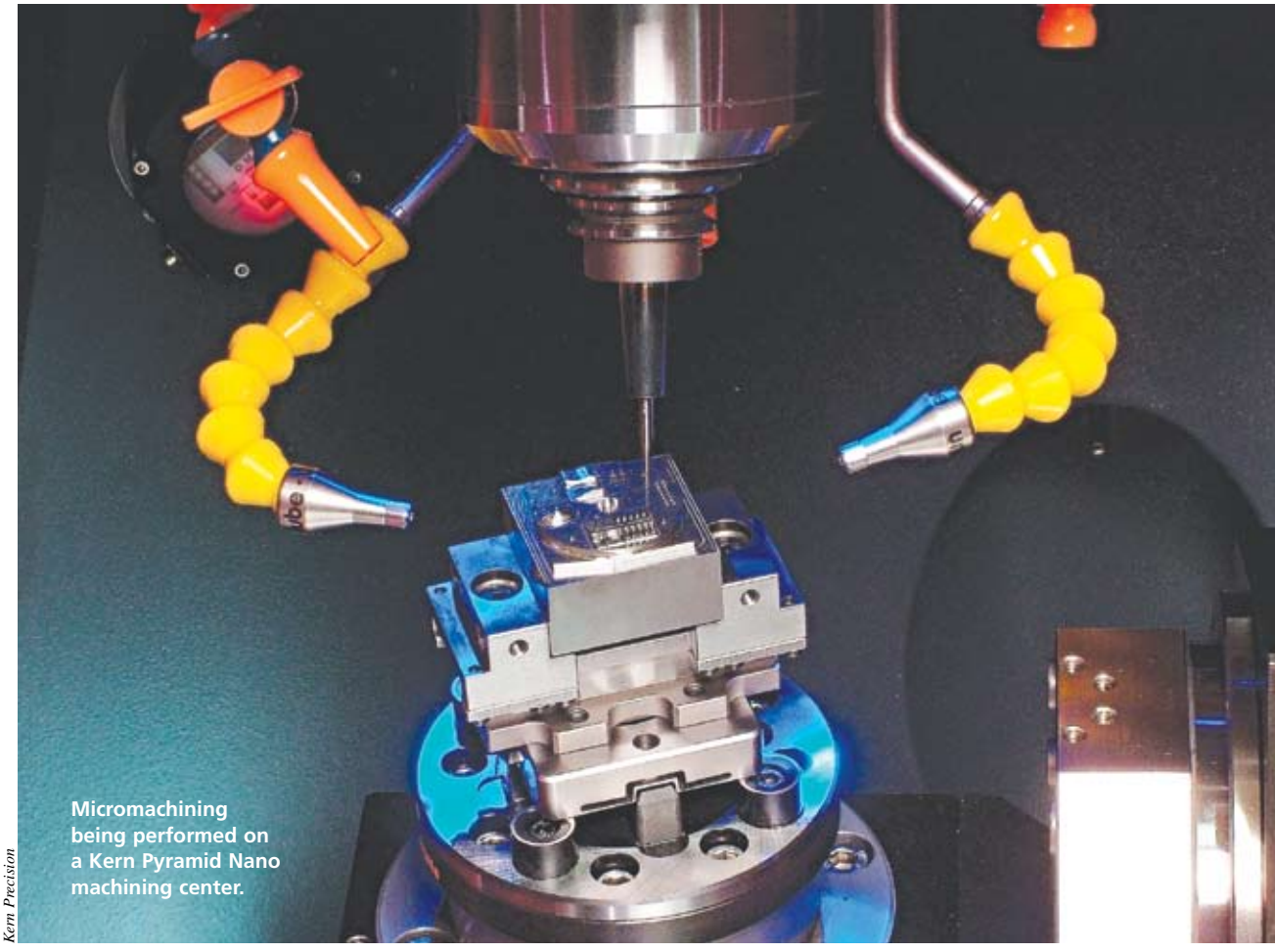
cover story

➤ BY ALAN RICHTER, EDITOR



Micromachining being performed on a Kern Pyramid Nano machining center.

Kern Precision

Building for Micromachining

Machine tool builders define and design the high-accuracy machines for making microparts.

Not only are more and more machined parts getting smaller and smaller, but their features need to be more precise. That requires machine tools designed specifically for producing microsize parts or features and meeting the ultratight tolerance requirements for them.

Various established and newer machine tool builders have risen to the challenge and offer machines to satisfy current customer demands while continuing to refine their equipment.

Defining Micro Machine

The definition of a micro machine tool is open to interpretation,

Learn more about micromachining tools

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but Gary Zurek, CEO of Kern Precision Inc., Webster, Mass., said such a machine must have four capabilities. (Kern Precision is the U.S. sales, application and service base for Kern Micro- und Feinwerktechnik GmbH & Co. KG, Murnau/Eschenlohe, Germany, a builder of hydrostatic machining centers.)

The four capabilities are:

1. All axes must contain glass scales having a resolution of 0.1µm.

2. Positioning accuracy of each axis on a 3-axis machine must be ±1µm or better.

3. The spindle must be able to accommodate a 50µm-dia. or smaller cutting tool and have a speed of at least 50,000 rpm with runout of no more than 1µm to avoid tool breakage and meet tolerance requirements.

4. If it's called a micro machining center with multiple axes, it must be able to accommodate a precision 2-axis CNC dividing head.

In addition, Kern developed definitions for various levels of precision based on accuracies achieved on the workpiece, including possible tolerance buildup from the spindle, toolholder, cutting tool and other machining system components. Kern defines microprecision as having a workpiece accuracy of less than 10µm, ultraprecision as less than 3µm and nanoprecision as less than 1µm, which equals 0.00004". Kern produces several 3- to 5-axis machines that achieve these workpiece accuracies and have microscale positioning accuracies. The Kern Micro, which evolved from a bench-type model, has a footprint of less than 32 sq. ft. and a positioning accuracy of ±1µm. The Kern Evo has a positioning accuracy of ±0.5µm, and the Kern Pyramid Nano, for larger workpieces, offers a positioning accuracy of ±0.3µm, according to VDI/DGQ 3441, the German accuracy specification standard.

Kern not only builds machine tools for micromachining but also performs it in Germany. "The micro machining department is by far the fastest growing department in Kern's job shop," Zurek said.

In addition to wire and sinker EDMs and surface grinders, that department has nine Evos and two Micros to produce parts with accuracies of ±2µm. The Evos have pallet systems for automatic workpiece changing, and six

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Kern Precision

The Kern Micro, which evolved from the company's previous bench-type model, has a footprint of less than 32 sq. ft. and a positioning accuracy of ±1µm.

of the machines are fully occupied with orders for all three shifts until the end of 2008. The shop makes parts for Swiss watchmakers, medical implants, aerospace parts and punches and dies made of steel hardened to 62 HRC.

"Oliver Fischer, head of our job shop, would desperately like to have even more Kern machines as he is fighting lead times of up to 6 months for micro milling applications," Zurek said, adding that the strong demand for the machines limits the company's ability to fit an additional machine into the production schedule. The shop is scheduled to take delivery of a Kern Pyramid Nano in June.

Shift from Macro to Micro

Atometric Inc. is also a builder of micro machine tools that provides contract manufacturing, but its primary focus is on selling machines. "We want contract machine houses to be our customers, so we don't want to be their competitor," said Thomas N. Lindem, president of the Rockford, Ill., company. "We offer low- to medium-volume contract machining to prove out a part or process."

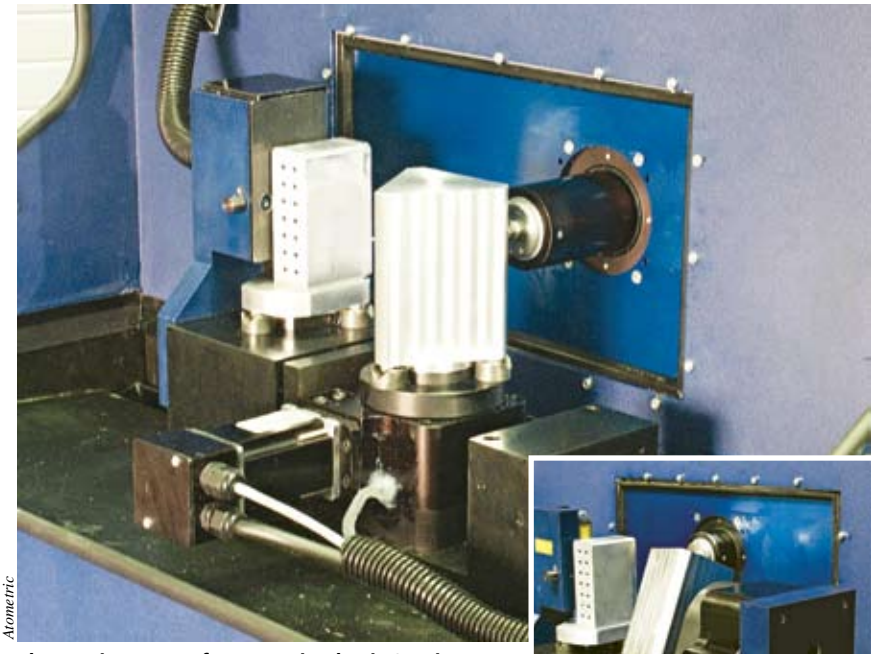
He added that Atometric people are from Ingersoll Milling Machine Co. and the auto industry. Lindem said: "We're used to big parts. We realize that everything we know about macro may not apply in the microworld, but we still bring our decades of experience. A lot of what we know from the macroworld does apply, even if not directly."

Lindem distinguished micromachining from the macroworld by the tolerance requirements, noting that microparts have tolerances often in the microns and that 0.0001" is a relatively open tolerance in the microworld. That means a manufacturer producing small parts on a macro machine or a Swiss-style machine that's struggling with holding tolerance might have more success on a micro machine tool because it's scaled to machine smaller parts and achieve micron-level tolerances.

Atometric offers its third-generation micro machine, which has a 3" work cube, and expects to have its fourth-generation machine, which will have a 4" work cube, available in March. Micro machines are often desktop size, run on 110v and draw about the same amount of power as a plasma TV, so some people don't view them as a serious production machine, according to Lindem. "Having come from the macroworld, we didn't want to make these small machines unless they have real productivity features that make them useful," he said. "Our slogan is 'office friendly, factory rugged.' "

To help achieve that, Lindem said a significant amount of engineering time was spent on developing a sliding, sealed metal wall that goes between the machine's stack of X, Y and Z linear axes and work area to keep chips contained. "The whole machine was designed as a mature macro horizontal machine would be in order to keep all of the chips from a wet or dry operation in the front area of the machine," he said.

Therefore, the front of the machine, where the cutting occurs, has a protected clean area that contains the automatic toolchanger area, the laser inspection device for detecting



Atometric

The cutting area of Atometric's basic 3-axis machine can be configured with a rotary table to enable 4-axis machining (top) or a trunnion and rotary table for 5-axis machining.

a microtool's tip within 1 micron and the optional confocal laser inspection probe. That probe will be available on the fourth-generation machine and inspects workpieces made of nonconductive materials on the machine before or after a workpiece is cut.

For conductive materials, probing is done through the cutting tools to verify the workpiece surface and monitor for tool breakage during machining. That feature is standard.

The basic 3-axis machine's cutting area can be configured with a rotary table to enable 4-axis machining or a trunnion and rotary table for 5-axis machining.

Another feature to prevent chip contamination is the machine's lightly pressurized back stack area. "Like a clean room, we provide a controlled leakage of a couple psi of air from the back of the machine to the work area so that dirt and chips stay out of the

machine's linear [or X, Y and Z] axes," Lindem said.

Because each tool tip is validated within 1µm, automatic tool change is reliable and allows tools to be stored in the ATC in "wine rack-style" cartridges in increments of 14 tools. In addition, the workpiece pallets and tool pallets have a common mounting, enabling an end user to set up a part fixture and tools offline while a different part is being cut. "When the machine stops, he can pull out the part fixture and tool cartridge and put in a new fixture and cartridge in a minute, select a new program and do a different part with another set of 14 tools," Lindem said.

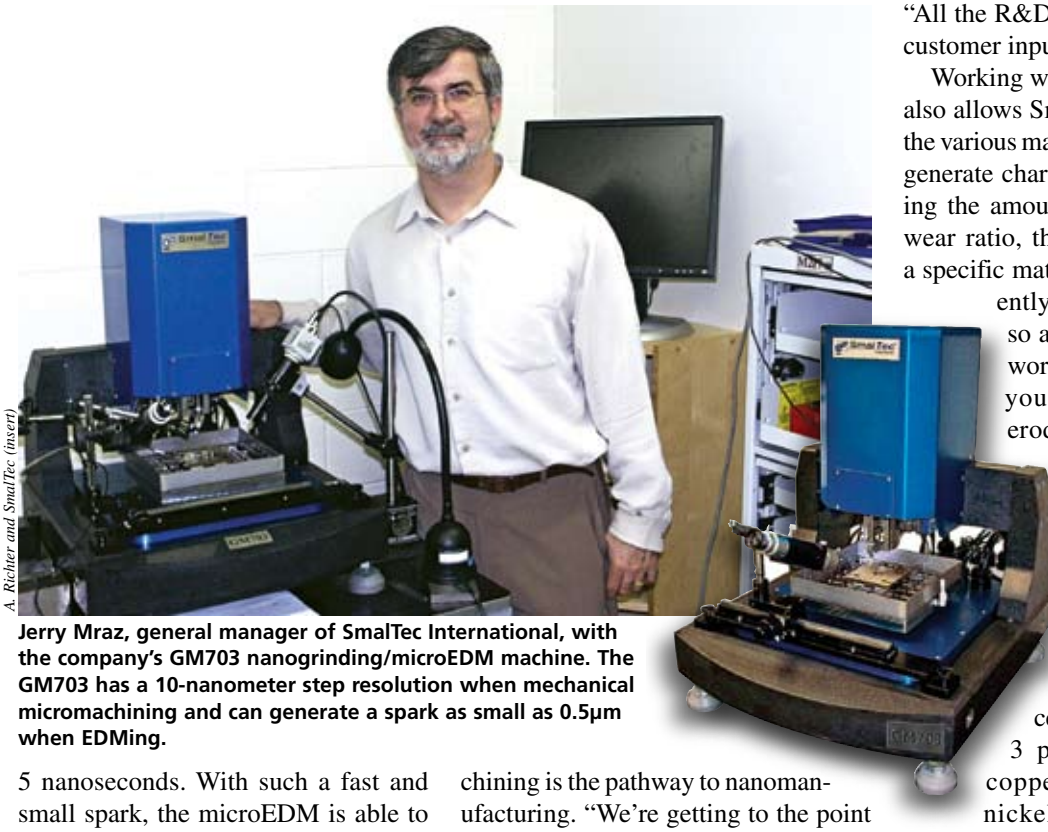
For rotating the tools, Atometric offers a servo-driven spindle with a maximum 100,000-rpm speed as standard and an optional 200,000-rpm servospindle. Microtools often need to rotate at a high rate of speed to cut efficiently and effectively. (Note: The equation for cutting speed is sfm = tool diameter × 0.26 × spindle speed.) However, Lindem said the standard spindle is suitable for most uses, and microtools might be too fragile for the higher speeds. "There aren't many current tools that we've seen from the production side that will survive beyond 75,000 rpm," he said. "We're quite happy to sell the 200,000-rpm option, which today is useful for microtooling research. We expect to see tools able to survive higher rpm in the near future."

Tool Talk

Mechanical micromachining can also be performed at lower spindle speeds. The spindle on the 3-axis GM703 nanogrinding/microEDM from SmalTec International, Lisle, Ill., can rotate at up to 6,000 rpm when doing mechanical cutting with the EDM voltage off, but Jerry Mraz, the company's general manager, said microtools typically need to be trued to size on the machine to minimize runout to an acceptable level. He indicated that a 40µm-dia. tool, for example, produced by a toolmaker on a CNC grinder might have a runout of 10 to 20 microns. "They can't hold better than that," Mraz said. "That's a very good tolerance for a CNC machine, but in our world that's a huge difference. Our machine can get it down to 1 micron."

He said that is possible because the GM703 has a step resolution of 10 nanometers for the grinding, or mechanical cutting portion, of the machine. SmalTec also offers the EM203 microEDM with a 0.1µm step resolution. For mechanical cutting or polishing, in addition to microtools, the machine uses 0.5µm-grain PCD chips embedded in a cobalt binder. "You literally have a million cutting tools on the surface, just PCD protrusions," Mraz said. A conventional EDM's smallest spark is 6 to 8 microns, but the GM703 can generate a spark as small as 0.5µm, according to Mraz. "That's the size of the spark itself, so that's the spark gap," he said.

In addition, the spark duration is



A. Richter and SmalTec (insert)

Jerry Mraz, general manager of SmalTec International, with the company's GM703 nanogrinding/microEDM machine. The GM703 has a 10-nanometer step resolution when mechanical micromachining and can generate a spark as small as 0.5µm when EDMing.

5 nanoseconds. With such a fast and small spark, the microEDM is able to impart "almost mirror" surface finishes as fine as 25 nanometers R_{max}, but 100 nanometers R_{max} is more common.

Unlike a conventional sinker EDM, Mraz said the microEDM has 3-D control and can produce contours in workpieces using simultaneous movement in all three axes.

The electrodes, which are produced in the microEDM, are drawn, or extruded, pure tungsten wire with no binder. Mraz said SmalTec even uses nanosize-grain material when producing electrode diameters as small as 1.5 microns. "Nanoparticle material is going to be in our future more and more," he added, noting that micromachining is the pathway to nanomanufacturing. "We're getting to the point where we can make a part so small by tearing it down that it will model what the part will look like when it is built up [atom by atom]," Mraz said. "We're trying to draw the bridge between the two technologies."

Wear Compensation

Besides its main business of building and selling micro machines, SmalTec produces prototypes to prove out the technology and sells 2-week blocks of time to use the machines. That enables SmalTec to not only generate additional income, but to gather insight into how its machines can be improved because satisfying one customer's requirements often transfers to others. "All the R&D work we do is based on customer input," Mraz said.

Working with an array of customers also allows SmalTec to collect data on the various materials being machined to generate charts for accurately predicting the amount of tool wear, or tool-wear ratio, that occurs when eroding a specific material. "EDMing is inherently an erosion technology, so as the components you're working on erodes, the tool you're working with also erodes," Mraz said, adding that the tool-wear percentage also depends on other factors, such as type of electrolytic fluid and amount of energy being applied to the electrode.

The tool-wear percentages vary from about 3 percent when EDMing copper to 34 percent for a nickel-titanium alloy. Once tool-wear ratios are established, Z-axis offsets can be entered in a machining program's code to accommodate for the tool loss.

Nanogrinding and microEDMing processes remove small amounts of material, so cycle times are generally long. That means the only way to do volume production is with multiple machines. To change that, SmalTec plans to add micro electrochemical machining, which is a significantly faster process for removing conductive material than EDM, to the same platform. The ECM process isn't as accurate, but a parts manufacturer could use it for roughing and then switch to

Fine finishes for a smooth fluidic flow

Biosite Inc. needed a micro machining center for quickly producing plastic prototypes of microfluidic devices rather than outsourcing the work. "When we send a design out, we're automatically behind a long queue of work from other companies, but we need designs done quickly so we can test them and move onto the next iteration," said Dan Bartholomeusz, process development engineer for the San Diego developer of diagnostic products. "To do that, we need to be able to do it in-house."

Microfluidic devices typically handle liquid samples of up to a couple hundred microliters and require the liquid to flow through tiny channels into compartments where chemical reactions, for example, are performed. "When you get to the microscale, which is typically anything less than half a millimeter, the precision and surface finish are very critical," Bartholomeusz said, adding that he was looking for surface finishes and feature repeatability on the order of 1 micron.

To achieve that finish, Biosite needed to purchase a micro machine tool that balanced performance and cost. Biosite evaluated machines that didn't provide the performance and ones that did but were beyond the company's budget before deciding to purchase a 363-S 3-axis micromilling machine from Microlution Inc., Chicago. The machine has a laser-based part surface sensor and tool tip locator, 2-micron positioning accuracy, 80-nanometer resolution and 200-nanometer repeatability. "Microlution's cost significantly less without a compromise in performance," Bartholomeusz said. The machine cost about $100,000.

A Microlution 363-S 3-axis micromilling machine with automatic toolchanger.

Bartholomeusz added that he was impressed with Microlution's attention to detail in machining the test patterns Biosite sent. "They didn't just run the CAM package and spit them out," he said. "Microlution understands the feed rates, spindle speeds and inertia issues that affect microscale features. They didn't just scale down a large machine. They started with microscale features in mind."

In addition, Biosite ordered the machine with an automatic toolchanger that holds 64 tools, some as small as 25 microns in diameter. "We wanted an automatic toolchanger not necessarily for throughput but for ease of use," Bartholomeusz said.

—A. Richter

EDMing for finishing. "You've taken a job that a microEDM may have taken 18 hours to do, and you cut it down to 3," Mraz said.

With their small footprints, low power consumption and minimal waste stream, micro machining centers can be set up just about anywhere—from an office to a factory environment—to target primary industries, such as medical, optics and aerospace, as well as numerous smaller segments. However, some emphasize that producing microparts is not like macromanufacturing but with smaller equipment. "It's not scaling down," Mraz said. "It's a completely different process."

With that difference in mind, he suggested the people most appropriate for operating micro machine tools are those who have a passion for doing something unique but not necessarily somebody well versed in machining. "I'm sure the guy who's got 20 years of experience is very good at what he does, but it doesn't apply to what we do here," Mraz said. "The kind of guy you want gets excited about making something that no one else can make. If you take that approach, you can use these tools and make these parts. The guy who says that can't be done, that's the guy who's going to hurt your business."

Others feel bringing macromachining experience to the table can be beneficial. "The main message is micromachining is not that different, but some things act a lot different," said Atometric's Lindem. "If you're trying to do a couple thousandths-wide feature, you're getting down to the grain structure of the metal, and you don't use the speed and feed handbook from the last 50 years of work there. You're going off the chart sometime. But everything people already know, they can apply as long as they keep an open mind."

Nonetheless, everyone seems to be in agreement that demand for microscale parts and the machine tools to produce them will continue to increase. "We see a constantly growing market in a rather unlimited world," said Kern's Zurek. "The trend of miniaturization is at its very beginning and will affect practically every sector in life." △