Waterjet goes mainstream

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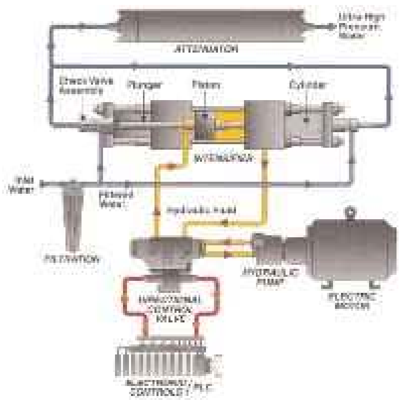
Cutting with water? Not as wild and wacky as some might think.

Abrasive waterjet has never been considered a run-of-the-mill machining technology. In its early days, shops thought it weird, typically using it only as a last resort when all other cutting methods failed. As if this wasn't enough of a setback, the process had problems with accuracy, reliability, and repeatability — not to mention noise and mess. But times are changing. Though most shops don't run out and buy one the way they would a lathe, abrasive waterjet has persevered and is now ready for prime-time action.



An illustration from Jet Edge shows how the intensifier acts as an amplifier as it converts the energy from low-pressure hydraulic fluid into ultrahigh-pressure water. The hydraulic system provides fluid power to a reciprocating piston in the intensifier center section. A limit switch, located at each end of the piston travel, signals the electronic controls to shift the directional control valve and reverse the piston direction. The intensifier assembly, with a plunger on each side of the piston, generates pressure in both stroke directions. As one side of the intensifier is in the inlet stroke, the opposite side is generating ultrahigh-pressure output. During the plunger inlet stroke, filtered water enters the high-pressure cylinder through the check-valve assembly. After the plunger reverses direction, the water is compressed and exits through a check-valve assembly as ultrahigh-pressure water. The attenuator smoothes pressure fluctuations from the intensifier and delivers a

Today, improvements in intensifier and crankshaft pumps, nozzle designs, and controls let these machines cut to tighter tolerances, program more easily, and run more quietly and with less mess. Jobshops, especially, can profit from using the new water-jet systems because of their versatility, explains Mike Ruppenthal of Flow International Corp., Kent, Wash. He says these systems can accommodate anything that comes through the door, whether it be titanium, Inconel, copper, brass, steel, aluminum, or molybdenum.

Waterjet systems can even tackle heat treated or laminated materials, adds Dan Gotz of Jet Edge, St. Michael, Minn. A shop cutting these materials can easily produce parts with good edge quality — almost a sandblasted abrasive look on softer materials and a true machine finish on harder materials — without having the machining process adversely affect the material, as it would in conventional machining. In addition, waterjet machining often eliminates secondary processing that is necessary with other cutting methods.

However, where today's abrasive waterjet cutting really shines is low-volume production and one-of-a-kind parts, remarks Dr. John Olsen of Omax Corp., also located in Kent, Wash. He says shops producing these kinds of jobs — prototype shops or specialty machinery rebuilders, for instance — often own no other piece of computer-controlled equipment. When this type of shop needs to make a part, it uses a manual machine because it's faster than programming a CNC machine. But that isn't true with an abrasive waterjet.

With waterjet systems, it's economical to make very small runs. In just a couple of minutes, a shop can go from making a part out of 10-in. aluminum to running a 1/4-in. stainless steel workpiece. And there are no toolchanges, fixturing changes, or additional setups required.

constant and steady stream of ultrahigh-pressure water to the cutting tool.

Fixturing a waterjet system is so easy, in fact, that shops typically use light clamping to hold the workpiece material in place. This is because the tool forces are very low, as compared to other machining processes. Shops can even use a few pieces of scrap to wedge a plate against a stop to prevent it from shifting during machining.

Controlling a wayward jet
According to Ruppenthal, a waterjet is a dynamic tool that, unlike a cutting tool or laser, doesn't always go exactly where it is pointed. When waterjet systems were first introduced, only experienced operators could control the stream going around a corner of a part, for instance. Thus, accurately cutting a 90° corner could be difficult.

"Standard CNC systems don't provide enough control for each part of the cutting path in water-jet cutting," says Olsen. "CNCs ensure that a tool follows a particular path to guarantee a geometry. However, they do not control exact speeds as a function of the geometry of the path, which is definitely required in waterjet cutting."

To get this control, waterjet manufacturers turned to PC-based systems. Using such a control, Omax, for example, builds a model of the cutting process into the controller so that the user specifies what kind of quality he wants. Does he want a separation cut because he's going to machine it afterward, or does he want a fine edge because it has some appearance or precision requirement? The user feeds that information into the controller, which determines the speed to run and the acceptable accelerations based on the cutting model.

In essence, the Omax system breaks the cutting path into small pieces, or more precisely 0.0005-in. steps, and controls each piece as far as machine speed is concerned. This lets the control automatically set the speed of each of these steps based on a model for better part accuracy. According to Olsen, if a shop is cutting something like $^{1}/2$-in. steel, and the part has dimensions of 6 in. or less, it is quite possible to hold ±0.001-in. tolerances.

Someone with a little bit of PC savvy can quickly pick up the basics of running the Omax system, says Olsen. "There are a lot of people with PC savvy that might not be able to run a standard CNC. But a PC seems natural to them. So shops can hire people who are not already trained machinists to run the Omax machines."

Besides providing improved cutting accuracy, today's water-jet machine controls make for smoother overall cutting operations. Both the Jet Edge and Omax controller, for example, let operators back up the entire program and resume cutting after the machine's head has been moved. This lets the operator halt the machine if a nozzle breaks while cutting, move the head to work on it, and then, with a push of a button, resume cutting at the point he left off. "If you do put a new nozzle in, you can offset for your new kerf at the controller," says Gotz, "without affecting accuracy. You compensate for that right at the controller."

Jet Edge's system also aligns plates so that a shop cutting a 5 10-ft plate of stainless steel that's 3-in. thick can set the motion system's *X* and *Y* to how the plate is laying on the table. "The last thing you want to do is try and line the plate to your motion system," says Gotz. Omax has a similar system, which it calls the Hole and Edge Finder.

Another benefit of PC control systems is that the knowledge of the cutting process is now inside the box, so to speak. That way users aren't required to know all the ins and outs of waterjet cutting.

The Jet Edge controller also includes a full-featured remote pendant, which, reports the company, is a first in the market. This pendant gives operators full system control of the nozzle, regardless of how large the system is. It also provides plate alignment, system jog in the *XYZ* axes, and individual sub *Z* adjustments for multiple heads. Users can also perform dry runs, test jets, and cycle start/stops and control feedrate override, return to path, block re-trace, single step, set zero, and pump on/off. The LCD display on the pendant supplies positioning messages and instructions for the waterjet operations.

Jet Edge not only improves machine accuracy and repeatability through its controller but also through the structure of its motion system. Directly coupling servomotors to the ballscrews means no belts and no backlash errors, says Gotz, and the motor output doesn't have to be reduced through gearing.

Jet Edge's cross beam (*X* axis) uses three high-precision preloaded linear-rail bearing blocks, which allow travel straightness of ±0.001 in. over the entire travel.

Side beams spanning over 72 in. — and all cross-beams — incorporate a honeycomb structure that makes the beams lightweight and more responsive to motion. Over-head-gantry construction keeps critical components above the abrasive environment. It also offers a more stable design because gravity holds the nozzle in position.

Pumping up intensity

Typical waterjet machine pumps generate between 55,000 to 60,000 psi, which quickly wears out pump components, especially seals. Ruppenthal says that before advancements in material science, seal life was maybe 300 to 400 hr, and seal changes required that the pump be split apart. Now, Flow uses a specially treated ceramic material in its pumps to increase reliability.

Inside of an intensifier pump are two pistons, or plungers, that were traditionally made out of stainless steel. In the early '90s, Flow developed a ceramic material that helped extend the maintenance interval of its pump seals up to 1,200 hours. "Some customers get even more hours," says Ruppenthal. "Conservatively, we doubled, and in some cases quadrupled, the maintenance interval because of the advance in material science."

In addition to intensifier pumps, Flow and Omax also offer a pump technology called direct drive, or crank drive, in which an electric motor drives a crankshaft that creates water pressure. Intensifier pumps use an electric motor to power a hydraulic pump that pushes hydraulic fluid on either side of a biscuit-like device to create water pressure. Direct-drive pumps do not.

Jet Edge uses what is called an attenuator on its machines. Gotz describes it as a hollow tube or pressure vessel where ultrahigh-pressure water travels after it is pressurized from the intensifiers. "The intensifier pump creates a pulsation from reciprocating back and forth, and the attenuator gives the high-pressure water a chance to rest." This eliminates pressure fluctuations, he explains, creating a smooth, steady, constant flow.

Jet Edge's intensifier is a hydraulically driven, variable-displacement pump that lets operators run pressures from 10,000 to 55,000 psi. "And it's a continuous 55,000-psi operational pressure," explains Gotz.

Advancements in pump technology have also cut down on another problem with older waterjet systems: noise. Omax's direct-drive pumps for instance, produce only 75 dB, says Olsen. However, the pump shouldn't get all the credit for the noise reduction. Most waterjet systems now perform the cutting process under-water, which not only makes for a quieter machine but also keeps abrasive particles from flying all over the place.

Nozzle improvements

The two most critical components of an abrasive waterjet nozzle are the water orifice and mixing tube. The water orifice shoots a high-speed stream of water down the middle of the long mixing tube where abrasive material, usually garnet, enters the water stream.

While most waterjet manufacturers optimize their mixing-tube geometry to get the highest possible cutting speed, Omax has opted for the greatest possible precision. The company modifies its mixing tube by making the I.D. of the chamber smaller and longer than most other models. While its systems still achieve a reasonably high cutting speed, they are not the fastest on the market. Instead, Omax shoots for a stream that delivers the greatest precision and minimizes taper in the cut.

There's an interesting tradeoff in waterjet cutting, says Olsen. On the one hand, shops can cut as fast as possible, but this tends to produce a taper at the bottom edge of the cut. Secondary operations such as milling are then needed to remove the taper, which drives up the cost of making the part. Focusing on precision, rather than speed, can eliminate secondary work, and in the long run, reduce part cost.

Manufacturers have also improved waterjet nozzles by making them more abrasion resistant. This quality is important because the same abrasive particles that are doing the cutting are surging through the nozzle, wearing out its internal parts. And nozzles aren't cheap, costing about $100 a piece to replace.

Flow addresses this problem by using nozzles made out of a boron-ceramic material, rather than carbide. The material's abrasion resistance keeps the machines running longer, which, in turn, decreases operator involvement. "We're not at the point yet that waterjets are a lights-out machine, although many of our customers use them as such," says Ruppenthal. "Customers increasingly want operators to run multiple machines simultaneously or do other things while they are operating the machines."

While mixing tubes are fairly abrasive-resistant, they are also brittle and fragile. "If you drop one on the floor, it can shatter like a piece of glass," explains Ruppenthal. Operators, therefore, risk breaking the mixing tube when they work on metal plate with a bit of a bow to it or when cutting smaller parts, which have a tendency to flip up and hit the nozzle. To prevent such mishaps, shops have their operators watch the head so they can stop the machine should either problem surface. Obviously, not a conducive scenario for automation.

To take the operator out of the equation, Flow uses a height-and-collision sensor that checks for height changes and to see if the head is going to run into something. The idea is that the machine automatically stops the head rather than the operator having to do it. "I'm always amazed at the idea of a height sensor on a waterjet. It's not a trivial undertaking to develop one," comments Ruppenthal. "Not only does a waterjet have to cut a wide variety of materials and thicknesses, but you've also got layers of water and sand on top of the material." All this adds to the complexity of the monitoring process.

Looking downstream

What the future holds for waterjet machines is pretty much the same as with any machine tool. Builders will continue to work on improving accuracy, lowering cost per part, and increasing overall machine productivity. In the case of waterjet machines, these improvements hinge on tighter machine movements, increased water pressures, recoverable garnet, and multiple heads.

According to John Olsen of Omax, one obstacle standing in the way of improved accuracy is the cutting model used by the machine control. Omax is working to refine its models, but as Olsen admits, no cutting model is perfect. No matter what speed is used, it is impossible to completely eliminate taper in the cut. He speculates that one way the waterjet system of the future could address the problem would be to use a multi-axis arrangement that would tilt the jet to remove taper in the part.

The second hurdle to improving accuracy, says Olsen, lies in the motion-producing equipment. He points to how milling machines position to tenths or less. "Their builders know how to make machines that execute precise paths. I think future waterjets could easily cut to one-thousandth tolerances on a regular basis."

To ensure motion system accuracy, many waterjet manufacturers use a Renishaw ballbar and/or laser during assembly for measuring system accuracy. Then, during site installation, service engineers use the ballbar once again and make any necessary adjustments to ensure the tightest tolerances possible.

Lowering cost per part means speed, and speed means higher water pressures. The industry standard is 55,000 psi, but Flow recently introduced 60,000-psi operating pressures and a pump capable of 87,000-psi sustained operation. This higher pressure lets end users cut up to 12% faster at a lower cost per inch, comments Ruppenthal.

But higher pressures also place more wear on the machine nozzle parts, which, in turn, increases cost per part. That's where advances in material science again come to the rescue, explains Ruppenthal. For Flow to achieve that extra 5,000 psi, without having maintenance intervals increase correspond-ingly, it had to develop better seal materials and more robust pump components.

While pressure is an important part of the cutting equation, velocity is just as crucial. High-pressure water enters the waterjet nozzle and exits through an orifice, a tiny opening about 0.014 in. in diameter. Here is where pressure is exchanged for speed, or as Ruppenthal explains, "The pressurized water goes from being at 60,000 psi and not moving very fast to being at ambient pressure (the water is no longer at 60,000 psi), but it's moving at 3 the speed of sound. As pressure increases, the water moves faster. This means a higher volume of water goes through that narrow orifice, carrying more abrasive to the worksurface to erode the material faster."

Understandably, with all this abrasive rushing around, the biggest cost of running an abrasive waterjet is garnet. In fact, says Ruppenthal, 66% of the hourly cost of running a machine is the garnet, or sand, waterjets use.

During the cutting process, not every grain of sand is pulverized, so the challenge is to separate the good stuff from that which has been literally turned to dust. And whatever garnet is recycled must be perfectly dried so that it can be metered and sent back into the system.

Flow recently introduced a system to the U.S. market that economically prepares this sand for reuse. "It has the potential of reducing operating costs, conservatively, by 25%. It's another advance that makes waterjet cutting more competitive versus other processes, because it brings the cost of operating these machines down further," says Ruppenthal.

Like Flow, Jet Edge also offers abrasive recycling systems but in various configurations. One version removes abrasive from the tank mechanically, while another takes the abrasive out of the tank, recycles it, and reuses it. The company also offers an option on both systems that lets a shop reuse its water — literally polishing and chilling it — and run it back into the intensifier. "This provides a 100% closed-loop system," says Gotz. Shops then minimize the amount of water they use, and drain clean water.

And finally, when it comes to upping the productivity of waterjet machines, all three builders agree that two heads are better than one — depending on the application, that is. "For example, if you're cutting 500 parts from a single sheet," says Gotz, "running multiple heads is a benefit. You still use the same amount of water and abrasive per part. It's just you are consuming more of it at a faster rate and more importantly, the job gets done in half the time, assuming only two heads are being used. Obviously, more cutting heads get your high-production jobs done faster, making waterjet more competitive in today's marketplace." Some companies don't even stop at two heads. For instance, Jet Edge has customers with as many as 10 heads on a system.

To accommodate these heads, Jet Edge adds a spreader bar so that the heads can be adjusted in a horizontal plane at a given distance, whether it's 4, 6, or 10 feet. However, if a shop has a 6-ft spreader bar and a 10-ft tank, its work envelope is reduced to only 5 ft per head. To eliminate this problem, Jet Edge can extend the tank the same length as the spreader bar on its overhead gantry system so that each cutting head maintains the existing work envelope of the table.

According to Ruppenthal, Europe is ahead of the curve when it comes to multiple heads. "In Europe, we don't sell a machine with less than two heads. In fact, we sell a lot of machines with up to four heads." But in the U.S., Flow sells mostly single-head machines. "About 30% of our machines have two heads, and 10% have more than two heads," estimates Ruppenthal. The rest have just one.

However, he adds, machines with more than one head are becoming more popular in the U.S. "I think we're going to see more and more heads over the next couple of years. With waterjet machines, you can buy a machine with one head and then simply add a second head. It's nothing complicated; it's not a huge cost. Really the cost is about the same as if you added it at the factory."

A new job for waterjet

For the first time the advantages of both a high-pressure waterjet and a YAG laser for cutting are combined into a single technology, called Laser-Microjet. The process involves a laser beam that is reflected at the point of the laser-water interface. The two media then join as a steady, parallel beam (50-µ diameter) that can be precisely guided over a distance of up to 100 mm.

Gem City Engineering Company of Dayton, Ohio, has partnered with Synova S.A. of Switzerland to further develop and market this new technology in the U.S. The system can process virtually any metal, alloy, ceramics, or silicon.

The Laser-Microjet handles difficult-to-process materials such as razor-thin coatings less than 0.0000391-mm thick and metal foils 0.1 to 0.3-mm thick. Such precision makes the technology well suited for industries like medical instruments, microelectronics, sensors, aerospace, semiconductors, nuclear, and automotive.

This technology offers a huge advantage over a conventionally focused laser beam, which is severely limited to a few millimeters as a result of beam diffusion, says Harry White of Gem City Engineering. The Laser-Microjet, however, uses a highly concentrated, low-pressure waterjet stream and laser beam with virtually no divergence. This lets it cut porous or layered materials with minimal thermal and structural distortion and with excellent edge quality.

The Laser-Microjet easily processes fine materials because its waterjet flows at low pressure, reducing the impact force on workpieces. Cutting waste is virtually eliminated, and clean, debris-free water exits the cutting area. The system's lower operating temperatures also minimize distortion or melting, which cut out secondary machining operations.

According to White, one of the most significant applications of Laser-Microjet technology is the wafer singulation used in the manufacturing of semi-conductors. Although using a laser isn't new in this particular operation, the use of a waterjet-guided laser certainly is, says White. "While the Laser-Microjet technology has a number of innovative advantages, probably one of the most important benefits is the cooling effect. In fact, the waterjet immediately absorbs the heat induced by the laser between the laser pulses because the heat doesn't have time to penetrate into the material," he comments.

Six-axis waterjet system

Huffman Corp., Clover, S.C., recently unveiled the WJ-156, a six-axis water-jet system for producing complex, near-net shapes in metals, composites, glass, and manmade fibers. The 64-ft ^{2} machine combines the advantages of six-axis CNC machine tool technology with the capabilities of waterjet. In addition, Huffman's Vision software lets users more easily and precisely locate and reopen holes such as those found on turbine components.

According to the company, the machine minimizes setup and cycle times and eliminates the secondary inspections needed with laser or EDM machines. It also eliminates material deformation, heat-affected zones, and delamination between a material's thermal-barrier coating and substrate.

Sense problem areas on waterjet machines

Ingersoll-Rand Waterjet, Baxter Springs, Kans., has introduced the Sensoline, a sensor for waterjet machines that lets operators do other tasks while it monitors system performance. The device quickly points operators or service technicians to problem areas.

The IR Sensoline identifies bad, damaged, or plugged orifices; high-pressure fluctuations; or worn or plugged focusing tubes. It also notifies the operator of unexpected changes in abrasive feed — either too much or not enough.

If any of these conditions are detected, the Sensoline signals the machine to stop motion to save material.

Machine combines waterjet and thermal processes

At Westec, Esab, Florence, S.C., will exhibit a low-rail version of its Hydrocut waterjet machine fitted with one 60,000-psi waterjet head, one PT-15 plasma-cutting head, a plasma marker, and a laser pointer. According to the company, the combination of waterjet and plasma lets the machine make intricate cuts in a part's internal geometry with waterjet and high-speed perimeter cuts with plasma. This increases productivity and throughput and greatly reduces cutting costs, says Esab.

The machine comes with orifice sizes ranging from 0.003 to 0.022 in. and nozzle sizes from 0.020 to 0.065-in.

I.D. This flexibility lets the Hydro-cut handle everything from small, intricate cuts to thick cuts requiring higher abrasive and water flowrates. The orifice and long-life

nozzle maintain a consistent tool centerpoint for the cutting stream, and the low-rail style lets the machine accommodate wide and/or long material sizes.

The PT 15XLS plasma-cutting head cuts from 100 to 1,000 amp on both ferrous and nonferrous materials.

Esab's Etch-Arc plasma marker reportedly creates a smooth, even mark for good legibility on alphanumeric marking, layout lines, punch and surface marking, and deep marking.

To compensate for uneven plate surfaces, the waterjet and plasma stations are equipped with height-control sensors. The model on display at Westec also features a laser pointer for plate alignment and accurate positioning of the machine to begin a program. Full process and motion control are provided by

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