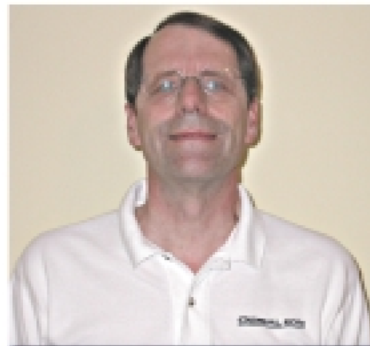
TechTips is a collection of useful ideas, techniques, and procedures designed to further EDM knowledge.

TechTips



by Roger Kern

WaterJet FUNDAMENTALS

Since both Wire EDM and Waterjet produce geometry by cutting a slot through material, it is important that Wire EDMers become familiar with Waterjet technology to determine if this fast growing, complimentary process can provide additional capabilities and opportunities for their shops. In fact, at last year's IMTS, Sodick displayed a machine that combined both Wire EDM and Waterjet technologies.

History of Waterjets

The use of ultrahigh-pressure (UHP) water as a cutting tool was first studied in the 1950's for the purpose of slicing trees into lumber. The term UHP is defined as pressure in excess of 30,000 psi. While the early studies did not reach their goal of developing a practical lumber cutting tool, these studies proved that a focused beam of water at very high velocity had enormous cutting power. Pioneering research by Dr. Mohamed Hashish in the late 1970's led to the development of the first practical abrasive Waterjet cutting system in 1980. Today, Waterjet technology has found wide application for high speed cutting of a diverse range of materials including food, fabric, paper, metal, stone, composites, and ceramics.

Types of Waterjets

Pure Waterjet ***(See Fig 1)*** employs a focused beam of pure water at high velocity to cut the following materials:

- Soft goods: vinyl, leather, cloth
- Food: Baked goods, meat, poultry
- Paper products: Disposable diapers
- Gaskets

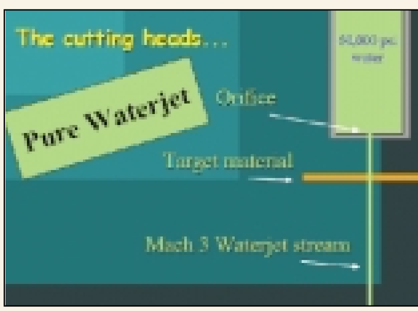


Figure #1

Abrasive Waterjet ***(See Fig 2)*** adds abrasive particles to the focused beam of water at high velocity to cut the following materials:

- Metals
- Glass
- Stone
- Composites

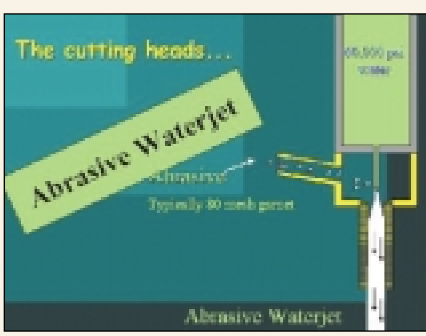


Figure #2

We will limit the following discussion to Abrasive Waterjets as they are the only ones applicable to shops in our industry.

Abrasive Waterjet Cutting Mechanism

Velocity vs Pressure

It is a common misconception that, in a Waterjet, the high pressure does the cutting. In fact, the high pressure developed by the pump is converted to high velocity at the cutting head by the orifice.

- 60,000 psi = Mach 3 = 2,100 miles per hour
- 87,000 psi = Mach 4 = 2,800 miles per hour

The resulting high velocity stream does the cutting, not the pressure. A typical Waterjet machine operating at 60,000 psi exerts only 1/2 pound of vertical force on the workpiece material.

Jet Stream Grit Concentration

It is also commonly assumed that the column of water that comprises the jet is packed with abrasive grains. In reality, under normal cutting conditions, there is only one abrasive grain per inch of water column. However, due to the high velocity of the jet, *the workpiece is subjected to the cutting action of thirty-seven thousand grains per second!*

Waterjet & Wire EDM Comparison

Waterjet Advantages:

- 10-100 Times Faster: Cutting speeds are measured in inches per minute instead of inches per hour
- Ability to cut non-conductive materials
- Leaves no Heat Affected Zone or other metallurgical damage
- Leaves no contamination on the cut surface — Some medical and aerospace applications prohibit even minute amounts of copper or zinc deposits left by Wire EDM
- Pierces its own start holes
- Accommodates very large table travels — The absence of a lower arm allows virtually unlimited table travels ***(See Fig 2A)***
- Simple workpiece fixturing- Parts can be clamped to the table without concern for lower arm collision or resisting high pressure flush

Figure #2A

Waterjet Disadvantages:

- *Only one tenth as accurate:* ±.003” tolerance possible vs ±.0002”
- Stream lag and taper inherent in the process can degrade contour accuracy at high cutting speeds
- Skim cutting is not possible to refine accuracy
- High consumable usage—Abrasive usage is measured in pounds per minute
- High degree of equipment maintenance — Generating and controlling Ultra High Pressure water requires regular component rebuilding and replacement

Key Waterjet Cutting Characteristics

Stream Lag

Abrasivejet cutting is a flexible process with bending and deflecting of the jet as it cuts material. As the jet travels through the material from left to right, the exit point of the stream in the material tends to lag behind the entrance point ***(See Fig 3)***. The faster an operator tries to cut the material, the greater the stream lag. This stream lag can cause significant errors on the inside corners of a part ***(See Fig 4)*** and on circular geometry. The thicker the material, the more significant the error. One way to solve this is to slow down machine travel speed as the jet approaches and leaves corners. PC-based control software (just like in a Wire EDM) helps slow the jet on corners to minimize inside corner damage at some sacrifice to part cycle time.

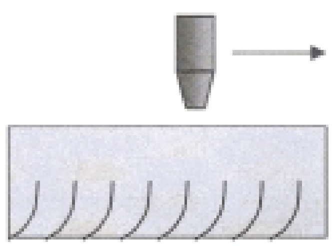


Figure #3

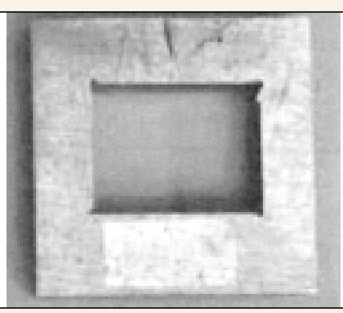


Figure #4

Taper

Another error caused by the jet is the creation of a “V” shaped taper, sometimes called a draft angle ***(See Fig 5)***. One might intuitively think that the stream would diverge as it leaves the nozzle generating the opposite taper to that shown, but the jet loses cutting power as it travels through the material creating a taper that always leaves more material at the bottom of the cut. Taper can also be reduced by slowing the cutting speed.

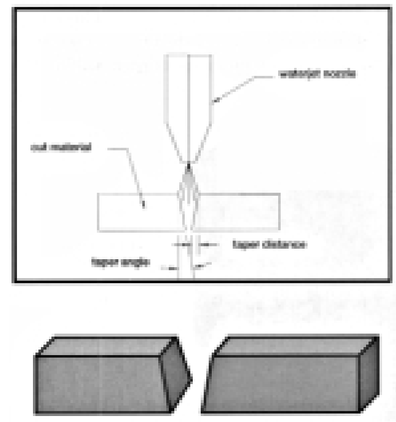


Figure #5

Developments that Correct for Stream Lag and Taper

Recently, leading Waterjet manufacturers have developed technology to substantially reduce the geometry errors caused by the stream lag and taper inherent in the Waterjet process. This technology includes both hardware and software.

Hardware

Two additional rotation axes are added to the cutting head to allow tilting of the jet perpendicular and parallel to the cut path to compensate for taper and stream lag. Simply put, the head is tilted by a few degrees to take all the error off the “good side” of the part and force the error onto the “waste” side of the part. Inside corners are improved and taper is eliminated because the jet is tilted to ensure the stream does whatever it needs to while in the material to produce an accurate contour with minimal speed reduction.

Software

Adding extra rotational axes to the head of the machine is only a small part of the solution to the contour precision problem. The PC control needs to “know” exactly what the stream is doing in the material by calculating how much the stream is deflecting, where is the exit point of the steam in relation to the entrance, and how the jet should exit an inside corner to produce the best geometry in the fastest possible cycle time. Thus, the heart and soul of contour precision are the mathematical models that control the jet angle of attack, the compensation of the X, Y & Z positions to maintain the pivoting jet focus on the contour & correct vertical distance above the contour, and the cutting speed.

Waterjet Components

A Waterjet machine is comprised of three major subsystems:

- The Table
- The Pump
- The Abrasive Delivery System

The Table

(this is industry jargon, most people would call it the machine tool)

The Table ***(see Fig 6)*** provides support for the workpiece & cutting head, controlled motion, and storage for the spent abrasive and water. The table consists of the following components:

- Machine frame
- X&Y axes
- Z axis
- A&B axes (if present)
- Tank
- CNC control

The Pump

The Pump is the source of the Ultra High Pressure water. There are two types of pumps:

- Intensifier
- Direct Drive

The Intensifier Type Pump ***(See Fig 7)***

The Intensifier is the most common type for UHP applications. The intensifier type pump consists of two distinct circuits: an electro-hydraulic oil circuit actuating a hydraulic water circuit. The hydraulic oil circuit consists of an electric motor (25 to 200 hp), hydraulic pump, oil reservoir, manifold, and piston biscuit/plunger. The electric motor powers the hydraulic pump. The hydraulic pump pulls oil from the reservoir and pressurizes it to 3,000 psi. This pressurized oil is sent to the manifold where the manifold's valves create the stroking action of the intensifier by sending hydraulic oil to one side of the biscuit/plunger assembly, or the other, powering the plunger in the water circuit. The water circuit consists of the inlet water filters, intensifier, and a shock attenuator. The intensifier is a reciprocation pump, in that the biscuit/plunger assembly reciprocates back and forth, delivering high-pressure water out one side of the intensifier while low-pressure

Figure #6

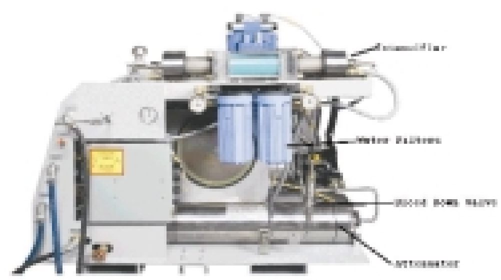


Figure #7

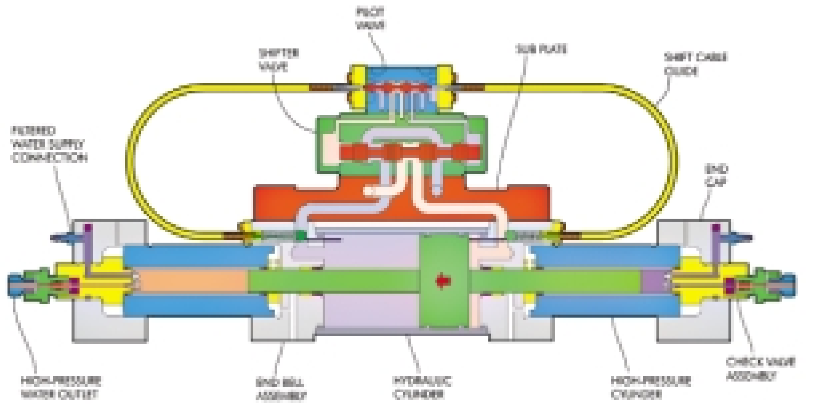


Figure #8

water fills the other side ***(See Fig 8)***. The Ultra High Pressure is generated as a result of the 20:1 area ratio of the oil piston and the water piston. ***(See Fig 9)*** Thus, 3,000 psi of hydraulic pressure is able to generate 60,000 psi of water pressure. Because the intensifier is double acting and double ended, it generates a high pressure pulse in both directions. The water is then fed into an attenuator which smoothes out the water pulses, delivering a steady, high pressure supply of water to the cutting head. The pump assembly also contains a by-pass valve to safely bleed off the high pressure when the pump is not operating. Intensifier Style pumps are capable of generating water pressures in excess of 87,000 psi. A typical 50 HP Intensifier style pump can produce 60,000 psi of water at the rate of 1 gpm.

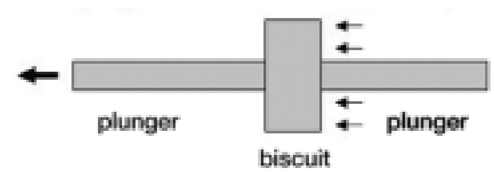


Figure #9

The Direct Drive Type Pump

(See Fig 10)

The Direct Drive pump is a multi-cylinder plunger type pump driven directly by an electric motor. Direct Drive pumps are generally limited to water pressures of 55,000 psi or lower, but are less costly than Intensifier pumps.

Figure #10

Water Quality

Due to the ultra high pressure environment in which Waterjets operate, extremely clean water is required. Pump, valve, and orifice damage ***(See Fig 10A)*** will occur if the slightest amount of dirt enters the system. Most pumps employ dual inlet water filter assemblies with ratings of 1 micron absolute for the pre-filter and .45 micron absolute for the final filter.

Figure #10A

Ordinary tap water is used to feed most Waterjet systems. Most Waterjet users require only water softening prior to sending the water through the pump's inlet filters and then on to the intensifier. Reverse Osmosis (RO) and De-Ionizers (DI) tend to make the water so pure that it becomes "ion starved." This aggressive water seeks to satisfy its ion starvation by taking ions from surrounding materials, such as the metals in the pump and high-pressure plumbing lines. While RO and DI water can greatly extend orifice life, it can cause very expensive damage to the intensifier and plumbing.

The Abrasive Delivery System

(See Fig 11)

The Abrasive Delivery System consists of the following components:

- The Abrasive Bulk Transfer Vessel
- The Metering Valve
- The Performance Monitor
- The On/Off Valve
- The Cutting Head
- The Pierce Shield

The Abrasive Bulk Transfer Vessel stores the abrasive and utilizes air pressure to deliver the abrasive to the Metering Valve.

The Metering Valve controls the flow of abrasive to the Cutting Head by means of a metering disk with a calibrated opening and an air operated valve.

The Performance Monitor is merely a calibrated vacuum gage which monitors the abrasive feed to the cutting head.

The On/Off Valve is pneumatically operated by the machine control to turn the jet stream on and off.

The Cutting Head ***(See Fig 12)*** consists of the following major components:

- The Nozzle Body which develops a laminar flow of water
- The Orifice ***(See Fig 13)*** is a jewel with a small opening which converts the Ultra High Pressure column of water into a supersonic water stream. Orifices are made from Sapphire, Ruby, or Diamond.
- The Mixing Chamber contains a venturi which draws the abrasive into the supersonic water stream
- The Mixing Tube ***(See Fig 14)*** acts like a rifle barrel to accelerate the abrasive particles and create a coherent, highly focused stream of water and abrasive. Mixing tubes are approximately 3 inches long, $^{1}/_{4}$" in diameter and have internal diameters ranging from .020" to .060", with the most common being .040". In order to withstand the aggressive abrasive action of the stream of water and abrasive, mixing tubes are made from specially formulated grades of carbide
- The Pierce Shield assembly consists of a plastic curtain which contains the spray-back of water during piercing operations and a Blast Disk which absorbs the reflected water stream to protect the cutting head.

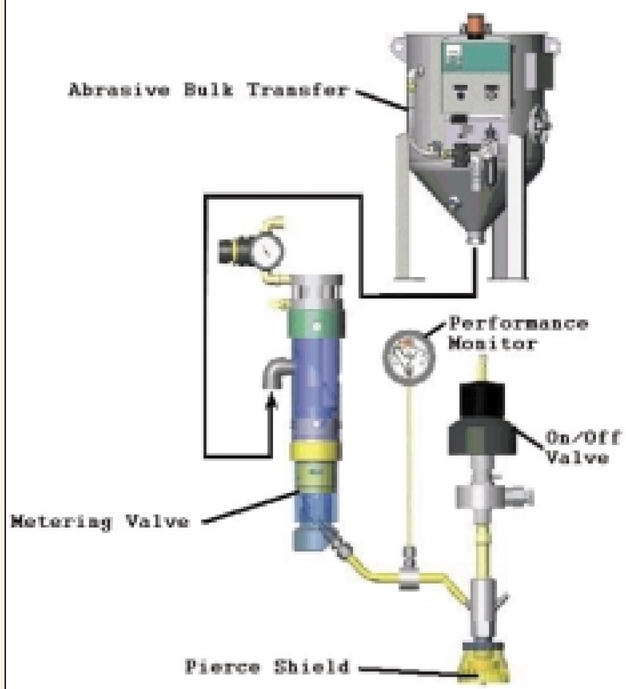


Figure #11

Figure #12

Figure #13

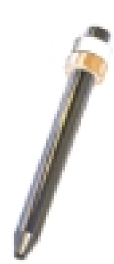


Figure #14

Abrasive Selection

Listed below are three abrasives utilized in waterjet systems.

- Garnet (The most commonly used and least expensive abrasive) Garnet is available in two types:

  Alluvial ***(See Fig 15)*** which is collected from stream beds and is distinguished by its rounded edges. Alluvial garnet is available in grit sizes ranging from 60 to 100 grit

  Mined ***(See Fig 16)*** which is mined and crushed is distinguished by its sharp edges. Mined garnet is available in grit sizes ranging from 50 grit to 120 grit

- Aluminum Oxide
- Silicon Carbide

Figure #15

Figure #16

Abrasive Jet Setup Parameters

The selection of the appropriate parameters for a Waterjet system depends on the material to be cut, the material thickness and the quality of the cut required.

- Orifice size ranges from between .003” to .023”
- Mixing Tube size ranges from between .020” to .060” and determines the Waterjet kerf
- Abrasive type and grit size
- The abrasive flow rate which is determined by the metering disk
- The cutting speed which is often dictated by the edge quality requirements
- The water pressure which can be controlled at the pump
- Standoff Distance which is the distance between the bottom of the mixing tube and the top of the workpiece and generally ranges from .010” to .200”.

The Orifice and Mixing Tube size are generally determined by the thickness of the material. The abrasive mesh size is determined by the mixing tube diameter and by the workpiece edge quality required.

The more sophisticated Waterjet systems have extensive technology built into the P/C based control that selects the correct parameters based upon job requirements input by the operator.

Orfice Size	Mixing Tube Size	Abrasive Mesh Size
.010”	.030”	100
.013”	.040”	80
.016”	.040”	60

The chart above contains some typical Waterjet setup parameters.

Safety

(See Fig 17)

Due to the nature of the Wire EDM process, safety practices are often only casually observed in the Wire Room. Touching the energized wire of an operating Wire EDM will throw you back a few feet and make your hair stand up on end, but generally will not result in permanent injury. *Touching the energized stream of a Waterjet will result in amputation.* Safety practices need to be rigorously observed and enforced when working with Waterjets.

Figure #17

Conclusion

Even though both Wire EDM and Waterjet produce geometry by making a slot in material, they are very different technologies with very different capabilities. Thus, Waterjet should be viewed as a complimentary technology to Wire EDM along with other members of the non-traditional machining technology family. However, the speed at which a Waterjet cuts, the range of materials it can process, and the absence of metallurgical damage & contamination from its cuts make Waterjet a process that EDMers need to consider in order to address today’s and tomorrow’s competition and customer requirements.

We would like to say a special thanks to Barton Mines Company, LLC for providing the photos for figures 15 and 16 — and to Flow International Corporation for providing all of the other photos and illustrations.

Any suggestions for future topics are welcome. Tell us what you would like to read about.

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