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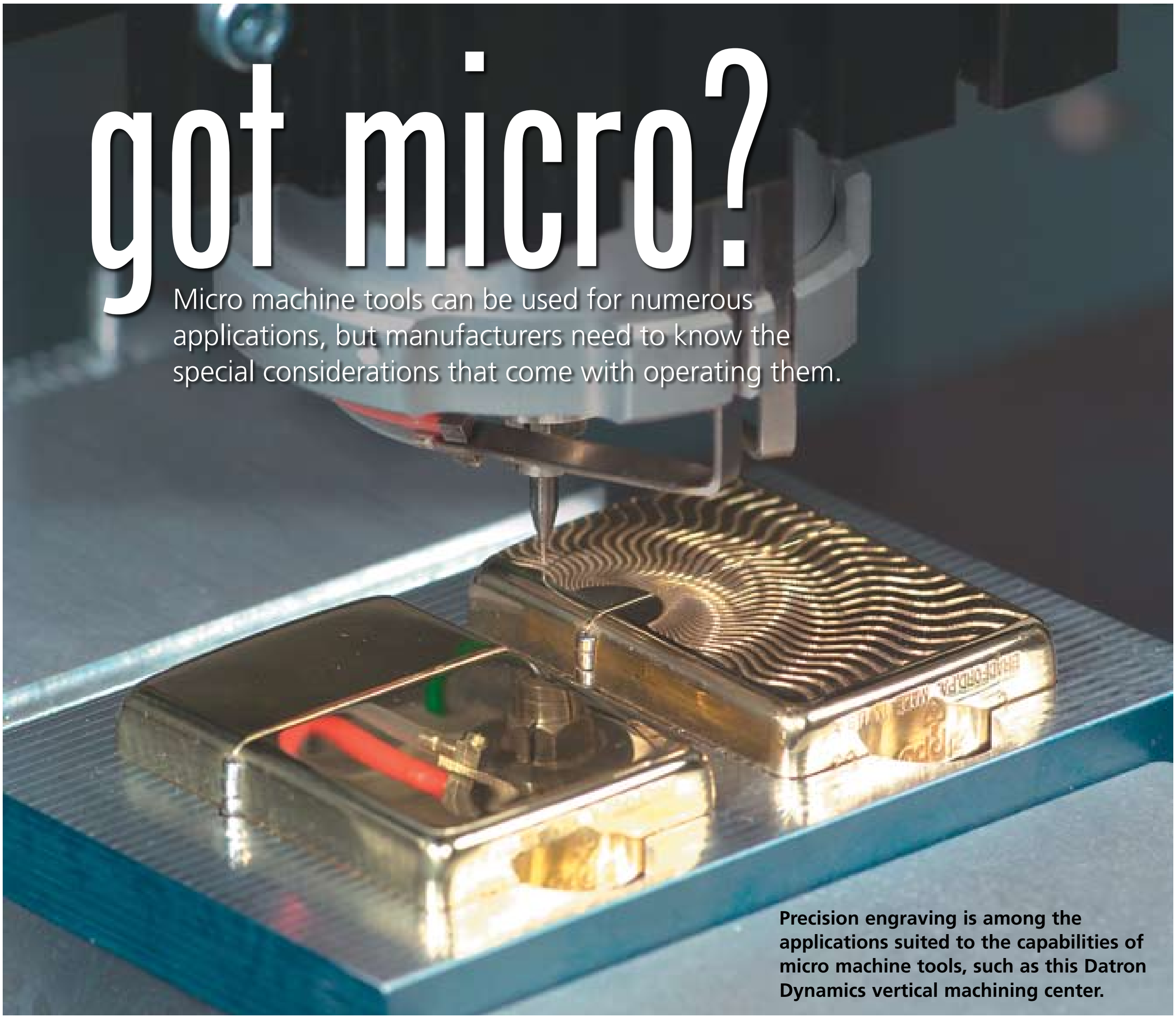
➤ BY BILL KENNEDY, CONTRIBUTING EDITOR

got micro?

Micro machine tools can be used for numerous applications, but manufacturers need to know the special considerations that come with operating them.



Precision engraving is among the applications suited to the capabilities of micro machine tools, such as this Datron Dynamics vertical machining center.

Datron Dynamics

From cell phones to medical implants, manufactured products are continually becoming smaller and more complex. Of course, the parts that comprise the products are shrinking, too. While it's clearly inefficient to turn out tiny parts on a machine that was designed to produce, say, engine blocks, small-part making isn't simply a case of acquiring a micro machine tool and turning it on.

A look at three different brands of machine tools engineered to make small parts found large differences among them. For example, while the machines weighed from 400 lbs. to 5 tons, the heaviest machine has the smallest X-Y-Z work envelope. Discussions with the machine makers revealed how they build their machines to meet specific applications and also touched on some of the challenges of small-part machining in general.

Good Things from a Small Package

Michael Ogilvy is vice president of sales and marketing for intelitek Inc., Manchester, N.H., the company formed in the merger of Eshed Robotec and Light Machines Inc., an early producer of benchtop CNC machine tools.

The company's top machine for industrial applications is the Benchman MX vertical machining center, which features a 19"×6" table and 12"×7"×9.5" X-, Y-, and Z-axis travels, respectively, weighs 400 lbs. and has a 48"×34" footprint.

Demand for the company's machines lags demand for small parts. Ogilvy thinks preconceptions about micro machine tools are the reason. "We do a lot of consultative selling and work in prequalifying customers, and what we find is most machine shops, unless they have tons of small work, don't really look at micro machines as viable," he said.

However, smaller machines can be used for other work, such as rapid prototyping. According to Oglivy, RP is an increasingly popular application for smaller machines. While additive RP processes, such as 3-D printing, get wide publicity, a subtractive machining approach can also be effective. "It really comes down to part geometries," Ogilvy said.

He pointed out that years ago, most parts were produced on 2- or 2½-axis machines, while today an increasing number of products have complex surfaces requiring machines with three or more axes. He acknowledged that additive RP technology enables production of "off the wall" part concepts, such as a sphere within a sphere. With an additive process, "You could grow that part in a couple of hours, but you could never get there with a machine tool," he said.

Another common use of intelitek's benchtop machines is machining electrodes for sinker EDMs. The application involves high-speed, tight-tolerance machining of graphite electrode material that's relatively easy to machine but is highly abrasive.

A third major application for the compact machines is mass production of small parts. One optical equipment maker uses a bank of the company's machines to produce interocular plastic implants for eye operations, Ogilvy said. The implants are machined to a tolerance of ±0.0002". Also, a turbine maker uses Benchman machines with 4-axis tables to cut both green and fired ceramics for turbine blades.

Because the machines are small, shops are often skeptical about rigidity and performance in terms of vibration control and part finish. Traditionally, a machine tool's quality was gauged by its weight, with heavier being better. Ogilvy said advances in materials used to construct machines, as well as advanced drive and guide technologies, counter that presumption. For example, the base and column of Benchman machines are cast from a proprietary granite copolymer composite. According to Ogilvy, the material is used extensively for grinding machines, in which vibration control is critical. He added the composite offers eight times the vibration damping characteristics of traditional cast iron, enabling the smaller machines to provide performance characteristics—in terms of vibration damping and stability—matching those of much heavier machines. Also, he said that the benchtop machines have the same linear guideways, zero backlash ballscrews and other high-accuracy machine-motion technology found on larger equipment.

intelitek

Major applications for the Benchman MX VMC from intelitek are rapid prototyping, machining of graphite EDM electrodes and production of small, precise parts. Depending on the machine and spindle configuration, applicable tooling ranges from 0.001"-dia. round tools to 2"-dia. shell mills.

You say micro, I say meso

Depending on who you're talking to, the definition of micromachining changes. Manufacturers of advanced electronics and nuclear components have a microscopically focused view of what's small.

Sandia National Laboratories, with locations in New Mexico and California, is a government-owned/contractor-operated facility managed by Lockheed Martin's Sandia Corp. for the U.S. Department of Energy's National Nuclear Security Administration. The lab develops technologies that support national security.

Gilbert Benavides, now manager of a components department at the lab, previously served in its manufacturing operations and developed definitions of micromachining that fit the organization's esoteric work. What he calls micromachining involves surface etching of silicon parts, with part features in the range of 0.00001mm (10nm, or 0.0000004"). He said that machining "is not about cutting tools, it's about photo-etching kinds of technologies." On the other, "big" end of the scale is what Benavides calls miniature machining, creating part features larger than 0.05mm. These parts, what most CTE readers would probably think of as micromachining, are machined with chip-removal technologies and EDM.

In between, Benavides said, "I tried to carve out another area of machining, called mesoscale machining. I defined that as millimeter-sized parts with micron-sized features—that is, features that have micron tolerances, something less than 0.001"."

At Sandia, the big end of mesomachining technologies involves micromilling and microturning with endmills about 20µm in diameter and turning tools 10µm wide. These technologies produce part features in the 25µm/0.001" range. Wire and sinker microEDMs can also produce part features of that size.

For features in the 1µm range, short-pulse lasers—with beams lasting quadrillionths of a second—remove material layer by layer. Focused ion beam machining, where the workpiece is bombarded with a controlled beam of ions, produces features in the area of 0.2µm. Sandia Lab, in fact, uses FIB machining on carbide to create the tiny endmills and turning tools used in its micromilling and microturning operations.

"They all have their attributes," Benavides said of the methods used for micromachining. The one chosen depends, he added, on the type of features each process can make, the precision it can produce and the material involved.

"There is no easy answer," Benavides said. "You have to tell me what it is you want to make, [then] we can see what technologies are going to get you there."

—B. Kennedy

Uncertainty about the applicability of a micro machine can be further resolved by engineering the machine for a specific application. Options offered by intelitek can be combined to present more than 1,000 different machine configurations. Ogilvy said that the options list includes "little things like a light or an enclosure or a long cross-slide," but also covers major performance-determining features, such as a large selection of spindles. "While our spindle speeds start at 5,000 rpm, we have five different options up to 50,000 rpm," he said.

Other options include automatic toolchangers, tool sensing systems, mist or flood coolant, and enclosures for milling graphite. "When the engineers design the machine, they work through a feature-based accounting system that supports it. The reality is that the machine is built with custom specifications to a particular order," Ogilvy said.

Small Parts on a Big Bed

The term "micromachining" is often associated with parts of submicron precision (see sidebar on page 38). Dr. Walter Schnecker, president of Datron Dynamics Inc., Milford, N.H., said not all small-part machining applications require supertight tolerances: "There are many industrial applications that don't really have the need for fractions of a micron on accuracy."

A key distinguishing feature of Datron Dynamic's top-of-the-line Velociraptor VMC is its 30"×40" table. "There is a lot of benefit in the combination of the microtooling and micromachining on a large bed," Schnecker said. "A large machine bed permits ganging multiple parts on the machine bed and running unattended."

intelitek

Produced as a test for a maker of coining dies for currency and tokens, this coin was machined on a Benchman MX VMC with a 0.001"-dia. endmill in a cycle time of 8 minutes.

He described the case of a Tennessee manufacturer that brought work back from the Far East. The work entails cutting out knife handles from a sheet of aluminum and involves drilling and tapping holes, milling pockets and beveling edges of 124 handle halves from a 36"×24"×⅛" sheet of aluminum. Tolerances are ±0.001" for details and ±0.0005" on some hole locations. Cycle time for a sheet is about 3 hours, during which the machine runs untended. Currently, the process runs three shifts, 5½ days a week.

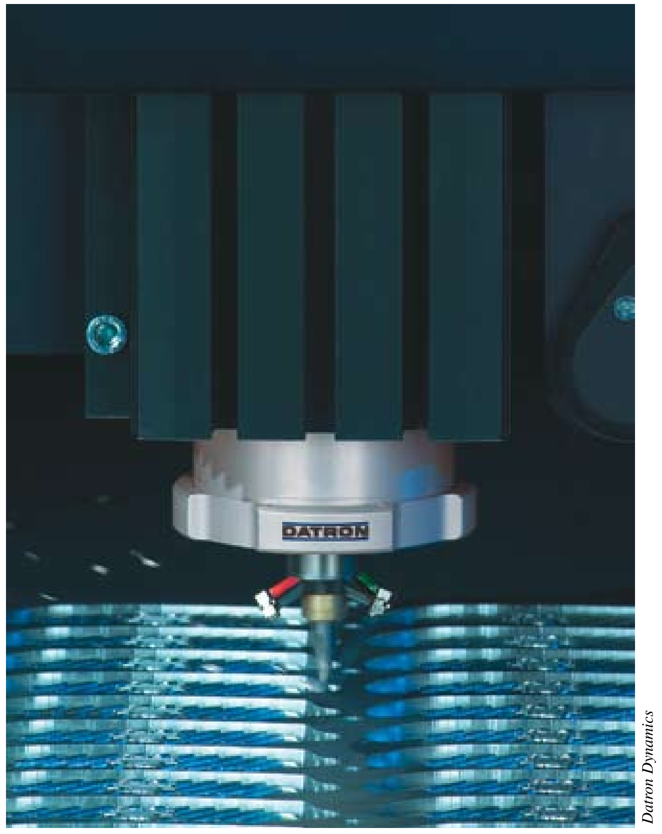
"This is not something very flamboyant, like drilling microholes in jet engines," Schnecker said, "but the untended machining is part of the attractiveness for using micromachining in an industrial environment."

According to Schnecker, a major issue in micromachining is maintaining the tiny tools required to produce small part features. "Chip load and other things aside, the smaller the tool, the more sensitive it is," he said. "It's all about the rpm. The higher the rpm, the less likely you are to break a tool." Schnecker said Datron machines are designed around a 3-hp, 60,000-rpm spindle, and the relatively high horsepower enables the spindle to maintain high rpm while cutting.

In addition to marketing machine tools, Datron Dynamics also produces a selection of micromachining tools for high-speed applications, with fewer flutes to afford more room for chip evacuation. Schnecker said: "We use the rpm and the centrifugal forces to make sure we fling the chip away. If you have a 3"-dia. flycutter and you catch a chip, that flycutter won't even

For more information, visit "Archived Articles" at www.ctemag.com and select the "Micromachining" category.

This application, performed on a Datron Dynamics VMC, involved drilling and tapping holes, milling pockets, and beveling edges of 124 knife-handle halves from a 36"×24"×⅛" sheet of aluminum. This photo shows how combining microtooling and micromachining on a large bed enables multiple parts to be ganged and machined unattended.

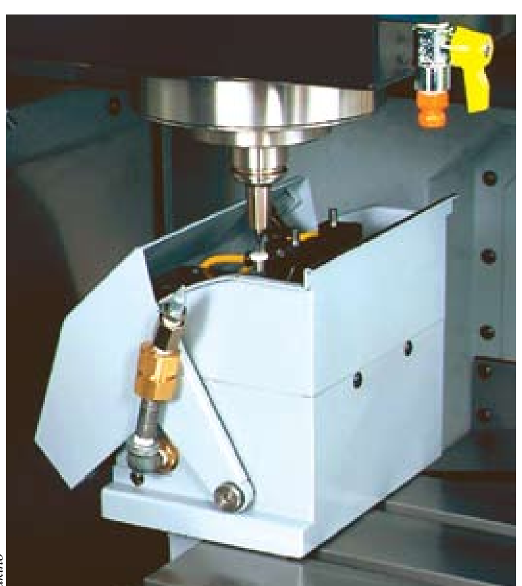


Datron Dynamics

notice. If you have a 0.020"-dia. drill or a 0.040"-dia. endmill, you catch a chip and the tool immediately snaps. The smaller the tool, the faster you have to go to make sure you fling the chip out."

Beyond the challenges of actually machining small parts, Schnecker said that "most customers struggle to hold them; workholding becomes an intrinsic part of the whole micromachining work flow." He noted that the lower cutting forces involved somewhat moderate the need to maximize rigidity, but gripping tiny parts remains a problem. Because many of the company's customers cut sheet products, Datron developed a vacuum workholding system called Vacumate. Schnecker said the system enables a shop "to just put a piece of acrylic or aluminum down, cut out all the parts, turn off the vacuum and the parts are lying there to be grabbed."

The specialized nature of small-part machining is requiring machine builders to provide machining solutions beyond the machine tool itself. In addition to workholding, for example, Datron can provide robotic workhandling systems to simplify work flow. In a typical application, a robot picks parts from a tray and moves them to pneumatic grippers on the machine's 4th and 5th axes, where they are positioned for machining. When the cycle is complete, the robot removes the parts from the machine and places them in a finished parts tray.



Makino

To accurately determine the position of the tiny tools applied in micromachining, Makino developed a hybrid automatic tool-length-measuring system that combines static low-pressure contact sensing with noncontact sensing performed while the tool is at operating speed, permitting submicron tool positioning accuracy during machining operations.

Small Parts, Tight Tolerances

In many cases, the critical application of a product demands that small parts be made to high precision. Lee Richmond, micro market manager for Makino, Mason, Ohio, said, "If you are talking about building a mold or a die for a precision medical part, such as the dissolving surgical staples that are used inside a patient, the tolerances are very tight and there are strict accuracy and surface finish requirements." He added that Makino's definition for micromachining is the machining of a part or mold in which each outer dimension is 10mm or smaller in size or that has details of 0.1mm or smaller.

Makino's response to the need for such precision is its Hyper2J VMC. With a footprint of 71"×93" and a weight of 11,000 lbs., it has a 12"×8" worktable with 8"×6"×6" X-, Y-, and Z-axis travels, respectively. The company says the machine provides positioning accuracy of ±0.3 microns and repeatability of ±0.2 microns.

According to Richmond, the actual button-pushing operation of high-accuracy micro machine tools doesn't differ much from that of their brethren engineered to make bigger parts. Considering the effectiveness of current CNC technology, he pointed out that the machine doesn't take excessively more expertise from an operating standpoint than that required to run any 3-axis machine. "Basically, it's a G code or an M code that the operator plugs in, and the machine does it itself," Richmond said.

Makino

The Makino Hyper2J micro machining center includes features such as a direct-chucking spindle designed to eliminate toolholder-induced variables and enable the machine to produce precise, small parts, such as medical instruments, semiconductor devices and optical products.

However, he added that the real challenge is preparing the entire machining system before the button pushing begins. One major factor is the machining environment, specifically the thermal conditions. As the temperature of the part and spindle change during operation, dimensional changes that would be negligible when machining a macroscale part become major on a tiny part.

The following companies contributed to this report:

Datron Dynamics Inc.
(888) CNCAT3D
www.datrondynamics.com
Information Services #320

intelitek Inc.
(800) 221-2763
www.benchman.com
Information Services #321

Makino
(800) 552-3288
www.makino.com
Information Services #322

Sandia National Laboratories
(505) 284-2001
www.sandia.gov

Richmond said the key is to have a stable environment and virtually eliminate spindle growth. "You can't just compensate, because now you are talking about trying to hold a micron or less in accuracy. All that has to be built into the machine tool. That is something that a lot of people don't understand when they are looking at micro machines."

Among the Hyper2J features that minimize thermal factors are an automatic spindle lubricant temperature controller and the machine's granite base, which, because granite's thermal conductivity is only 10 to 20 percent of cast iron's, minimizes the effects of changes in ambient temperature. For extreme cases, the entire machine can be enclosed in a "thermal chamber," effectively placing the operation in a controlled environment.

Tiny, precise part features require tiny, precise tools, the management of which is a challenge, too. "You aren't using a 5mm-dia. tool, you're using a 0.5mm-dia. or 0.05mm-dia. tool," Richmond said. "How do you even see your cutter, and how do you pick up the tool length?" The beam of a typical laser tool-measurement system may be larger than the tool. "How can you get any accuracy from that?" Richmond asked.

He added that Makino approached the problem by developing a hybrid automatic tool-length-measuring system. As its name implies, the system combines two tool measurement methods to determine the tool position with submicron accuracy.

First, with the machine stopped, the tool tip is touched to a low-pressure contact sensor to accurately measure the tip position. Then, the spindle is turned on and the tip position is measured at operating speed via noncontact electromagnetic sensing. That measurement takes into account the thermal displacement of the tip caused by rotation. The system's control merges the two measurements.

"We measure spindle growth and wait until it stabilizes within certain tolerances the user sets. If you want to hold 1 micron, you can set your variable at 1 micron," Richmond said. When the spindle is stable, it can cut at the desired level of accuracy.

It is not possible to change single elements of the machining system and achieve truly precise machining. For example, to attain the higher cutting speeds necessary with small tools, it is possible to buy a speeder head that fits a machine spindle and enables a traditional 12,000-rpm CAT 50 spindle to turn a small tool at 40,000 or 50,000 rpm. Richmond said, "It's great for picking small corners in a large mold, but you're not going to get the accuracy and the detail you need when you get down into the smaller radiuses. When you get below 1mm, it's not going to have success."

Richmond said many micromachining parameters are developed on a case-by-case basis. For example, very high-rpm and feed rate capabilities may not be applicable to very small parts. "If you've got a 100,000-rpm spindle, your chip load formula might say you can run up to 100-ipm feed. But when your part is only ¼" long, you're never going to get [the feed rate] going that fast." For some details, he said, "we are actually slowing our spindle down to 40,000 rpm because the detail is so small, we can't get up over 15 ipm. By the time we get [the feed rate] up to speed, we are slowing down because we have to do another corner."

Richmond said, "It's been our dream here to create a machinist's handbook with all the speeds and feeds for different cutters. However, when you get into what we call 'high-performance machining,' we don't follow the same rules anymore about speeds and feeds. It's a different approach. Twenty-five years ago, when I started out, you set your feed rate until you broke a tool and then backed it off one notch, and you felt good." He added the situation is different today. "Basically, all you can do is go from experience and general guidelines, then tweak it from there."

Finding the right micro machine tool for a small-part job starts with consideration of the part to be made, including its geometric configuration and the precision required. Then, by considering the capabilities of the variety of micro machine tools available, a shop can find the best way to turn out small parts in the required volume and precision. △