Milling in steps

How to define high-speed milling (HSM)? That's not so easy, though one statement is that the cutting speed is so high that this causes the forces for cutting the workpiece material to decrease. However, there is no doubt that the Mikron series machines from the GF AgieCharmilles Group are real "HSMs". Really innovative is that they are provided with ITM, a system for exactly defining the vertical position of the high-speed cutting tool edge. Besides that, the designers took a lot of measures to realise stable machines with very accurate high-speed spindles.

• *Frans Zuurveen* •

GF AgieCharmilles forms part of the Swiss GF Group. Already in 1802, Georg Fischer started a steel mill in Schaffhausen and succeeded in producing steel that could compete with steel from England, then fully involved in its Industrial Revolution. Today, the GF Group consists of GF Piping Systems, GF Automotive and, as said, GF AgieCharmilles. The latter combines Mikron, a famous producer of milling machines, and AgieCharmilles, specialized in EDM (Electrical Discharge Machining). AgieCharmilles is a cooperation of Agie and Charmilles.

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b

c

Figure 1. The GF AgieCharmilles Mikron HSM 400 LP Precision milling machine.
(a) Overview.
(b) Milling with rotating and tilting table.
(c) Precision milling a pump impeller.

# of a micrometer

Agie and Charmilles are well known for their die-sinking and wire-eroding machines. Recently, GF AgieCharmilles added laser machining to its skills, so that it now masters nearly all thinkable high-precision cutting and non-cutting machining technologies.

Mikron Machines

The Mikron HSM 400 LP Precision machine (LP: Linear Performance) has a work space of 500 mm x 450 mm x 360 mm; see Figure 1. The maximum spindle speed is 54,000 min^{-1} and the minimum endmill tool diameter is not less than 0.1 mm.

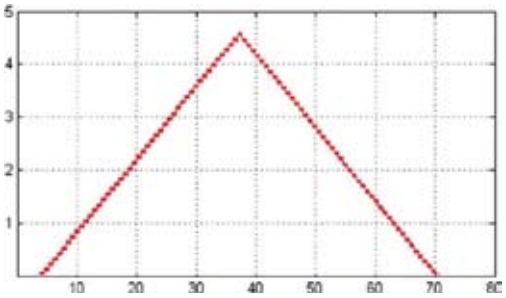

Figure 2. Diagram showing the stepwise movement of a slide, displacement [µm] versus time [s].

The adage "Precision" is not without meaning. Figure 2 shows that a linear slide of the milling machine is able to make extremely small steps of 0.1 µm. It goes without saying that such small steps can only be achieved by taking special design measures regarding mechanical and thermal stability, and regarding precision of slide positioning.

The machine base frame is formed as a force-closed gantry, made from material with good damping characteristics. That material obviously is not steel, nor cast iron, but polymer concrete casting material: Epument, fabricated by Epucret Mineralgusstechnik GmbH. It is a mixture of epoxy resin and mineral quartz with a specific gravity of 2.3 g/cm^3. Vibrations damp out more than two times faster than in cast iron. Young's modulus amounts to 35-40 kN/mm^2. This is about five times lower than Young's modulus of steel, which necessitates enlarging cross-sections to preserve the same frame stiffness.

Thermal stability is achieved by water cooling all spots where heat is being generated: motor drives, spindle, etc. Of course, the temperature of the cooling water is controlled within narrow limits. The water cools in particular the front nose of the tool spindle, which is very near to the workpiece, of course.

The spindle makes a separate story. Some years ago GF AgieCharmilles acquired StepTec, a Swiss firm specialised in the design and manufacture of turning and milling spindles, see Figure 3. StepTec applies hybrid roller bearings, which combine rolling elements from Si_3N_4 with steel races. The bearings are being lubricated by an oil-air mixture.
The slides are provided with precision rolling elements and driven by linear electric motors. Their position is being measured by Heidenhain optical scales, with interpolation between scale periods in the nanometer range.

Intelligent Tool Measurement

ITM is a hardware and software system for defining the vertical position of a high-speed cutting edge with an accuracy of ± 1 µm. The hardware makes use of a laser beam in which the tool "plunges" when moving downwards. The ITM software takes care of – digitally – removing errors from adhering particles or cutting oil; see Figure 4. This last feature is based on the detection of the

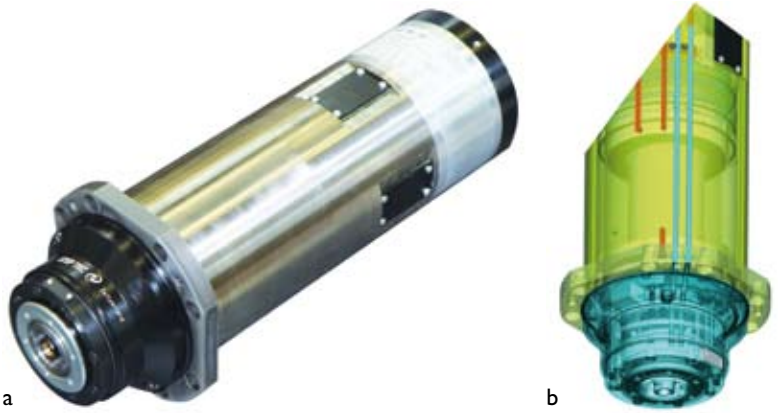

Figure 3. The StepTec tool spindle applied in Mikron HSM machines.
(a) Overview.
(b) Transparent view of the front nose showing the cooling channels.

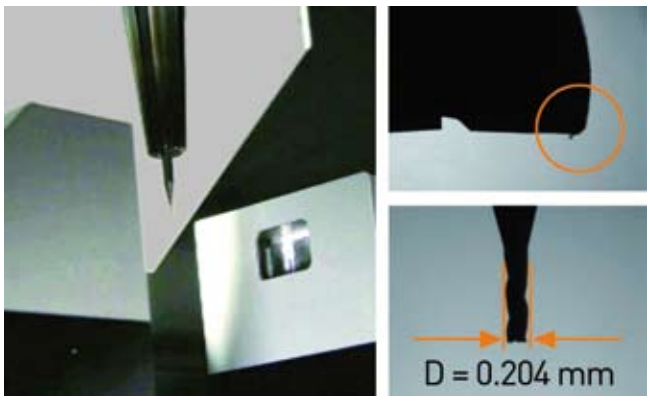

Figure 4. The ITM system. Errors from adhering particles (upper right) or cutting oil are digitally removed. Therefore, image sensors detect the complete tool tip (left).

complete tool tip with image sensors. Thus it provides an absolute *z*-reference with micrometer precision.
ITM takes action before starting the cutting operation, but with full tool rotation speed. As a result, ITM corrects the vertical tool position when necessary, thanks to a compensation mechanism inside the spindle.

Proving precision

Of course, the accuracy of the Mikron machines proves itself when producing precision parts in practice; see Figure 5. An ultimate test is shown in Figure 6. At first, different steps are machined with the same tool with successive *z*-position steps of only 2 µm. In some respects, this might be called “routine practice”. But the subsequent endmill machining of 1 µm deep slots with different tools and rotational speeds is quite a challenging masterpiece. Especially, because the slots are supposed to end exactly between the 0 µm and +2 µm step level.
These and other precision tests also show excellent surface finish conditions. Mean roughness values of R_a = 20 nm have been obtained.

To conclude

Mikron machines are frequently in use in the Swiss watch industry. Needless to say that precision engineers in other industrial branches can also take benefit from the skills of Swiss milling machine builders.

Reference

When fractions of micrometers count, Swiss Quality Production, Hanser Verlag, Munich, 2010.

Figure 5. HSM milling a precision part.

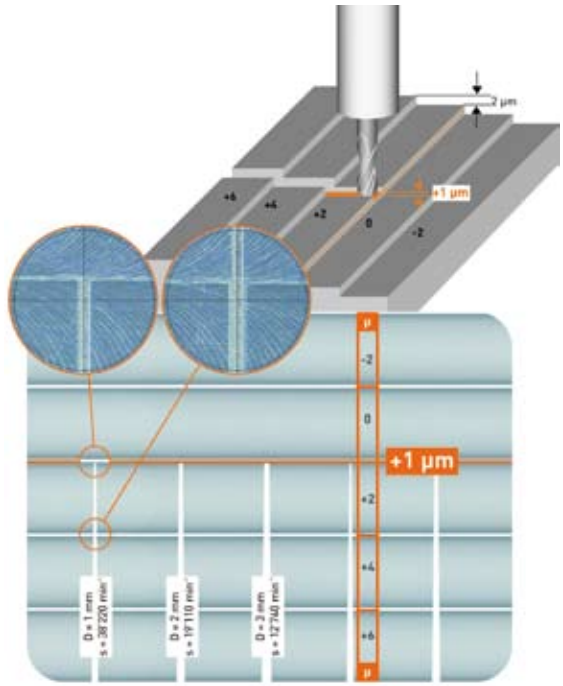

Figure 6. A testpiece machined in steps of 2 µm. Subsequently machined slots, with different tools, are 1 µm deeper.
D = tool diameter, *s* = rotational speed.

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Information

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