Close collaboration between industry partners creates efficient, productive, and high-quality solutions for gear milling, according to Sandvik Coromant.
Curved bevel gears are one of the most complex components in mechanical engineering, and special machines and tools have therefore been required to make them. The most significant disadvantages for manufacturers are the cost for expensive machinery, the large amount of programming, and the time involved. In particular, this has big effects on the production of small and medium batch sizes because the investment cannot be paid off as quickly as it can with large batch production. There are also growing demands on producers of gears to ensure that their production processes are cost-efficient, productive, and of the highest quality in order to fulfill the customer’s demands for durability and price, and to therefore remain competitive.

Of the various manufacturing procedures for gears milling applications are the most widely used, whether with special cutting heads and expensive special machines or with end mills on five-axis machining centers. Both procedures are complex and costly, but they also have a great potential for improvement.

**POTENTIAL FOR PRODUCTIVITY**

To exploit this potential Wolfgang Huetter, head of production at VOITH Turbo in Germany, worked with two selected suppliers as partners: Gebrüder Heller, and Sandvik Coromant. They tackled the challenge together, phrased by Huetter as “A long-lasting and efficient solution must eliminate the current disadvantages of both procedures, combine their advantages, and create a new solution that significantly improves the production of bevel gears in small and medium batch sizes.”

The solution for machine tools lies in using flexible five-axis machining centers instead of special machines. With this solution manufacturers can also carry out other machining operations and different components. To also reduce tool costs, the focus had to be on cutting tools that can be used flexibly as dedicated form mills. In this case the only tools worth considering are standard tools that can be fitted with standard indexable inserts. In addition to a machine and tool layout that reduces costs and ensures a satisfactory degree of flexibility, the optimum solution must make sure that the required quality levels are met and that the maximum possible level of reliability is achieved. The solution should also ensure an increased metal removal rate, and thus reduced machining time, especially during soft machining.

In their work to arrive at the solution, the project partners thought outside the immediate box. Although the milling of gears was the focus of the optimization measures, the entire process chain for soft machining was called into question and re-evaluated. The partners involved then agreed that a key objective of the development project—to increase productivity and cost efficiency—should mostly be achieved by the increase in

![Fig. 1: Turn milling the outer contour of a gear wheel using a Sandvik Coromant standard tool in a Heller machining center.](image-url)
the metal removal rate. The result of this collaborative work, “uP-Gear Technology,” now has a patent pending.

**CREATING PERFECT CONDITIONS**

With this new development rough cuts were processed first, with standard milling cutters used with a feed rate of above 2000 mm/min, providing metal removal rates of up to 400 cm³/min. The resulting cutting pressure puts a large load on the machine and, in addition, workpieces can weigh up to several hundred kilos. The choice of machine had to have specifications to well withstand the load conditions involved—specs including tool, main spindle, and rigidity of workpiece clamping.

The final choice was a Heller high-performance machining center capable of five-axis simultaneous machining, where stability and performance combined to provide the best conditions for the potential increase in output. The machine offers user-friendly NC cycles integrated into the machine controller for entering gear parameters. This eliminates the need for external programming to be carried out in CAD/CAM. Any necessary corrections can be made easily using parameterized input from the operator. Problem-free manufacture is also possible with the alternating machining of housings, bevel gears, and other components, emphasizing the required flexibility and performance of the machine, which can be enhanced even further using pallet or robotic automation.

The uP-Gear Technology takes place from the first machining operation. In previous machining procedures, the outer contour of the workpiece was first machined on a turning center in two separate setups. But these operations have been switched to turn-milling on the machining center. This means that the bevel gear’s outer contour and the spiral gearing are totally completed in just two setups. A welcome bonus is that absolute concentricity is achieved between the bevel gear contour and the gearing. This significantly improves the quality of the finished components as well as saving machine time.

The extensive range of tools and experience from turn-milling provided by Sandvik Coromant as a partner has made it possible to exclusively use standard tools with cutting data that compares favorably with the previous turning opera-

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**Fig. 2: Roughing milling of tooth-spaces on a bevel gear. The high-performance rough machining of the tooth spaces takes place in several steps using dedicated Sandvik Coromant standard milling cutter with standard indexable inserts.**
tion. The complete machining process means less idle time is clocked up, less setup time is needed, and less transport-time, as well as much simpler planning of machine utilization.

REDEFINING MACHINING
The next machining step, that of milling gear tooth spaces, was also completely redesigned. These were previously created by milling with an end mill in many passes. In comparison to this, the metal removal rate for the standard milling cutter with indexable inserts that is used for up-Gear method is considerably higher. As a result, machining rates much higher than those of the previous values for end milling are achieved so that the machine time is significantly reduced. Standard milling cutters equipped with round indexable inserts are the first choice throughout when large material volumes have to be machined. With this newly developed method the technical and economical advantages can also be incorporated for roughing tooth-spaces in spiral bevel gears.

After opening up tooth spaces using round indexable inserts, tooth flanks are finished using a new milling tool concept. The cutter types can be classified as intermediate to a hollow-mill and bell-type milling cutter. The variable setting angle of the mill axis, combined with the slender design of the milling cutter profile, allows a wide range of flank angles and modules to be machined. Both convex and concave tooth flanks can be finished with the same tool having inserts mounted on both sides. In the case of the cutter being equipped with inserts only on one side, in order to increase the number of effective inserts—and, therefore, the feed rate—considerable time savings are achieved. The required additional tool change adds only a marginal amount of time to the process.

Scratch-free machining of the tooth space base and transitions to the tooth flanks is an important quality feature of bevel gear manufacturing. This quality demand also applies for the machining of the protuberance. The new solution—a hollow mill with standard indexable inserts for milling the protuberance—does not just fulfill these requirements well. Another advantage is that, when compared with the previous end milling, the machining time is considerably reduced.

SUSTAINABLE SOLUTIONS
When developing the new milling tools for bevel gear machining, particular importance...
was placed on machine shop compatibility, stability, and efficiency. In each case the diameter of the milling cutters and the number of inserts was made to match each other to achieve high levels of performance. The new uP-Gear machining procedure and the advantageous machine control has meant that the special tools used before according to their special requirements can now be replaced by universal milling tools with standard indexable inserts.

Not only were the objectives set at the start of the project reached, they were greatly exceeded. After completing some batches of bevel gears in module 15, the advantages of the new procedure are clearly demonstrated by the results:

- Soft machining can be completed in just two setups, and the time required for this is significantly reduced;
- Thanks to the lack of interference during batch machining, the subsequent inspection of soft-machined bevel gears in the measuring machine revealed that the gear-wheel quality is consistently high;
- The new procedure offers decisive advantages for the machine operators. This is because correction values are easy to use for the operator and “setting cards” are no longer required;
- Machining costs have been reduced considerably through greater flexibility to lower investment costs. The high-performance standard tools combine a longer tool life with increased productivity. Also, with suitable automation, production can be left to run unmanned part of the time.

Encouraged by the success and the level of motivation and input from the partners involved in the project, the next step of optimization is already under way. The area being worked on now is hard-part machining, where significant results have already been achieved also using the new uP-Gear procedure. Other projects such as implementing modified gear tooth forms, machining bevel gears with axial offsets, and the milling of crown gears are also in the planning stages.

Fig. 4: Protuberance milling. Good surface finish and short machining times are achieved with this dedicated milling cutter that is equipped with CoroCut indexable inserts.

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