Recent Developments in Abrasive Jet Software

John H. Olsen

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Introduction

There are two functions for software in abrasive waterjet machining. First, software is used to transform the design intent into a tool path. This is generally referred to as CAD-CAM software and this field has been improving rapidly with multiple vendors in the market. While important for ease of geometry input, it has little effect on part production cost. The second function for software is to move the cutting jet so as to provide the most accurate part possible in a minimum time. This second function is supplied by the machine builder within the particular control supplied. It has a huge effect on part cost and there are tremendous variations in the sophistication of the controllers available. This article describes the software functions in an advanced controller made specifically for waterjet machining where the functions are broadly covered by patents[1].

An early article in this series, "Software for abrasive waterjet machining" pointed out first that software is critical for managing the jet and second, that improvements in software can be expected to improve machine performance. This article describes some of those improvements and the resulting performance increases. But first, let's review why software is important.

Those new to abrasive waterjet cutting often wonder why controller software is so important in comparison with other machines. The answer is that the abrasive jet is not a rigid tool that must simply be guided along a particular path to make a part. An abrasive laden jet of water as a tool introduces several kinds of errors when it is moved quickly:

1 **Lag**: As the nozzle moves, the bottom of the stream "lags" behind the top. The amount of the lag varies, depending on how quickly the nozzle moves. Lag is important on curves and corners, but not on straight lines.

2 **Striations**: As the nozzle moves faster, the bottom portions of the jet begin to oscillate from side to side producing marks much like flame cutting marks. These affect surface finish.

3 **Taper**: If the nozzle moves quickly, the kerf is widest at the top. As the speed is lowered, taper reduces and eventually reverses with the kerf becoming widest at the bottom.

4 **Width vs. speed**: As the jet slows down, the kerf becomes wider.

5 **Kickback**: The jet shape depends on acceleration as well as speed. A sudden acceleration at an inside corner causes the jet to kick back and gouge deeply into bottom surface at the corner.

See Figure 1 for an illustration of some of these effects. The advanced control software predicts and compensates for the complex behavior of the jet to achieve precision while producing parts quickly. Recent advances in this software with respect to various cutting functions are described here.

Piercing

An abrasive jet can pierce its own start hole for making parts with cut outs. In early machines the jet was simply left in one spot until the material was pierced. This often took a long time especially in thicker materials. In fact, very thick materials often never pierce with this method because the incoming jet is so disturbed by the flow coming out from the blind hole.

A great improvement was achieved with the use of 'Wiggle Piercing" where the jet moved back and forth along the path by about 0.10" until it pierced through. This allowed the reflected jet to escape without interfering with the incoming jet and cut the pierce time. Today, an even faster piercing method is available.

Model testing has shown that there is an optimum pierce length for minimum pierce time and for any chosen pierce length there is an optimum traverse speed at which to pierce. Today's software uses a cutting model to predict the optimal pierce distance and speed for piercing of any given material. It then grows or shrinks the lead in as appropriate to be the optimal distance without interfering with other features in the part. If there is not enough room for the fastest possible pierce, it automatically adjusts the speed of piercing to compensate, and shrinks the lead. All of this is automatic, and without user intervention. The result is a major time saving on each pierce achieved through software alone. See table 1. Imagine a piece with 50 pierces. The time saving of 88 seconds per pierce cuts the part time by 1.2 hours.

Static	95 Sec.
Wiggle	40 Sec
Dynamic	7 Sec

Table 1
Time per Pierce in 1" Steel using 3 Methods

External Corners

Normally, programmers or operators slow for corners to avoid the geometry errors caused by jet lag. But, there is no need to slow down for an external corner if you have room to go past it. This means that most outside corners can be cut at full speed. See figure 2.The jet moves past the corner by at least one jet lag length and then quickly returns to begin the next leg of the corner. Acceleration on the new leg is then limited to avoid kickback damage. The result is that the part is made in 39.4 minutes rather than 57.6 minutes and the precision of the part is increased by avoiding the slight kerf width growth that would normally be caused by slowing down.

Corner passing is set automatically by the latest advanced software, so there is no need to program anything special. The corner passing geometry, as well as jet kickback are optimized for speed and collision avoidance so that the part does not get damaged by the corner pass. See figure 3. The software even decides automatically whether to use corner passing for the following 2 cases:

1. Corner passing is most effective on parts where the cutting quality is low and the thickness is high because this type of part has the most jet lag. For higher cutting qualities or thin parts, corner passing might not offer a speed advantage.
2. Corner passing is not placed in places where either the corner passing itself or the resulting kick-back from the jet will interfere with other features in the path.

It is possible to disable corner passing for the case where the intent is to keep both the "scrap" and the part, such as when doing artistic inlay work.

Internal Corners

Corner passing is not possible in internal corners without damage to the part. What has been done is using completely different corner models depending on whether the jet is entering the corner or leaving the corner. The jet decelerates hard at the last minute coming into the corner and accelerates softly coming out of the corner to avoid kickback damage.

Taper Control

Usually, the jet produces a tapered edge. This can be avoided by two different software strategies. First, by specifying a quality of "Minimum Taper": the software will slow or speed up the cutting as necessary to provide the minimum amount of taper. In most cases, this means that the cutting speed will be reduced significantly. However, in some cases, where "reverse taper" would otherwise occur, the cutting speed will be increased. In either case, the part will be more precise due to the near elimination of taper.

Although quality of Minimum Taper is primarily a precision benefit, there is also a speed benefit in that the programmer no longer has to guess at the feed rate and therefore programming time is reduced, and there is no risk of "guessing" at a speed that is too slow for the desired result. Nevertheless, for some applications, the minimum taper speed is so slow as to be impractical except for especially critical areas on the part.

The second software solution is automatic control of a 5 axis machine (See figure 4) that tilts the jet to remove the taper[2]. The jet moves at the normal speed determined by the surface finish requirement. Then, a predictive model is used to predict the taper in the kerf at each portion of the path. Finally, commands are generated to tilt the head so that the part edge is vertical and that all the taper is placed in the scrap. The result is a square edge. See figure 5.

Purposeful Tilt

With the advent 5 axis motion it has become possible to introduce a small amount of desired taper in the part. Such taper might be used for die relief or draft angle for a casting pattern. In this case, a more complex data structure than for two dimensional cutting is required so that the operator can specify the desired taper at each portion of the path. The software then operates much as it would for a taper free part except that the requested additional taper is added to the head motion. A part with purposeful taper is seen in figure 6.

What is Next

There is still room for further improvement is jet cutting software both for precision and speed. New more accurate cutting models will better anticipate the jet behavior allowing the software to correct more accurately for the five jet behaviors listed above. Management of striation formation will lead to higher cutting speeds with the same surface quality. Tool offset compensation for speed variation will afford even higher precision.

Conclusion

Software is not an accessory for abrasive waterjets, but is an integral part of the machine. Advanced software dramatically improves the performance of the waterjet system by reducing the time to create parts. Shorter part time lowers part cost through lower abrasive consumption, lower maintenance cost and delivery or more parts per day. Software plays a central and critical role in advanced waterjet machinery.

Figure Captions

Figure 1

"Diagram of how the jet lags when cutting at faster feed rates, and its effect on surface finish. These are two of many jet behaviors to be optimally compensated for through software."

Figure 2

"Part Machined from 3.1" Steel. 18.2 Minutes Saved by Using Corner Passing"

Figure 3

"Green lines indicate areas where the software is testing the corner passing to insure that it will not damage other areas of the part"

Figure 4
"Tilting Head for Removal of Taper"

Figure 5
"Comparison of Parts Cut with and without Taper Control"

Figure 6
"Prismatic Part Cut with Purposeful Taper"

Footnotes

1. Patents discussed in this paper are US: 7,074,112 5,892,345 5,508,596 held by the OMAX Corporation
2. Such automatic control was first demonstrated by Axel Henning of the Fraunhofer Institute in Germany.