

ARE YOU USING IDEAL CUTTING PROCESSES? GRAPHICS-SUPPORTED OPTIMIZATION MADE EASY!



Highly productive cutting processes with extremely high, reproducible gear quality – the result of optimal interplay between innovative cutting tools and powerful Klingelnberg C-series bevel gear cutting machines. The cutting process is the link between the two elements.

Steadily growing competition and the related pressure, particularly in the automotive industry, call for cost-effective manufacturing in the face of increasing quality requirements in all areas, including bevel gear machining. This is why it is essential to exploit the full potential of all components involved in the process.

With simple processes, adaptive infeed regulation makes it possible to regulate the feed rate based directly on the drive utilization in order to utilize the machine capacity in the best possible way and therefore reduce the cycle time. However, due to the extremely complex production kinematics involved in bevel gear cutting, the cutting conditions are constantly changing during the process. "Simple" infeed regulation based solely on the spindle utilization and without adequate analysis or knowledge of the process sequences is therefore not optimal. Thanks to the continuous development of the Klingelberg machine operating software, users can now gain an insight into the process flow. This insight allows technologists to record the machine load and correlate it with the process sequences. The machine response to process changes can be precisely analyzed and tracked in this way. A new basis on which to optimize highly productive cutting processes has been created.

STATUS QUO

Adaptive infeed regulation for bevel gears – not optimal!

- Limited vision
- Adaptive modification
- Limited understanding

The new operating software supports the interaction between innovative cutting tools and the powerful bevel gear cutting machine C 30. Highly productive cutting processes with extremely high and reproducible gear quality are the result.

"Make-or-Break" Points of the Process Optimization

What are the hallmarks of an optimal cutting process?

1. The component quality corresponds exactly to the requirements.
2. The machining time is minimized.
3. The gear cutting tool lasts for as long as possible.
4. The most favorable situation has been found in terms of machine costs and tool costs.

This is a very simple "check list" at first glance. But when it comes to optimizing the bevel gear cutting process, conflicts often arise between objectives and technical implementation. If you want to improve the process, you must keep two objectives clearly in mind: higher productivity and improved process reliability. This will allow strict requirements for geometric component accuracy (pitch and topography) to be fulfilled in a reproducible and reliable way – without compromising the surface quality of the tooth flank as a measuring surface. However, higher productivity requires an increase in the machining parameters – and precisely therein lies the conflict. Increased machining parameters tend to worsen the wear behavior of the tool and increase the risk of damaging the flank surface due to surface defects such as scratches or even welding marks. Of course, this must be avoided at all costs.

Compact

Time is Money

Saving process time requires precise knowledge of the sequences and the conditions prevailing in the contact zone between the tool and the workpiece during gear cutting.

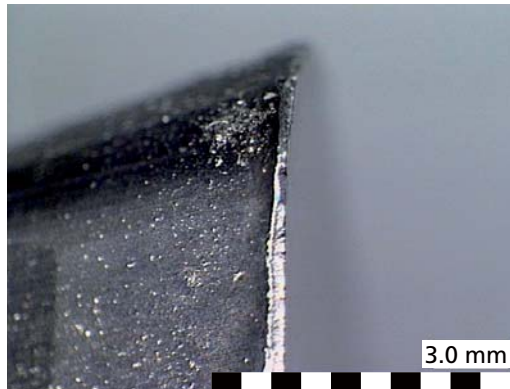


Fig. 1: Tool wear as a limiting factor for ring gear cutting



Fig. 2: Scratches on the surface during pinion cutting

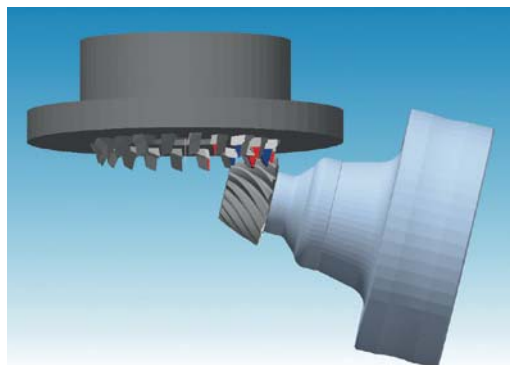


Fig. 3: Simulative process analysis

Limits of the Process Design

The options for optimizing a bevel gear cutting process are limited by various factors. The first of these to set a limit always depends on the component type and the different process characteristics associated with it: For non-generated components, i.e. ring gears only, it is the wear on the tool (see Figure 1). For generated components, i.e. always pinions but often ring gears as well, it is often the formation of surface defects which sets the limit (see Figure 2). The wear situation of the tools is another restriction. The cutting machine, on the other hand, plays a subordinate role in the majority of cases.

Getting the Most out of the Process: Empirical Evidence ...

In order to achieve an optimal result, experienced technologists or machine setters monitor the shape of the chips that are produced during the process directly on the cutting machine. They also maintain a basic overview of the machine load, the tool wear, the and flank surface quality attained that is at the end of the process. Changes to the process parameters are made based on experience, in conjunction with the subjectively assessed variables.

... or Simulation?

Alongside this empirical process analysis, there is the simulative process analysis: Here an experienced technologist can display and analyze a number of different process sequences at an office workplace, depending on the software that is available (see Figure 3). This process is relatively complex and is performed in theory only – many users have no access to appropriate software or there are no staff with the required specialist knowl-

"For every one of our customers, we develop the right solution to achieve the optimal cutting process."

Jürgen Weber, Application Engineering, Bevel Gear Technology Center

edge. The values determined by simulation must still always be verified by means of practical use.

Preferably Both!

The control units in modern CNC machines allow precise recording of signals. This makes it possible to collect and store various types of information at any given point in a process. The task is to identify which key criteria should be used to define a process as optimal. Whereas the "machining time" criterion is easy to read off at the end of the process, the "flank surface damage due to surface defects" criterion is more difficult to assess and evaluate. This is because the wear on a tool changes throughout its service life, and material batch influences also play a part. The most difficult criterion to evaluate is tool load and the resulting cutting edge wear. Contrary to many other machining processes, in the bevel gear cutting process, the contact situation of the tool cutting edges changes continually throughout the process sequence. The load on the cutting machine also varies accordingly. The special feature of this process is that the resulting tool wear that occurs varies in appearance along the entire cutting edge because of the local loads.

The only way to utilize information from the machine control unit as a basis for evaluating the cutting edge wear is by means of normalization. This juncture is where empirical evidence, i.e. measurements taken on the machine, meets theory, i.e. an analysis of the cutting edge length involved in the cutting process.

Process Optimization with Smart Process Control

Recording the utilization of the tool spindle helps with optimization as well as the monitoring of the process sequences.

The processes are defined by interpolation points from the working position and feed rate. Varying these parameters brings about a change to the tool spindle utilization.

The software, which is directly available to the user on the machine, makes it possible to carry out precise visualization of the machine load for every machining situation. The process sequence can therefore be assessed and easily understood at a glance. An experienced Klingelberg technologist will be happy to provide a short training session; the machine user will then be able to analyze and optimize his processes independently using Smart Process Control.

Automatic real-time logging of the spindle utilization (for a meaningful number of workpieces) also makes constant process monitoring possible. Data can be measured and evaluated throughout the entire process sequence. Noticeable variations in the spindle utilization provide clues to material irregularities or changes to the wear characteristics of the tool.

In the Field

After the initial plunging process and subsequent roughing-generating, finishing-generating is the final step in bevel gear cutting. Figure 4 shows the plotted utilization curve (in blue) of the tool spin-

INNOVATION

Klingelberg Smart Process Control provides:

- Extensive vision
- Good understanding
- Targeted optimization

ABOUT SMART PROCESS CONTROL

- Ability to analyze tool spindle utilization for an entire process sequence
- Precise correlation of spindle utilization and working position directly on the machine
- Automatic utilization curve recording for a selectable number of manufactured bevel gears
- Convenient evaluation of recorded data from the workstation using standard Office programs
- Software can be purchased as an option for the C 30
- Operation training provided by Klingelberg technologists

dle used in a finishing-generating process. The main focus during machining is on component accuracy, since this gear set in the example is manufactured using the continuous method and then attains its final quality by means of lapping after the heat treatment.

The process to be optimized (see Figure 4) starts with a plunging operation (I) at a working position of approximately 312°.

Once the tool has reached its working depth, it generates an initial area of the tooth flank (roughing-generating, II). After a short infeed (III), tool utilization then takes place for finishing-generating the gear teeth. The tool begins the finishing-generating (IV) at a generating angle of 321° and ends at a generating angle of approximately 300.5°. When doing so, it rolls through the roughing-generated area. The load increase around the 312°

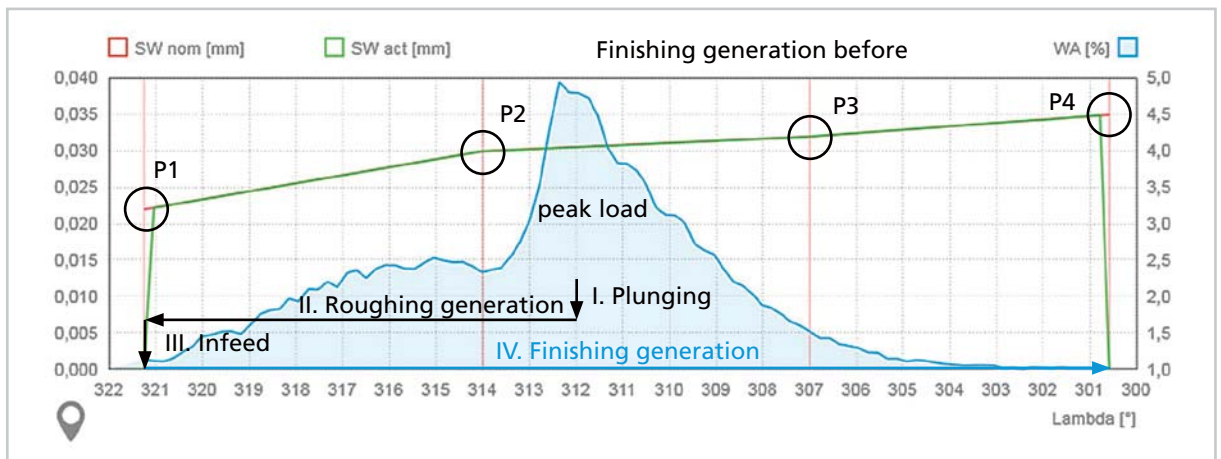


Fig. 4: Tool utilization curve **before optimization** (blue) finishing-generation process

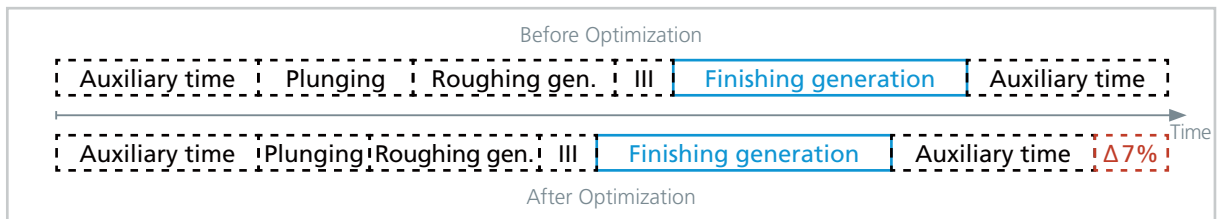


Fig. 5: Processing time

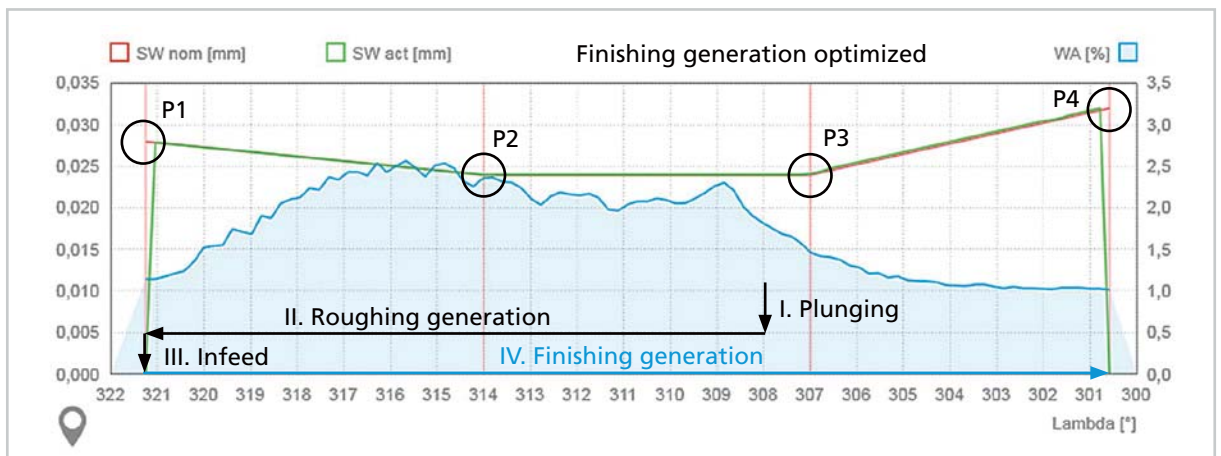


Fig. 6: Tool utilization curve **after optimization** (blue) finishing-generation process

generating angle is clearly visible; this is the result of the transition from the roughing-generated area to the non-generated area.

A measurement of the component under observation showed conspicuous features in the flank topography that were situated precisely in the area of the load increase, i.e. at 312°. The working position for the plunging operation was then moved to 308° in order to enlarge the roughing-generating area (see Figure 6). The interpolation points P1 to P4 were also adjusted by entering suitable feed rates.

The result is spindle utilization that is much more uniform during finishing generation, without a local load increase and with a normal flank topography. On this basis, it is now possible to raise the uniform load level by shifting the interpolation points P1 to P4 at the same time, thereby achieving a shorter machining time. The use of Smart Process Control also makes it possible to increase the feed rates for the plunging and roughing-generating area in a controlled way. In total, a seven percent reduction in productive time was achieved in this example process, as illustrated in Figure 5.

Reduce Your Auxiliary Time!

Machining time is comprised of productive time and auxiliary time. Higher cutting parameters decrease the productive time.

HOW KLINGELNBERG OPTIMIZES CUTTING PROCESSES

Checklist for best results:

- Record and analyze the actual condition
- Reduce auxiliary times by minimizing traversing paths
- Reduce productive times by optimizing the cutting parameters
- Ongoing inspection of component and surface quality, as well as tool behavior

When optimizing process parameters, however, it is essential to take into consideration the development of tool wear and the surface quality of the teeth. Auxiliary time optimization is therefore the priority, since the auxiliary time does not negatively impact component quality or tool wear. The correctness of the auxiliary movements should subsequently be checked, depending on the process sequence that is ultimately determined. ◆

NEW POTENTIAL

Result of optimizing the example process:

- Improved quality
- Seven percent reduction in productive time
- Even loading



Dipl.-Ing. Karl-Martin Ribbeck

Head of the Bevel Gear Competence Center,
KLINGELNBERG GmbH