Simulation of Deviations in Hobbing and Generation Grinding

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Abstract

The hobbing and generation grinding production processes are complex due to tool geometry and kinematics. When deviations occur, possible causes include tool deviations, tool setting errors or tool machine errors. Expert knowledge and extensive testing are required for a clear attribution of cause to workpiece deviations.

A newly developed software tool makes it possible to simulate the cutting procedure of the tool and superimpose systematic deviations on it. In this way, the consequences of tool errors and tool clamping errors on the workpiece can easily be predicted and represented as in a gear measurement report. The simulation includes the major profile and helix modifications and contains measurements of twist and topography and the measurement in the feed spiral. Finally, measured data of a hob measurement can be loaded and used for the simulation, making it possible to predict the workpiece quality that can be achieved under optimal conditions with the hob under consideration.

The performance of the simulation software is illustrated with practical examples. To this end, workpieces with defined deviations have been produced and measured on a gear measuring device. A comparison of measurement and simulation shows the accuracy of the calculations. The new simulation tool allows the user to accurately predict the effect of errors. With this knowledge, the user can design and operate optimal, robust gearing processes.

1. Introduction

The continuous machining of tooth flanks by a rolling motion process is used since a long time in order to manufacture gearings with a high accuracy economically. It is used for soft and hard machining by hobbing and generation grinding. The tool has the shape of a worm that is interrupted by gashes with hobs. Tool and workpiece operate in a kinematic coupling

with versatile motion options. In Fig. 1 the possible influence categories are represented that could be reason for deviations determined in the scope of measuring a workpiece.

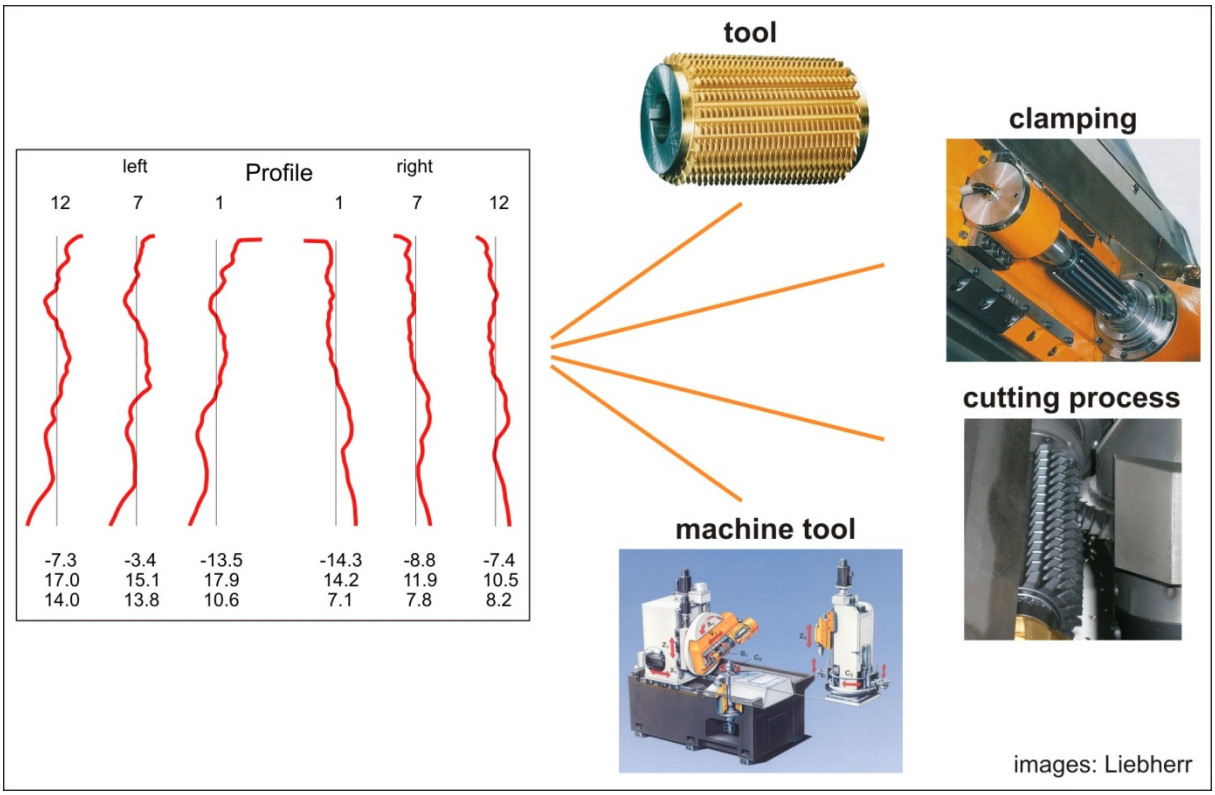


Fig. 1: Causes of deviations

The tool may have deviations when it is new and due to wear and damage. It can be clamped in the machine incorrectly thus indicating runout deviations. The cutting process on the tooth flank is controlled by technology parameters, such as feed rate and infeed. Foreseeable deviations resulting from this are feed markings but also deviations in the chip shape formation. After all, the machine tool must implement and synchronize the different movements at a high precision. Here deviations also result from the control processes, deformation or position errors of the axes. The user has to deal with a complicated scenario of fault possibilities as a result and is pleased when he can assign the cause of the fault to a category in order to then carry out further checks or changes to the parameters.

Against this background, a simulation software has been developed that simulates the effect of typical faults when hobbing and generation grinding to the workpiece and supports the user when searching for the cause. In the following, the layout and function of this software will be presented on practical examples. Basic requirements on the implementation are a simple operation and a quick and accurate calculation. In order to support a slight interpreta-

tion of the results, the simulation has been integrated in an analysis tool for gear measurements. Using this, the simulation results are thus represented in the same manner as the results of a gear measurement. At the same time, the effort for development is reduced considerably by using the numerous calculation and output routines of the analysis software.

2. Layout of the simulation software

The simulation software permits the representation of a rolling production by a worm-shaped tool. The only difference when considering hobs and grinding worms is that with hobs, the number of cutting edges is clearly determined whereas it is theoretically infinite with grinding worms but, can be approached well in its effect by a suitable quantity. As several deviations, such as the profile cut markings only occur when hobbing and hobs are compared with grinding worms relatively easy to measure on gear measurement devices, only examples of hobbing shall be considered in the following. All possibilities of the software described here also apply for the generation grinding.

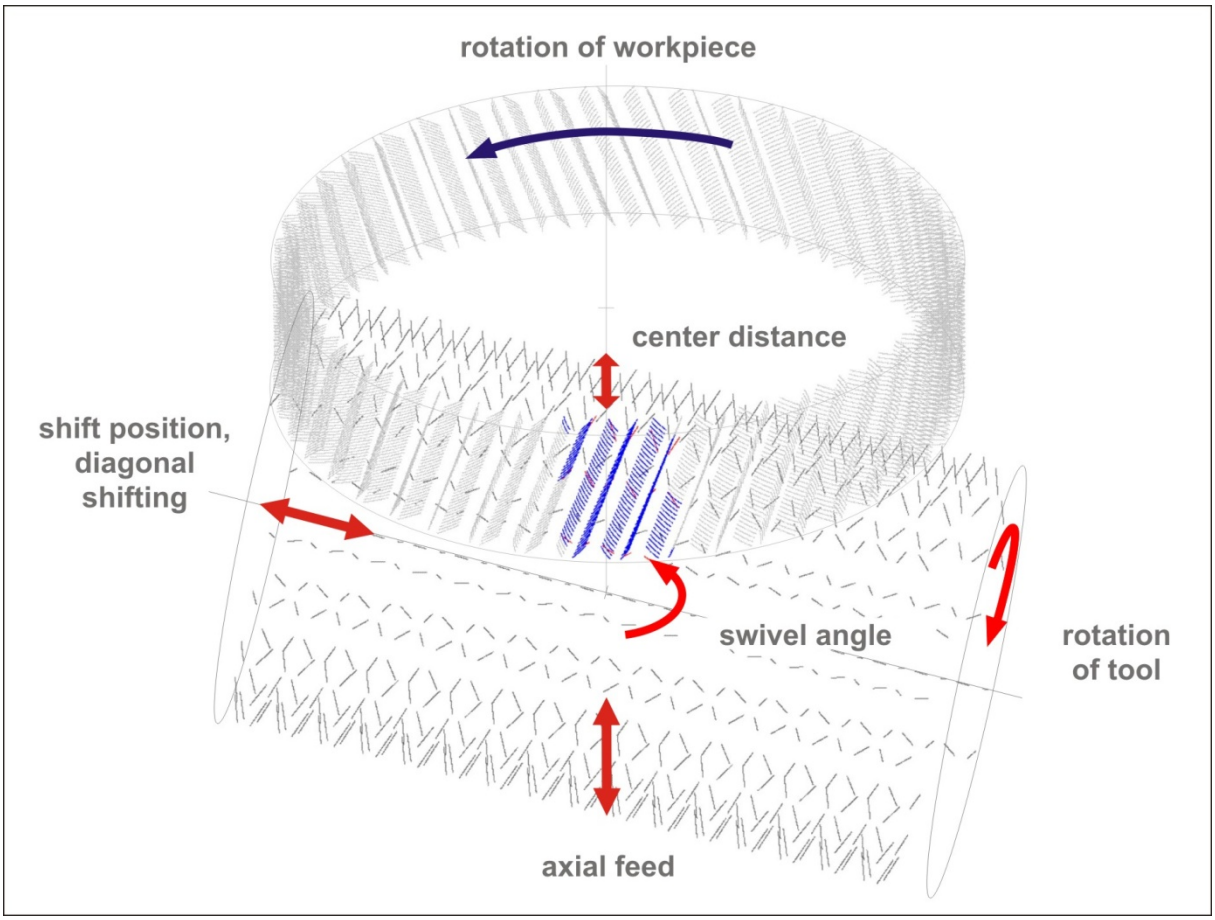
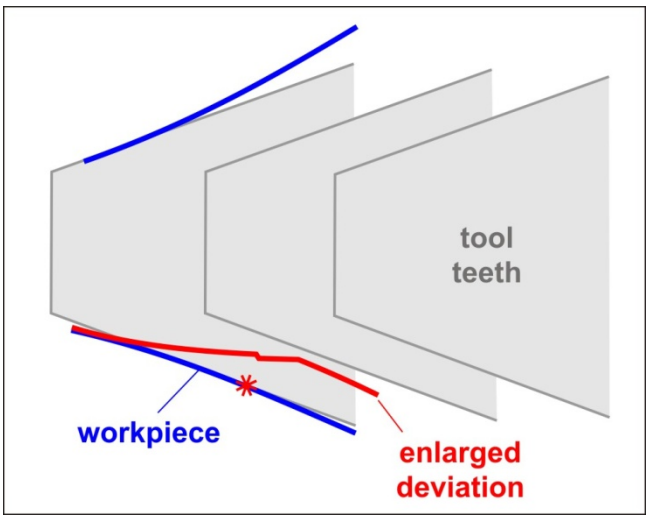


Fig. 2: Description of the kinematics

The fundamental basis of the calculation is the consideration of points on the surface of the workpiece and the description of the tool cutting edge as sequence of points. These points are equipped with possibilities for movement that obey defined dependencies. The workpiece points are treated as measuring points of a gear measurement that can then be used to calculate deviations using the conventional procedures of measuring technology. The tool cutting edges each have a cutting contour and a description for the position of this contour. In their basic state, these position parameters define the position of the cutting edge on the spiral-shaped tool body. All movements are only implemented by changing these position parameters. It is in this way easy to represent many tool errors as position changes.

The possibility of moving the workpiece is only a rotation in the Z axis that is coupled with the tool rotation. The tool carries out an axial feed per rotation in the direction of the workpiece axis. The position of the tool in the direction of the tool axis is determined by the shift position. With regard to this, a diagonal shifting permits a movement during the processing. The radial position of the tool to the workpiece axis is determined by the addendum modification. A movement during the machining is also possible here, for example, to generate a flank modification. After all, the tool is rotated around the swiveling angle from the horizontal position that is determined from the helix angle of the workpiece gearing and the lead angle of the tool worm.



Now, in the course of the simulation, every single workpiece point is provided with an allowance and considered accordingly as to which cutting edge makes contact with it in which position. When cutting, the allowance is reduced to the clearance to the cutting edge as illustrated in Fig. 3. On the measuring point considered here, the enlarged deviation curve of all measuring points is reduced rapidly as with the removal of chips.

Fig. 3: Calculation of cutting

The implementation of the procedure described here is sufficient for an exact simulation, but leads to a response time that is impracticable when each point of the tool contour of every tool tooth meets in relation to each workpiece point in any possible position. For a good performance, numerous rules have been implemented that limit the tool teeth and cutting zones

to be considered to the actually effective ones. In doing so, these rules also consider the possible tool errors.

3. Simulation results with error-free processing

Figure 4 shows the results of the hobbing simulation of a workpiece. An error-free processing is carried out with a relatively high axial feed. Profile cuts and curves of the tooth trace on the right and left tooth flanks as well as pitch points on all teeth are specified as measuring points according to a standard measurement on 3 distributed teeth. The markings of the axial feed arise on the tooth trace, the distance of the tips is equivalent with the feed rate. The crowning of the tooth trace results from the setpoint specification of a crowned flank modification.

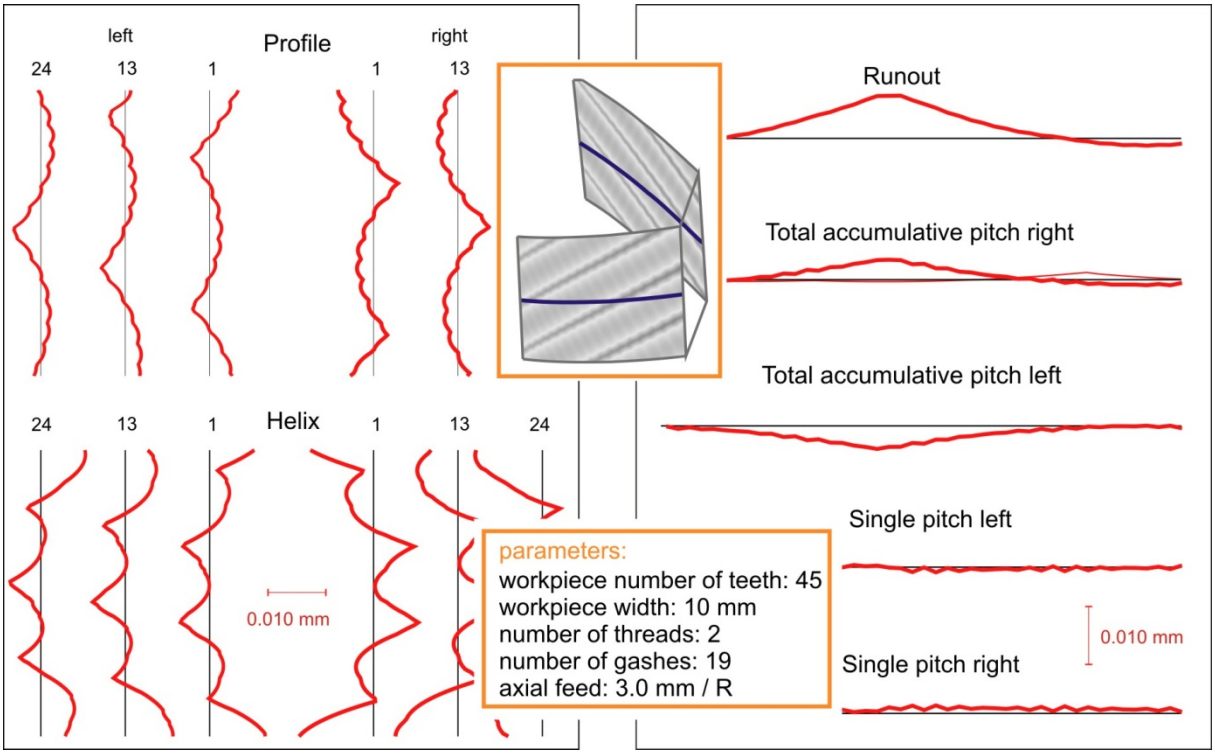


Fig. 4: Standard measurement

The 3D topography of a tooth is represented in the middle of the figure. An obliquely running ripple results over the tooth flank due to the axial feed. A usual profile measurement (blue line) is carried out in the transverse section and cuts this ripples. This then also results in a ripple in the profile with the same amplitude. Moreover, the profile indicates a more finer and higher-frequency ripple. These deviations in form are results of the generating cuts that results from the cutting sequence of the individual cutting edges. They can be clearly seen due

to the relatively small number of gashes per thread of this tool. As the ripples also moves from tooth to tooth due to the axial feed, the pitch variation also indicates irregularities depending on where the individual pitch point is located between peak and valley.

The deviation in form generated by the axial feed reflects the quality of the workpiece, but with regard to the manufacturing assessment, do not allow any statement about the accuracy of the profile generation or about positional deviation of the gear teeth (radial runout and pitch variation). It is therefore common on gear measurement devices to carry out a measurement in the spiral feed. With the profile and pitch measurements, the measuring probe then always scans in the base of the ripple, as illustrated in the middle of Fig. 5. The measuring points can also be distributed in this way in the simulation so that the deviations from the axial feed disappear in the result and only the generating cut deviation remains in the profile.

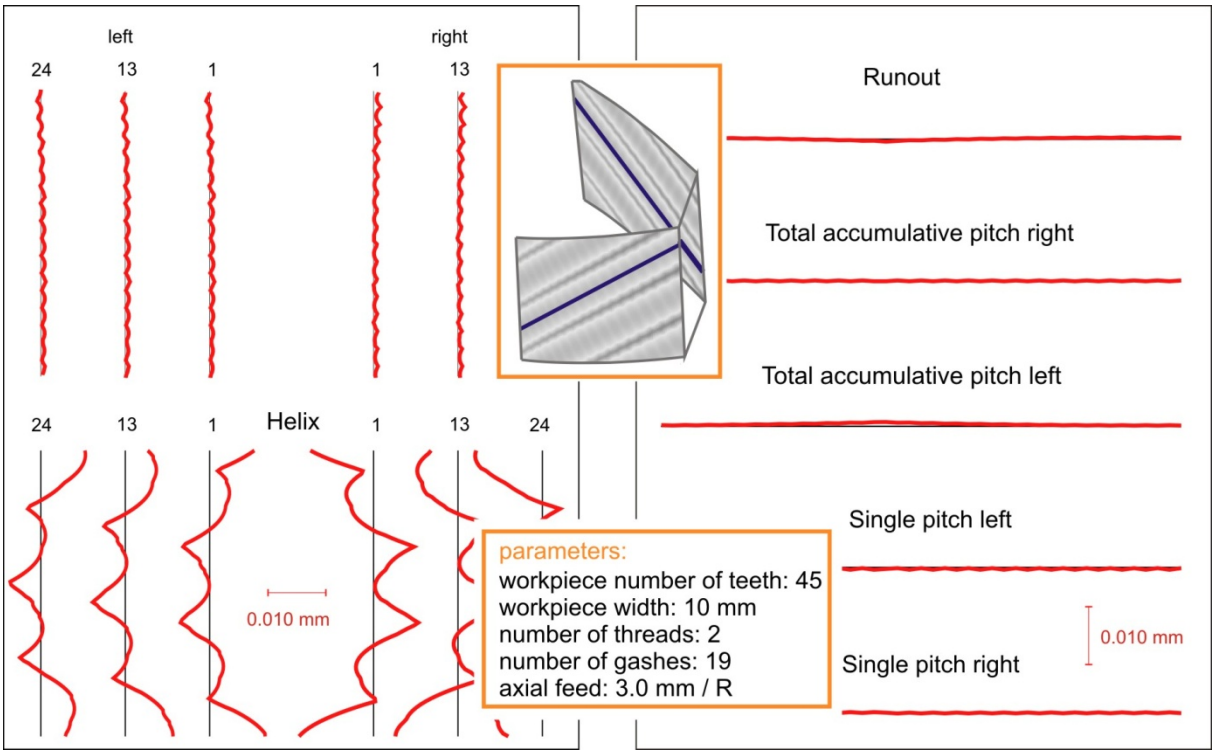


Fig. 5: Measurement in the spiral of feed

As the position of the measuring points on the tooth flank can be freely selected, it is also possible to generate three profile cuts, that is common when measuring the twist. Fig. 6 shows the deviations when using a considerably smaller axial feed during the simulation. The crowned contour of the tooth trace is generated by a correction of the axial distance during machining. As the tool is inclined by the swiveling angle and thus, does not only cut in the transverse section level of the workpiece, a tilting of the profile with changing signs results at the top and bottom that is designated as twist. Using the calculation of the standard charac-

teristic values, the twist can also be output numerically. In practical tests, a good match with the values calculated is observed.

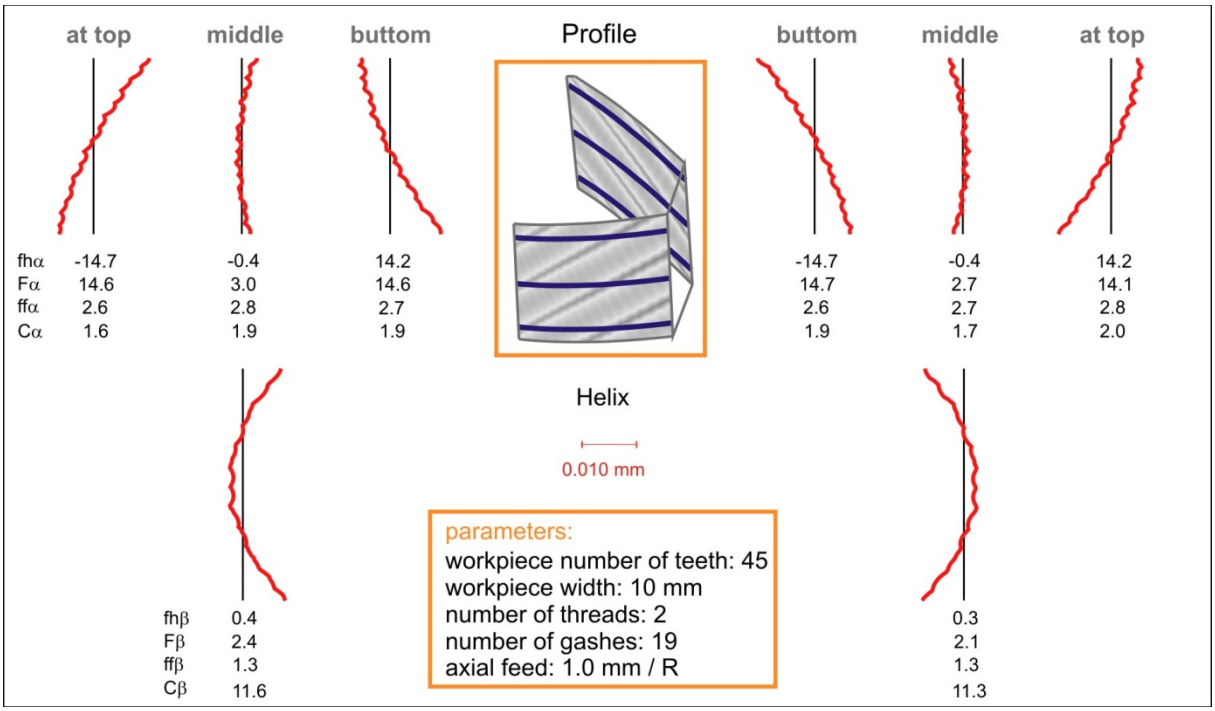


Fig. 6: Measurement of twist

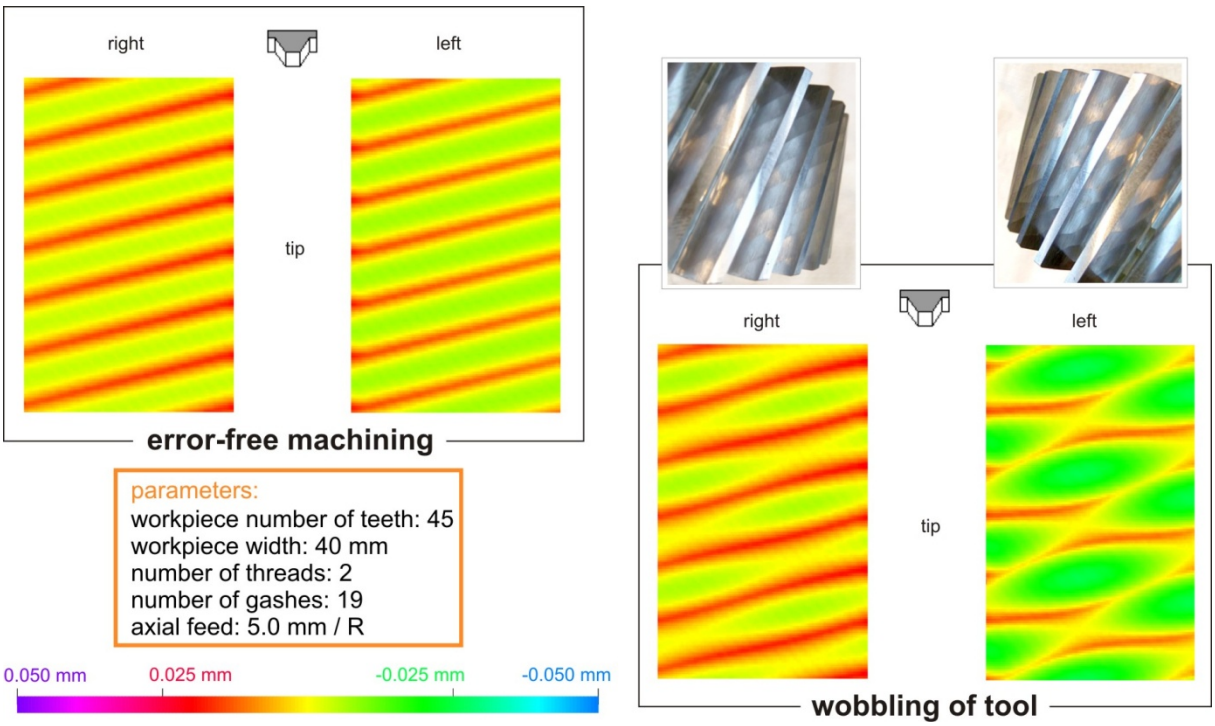


Fig. 7: Simulation of many sections and topography presentation

Fig. 7 shows the results of the simulation of much more profile cuts as a color coded representation of the deviations. On the left side an error-free processing had been carried out with a high axial feed and without crowned tooth trace. On the right side of the Fig. 7, in addition a positional deviation of the tool has also been specified in the form of a wobble. Whereas the right tooth flank of the workpiece does not show almost any changes, the left tooth flank shows significant deviation patterns that can also be recognized visually on the tooth flanks of the gear manufactured. If the measurement diameter of a tooth trace measurement is modified here (displacement of a vertical cutting line to the outside or inside), then the form of the deviation curves can modify significantly. This effect is comprehensible only by a topographical representation. The user of the simulation software is therefore also able to analyze surface effects of the machining.

4. Consideration of tool and clamping errors

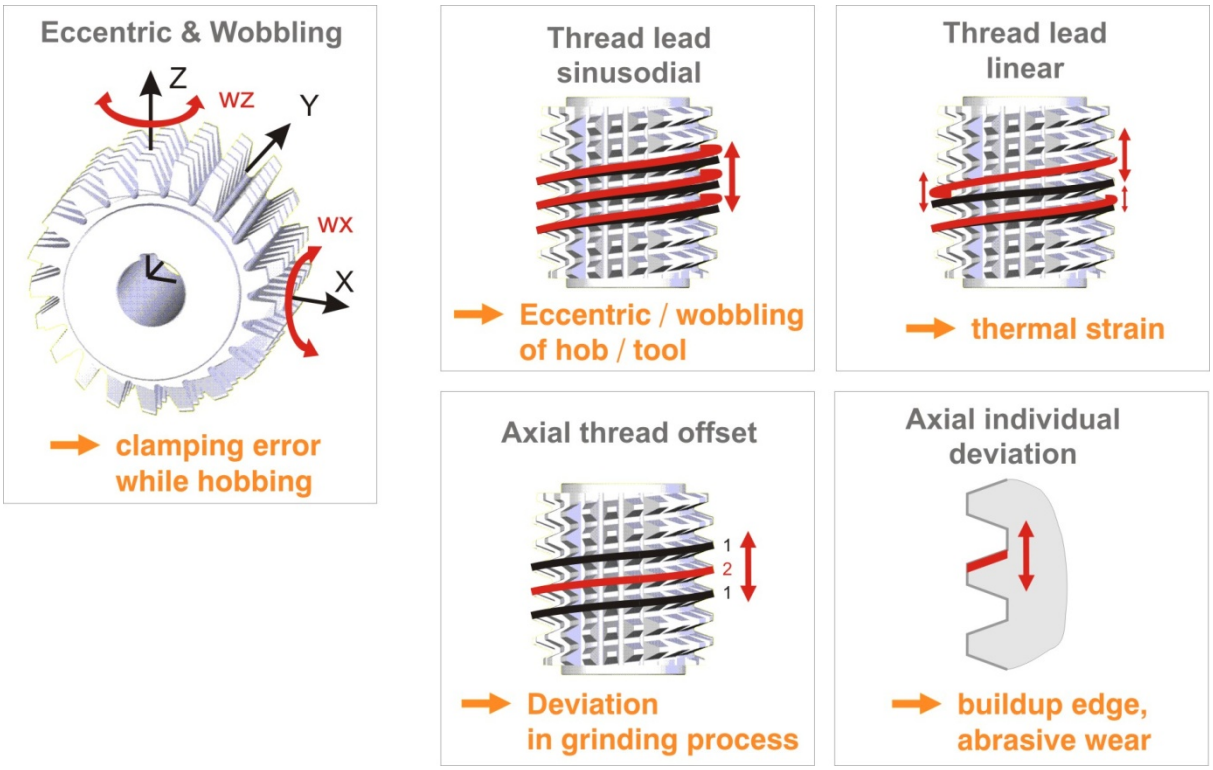


Fig. 8: Simulation of tool and clamping errors

Beside of an error free machining, the cutting can be simulated using a defective tool. Fig. 8 shows the possible tool errors that that can easily be generated as well as overlapped by a few mouse clicks. Corresponding to the clamping error in the hobbing or grinding machine, the tool can run wobbling or eccentric. This is described on the reference collar by radial and

axial runout deviations. The tool can have a sinus shaped thread lead deviation if the hob or the grinding worm does not run to the reference collars and, a linear thread lead deviation if a temperature expansion occurs. With multi-start tools, one thread can be axially displaced with respect to the others. After all, by specifying a deviation on a single cutting tooth, the effects of a buildup edge or wear or cutouts can easily be assessed on the quality of the toothed gear manufactured in this way.

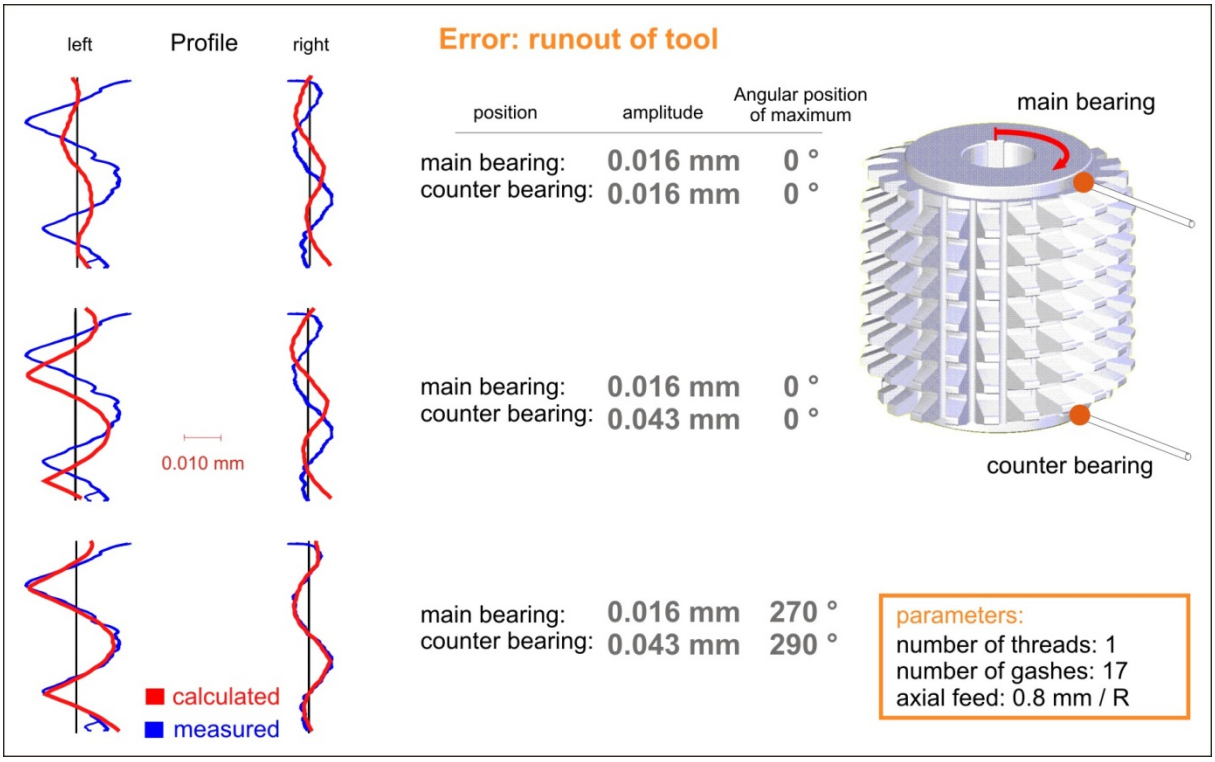


Fig. 9: Comparison of measured and calculated profile deviations

A hob has been purposely clamped eccentrically and a toothed gear has been machined with it to check the accuracy of the simulation. Fig. 9 shows the results measured in blue that are compared with the red ones of the simulation results. The concentricity variation on the main and counter bearings and their angular position to the machine axis has been modified in the simulation step by step until the test settings determined with a dial indicator have been reached. The deviation in form of the measurement and calculation correspond very well with one-another.

It is obvious that not only typical systematic errors should be considered in the simulation, but the actual errors for each individual cutting edge as they can be determined by a measurement of the tool on a gear measurement device.

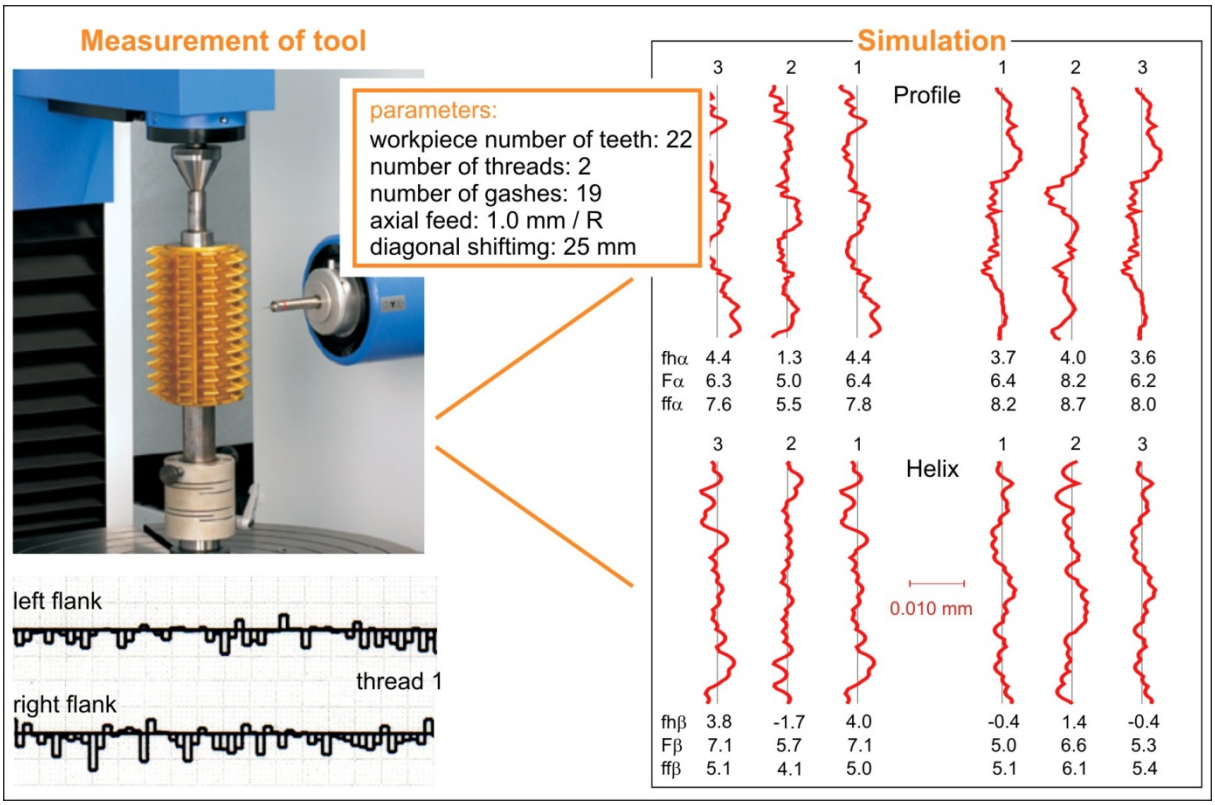


Fig. 10: Prediction of workpiece quality from a tool measurement

Fig. 10 shows the measurement of a double start hob. The profile deviation of the cutting edge and the axial deviation of each tooth are transferred via an interface and used for the simulation. The differences of the deviation on the left and right tool flanks and on the threads between one-another lead to different profile and flank deviations on the workpiece that, at this ratio of workpiece teeth to the thread mumber are the same on every second gear tooth. In this calculation a diagonal feed rate of the tool has been entered, that leads to the situation that not the same tool teeth are active in the whole tooth trace. This results in greater deviations in form there according to the deviations of the hob. The combination of the simulation with a hob measurement opens the possibility to predict highly precisely and in detail as to which quality the workpiece processed with the hob can have in the most favorable case. Clamping errors can then also be overlapped here in the simulation.

5. Summary

A new software tool has been presented that permits the simulation of typical errors in the production of toothed gears by hobbing and generation grinding with high accuracy. The software permits the consideration of any points on the tooth flank and represents all results in the form of a gear measurement familiar for the user. A 3D consideration of the twisting and of the topographical deviation pattern is possible. The comparison of the measured deviation on faulty components with the simulation results shows a very good correspondence.

This provides users and planners of hobbing and generation grinder processes in construction and production with a high-performance tool that supports them in the dimensioning of processes and tools and when looking for causes of deviations. As a result of the option to edit the process parameters quickly and easily, the understanding for this complex machining processes and its influence categories is increased significantly.

6. Literature

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