Flexible transfer machines...

...hybrids combining the flexibility of machining centers with the economy of transfer technology

By **James R. Koelsch**
Contributing Editor

Appealing to the individual tastes of consumers without sacrificing economies of scale is certainly not an easy task. For one OEM, however, producing 750,000 units a year economically in roughly 100 variations is becoming much simpler since its engineers collaborated with their counterparts at Hydromat Inc (St Louis) to consolidate the 50 or so special machines making the various cases and internal linkages. The outcome was the next generation in a line of new hybrid machines that cross machining centers with transfer technology.

To streamline loading, Hydromat's AT flexible rotary transfer machine comes with a staging table, on which the operator places preset fixtures. Once the machine indexes, a pick-and-place unit removes the pallet containing the finished piece from the table's loading station and inserts a new pallet

The common denominator among these hybrids is that the modules at each machining station are in fact three to five-axis machining centers inserted into a common base. A built-in conveyor, robot, or rotary table moves the parts from station to station, and a common controller coordinates all of the action. Essentially, these machines are complete manufacturing cells wrapped in a box.

In Hydromat's case, the new Advanced Technology (AT) rotary transfer machine is a cluster of nine machining centers and a loading station connected by a rotary transport table. Each three to five-axis module is a single-piece casting with a rotating pallet fixture and a combination of horizontal or vertical spindles, tool turrets for multitasking, or automatic toolchangers with redundant or common tools. Because the pallet fixture is servo-driven and can rotate as fast as 5000 rpm, the machine also can perform turning operations.

Consequently, the OEM is using its AT machines to turn the inside of a case, as well as drill holes and mill features in the case, linkages, and other components. The pallet apparatus is sturdy enough for heavier milling and turning, making pistons for small-displacement internal combustion engines good candidates for processing on the machine. "The parts are sophisticated enough to justify the investment in the machine," says Bruno Schmitter, president. "They need turning into an ellipse and receive wrist pin bores and recessing grooves for the wrist pins and oil grooves."

Mark Sokniewicz, president, Globtec International (Carol Stream, Ill) adds that hybrid machines, such as those in his company's IMAS Flex line, suit production volumes of 500,000 to a million pieces per year when produced in batches as low as 5000 to 10,000 parts. "Average changeover from part to part is probably 30 min, although it can be less than 30 sec if changeover is a matter of loading a new program," he says. This flexibility in middle- and high-volume allows OEMs to offer consumers more variety and lets suppliers deliver components just in time.

The flexibility also removes the risk that shorter contract periods have created for transfer technology. It reduces retooling costs significantly, making transfer technology practical for successive two-year contracts. The ability to retool and reprogram the machine extends the machine's life span and allows users to amortize the cost over a large number of jobs. Moreover, the machines have much greater residual value because another manufacturer with a part that fits in the work cube can reprogram the machine and use it.

Because of these abilities, David D'Aoust, vice president, Kaufman Mfg Co (Manitowoc, Wis) reports that business for hybrid machines is very good, even though the machine tool industry as a whole is in the dol-

drums. "We have a number of them on order," he says, attributing the backlog to the machines' satisfying a need. "Manufacturers just can't afford to allocate the floorspace and the operators to run multiple machining center installations."

He claims that his company's System 4, a rotary hybrid with four machining stations and one loading station, can produce the same number of parts as a line of six or seven machining centers. "Besides changing tools in 2.5 sec chip-to-chip, the rotary table indexes the parts from station to station in as little as 2 sec," he explains. "Because loading occurs at the fifth station, the spindles are machining constantly. Conventional machining centers, on the other hand, stop while an operator changes the part or a pallet changer is loading the work."

More degrees of freedom

Another reason for the success of this class of machines is that they offer more degrees of freedom and efficiencies than either dedicated transfer machines or banks of machining centers. Overspecifying spindles, for example, is unnecessary on lines wanting to complete a part in one setup, as it often is for machining centers. "If the machining center needs a 25-hp spindle, it usually needs the high power for the initial milling and boring operations to qualify the part," notes D'Aoust. "So you wind up buying big spindles to perform a small amount of machining that needs that capacity."

Many users avoid the expense of having to overspecify the spindle by buying a high-power machining center for the heavy work and some low-power machines for the light

Automotive suppliers line up for in-line flexible transfer systems

The automobile industry also has a keen interest in the concept of hybrid transfer machines to accommodate the changes occurring there. The first is the greater variety found in automobiles now. Not only are the automakers catering to the individual tastes and needs of their customers, but they also must offer products that they can sell globally but tailor for local differences. Every nation has its own cultural preferences and safety and emission laws and regulations.

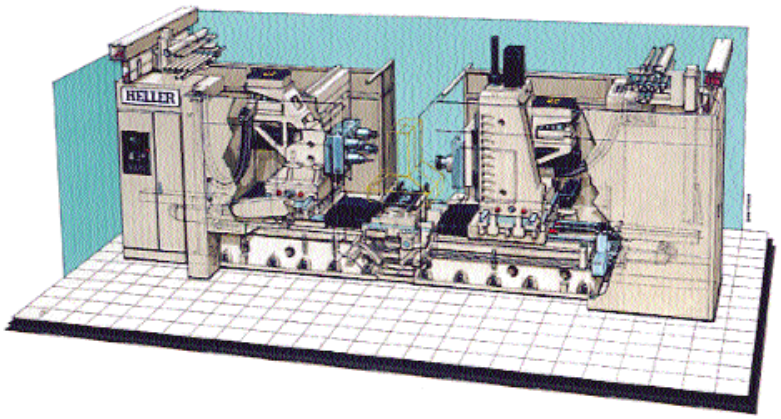
"The number of sold cars may still be the same, but the variation in these cars is increasing," says Manfred Maier, president, Heller Machine Tools (Troy, Mich), a builder of in-line transfer machines and lines. "In the past, a line of cars might have two engines, needing 500,000 a year of each. Today a line can have five types of engines, needing only 200,000 of each."

Another trend occurring simultaneously is that the OEMs are outsourcing more components that they considered core components only a few years ago. Today, the automakers are buying blocks, heads, and crankshafts from outside suppliers. "First tier suppliers need high-volume production equipment, but their contracts are for two years for 200,000 parts. Buying a transfer line and other dedicated equipment for a two-year job doesn't make sense financially, so they need equipment that they can switch over from, say, a GM block to a Ford block after two years."

Yet another trend gaining momentum over the last five years has been the greater use of both aluminum and precise near-net shapes for blocks and heads. "Because blocks and heads are increasingly made from aluminum today and the amount of stock to be removed has decreased, you can do more with machining centers and the standard machines," notes Maier.

For this reason, management at Heller decided to configure its horizontal machining centers into modules for an in-line transfer line. "About 10 years ago, Mr Heller had the vision to recognize the advantages of producing standard products and decided to design a transfer line concept that exploited our knowledge of standard products," says Maier. The resulting Flexible System Transferline (FST) module is a narrow-profile base unit that sits in a line beside and across from other modules. The units can be one, two, or three-axis stations fitted with standard interfaces for replaceable fixtures and multispindle heads.

To transfer parts between stations, Heller's engineers typically recommend pallets for parts not conducive for lift-and-carry mechanisms. For example, rear axle carriers and transmission parts are often put on pallets. Blocks and heads, on the other hand, are usually put on a lift-and-carry transfer. "Although manufacturing a block on a pallet without unclamping between operations is possible, it typically requires unclamping before finishing anyway to relieve the stress caused by material removal," explains Maier.



Heller constructs in-line flexible transfer lines from these standard machining modules

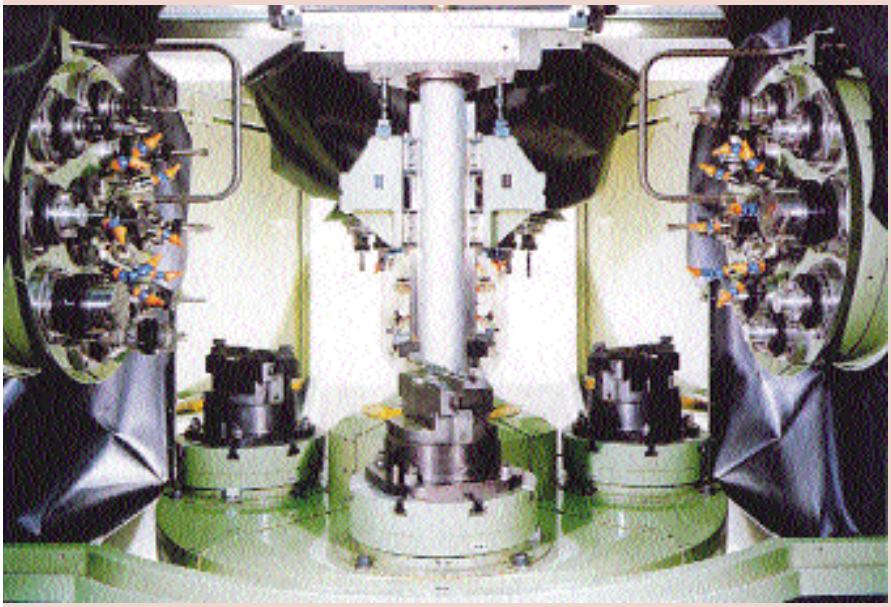
Because the bases are the same, a Tier One supplier machining a family of transmission cases can reconfigure a line made from the modules to machine another family of cases a few years later without a major rebuilding project. The changeover would be a matter of retooling and reprogramming the units and, if necessary, adding or subtracting units. Maier estimates that constructing a line from standard components can lower capital costs by 12% to 25%.

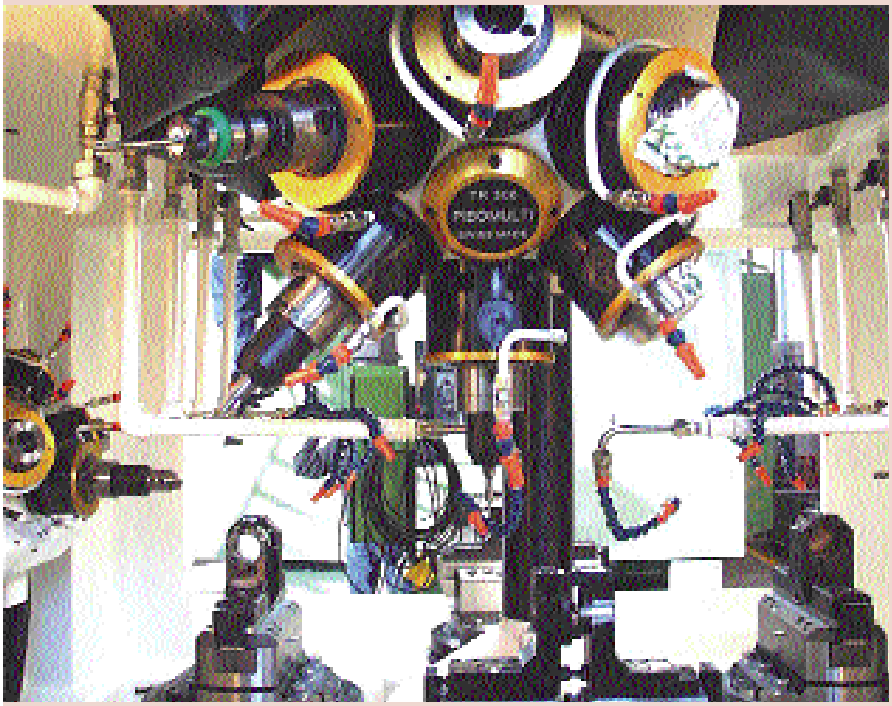
Unlike the builders of rotary machines, Heller installs a CNC in each module and connects them to a cell controller that oversees the whole line. The tactic gives Heller an important advantage during the initial setup and later reconfigurations. "We can run any one station without having the whole transfer line assembly completed," explains Maier. Technicians can assemble each station independently and deliver tested stations to final assembly. "So the time spent in final assembly, the most expensive phase, is shorter, which shortens delivery time and reduces cost."

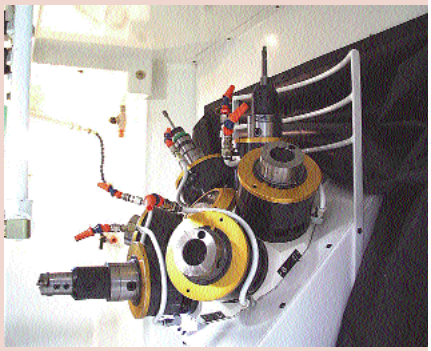
A new flexcenter at EMO

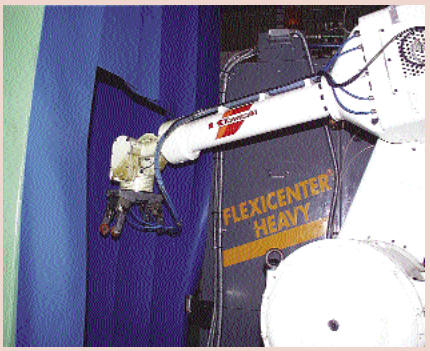
By Frederick Mason, Editor

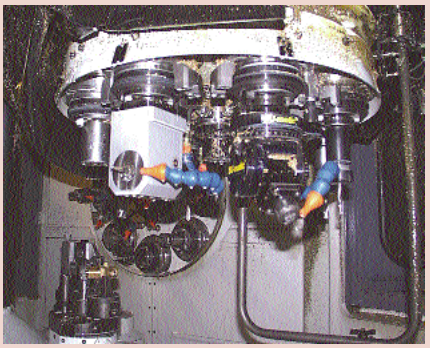
A new machine entry in the mid-volume flexible machining sector, introduced at EMO 2001, is the Flexicenter Heavy from Porta S.p.A./ Porta North America Inc (Newington, Conn). It is fully CNC with a Fanuc 18 series control and Fanuc drives. The control interface is through Windows 98. The main rotary indexing table carries four 320-mm diameter rotary tables that index in 1° increments to 360 positions, with a Hirth coupling. Main table rotation time, including unclamping and clamping, is a fast 1.3 sec. Auxiliary table rotation time is 0.7 sec. Other times are also pretty fast: toolchange is 0.8 sec. and rapids traverses are 30 m/min, with X, Y, and Z axis movements on preloaded linear bearings.





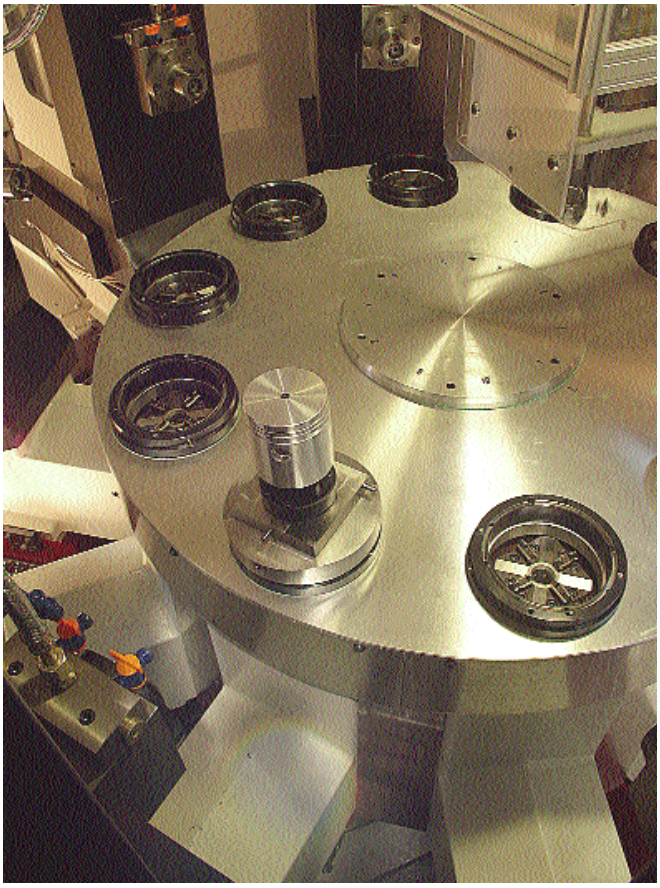






"The overall structure consists of a bed that is a single large weldment. There are no sections bolted on or hanging off a rotating drum," says Brian Fenwick of Porta. The four machining modules may be varied to suit, so that there may be, for example, two horizontal units and one vertical unit. Typically, each module is equipped with four to eight ISO 40-taper spindles, ABS or HSK, with 7.5 kW spindle-motor power, but various multi-spindle unit configurations are also possible.

One option that increases the Porta's flexibility further are U-axis facing heads, like the kind sometimes available for high-end machining centers. A U-axis head allows facing, single-point threading, grooving of recesses, and other turning-type operations. As on machining centers, this usually means that a workpiece may then be completed on the one machine and not have to be moved to another setup on a second machine.



Key to 2-micron locating accuracy in Hydromat's AT rotary transfer machine is the cast C-frame modules. The pallets rest on the frame itself. The indexing table simply lifts the pallet from the frame, moves it to the next station, and inserts it into the coupling in that module's frame

work. The downside, however, is that moving from machine to machine creates material handling, in-process inventory, and the time and error from fixturing parts more than once.

Flexible, hybrid machines have the advantage of allowing users to mix and match the optimum spindles for each operation, which makes hybrids much more cost-competitive for medium to low volumes. "When the volume requires a line of machining centers or when the volume is too low for a dedicated transfer machine, you should consider one of these machines," recommends D'Aoust. His rule of thumb is to consider hybrids when the cycle time to complete a part is 30 sec or less.

This class of hybrid machines also frees a project team to make design changes late in the program without incurring cost penalties and causing delays. "It used to be that after the first couple of months of a major program a design change would cause delays because the manufacturing engineers would have to redesign and remake the fixtures," says William Beck, operations manager, Kirby USA Inc (Statesville, NCar). "In many cases, a feature change can happen 6 months into a 9-month project" without requiring more than adjusting a portion of the toolpath.

Besides having the flexibility of a machining center, the flexible hybrid machines exploit the economies of scale by putting several spindles on one base. When Sokniewicz at Globetec calculates cost justifications for manufacturers debating whether to buy either a hybrid machine or a bank of stand-alone machining centers, he finds that the hybrids typically produce parts 30% cheaper. "If you were going to buy seven or eight stand-alone machining centers, you would need at least three operators," he explains. A hybrid machine needs only one.

Using common elements and not duplicating support mechanisms — such as the base, enclosures, cutting-fluid delivery and management devices, hydraulic and electrical systems — also helps to keep costs low. "Retooling a machining center requires tools, tombstones, and workholding devices that can cost $25,000 to $30,000 per spindle," says Sokniewicz. "Retooling our machines can cost as low as $7000 per spindle."

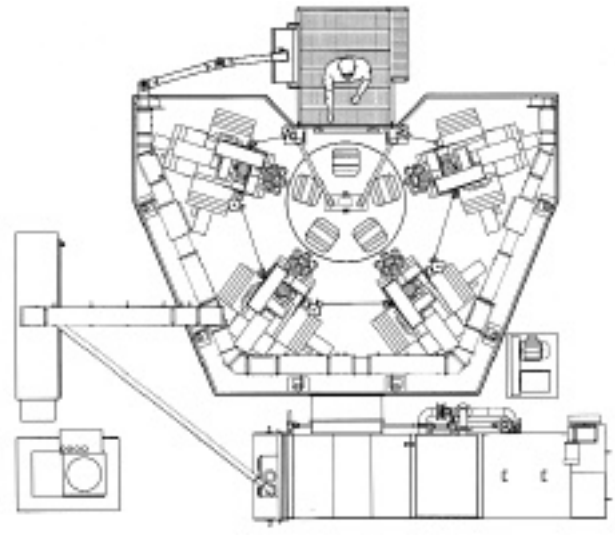
Because workholding on the IMAS Flex machines is with self-centering vises, accommodating new parts is a matter of redesigning the jaws. "The hydraulic system is already inside the machine," Sokniewicz points out. "Even if you were to design a custom fixture for each station, costs would probably be about $12,000 per station per spindle, which is still half the cost of retooling a machining center."

Another advantage of being able to program the machine is that it is possible to continue running it if a problem were to develop at one of the stations. "More than likely, you would replace the faulty component," offers Sokniewicz. "But if one of the stations developed a problem midday and the serviceman could not arrive at the scene until the next morning, then you could make some quick adjustments and run with seven stations, instead of eight. Instead of making a part every 12 sec, you might be making a part every 30 seconds, but you'd be producing parts until the problem was resolved."

Design limits error

According to the builders of hybrid rotary transfer machines, accuracy and repeatability are typically equal to those from conventional

Using a combination of turrets and a horizontal spindle, a System 4 rotary machine from Kaufman makes a family of 2 to 6-in. butterfly-valve bodies, producing about 80 bodies/hr. The machine transforms each ductile iron casting into a complete part in one chucking



Typical of the new breed of hybrid rotary machines, Kaufman's System 4 is essentially a cell of four independent, multiaxis machining centers. The table at the center serves as a material handling device that shuttles pallets from machine to machine

transfer machines and multiple machining centers. Most say that accuracy starts with modules that are one-piece castings. Kaufman says that it goes a step further by using large linear roller guideways. "A number of our competitors use quills for their Z axis," notes D'Aoust. "A quill really can't be preloaded as a way can, so we feel that our design has more rigidity."

To guarantee 2-micron locating accuracy from station to station, Hydromat deviated from its usual design of clamping the parts to a rotary table and indexing the table to move the clamped pieces from station to station. The builder's new design philosophy is to use the table as a transfer mechanism and leave the locating to the Erowa Power Chucks that fit the pallets directly to each module's one-piece C-frame casting. The table lifts and transports the modular portion of each pallet to the next fixture in the casting, lowering the module into the fixture for locating and clamping.

"The Erowa Power Chuck operates on the same principle as a Hirth ring coupling," says Martin Weber, manufacturing vice president at Hydromat. "A number of precision-ground teeth arranged in a 90° pattern engage and lock to provide clamping accuracy and rigidity." Clamping force is 9 kN.

The design streamlines both building the machine and setting up jobs. "The table is not a source of variability because it serves only as a transport mechanism," says Don Flanery, electrical engineering product manager, Hydromat. "Tweaking a table so the modules cut parts in exactly the same location is time-consuming and costly. Now we've taken that cost and time out of the equation because the table places the part into exactly the same location every time."

The Kira 4 Station CNC dial machine from Kira America Inc (Franksville, Wis) has a similar lift and carry mechanism. "Fixture locating is totally independent of the indexing mechanism and is positioned consistently within 0.0001 in.," says Arnold Jones, president. This builder's concept is essentially to cut the fronts and tables off three of its standard horizontal and vertical CNC machining centers and to attach them to the rotary table.

To keep repeatability high, the machine also compensates for slight variations in the fixtures fastened to the pallets, much like the pitch-error and thermal-growth compensation found in many machining centers today. "Because the fixtures on the pallets can never be exactly the same, the CNC moves the tool a few 'tenths' to compensate for those differences," says Jones. "We 'tune' the fixtures ahead of time, and the CNC remembers the offsets."

After machining, pallets containing finished workpieces can go directly to a nearby CMM or gaging station. "By not unclamping it, you can get true measurement on the part," notes Flanery at Hydromat. Because of the open architecture of the controller overseeing the CNCs inside the machine, the inspection station can feed the measurements back to the particular station for corrective action, usually adjusting tool offsets. "It's an application-driven type of problem, but the software exists."

Kaufman also offers similar software that allows the controller to compensate for tool wear and fluctuations in temperature based on feedback from an automatic gaging station. "In one application producing 450 parts an hour, the machine is holding tolerances within a 20-micron range," says D'Aoust. "Based on the drift, the controller automatically compensates the whole manufacturing line by calculating and adjusting offsets."

Smart pallets handle chaos

By fitting the pallets with erasable programmable read-only memory (EPROM) chips, Hydromat's AT machine can execute a concept that the Germans call "chaotic manufacturing," when translated literally. The better translation, however, is random manufacturing because the machine can cut a number of different parts at the same time. The operator can clamp the various parts on the pallets and feed them through the system in any order.

Upon reading the contents of the EPROM at the loading station, the machine's controller identifies the part and loads the appropriate toolpath programs in the CNCs running the units. If the parts are similar enough to use the same tools, then a program change is the only action necessary, and all spindles can be used to make all variations in the family of parts. If the variations require different tools, then the controller can track the parts through the machines, activating only those spindles fitted with the tools for workpieces under them.

Pallets fitted with EPROMs offer another technique for changing tools to boost spindle utilization. Just before feeding a batch of new parts, the operator would introduce at least one of these pallets containing the necessary tools. "Instead of clamping a part to the pallet, the operator can introduce a pallet with two tool pockets, one for offloading a tool at one of the stations and the other for holding a new tool," says Schmitter. "The EPROM tells the machine that the pallet contains a tool."

Like other hybrids, Kirby's Rotoplan reduces costs over banks of machining centers by eliminating queues and setup and needing only one operator to run the equivalent of as many as eight machining centers

Based on this information, the Fanuc CNC changes the tool in the correct station. The pallet has two pockets, one empty to receive the tool in the spindle and one loaded with a tool. When the tool pallet comes to the right station, it will discharge the old tool and load the new tool. The next pallet would contain the part.

The technique has its limitations, though. "Although the potential exists for every part to be different from the previous one," cautions Schmitter, "random manufacturing would have to be for batches using pretty much the same tools. Otherwise implementing it gets too complicated. But for batches of 20 of a particular style, you can run the tools through the machines first and then send the batch through next with no problem.

"The great news is that the new GE Fanuc 2050 controller can track the component parts visually and lead you through the system," he continues. "Ten years ago, writing the code would have been an impossible task." Windows NT operator interface allows programming a block at either the machine or an off-line PC and disseminating the information to the five Fanuc 16i CNC units controlling the various servodrives in the AT's 10 stations.

The Cimplicity software package serves as a system supervisor and coordinates the actions of the CNC units. It also allows technicians at a remote location to peer into the machine and troubleshoot problems at any station. "We see what the operator sees, but in a little different format," says Schmitter. "Although there is a slight delay, you can monitor what's going on and debug the problem." He admits that monitoring the PLC is possible, but says that doing so allows collecting less detail.

Jones at Kira, however, believes that PC-based CNCs are overkill for hybrid transfer machines. "Those CNCs are really good for molds, when you're calculating and processing a lot of information," he says. In mid- and high-volume applications, you are using a G-code program that is 25 lines. It isn't changing." So he recommends sticking with the simpler controls for production work.

He notes that PLCs also can report to a factory management system. "They can tell you whether there is any downtime and why," he continues. "They can issue an alarm for low coolant or a broken tool and report production every hour every day. If you want, you can pull up the PLC on your computer at home to see how the machine is doing."

For these reasons, Kira and other manufacturers of rotary machines no longer give each module its own CNC and link all of them to a central PLC. "Integrating individual CNCs into a PLC is a very cumbersome system and a bit archaic in this day and age," says D'Aoust at Kaufman. "Today's CNCs can run more than 60 axes without any major expansion, and all the functions for coordinating the machine are already integrated into the program."

Not only is the one CNC simpler for the builder to program, but using one controller to operate all axes on the machine can be more productive. "Having one controller handle everything eliminates the hand-shaking and talking back and forth between different controls, which takes time and adds complexity to the controls," adds Beck at Kirby. "It makes the system quicker and more reliable."