MAGARTICLEFILE

Manufacturing ENGINEERING

Manufacturing Engineering April 2005 Vol. 134 No. 4

It does more than cut chicken parts

Waterjets Move into the Mainstream

Robert B. Aronson, Senior Editor

MAGBUY

Multihead Bystronic unit with automated feeding system specializes in high volume-production.

Waterjet is said to be the fastest growing manufacturing technique. But can a process that's good at cutting chicken parts do anything for you? Quite possibly, yes.

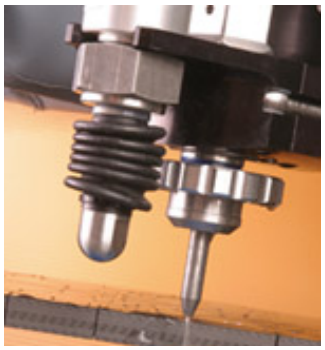
Waterjet, in a single machine, can greatly extend the manufacturer's capabilities. The buyers of waterjet systems seem equally split between companies that want them for production use and service groups, or job shops that want to serve a wider range of customer requirements.

There are two forms of waterjet cutting, pure water, and abrasive waterjet. In either case, the highly pressurized water passes through a narrow orifice in a cutting head positioned above the material to be cut. The size of the orifice is adjusted to suit the material density. Easily penetrated materials can be cut with an orifice as small as 0.003" (0.08 mm) while harder materials may require an orifice up to 0.030" (0.8 mm).

Abrasive waterjets can cut just about anything. In this process, abrasive, usually garnet, is drawn into the jet stream by Venturi action. Only about 60% of the garnet actually does any cutting. The rest is flushed through unused. But this rate is influenced by a number of factors. Generally, the increasing cutting speed increases the number of particles actually cutting but decreases the depth of material that can be cut.

Pressures generally range from a low of about 20,000 psi to a maximum of 60,000 psi (140 - 420 MPa). Several companies are working on advanced systems that achieve pressures around 90,000 psi (63 MPa). The process can be competitive with EDM, plasma, and laser cutting.

Although an abrasive waterjet can cut through anything, most work is done with material around 2" (50-mm) thick. The thickness practical for any given application is usually governed by time and accuracy considerations. Accuracy can be as good as 0.001" (0.03 mm). But more often it is in the 0.003 to 0.005" (0.08 - 0.13-mm) range. Kerf or jet diam is between 0.02" (0.5 mm) for an abrasive system and 0.003" (0.8 mm) for water only.

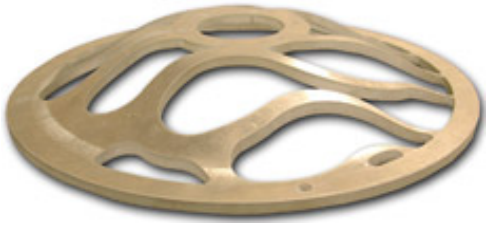


Detail of Flow system cutting layered material.

Tighter tolerances are possible but require the machine operator to closely watch the ID of the focusing tube. This ID grows as the abrasive waterjet erodes it. Software programs can help predict this critical ID, however, testing is the only way to be exact.

Cutting speed varies depending on the operating parameters and the

material being cut. According to engineers at Flow International (Kent, WA), a typical speed for cutting one-inch-thick mild steel ranges from 3.8 ipm (97 mm/min) cutting at 55,000 psi (38.5 MPa) to 8.4 ipm (213 mm/min) cutting at 60,000 psi. In general, the faster you cut, the poorer the edge quality, but it's possible to maintain edge quality by increasing pump horsepower.



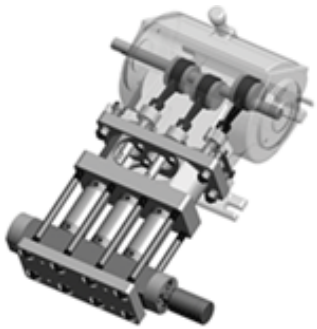
Complex shapes are not a problem for the Calypso waterjet system.

With abrasive waterjet, the cutting head consists of an orifice or "jewel" made of diamond, sapphire, or ruby. It focuses the waterjet. Diamond jewels are the strongest, longest lived, and have the highest initial cost. They may last up to 1000 hr. Other materials have a somewhat shorter life. High-pressure water exits the orifice and enters a mixing chamber. There, abrasive garnet is fed into the stream. The mixed abrasive and water stream then goes to a focusing tube or nozzle of a boride composite material that directs it onto the workpiece. With pure water, the systems are basically the same, but without the introduction of the grit.

Direct drive and intensifier pumps operate under the same principle. Each has a plunger that is pushed into a closed chamber to raise pressure and expel fluid through an outlet and check valve. The key differentiator between direct drive and intensifier pumps is the method in which the plunger is moved. The direct drive pump relies on a crank while the intensifier drives the plunger using an oil hydraulic cylinder.

Both have unique positive and negative performance variables. Direct drive makes more efficient use of power. For example, the direct drive has a 95% efficiency while the intensifier runs at about 70%. When evaluating power delivered to the cutting flow, a 30-hp (22.5-kW) direct drive would be equivalent to about a 45-hp (34-kW) intensifier.

The direct drive, or positive-displacement pump, is often used in applications that do not require 24-hr uptime. Examples include job shops, short production runs, and prototyping applications.



OMAX direct-drive pumps function much like automobile engines in reverse.

Many intensifier pumps operate as variable-displacement pumps. This means the pump produces only as much water as is needed by the orifice in the cutting head. When running a small orifice, less pressurized water is produced and so less electricity is consumed.

The pump has to be disassembled to replace the seals, so maintenance time is another critical issue. System designers have worked with the type, number, and replacement of seals to keep maintenance time low. But backers of both pump types claim major improvements in these areas. In general, the intensifier offers a longer time between maintenance. Flow

engineers report direct-drive seal life for an intensifier running between 600 and 2000+ hr while the direct drive is between 300 and 700 hr, depending on horsepower.

Because the process is very product-specific, all factors must be evaluated relative to the user's unique operating conditions to determine which pump is best in a given situation. This evaluation includes accuracy required, production volume, workpiece material, thickness and complexity, and user capabilities.

Water purity is an issue. Particles carried by the water can damage the pump and seals as well as deposit damaging materials within the system. This can be a particular problem if the water is very hard. Most machines have filtering systems, but in many cases tap water can be used directly. However, all potential users should have the water tested to be sure.

Because the orifice is subjected to water streams of up to 60,000 psi, very small contaminants in the water supply can fracture it. That's one reason why filtering is important.

Software is critical to waterjet performance. Most manufacturers offer packages that automatically adjust the cutting parameters based on type of material, cutting speed, and water pressure. In the more advanced systems the operator need only enter key parameters: material type, thickness, and cutting speed. The program varies operating parameters to ensure the proper cut.

Grit used is usually garnet. The type used can vary in hardness, sharpness, and size. For example, a 50 grit is a powerful cutter and is used on the harder metals and where cutting speed is most important. As grit size decreases, cutting power diminishes and finish improves. Grits above 150 are considered specialty grades for very fine work and for cutting composites. In a catch-22 situation, the better the grit's cutting power, the more damage it can do to the waterjet head.

Aluminum oxide can also be the cutting medium. It cuts very well, and some operators use it at low feed rates. But it's more costly than garnet and can be more erosive.

Waterjet equipment size information is usually given by worktable dimension. A small machine will have a worktable about 2 X 2' (0.6 X 0.6 m). Large machines can take plates of 12 X 40' (3.7 X 12 m) or more. Because loads on the workpiece from the waterjet are not great, size can easily be increased, sometimes simply by the addition of support bars.

Machines may have single or multiple heads. Generally, when making prototypes or small complex parts, single heads are preferred. For volume work and softer materials, multiple heads will be the choice. Parts may be stacked to increase productivity. With multiple heads, it's important to ensure that the water pressure is constant for each head, and that nozzle wear is monitored so cutting performance remains uniform in all heads.

There are some drawbacks to the waterjet process. One is that the jet deflects in the opposite direction of workpiece travel. As the cutting jet loses energy, this can cause a tapered as opposed to a perpendicular cut. In the last few years, this problem has been largely corrected though the introduction of multiaxis cutting heads, higher machine precision, and more sophisticated control programs.

Waterjet cutting is generally used on 2-D parts because of problems in controlling the depth and angle of the cut. Some 3-D cutting is offered, but the process does not have the versatility of conventional machining operations. However, as one waterjet manufacturer put it: "There are enough 2-D parts to keep us in business."

The key benefits to waterjet cutting include:

- Fixturing can be simple. The jet puts little force on the workpiece. Fixturing is rarely a problem. A small weight may be all that is needed to keep the workpiece in place. However, very small parts may require some special fixturing. Or, for parts in which waterjet cutting is followed by a finishing procedure such as EDM or milling, the part may be mounted on a fixture to help ensure precision.
- There is no heat-affected zone (HAZ) in the part cuts. When cutting metals, the material is free from heat-induced distortion and hardening so a separate clean-up cut isn't necessary. In addition, because there is no HAZ, parts cut from a sheet or plate can be nested more closely, thereby saving material and cost. It's also one reason why waterjet is a popular method for cutting soft products such as fabrics, meat and poultry, and some plastics.
- It needs only one tool. There is no tool changing. All the cutting is done with a single head.

Pollution is not an issue. There are no toxic fumes or gases. The waste material, the used grit, is nontoxic and therefore more easily disposed of. An exception is when cutting potentially hazardous materials such as lead. The scrap chips may contaminate the used grit.

Precision Is the Goal

Dr. John Cheung
Chairman and CEO
Omax Corp.
Kent, WA

We see the increased interest in abrasive waterjet cutting as due to increased precision. This has boosted the product's appeal both for cutting to finished shape and as an intermediate step before finishing by EDM or machining. And although waterjet cutting is slower than laser, it produces a more finished cut, and may eliminate other processes so that overall production time may be less. Abrasive cuts faster than EDM.

Omax stresses precision in their design. Most of our machines can offer ±0.001" (0.03- mm) precision, but typically operate at ±0.002 - 0.005" (0.05 - 0.13 mm). We specialize in small-volume and prototype work. We offer only a single-head machine driven by direct-drive pumps.

Wear is a particular issue for some waterjet-cut parts. The nozzle, which has to survive the abrasion of the cutting stream, is the most vulnerable component. Typically a nozzle on a high-precision machine will last a minimum of 40 hr.

We offer a five-axis head, but that is chiefly to allow a straight cut in thick material. You can achieve a kind of modified 3-D in those cases where the part can be rotated.

In a waterjet cutting operation, the control software is critical. In our systems the software includes an expert system that analyzes the operating parameters, then issues appropriate commands. It looks at water pressure, feed rate, type of nozzle, material being cut, and part thickness, then adjusts the system's operating commands accordingly. A key is knowing in advance how a material will behave.

Smaller Machines Have a Place

Angus Catterson
General Manager
Knuth Machine Tool USA Inc.
Wheeling, IL

The problem of taper has been resolved by most waterjet equipment manufacturers. We have eliminated that problem through five-axis heads and better control programs. Because the jet loses energy toward the bottom of the cut, the kerf at the top of the cut might have a 0.005" (0.13 mm) taper from the top to the bottom. Now we tilt the cutting head as it cuts. This compensates for the taper. We generally have only a 0.030 - 0.040" (0.78 - 1.0-mm) kerf. In operation, three axes control standard positioning and two axes handle the tilt. They allow us to cut at up to a 45º angle.

We use intensifiers as our pumps on some of our equipment because this version cycles at a lower rate, around 45 cycles per minute. Direct-drive pumps run around 1800 cycles. That means more rapid seal wear and more time spent on maintenance.

Although there is a lot of effort to achieve ever higher operating pressures, we have found there is a market at the lower-pressure end. Our latest new product, the ECO 1005, is a smaller machine that delivers 22,000 psi (152 MPa) using a direct-drive pump. It runs at about one third the speed of our 60,000-psi (413-MPa) unit. Cutting is slower, but it's a good, compact, low-cost package for the small shop or someone who is chiefly interested in prototype work. The cost of the machine goes down dramatically with lower operating pressure as does the cost of operation, because of less wear and less power draw. Smaller shops like the idea of being able to cut anything with minimal setup.

A single waterjet is usually slower than laser. But where cutting speed is a problem, we can add heads to compensate. They are slaved to the same control system and can be added inexpensively.

Maintenance Time Is Critical

Jon Dedic
KMT Waterjet Systems
Baxter Springs, KS

The trends we see are higher pressure, less maintenance, great ease in replacing seals, and lower prices. At the same time, cutting speed has been improved by the introduction of linear motors to drive the workheads. New tables can reach up to 4500 ipm (114 m/min). These speeds are used chiefly for cutting very thin materials such as metal foils, fabric, foam, or rubber gasket material.

The top pressure common in our industry has jumped from 55,000 to 60,000 psi, mostly due to improved precision in manufacturing. The maximum pressures are only available in intensifier pumps, which leverage the power of hydraulics to pressurize the water. When using the higher pressures, it's possible to cut metal up to 16" (406-mm) thick. Beyond 5" (127 mm) however, waterjet may not be the most efficient option. Tests should be done to determine if the cut speed and edge quality meet part requirements.

Maintenance is a key issue. Those considering a waterjet system should carefully evaluate the high-pressure seals and check valves. These are the most frequent consumables. In addition to frequency, maintenance time should be considered.

In any evaluation, carefully consider the types of material to be cut. One problem is inconsistent materials, such as castings with inclusions. Materials with air pockets or sandwich-style laminates are difficult to cut.

The number of heads you can run from one pump depends on head and nozzle size as well as needed operating pressure. Multiple heads with varying on/off times can be a problem with direct-drive pumps. It's not an issue with the intensifier.

Good Part Handling Speeds Production

Joe Cisar
Bystronic USA
Hauppauge, NY

The trend in waterjet technology seems to be leaning toward less input with more output. Advanced waterjet systems and operating software are engineered to minimize operator intervention. From running the system to part nesting and creation, today's waterjet is designed to run longer while requiring less by way of maintenance and pump rebuilds than ever before. On average, the Bystronic Byjet waterjet with its active pressure controller intensifier (5.0 L/min) needs a rebuild only once every 5000 hrs.

Bystronic's new intensifier, the Byjet 50 APC, reduces the end user's manufacturing and operation costs. It uses proprietary software that monitors the internal functions of the intensifier and allows the operator to perform tests without leaving the operator station. The software also identifies potential maintenance issues, and allows for easier maintenance scheduling. The High Precision Tool (HPT) cutting heads have tight tolerances so that the water stream makes little contact with the internal parts of the cutting head. This reduces wear on consumable parts, and generates about a 10% increase in cutting speeds.

Bystronic's units have a material shuttle table and swing arm loader that give a 30% increase in productivity with little operator interaction. The machine has the ability to load itself with the swing arm loader and, upon completion of one job, swap tables to start cutting a second job seamlessly. The machine continues to run while the operator unloads cut parts/materials.

In some specialty applications, we were able to make holes from 1 to 5 mm diam in 4" (102-mm) thick steel. We used our 30-15 machine which has a 70-hp (52.5-kW) pump. The garnet was 380 mesh delivered at 380 grams per minute using a 0.3-mm sapphire nozzle. Pressure was 3600 bar (52,210 psi) with a cutting speed of 80 mm/min.

Waterjets Can Do More

Johnnie Howard
President
Calypso Waterjet Systems
Dallas, TX

We find that a wide variety of manufacturers are interested in the waterjet because it is so flexible. Companies that survived the recent downturn are looking for expanded capability and diversity. They don't want to be locked into a specific industry, material, or process and waterjets give them the increased capability they need.

While abrasive machines are our primary products, we are seeing a real surge in the sale of water-only units, because customers are doing more with softer materials. Multihead machines are also very popular, because they achieve increased productivity.

We only use intensifier pumps at pressures to 60,000 psi and achieve 800 - 1000 hr per seal. Maintenance time is 1 - 1.5 hr.

Calypso utilizes a six-axis servo control platform that can manage multiple heads, auto height sensing, and drill tools all at the same time. In addition, we have recently added an integrated cutting capability that is achieved through our software and height-sensing options.

Not Just Metalcutting

David Dumas
Jet Edge
St. Michael, MN

Our machines are designed chiefly for high-production job shops. Our latest system has a Sercos Digital Control for higher speed communication and multiple communications to the system elements such as conveyors and robots. A scanner reads the part and automatically pulls the programs and cuts the part. It gives higher accuracy at high speed. There is less wiring because it's digital and uses fiber-optics for communications.

We use only intensifiers in our systems, but provide direct-drive parts that run at 55,000 psi (379 MPa) to an OEM. On multiple head units it's difficult to use direct-drive pumps. We offer units that operate up to 60,000 psi (413 MPa), but we have achieved 80,000 (552 MPa) in the lab.

To get a more uniform pressure we use a hydraulic accumulator in the system. This results in smoother pressure, which translates to lower maintenance cost because it reduces pressure fluctuations that can fatigue parts in a high-pressure system. We use an intensifier pump with an accumulator and digital control driven by a 200-hp (150-kW) pump. It delivers a 60,000-psi stream. How many heads are used depends on the product being cut. For example, with a 200-hp pump you might run a single head when cutting steel but 12 heads on the same system when cutting foam.

Our conventional worktable is 4 X 8' (1.2 X 2.4 m), but we can add spreader bars that allow us to work on a 14' (4.3-m) wide sheet. We make machines from 4 X 8' to 12 X 40' (1.2 X 2.4 m to 4 X 12 m). By using ground ballscrews on our tables, we get a repeatability of ±0.001" (0.03 mm) and a part accuracy of 0.002" (0.06 mm).

Unlike several other systems that use tilting heads, our units rely on the design of the nozzle, cutting head, and pressure variations to eliminate taper.

Our company supplies machines for an interesting "noncutting" application. Aircraft jet engines require the ceramic coating be removed for routine maintenance. Many airlines have found that waterjet is a faster, lower cost way to do that cleaning than previously used acid baths. One of our systems with a 150-hp (111.9-kW) intensifier essentially mills the unwanted coating off the burner can. The process takes only hours, as opposed to days formerly required.

Combined Waterjet / Plasma Heads

Robert Smallwood
ESAB Cutting Systems
Florence, SC

ESAB is normally associated with welding and plasma cutting, but we offer a system that combines both waterjet and plasma. The gantry-style machine carries both heads so the cutting can be programmed to use either or both on the same part. This can dramatically improve cut quality on parts that require higher tolerances on certain areas than plasma alone can give. Not all waterjet parts are required to have the entire part cut at waterjet quality--that is why you will see the different quality settings (Q1, 2, 3, 4, 5). We can either use the waterjet at a different quality setting or use plasma for the lesser quality cuts. The plasma/waterjet combination feature will increase production on those parts.

The design of the waterjet takes advantage of ESAB's cutting heritage, and cutting heads and pumps from KMT. Single or multihead systems are offered, and our machine's cutting areas range from 4 to 48' (1.2 - 15-m) in length and widths from 5 to 20'(1.5 - 6 m).

We have a diverse market: artists, job shops, steel service centers, and defense contractors (particularly those working with composites). Our CNC allows us to utilize several types of piercing routines which enables our customers to cut the many types of material. Composites take different piercing routines than steel.

We have a five-axis system that offers bevel cutting, and systems with pumps from 15 to 100 hp (11.3 - 75-kW).

We also offer height control, which means that a sensor monitors workpiece surface so that the cut height remains constant. The cutting height can also determine quality of cut parts, so multiple heads should be used with an Automatic Height Control. This will ensure that all cutting heads are starting (piercing) and cutting at the same height.

Composites Are a Major Market

Michael Ruppenthal
Flow Inc.
Kent, WA

I would rank our major markets in the US as job shop, aerospace and medical.

In this country, single-head systems are more popular since the market is often low-volume job shops. In Europe, volume production is emphasized so multihead systems, up to 10 heads, are common.

Paradoxically, we have found that getting involved with abrasive waterjet systems has allowed some of our customers to expand into new markets outside metal cutting. For example, cutting stone and ceramic is a rapidly growing market, as is fabric cutting.

Customers are wary of new technology, so we make a special effort to keep operations simple with a highly intelligent machine, especially with our graphic user interface (GUI).

We have found a major application for abrasive waterjet is in cutting composites used in commercial and military aircraft. A big problem with composites is that they tend to fray and delaminate when cut with conventional machining processes. Waterjets avoid this problem.

However, a problem that we had to resolve with waterjets is the initial piercing of the composites. In older systems the water stream, when it first leaves the cutting head, does not carry any grit for a short time. So the stream is briefly water only and tends to delaminate the composite rather than cut it. We resolved this problem with a combination of pressure ramping and a vacuum assist. This combination of techniques draws grit immediately into the water path, so piercing occurs when the program is first started.

Accuracy is application- dependent, but in most cases we can offer 0.001". There are two ways to maintain accuracy. Cut very slowly, or use a multiaxis cutting head. Any change in direction or contour has to be watched. The behavior of the jet does not parallel a cutting tool. It is much more dynamic. So Flow created and patented a dynamic waterjet system to account for such differences.

Because abrasive waterjet cutting is very process sensitive, we offer both intensifiers and direct-drive pumps. Once we have evaluated a potential customer's needs and maintenance capability, we help them decide which is best for their application.

We offer a 3-D cutting system which is CNC based, so requires a higher level of operator skill than a strictly 2-D application. These systems are about 10% of our sales, and the market is growing. With a 3-D system, using our proprietary software we control the *Z* axis both vertically and horizontally in a five-axis system. In one of our 3-D applications we cut a 8" (203-mm) thick Waspaloy section of armor plate.

Many systems offer some type of height sensor. That is, a means of determining the distance between the tip of the cutting head and the workpiece. This is particularly important with very thin or very thick material. Thin material tends to buckle and thin material tends to stress relieve as it's cut, because of dynamic stresses within the metal. In the Flow system, for example, it's called a dynamic contour follower, and is a kind of mechanical feeler gage that rides along the workpiece in advance of the cutting head. Electronic or optical sensing does not work reliably because water and grit are present.

MAGBUY

To find out more about the products and processes mentioned in this article, select the link(s) below:

- Bystronic Inc
- Calypso Waterjet Systems Inc
- ESAB Welding & Cutting Products
- Flow International Corp
- Jet Edge
- KMT Waterjet
- OMAX Corp

Society of Manufacturing Engineers
U.S. :: One SME Drive :: Dearborn, Michigan 48121 :: Resource Center (800) 733-4763 :: Phone (313) 425-3000
Canada :: 3761 Victoria Park Avenue, Unit 1 :: Toronto, ON M1W 3S2 :: Phone (888) 322-7333