Kapp Niles Examines Intelligent Rolling Grinding for E-mobility

Martin Witzsch, Freelance Journalist on behalf of Kapp Niles

Fully electric vehicle drives usually require two-stage, non-switchable transmissions. One would think that this greatly simplifies the production. Finally, the described transmission structure has just four gears, distributed on the drive shaft, the second stage with fixed wheel and intermediate shaft as well as the axle drive wheel. But the conditions are not that simple: First of all, the engine speeds of the electric drive with up to 16,000 rpm are much higher than those of the combustion engine.

For this purpose, electric motors deliver an almost constant torque over a wide speed range. Unlike the combustion engine, it is already attached to the transmission from zero speed. In addition, there is an additional boundary condition that makes production much more demanding than with the conventional powertrain.

"A combustion engine masks the transmission noise so that it is not even perceived. An electric motor, on the other hand, is almost silent. At speeds of around 80 km/h or more, rolling and wind noise are the dominant factor, regardless of the powertrain. But in the area below, the transmission noise can be disturbing in electric vehicles. We also have to take this into account when manufacturing the gears," said Friedrich Wölfel, head of machine sales at Kapp Niles.

Of course, the flank load capacity of the gears and good running properties are also in the foreground with electric drives. However, the almost constant torque level and the high speeds require a different design of the gearing, which in turn can affect the noise behavior. Here, the demands are higher than with the combustion engine.

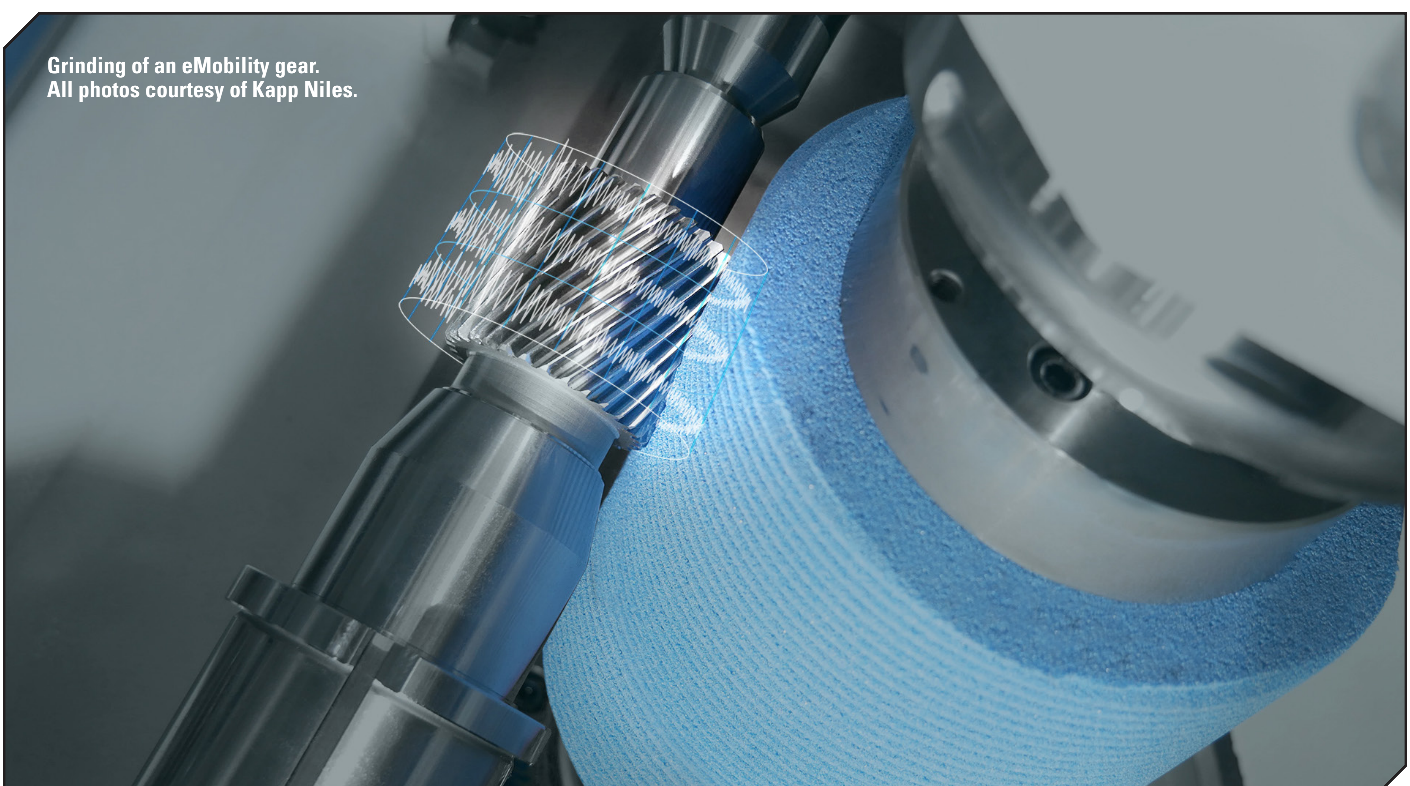
On the other hand, there is no difference between gears for electric vehicles and conventional drives when it comes to the pressure to produce them with maximum efficiency. Accordingly, the highly productive rolling grinding process is also generally used as a fine machining process in the series production of e-mobility gears.

For Kapp Niles the task is to realize an equally productive and, above all, optimized rolling grinding process with regards to the noise behavior.

Tracking down transmission noise

Here are the basics:

"Depending on the structurally defined modifications of the gears such as line corrections, width balls, head retractions, as well as the so-called process-typical profile and line entanglements, characteristic noises are generated in the gearbox during the procedure, which can be assigned to certain tooth intervention



Grinding of an eMobility gear.
All photos courtesy of Kapp Niles.

frequencies," said Achim Stegner, head of pre-development at Kapp Niles. "The entire gearbox, on the other hand, also has characteristic properties with regard to structure-borne noise and radiation, depending on the design. The excitation takes place in the tooth intervention frequency and its multiples. Manufacturers are trying to keep this effect as low as possible by adapting the design of gearboxes and gears."

Initially, these considerations only apply to 'perfect' gears. But of course, like any other mechanical component, gears also deviate from the ideal target geometry in series production. These have different causes and effects, as Stegner explained: "In addition to the stimulation caused by the tooth intervention, there are other disturbances that can lead to noise in the tooth intervention. These make themselves felt as so-called ghost frequencies. These are frequencies that do not coincide with the tooth intervention frequencies and their multiples, and which can also be introduced into the component during grinding."

The causes of ghost frequencies are minimal irregularities that can hardly be completely avoided in series production. It becomes particularly critical when these deviations are mapped almost integers on the circumference of a gear wheel, as this leads to a harmonious excitation. It requires a lot of know-how and process experience to identify the reasons for such irregularities and to avoid them as far as possible in advance.

The cause of such disturbances can be found, for example, in the axle drives of the machine tool used. Electric motors have certain pendulum torques. Measuring systems work with discrete line numbers and finite eccentricity errors from assembly. Finally, the balancing state and spindle bearings can contribute to possible irregularities. Even ripples in the size of 0.1 mm or more can lead to noise when geared.

"Every machine has natural vibrations. For example, the typical natural frequency of a workpiece spindle is about 250 Hz. In the event of an unfavorable speed constellation in the rolling grinding process, this can also be reflected in integers on the workpiece. We can eliminate such effects with our knowledge of the clever selection of a suitable speed window during machining," said Stegner.

Once the optimization potential on the machine side has been exhausted, there are also a number of technological possibilities to improve the component quality with regard to noise behavior. These include the choice of the gear number of the grinding screw, the speed ratio during dressing and grinding, the finishing speed and the feed speed.

Not all errors are the same

Roughly speaking, there are two typical types of defect patterns in gear grinding in the series: On the one hand, trends are emerging that show a continuous change in characteristics. On the other hand, there are individually conspicuous components. Trends are usually easier to master. They are caused, for example, by the gradual wear of a grinding screw. If permissible manufacturing tolerances are exceeded here, it is usually sufficient to shorten the cycle between two dressing processes. They can also be easily detected during component testing by gradually bringing the measured values closer to the tolerance limit.

Component-specific errors, on the other hand, are not foreseeable. They are noticeable by sudden deviations in one or more quality criteria. This can be caused by grinding screw breakouts, blank defects or set-up errors.

Since in highly efficient manufacturing processes such as rolling grinding, the actual machining of a gear wheel takes much less time than the control measurement, 100% of all components cannot be tested. In addition, as described at the beginning, the quality requirements for gears for electric transmissions are extremely high.

"The required tolerances of profile angle, flank line angle, concentricity, two-ball dimension are sometimes smaller by a factor of 3 than in the conventional drivetrain. With the flank line angle error $f_{Hß,}$ a typical requirement is ±4 mm, with combustion engine transmissions this was sometimes ±13 mm," Wölfel described the requirements of his customers. Together with the required machine and process capabilities, these quality requirements are on the edge of what is technically and economically feasible. And even static and dynamic stability of the processing machine and process cannot be increased arbitrarily. The only way out is to start with the analysis and control methods. Otherwise, the following applies: The tighter the tolerance limits become with the same machine/process capability, the greater the number of measured components must be. However, this is associated with great effort. And finally, a downstream component inspection is not adding value.

The closed loop has already established itself as an important tool today. This accelerates and improves the feedback between downstream gear measurement and the processing machine itself. Here, the results of the test are no longer printed out on the measuring machine and made available to the machine operator for evaluation on paper, but are transmitted directly to the processing machine as a standardized file. The grinding machine then independently decides on the basis of preselectable tolerance corridors whether the process needs to be intervened at all, for example with scalable correction values. If unexpectedly high deviations from the target geometry occur, the decision to proceed is then again up to the operator himself (Figure 1).

The arbitrator at the end of the manufacturing process

At the end of the manufacturing process of a complete gearbox, there is a so-called end-of-line test bench. There, not only individual gears are tested for their quality, but fully assembled gearboxes are evaluated. They undergo various test cycles that simulate subsequent operation in the vehicle. The operating noise is also recorded. Through a corresponding evaluation of this data, acousticians can read out intervention conditions, typical frequencies and possible disturbing noises.

"Unfortunately, gearing errors are only noticed at the end of the manufacturing process," Wölfel added. "Then the complete gearbox has to be dismantled, the individual components checked and, based on this, analyzed to determine which component is responsible for the conspicuousness on the test bench. A complete batch of components may also cause problems. However, this is only noticeable when the entire value chain has already been completed."

Today, there are certainly ways to identify components that could cause noise before they are installed in the transmission. A very common method in electric drives is the so-called waviness analysis on gear surfaces. Profile, line and pitch measurements are carried out on all teeth on the gear measuring machine and strung together in such a way that the gear wheel is mapped over its entire circumference. By means of mathematical methods, the ripple on the gear wheel can be detected. However, starting with the complete measurement of the gears, this method is very time-consuming and therefore unsuitable for 100 percent testing in series production.

"The grinding time of typical e-transmission components is less than one minute, while the measuring time is four to six minutes; with an all-tooth measurement as the basis of a ripple analysis even significantly more. And finally, a downstream component inspection is not value-adding. What is needed here is a further development of the in-process analysis, which already allows conclusions to be drawn about the generated component quality during machining," Wölfel said.

Detect possible noise problems already during processing

A promising approach is actually to identify possible errors during grinding. Process monitoring is the 'buzzword.' Stegner explained this approach: "We already have numerous sensors and measuring systems in the machine that can provide us with a lot of signals, measured values and information. At the moment, we only use them primarily to operate the functions of the machine. In the future, however, we also want to use them to assess the machining process directly in the machine."

Figure 1 Tolerance corridors for the closed loop.

However, this does not mean integrating an additional tactile measuring function into the grinding machine in order to achieve a faster closed loop. Nor is it a question of testing and evaluating a ground component directly in the machine and correcting any deviations in the production of further components. The focus is rather on the analysis of the machining process in real time to detect deviations from a previously defined reference process. However, it is not enough to define only envelope curves for signals from the machine. This can be explained by way of example using the signal 'Current consumption of the grinding spindle' in Figure 2. This signal can be used to detect a possible flank line angle error ($f_{Hß}$) at an early stage. "However, the method of envelope detection reaches its limits here, as the error is difficult to identify. As long as the signal remains within the envelope, no alarm is triggered. So, you need a more intelligent form of evaluation. An artificial intelligence that tries to recreate human decision-making structures. He makes decisions from a variety of different information — superimposed with his experience — according to which he acts," Stegner said.

Process monitoring: Intervene before it is too late

Process monitoring can be defined as component-specific monitoring and evaluation of the grinding process. As described, it is not trivial to generate instructions for action from the sensor signals. But it is possible. Various characteristic values can be formed from time signals. In the simplest case, these can be maximum or root mean square (RMS) values of the signals. The characteristic values are then combined with the known project data via algorithms and processed into indices, for example, into a noise or screw breakout index.

"For noise-critical components, an order analysis similar to the order spectrum on an end-of-line test bench can be created via fast Fourier transformation (FFT). This allows the recorded

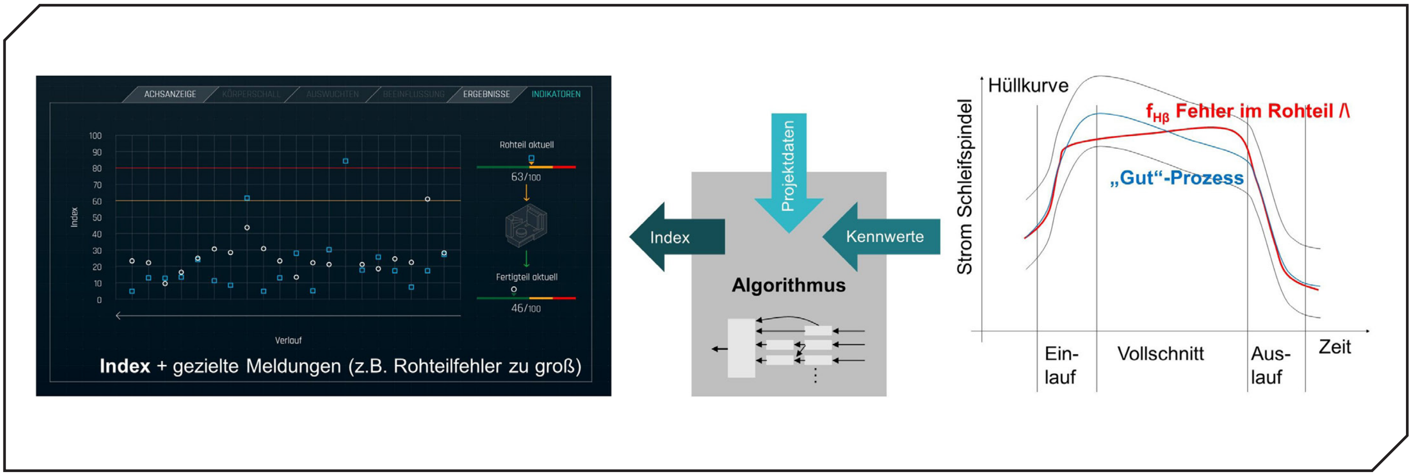


Figure 2 Error analysis and index calculation in the machining process.

signals to be better classified and related to results on the transmission test bench (Figure 3). Nonprepared measurement data have no use," Stegner explained specifically about transmission noise.

In the end, especially in the manufacturing environment, only appropriate indices help to identify very specific errors.

Benefits of process monitoring therefore can be determined by 100 percent testing of all components, the identification of abnormalities still in the grinding process, detection of component-specific errors, targeted reporting of irregularities, adaptive intervention in the process and parts tracking.

Next step: Standardization

Process monitoring is not yet an app that can be easily downloaded and used. Rather, it is a customer- and application-specific development that defines and monitors indices related to the respective component. But even this first step is much more than was thought feasible until recently.

"Several pilot customers are already using this functionality today. We can currently already detect various errors and also intervene on the process side. In addition, we are already working on ensuring that the grinding machine learns characteristic values for new components itself. Of course, this requires broad experience from fault patterns, the geometric quality of the components and corresponding feedback from the transmission test bench," Stegner said.

"The next goal is that the user can use this functionality even without our component-specific support. It is also important to understand that process monitoring, and the closed loop do not contradict each other, but complement each other," Wölfel said.

Both approaches to process-integrated quality assurance are already available for Kapp Niles machines today and are continuously receiving further functional scopes and possibilities of use through the experience gained from series production.

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(Additional edits by Matthew Jaster, Senior Editor, *PTE* and *Gear Technology*)

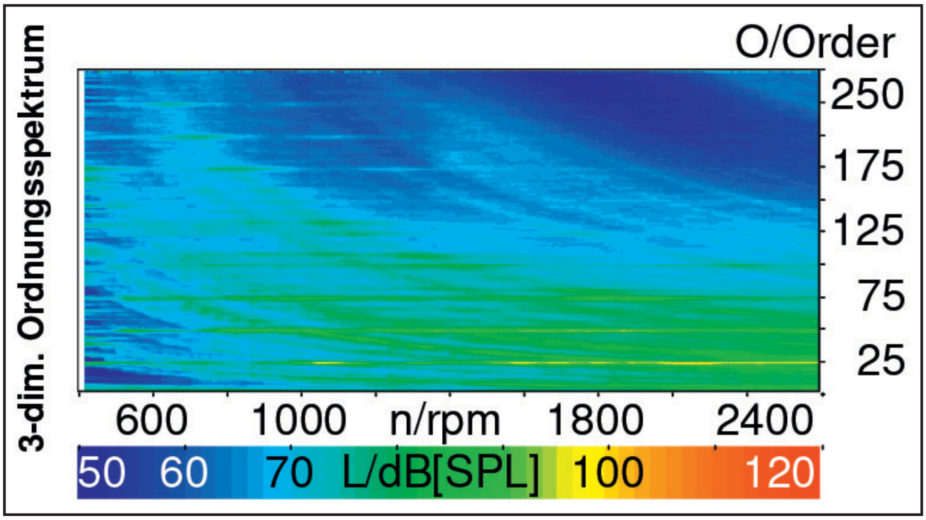

Figure 3 Order spectrum taken on a gearbox test bench.