CLOSED LOOP MACHINING OF CYLINDRICAL GEARS

Looking to raise the quality and accuracy of your gearing? Consider Closed Loop design and manufacturing, which has done away with the error-prone data transfer from the measuring sheet.

By Dr. Markus Brumm

Leonhard Euler's 1760 invention of making cylindrical gears with an involute profile was the beginning of a success story. As a tooth profile, the involute has many advantages that are still being used by engineers to design high-performance transmissions that even function under high loads and the consequential deformation of the shaft bearing system.

However, the convention of designing cylindrical gears with an involute profile also represents an obstacle for innovative solutions. For many years, the CAD-CAM process has been state-of-the-art in the metal-cutting production of general components. The workpiece is first described as a 3D model, and tools are then selected and NC files generated in the CAM process that follows. The digitally described workpiece is then produced on the machining tool on the basis of these files. This principle cannot be used with cutting machines because the gear is not described as a 3D model.

Based on the theory of involutes and other curves for gear drives proposed by Euler, a gear is always described by the geometry of the tool edge and a relative motion between this tool and the gear to be produced. Even though we now have five-axis machining principles capable of producing gears, this particular gear description is always the basis, and therefore the reason for the special nature of the cutting machine species.

Learning from Bevel Gearing

The geometry of bevel gears is not based on the involute, but on the octoid. A clear description of the flank profile requires a description of the gear geometry based on the tool profile and the manufacturing kinematics. For this reason, Klingelnberg has been applying the core idea of Industry 4.0 to bevel gear manufacturing since the early 1990s and has created a cyber-physical system that produces digital images of the gear along the entire value creation chain, therefore making it possible to introduce objective quality gates.

Figure 1 shows the value creation chain of a bevel gear set. It starts with the engineering of the gearing, which also includes the material specification. The gearing is first optimized in order to comply with the required specification in a given environment consisting of bearings, gear housing, and operating conditions. The result is a digital twin of the bevel gear, which does not just contain all of its geometrical information; due to the particular nature of a bevel gear's description, all of the information about the tool and the description of the manufacturing movement of a virtual cutting machine is present for both soft machining and hard machining. This data is automatically supplied by Klingelnberg's KIMoS program system, and represents the digital backbone of all stages of manufacturing. Horizontal integration of all machines and program systems involved in the process has been realized in this way, whereby the central database contains the digital images and the geometry-determining technological parameters for every stage of manufacturing.

Unlike bevel gear manufacturing, which is based on a database system, paper is the dominant data medium in cylindrical gear manufacturing. This simple and
seemingly unambiguous description means that toothing data still has to be manually entered into cutting machines and measuring devices multiple times. The many manufacturers of cutting machines and measuring devices have not been able to agree on interfaces for data communication to date.

**CLOSING THE LOOP**

The seemingly simple description of involute gearing leads to a false sense of security. Ultimately, mistakes occur during manual data transfer. Not least because the DIN, VDI, and ISO standards can differ in key points. One example is the sign for the lead angle deviation $\beta$, which can have opposing signs. The value of the respective parameters also depends on the underlying evaluation section, meaning that a parameter is only unambiguous if the evaluation section and the applied directive are specified. Misunderstandings and erroneous entries are commonplace due to this heterogeneity. Many users counter these errors by defining additional in-house conventions. Dealing with the error susceptibility of the antiquated data transfer from paper with additional processes unnecessarily complicates the transfer of the measuring results to cutting machines. Klingelnberg has therefore developed a Closed Loop for cylindrical gears based on the Closed Loop that already exists for bevel gears. The aim was to realize a robust and fault-resistant transfer of the gearing deviations determined on a Klingelnberg measuring device to production machinery.

To do this, it was necessary to clearly characterize the information on the measuring sheet and to transfer it via a general and open interface. Closed Loop for cylindrical gears uses the Gear Data Exchange (GDE) format. This format, which was defined in VDI/VDE guideline 2610, was chosen to ensure that measuring results could be transferred to the cutting machines of every manufacturer. The measuring sheet is incorporated in the production network in *.xml format.

The measuring procedure is carried out as shown in Figure 2. The component that is manufactured on a cutting machine is measured on a Klingelnberg measuring machine. When the measurement is complete, the digital measuring sheet is saved on the server. From there, it is transferred to the cutting machine, which must have an appropriate import function.

The Klingelnberg Gear Production machine software already has the functionality for reading in the digital measuring sheet. In the practical implementation of Closed Loop for cylindrical gears, there are a number of points that must also be taken into consideration in addition to those already mentioned. In many cases, customers have several measuring devices and several cutting machines. This makes it necessary to identify which digital measuring sheet must be assigned to which process and which machine. Before the measurement takes...
The measurement task is assigned to a production order by entering the order number and the serial number. This information was sometimes also entered to designate the measuring sheet and is stored in the digital measuring sheet and the file name.

The cutting machine on the shop floor therefore recognizes associated measuring results. The system actively notifies the operator that new measuring results are available for the current production order. During production, the machine operator can identify which gearing parameters need to be corrected based on a diagram. The parameters are color-coded and displayed for this purpose in the tolerance field on the machine control panel. A new machine setting is calculated at the touch of a button when the next component change takes place.

The first step in introducing a digital production system for cylindrical gears has therefore been taken. Closed Loop has done away with the error-prone data transfer from the measuring sheet.

The current version can be used for external and internal gearing. The system also recognizes inverted measurements compared with the clamping in the machine, and transfers the measuring results in a context-related way. But this is just the beginning. The bigger challenges exist in the manufacture of non-involute gearing or the production of topological modifications. The Klingelnberg Closed Loop for cylindrical gears is just at the beginning of development into an Industry 4.0-compliant production system.

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