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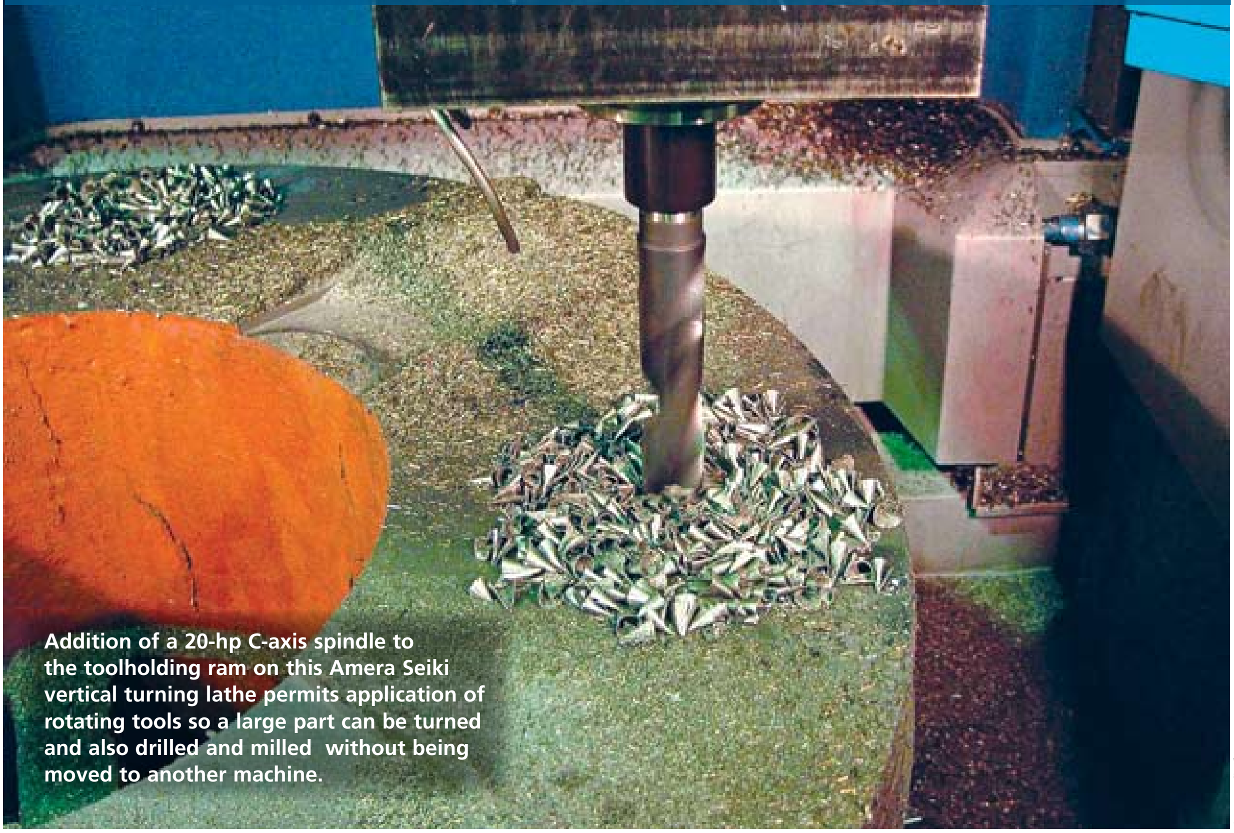
➤ BY BILL KENNEDY, CONTRIBUTING EDITOR



Addition of a 20-hp C-axis spindle to the toolholding ram on this Amera Seiki vertical turning lathe permits application of rotating tools so a large part can be turned and also drilled and milled without being moved to another machine.

Amera Seiki

LARGER Issues

Big machine tools are just like smaller ones. And they're not.

Relatively speaking, one shop's big bruiser is another's minimachine. So for this discussion a "big" machine tool can be defined as a machining center with a work envelope larger than a 36" cube or a lathe that can handle a workpiece greater than 2.5' in diameter. Defining what constitutes the step beyond big is less clear; most probably it is determined by a machine's degree of specialization as well as its size (See sidebars on pages S2, S8 and S10).

Obviously, big machines are similar to their smaller brethren in operation and results. However, the physics of processing a massive workpiece—as well as market forces that include shrinking lead times, controlling costs and machining challenging new materials—require large machine tools to offer features different from those of smaller machines.

Increasing demand for big parts is boosting interest in large machine tools. The booming aerospace market requires large structural airframe members and power generation components. A number of large parts that were previously fabricated are now machined from monolithic blocks, increasing the need for big, accurate machine tools.

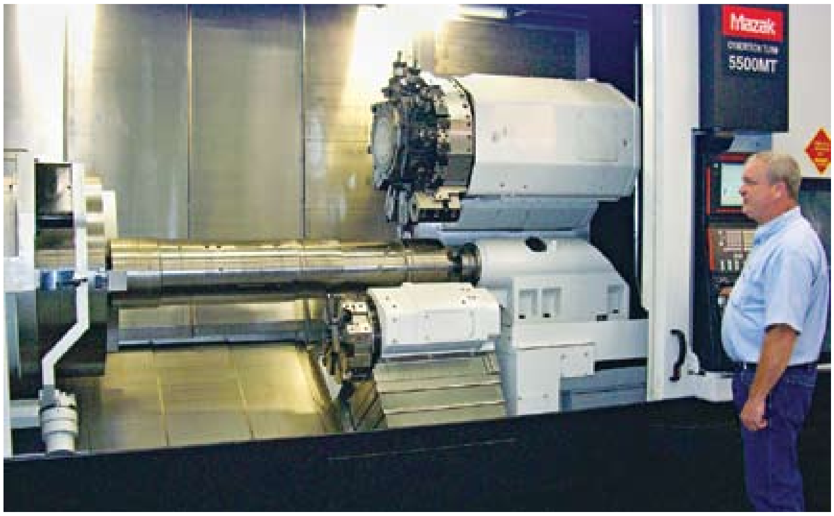
Many U.S. manufacturers also see machining large parts as a service that offshore competitors can't match. Transportation costs and low volumes usually make it impractical to source large parts overseas.

George Yamane, marketing manager for Mazak Corp., Florence, Ky., said that in prior decades, simply finding a way to machine a big part was the key challenge. Today, he said, "the technique of how to cut the part is one thing, but reducing production lead time is another dimension. The question is, 'How can I make this part faster?' "

Typically, large parts are more

difficult to handle and take more time to set up than smaller parts—especially when performing operations on several machine tools. "If a large part is moving around four or five machines, how much setup time do you accumulate? Doing all the machining in one machine makes much more sense for large parts," said Yamane.

Mazak addresses large-part setup with machines such as its Cybertech 5500 for machining long shafts and large-diameter pipes. The machine offers multitasking capability via a 12-position upper drum turret with turning and milling tools, an eight-position lower turret with turning tools, and a C-axis, said Yamane. An optional boring bar stocker can accommodate bars up to 31.5" long. Chucks to 33" in diameter are available, and maximum swing is 36.0". Depending on the bed specified, maximum machining length is 160". Workpiece (shaft) payload is 7,716 lbs. The machine's 60-hp main spindle offers nearly 8,500 ft.-lbs. of torque, and the upper-turret milling spindle has 15 hp.


Mazak

Adding capabilities to a large machine tool minimizes repeated handling of large parts for secondary operations. This Mazak Cybertech 5500, engineered for machining of long shafts and large-diameter pipes, features a 12-position upper drum turret with turning and milling tools, an eight-position lower turret with turning tools, and a C-axis.

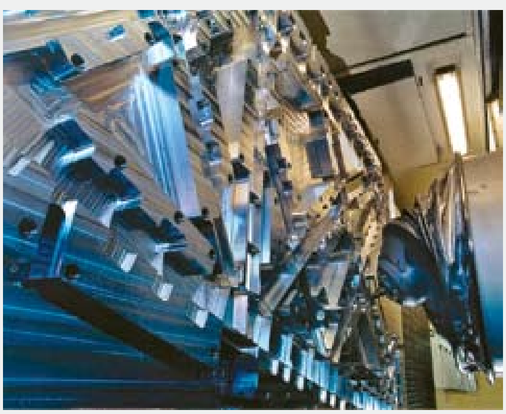
"With the milling operation incorporated into a turning machine, you don't need another machine for secondary operations, so you can cut setup time and maintain accuracy,"

Size XXL

For most shops, a machine with a cu.-yd. work envelope is bigger than they'll ever need. But those machines are small compared to some from DS Technology (USA) Inc., Cincinnati. The company provides very large machining centers from three German brands, Dörries, Droop + Rein, and Scharmann, as well as grinding machines from Berthiez. For example, the DS Aircraft line of machining centers includes Ecospeed machines that offer an X-axis travel up to 50' and can handle a pallet as large as 6.5'×23'.

Big machines have been around as long as there have been big parts. The difference today, said Dennis Lucas, president and CEO of North American operations for DS Technology, is higher speeds and higher accuracy. An illustration of high-speed technology, he said, is the company's Sprint Z3 parallel kinematic head, which can be oriented up to ±40° within a Z-stroke as large as 370mm and is engineered with low mass to decrease acceleration forces in X and Y directions. Even with big HSK A63-80 toolholders, Lucas said, "we'll run the spindle at 30,000 rpm and move at 800 to 900 ipm in five axes."

The other key difference is that as parts have grown bigger, tolerances have become tighter. "Aerospace customers look for 0.003" true position on a part 10 meters long," Lucas said. To maintain that tolerance level, the big machines have compensation systems that measure the part and adjust the machine in process.


DS Technology

This Sprint Z3 parallel kinematic head at right from DS Technology is engineered with low mass to decrease acceleration forces in the X and Y axes.

Lucas pointed out that temperature changes have effects in proportion to the size of the part. "Since aluminum's expansion rate is about 0.001" per foot per 10° F of temperature, when a 10'-long workpiece is exposed to a 10° F temperature change, your hole has already moved 0.010"," he said. Accordingly, large, precise parts are often machined in temperature-controlled environments, and before machining are "doused with coolant to bring them to the correct temperature so you don't have any part movement," he said. He added that most of DS Technology's machines are modular and assembled to customer specifications because, "everybody wants their own little niche. Every one is a little bit custom, a little bit special."

—B. Kennedy

said Yamane.

Amera Seiki Corp., Cedar Rapids, Iowa, employs a similar combination of capabilities so multiple operations can be performed on large vertical lathes, according to Ron Gauthier, sales manager. Instead of a toolholding turret, Amera Seiki vertical lathes with chuck diameters larger than 32" have a ram-style toolholder serviced by a toolchanger. The vertical ram travels on a cross rail in the X-axis. In addition to accommodating 50-taper toolholders, the ram can also be fitted with a C-axis spindle.

"About half of those inquiring about this machine are looking at putting a live tooling spindle in the ram," Gauthier said. Typical customers for this configuration include makers of large pumps and flanges that traditionally turn parts on vertical lathes and move them to machining centers for drilling, threading and milling. "They are looking at putting a big part on one machine and doing as much as possible in one setup," he said. Amera Seiki's biggest vertical lathe is its 100-hp VT2000 vertical turning center, which can handle parts as large as 98" in diameter and weighing up to 10 tons. The machine's 10"-square ram provides 39" of vertical travel, which can be extended to 45" by adding a column riser. The addition of a 20-hp C-axis spindle permits application of rotating tools.

A Different Approach

Tim Jones, horizontal machining center products manager for Makino Inc., Mason, Ohio, agrees that big-part machining techniques are changing. "The traditional method of machining large parts employed big boring mills, but shops now want to eliminate setup times," he said. "They are looking more at a machining center concept than a boring mill."

Even though modern machining centers have torque capabilities in the range of 700 to 800 ft.-lbs., they usually don't have the 70-plus hp and the 1,500-plus ft.-lbs. of torque offered by some traditional boring mills. As a result, "you need to approach the part differently," said Jones.

He described a manufacturer that machines 2½"- to 6"-dia. holes as deep as 36" in the course of producing steel mud-pump components for the energy industry. Previously, the shop made the holes on a boring mill by step drilling with increasing drill diameters, then applying one or more boring bars. "They used three or four tools to get the thing done," Jones said. To machine the parts on a machining center, operators "had to unlearn what they knew and learn new tooling techniques. The shop now helically interpolates the large-diameter holes," Jones said. He added that besides the flexibility gained by processing the part on a machining center, the manufacturer found that interpolation can be significantly faster than step drilling on the boring mill.

Machine tool builders now design

machines for specific large-part applications. Jones cited Makino's a92 machine for which "the bullseye part is a diesel block or head." The machine has X-,Y- and Z-axis travels of 59", 49" and 53", respectively, and its 31"×39" pallet can handle workpieces up to 59" in diameter and height, weighing as much as 6,600 lbs. "When the parts are large, you machine features that are way off the centerline of the pallet, as well as high off the surface of the table, at high levels of force," Jones said. "So this machine was designed to withstand heavier forces up high in the Y-axis and far out in the X-axis."

The diesel engine application also requires a surface finish that dictates use of a cutter with a diameter larger than the width of the head deck, eliminating overlapping passes that could compromise the finish. Large-diameter facemills are "real heavy," Jones said, noting that big parts in general are more likely to require big tools. "The ability to change big, heavy and long tools is a major issue," he said. The a92's toolchanger can handle tools up to 14" in diameter, 35" long and weighing up to 77 lbs. Jones added that the machine's positioning accuracy is ±0.0001" and repeatability is ±0.000060".

The following companies contributed to this report:

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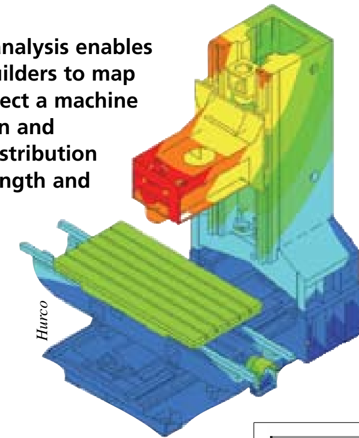


Finite element analysis enables machine tool builders to map stresses that affect a machine during operation and manage their distribution to optimize strength and rigidity.

Design Considerations

A common thread in machine tool design discussions is the comparison of box ways vs. linear guides. Box ways traditionally are valued for their ability to control and absorb large cutting forces and vibration; linear guides offer the advantages of faster movement and low friction.

"We have large machines with linear guides; we also have large machines with box ways," said Makino's Jones. The choice generally is application-based. Die/mold machines typically use box ways because molds may be on the machine for many hours, if not days. Where the focus is on production volume, speedier linear guides may be preferable.

Jones added that there are many sizes and styles of linear guides to accommodate different cutting forces and part weights. The a92, for example, employs roller bearing rather than ball bearing guides because rollers offer much greater contact area than balls and therefore provide higher dynamic and static load capabilities. "On a small machine, it doesn't make a difference, but on a larger machine, roller guides may provide some benefit," Jones said.

Finding Strength

No matter what guide way is used, machine structural strength and integrity are crucial, especially when machining larger parts. A weak structure leads to surface finish problems or may limit cutting parameters. Himat Patel, executive vice president, machine tool engineering for Hurco Cos. Inc., Indianapolis, said it's not just a case of making a big machine heavier.

"Structural design is the key factor in making a machine rigid," he said. "We don't put weight where it is not needed. Weight costs money, so we have to optimize it." Hurco uses finite element analysis to design its machines "to determine machine stresses and make sure cutting forces are applied to the right parts of the machine," Patel said.

FEA can also determine the resonant frequency of the machine structure. "If the frequency is too low, you run into performance issues because you can't run the machine very fast," Patel said. "When we design a machine for 300 ft.-lbs of torque, through FEA modeling the spindle is going to see 300 ft.-lbs. of torque in

axial, radial and tangential directions. That's the beauty of FEA; it tells you what to expect and what problems to solve," he said. Hurco recently introduced its largest machining center. The VMX84 VMC has X-,Y- and Z-axis travels of 84", 34" and 30", respectively, an 86"×34" table and a workpiece capacity of 5,000 lbs.

Size Without Compromise

In prior years, a big machine tool wasn't associated with the concepts of high precision, speed and convenience. Jeff Law, product manager for large machines at Haas Automation Inc., Oxnard, Calif., said shops today "aren't willing to sacrifice accuracy just because a machine is big; the accuracy and repeatability of our big machines is comparable to the rest of our product line."

He cited the example of Haas's Extra Large Specialty HS (horizontal) and VS (vertical) machines. These bed mill-type machines weigh from 60,000 to 75,000 lbs., feature X-axis travels as large as 150" and can be built with a vertical or horizontal spindle head. The horizontal machines can be configured with three axes or can have an embedded full 4th axis.

The big machines reliably hold tight tolerances on large parts. Law said Haas uses 10 of the VS units in

Haas

Extra-large specialty bed mill-type VS machines from Haas weigh from 60,000 to 75,000 lbs. and feature X-axis travels up to 150".

Another size of big

Hear "router" and think "Home Depot, light duty, maybe cabinet makers"? How about 3-ton table capacity, 40-taper tooling and 20 hp? GR CNC gantry router machines from Haas Automation Inc. fill a niche in the large-part machining spectrum. Machine table sizes range from 5' wide × 10' long up to 7' wide × 12' long. Standard Z-axis travel is 11", with 24" optional. Spindles come in 5,000-, 10,000- or 15,000-rpm versions, with 15 or 20 hp. The machines have 10- or 20-position carousel toolholders and a Haas CNC. Workholding alternatives include a plain table, one drilled and tapped for bolt-down fixtures, and a vacuum arrangement.

Dave Hayes, product manager for the GR machines, said end users vary. "In almost every different industry, someone owns a GR," he said. The list includes aerospace manufacturers that often use them to machine fixtures, fabricators that employ them to process awkward weldments, patternmakers that cut wood and high-density foam, and even one shop that machines limestone for garden statuary using diamond tools.

They're not light-duty machines. Hayes said one shop is using carbide-inserted drills to drill thousands of ¾"-dia. holes through 5'-dia., 5"-thick steel plate used in heat exchangers. Ballscrews drive machine movement and the structure consists of 1½"- to 2¼"-thick weldments, "which is why you can throw 6,000 lbs. up there," Hayes said. He pointed out that a machine's size and gantry design determines its level of precision; he generally quotes accuracy in the range of ±0.002".

The routers' open construction makes for convenient loading and unloading. "They're open on three sides," said Hayes, adding that perhaps a third of the machines go to manufacturers processing aluminum extrusions. "They can feed parts through the machine because it's open on both ends. One customer has two of them front-to-front and uses the combination like a big gantry. All they are doing is drilling and tapping and some small cutouts, so it's kind of overkill to throw it up on our more expensive VF-8 VMC."

—B. Kennedy

Haas

With table sizes from 5' wide × 10' long to 7' wide × 12' long, GR CNC gantry router machines from Haas are favored by manufacturers who drill, tap and mill large aluminum extrusions because they can feed the unwieldy parts through the machines from both ends.

its own factory to machine large base castings for its small and medium size vertical machining centers. "We have been cutting cast iron and maintaining flatness, straightness and parallelism of critical features for 10 years of continuous operation on some of these machines, holding 0.0002" to 0.0003" over 60" of travel or more," he said.

Big doesn't mean slow, either. "In the past, bigger machines generally had slower spindle speeds, but that is not the case today," Law said. A 10,000-rpm, 50-taper spindle is optional on even the largest machines.

Finally, shops don't want to compromise convenience when machining big parts. Law said users "want a machine that's easy to load, fixture, program and set up. Shops that want big machines always seem to want lots of tools." Other features that provide increased utility include "big tables, lots of T-slots, built-in fourth axes with platter surfaces cut coplanar to surrounding tables and big doors for ease of loading," Law said.

Material-Driven Development

To improve product performance, manufacturers continually seek and apply higher-performance (i.e., difficult-to-machine) workpiece materials. The new materials in turn drive developments in machine tool technology. Gregory A. Hyatt, vice president and chief technical officer for Mori Seiki U.S.A. Inc., Rolling Meadows, Ill., said advances in the construction of airframe structures are fueling a move away from aluminum to composites and titanium alloys. "The change is demanding recapitalization of the metalworking industry because the ultra high-speed, low-torque machines purchased over the last decade to machine aluminum are ill-suited to cut materials like titanium."

Cutting conditions for composites are similar to aluminum in that the forces involved are low and spindle speed is high, but chip disposal issues are completely different, Hyatt said. The dust-like fragments of cut fibers and resin are difficult to handle and may pose health risks if inhaled. To address the issue, Mori Seiki is developing special vacuum systems integrated into machine spindles for disposing of carbon-fiber and graphite dust. "We suction the dust and the debris through the tool and into the spindle, and safely dispose of them without the interior cavity of the machine ever having been charged with the dust," Hyatt said. He added that the carbon-fiber disposal system is relevant to larger envelope machines because composite skins and stringers tend to be large. Mori Seiki expects to begin selling the systems in 2008.

Titanium's ascendance as an aerospace material also challenges existing machine tool technology. Unlike aluminum, machining titanium requires high torque. While ceramic tools have been developed for nickel-base alloys to support relatively high-speed machining, new beta-phase titanium alloys such as 5553 are significantly tougher and more abrasive than traditional Ti6Al4V. The new alloys' characteristics drive cutting speeds down and raise torque requirements.

Hyatt said new spindles in Mori Seiki's larger horizontal machines provide 1,000 Newton-meters of torque via a direct-drive system that requires no gear set. "The combination enables the spindles to achieve surface finishes associated with a smooth direct-drive spindle and still have 1,000 N-m of torque for running the big tools at 100 rpm," he said. One of Mori Seiki's large machines, its horizontal NMH8000 DCG, has X-, Y- and Z-axis travels of 55", 47" and 53", respectively, and a 32"×32" pallet capable of supporting 4,400 lbs. The 10,000-rpm spindle handles 50-taper or HSK-A100 tool shanks. Hyatt said the machine's twin ballscrew drive enables it to push parts at their centers of gravity, reducing vibration that can affect part quality.

As the market for large parts expands, so does the supply of machine tools that can handle these parts. And shops no longer have to sacrifice performance in manufacturing these sometimes monstrous parts. △

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

Universal utility

All else being equal, the bigger the machine, the bigger the capital investment. But that big asset is dormant—not making chips—when parts are being moved off, on and between machines for different operations and when an operator tends tooling, said Randy Von Moll, a platform manager involved in product development at Cincinnati Machine LLC, Hebron, Ky.

Von Moll said 5-axis machining capability helps maximize machine utilization. Five-axis contouring in aerospace applications and five-sided machining of other large parts reduces setups because a shop can machine all sides of the part, except the bottom, in one setup. "Many shops will do a prep operation on the bottom surface to qualify the part, then they can finish the entire part in the 5-axis machine," said Von Moll. Part accuracy is also improved through minimizing tolerance stacking and reducing fixturing errors.

As shops realize the benefits of five-axis machining, they want to use the approach on larger and larger parts. Over the last 5 to 10 years, manufacturers have come to expect bigger machines to offer the flexibility of smaller machines, Von Moll said. A key feature is a large-capacity automatic toolchanger. "Shops will load up a library of tools to cut any of the parts in their current product mix," he said. The flexibility provided by a large, programmable choice of tools facilitates just-in-time production and reduces operator interaction.

Cincinnati Machine

Manufacturers increasingly expect machine tools, no matter the size, to feature large-capacity automatic toolchangers.

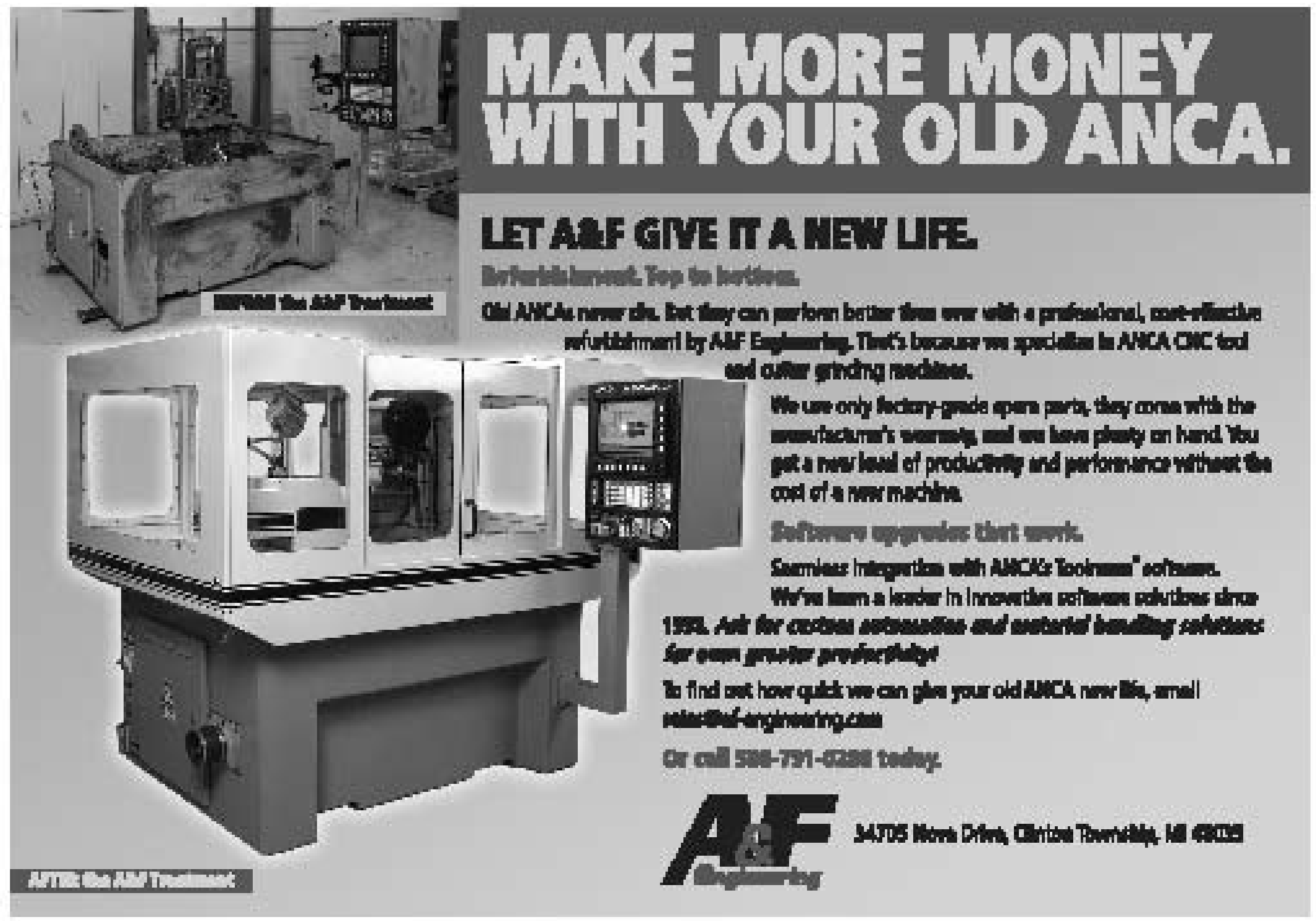
Von Moll cited Cincinnati Machine's newest addition to its U5 family of vertical gantry machines as a response to demand for increased flexibility in big 5-axis machines. The U5 1500 is large; standard X-axis travel is 14', expandable in 12' increments. Y-axis travels are 8' or 12', and Z-axis travel is 5'. Workhandling options include a rail system or a moving table platform.

The machine takes automatic toolchanging a step further, to include automatic spindle head changes. Four different heads, stored in cradles and changeable in less than 2 minutes, enable a variety of part and material situations in one setup. There are two 5-axis heads: a 50-taper, 30-hp unit with 4,000- or 6,000-rpm capability, and an HSK 63A 50-hp spindle with top speeds of 15,000 or 24,000 rpm. Straight horizontal or vertical 30-hp spindles can reach 6,000 rpm. The selection of spindle technologies offers both high torque for cutting materials like titanium, and high speed for light alloys.

"Once you get your part program set up, your process defined and your tool magazine loaded, this machine can automatically select a different head with a different spindle to suit specific part features," said Von Moll. "And it's all within the same part program."

Von Moll pointed out that the "U" in U5 stands for universal because the machine is a flexible platform and the machines fit a range of industries. For example, one company is processing titanium landing gear components for the new Boeing 787 on a U5 machine, while another is machining cast iron gear set housings for windpower generation units. In the latter application, a typical housing—about 11' wide × 5.5' high × 14' long and weighing 33,000 lbs.—requires extensive internal machining to create features supporting the gear set's bearings and shafts. "The design of the machine allows the entire head to go down inside the housing of this boxy structure and machine details that, before you had this type of machine capability, no one would have been crazy enough to even design."

—B. Kennedy



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