Technical Article

Waterjet Cutting: *The Other "Non-Traditional" Process*

by Christopher Wilkins

When all you have is a hammer, everything else looks like a nail. That might have described the traditional outlook of machining, where the tool is in a hard form such as a drill, tool bit or saw blade. Over 50 years ago, the "new tool" on the block was the tap buster, where the tool was nothing more than sparks. In the early 1970's, the invention of the first waterjet cutting machine again demonstrated that the concept of a cutting tool need not be limited to something that has a sharp metallic edge.

A Condensed History of Waterjet Cutting

The mother of inventions is usually not a single mother, but usually the result of independent research. So it appears to be with waterjet cutting. In Russia, the first patent for the use of waterjet cutting was in the field of boreholes in the mining industry. In 1936, Peter Tupitsyn, who was working in the Donetsk Coal Basin in the Ukraine, had the idea to use water jets to cut boreholes (into which pipes would be lowered) into the coal bed. In the 1950's and 1960's, the need to mine uranium and the risks associated with getting it (radiation), revived interest in the use of remote borehole mining with high pressure water jets. High pressure borehole mining has found several applications including the creation of large underground storage caves. The idea here is to construct salt domes for the storage of liquefied gasses, oil etc. by dissolving a salt stone mass by pumping down water and receiving the pregnant brine. This process usually takes three to five years to accomplish. The result is a man-made cavern.

According to Flow Corporation (a major manufacturer of waterjet cutting equipment), Dr. Norman Franz is regarded as the father of the waterjet. He was the first person who studied the use of ultrahigh-pressure (UHP) water as a cutting tool. The term UHP is defined as more than 30,000 pounds per square inch (psi). Dr. Franz, a forestry engineer, wanted to find new ways to slice thick trees into lumber. In the late 1950's and early 1960's, Franz first dropped heavy weights onto columns of water, forcing that water through a tiny orifice. He obtained short bursts of very high pressures (often many times higher than are currently in use), and was able to cut wood and other materials. His later studies involved more continuous streams of water, but he found it difficult to obtain high pressures continually. Dr. Franz never made a production lumber cutter. Ironically, today wood cutting is a very minor application for UHP technology. But Franz proved that a focused beam of water at very high velocity had enormous cutting power— a power that today is utilized in applications beyond his imagination. Today, the process of waterjet and abrasive waterjet cutting is seemingly finding new applications daily. A glance at Figures 8 through 11 will give you some idea of the range of applications that use waterjet and abrasive waterjet machining.

In the early 1990s, Dr. John Olsen, a pioneer of the waterjet cutting industry (and co-founder of OMAX Corp.), began to explore the concept of abrasive jet cutting as a practical alternative for traditional machine shops. The goal was to develop a cutting system that would advance the art and science of this process even further. His initial technology focus was in the design, development and manufacture of an improved high-pressure pump for this emerging, demanding application.

He then went on to develop specialized waterjet control software that eliminated the need for operator expertise and trial-and-error programming. This research and other developments lead to the formation of OMAX Corporation, which lays claim to the first abrasive jet cutting system designed specifically for the short-run and limited-production machine shop market.

Complimenting Or Competing Technology?

It depends on where you are standing. If you are on the railroad tracks, sooner or later you are going to get run over. That is why a growing number of shops are adding waterjet and abrasive waterjet technology to their arsenal of cutting processes (which of course include wire and sinker EDM). The waterjet has shown that it can do things that other technologies simply cannot. From cutting whisper thin details in stone, glass and metals; to rapid hole drilling of titanium; to cutting of food, and even as we will see (in a spin-off technology), to the killing of pathogens in beverages and dips, the waterjet has proven itself unique. According to Frost & Sullivan and the Market Intelligence Research Corporation, waterjets are said to be the fastest growing and most versatile process in the world. Even if you maintain a healthy dose of skepticism, there still can be no doubt that they compliment other technologies, such as milling, laser, EDM, plasma, as well as a host of other traditional and non-traditional processes used in the manufacturing industry. They create no noxious vapors, heat affected zones, nor do they leave mechanical stresses on the cut surface.

Waterjets remove material without heat (although strictly speaking, if you cut a piece of say 2" thick material with abrasive waterjet, the material will get up to 120 degrees F.). In this cold cutting process, the supersonic waterjet stream performs a supersonic erosion process to "grind" away small grains of material. After this waterjet stream has been created, abrasive can be added to the stream to increase the power of the process many times. But exactly how does it work, you ask?

How Does It Work?

Waterjet cutting technology is a unique process that is able to cut almost all materials cost effectively. Simply put, the energy required for cutting materials is obtained by pressurizing water to ultra-high pressures, and forming an intense cutting stream by focusing this high-speed water through a small, precious-stone orifice. However, in order to achieve these types of results, some complex technology and close tolerance machining is required for all of the pieces to work properly.

Waterjet Types: There are two types of waterjets. The first version, circa mid 1970's, uses only water, and found early applications cutting corrugated cardboard and food items such as cakes and candy bars. This is sometimes referred to as pure waterjet (PWJ) to differentiate it from a later development. Even though early users sometimes found the technology expensive and temperamental, the benefits far outweighed mechanical cutting devices, such as slitting knives. Today, applications include cutting diapers, tissue paper and automotive interior parts, such as headliners. The second version, which appeared in the early 1990's, introduced an abrasive sand type media into the high pressure stream to assist the cutting action, and in doing so, greatly expanded the scope of what is possible. This version is called abrasive waterjet machining (AWJ). Since the AWJ version is hundreds of times more powerful when compared to PWJ, the range of work includes cutting stone, ceramic, glass, composites and metals.

There are two main steps involved in the waterjet cutting process. First, an ultra-high pressure pump or intensifier generally pressurizes normal tap water at pressure levels up to 60,000 psi (4140 bar) to produce the energy required for cutting. Second, water is then focused through a small precious stone orifice (typically ruby, sapphire or diamond) to form an intense cutting stream. The stream moves at a velocity of up to 2.5 times the speed of sound, depending on how much water pressure is created.

The Pump: There are three types of pumps that can be used in waterjet cutting equipment, an intensifier type pump, a crankshaft type pump, and a direct drive type pump. An example of a direct drive type pump is the 'low pressure' type sprayer that you may have rented or own to wash down your porch deck, or to clean the house siding during spring clean up. These types of pumps are simple and reliable and operate at 20-55,000 p.s.i. Intensifier type pumps see applications where the direct type pump cannot go, and operate in the range of 40-87,000 p.s.i. The third type of pump is a crankshaft type pump that can provide pressures to 55,000 p.s.i. Different type of pumps are favored by different waterjet manufacturers, and like everything else, have benefited from advances in metallurgy and other technologies to give improved operating performance, reduced service requirements, and lower operating costs.

Here is how an intensifier type pump works. An engine or electric motor drives a hydraulic pump, which pumps hydraulic fluid at pressures from 1,000 to 4,000 psi (6,900 to 27,600 kPa) into the intensifier cylinder.

The hydraulic fluid then pushes on a large piston to generate a high force on a small-diameter plunger. This plunger pressurizes water to a level that is proportional to the relative cross-sectional areas of the large piston and the small plunger.

Figure 2: shows a crankshaft type pump. The centuries-old technology behind crankshaft pumps is based on the use of a mechanical crankshaft to move any number of individual pistons or plungers back and forth in a cylinder. Check valves in each cylinder allow water to enter the cylinder as the plunger retracts, and then exit the cylinder into the outlet manifold as the plunger advances into the cylinder.

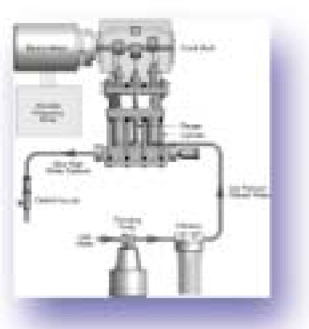

Figure 2: *Crankshaft Schematic (Courtesy of OMAX Corp. Kent, WA)*

Crankshaft pumps are claimed to be inherently more efficient than intensifier pumps, because they do not require a power-robbing hydraulic system. In addition, crankshaft pumps with three or more cylinders can be designed to provide a very uniform pressure output, without needing to use an attenuator system, that is used to modulate the fluctuations in pressure created by the pumping action of the plunger.

Figure 3: *Nozzle assembly (Courtesy of OMAX)*

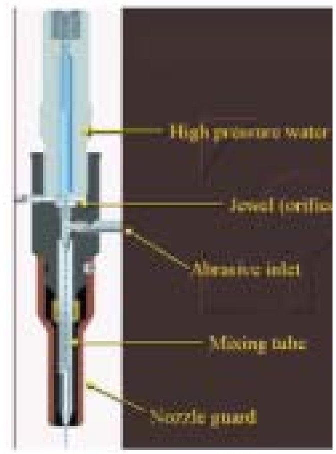

Figure 4: *Water Jet (Courtesy of www.waterjets.org)*

Cutting Heads (Nozzles): All abrasive waterjet systems use the same basic two-stage nozzle design shown in ***Figure 3***. First, high pressure water enters the upper portion of the nozzle assembly and passes through a small-diameter jewel orifice to form a narrow jet. The water jet then passes through a small chamber where a Venturi effect creates a slight vacuum that pulls abrasive material and air into this area through a feed tube. The abrasive particles (typically garnet) are accelerated by the moving stream of water, and together they pass into a long, hollow cylindrical ceramic mixing tube. The mixing tube acts like a rifle barrel to accelerate the abrasive particles. The abrasive and water mixture exits the mixing tube as a coherent stream and cuts the material. You can see in ***Figure 4*** how focused the cutting stream actually is. It's critical that the jewel orifice and the mixing tube be precisely aligned to ensure that the water jet passes directly down the center of the mixing tube. Otherwise the quality of the abrasive waterjet will be diffused, the quality of the cuts it produces will be poor, and the life of the mixing tube will be short. In the past, most nozzle designs required the operator to adjust the alignment of the jewel and mixing tube during operation. Modern nozzle designs rely on precisely machined components to align the jewel and mixing tube during assembly, thereby eliminating the need for operator adjustments.

Mixing tubes are approximately three inches long, about 0.25" diameter with inside diameters that can vary from about 0.020" to 0.060" with the more common size being, you guessed it, 0.040". The normal standoff distance between the nozzle and the workpiece is usually between 0.01" and 0.1". Any more and the cutting efficiency goes way down (just like it does when you cut on a wire machine with the flushing nozzle too far from the workpiece surface).

Table and Motion Control: In order to make precision parts, a waterjet cutting machine must have a precision X-Y table and motion control system. Tables fall into four general categories:

1. Floor-mounted gantry systems with separate cutting tables
2. Integrated table/gantry systems
3. Floor-mounted cantilever systems with separate cutting tables
4. Integrated table/cantilever systems

Figure 6: *Operator control and cutting path.*

Waterjet cutting machines come in too many sizes and types to detail here, suffice to say that no matter what your application, there is a standard or specialized version to suit your exact requirements.

Figure 5: shows a typical standard XY type machine The heart of any modern CNC machine tool is its control system. Specialized control algorithms and user friendly controls are the norm today for waterjet machines as well. However, the rigid control structure of G-code programming with fixed feed rates has proven unsuited (according to some manufacturers) to the precise control demands of waterjet cutting. As you can well imagine, any unnecessary dwell times during cutting (say in the corners, for example) will result in variations in cut quality at the surface. For example, OMAX has taken the route of eliminating G-code output from their machine, and instead stores the entire program in the machine memory, where specialized control algorithms compute exactly how the feed rate should vary for a given geometry in a given material, to make a precise part. The algorithm actually determines desired variations in the feed rate every 0.0005” (0.012 mm) along the tool path, to provide an extremely smooth feed rate profile and a very accurate part. ***Figure 6*** shows the CNC control screen with the part piece layout and machine control parameters *(Courtesy of OMAX Corporation, Kent, WA).*

Figure 5: *A small XY type water jet cutting machine. (Courtesy of Flow Corp)*

Application Overview

Speed, Speed and More

Speed: A table with typical abrasive waterjet speed capabilities in 0.5” materials can be seen in ***Figure 7***. Of course these aren’t guaranteed numbers, but reflect cutting with a reasonably good edge quality. The speed of abrasive jet machining is a function of how much water and abrasive you push through your nozzle, as well as how thick and how hard your material is.

It is said that a picture is worth a thousand words, so here are four examples of the type of things you can do with a waterjet. Just like wire or sinker EDM, the real limiting factor is your imagination and your customer’s willingness to pay for it!

	10 Hp Direct Drive*	20 Hp Direct Drive**	50 Hp Intensifier***	30 Hp Direct Drive****	40 Hp Direct Drive*****
Hardened Tool Steel	1.26 IPM	3.23	4.43	5.44	7.22
Stainless Steel	1.29	3.29	4.53	5.55	7.38
Aluminum	3.88	9.89	13.59	16.67	22.14
Titanium	1.91	4.87	6.69	8.21	10.90
Copper	1.81	4.62	6.36	7.80	10.36

Figure 7: *(Courtesy of www.waterjets.org — “Waterjet Web Reference”)*

Fresher Under Pressure: The next time you are in your supermarket, look carefully at the packaging of the food that you buy. There is a revolution going on. The winner is the consumer who gets fresher, longer lasting food. The losers are the potentially dangerous bacteria such as E.coli and listeria, which if not properly treated at the manufacturing source, can cause serious problems if they are later ingested. One of the new technologies is the treatment of food with ultra high pressure (UHP) to keep food fresher, longer. Most recently, the high pressure technology incorporated in waterjet cutting has been adapted by a Flow Corporation sibling company, Avure Technologies, to achieve the benefits of pasteurization without the undesirable effects of heat. Known as High Pressure Processing (HPP), it is gaining in popularity with the North American food industry, because of its capacity to inactivate pathogenic microorganisms with minimal heat treatment, resulting in the almost complete retention of nutritional value and the textural characteristics of fresh food, without sacrificing shelf-life. As long as the food is mostly air-free and contains water, hydrostatic pressure used during the processing and packaging will not crush the food. Heat treatment on the other hand, the traditional method the food industry uses to inactivate micro-organisms and enzymes, degrades taste, color, nutritional value and vitamin content in varying degrees. High pressure has the same inactivating effect on the micro-organisms and enzymes, but it does not affect the taste, color, nutritional value or vitamin content.

Compare the two packages of fruit. ***(Figure 12)***. The one on the right has been pressurized using the HPP process to reduce spoilage and increase food safety, without changes to the structure of the food. Any bacteria that might be present during preparation and packaging will be killed by the effects of the high pressure on their cellular structure.

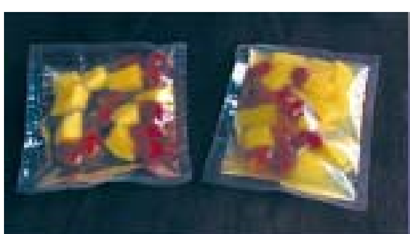

Figure 12: *(Courtesy of Avure Technologies, Kent, WA.)*

It's a Boring Job: But somebody has to do it. Could be the refrain of the utility person you may have seen by the roadside with jackhammer and shovel, as he labors away digging a shallow trench across someone's driveway to lay a service cable. Now imagine that some smart engineer figured out that by using an apparatus specially designed to bore under the driveway with a high pressure jet of water, a bore hole could be made to feed the utility wire under the driveway. What a much neater and more cost effective way to go. No more surface trenching, asphalt patching, traffic disruption (and the list goes on).

Figure 8: *Intricate glass work (Courtesy of Nova Classique Glass Industries, Downsview, Ontario)*

Figure 9: *This photo of nested shapes (Courtesy of Flow Corp, Kent, WA)*

Figure 10: *This photo is of a 1/2" aluminum honeycomb part with 0.025" walls. (Courtesy of www.waterjets.org (the "Waterjet Web Reference")*

Figure 11: *This photo shows 2" thick concrete (the pink color is from pigment added to the material) (Courtesy of www.waterjets.org the "Waterjet Web Reference")*

Utility companies (and utility subcontractors such as UtilX Corp, Kent, WA) are now using specially developed waterjet boring equipment such as the FlowMole (that is self-advancing, steerable, and capable of traveling up to 500 feet. Boring accuracy is +/- one foot from desired location. A boring tool (used in conjunction with the waterjet assist) can bore a four inch diameter hole at a rate of about three feet per minute, all without muss or fuss.

This application is all wet!: Forty leagues under the sea, you will also find waterjet cutting at work. Oil States MCS (Houston, TX) uses specially built manipulators to attach to the piles, or structural braces of oil rigs (or on below-ground piping shafts on oil fields) to sever structures for repair, or when abandoning oil exploration sites.

Conclusion

Have we covered it all? Not by a long shot, but unfortunately we have run out of room for a more in-depth review. EDM and waterjet machining are two disciplines that provide real-world solutions for manufacturing companies who are continually challenged to do more, and at lower cost. Neither one is the be-all-and-end-all answer, but each one deserves a place in the home of a diversified manufacturing environment. Advances in EDM technology over the past several years have made EDM a mainstream process no longer deserving of its ‘non traditional’ label. And I suspect that the waterjet equipment manufacturers would say the same about the equipment that they make. If you haven’t seriously considered waterjet, the maturing of this technology may mean that it is time to give it a second look. After all, the technology is fast approaching thirty years old, and in today’s terms, that is a long time.

Thanks to the following sources of information, Flow Corporation , OMAX, and to www.waterjets.org (the “Waterjet Web Reference” which has lots of interesting material including videos of waterjet machining).

EDM

Figure 13: *Underground trenching using FlowMole equipment. (Courtesy UtilX Corp, Kent, WA)*

Figure 14: *shows a jacket being removed after cutting with such equipment.*

Figure 15: *shows a large diameter cutting manipulator with centralizers, abrasive waterjet cutting head (near the lower left).*

Figure 14 *and* ***Figure 15:*** *(Both courtesy of Oil States MCS, Houston, TX)*