What do the gears that end up in trains, wind generators, speed reducers, marine transmissions, off-road equipment, and printing presses have in common? They must run quietly, carry heavy loads, have excellent pitch variation, be very accurate, and offer a long service life. This would normally dictate a post heat-treat process of tooth finishing, the most common being grinding. The solution could be the RZ 1000, Reishauer’s newest generation of large continuous generating gear grinders. Making larger gears in smaller lot sizes represents a challenge for all manufacturers, due in part to the hurdles of high material/manufacturing costs, the pressure of a time deadline, and the skill level required to produce such high-speed gears. There has never been any argument that continuous generating tooth grinding results in the lowest cost per piece, highest throughput, and superior index accuracy as compared to single tooth form grinding—although that process has made significant improvements in the last decade. If we identify the key elements a machine must possess in order to grind large gears they are dynamic stiffness, flexibility, short setup and run times, and onboard inspection. Let’s break them down to their rudimentary form.

If the control is considered to be the brain of the machine, it’s a natural assumption that the workspindle could be considered the heart. In order to transmit smooth motion, high torque, and the necessary workspindle speeds ranging from grinding to inspection, a nontraditional approach was necessary.

The table drive is rather unique and patented for this type of application. A gearless planetary drive provides the static and dynamic rigidity unmatched by any machines of this type. This type of friction drive also eliminates the “ghost” frequencies of past designs, as there are no gear teeth in the drive assembly. The Chart in Fig. 1 illustrates the uniformity of rotation of the workspindle of the RZ 1000. With an acceptable deviation of < 0.3 arc seconds peak to peak, you can understand how accurate the assembly is.
The design also allows for a broader range of workspindle RPMs and is not limited like conventional designs driven by spur/helical gear sets or bronze worm wheels and steel worms. A “direct drive system” (as used by a few manufactures) was given some initial consideration, but it did not achieve the desired results and presented a new set of workspindle speed limitations. A set of high precision rotary encoders keeps this axis in sync with the other rotary axes of the machine.

The control, or “brains,” of the machine is the next vital element in the solution chain. A high-speed, very precise “generation” module in conjunction with a flexible operating system are the prerequisites for a perfectly controlled process from the standpoint of grinding as well as inspection. Due in part to its configurable design concept, the Siemens 840D CNC provides the perfect platform for the integration of the Reishauer electronic gearbox and the MMI (see Fig. 2). The main features are:

- Windows operator interface with real-time data inputs during the running process for quick online optimizing
- Open architecture for the user to program virtually any geometry and technology function for grinding, dressing, and inspection to increase quality and efficiency
- Display of supported diagnostics system for all critical machine functions, including the potential connection to an external network
- Display of supported diagnostics system for basic process analysis with graphic assistance of error detection
- Assistance to the operator during data input via Reishauer technology software for the automatic calculation of machine data settings
- Comprehensive safety functions for axis monitoring (with SSI) to protect operator and machine
- Moving all relevant setup and drive axes with the help of automatic or manually activated electronic hand wheel for safe and fast setup of the machine
- Computer-assisted setup technology

The base or foundation for any constitution—whether it be a house, commercial building, or a machine tool—has to provide the static rigidity to support the function of the structure. When the new machines were first envisioned, we knew that the base had to possess the utmost in structural integrity, be resistant to thermal growth, and provide the platform to build upon. A fabricated base with cast iron subassemblies seemed to satisfy all of the design parameters and objectives perfectly. Any machine we designed had to be easily accessed for loading and unloading, setup, and changed over quickly, while occupying a minimum of plant real estate. You might call it a hybrid of a machine, as the bed is constructed out of steel and the tailstock, workspindle assembly, and tool holding axes are made of cast iron. No other gear-manufacturing machine has such a unique configuration (see Fig. 3).
The entire C1 axis, which houses the grinding spindle and all of its related axes, rotates 180° to facilitate wheel change and dressing of the grinding wheel, as well as its home position when in the grinding mode. In its three o’clock position (as seen from the operator perspective) the main column is in the grinding location, which allows for easy access whether manually or automatically loading the workspindle. When the column is in the six o’clock position the grinding spindle affords an ergonomic position for the operator to change the grinding wheel, and to that end it can be programmed to suit the height of the operator. As an alternative, an optional wheel-changing device is available. Rotate the column to the nine o’clock position and witness the speed at which the wheel is dressed, with the infeed at both ends of the stroke making the dressing process a breeze, even for wheels having up to seven starts. The 12-axes machine (six rotary and six linear) is configured for just about anything that one can throw at it.

To be in accord with the “flexibility” concept of the machine, the wheel dressing operation had to incorporate an efficient means to dress wheels for higher volume jobs as well as the single piece lot size or prototype work. Enter the RP 160-2 dressing unit.

Designed to offer the best of both worlds, the RP 160-2 dressing unit (two rotary axes and one linear) serves as a well-conceived platform that can house a single rotary diamond tool to “line dress” nearly any tooth modification without the need for a dedicated tool for prototype or low-volume work. Conversely, this unit can be equipped for use with a traditional set of single tapered diamond disks for series production (see Fig. 4).

Onboard inspection for gears that can be ground on the RZ 1000 was a natural progression, given the fact that typical gears could tip the scales at well over half a ton. The weight—coupled with the time consumed to lift the gear off its fixture, transport it to the gear lab, measure the results, and then return it to the grinder, remount the part, and make the necessary corrections—was enough justification to
integrate the process into the machine. The technical arguments against using a valuable piece of production equipment and turning it into the world’s most expensive gear checker were outweighed by the economics of time and throughput. All of that said, the final accuracy certification should always be carried out on a dedicated gear inspection machine, and the machine-mounted inspection should be used solely as an in-process operation.

The hardware consists of a touch trigger probe manufactured by Renishaw that is installed in place of the current automatic meshing sensor that is positioned below the grinding spindle (see Fig. 5). The operational software is part of the Reishauer machine software package. The operator interface for the inspection parameter’s input and output are fully integrated into the Reishauer HMI. The following measurements are possible:

- Profile
- Lead
- Index variation
- Runout
- Tooth width (size)

**Application 1**

In order for manufacturers of wind turbine generators to compete globally in a price-sensitive market, gear manufactures have to be carefully aware of material costs, the reduction of scrap rates, and the selection of the most cost-effective manufacturing processes available today. Typically, the low-speed stage of the gearbox is a planetary configuration with either spur or helical gears. The sun pinion drives a parallel intermediate shaft that in turn drives a high-speed stage. Both the intermediate and high-speed stages use helical gears. Although a relatively small percentage of gearbox failures are actually caused by gears that were made improperly, it is incumbent on all manufacturers to reduce costs, improve throughput, and increase accuracy. In Fig. 6 you’ll see the inspection chart of a heavily modified turbine gear that has been ground on the RZ 1000. Gear parameters were:

- Module 8 mm
- Number of teeth 62
- Face width 140 mm

**WHEEL PARAMETERS:**
- Outside diameter 300 mm
- Width 145 mm
- Number of starts 3

**PROCESS DATA:**
- Grinding time 16 minutes
- Floor to Floor time 21 minutes

**Application 2**

Industrial gearbox manufacturers have many of the same challenges as those making wind turbine gearing, although their gears are used to slow things down rather than increase the speed of the output shaft. Widely used in mine machinery, robotics, building machinery, and other industrial machines, gear reducers are used to minimize power and total machine size and handle heavy shock loads. Most gear reducers are lightweight and have low consumption while maintaining heavy transmission torque and steady startup. When used in mechanical systems, gear reducers must be chosen selectively, depending on the characteristics of the gear system. Important considerations include price, weight, size, construction, reduction ratio, and behavioral traits. They may also be combined with other reducers in order to meet specific requirements. For optimal performance, gear reducers with lower torque ripple and velocity are ideal, as high speeds and torque ripple can cause excitation for the driven machine system. In Fig. 7 you’ll find the inspection chart of a heavily modified shaft that has been ground on the RZ 1000. Gear parameters were:

- Module 8 mm
- Number of teeth 22
- Face width 140 mm

**WHEEL PARAMETERS:**
- Outside diameter 300 mm
- Width 145 mm
- Number of starts 3

**PROCESS DATA:**
- Grinding time 5.0 minutes
- Floor to Floor time 6.5 minutes

**Application 3**

A printing press is a complex piece of high-precision industrial equipment that is designed to produce printed material at a high rate of speed and low cost per page or sheet. Printing presses are commercially available which use several different types of printing technologies, but the most common type is called offset lithography. These presses are commonly designed in either sheet-fed configurations, which print on individual sheets of paper or other material, or web-fed configurations, which print on long webs of paper or other material, supplied on large reels. The drive for reels of an offset printing press have a gear train consisting of helical gears that are mounted on the respective shafts of the reels, so they must be very accurate and possess particularly good tooth spacing characteristics.
to assure print and color separation. In Fig. 8 you’ll see a press gear being ground on a RZ 1000. Gear parameters were:

- Module 4.5 mm
- Number of teeth 163
- Face width 80 mm

**WHEEL PARAMETERS:**
- Outside diameter 300 mm
- Width 145 mm
- Number of starts 3

**PROCESS DATA:**
- Grinding time 17 minutes
- Floor to Floor time 18 minutes

The RZ 1000 is the largest continuous generating gear grinder in the Reishauer product line, providing outstanding productivity and flexibility for an entire variety of parts and meeting all demands for quick setup and short changeover times, highest accuracy, and advanced software for improved process and onboard inspection capabilities.

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