Analysis of gear measurement to solve noise problems in gear boxes

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Abstract

The noise made by gears is increasingly being focused on by automobile manufacturers. When it occurs, the search for causes and solutions takes on high priority. This paper describes new methods for extrapolating the causes of noise problems on the basis of geometric measurements of gears. A digital comparison of deviation curves makes it possible to recognize differences between loud and quiet gears as an initial step. Proceeding from this, ripples can be determined that describe the periodic deviations of the tooth flanks in context. A determination of the helix angle of the ripple supplies insights into the progression of the ripple in the topography of the tooth flank. In addition, the application of a software for the determination of deviations during hobbing and generating grinding is presented. It becomes clear that this procedure also makes it possible to estimate the sources of ripples and to formulate measures to be applied during production.

The insights gained for the simulation and determination of ripple parameters are explained on the basis of practical examples for which noise relevance is present. In summary, the article makes clear which possibilities exist today to extrapolate essential findings into their function and the source of deviations from the measurement of the gears.

Keywords: noise, gears, ripples.

1. Introduction

In passenger cars the acoustic is an important quality and comfort feature. In the realization of the requirements deduced from this fact, the noise created by the gearbox comes more and more into the focus [1][2]. This is especially true for electric drives.

Figure 1 illustrates a typical approach in the presence of noise problems or general quality problems as well with gears. Starting with a gearbox that has been detected either subjectively or by the measurement of air or structure-borne noise, a noise test is carried out during which the gears are started up under load and a continuous noise measurement is performed.

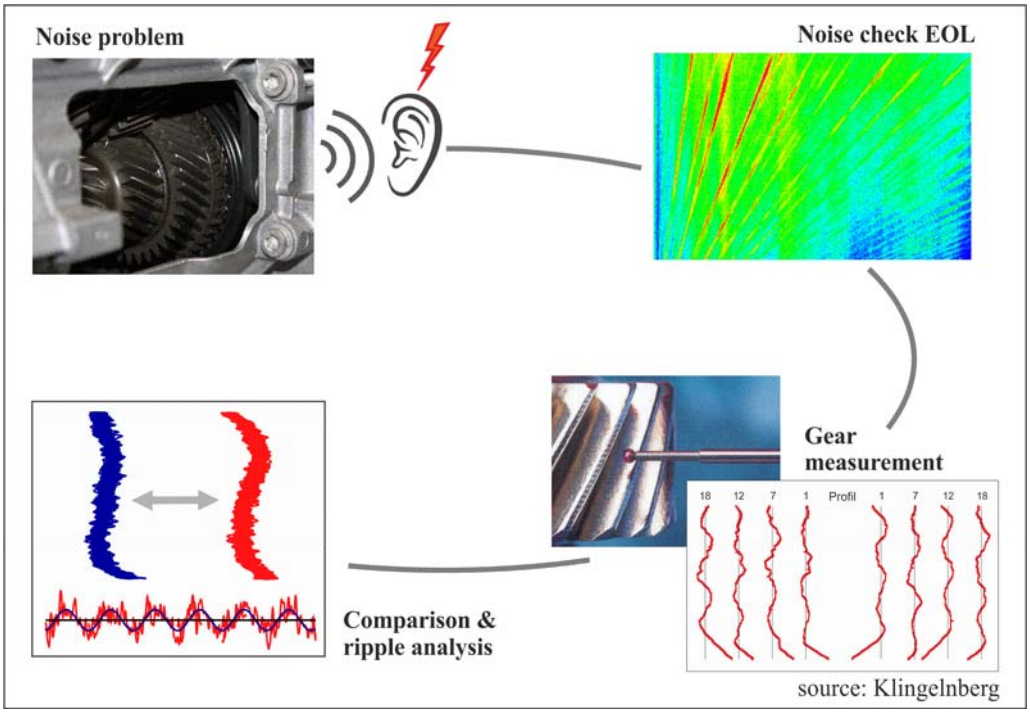


Fig. 1: *Analysis of noise and quality problems.*

The results are color-coded in waterfall diagrams and allow the acoustics specialist insights into the noise-causing components [1]. In the automotive industry, this noise test is conventionally performed as an End-Of-Line (EOL) check.

2. Procedure for troubleshooting

If a gear is suspected as being the source of the error, then this is often followed by its replacement and the performance of a new noise measurement. To determine the source of the noise on the loud gear or gear pair, loud and quiet components are measured on gear measurement devices. The results must then be subsequently analyzed in order to initiate corrective measures in the production process. This analysis will be explained in the following.

Usually the first step is the comparison of the characteristics that describe the measured curves as is defined in the standards and directives [3][4]. If no clear differences can be seen at this point, then a graphic comparison of the deviation curves will ensue. In the past, this was accomplished by laying the measuring sheets on top of one another. Nowdays, the measurement curves can be presented and compared together digitally.

Figure 2 shows at the left side the deviation curves of all of the teeth of one loudly and one quietly honed gear for the involute profile and the helix of the left flank. No differences can be seen in connection with the large desired modifications. A new developed evaluation method allows to correct the curves by the actual values of the modifications. This enables a higher resolution of the progressions of the curves. It can be readily seen in the right part of the picture that the loud gear exhibits a clear periodic deviation in form that is similar on all of its teeth.

In general the quality assurance of components nowadays proceeds through the objective determination of characteristics that describe the function or the geometry of a component. The periodic deviations in form in the example must also be described unambiguously in order to enable a differentiation between loud and quiet. If this is successful, then even an early geometric measurement performed during production can be indicative of possible noise problems with the gear without requiring actual assembly and a noise test. The construction of effective and short control loops will then become possible.

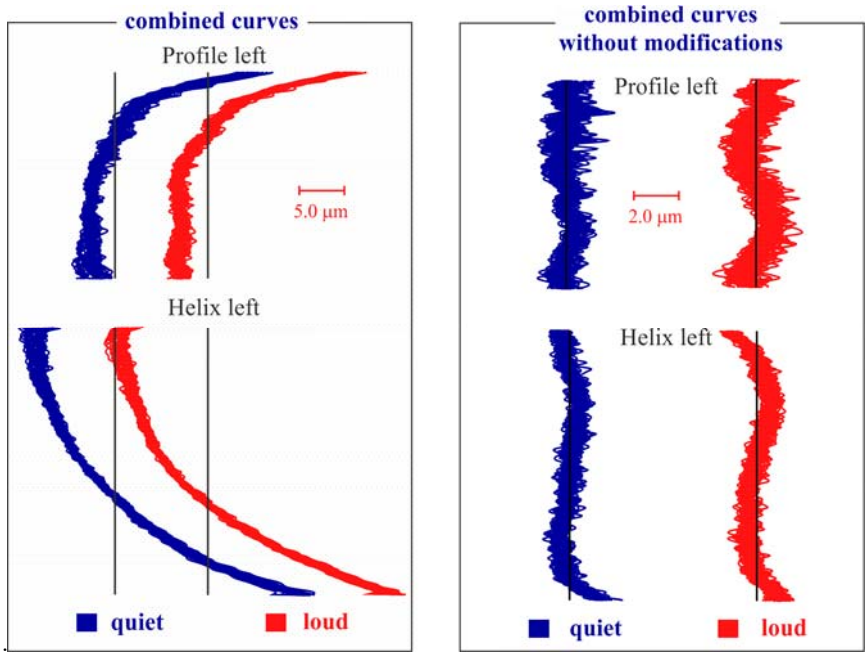


Fig. 2: *Comparison of measurements.*

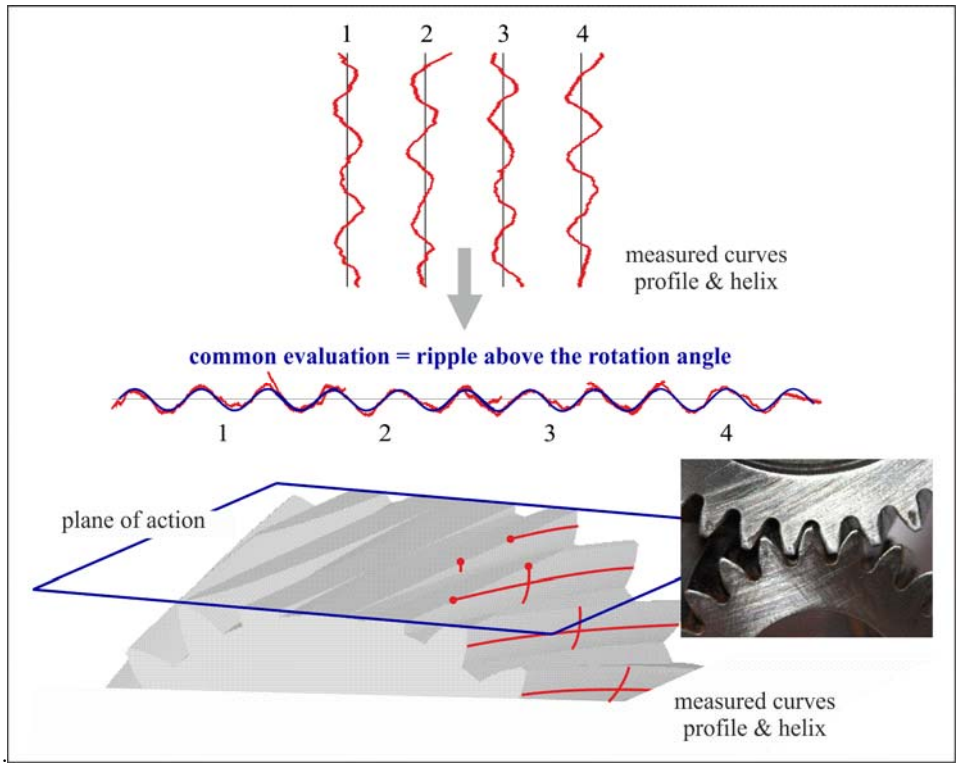


Fig. 3: *Method of ripple evaluation.*

3. Analysis of ripple

For the description of periodic signals compensation sine functions have proven their effectiveness [5]. In comparison with a fast Fourier transformation, they have the advantage of also providing exact descriptions of open curves and ones with overlaps and gaps. It is however not expedient to calculate a separate spectrum of ripples for every measured curve. It is useful to combine all measured curves around the circumference into one curve and then to calculate from this the spectrum of one circumferential ripple [6]. The orders of this spectrum can be compared directly with the noise orders that are referenced to the gear; they describe the function. Figure 3 makes this method clear. All of the points of intersection between the gearing and the plane of action have the same angle of rotation when rolling with a mating gear. An angle of rotation can be assigned accordingly to each measured point. When the deviations of all of the teeth are now drawn above to the angle of rotation, this results in a deviation curve during a rotation of the gear.

For profile sections Figure 4 shows the formula for the calculation of the angle of rotation from the generating angle and the angular pitch. For helix curves, the angle of rotation that is determined from the axial position of the measuring point depending on the size of the lead is added in as well.

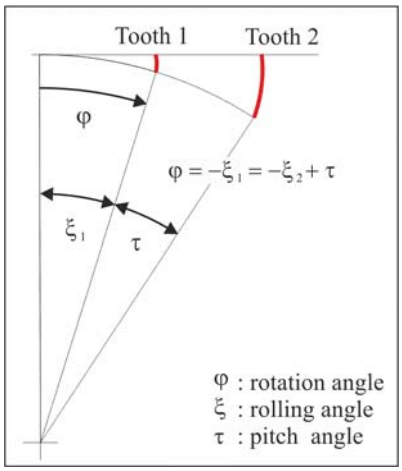


Fig. 4: *Calculation of rotation angle.*

Figure 5 depicts the practical application of ripple evaluation using the measurement of the gear from figure 2. The order of 42 can be seen in the spectrum, which clearly differs in amplitude between loud and quiet. This is also reflected in the progressions of the curves in which several teeth are applied together. The calculated sinus function matches the progress of the curve very well. In the noise measurement, the order of 42 was the reason for rejecting the loud transmission. Generally speaking, it can be seen that a good correlation exists between the noise measurement and the ripple analysis, insofar as ripples and not damage to the gear are causing the noise. This evaluation is 'state of the art'.

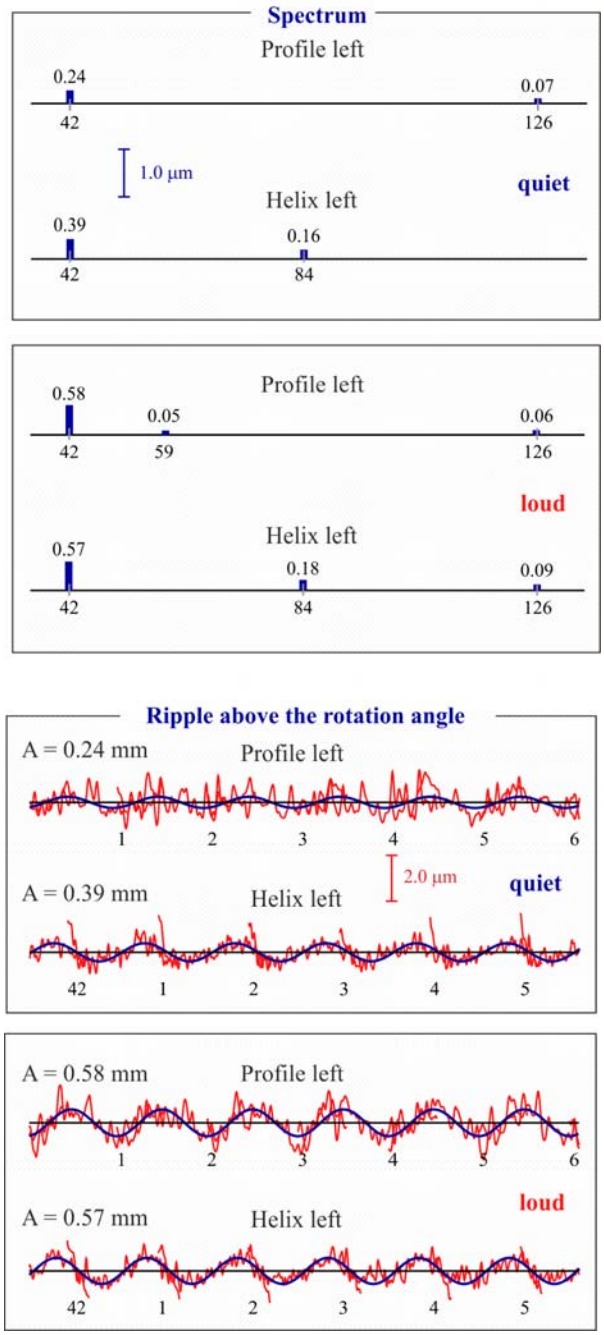


Fig. 5: *Ripple analysis of honed gears*

4. Direction of the ripple

For an in-depth investigation of ripples on tooth flanks with respect to cause and effect, it is helpful to have measurements of many sections on individual tooth flanks. The deviations can be applied with color codes in the form of a topography presentation, Figure 6. Inscribed here is not only the actual value of the helix angle $ß_w$ but also the base helix angle $ß_b$. $ß_w$ is calculated for each order from the phase shift of the ripple in the individual sections. During the rolling with the mating gear, the contact line that is tilted by $ß_b$ migrates across the tooth flank. It can be assumed that ripple which exhibit a helix angle similar to $ß_b$ will be particularly noise-generating, as the contact line then moves through peak and valley [2].

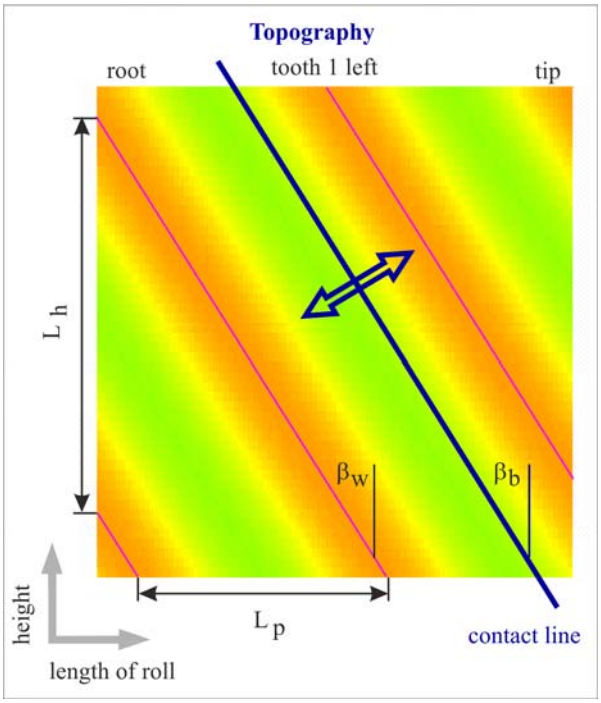


Fig. 6: *Topography with helix angel of ripple.*

The helix angle $ß_w$ is determined by the wavelength of the ripple in the profile L_p and the wavelength in the helix L_h. A determination from the respective orders of ripples is accomplished per equation (1).

$$\tan ß_w = \frac{L_p}{L_h} = \frac{d_b * \pi}{O_p} * \frac{O_h}{p_z} = \frac{O_h}{O_p} * \tan ß_b \qquad (1)$$

with d_b = base circle diameter, p_z = lead and

$$\tan ß_b = \frac{d_b * \pi}{p_z} \quad \text{according to [7]} \qquad (2)$$

If the order of profile ripple O_h corresponds to the order of the helix ripple O_p, then the helix angle $ß_w$ has the size $ß_b$ (3).

$$O_p = O_h \Rightarrow \tan ß_w = \tan ß_b \qquad (3)$$

This new deduction means that conclusions can be drawn regarding the helix angle $ß_w$ when the orders in the profile and helix assigned to one another are known or regarding the

complementary order O_p when $ß_w$ and O_h are known. In the future this new evaluation will allow a deeper look at the surface characteristics of noisy ripples.

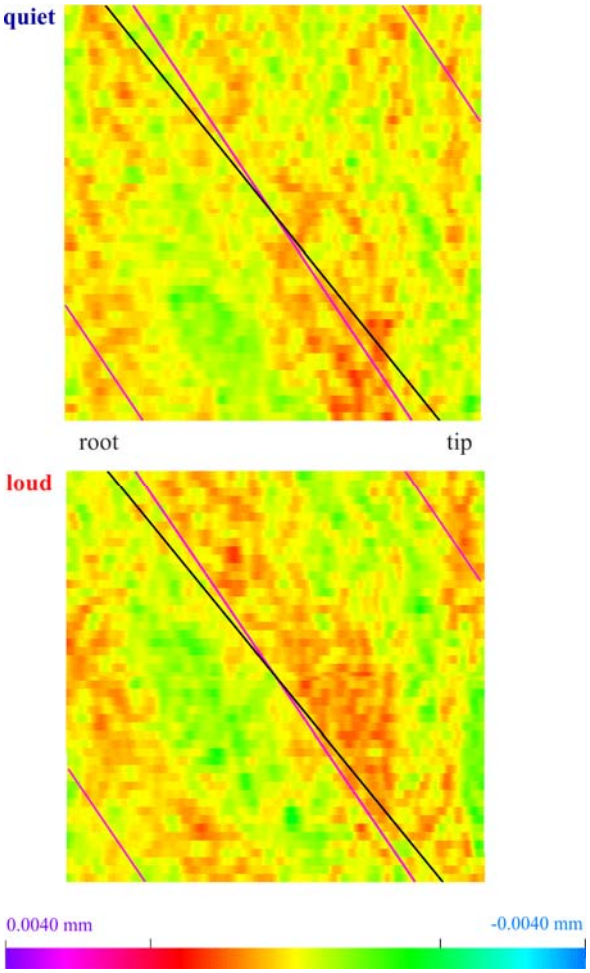


Fig. 7: *Topography of honed gears.*

As a practical example for the evaluation of helix angle of ripple, figure 7 compares the topographies of the quiet and loud gear under observation. Both of these result in a $ß_w$ of approximately $ß_b$. Nevertheless, the loud gear exhibits a more pronounced ripple while the ripple of the quiet gear is weaker and less sharp and tends towards a helix angle of 0° in the left-hand area (root).

5. Simulation of hobbing and generation grinding

If a noise can be unambiguously assigned to the gear and if the ripples on the tooth flanks corresponds to the noise order, then the extensive search for the causes follows in a subsequent step. The complex kinematics of hobbing and generation grinding production is not easy to understand, particularly with the use of multi-start tools that is commonly encountered today. It was for that reason that many simulation tools have been developed for the purpose of calculating the forces, tool wear, excitations and even the effects of errors [8][9]. In using these tools it is possible to design and optimize manufacturing processes [10].

A newly developed software tool [11] was used for the search for the causes of ripples that is outstanding for its high calculation precision and that can be linked with a ripple evaluation. The essential properties are depicted in Figure 8. At the core of the calculation, it enables the simulation of the kinematics of the machine tool to bring the tool and the workpiece into contact with one another. The deviation that the tool blades generate over time is determined for each workpiece point in the section calculation. The application of extensive exclusion rules makes rapid calculation possible. The virtual tool blades can now be assigned typical tool errors. In doing so, the results of a hob measurement can also be applied to the individual teeth. Furthermore, clamping errors such as are often encountered in everyday practice in the form of eccentric and wobble can also be superimposed on the movement of the tool. The result provides the user with deviation curves in profile, helix and pitch. The calculation of many sections can ultimately also enable the determination of the topography of a tooth flank.

Figure 9 shows the application of the simulation software with a noise problem in a generating grinding process. At the top left the ripple spectrum of a quiet gear is depicted, at the top right the spectrum of a loud gear. The peculiar order of $O_p=O_h=57$ corresponds to the order of noise in the vehicle. In the simulation, a wobble of the grinding tool was assumed to be associated with a radial run-out of 1µm at the main bearing. At the bottom in the figure a section of the deviation curves that arose for the profile and helix of the right tooth flank can be seen. The calculation of compensation sine functions provides a spectrum in which an order of $O_p=56$ appears dominant in the profile. The calculated helix angle of ripple does however exhibit a considerable deviation from the base helix angle. The equation (1) results in the complementary order of $O_h=179$. This helix angle $ß_w$ arises here from the axial movement with which the error pattern generated by the wobble error is shifted.

The surface data calculated in the simulation surely does not correspond to the surfaces generated, as the cutting process is depicted only geometrically without taking into account the considerable influences of forces and the rigidity of the components [2]. It does however become clear that a ripple that matches the noise order is generated geometrically by the wobble in the profile. This ripple can excite the entire system and lead to a vibration that ultimately proceeds according to $ß_w=ß_b$, as suggested by the spectrum of the loud gear.

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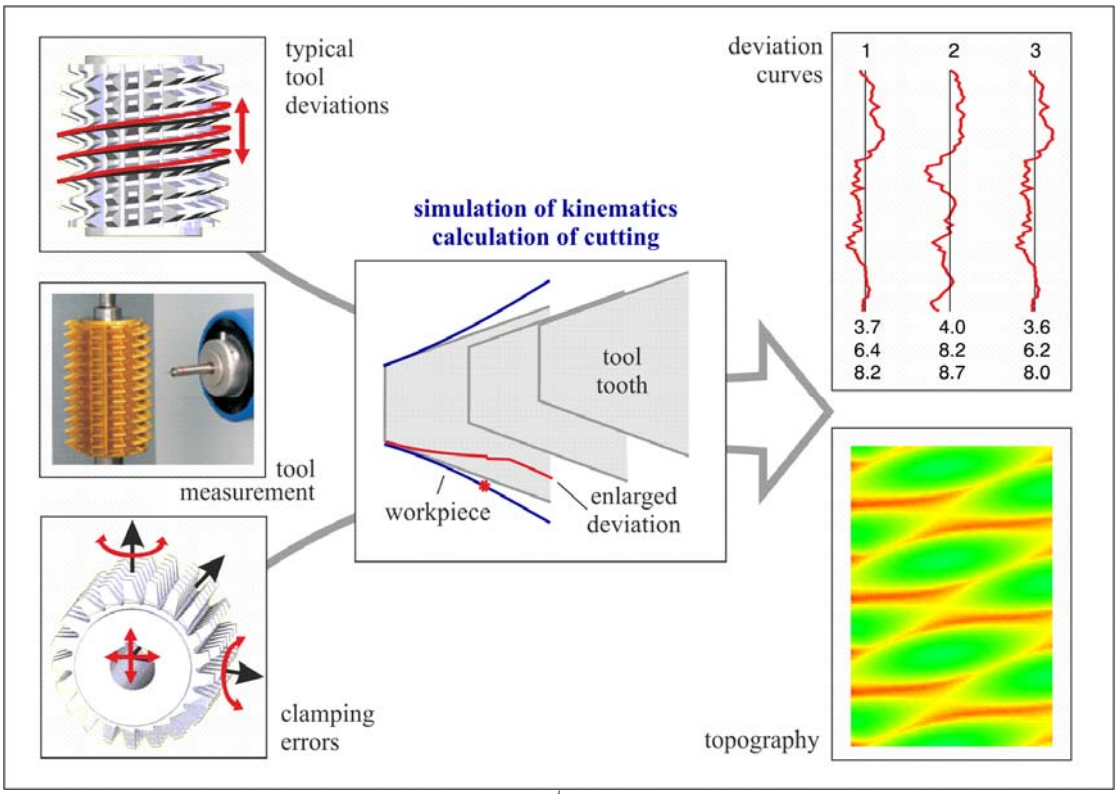


Fig. 8: *Simulation of hobbing and generation grinding.*

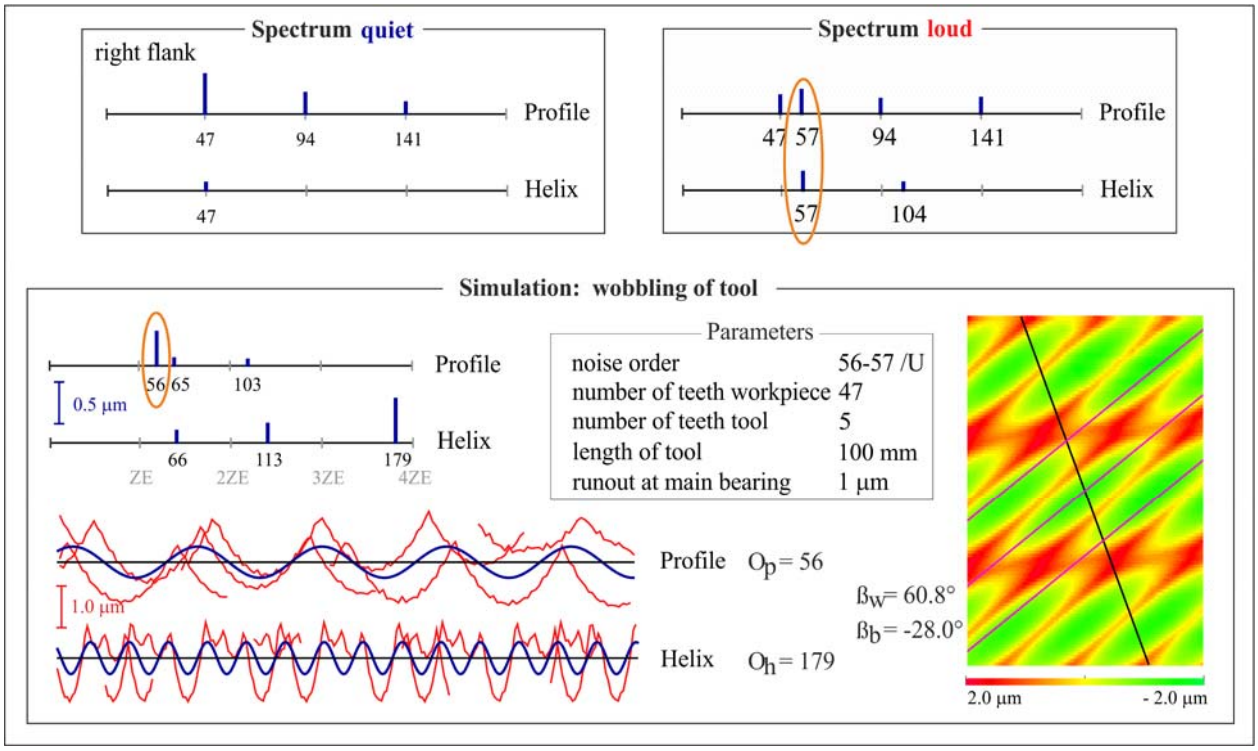


Fig. 9: *Noise Problem with generation grinding.*

6. Conclusions

The examples show how today's users can easily produce comparisons between gear measurements through the use of modern software tools. Ripples can be calculated for the description of periodic structures which very often make it possible to distinguish between loud and quiet gears in everyday practice. The helix angle evaluation of the ripple provides additional information not only regarding the functional effectiveness of the ripple but also regarding the causes of its generation. The deduced relationship between the order of profile and the order of helix allows a better understanding of the shape of the ripples on the surface.

The simulation of deviations for hobbing and generation grinding processes enables a variety of analyses ranging up to the prediction of workpiece deviations based on a hob measurement. Using this software for the study of noise problems indicate, that also small and periodic deviations can be detected. It can be demonstrated in the example shown that a typical tool error will supply an excitation which matches the order of noise. The methods and tools presented are very helpful in connection with the troubleshooting of noisy gears which is very complex and tedious in everyday practice.

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