Innovations for High Productivity Generating Grinding

Four Recent Developments Expand on Proven Technologies

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In comparison to the visionary Industry 4.0 — or the Fourth Industrial Revolution — the machine tool industry can appear rather down-to-earth.

But even in long-established technologies such as generating gear grinding, substantial improvements in terms of speed and quality have been made. Gear machine tools for generating grinding target high production volumes in industries that require large-lot, series production such as automotive. These industries are known for continuously growing demands in the areas of cost reduction, energy efficiency and environmental improvement. To serve these markets, machine and process developers react with solutions that cross technological boundaries. This article presents four developments by the company Kapp Niles that tap into new arenas using proven technologies, making them yet more efficient.

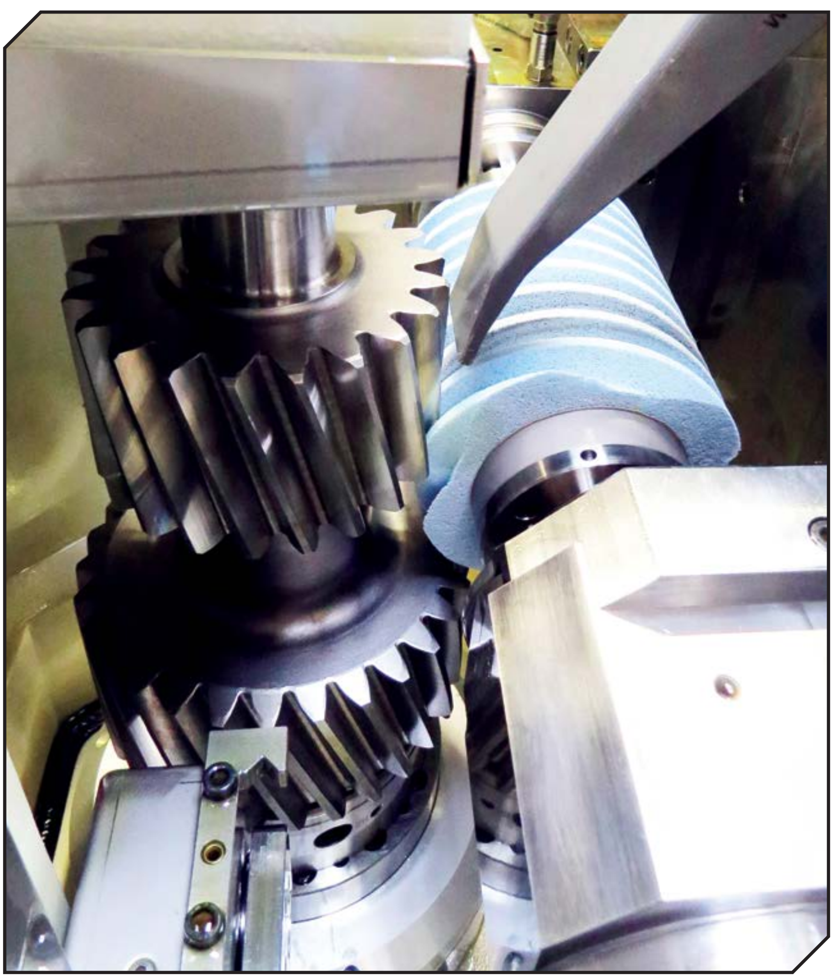

Figure 1 Generating grinding of a gear with interference contours.

Feasibility – Generating Grinding of Gears with Interference Contours

Cutting speeds for generating grinding between 63 and 80 meters per second yield huge productivities. This is accomplished with common tools — grinding worms with a typical diameter of 300 mm and with an rpm of 5,000 to 7,500. However, the large tool diameter presents a problem with interference contours because the tool requires room to finish its path on both ends of each grinding stroke. Typical examples are a bearing seat with a hob breakout, or a larger secondary gear close to the gear to be processed (Fig. 1).

Profile grinding of such workpieces would be very time intensive. Generating grinding technology is a viable alternative, but it requires a smaller grinding worm. However, smaller grinding worms require a higher rpm in order to reach the same cutting speed as that of a larger tool. Traditional gear grinding machines don't measure up to the task of meeting the dynamic requirements of tool and workpiece drives.

Modern grinding machines offer new alternatives. For example, the KX 160 Twin and KX 260 Twin from Kapp Niles now offer synchronization of dressing tool, grinding tool and machine in order to handle such complex tasks.

"Thanks to high speed grinding spindles, it is now possible to generate grind gears that require a tool diameter as small as 55 mm," says Dr. Sergiy Grinko, project manager at Kapp Niles. "In conjunction with the maximum possible width of 180 mm for the grinding worm, it is now possible to reach previously unattainable cycle times for critical gears with interference contours as well as cut production costs while still meeting the high quality requirements of series production."

The tool drives of the Kapp Niles KX 160 Twin and KX 260 Twin machines are able to run at a speed of up to 25,000 rpm. This necessitates the workpiece rotating at a faster speed as well. Kapp Niles standard machines offer a workpiece drive with 5,000 rpm.

To demonstrate the process improvement, Grinko calculated the cycle time for one workpiece for one of Kapp Niles' customers. The conclusion: non-dressable profile grinding with a CBN wheel results in a cycle time of 5.4 minutes. In contrast, dressable generating grinding of the same workpiece resulted in a cycle time of 2.9 minutes, with dressing intervals every 25 workpieces.

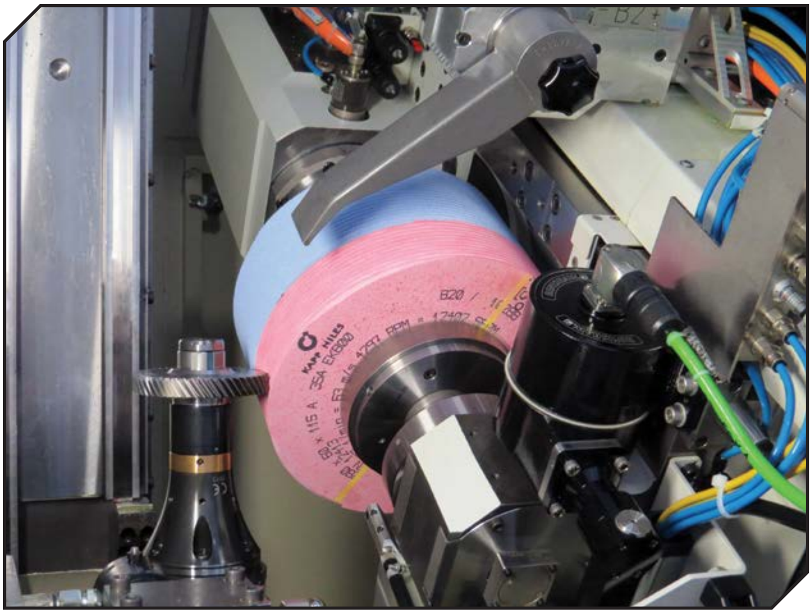

Figure 2 Combined tool with conventional and superfinishing section.

Quality in Micro-Geometry — Finish Grinding

Gear finishing, such as finish grinding, can considerably improve the characteristics of a workpiece. For example, with a better surface finish on the tooth flanks, it is possible to use transmission oils with lower viscosity. Consequently, the efficiency of the transmission improves, without the risk of reduced stability. This requires an 80–90 percent bearing ratio over the contact load area, which during the finish grinding process is obtained by mechanically removing the roughness peaks of the surface. This has so far been a challenge.

The required surface finish has traditionally been attained via time consuming processes, such as isotropic superfinishing (ISF). This process entails submerging the workpieces with small non-abrasive pellets into a vibration tub filled with a watery solution and an additive. While this process offers very good results, it could very well require several hours to complete, depending on the type of workpiece.

Compare that to a cycle time of one minute per gear that series manufacturers operate with.

"Series transmission manufacturers require automated process chains, ideally with a single-piece-flow," Grinko says. "Variable processing times are therefore not practical."

And he notes an additional problem: "ISF requires chemical additives that are subject to a number of regulations and safety measures, as well as recycling and disposal, all of which are a burden for the manufacturer to comply with. It is therefore more sensible to equip existing grinding machines with superfinishing capabilities to meet production requirements."

The German research association for drive technology (*Forschungsvereinigung Antriebstechnik, or FVA*) presented proof with the results of project 654 I: Finish grinding with conventional gear grinding machines produces surface finishes of Rz ≤ 1 µm. Kapp Niles offers special combination tools with two functional zones (Fig. 2). With these special tools, the newer generating gear grinders of the KX and ZX series are able to reach a surface finish of Rz 0.5–1 µm in one clamping setup (Fig. 3). With cutting speeds of up to 63 meters per second, the cycle time is higher but generally not more than 50% higher than the cycle time of conventional finish grinding.

"Generating grinding is substantially more efficient than profile grinding with a finishing wheel," Grinko says. "Our expertise allows us to make informed decisions concerning the most effective segmentation of the grinding zones on the combination grinding tool. Our software complements the set-up for optimal results."

Quality of the Macro-Geometry — Topological Generating Grinding

Gears rarely are manufactured without lead modifications. A simple involute exists only in textbooks, but not in reality. In the real world, engineers have to deal with tolerances such as misalignment of axes in the gear box. To address this issue, the tooth flank is designed to have a crown of several µm (0.001 mm). If a gear had no lead modification, the slightest deviation would result in a negative impact on load and noise behavior.

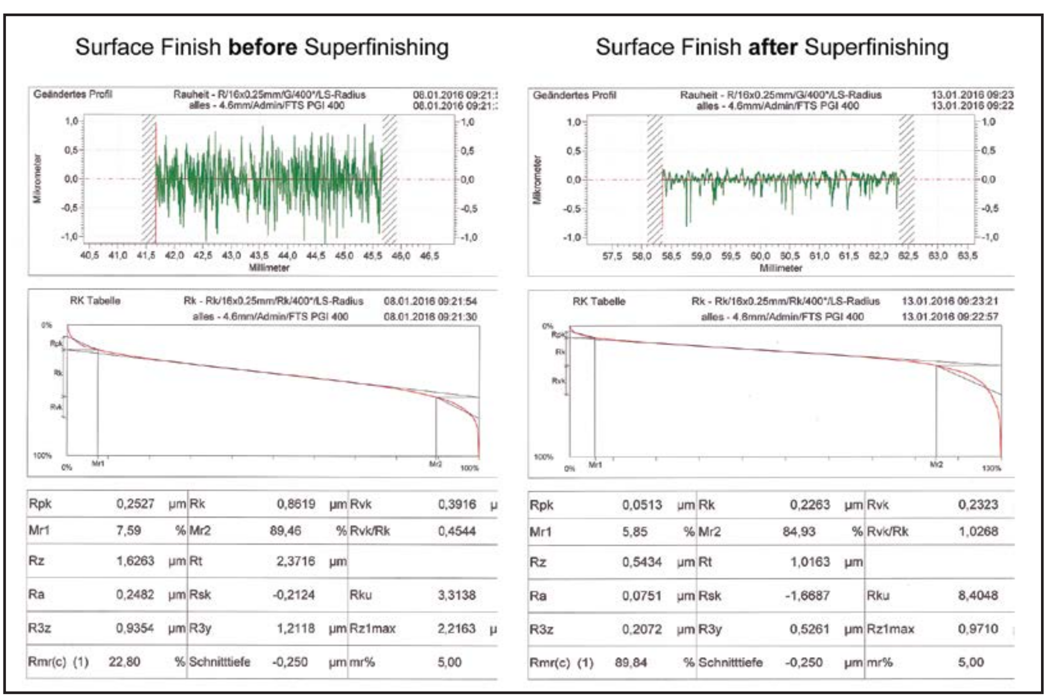

Figure 3 Comparison of surface finish before and after superfinishing.

Processing such gears with generating grinding technology imposes special demands on the machine: the distance between tool axis and workpiece axis will have to be modified repeatedly throughout the process. However, this creates a bias error due to the position of the contact lines and the axes, which means instead of a symmetrical crown there could be a lead distortion.

"Generally, it is not the goal to simply eliminate bias but rather to manipulate it," Grinko says. "If the customer knows what the load will be and how the load will affect the behavior of the workpiece, it is possible to calculate the best generating contact for that application. Sometimes the noise behavior is better with minimal bias than having no bias at all."

So, such complex gears can be produced with generating grinding. This requires that during the grinding process, the tool shift position be interpolated with the axial feed position. Additionally, the process requires a modified tool: the grinding worm needs to have segments with different geometries specific to the requirements. Standard dressing tools can generate such varying geometries during the dressing cycle. It is apparent that such complex calculations of the worm geometry, the grinding and the dressing process require a highly sophisticated software. Some manufacturers do such calculations in-house and upload the data to the customer machines. However, this takes significant time. In prototype manufacturing or a test environment, this would mean substantial machine idle times for each slight modification.

"We have a user-friendly interface for topological generating grinding," Grinko says, "and calculations for geometry, dressing and grinding paths can be done in the machine control itself. Our customers are able to manipulate the lead modifications to their requirements all the way from simulation to final setup in 2D and 3D."

After the data is entered, the machine calculates the maximum possible number of shift areas for the specific worm width at hand (Fig. 4).

"For the topological generating grinding process, the goal is to have as many segments on the worm as possible for highest utilization of the grinding tool," Grinko says. "However, the segments have to be large enough to generate the desired geometry."

Once the number of segments is determined, the machine operator can monitor them in the simulations screen (Fig. 5). Should the machine operator notice tool wear and loss of quality during grinding due to a high number of shift areas, it is possible to reduce the number of shift areas to produce the best possible gear quality.

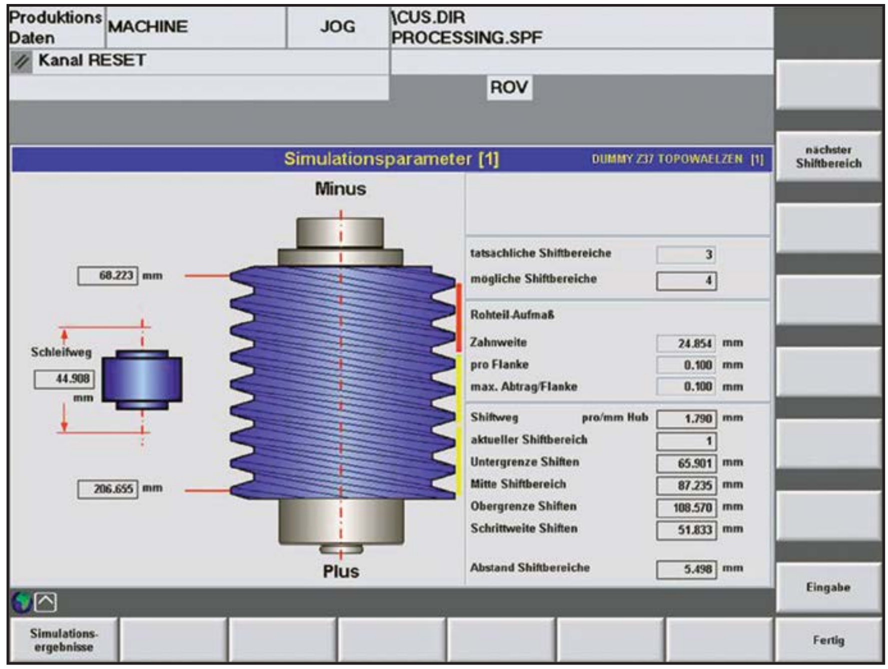

Figure 4 Input screen with illustration of possible shift area.

Speed — Multi-Rib Dressing

One primary advantage of generating grinding is time savings. A higher number of threads on the tool allows for an increase in feed rate and subsequently a reduction of processing time. The next natural step after processing time reduction is to reduce the dressing time. This is accomplished by dressing multiple threads with one tool simultaneously (Fig. 6). Kapp Niles investigated this process in detail in order to explore all possibilities for improvement.

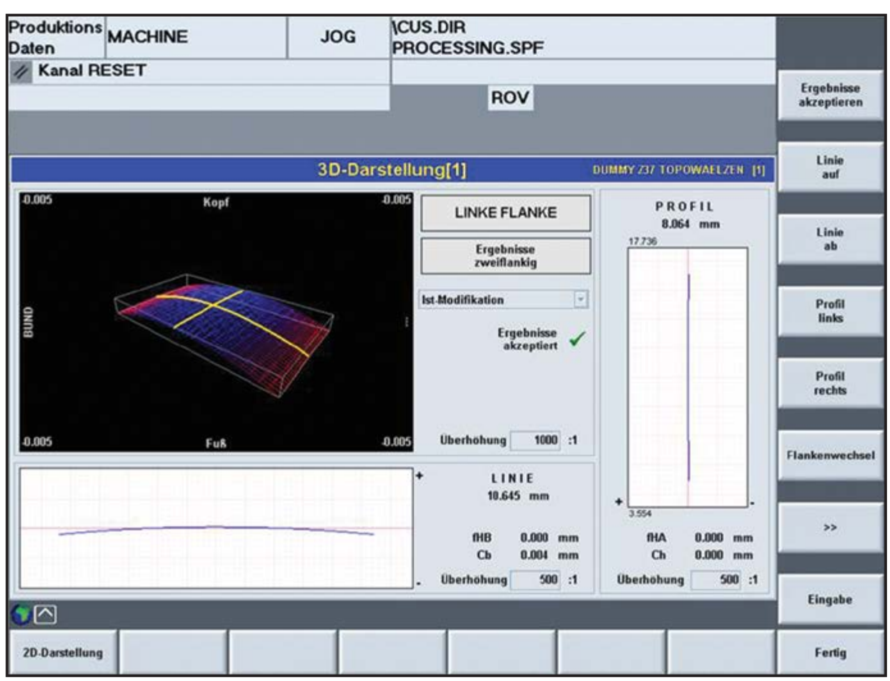

Figure 5 Simulation enables monitoring and controlling the topology before processing.

Figure 6 Multi-rib dressing of a sintered grinding worm saves time.

"Multi-rib dressing requires full-profile dressing rolls, which means they do not require a separate tip dresser," Grinko says. "Multi-rib dressing tools are manufactured by means of a negative-plating process."

This process does not place the diamond grains directly onto the steel body but rather into a negative form which then goes through the nickel-plating process. The negative form with diamond grains is then molded to the steel body.

In order to keep the dressing time to a minimum, it is necessary to coordinate the number of ribs on the dressing roll and the number of threads on the worm. The best scenario would be to have the same number of ribs and threads. That would result in all threads being dressed during each infeed pass. However, this is not always possible. A combination of five threads on the worm and three ribs on the dressing roll, however, would lead to the latter wearing more quickly. In order to avoid this and to increase the tool life of the dresser, Kapp Niles machines utilize an algorithm that guarantees uniform wear.

Conclusion

The examples prove that significant progress in productivity and quality is still possible even for a well-established technology such as generating grinding. Beyond faster drives, new tool concepts and intelligent controls, additional advances allow for further improvements such as fully automated clamping change and integrated automation solutions, as offered by the new pick-up generating grinding machine. All these factors allow for cycle times and process qualities that were inconceivable only a few years ago.

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