is zero degrees at best (0°) and during the process it can take on negative values down to minus fifty degrees (-50°). It is easy to appreciate that even the most suitable cutting material is subjected to stresses in excess of its limits. This is intensified even more by the fact that negative rake angles always lead to an increase in cutting forces and result in considerable challenges to machine tools with respect to profile accuracy, dynamics and stiffness.

It is because of this combination of tool problems, unfavorable chip formation and extremely high demands on the machine tool that skiving, despite its benefits, has still not become accepted.

**Machine and tool – The success factors for skiving**

Modern machine concepts, which are optimized with respect to chip flow, stiffness, attenuation and geometric accuracy, have made tremendous advances recently. An example is the Oerlikon Spiral Bevel Gear Cutting Machine C 29. This was originally developed for the high-performance dry cutting of bevel gears. In addition, it offers ideal characteristics for skiving. The outstanding stiffness, the highly dynamic direct drives and the chip flow which is optimized by the vertical concept, along with precision axis alignment, are necessary prerequisites for the success of skiving.

In addition to the machine tool, the tool itself is the decisive success factor. As was shown above, chip formation is quite complicated with skiving and always associated with disadvantageous conditions for the classical tools, no matter whether they be cylindrical or conical in design. Usable relief angles lead to conical tools which cannot be implemented in a cost-effective manner. Cylindrical tools which can be resharpened in a way which is acceptable from the point of view of cost-effectiveness, do not offer sufficient tool life. Under ideal circumstances the tool design would only take the cutting edge into account. Any compromises with regard to the cutting wheel would become obsolete.


*Fig. 5: Skiving on an Oerlikon Spiral Bevel Gear Cutting Machine C 29 – the machine axes are shown in red.*

*Fig. 6:*
*Stick blade cutting wheel*

This tool technology is already available and has been tested worldwide for a very different application. The Oerlikon stick blade system with the ARCON® and SPIRON® cutter heads offer precisely these possibilities for spiral bevel gears. A rectangular carbide bar is ground to produce a cutting pro-file and then coated and inserted in the core of the cutter head, where it is built with high precision.

The solution is thus, in simple terms, to apply this stick blade system to skiving. Instead of a cylindrical or conical completely carbide cutting wheel, now only the cutting geometry is ground into a carbide bar blade. These profiled bar blades are fastened in a suitable cutter head core in order to form the cutters of a stick blade cutting wheel (Fig. 6).

**The advantages of this tool are immediately evident:**

• Rake and relief angles can be freely selected and can be optimized for chip flow

• Resharpening is a reliable process which has been mastered worldwide for more than ten years for bevel gear tools

• Profile modifications can be implemented immediately by grinding the bar blades

A tool system is thus created which for the first time permits the optimization of the blades for skiving. Together with the proven Oerlikon bevel gear cutting machines, a manufacturing system is available with which skiving can now finally make a successful appearance on the market, 100 years after its invention.

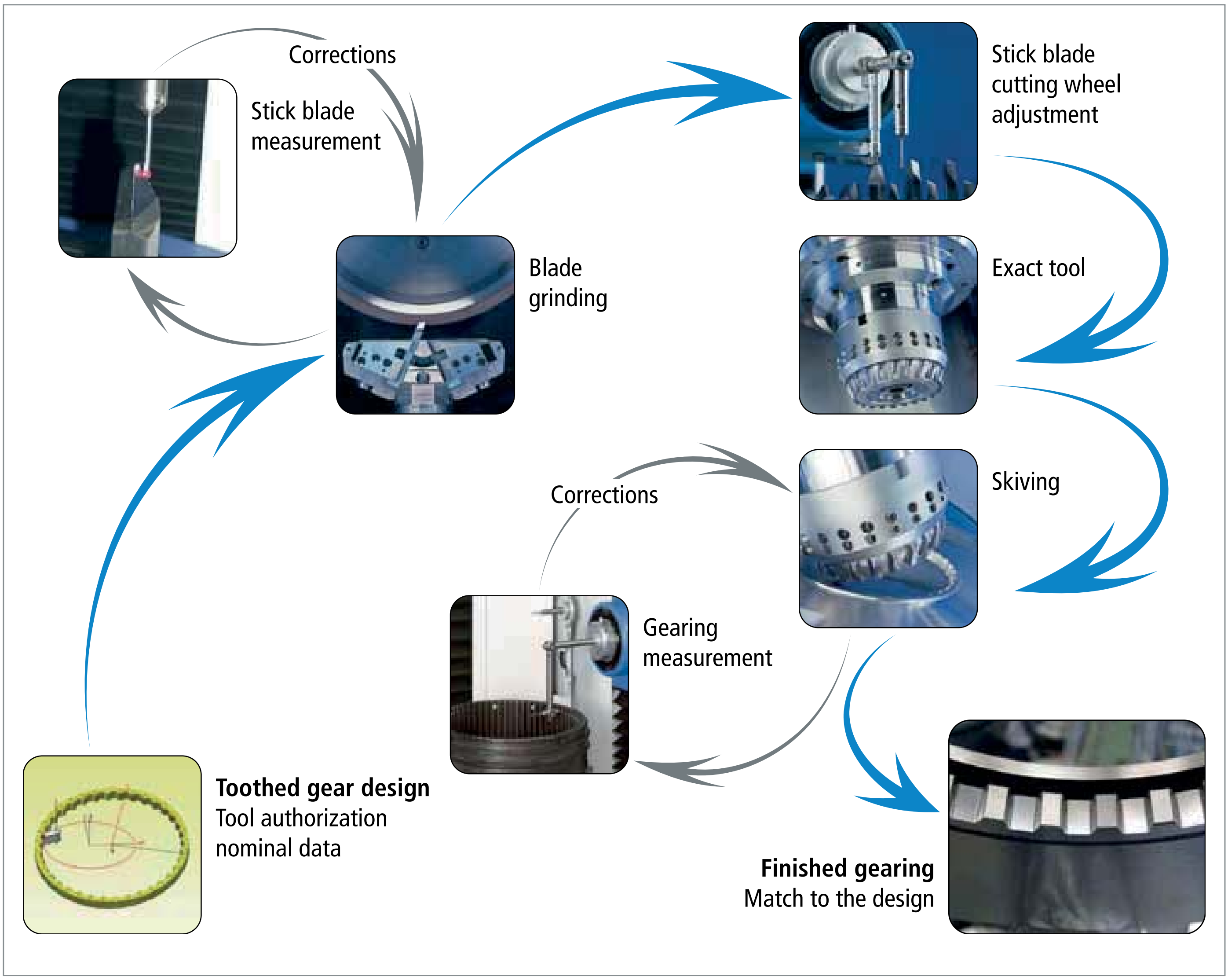
**Closed loop production**

Reliable processes require far more than reliable machines and suitable tools. It is only the integration of all steps along the process chain into a continuous data technology composite which can guarantee stable and reliable results. This method of approach is familiar to Klingelnberg. The closed loop has been a proven standard worldwide for bevel gears for many years. In order to ensure that the user profits from the same process reliability with skiving that he has with bevel tooth cutting, Klingelnberg has developed the closed loop for cylindrical gear machining by means of skiving. The structure of closed loop production can be seen in Fig. 7. Everything begins with the design of the gearing. Here the macrogeometry of the component is defined and the tooth profile is modified in accordance with various optimization criteria. In contrast to the approach with bevel gears, here only one single internal gear, is observed. It is usual with involute cylindrical gears to observe the topography deviation between the optimized and the non-optimized tooth flank instead of the ease-off. As soon as the complete gearing geometry is calculated, the theoretical nominal data of the tooth form is generated and the calculation of the tool and of the kinematics begins.

Kinematics and the tool exhibit an influence on one another in this iterative process. The user is shown the important parameters for chip formation as the basis for the manufacturing simulation of the skiving process. He has the opportunity of optimizing the tip rake angle, the flank angle and the relief angle at the head and flanks. As a by-product, he obtains the appropriate kinematics for the machining equipment and the form of the cutting edge. This software package supports not only stick blade cutting wheels but also just as much the classical cylindrical or conical cutting wheels with and without rake face offset. The gearing design is completed after these steps and the data for the component to be produced, the data for the tool and the data for the machine tool are all completed.

The next step in the process chain is the tool production. For stick blade cutting wheels, it is here that the tool closed loop comes into play, as has been known for many years for bevel gear tools. The description of the tool contains not only the number of teeth and the form of the cutting edge, but also all of the geometric parameters of the tool. These include all rake angle and relief angle information as well as all data regarding the position of the stick blade in the cutting wheel. Once a stick blade has been ground, it can be dimensioned geometrically. Even the smallest deviation of the stick blade profile from the nominal form is recorded and processed in a correction algorithm. The results are modifications to the setting values of the grinding machine, so that the measured deviations are minimized. There are now stick blades completed which exactly possess the specified profile. These are positioned in the cutter head with micrometer exactitude by the

## Closed loop for skiving




Oerlikon CS 200 cutter head adjustment device and screwed in place. Starting here, it is ensured for the remainder of the process that a tool will be used which corresponds precisely to required specifications.

The truly distinctive features of skiving a gear on an Oerlikon cutting machine of the C series are the very short processing times and the manufactured qualities. Once a part has been milled, its dimensions are recorded in order to determine their deviations from the theoretical form. Klingelnberg follows a new path for the measurement of these parts. Instead of the usual measurement of profile and lead trace as deviations from an involute tooth form, measurement is carried out here with a topographic grid. If the deviation at all grid points is practically zero, then the manufactured component will correspond to the specifications resulting from the tooth design. Deviations will once again be fed into a correction algorithm which calculates the correction values for the cutting machine motions. As is the case with the machine tool, these are fed per network to the machine control unit which then automatically grinds the next part in such a way that the deviations become minimal.

All closed loop users worldwide now agree that the main advantage of closed loop production are the reliable processes. In addition to process-capable machines and tools, it requires control loops which keep the process stable. It is only when one produces precisely what was designed that gearing optimizations can occur.

**So why skiving?**

Internal gears which previously could only be manufactured through the use of shaping can now be manufactured very productively and with high precision when skiving is applied.

Even though the kinematics of the skiving process appears simple at first glance, the chip formation is actually very complex. Rake angles and relief angles which are subject to continuous changes during the intervention lead to unfavorable chipping conditions with classical cutting wheels – no matter whether they are conical or cylindrical in shape. This is precisely the reason for the previous lack of success of skiving during the last 100 years.

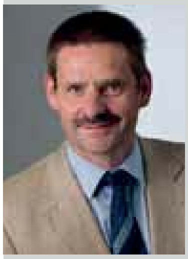
The decisive success factor for skiving is the stick blade tooling system with its open design of relief angles and rake angles. These kinds of tools have been successfully utilized around the world for the dry cutting of spiral bevel gears for more than a decade.

Thanks to the very short machining times and the high component quality, it has become possible to reduce manufacturing costs drastically – while as a "by-product" the energy consumption per component is falling and the stick blade tool system is ensuring exceptionally short run-through times. All prerequisites, both for large lots and for individual piece manufacture, are thus fulfilled.

The system process reliability of the procedure is based on the closed loop for the production. In terms of data, the tool preparation and the skiving process are in a continuous data network with the internal gear design. Thanks to the underlying quality control loops, it is ensured that that which is produced is also exactly what was designed.

The actual principle has not changed since the registration of the Von Pittler patent. However, technical progress with respect to machinery, tools and production processes in general has ensured that it turned out well after all.

Dr.-Ing. Hartmuth Müller



Dipl.-Ing. Frank Seibicke
Chief Engineer Calculation Software