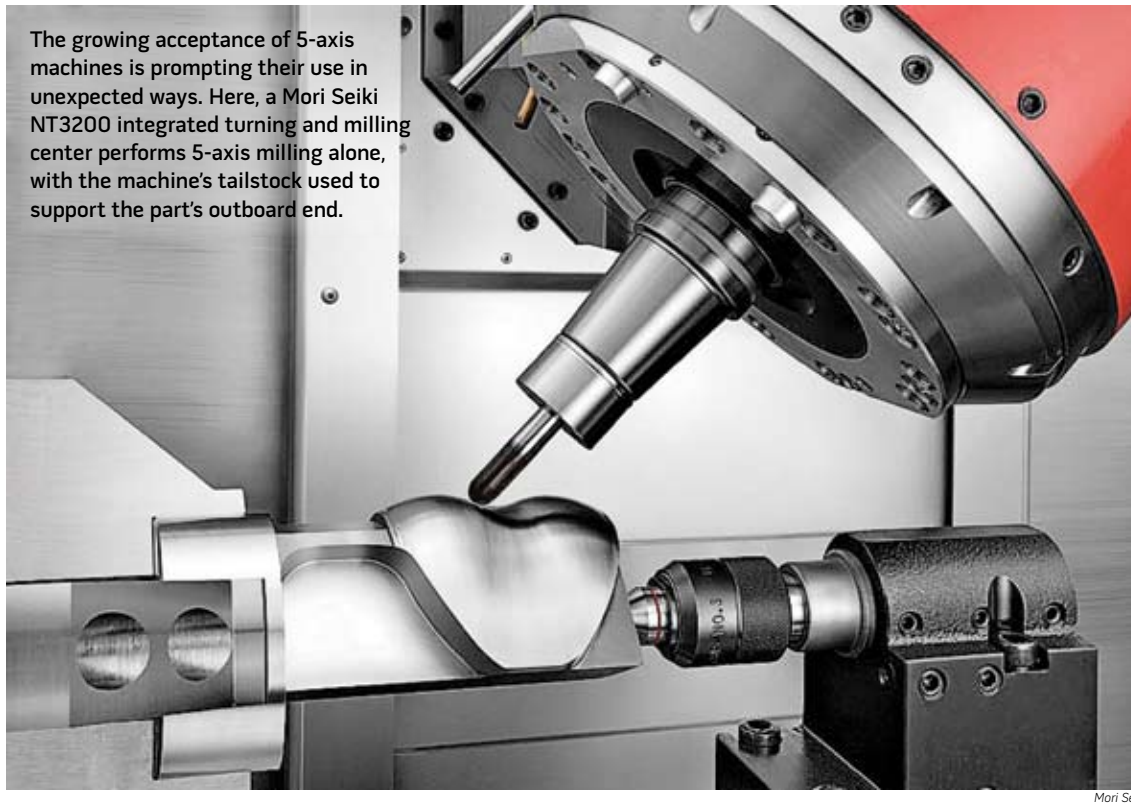


The growing acceptance of 5-axis machines is prompting their use in unexpected ways. Here, a Mori Seiki NT3200 integrated turning and milling center performs 5-axis milling alone, with the machine's tailstock used to support the part's outboard end.

Mori Seiki

Mastering the Metalcutting MACARENA

Machine tool builders and CAM software developers work to make 5-axis machining more flexible and accessible.

By Bill Kennedy, Contributing Editor

Operating a 5-axis machine tool is the machine shop equivalent of dancing the Macarena on a merry-go-round. It's a kinesthetic challenge.

In 5-axis machining, there are the X, Y and Z axes that comprise 3-axis machining as well as two additional rotating axes. The added axis movement may be provided by a trunnion rotary table on which the part is mounted or via a tilting or articulated head that moves around the part. The machines can operate in a 2+3 mode, in which the two rotary axes position the part and are locked in place during 3-axis machining (see related article on p. 84), or in a simultaneous 5-axis mode, in which all five axes are guided by the CNC and move at once to machine complex contours. It's like thinking about two things at once, times two-and-a-half.

Previously, the complexity and expense of 5-axis machine tools limited their application to only the most sophisticated and well-funded factories. Today, though, the versatile machines are finding use in shops of nearly every size and description, and advancing technology continually improves their computers' performance. Finally, mastering the 5-axis dance is becoming less daunting; machine tool builders and CAM software developers are working to make a wider range of 5-axis products and make them easier to use.

Learn more about 5-axis machining

Read more commentary on making 5-axis machining simpler and more accessible by visiting Bill Kennedy's Web log in the CTE Community section on www.ctemag.com.

5-Axis Attraction

Aerospace manufacturers and other makers of complex parts are the traditional customers for simultaneous 5-axis machining. Many machine shops, however, are buying 5-axis machine tools not because of the industry they serve or the parts they make, but for marketing purposes, according to Gregory Hyatt, chief technical officer for machine tool builder Mori Seiki U.S.A. Inc.'s Machining Technology Laboratory in Rolling

Meadows, Ill.

"There are job shops that want to differentiate themselves by offering quicker delivery and quicker turnaround," Hyatt said. "The part may have tolerances that allow it to be made in a conventional 3- or 4-axis machine—there is no 5-axis simultaneous geometry. But, in fact, by combining all the operations in the single 5-axis machine, they have fewer setups, they can deliver urgently needed parts to their customers more quickly and can differentiate themselves."

Jeff Law, marketing manager for HMCs and rotary products at Oxnard, Calif.-based Haas Automation Inc., agreed that minimizing setups and maximizing the number of features machined in the same operation are typical reasons for adopting 5-axis technology. "However, the choice needs to be made with eyes open. Sometimes, you can be more productive with two setups simply because you can have two machines making chips simultaneously," Law said. "Furthermore, 5-axis typically means a sacrifice in rigidity—longer tools, spindly workholding standing off from the table surface—and a corresponding decrease in feed rates. However, for the right kind of part, 5-axis can't be beat."

Machine tool builders offer different types of 5-axis machines so machine shops have more choices. For example, a classic form of 5-axis technology is a mill/turn machine: a lathe with 5-axis milling capability. Mori Seiki builds several 5-axis vertical milling machines that now have turning capacity, with one rotary axis capable of the rpm necessary for lathe operations. Hyatt said Mori Seiki offers three options for the C-axis' rotational speed in its NMV series machines, with the highest speed exceeding 1,000 rpm. The company debuts a new NMV 8000 for large parts and an NMV 5000 with enhanced automation features at IMTS '08. For another 5-axis machining concept, see the sidebar on page 77.

Also, some of these 5-axis machines are better suited to a certain class of parts. In general, Law said, a 5-axis machine that features an articulated spindle is effective on long parts and light cuts, so it's suitable for aircraft wing spars. Trunnion tables can be best for cube-shaped workpieces, such as impeller blades, valve bodies and cylinder heads for single-cylinder engines. A long subtable that spins in one axis with a rotary table and

Haas Automation

Cylinder head porting is performed on a Haas ES-5-4T HMC, a compact machine with a VMC-style enclosure that provides good visibility and access. A 5th-axis rotary table and fixture permits complex operations.

Mastering the Metalcutting Macarena *(continued)*

tailstock at opposite ends is a good choice for prismatic parts like a V-8 engine's cylinder heads. To handle various applications, Haas offers a range of 5-axis vertical machining centers (both trunnion style and articulated spindle) and 5-axis horizontal machining centers. The machine tool builder also offers dual-axis rotary tables and trunnion tables for use in 3-axis machines so they have 5-axis

Haas Automation

Five-axis machining of an impeller using a Haas TR-210 trunnion rotary table mounted on a Haas VF-5 VMC. Such dual-axis trunnion tables convert VMCs into affordable 5-axis machining centers.

capabilities.

Scott Baldus, application engineer for Okuma America Corp., Charlotte, N.C., said shops looking at 5-axis technology should realistically consider their needs. If the machine will be used for basic positioning alone, numeric control of the rotary axes is not necessary. But jobs involving generation of odd angles and finer than 1° accuracy will require NC axis rotaries, as will continuous cutting of 5-axis contours on complex aerospace and medical parts, as examples. For heavy-duty applications, he cited Okuma's MU series machines, which features

a fixed spindle for maximum rigidity and a trunnion table to provide multimotion capability.

In addition to increasing the variety of 5-axis machines, machine tool builders are making them easier to operate. As an example, Law cited Haas' most recent version of its control software. It features a graphic user interface that puts more information onscreen in every mode so the operator can more easily set up, program and operate the machine, without having to move between multiple screens to find needed information.

As they are more widely accepted, some 5-axis machines are being used in unexpected ways. Hyatt said a growing application is the use of mill/turn machines for 5-axis machining even though no turning is being performed (see photo on page 68). The reason is fixturing for a long workpiece on a typical 5-axis machining center can interfere with the machining process. According to Hyatt, some manufacturing engineers have assigned long parts to a mill/turn center and used the tailstock or subspindle to support the part's outboard end. Typical workpieces are long aircraft structural parts, but components for oil field machinery, heavy equipment and machine tools also are candidates.

When running multiple sides of a part with individual setups on a 3-axis machine, an operator can indicate each side and run a program for it. That procedure changes, though, when a part is indexed on a trunnion table on a 5-axis machine.

Making the Move

Consolidating multiple operations on one machine via 5-axis technology can save time and reduce workhandling, according to Rich Klein, applications manager for high-speed machining with machine tool builder OKK USA Corp., Glendale Heights, Ill.

However, he cautions that "programming issues can be a little more complex to work with. The part might be simple as far as the actual programming code that is required for each feature on the workpiece, but calculating correct positioning angles for the part is a little bit harder on the 5-axis side."

When running multiple sides of a part with individual setups on a 3-axis machine, an operator can indicate each side and run a program for it. That procedure changes, though, when a part is indexed on a trunnion table on a 5-axis machine. "The need to have a work

coordinate for each face can result in long setup times," Klein said.

To simplify the situation, OKK developed software called Multifacer II, which enables an end user to write programs for a part's multiple faces by entering part-print dimensions at the machine control's screen. Then, when moving from one side of a part to its next, the software creates programs to tilt the axis and define the new work offset. "You are only required to touch off your tools and set up your work offset for one side of the part. The software keeps track of part position and adjusts the offsets each time the part is indexed," Klein said.

Intended only for 5-axis positioning—not simultaneous 5-axis machining—the software (recently updated with additional features and a simpler user interface) can save a shop the expense of a new 5-axis CAM system. Toolpaths can be programmed in a 3-axis CAM package or a program can be written manually for the part as if it was in an X-Y plane. Klein said an end user can put a part anywhere on the rotary table (further simplifying the setup process) because the software calculates the part position in relation to the rotary axis pivot points.

For a shop considering using 5-axis technology for more than positioning work, the choice of CAM software is crucial, according to Okuma's Baldus. "If the shop is not accustomed to 5-axis work and they are looking at bidding on it, it's a fairly big step. When they get into actually machining on a rotary 4th and full 5-axis, there are a lot of things to take into account. In my experience, if they don't already have a suitable CAM system, they need to evaluate their needs and then take a look at the players out there. Once they learn how to put out good code, setting up the job is no different that setting up any other job." CAM programs differ in power, complexity and ease of learning, so Baldus suggested that a shop "sit down with a CAM program and get a feel for it."

Getting a feel also allows a machine shop to learn whether the program works as advertised, especially the post-processor, which outputs the G code. "Some CAM systems claim 5-axis capability, but the actual G code is not very clean when it comes out to the control," said OKK's Klein. "If it isn't clean, you will not be able to get accurate, fluid motion out of the machine itself. We've seen quite a few instances where low-end software is used to do the programming, and when it is switched over to a more capable CAM system, the result is cleaner codes, and the performance, part accuracy and part finish improve."

Sim Saves Machine Time

Another key facilitator in the application of 5-axis technology is accurate and reliable process simulation. "Simulation eliminates guesswork and the need to prove out new machining processes on real machines," said Karlo Apro, senior applications engineer for Mastercam CAM software developer CNC Software Inc., Tolland, Conn. "Using a real machine to prove out a toolpath wastes valuable production time and risks potential collisions." Apro added that machine simulation is not only useful for finding errors in machine code, but also permits testing of different approaches and different cutting strategies on different machines to boost productivity, without the programmer leaving his desk.

CNC Software

Simulation software, such as this Mastercam module that employs graphic displays of machine and tool interaction, eliminates guesswork and the need to prove out new machining processes on the shop floor.

Tom McCollough, vice president of development at FeatureCAM, Salt Lake City, agreed that interest in 5-axis machining is growing across the board. He

Drawing a bead on 5-axis laser machining

IT'S THE MULTIPLE AXES of motion, not the cutting tools, that normally sets 5-axis machines apart. Mitsui Seiki (USA) Inc., however, added a cutting tool not usually associated with 5-axis machining, an Nd:YAG laser, and recently launched the resulting machine tool as its VLD-300 5-axis vertical drilling machine.

The Franklin Lakes, N.J.-based machine tool builder is known for offering ultra-precise 5-axis machines. According to Scott Walker, president, a majority of Mitsui Seiki's machine tools have 5-axis capability. Walker estimates that about 25 percent of those units machine prismatic parts, reducing workholding and fixturing, and 75 percent are for simultaneous 5-axis machining. The 75 percent indicates the sophisticated work being done by shops, many of them aerospace manufacturers, using the machine tools.

About 3 years ago, some of those customers approached Mitsui Seiki seeking a way to increase speed when drilling thousands of small holes, typically 0.008" to 0.020" in diameter and 0.050" to 0.100" deep, in difficult-to-machine, high-temperature aerospace alloys. Engine components such as combustors, combustor liners and turbine blades may require as many as 3,000 small-diameter holes for cooling, and they have to be drilled at various angles in a noncontact manner.

Mitsui Seiki combined its machine tool building and tool- and part-motion experience with an Nd:YAG laser to create its 5-axis vertical drilling machine. Engineered to handle smaller parts, the VLD-300 features an X-Y-Z capacity of 300mmx300mmx300mm.

According to Tom Dolan, vice president, laser equipment requirements dictated that the spindle move only in the Z-axis, so all other axes of movement are controlled by the trunnion below the optic system. The machine features a rigid, cast iron bed and linear motor drives throughout, "something Mitsui Seiki has had a lot of experience with in our machining centers. We applied the same basic machining technology to the laser center," Dolan said. He added that lasers offer a number of advantages including essentially zero tool wear, smaller heat-affected zones than EDM creates and the ability to produce shaped holes and angled holes in extreme length-to-diameter situations.

Although introduced with an Nd:YAG laser, the VLD-300 is engineered to also work with CO_2, diode-pump and fiber lasers for different applications, including aerospace, electronic, medical and automotive parts. The equipment is ready to enable palletized robotic part loading.

Mitsui Seiki

Employing an Nd:YAG laser, the Mitsui Seiki VLD-300 5-axis vertical drilling machine is engineered to permit fast, noncontact drilling of thousands of 0.008"- to 0.020"-dia. holes in difficult-to-machine aerospace alloys. The laser spindle moves only in the Z-axis; all other axes of movement are controlled by the trunnion below the optic system.

described the rising interest as "an outgrowth of more affordable 5-axis machines, more affordable CAM technology and the general increasing sophistication of the customer."

FeatureCAM offers a 5-axis positioning module and shops have licensed it to reduce their workholding and fixturing requirements. Also, FeatureCAM added 5-axis simultaneous machining capability to the 2008 release. The addition is linked with FeatureCAM's parent company, Engineering Geometry Systems, being acquired in 2005 by Delcam. Delcam provides 5-axis CAM software. "We take that experience that Delcam has been generating over the years and put it into a version-one product in FeatureCAM, which is really not version one because it has been tested worldwide," McCollough said. "We share not just knowledge but even actual code."

Also, FeatureCAM worked to include the 5-axis programming capability without making its software more difficult to use. "We took a long hard look at how we were going to put 5-axis simultaneous cutting into FeatureCAM and not wreck it in terms of ease of use and automation," McCollough said. "In a large variety of cases, it's really an extension of our 3-axis product. There is a lot of automation so that the customer

LIGI Tool & Engineering puts 5-axis to work

FIVE-AXIS MACHINING IS essential to keep pace with the technological progress of LIGI Tool & Engineering's customers, according to the machine shop's leadman, Bob Bacon.

Bacon made that statement to explain LIGI Tool's purchase of a large Parpas Famu 5-axis Master P VMC at IMTS 2006. "With the proliferation of complex solid-modeling projects our customers produce, we are more than able to support them."

Located in Deerfield Beach, Fla., LIGI Tool provides precision production and prototype metalworking services and produces workholders and tool accessories. The shop's capabilities include CNC turning and milling, sheet metal work and wire EDMing. Its shop equipment includes two 5-axis machining centers: the Famu machine and a Deckel Maho unit.

Using 5-axis machining presented LIGI Tool with challenges, though. "When you see one of these machines in action at a show, it makes perfect sense to snatch one up and put it to work," Bacon said. "Once it's on the shop floor, you become a bit overwhelmed until you really think about it."

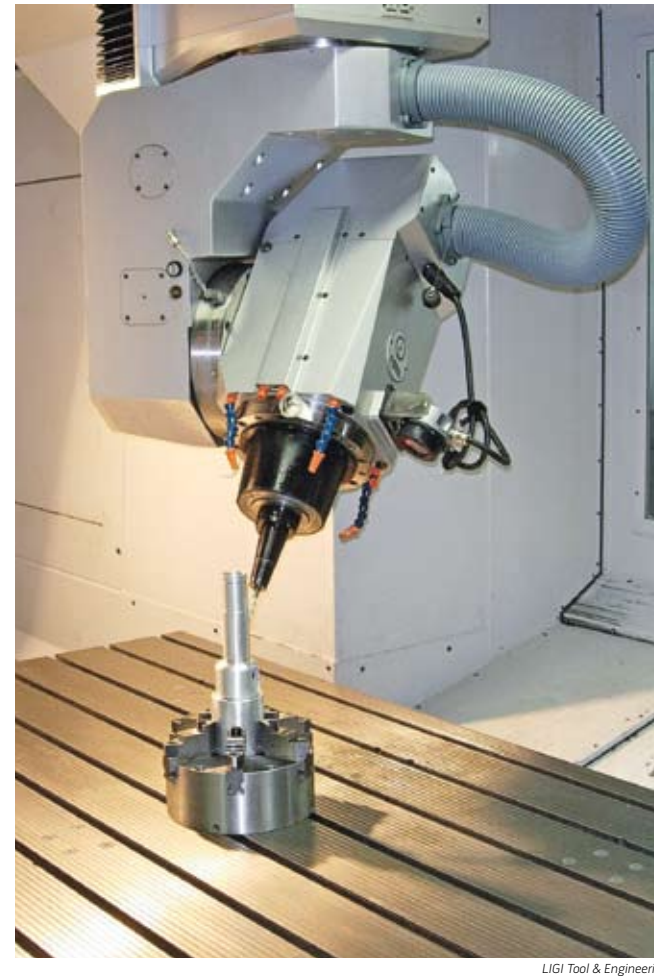
Besides the complexity of 5-axis machining operations, another challenge was holding the part to maximize tooling access. "Multiaxis machining is all about strategies and fixturing," Bacon said. "The elegance of 5-axis is realized by the user/programmer. It's actually a simple understanding between figuring how to position a part multiple times—3+2 axis—or moving the tool to all the features. It takes seeing this in your mind's eye and visualizing how to hold the part so the machine can get to it."

LIGI uses Alphacam software for positioning work and Delcam's PowerMILL for simultaneous 5-axis machining. "It still comes down to the post-processor," Bacon said. "Quality time dedicated to producing a reliable post makes the rest easier."

"Basically, everybody needs 5-axis because it saves on setups," said Sean Devanney, also a leadman at LIGI. "One setup and you do the whole part. On this machine, the head articulates all around the part, even comes up underneath it 5°. It's a wonderful thing."

Devanney added a cautionary about programming in five axes. "There was a learning curve," he said. "You have to consider three-dimensionally how programs might be being called up. In the old world, you've got X-Y-Z, and if something happens or a tool breaks, you just move the Z. But now the Z could be at a 40° angle. You can't just go Z anymore, you have to go to combinations, so it's a whole different mentality."

Bacon said 5-axis machining is "quite the adventure and a bit trying, but at the end of the day you can look at a part and say, 'I can make that in one setup, no problem.' And with enough practice, you actually can." *—B. Kennedy*



LIGI Tool & Engineering

The articulated 5-axis head on the Parpas Famu 5-axis Master P VMC at LIGI Tool & Engineering can move around a part and even approach it on a 5° angle from underneath.

doesn't have to make as many settings as he would have to in a more complex package. There are fewer things to interact with, and that is a huge part of what makes software easy to use."

McCullough, however, advised caution about 5-axis machining even though interest in it is growing. "It is important to know when 5-axis is appropriate and when it is inappropriate. We tell our customers: If you don't need 5-axis, don't use it! It adds an extra level of complication. I don't know of any CAM vendor or machining expert who wouldn't say the same thing." A sidebar on page 78 describes one shop's reasons for, and experience with, 5-axis technology.

Nonetheless, many companies looking for CAM software seek a package that can handle both 5-axis indexing and simultaneous 5-axis machining—even if their production doesn't currently require such machining, said Olivier Thenoz, mill/turn product manager for DP Technology Corp., Camarillo, Calif., developer of Esprit CAM software. "This trend goes along with the big boom of the mill/turn machines that are very competent 5-axis machines," Thenoz said. "In the mill/turn market, there are also a lot of requests for 4-axis continuous milling with the B-axis locked in position. Such machining is handled by the

contributors

CNC Software Inc.
(800) 228-2877
www.mastercam.com
IS #320

DP Technology Corp.
(800) 627-8479
www.dptechnology.com
IS #321

FeatureCAM by Delcam
(877) 335-2261
www.featurecam.com
IS #322

Haas Automation Inc.
(800) 331-6746
www.haascnc.com
IS #323

LIGI Tool & Engineering
(877) 523-6693
www.ligi.com
IS #324

Mitsui Seiki (USA) Inc.
(201) 337-1300
www.mitsuiseiki.com
IS #325

Mori Seiki U.S.A. Inc.
(847) 593-5400
www.moriseiki.com
IS #326

OKK USA Corp.
(630) 924-9000
www.okkcorp.com
IS #327

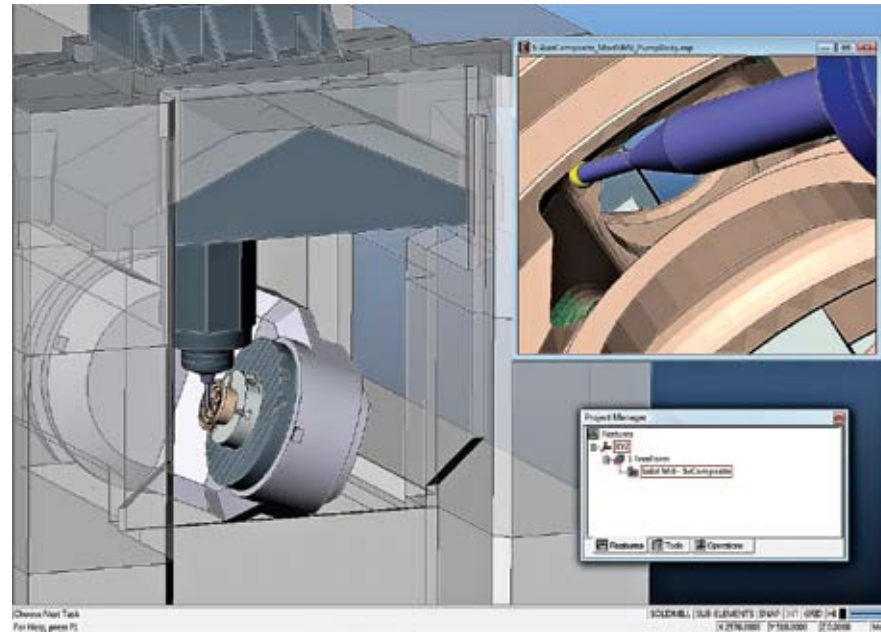
Okuma America Corp.
(704) 588-7000
www.okuma.com
IS #328

5-axis module with most current CAM systems."

Thenoz added that CAM software developers are responsible for adapting to changing machine tool technology. "CAM programs have to adapt to the machine and not the opposite. Machines have limitations, maximum axis feed rates and travel limits, for instance, and CAM systems must be able to work around them."

Key to Wider Adoption

DP Technology CEO Daniel Frayssinet said the key to wider adoption of 5-axis machining is increased ease of use in CAM programs. "The prices of the machines are coming down, the technology is better and there are better holders and controls," he said. "The big bottleneck right now is the programs." Learning to program in five axes has traditionally been a lengthy process. According to Frayssinet, DP Technology responded by creating for Esprit a CAM platform



DP Technology

Increased ease of use is a key to wider adoption of 5-axis machining technology. This screen shot from the upcoming 2009 release of Esprit CAM software shows a new 5-axis composite cycle based on decoupling the tool's orientation from its motion on the part surface. The cycle gives users the flexibility to create a variety of 5-axis functions, according to DP Technology.

that compares with other platforms the way Windows or Macintosh operating systems compare with DOS.

Also, Esprit's 2009 release includes a new, patent-pending "5-axis composite cycle." It involves entering parameters on a single page that "is very graphic," Frayssinet said. The cycle is based on decoupling the tool's orientation from the tool motion on the part surface. This enables the user to independently define the toolpath and the tool orientation, which, in turn, defines the position of the tool axis while machining. DP Technology's Thenoz said the composite cycle "provides maximum flexibility by allowing the user to select from a wide range of machining patterns and, likewise, a wide range of tool axis direction rules. The variety of choices gives the user the creativity to compose any complex 5-axis function with few limitations. Combining all the options, the composite cycle offers 20 different strategies in a single cycle with logical choices for the user."

CNC Software's Apro said CAM software, "in general, is always on the leading edge of technology, playing a balancing act between dreams and possibilities. Today, there are a number of machine builders offering a variety of multiaxis equipment in a wide range of configurations, quality and price. Computers are cheaper and CAM systems have come a long way, offering excellent multiaxis cutting strategies, with great tool control and large post-processor libraries for a reasonable price. As a result, even mom-and-pop shops can and do implement multiaxis machining." CTE

The key to wider adoption of 5-axis machining is increased ease of use in CAM programs. The prices of the machines are coming down, the technology is better, and there are better holders and controls. The big bottleneck right now is the programs.

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