

INDUSTRY 4.0 FOR GEARS



Klingelberg has long focused on the development of integrated systems for gear production. Assistance systems such as the Closed Loop support efficient, reliable process control in both bevel gear and cylindrical gear production. For total integration of all process information into the complete cyberphysical system in line with Industry 4.0, Klingelberg is now making available for the first time a powerful shared information infrastructure – GearEngine®. SmartTooling for identifying operating resources is the first of many modules with a growing performance range.

Industry 4.0 means production facilities that exist not only in the real world but also, with their digital twin, in the digital world. This gives rise to a bidirectional system: Data from the real world is mapped to the digital twin and analyzed. Actions are identified based on this, and these in turn are implemented in the real process. The result is a self-learning, self-optimizing, and self-controlling production system. Changes in and information about the real process affect the digital twin, and vice versa.

Closed Loop: tried and tested in bevel gear production ...

In modern bevel gear manufacturing, the Closed Loop has been an established part of Industry 4.0 for many years. The geometry of gear pairing, the machine kinematics required to produce this geometry, and the necessary tool geometry are designed and optimized in a virtual production simulation – to then serve as the basis for manufacturing and quality assurance of the tools and the bevel

gear system itself. The measuring results for the manufactured gearing are the prerequisite for optimizing the machine kinematics. All information used in the process is available in digital format and documents the history of the component geometry and machine kinematics. Secondary processes such as deburring are also designed through a virtual manufacturing simulation.

... and new in cylindrical production

And so it was, and is, time to develop and establish a comparable system for manufacturing cylindrical gears. Klingelberg has systematically adopted this approach for developments in generating grinding of cylindrical gears.

Unlike bevel gears, gear geometry design for cylindrical gears takes a function-oriented approach, without taking into account a potential manufacturing process. This is where the new developments come into play: A manufacturing simulation that virtually represents grinding worm dressing and, subsequently,

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Closed Loop

In bevel production, a digital connection between the production and measuring machines via the appropriate software has enabled fully automatic correction runs for many years. This Industry 4.0 standard is now establishing itself for the generating grinding of cylindrical gears – though on a fully new technical basis.

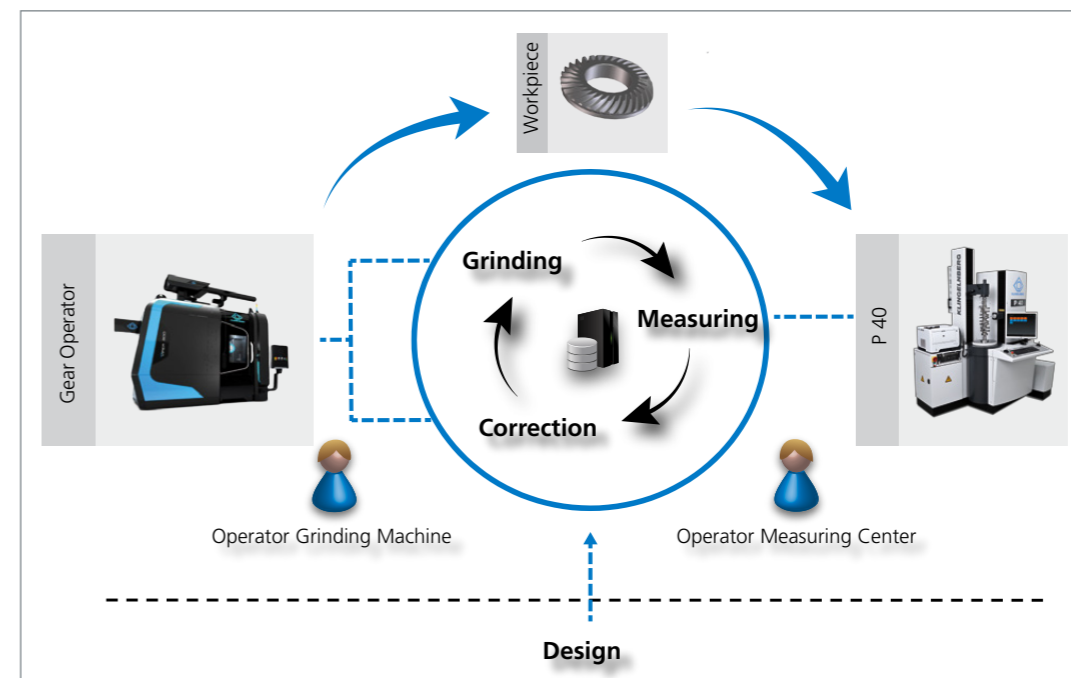


Fig. 1: Closed Loop

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Gear Operator: next-generation production control

To operate the Closed Loop on the Speed Viper cylindrical gear grinding machine, a newly developed graphical user interface is used with Gear Operator; this interface allows interventions in the overall process and parameter modifications to be made parallel to the grinding machine control.

generating grinding with this exact tool geometry is used to determine an initial approximation of the producible geometry. This is then compared with the function-oriented geometry; resulting deviations are analyzed and reduced, if necessary, in one or more optimization loops. If the specified tolerances are met, the data is approved for production. The production process is then carried out in a Closed Loop, in a process comparable to that of bevel gears (see Fig. 1, pg. 13).

Agility and transparency thanks to distributed intelligence

In addition to intelligent, predictive process control, a particular prerequisite for the successful performance of this type of feedback optimization loop is the immediate information of the controlling station, as well as the availability of a comprehensive range of interaction options allowing for specific actions aimed at influencing the production process. For this reason, the long-familiar, well-established Höfler graphical user interface has been upgraded to the next-generation Gear Operator software for the Speed Viper – the youngest and most agile member of the Klingelberg family of cylindrical gear grinding machines. Thanks to a new, modular architecture, an intuitive and dynamic user interface, and numerous in-

terfaces, Gear Operator can now provide its strengths for higher-level and parallel systems as well as utilizing the services of other applications. For integration in the Closed Loop described above, this occurs through messaging and assistance systems operating independently of the machine control unit: As soon as new measurement information is received from the measuring machine connected via the production network, the operator is alerted by a graphical element, the so-called “toast notification”, and can then immediately view further detailed information and, if necessary, intervene directly in the production process. This is possible regardless of where the machine currently is in the production process. Thus, unlike with other, conventional graphical user interfaces, the operator is able to intervene in a operator guidance operating in parallel, that is, to decide when to see what detailed information and what actions to perform or to configure for later performance.

The operator can not only see how the selected measurands have developed within the specified tolerance interval, but can also choose to view how various correction strategies are likely to play out – and, with this information, control the further production and testing process to achieve the best possible outcome. Disconnecting the control of the overall process from the grinding machine control now also offers the possibility of offering such functions on other terminal devices, such as mobile devices.

GearEngine®: the ultimate in data and process management

Requirements in the age of Industry 4.0 go far beyond this, however: It's not “just” about ensuring the necessary workpiece geometry – it's about traceability and optimization of the complete



Fig. 2: Process control with the integrated Closed Loop system

process. This includes identification of the necessary tools and clamping devices as well as complete traceability of production conditions and the quality of each and every workpiece. The solution to this is the currently evolving Klingelberg GearEngine®: It is THE pivotal element for data acquisition and saving, as well as for communication management. The fundamental idea is to save data for manufacturing and quality assurance, data on the tools and production equipment in use, and a complete parts history in individual databases. GearEngine® provides all this information by means of various interfaces, so that it can be used for analysis of any type of evaluation in the appropriate applications. (See Fig. 3) This gives rise to an entire range of possibilities for analyzing previously unknown relationships in production, identifying their effects on the quality of individual components, and intervening with corrective action. Thus it will soon be possible to analyze, based on the data acquired, the relationship between the status of a tool spindle main bearing and the service life of the tool. Of course, appropriate actions can be identified on this basis and implemented in the system.

Complete documentation of all data provides both a digital twin for every component produced and 100 percent traceability. The user benefits from this on many levels: Relationships can be identified, the production process becomes more easily predictable and reproducible, and it can thus be better controlled. Additional advantages arise because dedicated applications for analysis and optimization can easily be adapted through clearly defined interfaces.

GearEngine® and Gear Operator – a combo with countless possibilities

There are numerous variables – so let's get started! In particular, the varying properties of the machine environment and the changing dimensional accuracy of the used tools influence the workpiece quality in practice. Add to this a rapidly growing number of measurands thanks to advances in sensor technology and declines in hardware costs; these can be used as indicators for various process disturbances. The most important representatives of these would be loading and imbalance of the tool spindle, as well as temperature or acceleration values. The collection and exploration of these large data volumes thus reveals tremendous potential, hardly utilized until now, for sustainable quality improvements. However, the largest data volumes only divulge the information inherent within them when data, statuses, and process steps are associated with each other and can thus be correlated. This is where the machine control software takes on a key role as the central hub and interface between humans, the machine, and the database: It links imported tool identification to subsequent process steps as well as to the associated measured data for the relevant machine parameters. It thus provides the opportunity for evaluating applications to display

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GearEngine®

Complete traceability of production conditions and the quality of each individual workpiece, down to the exact identification of the tools and clamping devices used – it's the job of GearEngine®, the central element currently in development, to collect, evaluate, and save this data volume.

For Klingelberg, Industry 4.0 covers the complete traceability of all processes and production conditions, including the tools used.

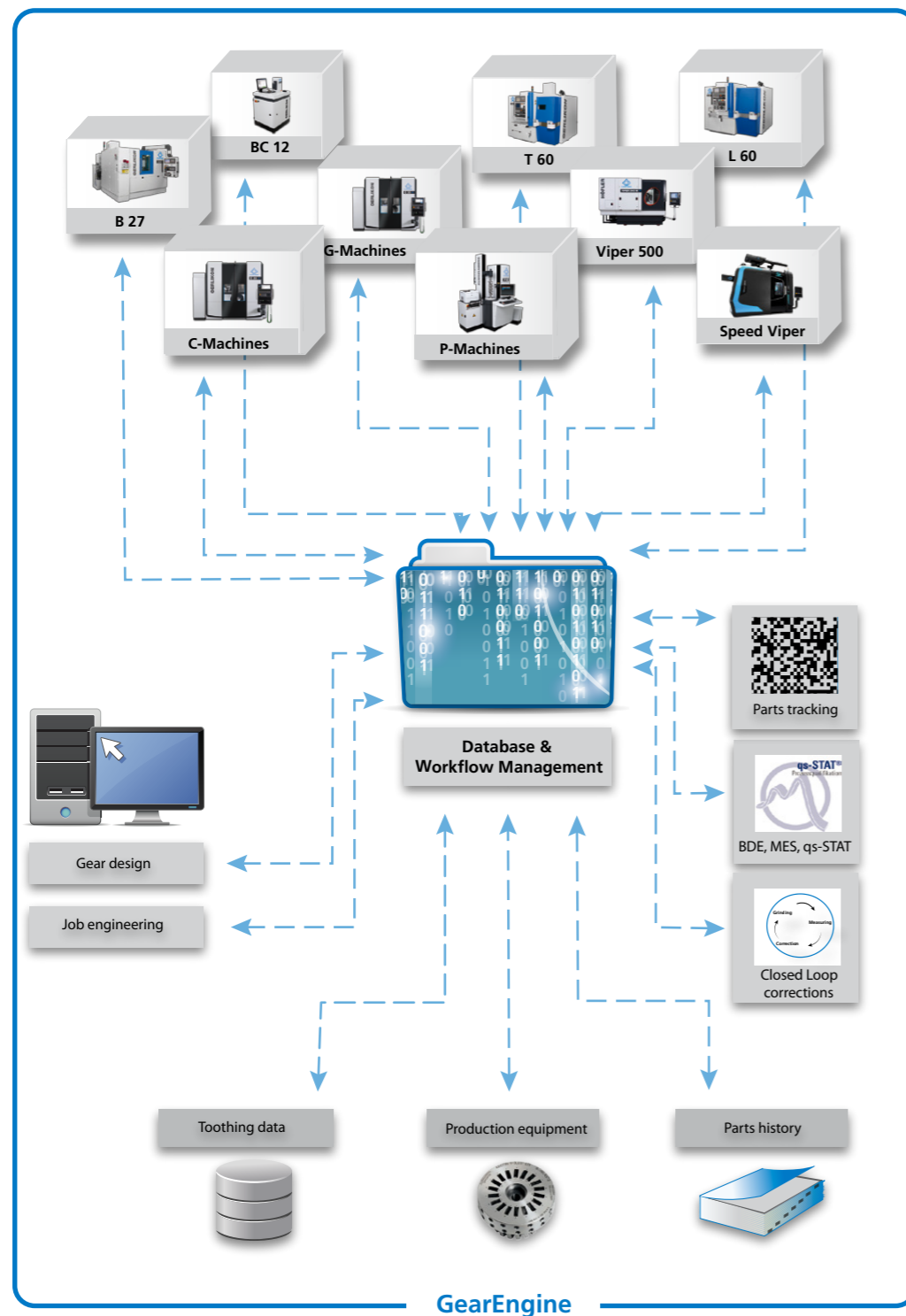


Fig. 3: GearEngine® is the digital bridge between development, production, quality assurance, and product documentation.

the process status, to monitor it, or to subsequently track down correlations.

Example: In profile grinding, it is often the wear condition of the dressing roll that is a determining factor for the profile form error of the generated tooth spaces. The relationship between the service life and process parameters such as the dressed volume or length of the contact path at the circumference of the grinding wheel is obvious and known – but without a comprehensive database, it cannot be quantified or utilized accordingly. With Gear Operator as the process-controlling element, with the unique identification of dressing tools, and with GearEngine® as the managing unit, it is now possible to trace a quality loss sustained far back into the past – and to prevent its occurrence far ahead in the future.

Think in terms of systems: process information and tool identification

The profile grinding example just described again clearly shows: With GearEngine® as the managing unit, the machine software as the process-controlling element, and unique identification of the tools, Klingelberg is taking the notion of Industry 4.0 to levels far beyond an intelligent machine user interface. Rather, systematic networking, provision, and seamless integration of process information are at play here. In the future, the use of digital identification methods for tools and clamping devices in particular will gain importance when it comes to making processes still carried out manually today more efficient tomorrow – while at the same time making all available information available for the further process.

GearEngine® forms the backbone of Klingelberg's cyberphysical production system!

Tool identification with SmartTooling

The ingredients of the new SmartTooling system from Klingelberg are manageable and therefore represent a low-risk investment: In the initial step, our SmartTooling database is made available in the network. A hand-held reader is added to the machine; it will be capable of transforming a data matrix code into digital information. In the third step, each tool is labeled with an imprinted code, making it a unique, individual piece anywhere in the world. The code, consisting of an article number and a serial number, represents an "admission ticket" to the digital tool management. Now information such as the geometry, blade configuration, concentricity tolerances, tool life quantities, or even material numbers can immediately be accessed from a central database or can be written to this database by the machine. This makes change-overs significantly easier on the one hand, and on the other hand, the users of this SmartTooling system benefit in terms of the traceability of tool information from the advantages of an integrated database. Thus for example, manual data entry of geometric features when mounting a tool can be replaced by automatic provision of the geometric data. This makes tooling as reliable as it is efficient. Costly accidents due to the use of the wrong tools or tool data are now just as much a thing of the past as is the use of handwritten notes.

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SmartTooling

To have an overview of the condition of your tools at any point in time – that is also part of the Industry 4.0 philosophy. Klingelberg has implemented such a digital tool management system via SmartTooling.

A special kind of quality management

However, the use of a tool identification system can help for more than just setup. Monitoring of unused remaining parts per grind for tools can also be used to lower investment costs for new tools. Moreover, the seamless traceability of all relevant information such as tolerances for runout, measurement reports, and overhauls enables an entirely new type of integrated quality management: Seamless documentation and monitoring of the entire life cycle of a tool is possible. With the help of statistical evaluations of these data, production processes can be analyzed in unprecedented ways. In

particular, in conjunction with the Smart Process Control in the C 30 machines, users have a “toolkit” for optimizing the service life of tools and cycle times for component production extending beyond individual machines and components.

Even at the end of a tool’s life cycle, users will soon benefit from the Smart-Tooling system: Since the article number of the tool is integrated directly in the data matrix code, users can quickly and easily order new tools or services for the existing tools. ◆

SMARTTOOLING – THE ADVANTAGES

- **Reliability for data entry:**
Manual data entry of geometric features during tooling is replaced by automatic provision of the geometric data.
- **Management and better use of remaining parts per grind:**
The monitoring of remaining parts per grind for tools helps to lower investment costs.
- **Integrated quality management:**
Seamless traceability of all relevant information makes end-to-end documentation and monitoring of a tool's entire life cycle possible.
- **Simplified replacement:**
Since the article number of the tool is integrated in the data matrix code, new tools or services are easy to order.



Fig. 4: SmartTooling



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