WHAT'S NEW WITH SPEED VIPER

SPEED VIPER WITH INNOVATIVE FEATURES

Optimally designed for the Industry 4.0 production environment, there is virtually no other machine design that realizes high performance generating grinding in large-scale production better than the Höfler Speed Viper cylindrical gear generating grinding machine. Not only has it earned the trust of the industry, it has also won an iF Design Award. Klingelnberg has now taken this successful platform a step further, with new features focusing on the noise behavior of transmissions and extending the service life of grinding wheels.

Maximum productivity, reliable processes and ease-of-operation are the keys to success for a production system. This is especially true for gear manufacturing, where not only the measurable geometry plays an important role, but so do softer factors such as noise perception. Thus in addition to hardening distortions, many gear experts struggle on a daily basis with higher harmonics and ghost orders that acoustic engineers find in transmissions. And when they do manage to deliver good technical results, they find themselves confronted with the next obstacle: cost pressure.

A Cyber-Physical Production System

With the Speed Viper machine family, Klingelnberg has launched an innovative concept that is embedded in a cyber-physical production system. Complete digitization of the system results in a digital image for every step in the development and production process. This eliminates the need for expensive rework – and creates complete transparency by the way, beginning with the gear design stage. To develop high-performance gears, tooth flank modifications are used to ensure a good noise behavior and high load carrying capacity for all operating conditions in spite of temperature and load-induced deformations of the components. These tooth flank modifications are made based on functional aspects. Exactly how to implement this on an existing machine fleet with the tools available is one of the many challenges in production.

The duality of a cyber-physical production system helps in this respect. The Gear Designer software checks whether the desired, geometrically ideal tooth flank form can be manufactured economically. Based on a manufacturing simulation and the degrees of freedom in the production process, it calculates a tooth flank modification that can actually be manufactured. Of course, there will be discrepancies between this calculated modification and the originally desired modification. The advantage of the Gear Designer software is that it shows the design engineer everything in advance that is bound to happen later on during production. Instead of long, drawn-out and expensive prototype phases, the gears can be analyzed and optimized ahead of time in the design phase. At

HIGHLIGHTS IN BRIEF

Three highlights of the Speed Viper family at a glance:

- The Speed Viper platform is embedded in a cyber-physical production system that enables a Closed Loop for both production as well as development.
- With QSS – Quiet Surface Shifting – the roughness values of the tooth flanks can be modulated to achieve a positive noise behavior.
- Using adaptive shifting, Klingelnberg has achieved a longer service life for the grinding wheel and increased the number of parts that can be ground.

Fig. 1: Klingelnberg's cyber-physical production system

FILM ABOUT GEAR DESIGNER:

Compact

QSS – Quiet Surface Shifting

Evaluating the noise behavior of gears by means of the order spectrum alone simply is not enough. The psychoacoustic parameters of sharpness and tonality are influenced to a great extent by the roughness of the tooth flanks – and this can be modulated in a targeted manner with Klingelnberg's QSS method.

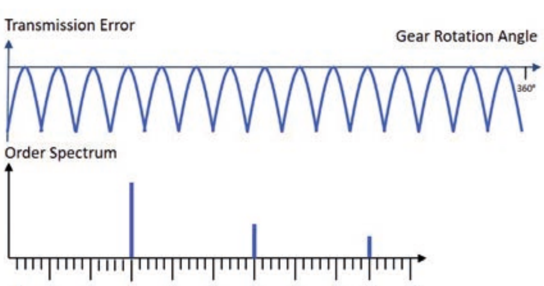

Fig. 2: Transmission error and order spectrum in identical teeth

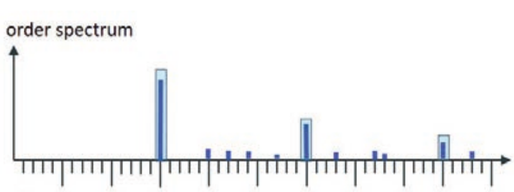

Fig. 3: Order spectrum with ghost orders

the end of the development phase is the digital twin of a toothed gear, which will be able to be manufactured as an actual component in this exact form. Welcome to the world of cyber-physical production systems!

Another advantage of this principle is that the pure production deviation is determined based on the measured data from conventional cylindrical gear measurement. This alone allows the Gear Corrector program to minimize production deviations automatically by calculating corrected setting values for the machine movement or – if required – the dressing process. The result is one Closed Loop for production, which automatically minimizes production deviations, and one Closed Loop for development, which generates tooth flank modifications that are designed for ease of manufacture and to satisfy the requirements.

Now, everybody knows that even with precise toothed gear geometry, noise perception follows a different set of rules. The more precisely a toothed gear has been manufactured, the more prominently individual orders in the spectrum appear. Is the answer therefore to produce toothed gears of poorer quality? This certainly would change the noise perception – but it is doubtful whether this is the right approach. Nevertheless, any consideration of precision must also include a consideration of the technically and economically feasible production tolerances.

Roughness Made-to-Order: QSS – Quiet Surface Shifting

Until now, the tooth geometry has been (and continues to be) the focus of the design considerations: Simulation programs predict the exact way in which the rotary motion of one gear is transmitted to the other. Although practical parameters such as loudness, sharpness, tonality, roughness, fluctuation strength, etc. are now used in psychoacoustics to define the noise perception of a transmission, many experts today still rely on the order spectrum when evaluating noise behavior. To do so, the deviation from the rotational error-free transmission is converted to an order spectrum by means of a Fourier transform. Here, the first order corresponds to one rotation of the toothed gear to be evaluated. Accordingly, the spectrum will consist only of orders of the number of teeth and its multiples – provided all teeth have an identical geometry and there are no run out deviations.

Figure 2 shows an example of this: A toothed gear has 15 identical teeth and exhibits no run out. Consequently, the order spectrum shows the 15th order and its multiples. The amplitude of these orders depends on the profile of the transmission error.

One aspect that has been neglected in the analyses up to now is the surface quality of the tooth flanks. How do different roughness characteristics affect the order spectrum? Without entering into a philosophical debate about whether roughness should be interpreted as a geometric modification of the tooth flank or simply as an aspect of surface quality, roughness is characterized by the presence of a slightly modified behavior of the tooth contact and thus a different transmission error.

This effect is demonstrated in figure 3: The amplitudes of the original higher-harmonic orders have become slightly smaller, and the order spectrum exhibits its so-called ghost orders. By definition, ghost orders are orders that cannot be divided by the number of teeth. The energy that was previously in the higher harmonics only is now distributed across several orders. This is why the noise perception changes, since the way in which the higher harmonics are perceived is influenced by the ghost orders. This effect manifests itself in improved psychoacoustic characteristics of sharpness and tonality.

So how can a stochastic change in roughness characteristics be achieved on the tooth flanks? The answer lies in the dressing process. The roughness of the tooth flanks is determined by the properties of the grinding worm, which can be influenced by the dressing process. By changing the speed ratio between the dressing roll and the grinding worm, the properties along the axial expansion of the grinding worm can be modulated.

In the Speed Viper machines, the variation in speed ratios between the dressing roll and the grinding worm is not realized simply by modulating the dressing roll speed, but rather by modulating the shift speed. Of course, to obtain the correct form of the grinding worm, its angle of rotation must be controlled as a dependent variable based on the shift position. The desired modulation of the grinding worm properties can thus be achieved in this way. The fixed kinematic link up between the shift position and the angle of rotation position of the grinding worm is realized in the machine's control unit. The accuracy of this kinematic link up is always limited. This may seem disadvantageous at first glance – but on closer examination, it reveals itself to be a further advantage of this method. This is due to the fact that the smallest inaccuracies in the kinematic link up produce tiny geometrical errors, which are distributed along the grinding worm. As a result, each tooth looks slightly different and the tooth meshes are therefore no longer absolutely identical. Accordingly, the transmission error is subject to extremely small variations. This has a positive effect on the noise perception.

The result is illustrated in figure 4: Side bands to the higher-harmonic orders are produced by the small geometric inaccuracies. Orders below the first tooth-mesh order also occur, as they otherwise stem from run out. The psychoacoustic parameters of sharpness and tonality decrease. Klingelnberg has named this method QSS – Quiet Surface Shifting. Although the purely physical sound field parameters undergo only negligible changes, the human perception of the sound is significantly more pleasant nonetheless. The inaccuracies generated with QSS are not the result of chance, however. They are instead measures that can be used in a targeted manner to improve noise perception.

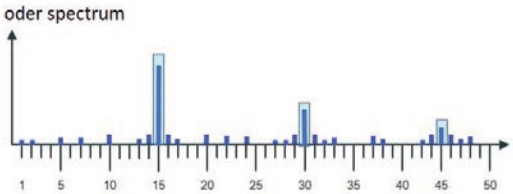

Fig. 4: Order spectrum with modulated roughness and minimally different flank topographies

Adaptive Shifting Makes the Tool Last Longer

The third specialty of Klingelnberg's generating grinding presented here is aimed at reducing tool costs. The shift strategy is typically designed to ensure the process reliability of grinding with the smallest grinding wheel diameter. This fixed shift strategy is also used for a new, unused grinding worm. Figures 5 a and 5 b illustrate the conditions on a single-thread grinding worm. Shift-

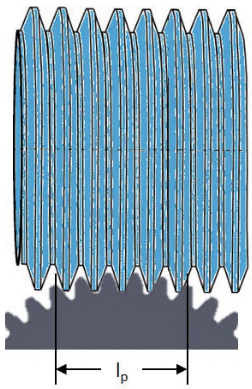

Fig. 5 a: Profile development zone on the grinding worm

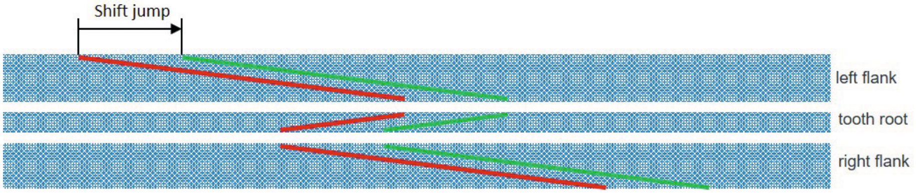

Fig. 5 b: Active grinding grains and shift jump

Changing the shift strategy to adaptive shifting reduces tool costs by over 18 percent.

Shift distance:	$s_w = s_v \cdot \frac{g}{z}$
Lead angle:	$\tan(h) = 2 \cdot \frac{\pi \cdot m}{D}$
Helix distance:	$\frac{s_w}{\sin(h)}$
Meshing density	$d = \frac{\sin(h)}{s_w}$

s_v	Shift ratio
g	Number of starts on grinding worm
z	Number of teeth on workpiece
m	Module
D	Outside diameter of grinding worm

Compact

Adaptive Shifting

The idea of adaptive shifting changes the shift ratio and the shift jump in such a way that the same technological parameters are always given, regardless of the grinding wheel diameter. Klingelnberg has introduced the meshing density as the key parameter. (See formula to the right.)

ing is divided into two categories: shift ratio and shift jump. Whereas with the shift jump, the grinding worm is shifted axially by a specific amount before the next component, with the shift ratio, the grinding worm is shifted continually with each revolution of the workpiece.

The axial length l_p of the grinding worm's profile-defining area is independent of the diameter, but its length of development is not. The lines shown in red (see figure 5 b) indicate which abrasive particles are active during machining of a toothed gear. A larger shift ratio is reflected in the development diagram by a greater length and flatter inclination of the lines. With a shift jump, the lines of consecutively ground toothed gears are shifted in parallel to each other.

The idea of adaptive shifting changes the shift ratio and the shift jump in such a way that the same technological parameters are always given. Klingelnberg has introduced the meshing density as the key parameter. The shift ratio is a good example of the adaptive shifting principle: Shift ratio s_v is the shift distance per workpiece revolution. Shift ratio s_v is initially converted to a shift distance s_w per tool revolution. Based on this, the helix distance per tool revolution can be determined. The meshing density is then the inverse value of the helix distance per tool revolution.

Meshing density d therefore indicates how high the load of the abrasive particles is on a millimeter flank length of the grinding worm. A constant meshing density d is assumed for adaptive shifting. Meshing density d is calculated for the proven shift ratio s_v at the smallest grinding worm diameter D_{min}. Using specified formulas, shift ratio $s_v(D)$ is then calculated for the given meshing density d.

What exactly does this achieve? The extent to which the grinding worm's service life actually improves is illustrated with an example (see table 1): If the grinding worm has always been dressed after 80 parts with a shift ratio $s_v = 0.3$, a shift ratio $s_v = 0.205$ can now be used with a constant meshing density for the grinding worm with maximum diameter. This new shift ratio increases the number of parts before a dressing process is required from 80 to 117 for the respective shift ratios. With an average of 98 for the entire service life of the grinding worm, the number of parts that can be ground with one grinding wheel improves.

FILMS ABOUT ...

... Speed Viper with dual-spindle concept

... Speed Viper

If a dressing amount of 0.25 mm is used, the grinding worm in this example can be used 196 times in total. Thus with adaptive shifting, the tool cost decreases by over 18 percent (see table 2), with absolutely no technological risk involved. In addition, the processing time is reduced on average, since the dressing frequency is significantly lower from the start.

Three Advantages out of Many

The special features of the Speed Viper concept presented here offer the greatest possible support in day-to-day production with respect to the challenges mentioned at the outset – maximum productivity, reliable processes and ease-of-operation. All features of the Speed Viper family are designed to realize high-volume generating grinding in series production in an Industry 4.0 environment, with a focus on cost-effectiveness. ◆

Gearing Example		
Number of teeth	z	29
Face width [mm]	b	40
Module [mm]	m	2.5
Number of starts on grinding worm	g	5
Smallest grinding worm diameter [mm]	Dmin	210
Largest grinding worm diameter [mm]	Dmax	308
Shift ratio [mm/workpiece revolution]	sv(Dmin)	0.3
Number of parts before dressing		80
Meshing density	d(Dmin)	1.441
Shift ratio [mm/workpiece revolution]	sv(Dmax)	0.205

Table 1: Sample calculation of the service life of a grinding worm

	Constant Shifting	**Adaptive Shifting**
Grinding wheel diameter 210 mm	s_v = 0.300 mm	s_v = 0.300 mm
Grinding wheel diameter 308 mm	s_v = 0.300 mm	s_v = 0.205 mm
Radial dressing amount	0.25 mm	
Number of parts before dressing	80	117 … 80
Number of parts per grinding wheel	15,680	19,208
Tool service life	**100 %**	**122.5 %**

Table 2: Constant versus adaptive shifting

Dr.-Ing. Hartmuth Müller

Head of Technology & Innovation,
KLINGELNBERG GmbH