Hypertherm®

Thick metal cutting techniques

For HPR400XD™ and HPR800XD plasma cutting systems

White paper

Introduction

Using plasma to successfully cut thick metal requires more skill and technique than using plasma on thinner metal. The thick metal cutting techniques described in this document may be needed from the beginning of the cut with an edge start all the way to finishing the cut with a completely severed part.

> **Note:** Unless otherwise specified, for the purposes of this document, *thick metal* consists of stainless steel and aluminum from 5 inches to 6.25 inches (125 mm to 160 mm) thick. The techniques detailed in this document were developed using 304L stainless steel. Materials used for the development of this white paper were based on U.S. customary units (inches). Metric conversions are provided for reference.

This document describes thick metal cutting techniques developed for the HPR800XD that can help manage the large plasma lag angles associated with thick metal cutting. It also describes the timing and sequencing needed to be successful in piercing up to 4 inches (100 mm) stainless steel and 3 inches (75 mm) aluminum. This document is broken into four sections:

- *Thick metal cutting techniques overview* on page 2 is an overview of different lag angle management techniques for thick metal cutting that covers a plasma cut from the beginning to completion.

- *Dogleg lead-out details for thick stainless steel* on page 4 covers the details of a special lead-out technique (known as the dogleg or acute angle lead-out) that can allow you to completely sever a stainless steel part up to 6.25 inches (160 mm) thick.

- *Stationary piercing (up to 3-inch stainless steel and aluminum)* on page 8 describes the timing and sequence to be followed to perform stationary piercing on 3 inch (75 mm) stainless steel and aluminum.

- *Moving pierce technique (up to 4-inch stainless steel)* on page 10 describes a moving pierce technique for thick stainless steel that can be used with both the HPR800XD and the HPR400XD. This technique, combined with PowerPierce® technology, extends the pierce capacity for the HPR800XD to 4 inches (100 mm) and for the HPR400XD to 3 inches (75 mm).

Edge start

Positioning

Proper positioning of the torch is important to allow the molten metal (or melt) to carry down the majority of the thickness (especially when starting on a rough edge). Set the height of the torch to the cut height listed in the cut chart, which you can find in the *Operation* section of the *HPR800XD Instruction Manual* (806500 [Auto Gas] or 806490 [Manual Gas]). Place the torch center-line about 0.25 inches (6 mm) from the workpiece edge. The edge of workpiece should be approximately lined up with the shield face diameter, as shown in Figure 1.

Figure 1 – Edge start positioning

Approximately 0.25 inches (6 mm)
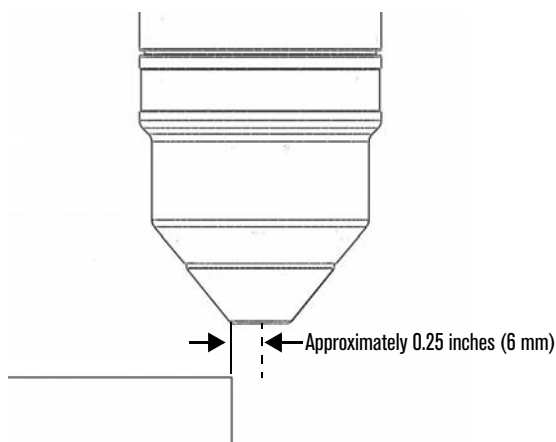
Motion (or pierce) delay

An adequate motion delay must be used to allow enough time for the arc to melt the majority of the edge prior to motion being initiated. Suggested motion delays for 800 A thick metal cutting are listed in the cut charts in the *HPR800XD Instruction Manual*. These times may need to be adjusted based on your application.

Initial cut speed (lead-in speed)

A reduced cut speed should be used for at least the first 1 inch (25 mm) of the cut before traveling at the full cut speed. The recommended initial cut speed should be 75% of the full cut speed.

Cornering

Special cornering considerations may be necessary when working with thick metal due to the extreme lag of the tail (bottom portion) of the arc. If no technique is used, the cut edge may lose its form, especially near the bottom of the cut. Use one of the following methods:

- Rounding corners
- Corner delay
- Corner slow-down

Rounding corners

One method to maintain edge form is to round off corners of 90 degrees or less. In general, the radius should be equal to or greater than the kerf value (larger is better).

Corner delay

Allow the motion to dwell in the corner for approximately one second to allow the arc tail to "catch up."

Corner slow-down

Approximately 1 inch (25 mm) before entering the corner, slow down the cut speed to 75% of the full cut speed. Maintain 75% of the cut speed for approximately 1 inch (25 mm) after the corner before resuming the full cut speed.

Completing the cut

One of the following techniques may be necessary on metal 5 inches (125 mm) thick or greater to fully complete the cut. Otherwise, the arc may jump the very bottom portion of the cut as it exits the edge of the metal or enters the kerf, resulting in an incomplete sever of the cut piece.

Exiting the edge of material (lead-out speed)

For cuts that involve the arc exiting the edge of the material (as shown in Figure 2), a reduced cut speed should be used for the last 1 inch (25 mm) of the cut. The recommended final cut speed should be 75% of the full cut speed. **The cutting table must continue motion beyond the edge of the plate.**

Figure 2 – Lead-out exiting the edge of the material

External contour part cut (dogleg or acute angle lead-out)

The dogleg (or acute angle) lead-out technique can be used to redirect the tail of the arc and the molten metal flow into the remaining portion of the cut (or "tab"), thereby allowing for a complete cut (see Figure 3 and Figure 4).

1 Follow the edge start, lead-in, and cornering recommendations previously listed.

2 Cut the external contour of the part and approach lead-out.

3 Just as the arc breaks through to kerf, change the cut direction by approximately 120 degrees into the skeleton at 115% of the cut speed.

4 Continue the lead-out segment for approximately 1.25 inches (32 mm) – the molten metal flow from cutting into the skeleton melts the tab, which completes the cut and allows the part to "drop."

Dogleg lead-out details are included in the *Dogleg lead-out details for thick stainless steel* section in this document.

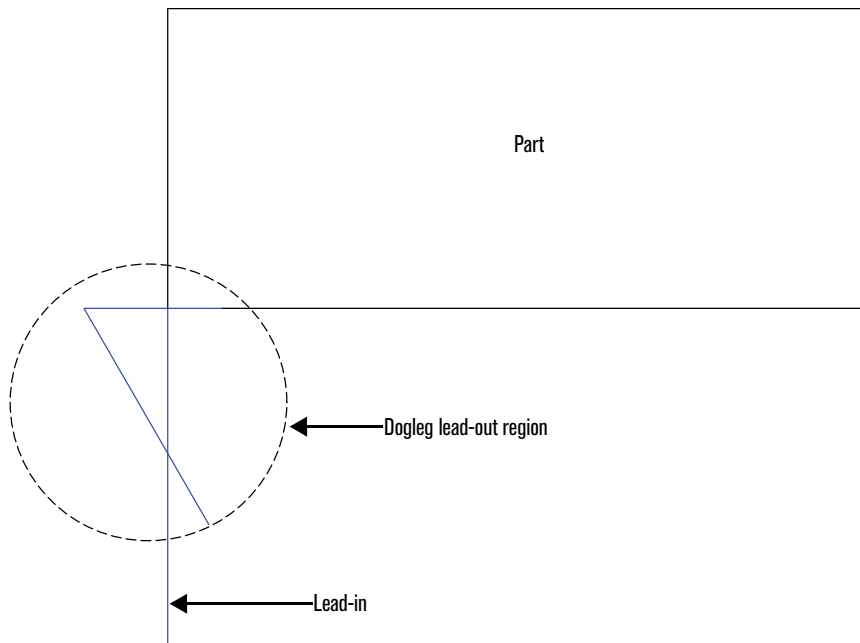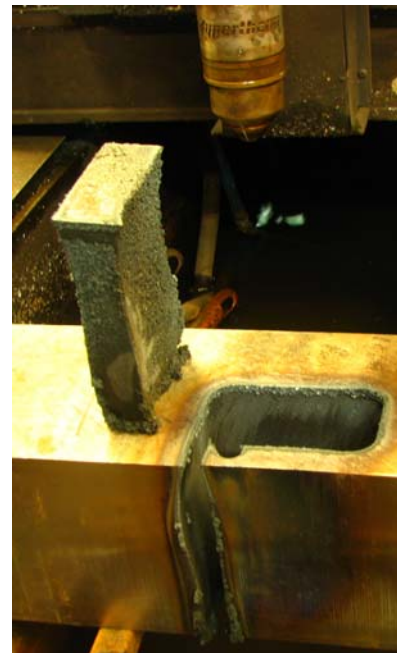**Figure 3** – Example of dogleg lead-out programmed cut path

Figure 4 – 6 inch (150 mm) "dropped" external contour cut

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Proper lead-out for thick material is critical to completely sever a part; otherwise, a small tab may keep the part attached to the skeleton at the point where the lead-out enters the lead-in (as shown in Figure 5).

Figure 5 – Example of a "tab" in a thick stainless steel contour cut

Location of tab
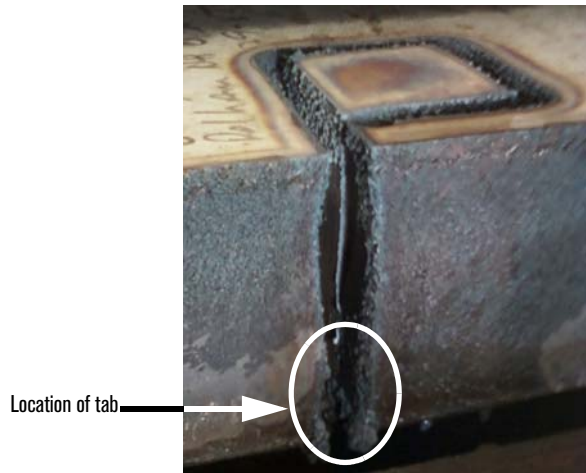
This tab is due to the extreme lagging tail of the arc, the lack of molten material flowing through the kerf, and the insufficient voltage to maintain the arc attachment at this distance from the torch. Crossing the kerf for the thickest materials may not be possible for the same voltage limitation reason, and even if the arc does transfer to the opposite side of the kerf, the arc tail is likely to jump over the tab.

The dogleg method for stainless steel takes advantage of this lagging arc by focusing it onto the tab section of the cut. At the point where the leading kerf edge breaks into the lead-in edge (and before the voltage reaches the critical value of the transformer), the cut path changes direction into an acute angle (60 degrees works well) toward the skeleton (see Figure 6). This allows the arc to transfer to the skeleton material, which reduces the voltage while driving the molten material down towards the tab and subsequently melting it off.

Overshoot

In order for the leading kerf edge to enter the lead-in edge (with kerf compensation active), the programmed path must overshoot by some distance (see Figure 6).

Figure 6 – Overshoot definition
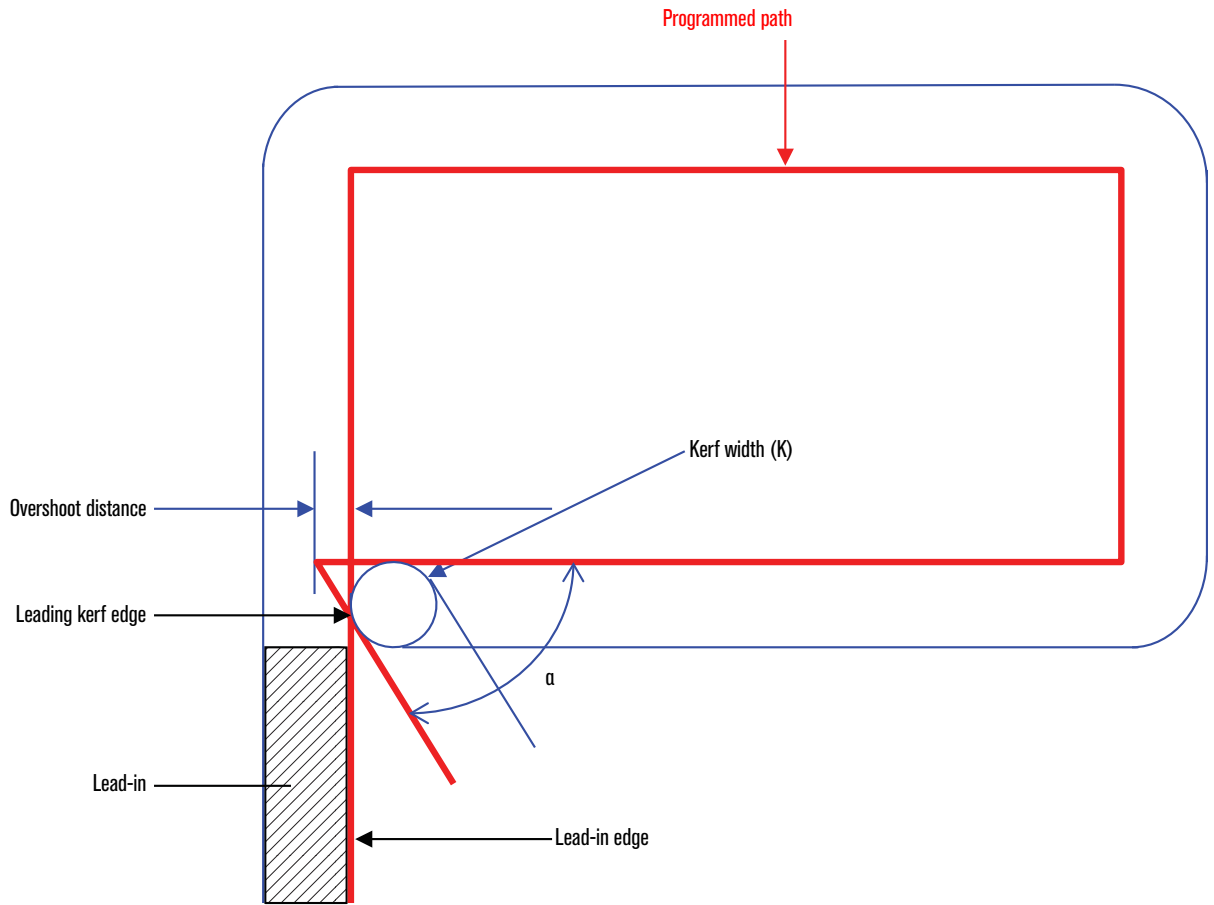
This overshoot distance can be calculated using the following equation:

$$Overshoot = K\left(\frac{1}{2\tan\left(\frac{\alpha}{2}\right)} - \frac{1}{2} + Correction\right)$$

where K is kerf, α is angle, and *Correction* is an additional factor necessary to ensure adequate penetration of the arc into the lead-in section. The *Correction* factor values for 5–6.25 inches (125–160 mm) are shown in *Table 1*.

Table 1 – Correction factors.

Thickness	Kerf	*Correction Factor*
5 inches (125 mm)	0.530 inches (13.43 mm)	0.30
6 inches (150 mm)	0.680 inches (17.27 mm)	0.25
6.25 inches (160 mm)	0.700 inches (17.78 mm)	0.25

As an example, if α = 60° for a thickness of 6 inches, the overshoot value is:

$K(0.866-0.5+0.25) = 0.68(0.616) = 0.419$ *inches*

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First segment and geometry limitation

A geometric limitation was found during the development of the dogleg method that resulted in a "Kerf Too Large" CNC error message. This limitation had to do with the length of the first segment approaching the 60-degree corner of the dogleg (refer to the first segment, highlighted in green, in *Figure 7* on page 7). Essentially the first segment length has to be long enough that, at a minimum, the kerf right-hand side enters this segment. For the 6 inch (150 mm) thickness the minimum length is 0.589 inches (14.96 mm) or

$$First\ Segment = \frac{K}{2\tan\left(\frac{\alpha}{2}\right)}$$

where K is kerf and α is angle.

Assuming 60 degrees, the minimum length of the first segment would have to be:

- 0.459 inches (11.66 mm) for 5 inches (125 mm) stainless steel, based on 0.530 inches (13.46 mm) kerf
- 0.607 inches (15.42 mm) for 6.25 inches (160 mm) stainless steel, based on 0.700 inches (17.78 mm) kerf

It is recommended that a value larger than the minimum length be used to allow minor adjustments to the kerf value (for part dimension adjustment) without causing a geometric "Kerf Too Large" error.

Second and third segments

It was found that an increased speed during the second segment was useful to minimize the time it takes for the arc to reattach to the opposite side of the kerf, which minimizes any voltage spikes. Therefore, for the second segment the feed rate should be increased to 400% of the cut speed, after which, during the third segment, it should be slowed down to 115% of the cut speed. This last section of the move (or third segment) is where the tab will finally be melted. *Table 2*, together with Figure 7, summarizes the parameters for stainless steel thicknesses of 5 inches (125 mm), 6 inches (150 mm), and 6.25 inches (160 mm).

Table 2 – Dogleg parameters for 5 inch (125 mm), 6 inch (150 mm), and 6.25 inch (160 mm) stainless steel

Thickness	Lead-in length	Kerf	Angle	Calculated first segment minimum length at cut speed	Overshoot length	Second segment length at 400% cut speed	Third segment length at 115% cut speed
5 in (125 mm)	1.5 in (38 mm)	0.530 in (13.46 mm)	60°	≥0.459 in (≥11.66 mm)	0.353 in (8.97 mm)	0.720 in (18.29 mm)	0.307 in (7.80 mm)
6 in (150 mm)	1.75 in (45 mm)	0.680 in (17.27 mm)	60°	≥0.589 in (≥14.96 mm)	0.419 in (10.64 mm)	0.888 in (22.56 mm)	0.362 in (9.19 mm)
6.25 in (160 mm)	1.75 in (45 mm)	0.700 in (17.78 mm)	60°	≥0.607 in (≥15.42 mm)	0.431 in (10.95 mm)	0.911 in (23.14 mm)	0.334 in (8.48 mm)

Figure 7 – Dogleg (acute angle) lead-out geometry
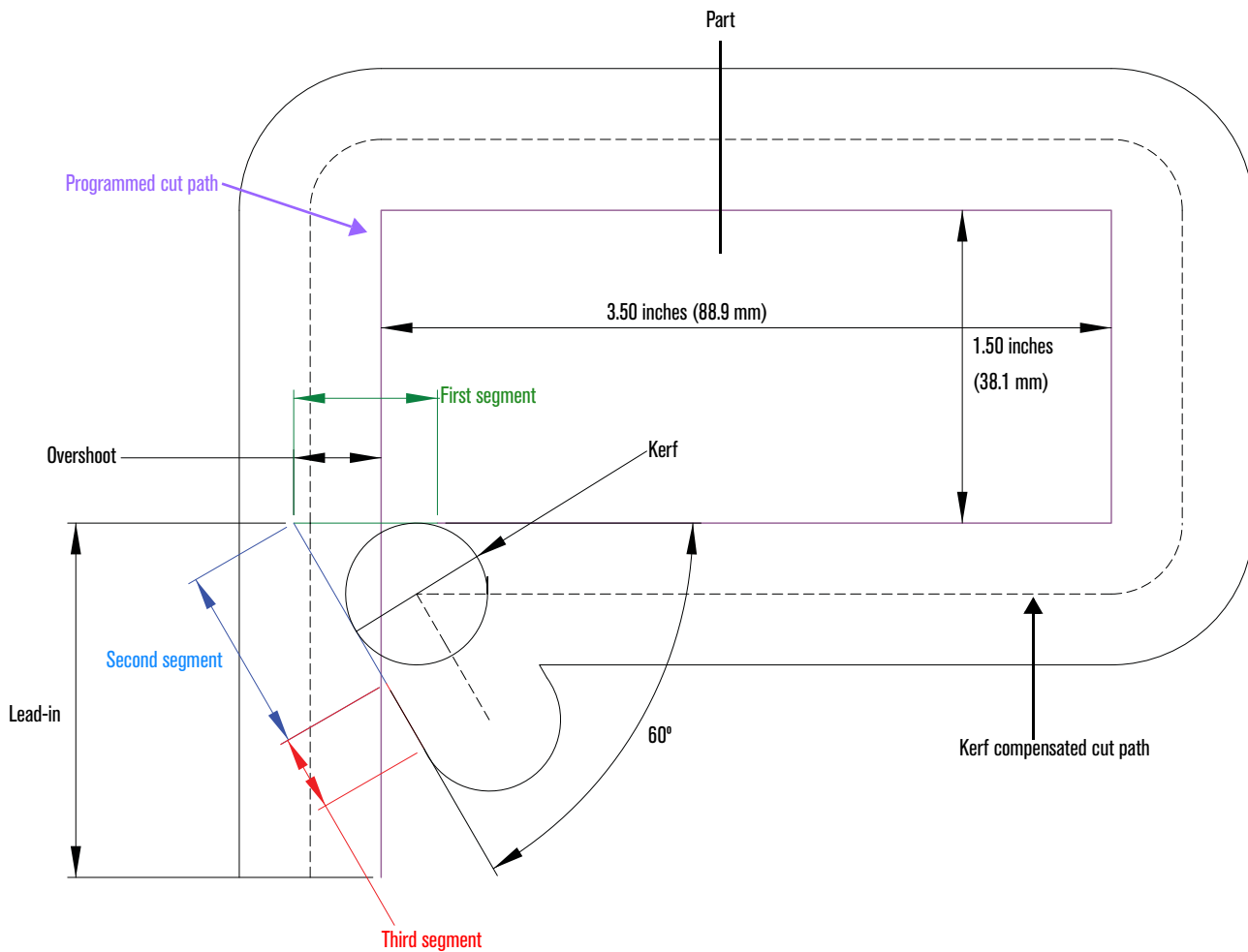
Stationary piercing (up to 3-inch stainless steel and aluminum)

Piercing thicknesses over 2 inches (50 mm) has been challenging in the past. As a result of the PowerPierce technology incorporated into the HPR800XD, piercing up to 3 inches (75 mm) is easily achievable with stainless steel and aluminum. **The torch lifter must have the capability of using transfer height, pierce height, and cut height settings**.

Pierce control (or pierce complete) signal

High amounts of shield flow during the piercing operation can be helpful in:

- Clearing the molten pool of metal away from the pierce hole
- Deflecting slag away from the torch
- Cooling the shield

Normal gas operation for HPRXD power supplies switches both the plasma and the shield gases from preflow to cutflow as soon as arc transfer is sensed. HPRXD power supplies incorporate a "pierce control" signal that, when turned on, delays the switching of the shield flow from preflow to cutflow until after the pierce delay has expired.

For any HPRXD process with the shield preflow setting *higher* than the shield cutflow setting, the pierce control signal must be turned ON. Conversely, for any HPRXD process with the shield preflow setting *lower* than the shield cutflow setting, the pierce control signal must be turned OFF. **For the 600 A and 800 A processes, the pierce control signal must be turned OFF.** For HPRXD processes where the shield preflow setting is equal to the shield cutflow setting, it does not matter whether the pierce control signal is turned on or off.

Initial height sense

Position the torch over the pierce location and command the torch lifter to perform the initial height routine. Refer to the timing diagram (*Figure 8* on page 9).

Move to transfer height

Position the torch to the transfer height as listed in the cut chart (by process and metal thickness).

> **Note:** You can find the cut charts in the *Operation* section of the *HPR800XD Instruction Manual*.

Initiate arc transfer

Initiate the arc firing sequence. The arc will extend from the torch and transfer to the surface of the plate.

Pull torch back from plate to pierce height

Immediately after arc transfer, move the torch to the pierce height as listed in cut chart.

Allow arc to penetrate material

Remain stationary for the duration of the pierce delay as listed in the cut chart. The arc should be fully through the plate prior to initiating motion. Some adjustment may be necessary to the pierce delay based on the material type and the condition of the consumables in the torch.

Initiate motion into part lead-in

Maintain the torch at the pierce height and begin motion into the part lead-in. Drop the torch to the cut height before the end of the lead-in section. Lead-in lengths may vary, but as a general rule lead-in length should be equal to the material thickness to ensure the pierce puddle has been cleared prior to initiating the cut.

Cut the part

Finally, complete the contour cut of the part.

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Figure 8 – Stationary pierce timing diagram

Torch height

Time →
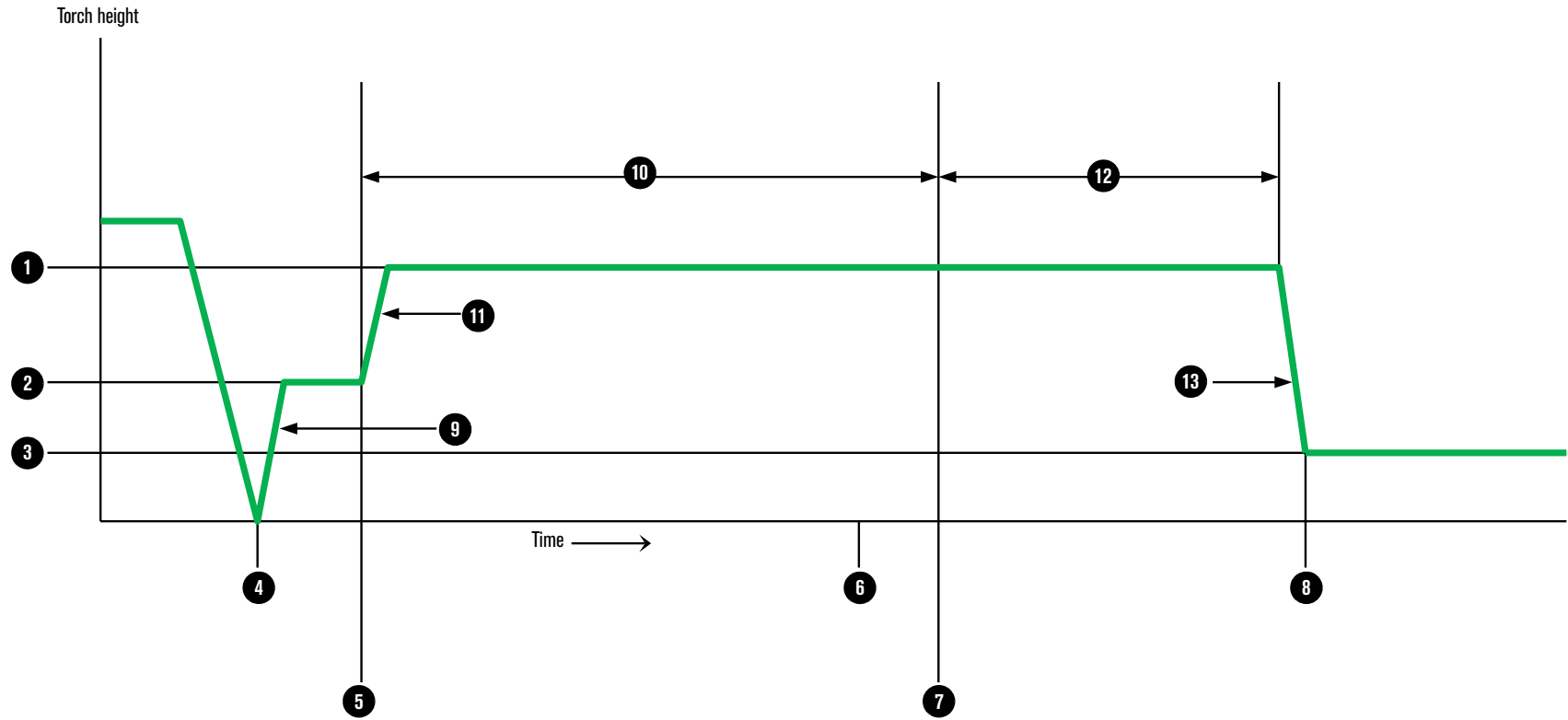
1 Pierce height	**6** Arc penetrates plate	**11** Move to pierce height
2 Transfer height	**7** Motion begins	**12** Lead-in
3 Cut height	**8** Torch drops to cut height prior to beginning contour cut	**13** Move to cut height
4 Initial height sense	**9** Move to transfer height	
5 Arc transfer, shield flow switches from preflow to cutflow	**10** Pierce delay	

Moving pierce technique (up to 4-inch stainless steel)

Pierce capacity can be extended by utilizing a technique known as "moving pierce." This technique combined with PowerPierce® technology has extended the stainless steel pierce capacity for the HPR800XD to 4 inches (100 mm) and for the HPR400XD to 3 inches (75 mm).

The torch lifter must have the capability to use transfer height, pierce height, and cut height settings along with cut height and automatic voltage control (AVC) delays. The cutting table and controller must be able to allow motion upon transfer. Hypertherm's EDGE® Pro controller (running Phoenix™ 9.72 or later), Sensor™ THC or ArcGlide® lifter, and ProNest® nesting software all support this technique with the provided parameters.

Basic description

Moving pierce (also known as a running pierce or flying pierce) is a technique that has been used by plasma operators for years in order to have their plasma systems penetrate thick plates without having to resort to other operations such as drilling.

The method of moving pierce described here utilizes a synchronization of torch lifter positioning, table motion, and plasma current ramping to achieve a relatively short pierce lead-in that directs the molten material to the side and away from the torch. At the same time, it keeps the torch as far away from the molten material as possible while also maintaining an arc voltage that the HPRXD power supply can sustain.

The basic process consists of combining motion during piercing to create a trough in the plate that can then be used as an evacuation channel for the molten material to be directed out of the deepening pierce "slot." The molten material is directed to the side of the torch in the opposite direction of the table motion, with the majority being deposited onto the top of the plate surface. Once the arc penetrates the plate the standard settings for cutting can be used.

Limitations and equipment and safety hazards

Using this technique results in a "rooster tail" of molten material and hot gases that can cause personal injury, damage to equipment, and fires if proper precautions are not taken. Guards may be required to protect operators and to prevent the molten material from reaching any flammable materials (flammable materials should be kept away from

plasma cutting operations). Moving pierce direction should be planned such that the molten material is not directed at the lifter, gantry, adjacent torches, controller, or other sensitive equipment.

> **Note:** The moving pierce parameters in this document were developed using linear motion only.

Molten material accumulated on the plate can impact subsequent cutting paths, so you may be required to either carefully plan cutting paths that avoid the slag pile or to stop the cutting process (after the arc has penetrated the plate) to scrape the slag pile from the plate.

Lifter and table motion sequencing

During the moving pierce, both the torch height and the table motion are simultaneously controlled to optimize the thick plate piercing capability. The details for a typical pierce are listed in the following *Lifter sequence* and *Table motion sequence* sections.

Lifter sequence

Refer to Figure 9 for an illustration of the following sequence.

1 An initial height sense (IHS) is performed, and the torch is positioned at the **transfer height**.

2 The torch is started and transfers to the workpiece; current ramp-up begins.

3 After transfer, the torch quickly moves to the **pierce height**, and the table motion begins at the first speed programmed using an embedded "F" code. (See *Table motion sequence* on page 12.)

4 The torch is maintained at the **pierce height** until the **moving delay** has expired (percentage of the total pierce delay).

5 When the **moving delay** has expired, the torch will move to the **pierce end height**. This move is timed to arrive at the end height when the **pierce delay** has expired.

6 The torch will remain at the **pierce end height** for the duration of the **cut height delay**. When the **cut height delay** expires, the torch will move to the **cut height** and will remain at this height until the **moving pierce (MP) AVC delay** expires.

7 When the **MP AVC** delay expires, the arc voltage control will begin.

8 The contour cut of the part is completed.

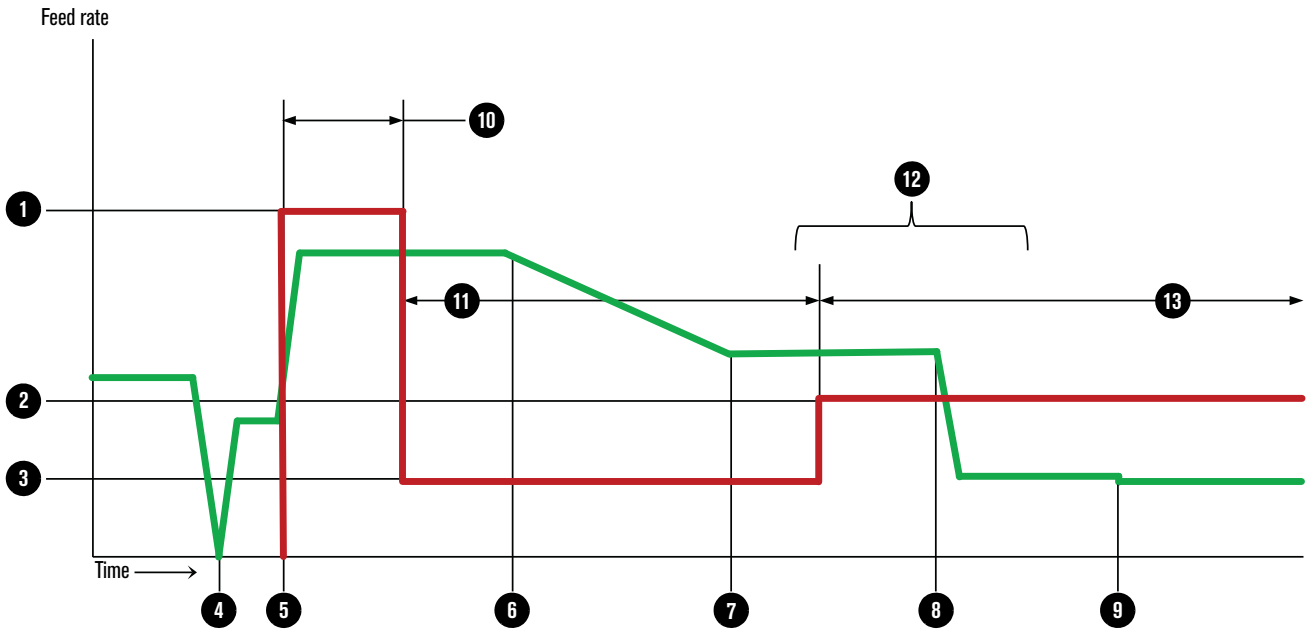**Figure 9** – Moving pierce torch height timing diagram
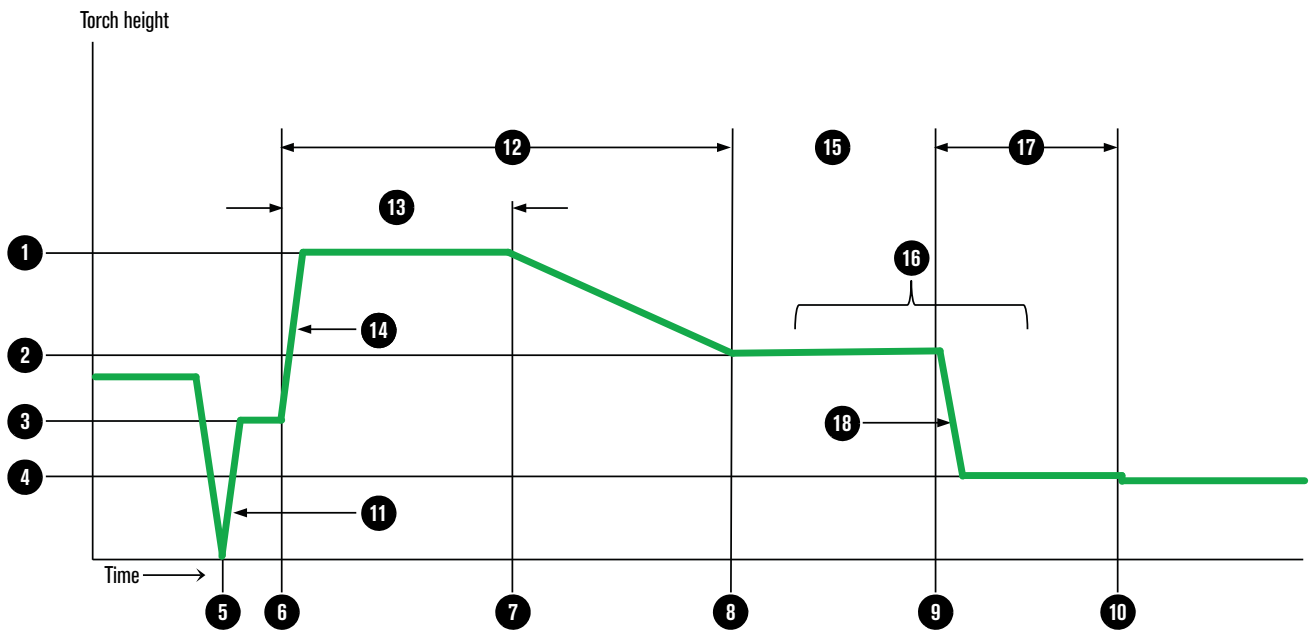
1	Pierce height	**10**	AVC begins as MP AVC delay expires prior to starting cut
2	Pierce end height	**11**	Move to transfer height
3	Transfer height	**12**	Pierce delay
4	Cut height	**13**	Moving delay
5	Initial height sense	**14**	Move to pierce height
6	Arc transfer, motion begins, shield flow switches from preflow to cutflow (if preflow is lower than cutflow)	**15**	Cut height delay
		16	Arc penetrates plate in this region
7	Torch begins to lower toward pierce end height	**17**	MP AVC delay
8	Torch reaches pierce end height as pierce delay expires	**18**	Move to cut height
9	Torch lowers to cut height as cut height delay expires		

Table motion sequence

Refer to Figure 10 for an illustration of the following sequence.

1 After transfer, the table motion begins for the first segment at a fast gouge speed (the first "F" code) for the required segment length necessary to establish the evacuation channel (or trough).

2 The second segment table motion begins at an intermediate speed (second "F" code) for the required segment length necessary to penetrate the plate.

3 The third segment of table motion begins at the programmed **cut speed**. The remainder of the cut is completed at this speed (third "F" code).

4 Finally, the contour cut of the part is completed.

Figure 10 – Moving pierce table motion timing diagram

1	Gouge speed	7	Torch reaches pierce end height as pierce delay expires
2	Cut speed	8	Torch lowers to cut height as cut height delay expires
3	Creep or intermediate speed	9	AVC begins as MP AVC delay expires prior to starting cut
4	Initial height sense	10	Establishes evacuation trough
5	Arc transfer, motion begins, shield flow switches from preflow to cutflow (if preflow is lower than cutflow)	11	Penetration of plate advances while molten material is evacuated via trough
6	Torch begins to lower toward pierce end height	12	Arc penetrates plate in this region
		13	Transition to cut speed as arc penetrates plate

Embedded part program parameters

If you are using the EDGE Pro controller, use the following list of parameters to control the moving pierce (MP) sequence.

Table 3 – Moving pierce (MP) embedded part program parameters

Parameter name	Embedded program code	Description
MP feed #1 - fast gouge	F45 G01 X0 Y1	Speed = 45 ipm (1143 mm/m) Move 1 inch (25 mm) Y axis
MP feed #2 - intermediate	F20 G01 X0 Y0.5	Speed = 20 ipm (508 mm/m) Move 0.5 inch (13 mm) Y axis
MP feed #3 - cut speed	F10 G01 X0 Y2.5	Speed = 10 ipm (254 mm/m) Move 2.5 inch (65 mm) Y axis
Transfer height factor	G59 V604 F300	Transfer height = 300% of cut height
Pierce delay	G59 V601 F8.0	Total pierce delay = 8.0 seconds
Moving delay (lifter)	G59 V610 F50	Percent moving delay = 50% of pierce delay
Pierce height factor	G59 V602 F500	Pierce height = 500% of cut height
Pierce end height factor	G59 V611 F250	Pierce end height = 250% of cut height
Cut height delay	G59 V605 F3.0	Cut height delay = 3.0 seconds
Cut height	G59 V603 F0.25	Cut height = 0.25 inches (6 mm)
MP AVC delay	M51T15	MP AVC delay = 4 seconds (the M51T value is the sum of MP AVC delay, cut height delay, and pierce delay)

Thick stainless steel moving pierce parameters

The following tables contain the moving pierce parameters (both English and metric) that have been developed for piercing up to 4 inches (100 mm) of stainless steel.

Table 4 – Thick stainless steel moving pierce (MP) parameters – English

Process	Thickness (inch)	Speed 1 (ipm)	Speed 2 (ipm)	Speed 3 (ipm)	Segment 1 (inch)	Segment 2 (inch)	Segment 3 (inch)	Transfer Height Factor (% Cut Height)	Pierce Delay (Seconds)	Percent Moving Delay (% Pierce Delay)	Pierce Height Factor (% Cut Height)	Pierce End Height Factor (% Cut Height)	Cut Height Delay (Seconds)	Cut Height (inch)	MP AVC Delay (Seconds)
800 A H35/N₂	4	40	6	11	2	1	1.5	150	6	50	475	275	8	0.5	2
400 A H35-N₂/N₂	3	45	20	10	0.998	0.417	2.5	300	8	50	500	250	3	0.25	4
400 A H35-N₂/N₂	2	45	15	20	0.75	0.417	1.5	300	4.8	50	500	250	0.5	0.25	5.7

Table 5 – Thick stainless steel moving pierce (MP) parameters – metric

Process	Thickness (mm)	Speed 1 (mm/m)	Speed 2 (mm/m)	Speed 3 (mm/m)	Segment 1 (mm)	Segment 2 (mm)	Segment 3 (mm)	Transfer Height Factor (% Cut Height)	Pierce Delay (Seconds)	Percent Moving Delay (% Pierce Delay)	Pierce Height Factor (% Cut Height)	Pierce End Height Factor (% Cut Height)	Cut Height Delay (Seconds)	Cut Height (mm)	MP AVC Delay (Seconds)
800 A H35/N₂	100	1016	152	279	50.8	25.4	38.1	150	6	50	475	275	8	12.7	2
400 A H35-N₂/N₂	75	1143	508	254	25.3	10.6	63.5	300	8	50	500	250	3	6.4	4
400 A H35-N₂/N₂	50	1143	381	508	19.1	10.6	38.1	300	4.8	50	500	250	0.5	6.4	5.7

Sample EDGE Pro code for 400 A – 3-inch (75-mm) stainless steel

The following sample code from a Hypertherm EDGE Pro CNC assumes the use of U.S. customary units (inches) and is intended to provide an example of the codes that may be used to perform a moving pierce on a 3-inch (75-mm) stainless steel plate at 400 A.

Code	Description
G99 X1 Y180 I0 J0	
G20	(select English units [inches])
G91	(incremental programming mode)
G43X0.265	(kerf value = 0.265 inches)
G41	(enable left kerf compensation)
G59 V502 F35	(plasma torch/consumable type)
G59 V503 F2	(material type)
G59 V504 F400	(current setting)
G59 V505 F23	(plasma/shield gas type)
G59 V507 F58	(material thickness)
G59 V600 F202	(arc voltage)
G59 V601 F8	(pierce delay)
G59 V602 F500	(pierce height factor)
G59 V603 F0.25	(cut height)
G59 V604 F300	(transfer height factor)
G59 V605 F3	(cut height delay)
G59 V610 F50	(moving delay = 50%)
G59 V611 F250	(pierce end height = 250%)
M07	(plasma start)
M51T15	(MP AVC delay = 4) (Add pierce delay, cut height delay, and AVC delay)
F45	(gouge speed)
G01 X0 Y.9975	(linear motion)
F20	(creep speed)
G01 X0 Y.4166	(linear motion)
F10	(cut speed)
G01 X0 Y2.5	(linear motion)
M08	(plasma stop)
G40	(disable kerf compensation)
M02	(end of program)

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