Water Jet Automation

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Abstract— Water jet cutting has been an extremely helpful tool that creates flawless parts with tolerances up to ± 0.1 mm. During the cutting process, it is important to note that each step must be optimized to create the best finish or maintain the correct tolerance zone. These steps are composed of abrasive mass flow rate, traverse speed, and standoff distance. In order for these optimization techniques to be followed a strict set of rules must be followed to ensure consistent progression. Programs such as MATLAB can be utilized to reduce human error in the calculations. MATLAB files can then be saved to use with other materials and thickness combinations.

Keywords--Abrasive Water Jet, Automation, Calculations, CAD

I. INTRODUCTION

The future of automation is looking towards Abrasive water jet cutting (AWJ) for longer tool life and easier waste removal. AWJ can be defined as the erosion of material through the use of abrasive particles accelerated by a high speed water jet. Common problems that arise when looking at AWJ is how to optimize all parts of the process. Two main objectives that control the optimization are the machining time needed to produce a unit of cut surface and operating cost per meter of cut. Some jobs can require various pressures and nozzle heads. The thickness of material and the type are major things to take into consideration. The use of AWJ is common on a wide variety of materials. With this diverse manufacturing process, it is easy to see how these machines are becoming popular among industries.

When the first AWJ systems were created in the early 1980's, the abrasive particles were projected at various pressures to cut through practically any material. Pressures ranging from as little as 15,000 psi up to 75,000 psi have been developed over the years creating even more materials that the abrasive particles can cut through. Creating these higher pressures also allowed the parts manufactured to have higher quality and higher production rates.

Throughout history many studies have been conducted to find the optimum placement of the nozzle, orifice size and different types of mediums to use as abrasive particles.

The purpose of these AWJ systems is to create a safe atmosphere along with increasing the production rates of industries around the world. In order for these systems to be controlled and operated safely, the medium must be combined with a filler material to ensure the cutting is directed in the right direction at all times. This includes the pressure, feed rate, and water levels to remain constant establishing a smooth operation. Production rates would in turn skyrocket from previous subtractive methods. AWJ systems use the cooling of water to eliminate any form of intense heat from warping or damaging the part being cut.

The purpose of this paper is to establish a foundation on the fundamentals of AWJ systems, to create an understanding of how the system works, and the various uses it has. This paper will touch on points that describe how the computer communicates with the jet and how it regulates all the required functions.

II. LITERATURE REVIEW

Water jet technology existed since 1965, created by the McCartney manufacturing company [1]. McCartney-Ingersoll Rand installed the first commercial water jet system at Alton Box Board Company for cutting cardboard boxes in 1971. In 1983, the first mainstream AWJ systems were created. In order for this system to work, a high-pressure pump is added to create the jet. During the early 1980's high pressure was considered to be from 15,000 psi to 40,000 psi. Ultra-pressure was anywhere from the 40,000 psi to 70,000 psi. As time went on, the standard for working pressure increased. In the 1990's standard operating pressure became 60,000 psi, while some special jets created a hyper pressure of 94,000 psi. This high-pressure pump has the capabilities to be variated. This allows the user to either increase the pressure for a harder material or decrease the pressure for a softer material. As the years went on, jet pressures have increased as well as the different types of abrasion mediums used.

As the development of AWJ systems became more complex, it was apparent that the material being cut through needed to be researched more. Aultrin and Anand researched the effects of AWJ systems on aluminum alloy 6061 [2]. They determined that each nozzle used created a different surface roughness. As the nozzle increased in size, the pressure decreased but the kerf value increased. Kerf is the width of the jet stream or the width of a saw blade in any cutting application. This value refers to the amount of material taken away from the stock purely from the cutting tool.

III. AWJ PROCESS

There are typically 5 phases in every AWJ system that consists of 3 major parts. The pump, orifice, and nozzle. In any AWJ system, a high-pressure pump is needed to create the needed pressures to power the water and abrasive material through the orifice. Typically, these pumps are used to supply water and make sure the flow is constant. Without the water supply the system will not work the way it is intended. For the high pressure to be created, smaller diameter hoses must be used. For example, when a garden hose is used to water the grass or flowers, people find themselves putting their finger on the end of the hose to create a smaller diameter opening. This creates a way that the same pressure is applied at the nozzle, but the water flow decrease creates the illusion of an amplified pressure. This is called Bernoulli's principle that states, that an increase in the speed of a fluid occurs simultaneously with a decrease in static pressure or a decrease in the fluid's potential energy.

Fig. 1 – Section view of AWJ system head unit.

(source: <https://commons.wikimedia.org/wiki/File:Head.jpg>)

The next phase of the AWJ system starts at the cutting head. Figure 1 is a diagram of a section view of a head unit, and all the hardware needed for a typical AWJ system. After the pressurized water is supplied to the cutting head it has potential energy. Potential energy is stored energy. There is no motion in the fluid. The orifice is built to hold this potential energy and then converts that energy to Kinetic. Kinetic energy is the fluid in motion. Therefore, the orifice must be made properly to handle both forms of energy.

Once the water is pressed through the orifice, abrasive particles are then metered in to create the slurry for cutting. The abrasive particles are held in a mini hopper waiting to be dropped down into the mixing chamber. This mixing chamber creates a small thin stream that focuses the fluid in one central area. Therefore, a Venturi effect is created to suck the abrasive particles in the stream. A Venturi effect is essentially a vacuum in a closed system which allows the particles to feed in a controlled way.

After the abrasive material is sucked into the mixing chamber, it passes through a nozzle to focus the mixed fluid. As the mixed fluid goes through all these various phases, it creates an increase in kinetic energy. All this energy is then dispensed in various nozzles creating the finish desired. As the mixed fluid is dispensed, the jet head is moved on an x-y axis to create the desired conjures. In order for the head to travel around the work piece, it is important that the head travel on traverse speed. This speed is calculated by the cutting energy [4].

$$V_f = \frac{\xi P_a}{e i h w} \quad (1)$$

In this equation, the variables include traverse speed (V_f), cutting energy efficiency coefficient (ξ), abrasive jet power (P_a), specific cutting energy (e), quality number (i), material thickness (h), and kerf width (w). This equation finds the correct velocity for given material type, thickness, surface quality, and desired kerf width. Therefore, with many variables, it is important to note the water jet can be easily changed by using a different nozzle or distance from material.

$$P_a = \frac{1}{2} m_a v_{awj}^2 \quad (2)$$

Abrasive jet power (P_a) is defined by this equation that includes abrasive mass flow rate (m_a), velocity of abrasive water jet (v_{awj}).

$$v_{awj} = \frac{\eta}{1 + m_a/m_w} v_{wj} \quad (3)$$

Velocity of abrasive water jet is defined by this equation, including momentum loss ($\eta = 0.65-0.85$), velocity of water jet (v_{wj}), abrasive mass flow rate (m_a), water jet mass flow rate (m_w). This is important to remember, as the final velocity of the abrasive water jet velocity will be reduced during the mixing process by loss of momentum [5].

$$v_{wj} = c_v \sqrt{\frac{2p}{\rho}} \quad (4)$$

Velocity of water jet is based on Bernoulli's equation where water jet velocity (v_{wj}), coefficient of velocity ($c_v = 0.85-0.98$), water pressure (p), and water density (ρ).

$$m_w = \rho q_w \quad (5)$$

Water jet mass flow (m_w) is defined by this equation where m_w -water jet mass flow rate, ρ -water density, q_w -water jet flow rate. This is an essential factor in water jet power, as it represents the kinetic energy of the abrasive water jet stream [6].

$$q_w = c_d \frac{\pi d_o^2}{4} \sqrt{\frac{2p}{\rho}} \quad (6)$$

Water jet flow rate is defined by this equation where q_w -water jet flow rate, coefficient of discharge ($c_d = 0.6-0.8$), orifice diameter (d_o), water pressure, and water density. Not that kerf width will be about 10% larger than the nozzle orifice diameter, and that this diameter can change over time. or even through actions of the operator, as will be discussed later. Finally, we can calculate the traverse speed, of the head based on the previous equations:

$$v_f = 0.898 \left(\frac{\left(\frac{\eta^2 c_v^2 p}{\rho} \right) m_a^{1.155}}{\left(1 + \frac{4}{\pi c_d d_o^2 \sqrt{2p\rho}} m_a \right)^{2.31}} \right) \quad (7)$$

IV. APPLICATIONS

These AWJ systems have been used virtually all over the world. There are numerous applications for this cutting process such as sheet metal, stonework, and plastic trimming. AWJ systems are most often found in commercial use for cutting various parts. An example of this would be automotive custom shops. Typically, a custom shop cannot go out and buy the parts needed to fulfill someone else's vision so they must build the parts themselves.

An employee would scale the model in a program (that will be talked about later in the paper), which is then cut out by the AWJ systems and later welded by a fabricator. In the automotive industry there are many different types of metal used on cars that often have different thicknesses. It is up to the engineer to figure out what specific metal is needed to both create a ridged surface that will not collapse, but at the same time not be too bulky or heavy. It can be seen on any television show when they are building a frame or even patching other body problems on the car.

Another application of an AWJ system is cutting through stone on a commercial scale. When samples are needed of quarry mining, water jetting is used to lower the risk of fire hazards and laser work.

Fig. 3 – Schematic diagram of quarry application of an AWJ system

Figure 3 is a diagram that represents the location of all parts of quarry application of an AWJ system. Includes pump location, along with storage tanks and uses a cross hatched visual to represent the quarry walls being cut. Looking at this schematic, the downward facing part is redirecting the back-flow which is the results from the cutting. During the cutting the fluid passes through a valve and into a crossover to a one inch hose. It then was filtered to retrieve the cuttings and guided them to a container for storage. That fluid is then returned and can be measured. On the collinear side of the T-piece, another T-piece was connected for another measuring site. For jetting and injection testing, two pumps were used. For the injection testing, a low-pressure pump was used, and a high-pressure pump was used for jetting. This makes sense due to the topics covered previously. Jetting processes need a high-pressure pump in order to operate.

International Journal of Emerging Technology and Advanced Engineering

Website: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 11, Issue 10, October 2021)

In order for the AWJ system to operate correctly, it needs a large amount of water. Since the system will be subjected to water it is important that the system has a chain of valves that can protect the rest of the mining operation. The experiment resulted in inconclusive data due to the contamination of other materials in their samples. Although the process of use a AWJ system worked flawlessly.

Since AWJ systems can be used in various manufacturing systems, different plastics can be used to cut off unwanted materials from plastic molds. In injection molding or any molding of a plastic, there is a waste product from the casting material. This extra waste material must be dealt with and be controlled on a tight tolerance value. It is important to note that some plastics can react with water and either disintegrate or morph out of shape. A MSDS is always kept on hand for the operator to know if the composite or plastic they are using can be cut via AWJ system.

V. PROGRAMMING

While the AWJ system is one of the most versatile machines in the world, it also needs some more of information to create the parts. Industries use AutoCAD, Flow Cut, Softec, and others for CAD/CAM application and processing of the part geometry for the specific AWJ system. In order for the machine to function, it must also have some sort of direction from the operator. Depending on the company, training is necessary, which incurs a cost but yields better production and quality [7]. If operators either did not know how to use the software or made errors in the process, it would create costly waste. Operators should also understand the process of creating parts out of the least material possible, as parts of the lean manufacturing concept of avoiding scrap material. Companies dedicate considerable effort in this process alone. It reduces the waste both of scrap material and machine processing time, so the time and operator training will justify this effort.

Another reason a company would want to increase their portfolio of programs for an AWJ system would be to have access to MATLAB. This program allows users to apply equations and matrices to create a faster solution to complex problems. The use of MATLAB can be implemented in any of the equations listed above.

MATLAB is another example of implementing a system to better the usage of processing time in the AWJ system. This will also reduce the risk of human error and miscalculations, yielding better quality parts and less scrap.

Programming a water jet seems complex, but normally the programming would relate somewhat to a laser cutter. Since the transverse movement is going to be the same, it is important to know the different applications of this program. In a typical CAD/CAM application, the part geometry can be utilized to plan the cutting paths, parameters, and setup for the AWJ process. These applications will also work with the available work piece sizes to plan nesting and optimal placement of the cutting. This can be shown graphically and through simulation of the process, giving the user a sense of realism with a visual presentation of what is going to be cut away from the part and how to orient the work piece in the machine. Additionally, CAD/CAM systems apply given constraints and limits of the AWJ system, which helps prevent errors and crashes. For example, if a constraint was not relayed to the machine to stop at a certain height, it could easily ruin the head unit of the AWJ system.

During the programming process, it is important to note that while AWJ systems are good for virtually every material, they must be maintained, as the internal parts are vulnerable to wear and contamination. Since the water jet is able to cut through these materials like a hot knife through butter, the internal parts of the AWJ system can also be compromised. As the high-pressure water goes through the nozzle, the water given time is going to widen out the diameter. Therefore, to counteract this, an operator must either replace the nozzle with another new part or attempt to clamp the nozzle back to its original diameter or parameter. As the diameter changes, this will affect the tolerance zone of the part geometry. The required cutting pressure can be affected by a bigger area of the nozzle. An example of this is putting bigger tires on a vehicle and not reprogramming the PCM to accommodate for the increase in size, which would affect the accuracy of the speedometer.

VI. CONCLUSION

The main parameters that control the optimization of an AWJ system are the machining time needed to produce a unit of cut surface, and the nozzle pressure and geometry.

International Journal of Emerging Technology and Advanced Engineering

Website: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 11, Issue 10, October 2021)

Not only the part geometry, but the thickness and type of material are major things to take into consideration in these parameters. The use of AWJ is common on metal materials like titanium, steel, nickel alloys, brass, and aluminum. AWJ can also be used on non-metallic materials such as stone, ceramics, glass, composites, and plastics [8]. With this diverse manufacturing process, it is easy to see how these machines are becoming popular among industries.

During the research of AWJ systems, the efficiency has been off the charts, it all starts with the use of only water and the abrasive material. Typically, this system would prove cost effective and relatively easy to maintain. Common forms of subtractive manufacturing include drilling and contour cutting often using machining or hot working processes, all of which apply heat to the material. With AWJ systems, there is very little heat so parts materials are not subject to war page or other heat-related changes.

Therefore, AWJ systems will have a strong presence in the future of manufacturing due to their versatility and all-around ease of use. Operators are not always going to be challenged by overheated parts and can easily stop the program without the harm of a machining cutter or the blinding effects of a laser beam.

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