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Inside...

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SELECTION



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SMALL HOLES

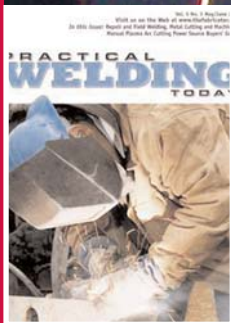
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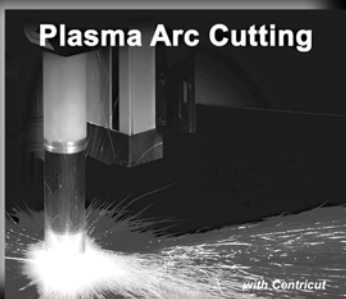
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CLASSROOM

Written By: Kirk Ferland
Centricut Technical Services Director

Troubleshooting PAC Systems: How to Nullify Noise

Symptom: The cutting machine behaves erratically during piloting of the plasma torch: the CNC may "lock up," or the torch carriage or beam may lose position and "run away." The machine motion is normal in a dry run or manual operation.

Background: The high voltage spark required to create a pilot arc in plasma systems (3,000-10,000 VAC) creates radio frequency (RF) electrical noise. This noise can interfere with operation of nearby electrical equipment.

WARNING! Read all safety information in your operations manual before operating or repairing PAC equipment. PAC systems use high voltage and direct current (DC) electricity. Electric shock can injure or kill.

Earth ground vs. noise ground: Although used interchangeably, these terms represent two different grounding schemes. The earth (or power) ground uses the earth as the conductive current return path to the lowest potential point of a power generation system. A true earth ground, as defined by the National Electric Code, consists of a conductive (usually copper) rod or pipe driven into the earth to a minimum depth of eight feet. The rod should be at least $\frac{7}{8}$ in. diameter to ensure a proper ground.

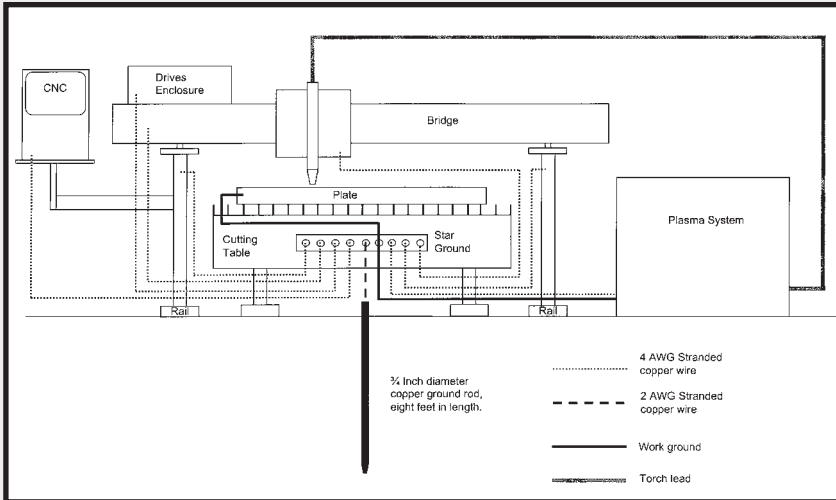
While the earth ground conducts electricity, the noise ground diverts RF electrical "noise" to the earth. RF noise emanates radially from the

pilot arc cable inside the lead set. If not shielded and grounded properly, any component on the cutting machine can act as an antenna—picking up RF from the plasma leads and transmitting it to electronic equipment. Encoder wires, motor wires, THC cables and CNC cables are particularly susceptible. If these cables and devices pick up noise they may malfunction, causing erratic machine performance.

The work cable is neither an earth ground nor a noise ground, although it is connected to the same terminal strip as the earth and noise grounds (see Fig. 1). The work cable is the positive (+) lead from the PAC power supply to the workpiece. This cable completes the circuit from the torch back to the power supply, allowing main DC current flow during a cut. (PAC is a DC electrode negative (DCEN) process with the electrode inside the torch negative (-) and the workpiece positive (+).

Earth grounding recommendations: Install only one ground rod, but make it as deep as necessary to obtain the proper resistance reading for your particular area. Ground rods of over 200 in. are not uncommon in dry, rocky ground. The more ground rods driven, the more capacitance is added to the system. This could cause a "flashback" of power to the cutting machine in the event of a catastrophic electrical failure.

Make all of the machine connections in parallel, not in series. If the earth grounds are in series, the noise from each conductor will be transmit-



ted to the next connection point and then dissipated into that device. Note that in the Star Ground setup, all connections are in parallel, which also reduces the chances of encountering ground loops.

Be sure to test each rod and record initial readings. Ground rods should be tested periodically to make sure that they are still able to function properly. If it is discovered that the conductive properties of the ground rod have decreased over time, a material called bentonite (available from any well drilling company) can be mixed with water and poured down the hole of the ground. This will reestablish the connection between the rod and earth. **DO NOT USE SALT**, as it can corrode any ground rod material and cause a complete grounding failure.

If correct readings cannot be obtained by a single ground rod, move at least 25 in. from the original ground rod and drive another. Link these two rods with 4/0 cable. Again, test each rod and record its progress. However, there should never be more than two ground rods for any PAC system.

Noise grounding recommendations: Connect a wire from the Remote High Frequency (RHF) enclosure to either the Star Ground bus strip or to the ground rod directly. Wire gauge should be 4-10 AWG stranded copper wire.

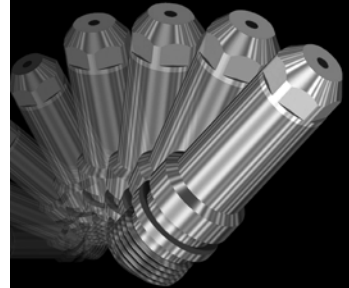
Run a separate wire from the machine beam, each rail, and torch carriage to either the Star Ground bus strip or ground rod. Again, use 4-10 AWG stranded copper wire.

Use braided metal shielding to cover the torch leads. The shielding should go from the back of the torch mounting tube to the power supply cabinet, which is grounded. This shielding is very important for noise control!

When noise problems occur, first verify the earth ground is good and check all noise ground connections for looseness or corrosion. PAC systems use water tables in their process, and often the terminal strip for a Star Ground setup is in an area that is exposed to moisture and heat. Corrosion on these terminals may prevent good conductivity. One loose connection may cause the cutting machine to act possessed.

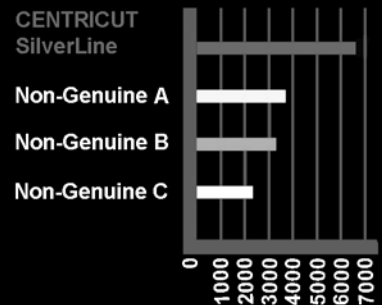
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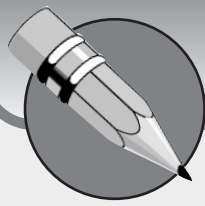
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CLASSROOM

Written By: David J. Cook
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Guide to Plasma Gas Selection

How to Choose the Best Gases for your Multi-Gas Plasma Torch

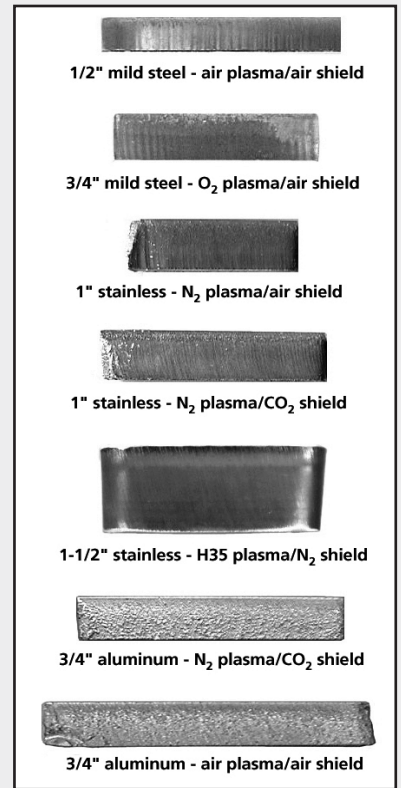
Many fabricators choose plasma systems with 'dual-gas' or 'multi-gas' capability. This means that a variety of plasma and shield gases can be used for various applications. Multi-gas torches offer the most flexibility for shops that cut a variety of materials. Different gases are used, depending on material type and thickness, in order to achieve the best balance of cut quality, part life, productivity, and overall cost of operation.

Some plasma system manuals overwhelm the operator with a confusing array of cut charts and gas choices. Often, when you ask an operator why a particular gas is used for a cutting task, a typical answer is: "My gas supplier told me to use this gas."

The intent of this article is to provide a brief overview of the advantages and disadvantages of each gas and make "best case" recommendations for cutting the three most common materials: mild steel, stainless steel, and aluminum.

Plasma Gases

The most commonly used plasma gases today are air, oxygen, nitrogen, and argon-hydrogen. Air is the most versatile plasma gas. It produces good cut quality and speed on mild steel, stainless, and aluminum. Air also lowers the cost of operation because it is not necessary to purchase gases. However, air is not free. Shop air must be cleaned to remove contamination such as particulates, oil mist, and moisture. The best solution for air plasma systems is a good-sized, dedicated air compressor, a refriger-



ated dryer, and a bank of filters to take out all contaminants. Another concern with air plasma is weldability of the cut edge. Some nitriding and oxidation of the cut surface occurs with air plasma, which can cause porosity in welds. The problem is usually easily corrected by using good quality weld wire with denitriders and deoxidizers. For versatility, good speed, low dross levels, and parts life up to 600 starts, air is a good option for many shops. Air shield gas is the best choice when using air plasma.

Oxygen has become the industry standard for cutting carbon steel

Plasma Gas / Shield	Mild Steel	Stainless	Aluminum
Air / Air	Good cut quality/speed Economical	Good cut quality/speed Economical	Good cut quality/speed Economical
Oxygen (O ₂) / Air	Excellent cut quality/speed Very little dross	Not recommended	Not recommended
Nitrogen (N ₂) / CO ₂	Fair cut quality, some dross Excellent parts life	Good cut quality Excellent parts life	Excellent cut quality Excellent parts life
Nitrogen (N ₂) / Air	Fair cut quality, some dross Excellent parts life	Good cut quality Excellent parts life	Excellent cut quality Excellent parts life
Nitrogen (N ₂) / H ₂ O	Fair cut quality, some dross Excellent parts life	Excellent cut quality Excellent parts life	Excellent cut quality Excellent parts life
Argon Hydrogen / N ₂	Not recommended	Excellent on thick >½inch	Excellent on thick >½inch

because it provides the best cut quality and fastest cutting speed of any plasma gas. Cutting stainless or aluminum with oxygen plasma gas is not recommended. Oxygen plasma gas reacts with carbon steel to produce a finer spray of molten metal, each droplet having a lower surface tension. This molten spray is more easily ejected from the kerf. The disadvantage of oxygen is the cost of the gas and the consumable parts life. However state-of-the-art oxygen plasma systems use inert starting gases (such as nitrogen) with oxygen plasma to achieve similar parts life to nitrogen or air systems. These systems may have parts life in the 800-1500-start range. Increased consumable and gas costs are usually offset by a decrease in expensive secondary operations to remove dross and straighten beveled parts. Air shield is typically used with oxygen plasma.

Nitrogen was used in most early plasma torches. It is still the best choice if you cut a lot of aluminum and stainless. The cut quality and parts life is excellent (more than 1,000 starts is normal). However, on thick materials (usually more than ½ in.), at the high end of your plasma system's capability, switch to argon-hydrogen. Generally, air is the best secondary when using nitrogen plasma. CO₂ works well, slightly improving surface finish, cutting speed, and parts life over air. But CO₂ costs more than air and requires multiple manifolded gas cylinders or a bulk system to deliver adequate flow. Water is a good secondary to use with nitrogen plasma if the system allows. It makes a very smooth shiny cut surface on stainless and aluminum. Water secondary must be used with a water table.

Argon hydrogen is the gas of

choice for thick stainless and aluminum cutting (more than ½ in.). The mixture typically used is 35 percent hydrogen, 65 percent argon (H-35). Argon hydrogen is the hottest burning plasma gas and provides the maximum cutting capability. Argon hydrogen is used in water injection torches up to 1,000 A for cutting up to 6 inch stainless. In multi-gas torches, argon hydrogen provides a straight cut and a very smooth, almost polished surface on stainless steel. Some jagged dross may occur along the bottom edge. Nitrogen is typically used as the shield gas with argon hydrogen. The disadvantage of this combination is its expense.

Conclusion

So what is the best gas to use? It depends mainly on three considerations: cut quality, productivity, and economy.

- For mild steel use oxygen plasma and air shield for the best cut quality, lowest dross levels, minimal rework, excellent weldability, and highest cutting speed/productivity.

- For best cut quality on stainless and aluminum less than ½ in. use nitrogen plasma and air secondary for a good balance of cut quality and affordability. For a slightly better and faster cut, use CO₂ as the secondary. If your system allows, water shield will provide the best edge quality.

- For best cut quality on thick stainless and aluminum use argon hydrogen with nitrogen secondary. WARNING! Your system must be equipped for safe operation with argon hydrogen gas.

- For most economical cutting, clean dry shop air is the best choice for mild steel, stainless, and aluminum.

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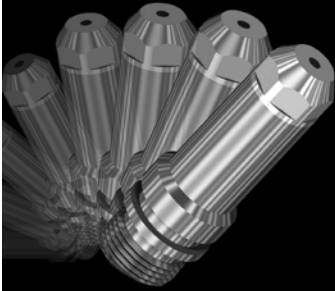


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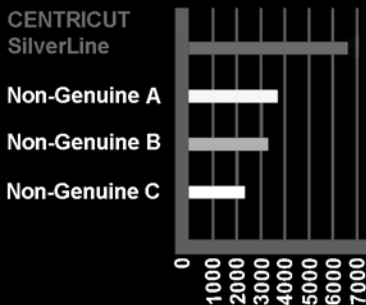
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

Solving PAC Cut-Quality Problems Dross

Many fabrication shops spend a lot of time and money grinding, chipping, and sanding parts cut on a plasma-arc-machine to remove dross. By controlling the critical process variables, a machine operator can minimize or eliminate dross and the associated costs of secondary operations.

Dross is re-solidified oxidized molten metal that is not fully ejected from the kerf during cutting. It is the most common quality issue related to plasma-arc cutting. Dross may form as a thick bubbly accumulation along the bottom edge of the plate (low speed dross), a small hard bead of uncut material (high speed dross) or a light coating along the top surface of the plate (top spatter).

Dross formation depends on many process variables including torch travel speed, standoff distance, amperage, voltage, and consumable condition. It is also affected by work-piece variables such as material type and thickness, chemical composition, surface condition, flatness, and temperature changes in the material as it cuts. However, the three most critical variables to consider in dross formation are cutting speed, amperage, and standoff distance.

Low speed dross. If cutting speed is too slow, the plasma jet begins to look for more material to cut. The arc column grows in diameter, widening the kerf to a point where the high-velocity portion of the plasma jet no longer ejects the molten material from the cut. The molten material begins to accumulate along the bottom edge of the plate in a thick globular form, called low-speed dross. At extremely low speeds the arc extinguishes

because there is not enough metal to sustain a transferred arc.

Increasing the amperage or decreasing the standoff (while keeping material thickness and speed constant) have a similar effect on the cut as slowing down the cut speed. Both of these changes cause more energy from the plasma jet to contact a given area of the material in a given period of time.

Excessive amperage or low standoff can also cause low-speed dross. (Some low-speed dross in the corners of a plasma cut is normal since velocity does not remain constant through a sharp turn.)

To eliminate low speed dross:

- Increase the cut speed in 5- $\frac{1}{16}$ -in./min increments
- Increase the standoff in $\frac{1}{16}$ -inch increments or 5-V increments
- Decrease the amperage in 10-A increments
- If none of these measures improve the cut, consider a smaller nozzle.

High speed dross. If cutting speed is too fast, the arc begins to lag back in the kerf leaving a small hard bead of uncut material or rollover dross along the bottom of the plate. This high-speed dross is more tenacious and usually requires extensive machining to remove. At extremely high speeds the arc becomes unstable and begins oscillating up and down in the kerf, causing a rooster tail of sparks and molten material. At these speeds the arc may fail to penetrate the metal or extinguish.

High standoff or low amperage (for a given material thickness and cutting speed) can also cause high-speed dross since both of these

HOW CUTTING SPEED AFFECTS CUT QUALITY



Cutting speed just right



Cutting speed too fast



Cutting speed too slow

changes cause a reduction in the energy of the plasma jet.

To eliminate high speed dross:

- Check the nozzle first for signs of wear (gouging, oversize or elliptical orifice)

- Decrease the cutting speed in 5-in./min increments

- Decrease the standoff in 1/16-inch increments or 5-V increments

- Increase the amperage (do not exceed 95 percent of the nozzle orifice rating)

Top spatter dross. Top spatter is an accumulation of re-solidified metal that sprays along the top of the cut piece. It is usually very easy to remove. A worn nozzle, excessive cutting speed, or a high standoff is usually the cause. It is caused by the swirling flow of the plasma jet, which at a certain angle of attack flings molten material out in front of the kerf rather than down through it.

To eliminate top spatter:

- Check the nozzle for signs of wear

- Decrease the cutting speed in 5-in./min increments

- Decrease the standoff in 1/16-inch increments or 5-V increments

Finding the **dross-free window** between high- and low-speed dross is the key to minimizing secondary operations on plasma-cut pieces. The window varies with plasma gas used. For example, nitrogen and air plasma gases have a relatively narrow dross-free window on carbon steels, while oxygen plasma has a wider dross-free window. Oxygen plasma gas reacts with carbon steel

to produce a finer spray of molten metal, each droplet having a lower surface tension. This molten spray is more easily ejected from the kerf.

The dross-free window is also affected by material type. For instance, cold-rolled steels cut more cleanly than hot-rolled, and pickled steels cut cleaner than non-pickled.

Tuning the speed There are two good ways to judge the optimum cutting speed. The first method involves making a series of test cuts at various cutting speeds and choosing the speed that produces the cleanest cut. Lag lines—small ridges in the surface of the cut—indicate use of proper or improper cutting speed. Slow cutting speeds produce vertical lag lines that are perpendicular to the plane of the plate. Fast cutting speeds make slanted s-shaped lag lines that run parallel to the plate along the bottom edge. Many operators have the tendency to slow the machine down at the first appearance of dross, but often an increase in speed is necessary.

The second method to judge cutting speed is to watch the arc during the cut and dynamically change the speed to produce the optimum arc characteristics. To do this, observe the angle of the arc as it exits the bottom of the workpiece. When cutting with air plasma gas, the arc should be vertical as it exits the bottom side of the cut. With nitrogen or argon/hydrogen, a slight trailing arc is best. With oxygen plasma gas, the best cut speed is one that results in a slight leading arc.

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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

Solving PAC Cut-Quality Problems: Bevel Angle

Dimensional Inaccuracies

Many fabrication shops spend a lot of time and money reworking plasma-cut parts to remove dross or correct dimensional inaccuracies. Some of these cut-quality problems are caused by mechanical and electrical problems of an old or poorly maintained cutting machine; others are related to the plasma process itself. Here we discuss the critical process variables that affect dimensional accuracy of a plasma-cut piece. By carefully controlling these variables, the operator can minimize or eliminate dimensional problems and the associated costs of secondary operations or scrap parts.

The diagram shows cut-away views of plasma-cut pieces and illustrates several elements of cut quality. The dimensions of a part are most affected by two of these elements: **kerf width** and **bevel angle**.

Kerf is the void created by the plasma-cutting process, or the amount of metal removed by the plasma arc. The plasma arc changes in size and shape depending on amperage, voltage, gas flow, and velocity of the moving torch. As the plasma-arc column changes so does the kerf.

Nozzle size also has a direct affect on kerf width since the nozzle orifice constricts the plasma-gas jet to a particular diameter. Nozzles are sized according to amperage rating: the bigger the hole the more power it can handle. **A good rule of thumb for estimating kerf width:** multiply nozzle-orifice size by 1.5. For example, a 200-A air nozzle with an orifice of 0.086 inch will generate a kerf width of 0.129 inch.

Kerf compensation

CNC controls for plasma-arc cutting have an adjustable parameter called **kerf compensation**. The operator enters a value for kerf compensation usually equal to the kerf width—some controls use half the kerf width. The CNC then automatically calculates to compensate for the width of the cut, keeping the kerf on the waste side of the part. To find the proper kerf-compensation value, operators often use trial-and-error, first estimating kerf using the rule of thumb or physically measuring it. They then cut and measure test pieces and adjust the kerf compensation up or down, repeating the process until the part measures correctly.

Kerf too wide (part too small)

This problem can be caused by a worn nozzle, high torch standoff (arc voltage), excessive amperage, inadequate gas flow, or low speed. Each of these variables will cause the arc column to grow, widening the kerf. An incorrect (small) kerf-compensation value will also cause an undersized part.

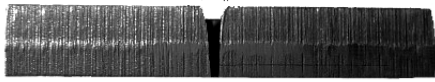
Kerf too narrow (part too big)

This problem can be caused by low torch standoff, inadequate amperage, excessive gas flow, or high speed. These variables cause the arc column to shrink, narrowing the kerf. An incorrect (large) kerf-compensation value will also cause an oversized part.

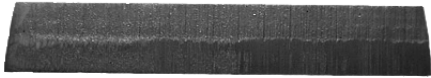
Bevel angle is the angle of the cut edge. A cut with 0-degree bevel is a straight cut, perpendicular to the plane of the material. Most plasma torches use a clockwise swirling flow of plasma gas, which produces a straighter cut on the right-hand side

CROSS SECTION VIEWS OF PLASMA-CUT PIECES

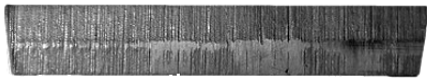
Kerf Width → ← Bevel Angle



Normal Cut



Positive Bevel



Negative Bevel



Concave/Convex Cut Surface

of the kerf with respect to forward torch motion. Typical bevel angles for conventional plasma torches range from 1-3 degrees on the good side of the cut and 3-8 degrees on the bad side of the cut. High-tolerance plasma-cutting systems can achieve lower bevel angles. Although some bevel is inherent in the plasma process due to the shape of the gas jet as it exits the torch nozzle, it is possible to minimize it. Bevel angle greater than 5 degrees may indicate a problem with pac-machine parameters.

Excessive positive bevel (top of part smaller than bottom) This problem may be caused by a worn nozzle, high torch standoff (arc voltage), inadequate amperage, or excessive speed. All of these variables cause the arc to lag which causes more energy to contact the top of the kerf than the bottom. As a result, the kerf is wide at the top and narrow at the bottom. Improper cut direction around the part may also cause excessive positive bevel angle. A part with excessive positive bevel all around it may also have a hard bead of high-speed dross at its bottom edge.

Negative bevel (bottom of part smaller than top, undercutting)

This problem can be caused by low torch standoff (arc voltage), excessive amperage, or low speed. These parameters cause the arc to remove more material at the bottom of the plate. Usually a consistent negative bevel around the part is accompanied by low-speed dross.

Irregular bevel (positive and negative bevel on the same piece) This problem usually indicates that the nozzle has failed,

the torch is out of square, or the electrode and nozzle are misaligned. These variables cause the arc to deviate from a straight path through the material. Often one side of a square part will have a positive bevel and the opposing side a negative. The cross section of the part looks like a parallelogram rather than a rectangle. Sometimes the cut surface may not be flat, but concave on one side and convex on the other. These are all signs of severely worn or misaligned parts.

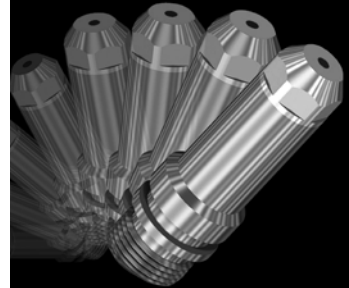
Six rules to live by

These six recommendations will help the PAC operator to improve the dimensional accuracy of plasma-cut pieces:

- Adjust all PAC machine parameters to exact recommended settings.
- Set the kerf compensation to the correct value.
- Check torch squareness to the plate regularly.
- Monitor speed and voltage; make slight adjustments as necessary as parts wear.
- Check consumable parts at pre-established intervals; change before cut quality deteriorates.
- Use in-process quality-control checks to monitor cut quality.

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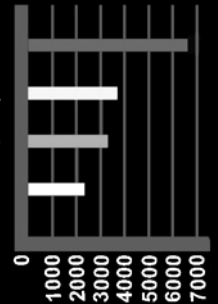
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

Solving PAC Cut-Quality Problems

Cutting small holes and intricate shapes

Too many fabrication shops spend time and money reworking parts cut on their plasma machine removing dross or correcting dimensional inaccuracies. Here we discuss the critical process variables that affect dimensional accuracy of plasma-cut pieces. By carefully controlling a few variables, the operator can minimize or eliminate dimensional problems and the associated costs of secondary operations and scrap parts.

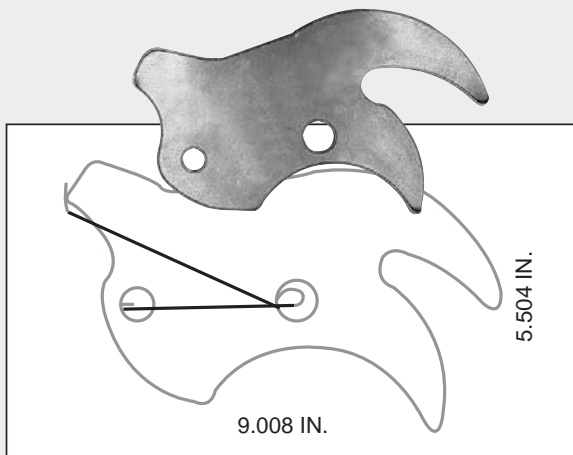
Small holes and intricate shapes such as slots, sharp corners, and tight radii present special problems for the PAC-machine operator. For our purposes, we will define a small hole as any hole whose diameter is less than 1.5 X the material thickness. Not only is it more difficult to cut these shapes cleanly with conventional systems, but reworking out-of-tolerance parts is more difficult as well—reaming out undersized or non-cylindrical holes and grinding into tight corners to remove dross isn't fun or cost-effective.

Many shops solve these problems by buying expensive high-tolerance cutting machines or even more expensive laser systems. But it is possible, with a well-maintained plasma-cutting machine and conventional torch, to achieve near-high-tolerance cuts with careful programming and a good understanding of cut-quality variables.

Bolt-holes should be cylindrical—hole diameter at the top and bottom should be nearly equal—in order to ensure a good fit with the bolt. One critical parameter that affects cylindricality of the hole is cutting speed. Programmers enter cutting speed as

a lineal rate in inches per minute (in./min) or millimeters per minute (mm/min), but when cutting a circle the torch must slow down to compensate for the natural lag of the plasma arc as it cuts. Most CNC controls automatically compensate for this phenomenon with an algorithm that factors down the velocity for hole cutting. Called **centripetal limiting**, this calculation accounts for the length of the radius, torch acceleration, and minimum corner speed to adjust the actual cutting speed around a circle. The programmer or operator may be able to adjust the lineal speed up or down to optimize actual circular-cutting speed for improved cylindricality. This would mean programming different, lower speeds for bolt-holes than for straight cuts on the same part.

Cut height, or voltage setting, is another parameter that affects cut quality on bolt holes. For small holes, cut height should remain constant throughout the cut. With voltage-regulated torch height control (THC), cut height is determined by an arc-voltage setting of typically 100-180 V. Depending on the responsiveness of the system, using THC for small holes may worsen rather than improve cut quality. It may be necessary to lock-out the THC during cutting of small parts to prevent the torch from cutting too high or low and to prevent the torch from diving at the end of the cut. The THC can be locked out by switching into manual mode after the pierce is complete, or reprogramming the part to specify corner-slow-down—no THC—during hole cuts. Newer more-responsive torch-height controls may help with defects caused by improper cut height.



Programming: Lead-ins and lead-outs

The type and size of lead-in and lead-out can significantly effect cut quality, particularly with bolt-holes and slots. Two common defects are **divots and bumps**. A divot occurs when the arc removes too much material at the end of the cut. As the plasma arc crosses the lead-in kerf—the removed material from the beginning of the cut—it transfers to the saved part, causing a small indentation or, sometimes, a larger scooped-out region. This makes the hole out-of-round.

A bump occurs if the lead-in and lead-out do not adequately overlap. Some of the material in the hole is not completely removed, leaving a bump of uncut metal that prevents the hole from accepting a bolt.

Finding the appropriate lead-in and lead-out to minimize divots and bumps at start and end points can be challenging. Operators can use a trial-and-error process to find the appropriate combination. Generally, a radiused lead-in with a very small or negative lead-out (negative overburn) to the saved part will produce the best hole. Sometimes a short, straight lead-in works better with a small lead-out (positive overburn).

The outward-spiral lead-in (see the figure) is a special design that can be very effective for hole cutting. (Note: This differs from the traditional locking lead-in used in oxyfuel cutting, typically not used for plasma cutting.) The outward-spiral lead-in allows the machine to reach full speed and the arc to stabilize before cutting the hole perimeter, providing the smoothest machine motion throughout the cut.

Nozzle size and amperage

In general, a small nozzle with

lower amperage and slower speed will produce a smaller kerf and a finer cut. For example, with a 200-A plasma system, the highest power—200A, 0.086-inch orifice, 0.130-inch kerf) may not be suitable for cutting small bolt holes and intricate details. Let's say you want to cut a precise 1/2-inch hole in 1/2-inch mild steel. A 100-A nozzle with a smaller orifice, 0.059 inch, and kerf width, 0.089 inch, cutting at a slower speed will produce a much finer cut. (To get the best cut from a given nozzle, always set amperage at 95 to 100 percent of the nozzle's rating.) The downside: reduced consumable life and slower cutting speeds. The upside: a near-finished part with minimal rework.

When to use high-tolerance plasma

High-tolerance plasma uses a small nozzle orifice and intense gas swirl to constrict the arc. The result is an energy-dense arc with a very narrow kerf that can cut intricate details and very small holes. Conventional plasma systems can cut within .030-inch accuracy and produce cuts with 3-5 degrees of bevel, sometimes as little as 1 degree. High tolerance systems can cut with 0.010-inch accuracy and 0-3 degrees of bevel. They can accurately cut holes as small as 3/16 inch.

Six rules for cutting bolt holes

- Use the smallest nozzle size rated to pierce and cut the material
- Make sure the pierce-delay allows full arc penetration before machine motion starts
- Lock out voltage-regulated THC
- Use a radiused or spiraled lead-in
- Program a slower cutting speed
- Use a short or negative lead-out to the saved part.

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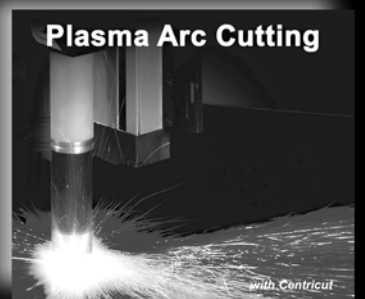
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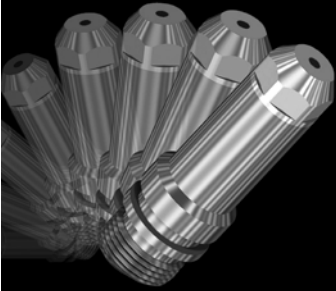


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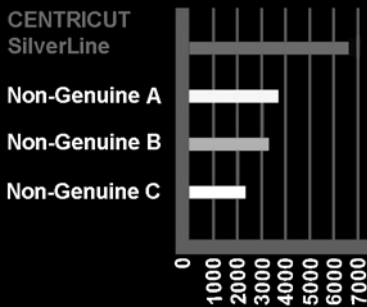
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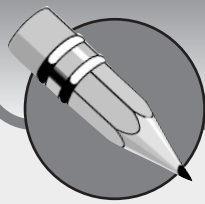
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

Tips and techniques for mechanized plasma cutting: Piercing

Here's a pop quiz for the PAC supervisor, industrial engineer, purchasing agent, or maintenance man:

What is the number-one cause of premature parts failure in plasma torches?

- Inadequate plasma-gas flow
- Inadequate coolant flow
- Machine malfunction
- Improper piercing technique

If you answered *a*, *b*, or *c*, you get partial credit. If you answered *d*, you're correct and on your way to saving money and decreasing downtime on the plasma-cutting machine.

Piercing too close to the material is the most common cause of premature consumable-parts failure. The problem sounds simple enough to correct, yet it persists in many cutting operations. One reason is the lack of good technical training for PAC-machine operators. Armed with a fundamental understanding of the process and a couple of simple tips and techniques, an operator will spend more time cutting parts and less time changing consumables.

What happens during a pierce?

When the torch fires, a high-voltage spark combined with a limited amount of DC current produces a pilot arc at the torch. This pilot arc projects from the end of the torch in a steady, white-blue arc. The pilot arc forms an electrical path from the cathode—the electrode in the torch—to the anode—the conductive workpiece. If the torch is within transfer distance, the arc will transfer to the metal and begin to pierce. Every torch has a maximum transfer distance that is also its maximum pierce height. If the torch is higher than this distance it will pilot in the air; if it is lower, it will transfer and begin to pierce.

Stage 1. The transferred arc instantly heats the workpiece to its melting point and begins blowing the molten material away. In the initial stage of the pierce, the molten metal sprays out radially from the pierce point over the top of the plate in a shower of sparks.

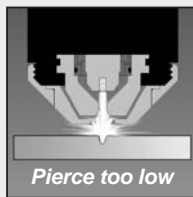
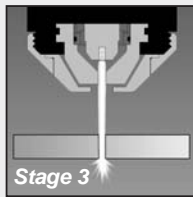
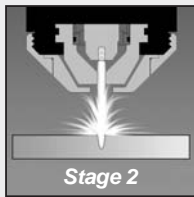
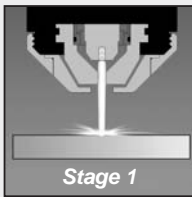
Stage 2. As the plasma jet penetrates deeper into the material, a round-bottomed hole forms. This hole begins to direct the molten spray upward toward the torch.

Stage 3. Once the arc breaks through the bottom of the plate, the sparks and molten material exit out of the pierced hole. When the pierce is complete and the arc has grown to its full strength, the torch begins to move. If the torch moves too soon, the arc may not fully penetrate the material. If the torch delays too long, the arc will continue to remove material, enlarging the hole until the arc extinguishes.

Piercing problems

The most common piercing problems are double arcing, bridging, and snuffing. These occur during the second stage of piercing when a fountain of molten metal is sprayed back up at the torch. Under normal conditions, the arc column is controlled and focused by a swirling vortex of gas as it passes from the electrode through the nozzle to the plate. This boundary layer of gas prevents the arc from contacting the copper nozzle. If the arc does contact the nozzle it will cut it as it does to any conductive metal.

Double arcing describes any arcing that occurs secondarily to the main cutting/piercing arc. It occurs when current flows through the nozzle, or through another conductive path, to the plate other than directly through the arc column. This can occur due to low plasma-gas flow,



excessive amperage, or a serious disturbance in the plasma jet. Such a disturbance happens when the torch is piercing too close to the plate. The spray of electrically conductive metal disturbs the plasma-gas jet by disrupting the electric field surrounding the arc and causing the arc column to grow. It's theorized that multiple arc paths develop through these tiny bits of metal, pulling the arc out of its axial-symmetric path. If the arc is pulled into the sidewall of the nozzle, it causes a gouge, nick, or sometimes a symmetrical chamfer along the exit orifice. Damage to the nozzle leads to serious cut-quality problems such as excess bevel angle, dross, and failure to penetrate the material.

Bridging, a more extreme form of double arcing, occurs if the molten material builds up in a puddle that contacts both torch and plate. Since this puddle is electrically conductive, it provides a short circuit to the workpiece. The arc sees a path of lower electrical resistance and takes it, usually causing failure of the shield and nozzle. Even state-of-the-art electrically isolated copper shields are not immune to this type of failure. Once the shield contacts a ball of molten material it is at the same potential as the plate, therefore the arc will conduct through the shield and cause it to fail.

Plasma-gas snuffing, the most extreme form of double arcing, occurs when the torch begins to pierce with the torch nozzle or shield pressed against the plate. For example, if the automatic torch-height control finds its initial height by pushing against the plate, and the plate is bowed or thin enough to be pushed down, then the retraction of the torch will not set the correct initial height. The torch will fail to clear the plate because the plate follows the torch back up to its initial height setting. This often occurs in underwater cutting when the operator cannot see the front end of the torch. Snuffing of the plasma gas leads to uncontrolled double-arcing in the plasma chamber, causing catastrophic failure of the electrode, nozzle, and shield.

Tips and techniques

- **Pierce high and cut low**—The rule of thumb is to pierce at 1.5-2X the cut height or at the maximum transfer distance. Piercing high prevents double arcing, bridging, and snuffing.

- **Use a creeping pierce**—If your CNC is capable, program it to slowly move the torch during the pierce operation to form a "rooster tail" of molten material to miss the front end of the torch.

- **Don't "eyeball" the pierce height**—Use the initial height sensing if it's available. Manual piercing is usually not recommended; even experienced operators lack a perfectly calibrated eye.

- **Don't pierce beyond system limits**—Pierce rating is typically 1/4 the cut rating.

- **Avoid piercing**—Whenever possible, use chain cutting or edge starting to reduce the number of pierces.

Special Techniques

Experienced operators sometimes use two special tricks for piercing through thick plate. **WARNING:** Don't try these techniques unless you have an experienced operator familiar with safe operation of the machine.

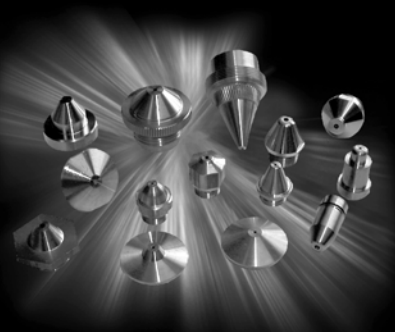
Double shot—This technique involves blowing through the plate in two or more successive pierces rather than one. The first pierce establishes a round-bottomed hole about halfway through the plate. The operator then manually jogs the torch slightly toward the edge of the hole and pierces again. The second shot blows through the material as the "rooster tail" of molten metal is deflected away from the torch.

Rising pierce—To perform this manual pierce, the operator brings the torch down to the plate with the pilot arc on. As soon as transfer occurs, he raises the torch to stretch the arc to as high as 1 inch above the plate. As the plasma jet blows through the plate, the operator lowers the torch to normal cutting height. This protects the torch and shield, but shortens electrode and nozzle life.

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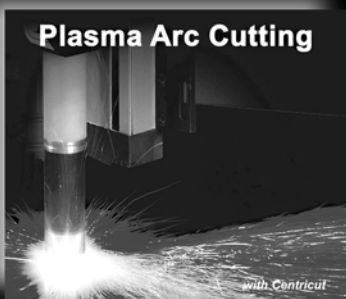
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

Troubleshooting PAC Systems: Starting Problems

WARNING! PAC system maintenance and repair should only be attempted by those skilled in electrical troubleshooting. PAC systems use high voltage and direct-current (DC) electricity. Electric shock can injure or kill.

Symptom: The torch fails to initiate the cutting arc when all other conditions for normal operation are correct—power supply energized, safety and parts-in-place interlocks satisfied, gas pre-flow at torch, and torch within transfer distance.

The sequence of operation for the typical PAC system is as follows: The start-cut signal is sent to the power supply to energize the system. A solenoid opens, allowing gas flow to the torch. The pilot-arc relay latches, activating open-circuit voltage (OCV) between the nozzle (+) and the electrode (-). A high-frequency (HF) spark (see illustration 1) is supplied to the torch by a high-voltage generator with 3,000-10,000 V AC output. The high-frequency generator usually includes a high-voltage transformer, capacitors, spark-gap assembly, and coil.

The high-frequency spark ionizes the gas flowing through the torch, making it electrically conductive. The ionized gas allows current flow between the electrode and nozzle. This current is limited to 20-40 A DC by the pilot resistor. The arc blows out of the orifice and reattaches to the face of the nozzle, forming a pilot arc (see illustration 2).

The pilot arc forms the electrical pathway to the workpiece. If the torch is within transfer distance, usually 0.25 to 0.50 inch from the

material, the pilot arc will transfer to the plate since the plate is connected to the positive pole of the DC circuit and is not limited by a resistor (see illustration 3). A current-sensing circuit senses arc transfer, shuts off the HF generator, and opens the pilot-arc relay.

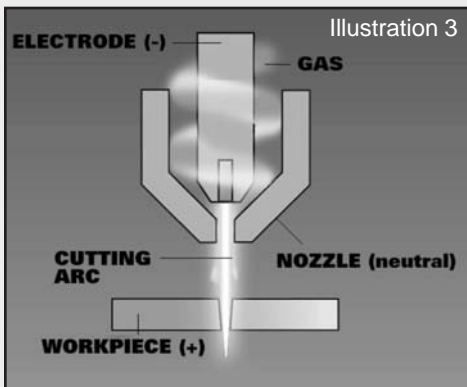
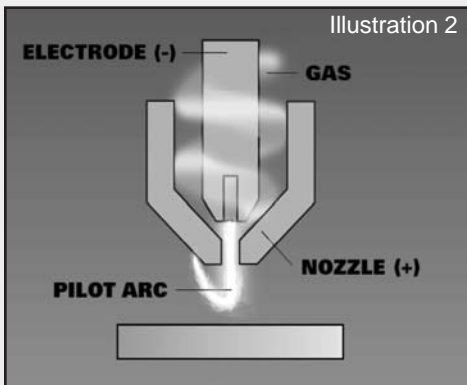
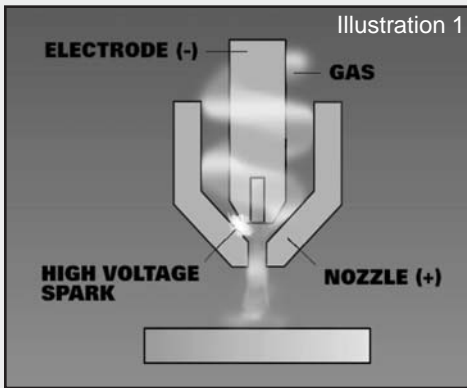
In simple terms, the torch needs three ingredients to form a pilot arc: plasma gas, DC power, and AC high frequency. With any of these ingredients missing, the torch will not fire, transfer, or cut.

Troubleshooting starting problems

When starting problems occur, the operator should first evaluate the pilot arc. He raises the torch several inches above the material to provide a good, clear view of the torch. He then signals the torch to fire. After several seconds of gas flow, a pilot arc should form at the torch. A healthy pilot arc will sustain itself in the air for several seconds. He looks for an arc with a bright white-blue color that projects 0.25-0.50 inch from the end of the nozzle. The arc should not spit and sputter or sound raspy; it should be smooth and steady. He should test the pilot arc a number of times in the air to see if the condition repeats.

Problem 1: Hard Starting

If the pilot arc spits and sputters but fires intermittently, the problem may be hard starting. Hard starting occurs when the HF struggles to break down the high-pressure barrier between electrode and nozzle. This can be caused by insufficient HF or excessive gas pressure. Here are four steps to remedy hard starting.



- Check the gas pressure and flow. The plasma gas pressure or flow setting should not exceed factory-recommended settings. Excess pressure in the plasma chamber makes it harder for the HF spark to jump the gap, so that the pilot arc is effectively blown out before it can fully establish. High-gas pressure accounts for the majority of hard-starting problems, and is often overlooked—a zealous troubleshooter might replace every component in the pilot circuit, only to find the air pressure had been turned too high.

- Clean the hoses and wires that carry gas and power to the torch, and inspect them for visible damage

or loose connections. If the shielding is covered with dirt, metal dust, or moisture, the high-frequency energy can be dissipated. Blow off the leads with an air hose or wipe them down with a clean cloth. Eliminate any coils in the leads—they can cause a large inductance. Insulate the leads from the cutting machine.

- Inspect, clean, and re-gap the spark-gap assembly. High frequency from the high-voltage generator is usually sent to capacitors that discharge the electricity across a spark-gap assembly. Over time the spark-gap electrodes can deteriorate or become contaminated with metal dust and dirt. Clean and re-gap the electrodes to the manufacturer's specifications. Gap should be 0.015 to 0.030 inch, depending on the system.

- If using a water-cooled torch, check coolant resistivity. For most systems it should be less than 10 Kohms/cm or 10 micromhos.

Problem 2: Weak, blue spark at torch

If there is a visible spark at the torch but it is a small blue spark that looks similar to the spark at the spark-gap

points, then the pilot arc has high frequency but no DC component. The most likely causes for loss of DC in the pilot arc are worn contacts or a bad coil in the pilot-arc relay; or a defective pilot resistor.

Problem 3: No spark visible at torch or at spark gap

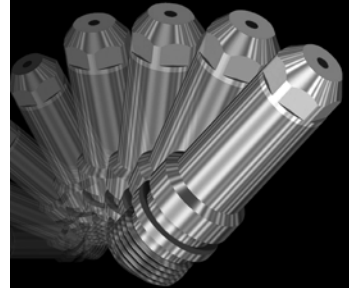
No AC power to high voltage generator; defective high-voltage generator; defective capacitors; shorted or damaged spark-gap assembly.

Problem 4: No spark at torch, spark at spark gap

Severe hard starting—refer to problem 1; shorted or open torch lead; shorted or open connection in torch body.

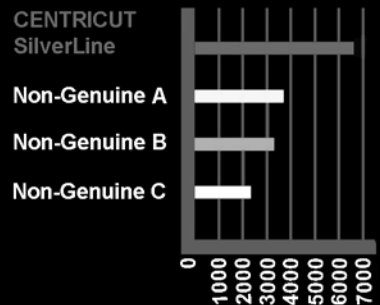
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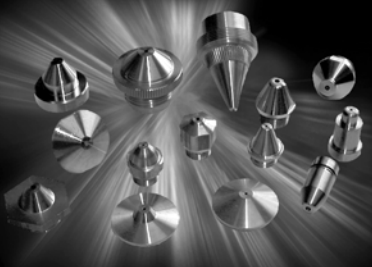
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

PAC-Machine Maintenance

Murphy's Law says the plasma-cutting machine will break down when you need it most—usually right in the middle of a big plate-cutting job. At up to \$200 per hour fully burdened, cutting-machine downtime gets expensive.

Many shops do not have a regular preventive-maintenance schedule for their plasma-cutting systems. After a few months of neglect, the machine will no longer perform as designed. Mechanical parts will prematurely wear, causing rough machine motion. This may lead to out-of-tolerance parts and poor cut quality, particularly at higher cutting speeds. When machine components fail, trouble-shooting and servicing can take days.

Here is a checklist that serves as a good starting point for a preventive-maintenance program.

- Clean the torch body. Remove the torch parts and examine the inside of the torch. Check for signs of mechanical damage to threads. Clean the inside of the torch with electrical contact cleaner and a cotton swab. Disconnect the torch from its mounting tube and slide the tube back to reveal the torch-lead fittings. Check for leaks or damage to any of the connections. Blow out any accumulated metal dust.

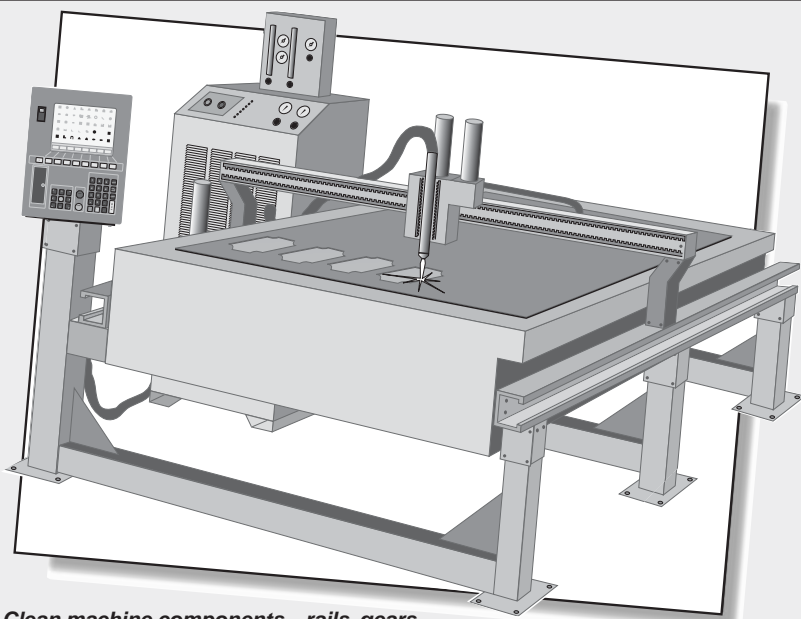
- Clean the torch leads. Wipe down or blow off the entire length of the torch leads to remove accumulated metal dust and dirt. Metal dust can cause dissipation of the high voltage needed to start the plasma arc. Check for kinked or worn hoses, exposed wires, cracked fittings, or other damage. Check high-frequency shielding for proper connection to earth ground.

- Clean out the power supply. Blow out any accumulated metal dust using clean, dry, shop air. Metal dust can cause damage to power-supply components, especially PC boards. Contactors, relays, and spark-gap assemblies can also malfunction due to excess buildup of metal dust. Check air filters on the power-supply housing; replace as necessary.

- Check torch-cooling components. With water-cooled torches, check the coolant stream in the tank for signs of aspirated air or reduced flow. Make sure that the return flow is at the specified gallons per minute. Check that flow switches on the return line function properly—insufficient coolant flow can cause the torch to overheat. Check coolant filters and pump screens and clean or replace as necessary. Check coolant resistivity using a conductivity meter, if available. Resistivity should not exceed 10 micro-ohms for most systems. Flush and replenish coolant every 6 months.

- Check water quality—secondary water quality is particularly important with water-injection torches. Water hardness should not exceed 8.5 ppm or 0.5 grains. Hard water causes mineral deposits to build up on nozzles, leading to shortened life. Use a commercial water softener if necessary. Water quality in water tables is also important. If the water in the table is heavily contaminated with slag and metal dust, it can cause hard-starting of the plasma torch. It may also cause rust accumulation on the cut pieces.

- Check plasma-gas quality, critical to maintaining good parts life and cut quality. To check air quality, hold a clean paper towel under the torch



Clean machine components—rails, gears, racks, and such. Level and align rails. Align and adjust gears and bearings. Check the squareness of the torch with respect to the table and workpiece. Check safety limits, which need to operate properly to ensure operator safety and prevent damage to the machine. Tune the drive motors and control.

while purging air through the system in the TEST mode. Check for water, oil mist, or particulate contamination. Check filters weekly; empty moisture traps whenever they begin to accumulate water.

- Clean machine components—rails, gears, racks, and such. Use a degreasing agent and an abrasive pad to remove grease, dirt, and metal dust. Lubricate gears with dry lubricant such as graphite powder. If bearings have grease fittings, lubricate them. Do not lubricate rail sections—lubricants will attract contaminants that lead to excessive wear.

- Level and align rails. Check joints where rail sections meet with a piece of tool steel or other precision straight edge, feeling for misalignment. Rail alignment will prevent drag on drive motors. Distances between the rails should be constant across the entire length of the system.

- Align and adjust gears and bearings. Gears should not overlap above or below the rack. Adjust gear alignment to remove play between gears and racks. Make these adjustments for rail and cross drives. Alignment bearings should have minimal play between them and rail or cross-rail surfaces. These bearings are usually mounted on an eccentric. Adjust until no light can be seen between bearing and rail surface. Do not over-tighten. With drive gears

disengaged, roll the beam across the rails to check for binding. Adjust accordingly until the beam rolls free with minimal vibration and little resistance.

- Check the squareness of the torch with respect to the table and workpiece. Collisions can knock the torches out of square with the workpiece. Check for looseness in the torch-mounting device—this can cause vibration that will translate into a wavy cut.

- Check safety limits, which need to operate properly to ensure operator safety and prevent damage to the machine. Move the machine to each limit to test switches. Make sure the machine stops when each switch is reached. Inspect mechanical stops to make sure that they are in proper working order.

- Tune the drive motors and control. Drive-motor tuning may be necessary if the motors appear to be out of synch—the torch may not return to its home position, or inaccuracies in cut pieces may develop, particularly in combination moves where both x and y drives are operating. Speeds for each axis need to be equal for proper torch positioning. Motor drift must also be minimized. As these adjustments differ from system to system, consult the manual or an authorized representative for your particular machine to tune the drive package.

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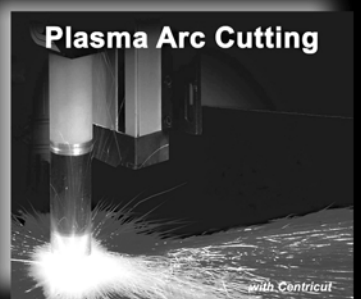
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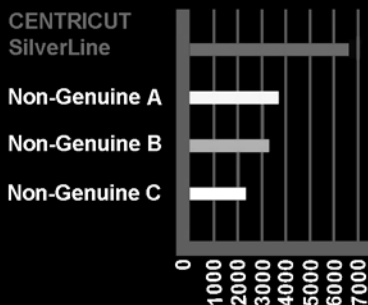
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

Upgrade and Retrofit a Plasma-Arc-Cutting Machine

Are you spending a lot of time and money on secondary operations to clean up dross, remove bevel angle, or rework out-of-tolerance parts that were cut using plasma? Does your cutting machine vibrate? Does it break down and stay down for days or weeks? Is your CNC control outdated and slow? Many of these problems can be eliminated through operator training and proper machine maintenance; others are best solved by equipment upgrades.

Plasma-system upgrades

A new plasma system retrofitted onto an older cutting machine or punch press can mean improved cut quality, increased cutting capacity, and faster cutting speeds. Today's plasma systems offer significant improvements in power supply and torch technology, including micro-processor-controlled power supplies, sophisticated gas-flow controls, and optimized torch and parts designs. Consumable-parts life has improved with the use of inert start gases for oxygen-plasma cutting. Current- and gas-pressure ramping or stepping devices soften the plasma arc during ignition and cut off.

When selecting a new plasma system consider these variables:

Material type will determine the plasma gas used. If you only cut stainless steel or aluminum, an older nitrogen-plasma system may be adequate. Air plasma may also be a viable low-cost alternative. For mild-steel cutting, oxygen plasma is becoming the industry standard for

cut quality and weldability. Air plasma offers similar cut quality on carbon steels, but may produce nitriding along the cut surface.

Material thickness will determine the size of plasma system needed. Determine the thickest material that you regularly cut and select a system that will cut this material at a reasonably fast speed. Manufacturers rate their systems by maximum cut capacity from an edge start; pierce ratings are typically half the cut capacity.

Cutting-machine upgrades

Cutting machine upgrade options include:

Mechanical reconditioning to add rack and pinion drives is now the most commonly used method of upgrading motion transmission. Installing new gears and racks on older machines will improve their performance. Bearings to support the moving elements of the machine in longitudinal (the bridge moving along the rails) and transverse (the torch carriage moving along the bridge) axes are critical to smooth motion and accurate positioning.

New drive packages include servo motors, drive amplifiers, and encoders retrofitted to an old machine. PWM (Pulse width modulation) DC servo motors are typically used for plasma machines and are available as retrofit kits. The result: greater positional accuracy, higher torque motors, and faster acceleration times.

Torch height control (THC) adds

technology to many old cutting machines that were not equipped with adequate torch-height controls. Many shops simply do without this valuable tool. Most THC's are voltage regulated—they regulate position of the torch by sampling arc voltage and comparing it to a preset value, then drive the torch up or down to maintain that voltage and corresponding standoff. The latest THC's control standoff distance to within .005 inch. Because the plasma-arc column can be fixed to its optimum position to deliver a straight jet, this leads to substantial increases in cut quality, particularly bevel angle. Height controls also pay for themselves in reduced consumable usage. Most have an initial height sensing function that allows an initial height to be set independently of arc voltage. This allows the operator to pierce high and cut low, enhancing nozzle and shield life.

New cnc controls offer retrofit options for most old cutting machines. Newer controls offer more storage capacity, increased speed and accuracy, better programming features, faster communications, and more user-friendly design. Most are industry standard, EIA and ESII code compatible and support third party PC software and part-nesting programs.

The latest generation of controls is PC-based to take advantage of increased processing speed and lower cost of the industry-standard computer processors. They use off-the-shelf computer components that

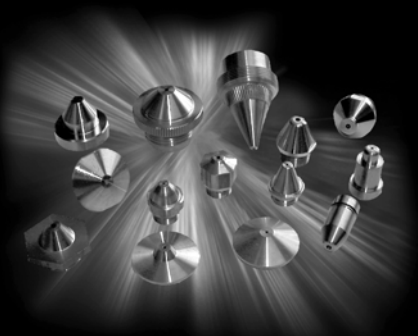
are lower cost and open-architecture in design. The best controls offer communication rates as high as 230 kbaud (10 times faster downloads than older models), gigabyte hard drives for file storage, and real-time graphic displays. Some can even receive software updates via e-mail—no e-proms or other firm-ware upgrades are necessary.

With a comprehensive refurbishment and upgrade of an existing plasma-cutting system, a fabricator can realize big gains in productivity and see an improvement in the bottom line without spending six figures on a new machine.

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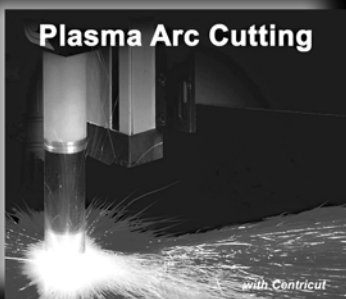
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

Operational Costs of Automated Plasma Cutting

How to calculate cost of operation and benchmark for improvement.

In typical mechanized plasma cutting operations there are four major costs beyond the initial capital investment: power, gas, consumables, and labor.

Power Costs

In typical plasma cutting operations there are four major costs: power, gas, consumables, and labor.

*Power Cost = power consumption
x arc-on time x \$/kWh*

The major power consumer in a cutting machine is the DC power supply. Most of the energy consumed by the system is put directly to work on the material in a very hot energy-dense arc. To get a rough idea of the power consumption of a plasma system multiply the amperage output by the average operating voltage. To calculate kilowatts of input consumed, multiply by a power supply efficiency factor of around 85%. For example, a 200 A plasma system has an average operating voltage of about 140V. This means the power supply puts out 28 kVA, so input consumed is calculated as $28\text{kVA} \times .85 = 23.8 \text{ kW}$

To arrive at daily or yearly power consumption multiply by the average up-time or arc-on time in a day. Arc-on time is the amount of time actually spent cutting during a given time interval. This can be measured by a pierce and arc-on time counter, or calculated from programming distances and speeds and daily throughput. Arc-on time will vary with material type and thickness, size of cut pieces, material handling, machine speed, torch height control speed, and many other factors. Most shops average about 35% actual arc-on time. This means in an 8-hour shift only 2.8 hours are spent

cutting and in a 2080-hour year only 728 hours are spent cutting. Multiplying this by a typical power cost of \$.10/kWh yields annual power cost.

*Annual Power Cost = 23.8 kWh x
728 hours/yr x \$.10/kWh =
\$1,730/yr.*

Gas Costs

Plasma systems use oxygen, air, nitrogen, argon-hydrogen, and other gases.

*Gas Cost = consumption x arc-on
time x \$/100 ft³*

The consumption rate varies with the size of the plasma system and various operating conditions. Generally, the operations manual will provide consumption rates in ft³/hr for a given nozzle size and operating pressure or flow tube setting. For example, a 200 A oxygen plasma system consumes 70 ft³/hr of oxygen when cutting. To find the cost of operation multiply the consumption rates of plasma gas by the arc-on time and cost of the gas.

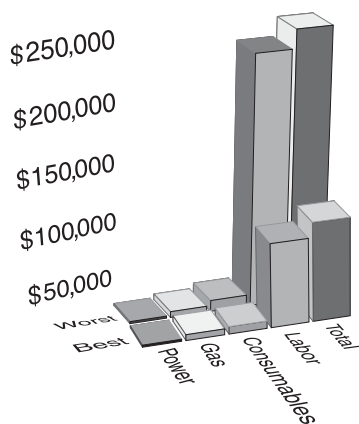
*Annual Gas Cost = 70 ft³/hour x
728 hours/year x \$10/100 ft³ =
\$5,096/year*

The same system may use 300 ft³/hr of shield air. Shop air is generally considered free other than associated maintenance costs to keep it clean. Cut-water or water shield are also inexpensive, but shield gases such as nitrogen, CO₂, and mixes can be costly and should be calculated as above.

Consumables

Consumable costs can be tracked on a weekly, monthly or yearly basis.

Plasma Cost of Operation Best and Worst Case



These costs vary widely, depending not only on the cost of the parts but on the performance and life of the parts, which are dependent on many factors. Consumable and plasma torch life varies with application, operating parameters, duration of cuts, number of pierces, operator skill, etc. The best way to capture and begin to control consumable costs is to keep daily logs of parts life measured in number of pierces and arc hours.

Consumables Cost = consumption rate x arc-on time x parts cost

Over time, in a production environment, it is possible to closely track the number of pierces and the total arc-hours for a given set of parts on a given cutting job. If a plasma torch is operated and maintained correctly the annual cost of torches, gas swirling devices, shields, retaining caps and other parts should be low compared to the nozzle and electrode cost. But the reality in many shops is that overall consumable cost is twice the nozzle and electrode cost.

Annual Consumables Cost:

1 set/3 arc-hours x 728 arc-hours/yr = 243 sets/yr
243 sets/yr x \$20/set = \$4,860/yr
\$4860/yr x 2 = \$9,720

Labor Costs

Labor costs can be calculated using the following equation:

Labor Cost = total hrs/yr x shop hourly rate x no. of people

Most shops have one operator and one helper per machine per shift. Depending on the quality of the cuts from the machine, there may be multiple workers on secondary operations or none. A typical fully burdened shop rate is \$35 /hour. Annual labor costs would then be calculated as:

Annual Labor Cost = 2080 hr/year x \$35/hr x 2 workers = \$145,600

Obviously, labor is the major cost of operation for plasma cutting. To get the most out of the plasma cutting operation, the fabricator must use labor wisely. That doesn't mean that each operator needs to run three plasma tables. A better solution is to pay for and train a good operator who can keep the machine running and produce good parts

Recommendations

Here are some recommendations to optimize your cutting machine costs and productivity.

- Maximize up-time on the machine—A cutting machine should be cutting. Preventative maintenance is essential to prevent costly downtime for repairs. Material handling solutions such as multiple cutting beds, overhead cranes, and plate handlers can minimize manual loading and offloading and keep the operator focused on the cutting process. Machine motion parameters matter as well. If the torch height controls or machine traverse speed is slow the machine spends more time positioning the torch than cutting metal.

- Minimize secondary operations—Controlling costs of secondary operations is achieved by optimizing cut quality. To do this requires not only a well-maintained machine but also a well-trained operator. The highly skilled operator produces more cut pieces of higher quality, with less scrap material and less rework down the line. Getting good cut quality from the PAC process requires careful control over process parameters and attention to detail.

- Control consumable costs—Controlling consumable costs, like controlling cut quality is part equipment and part operator. A good operator will get the most out of a set of parts and prevent catastrophic failures.

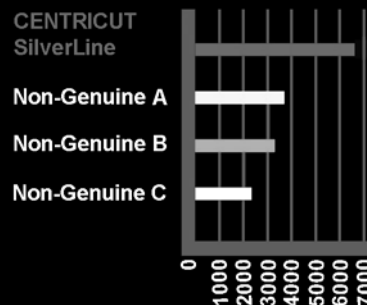
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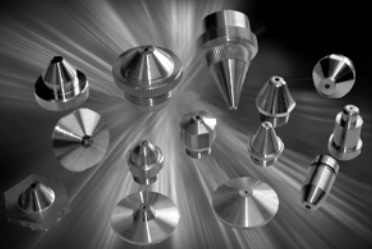
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

Torch Height Control for Plasma Cutting

The automatic torch height control or (THC) is one of the most important elements of the mechanized shape cutter. But it is also the piece of equipment on the cutting machine most likely to be misused, nonfunctional, or even missing. In many fabrication shops you will see the torch operator manually driving the torch up and down while cutting—his eye on the torch and his thumb on a toggle switch. The THC is either not working properly or the operator has not been trained on how to use the equipment. In either case the shop is not getting the most out of its cutting operation.

There are a variety of torch height controls, or “standoff controls,” on the market. Each of these automatic THCs has a variety of functions and features. But all use the same basic elements to control position of the torch relative to the material being cut. This “torch to work” distance or “standoff” is critical to both cut quality and parts life.

Elements of the THC

- Motor-driven torch positioner—This device moves the torch up and down in response to signals from the control console. Screw drive, rack and pinion, and belt driven mechanisms are used to translate motion.

- Control console—This is the brain of the system. It receives input commands from the remote control, sends output commands to the torch positioner, and monitors position feedback and voltage signals.

- Plasma system interface—This device usually consists of a voltage divider card that is mounted inside the plasma power supply. The voltage divider card monitors power supply voltage during cutting. It

“divides” the voltage signal and sends a smaller signal voltage to the control console.

- Remote control—The remote control is the HMI, or human machine interface. This is where the operator sets two critical cutting parameters: initial height and arc voltage. It may be located inside the CNC control or in a separate remote box.

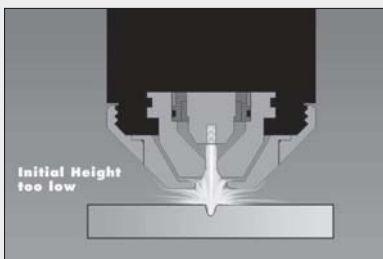
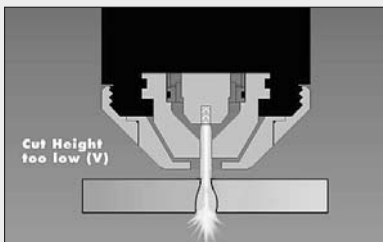
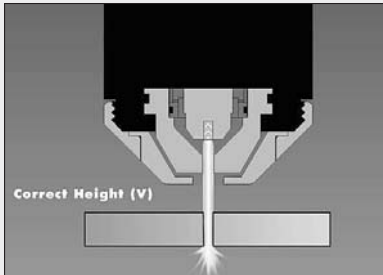
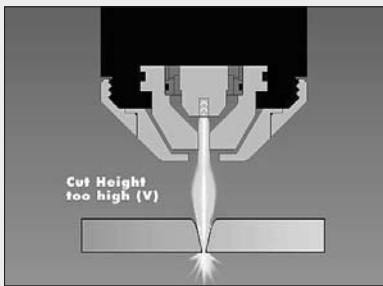
The difference between IHS (initial height sensing) and voltage setting is very important to understand and is often confused.

IHS is an adjustable parameter that determines the height at which the torch will fire and begin piercing through the plate. In order to set the initial height (also called retract distance) the THC must first find the position of the plate. A variety of schemes are used for sensing the plate from simple mechanical devices, to motor stall technology, proximity sensors, and electrical circuits that sense nozzle or shield contact. Regardless of the method used, the most important thing is that the torch finds the plate and accurately retracts to the proper pierce height, whether on thick plate or thin, rusty plate or clean, above water or below.

Correct pierce height is essential. If the torch pierces too low the consumable parts will be damaged. This is the number one cause of premature parts and torch failures (see Fig. 1). If it attempts to pierce too high, the arc will not transfer, causing a misfire. The rule of thumb is to pierce at 150-200 percent of the cut height. Pierce high; cut low.

Torch to Work Distance

Torch to work distance, or standoff, during the cutting process is



adjusted by monitoring and controlling the arc voltage. Note that arc voltage is the same thing as power supply output voltage. Plasma power supplies are a current source—they generate a very steady operating current when the torch is cutting. Voltage, on the other hand, varies depending on the distance between the cathode (the electrode in the torch) and the anode (the material being cut). Voltage is directly proportional to resistance (Ohms Law states that $V=I \cdot R$). The resistance in the arc is a function of the distance. When the torch to work distance increases the voltage goes up; when the torch-to-work distance decreases the voltage goes down.

The torch height control uses arc voltage to maintain a consistent distance from the plate while the torch is cutting. This allows the system to

maintain proper torch height regardless of variations in the material, or flatness of the cutting bed. The operator sets the arc voltage on the remote control according to the cut charts in the plasma system's operations manual. This voltage setting is usually between 100 and 200 VDC.

After the torch height control has completed initial height sensing and the torch has pierced the plate, motion of the cutting machine is enabled and the torch begins to move. Once the cutting begins, the THC starts sampling arc voltage from the power supply and comparing it to the target voltage set by the operator. It adjusts the torch up or down to maintain that target voltage.

Each voltage setting corresponds to a specific height that optimizes the arc characteristics for a clean, straight cut. Torch height has the greatest affect on bevel angle of the plasma cut piece. Setting the voltage too high results in more material being removed from the top of the kerf than the bottom. This causes excessive top rounding and positive bevel (see Fig. 2). Setting the voltage too low results in too much material being removed from the bottom of the plate. This causes undercutting or negative bevel (see Fig. 3).

Today's torch height controls have many features and capabilities. But the two most important to understand are initial height sensing and arc voltage control. Piercing at the right height will save you money on parts. Cutting at the right height will ensure good cut quality and minimize expensive rework operations. When properly used a torch height control pays for itself in a short time.

Here are three recommendations for torch height controls:

- If your THC is broken fix it; if it is ancient, retrofit to a new one.
- If you don't have a THC on your plasma profiling machine, get one.
- If you are buying a new machine, get the best THC you can afford. To get the most out of your investment train your operators to use all of the THC functions.

A good THC with a well-trained operator at the controls will pay for itself in improved parts life, enhanced cut quality, and decreased downtime.

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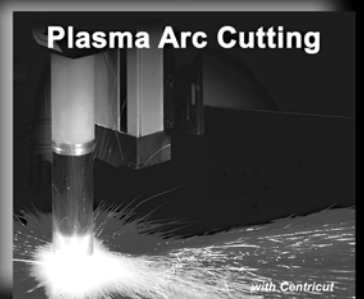
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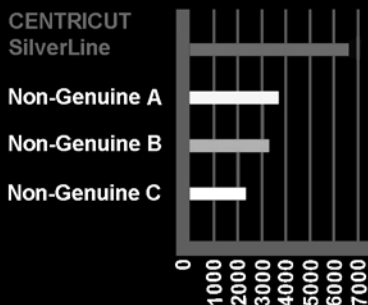
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

Troubleshooting PAC Systems: Parts Life Problems

One of the most common and frustrating problems in plasma-arc cutting (PAC) is short service life of parts. This problem hurts the fabricator both in increased consumable expense and in machine downtime for changing parts and troubleshooting. Most companies keep some record of parts life based on pierce counts, arc-on time, or the number of plates processed. The operator is usually the first to know when the parts aren't lasting as expected. Here are some technical tips to help the operator or maintenance man troubleshoot a parts' service life problem.

WARNING! Read all safety information in your operations manual before operating or repairing PAC equipment. PAC systems use high voltage and direct current (DC) electricity. Electric shock can injure or kill.

Symptom: The electrode and nozzle fail prematurely, causing a deterioration in cut quality, failure to pierce, or sudden loss of arc in the middle of a cut.

Background: The electrode carries the negative DC charge from the power supply. It is comprised of a copper holder that contains an emissive element of hafnium or tungsten—metals with high melting points that will sustain an arc. The emitting element is slowly eroded away by the heat of the arc, and the high velocity plasma gas stream. During normal wear a small concave pit is formed in the end of the part which steadily wears away, a few

thousandths of an inch at a time, to a depth of 0.040 to 0.125 in. deep. When the pit becomes too deep, the arc attaches to the copper holder and melts it. The electrode "fails" when it will no longer initiate and sustain an arc. It is a good practice to remove the electrode before it fails.

The nozzle focuses the plasma jet. The hole in the nozzle should be perfectly round and concentric. Both the diameter and length of the hole are critical: any damage to the orifice will affect the shape of the arc and, therefore, the quality of the cut piece. The plasma arc passes through the nozzle without contacting the copper material because the walls of the nozzle are protected by a boundary layer of swirling gas. If the arc does contact the nozzle it will melt some material away. Normal wear for a nozzle is slight chamfering or enlarging of the hole on the leading edge of the orifice. Some damage occurs to the face of the part during each pilot, causing heat discoloration around the orifice. Deposits of hafnium oxide can build up on the interior surface causing disruption of gas flow. The nozzle "fails" when it will no longer produce a straight arc and a good clean cut.

Normal parts life for state-of-the-art air and oxygen plasma systems is 1-2 hours of arc-on time and several hundred pierces. Some systems can reach 1,000 or more starts before a parts change is necessary.

Troubleshooting: The first step in solving any parts life problem is to examine the parts thoroughly and determine which part failed. The parts usually provide visible clues to the root cause of failure.

There are 3 possible cases:

• **Case 1:** Electrode Bad and Nozzle Bad

If inspection of the parts' service reveals that both electrode and nozzle are severely worn, it is likely that the electrode caused failure of the nozzle. Since the electrode is upstream, it will cause damage to the nozzle when molten material is blown out of the end of the part and deposited into the nozzle interior. If run long enough, all parts will fail in this way.

If the electrode has a deep wide pit and the copper has turned straw colored, blue, or black from overheating, the likely cause is low coolant flow. In extreme cases the end of the electrode may be melted away. Verify the flow rate of the cooling medium. In water-cooled torches check the cooling water flow rate with a bucket test at the return to the coolant tank. If it is not to spec, check for pump problems, kinks, leaks, plugged filters, or other restrictions. In gas cooled torches check for low gas flow.

Small pock marks all over the end of the electrode with corresponding damage to the interior of the nozzle indicates low gas flow. Low gas flow allows uncontrolled arcing between the nozzle and electrode. Check the gas flow rates to the torch. The best way to do this is with a flowmeter (0-400 cfh) and hose placed on the outlet of the torch with the system in test. If not available, a quick check is to feel the gas flow at the outlet of the torch with only plasma gas turned on. You should feel a swirling flow of gas that actually has a suction force.

If the electrode has a heavy layer of black residue, check for gas contamination. One quick check is the paper towel test. Hold a clean paper towel under the torch with gas flowing through the system. There should be no sign of moisture or contamination.

• **Case 2:** Electrode Good and Nozzle Bad

If the electrode appears virtually

new and the nozzle is severely damaged, the most likely cause of failure is double arcing of the nozzle. This occurs if the arc contacts the nozzle and erodes copper material from the orifice.

Damage to the interior of the nozzle such as a slot or "keyhole" indicates low pressure in the plasma chamber. This allows the arc to attach to the nozzle. Check for leaks in the gas lines by pressurizing the lines and using soapy water on all fittings.

Damage to the exterior of the nozzle often indicates a problem with torch-to-work distance. First check the pierce height; it should be two times the cut height to avoid metal spatter. Piercing too low is the number one cause of premature nozzle failure. Check for proper operation of the torch height control. If the torch pierces when it is pushed against the plate, or scrapes the plate during a cut, the nozzle will be instantly destroyed.

If the nozzle looks extremely hot, straw colored, blue-or black in color, check the shield gas flow. The shield gas helps to cool the nozzle and protect the front end of the torch.

• **Case 3:** Electrode Bad and Nozzle Good

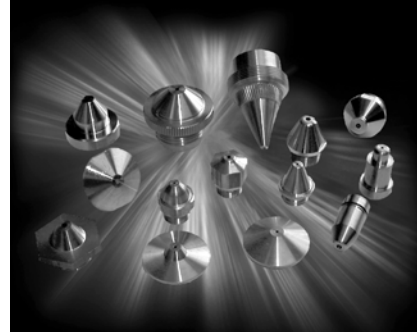
If the nozzle is in good condition but the electrode has a deep concentric pit, the plasma gas flow rate may be too high. When the plasma gas swirl is too intense, the element erodes quickly. This causes a rapid deep wear pattern. Check the volumetric flow rate of the plasma gas.

A fourth case also exists: if both parts look virtually new but the torch failed to "fire," and a new set allows the torch to start, the problem is not parts life; it's hard starting. Often, perfectly good electrodes and nozzles are discarded because they failed to fire. Hard starting is most often caused by excessive plasma pressure during preflow when the torch is igniting. Usually the torch "spits and sputters" and struggles to start.

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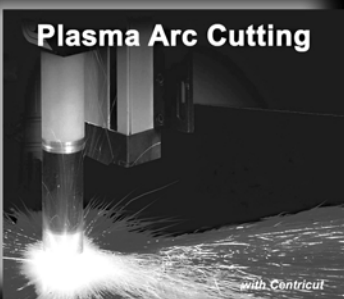
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Troubleshooting PAC Cooling Systems:

Increase Uptime and Parts Life by Keeping Cool

What is Torch Coolant?

Torch coolant is a working fluid composed of de-ionized water and a solute to depress the freezing point. Where there is no risk of freezing, many shops use plain de-ionized water. De-ionized water is used because it is free of conductive ions that can contribute to deterioration of the cooling lines and hard starting of the plasma torch. Figure 2 is a diagram of the internal coolant passages in a plasma torch. The coolant is similar to the agents used in an automotive cooling system with an important distinction: radiator antifreeze has materials to clog up leaks. These are not suitable for plasma systems.

The Cooling System

A typical PAC cooling system consists of a motor, pump, cooling lines, torch, flow switch, heat exchanger and reservoir (see Figure 1).

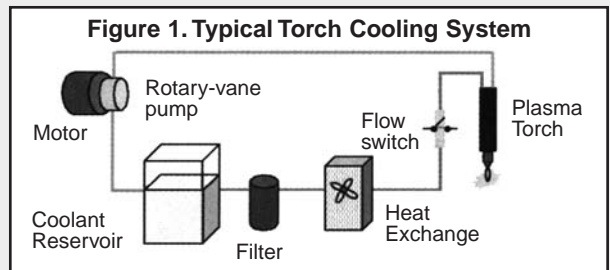
Motors $\frac{1}{8}$ to $\frac{1}{2}$ hp are standard. Usually the service of a motor is long unless there are constrictions in the system causing the motor and pump to work harder.

Pumps. Rotary vane pumps are typically used in plasma systems. These have an adjustable bypass screw that increases or decreases the operating pressure and flow of the pump. Bearings in these pumps wear out. The coupling between motor and pump can break. The vanes inside the pump can become worn down until the pump will no longer develop pressure.

Cooling Lines. Cooling lines carry coolant to and from the plasma torch. These usually contain the main DC power cables as well. Water-cooled power cables prevent the multi-stranded copper wire from overheating. In mechanized applications, cooling lines are usually routed through flexible power track or festooned above the cutting machine. They are subject to leaks from cracked or cut hoses, melted holes, damaged connectors, etc. Constructions are also common, particularly in the return hose from the plasma torch. Debris from parts failures may accumulate in the torch or in the return lead, restricting flow. The copper power cables can also break down from constant flexing allowing filaments of copper to clog up the ends of the hoses. Constrictions in the leads cause reduced flow and increased wear on the pump and motor.

Torch. The torch is usually the major constriction in any PAC cooling system. The internal water passages are small in order to increase the velocity of the coolant and maximize heat exchange. Most high amp electrodes are hollow-milled on the inside to create a post of copper around the emitting element. A water tube in a torch extends over this post and forces coolant along the post and against the back wall of

Figure 1. Typical Torch Cooling System



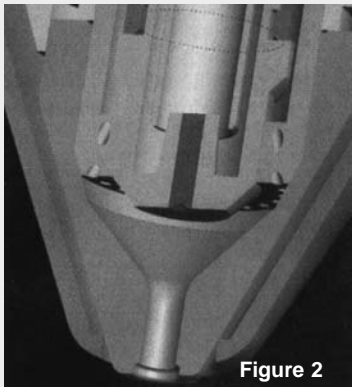


Figure 2

the electrode to remove the heat (see Figure 2). It is critical that the torch and coolant remain free of contamination to allow proper flow through these passages.

Flow Switches. Flow switches are designed to prevent catastrophic failure of the torch and parts in the event of low coolant flow. Brass block plunger type devices are typically used with a microswitch that must be satisfied for the system to run. Flow switches fail mechanically or electrically: either the plunger can stick or the switch components can fail.

Filters. Most systems use a particular filter similar to most commercially available water treatment filters. Five-micron paper filters or deionizing filters are standard. These should be changed every few months or whenever a drop in flow or pressure occurs.

Heat Exchangers. Most systems use some type of heat exchanger with radiator fins and fan to remove heat from the working fluid. Some systems actually chill the coolant using a refrigeration unit. The most common failure in these simple systems is fan motor burnout.

Coolant Reservoirs. These are typically equipped with a level indicator or float switch. The tank should be checked daily to make sure there is adequate coolant. Low coolant levels can cause air to be introduced into the coolant stream, which reduces cooling. If the system is interlocked, low coolant may cause intermittent or total shut down of the system. Particulate may accumulate in the bottom of the tank. This should be flushed out and removed. Usually the returning flow of coolant can be seen through the filler cap of the coolant reservoir.

Troubleshooting

Checking the coolant stream: If the coolant pressure or flow appears to fluctuate, check the coolant stream as it enters the top of the reservoir—it should be clear. If it

appears milky white then air is probably getting into the system—usually because of a low level in the reservoir. Add coolant over a two-minute period, while the pump is running, to keep the coolant at the recommended level. If this does not correct the milky white conditions there may be a loose connection on the inlet side of the pump that allows air to aspirate into the system. A common problem with rotary vane pumps is that the acorn nut and sealing gasket are sometimes left off after an adjustment is made to the output pressure. The acorn nut and gasket must be in place to prevent air from entering the system.

Checking the coolant path: If the pressure or flow readings are below the manufacturer's recommendation the complete coolant path must be checked. First, check the filter located just before the pump. Next, check the pump itself. Over time pumps will have to be adjusted to compensate for wear. Adjustment procedures vary with the type of pump and should be detailed in the instruction manual. Finally, inspect all hoses, leads and fittings to ensure everything is properly tightened and there are not any kinked or broken hoses.

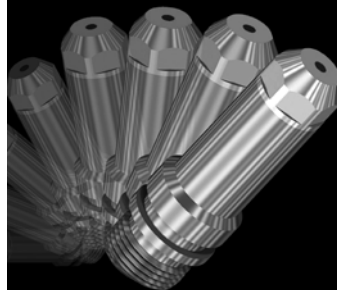
Checking the coolant flow rate—"the bucket test": To verify the actual flow through the system, perform this simple test. Remove the coolant return lead from the reservoir. Start the pump. Collect the returning flow of coolant in a clean container for a determined period of time (usually ½ to 1 minute), then shut off the pump. Measure the volume and convert this to gallons/ liters per minute/hour. Compare the findings to the manufacturer's recommendation.

Checking Coolant flow rate—flow meter: An even better way to ensure proper coolant flow is to install a water flow meter just before the return line to the coolant reservoir. A simple 0-4 gpm flow tube (under \$50) works well. This is cheap insurance against parts or torch failure.

Check coolant conductivity/resistivity: Over time coolant can begin to ionize and/or become contaminated with copper particulate or other conductive material. This can cause hard starting of the plasma torch because of the high voltage electricity used to initiate a pilot arc can be dissipated through the cooling water. A conductivity meter can be used to check the coolant. Coolant resistivity should be less than 10 microOhms or greater than 10,000 Ohms/cm resistance.

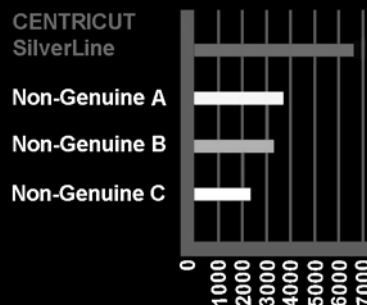
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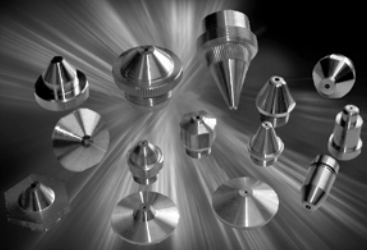


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CLASSROOM

Don't Cut Your Profits With Plasma

A productive and efficient mechanized plasma-arc-cutting operation can make the difference between profits and losses on a metal-fabricating job. A highly skilled operator produces more cut pieces, of higher quality, with less scrap material and less rework down the line. He saves money on torches and consumables by using them correctly, and minimizes machine downtime through simple preventive measures. Here we discuss 10 common mistakes that companies make in their plasma-cutting operations, and how to avoid each of them.

1. Using consumable parts until they blow. Look in your used-parts bucket and you will probably see parts that have been run to failure. Using severely worn consumables can not only ruin a good piece of metal, it can cause expensive torch failures and unnecessary downtime. The experienced operator can often tell by sound or arc color, or by subtle changes in torch height, when parts have worn. The best way to judge the condition of torch parts is to periodically check the cut-edge quality and check torch parts when the cut begins to deteriorate. Keep a record of the average parts life over time (in number of starts or arc-on time) and develop guidelines for expected parts life based on the amperage, material, and thickness. Once average parts life is established the operator will know when to check and replace the parts, preventing a failure.

2. Changing consumable parts too frequently. Look in your used-parts bucket and you may also find parts that are still usable. It is a common and expensive practice to change-out consumables too frequently. When an operator changes the parts, he needs to know what to look for. If a nozzle is gouged or if the

hole is worn out-of-round it should be replaced. To tell if an electrode is spent, check the pit in the electrode element—the element is the silver-colored insert held in the copper: hafnium for air and O₂, tungsten for N₂ or Ar-H₂. Generally, the pit should not exceed 1/2 inch for air and O₂ and 1/8 inch for N₂ or Ar-H₂. Gas swirlers should only be changed if a close examination reveals dirt or grease in the holes, cracks, arc burns, or excessive wear. The same holds true for shields, which should only be replaced if they show signs of physical damage. Often shields can be cleaned of metal spatter and reused.

3. Using the wrong parts and parameters for the job. Consumable selection depends on the material and thickness being cut, the amperage and plasma gas used, and other parameters. The operator's manual will define which consumables are appropriate for various types of cutting. Using incorrect consumables can lead to shortened parts life and reduced cut quality. It is particularly important to run parts at the correct amperage. The best cut quality and parts life is usually achieved when amperage is set to 95 percent of the nozzle rating. Insufficient amperage causes sloppy cuts; excess amperage shortens nozzle life.

4. Assembling the torch incorrectly. The torch should be assembled so that parts align correctly and fit together snugly. This ensures good electrical contact and the correct flow of gas and coolant. When changing parts, keep consumables on a clean shop rag to prevent dirt or metal dust from contaminating the torch. When applying o-ring lube, use just enough to put a shine on the o-ring. Excess lubrication can cause clogging of the gas swirler and metal-dust contamination in the torch. This can lead to

uncontrolled arcing in the plasma chamber and, ultimately, torch failure. Grease should never be applied to the torches—it can cause destructive arcing and burning within the torch.

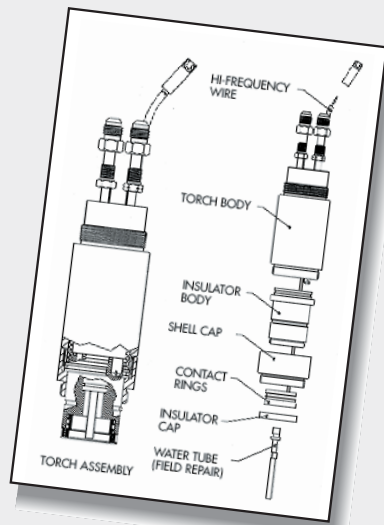
5. Neglecting routine torch maintenance. Torch threads must be kept clean and seating areas should be checked for contamination or mechanical damage. Clean any dirt, metal dust, or excess o-ring lubricant out of the torch using a cotton swab and electrical contact cleaner or hydrogen peroxide.

6. Not checking gas and coolant flow. Check the flow and pressure of gas and coolant every day. If flow is insufficient, consumables will not cool properly and parts life will be reduced. Inadequate flow of cooling water, due to worn pumps, clogged filters, low coolant level, etc... can cause parts and torch failure. Constant gas pressure is important to maintaining the cutting arc. Excess gas pressure is a common cause of hard starting, and can also cause rapid deterioration of electrodes. Likewise, plasma gas must be kept clean to prevent short consumable and torch life. Compressed-air systems are especially prone to oil, moisture, and particulate contamination.

7. Piercing too low. Even slight variations in torch height can affect the angularity of the cut surface. Torch height during piercing is particularly important. One common error is to pierce too low. This causes molten metal to spatter the front of the nozzle and shield. Arc snuffing can occur if the torch pierces when touching the metal, or drags along the surface while cutting. If the arc is snuffed, the electrode, nozzle, gas swirler, and sometimes the torch are destroyed. Piercing at a height of 1.5-2 times the recommended cut height protects the torch and parts.

8. Cutting too fast or slow. Cut too slow and cut pieces will develop low-speed dross—a large, bubbly accumulation of dross along the bottom edge. Slow speeds may also cause a widening of the kerf and excessive amounts of top spatter. Cut too fast and the arc will lag backwards in the kerf, causing a beveled edge, narrow kerf, and a small, hard bead of dross along the bottom edge of the cut piece, that is difficult to remove.

9. Stretching the arc. Arc stretching can occur at the beginning and end of the cut if the arc has to stretch, or



The torch should be assembled so that parts align correctly and fit together snugly. Torch threads must be kept clean and seating areas should be checked for contamination or mechanical damage.

deviate from a straight, perpendicular path, to find metal. Arc stretching can cause the arc to cut into the side wall of the nozzle. When performing an edge start, the plasma arc should be started with the nozzle orifice centered directly over the edge of the workpiece. This is important to remember in punch press-plasma operations where the arc is started from a punched hole. In this application, the arc should be started off the edge, not the center of the punched hole. Arc stretching can also occur at the end of the cut if the torch is programmed to run off the plate with the arc on, or if the lead-out follows the kerf of previously cut metal. Timing of the arc-off signal and programming of the lead-out can minimize this effect.

10. Crashing the torch. Torch collisions with the workpiece can be prevented by programming the shape-cutting machine to travel around, rather than over, cut parts. Torch-height sensors also offer protection from torch crashes by correcting for variations in the material. However, voltage-regulated height controls can fail to protect the torch. For example, torch diving often occurs at the end of a cut if the torch follows the kerf for too long. The torch-height control dives to compensate for increased voltage as the arc stretches. Careful programming of the lead-out and torch-height control function can minimize this. Finally, breakaway torch-mounting devices can help prevent damage to the torch if a collision does occur.

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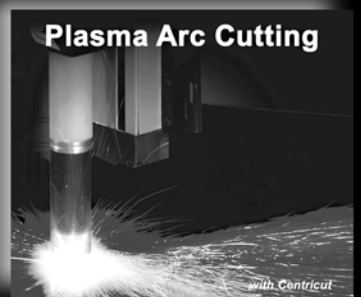
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CLASSROOM

Written By: David J. Cook, Kirk Ferland, and Jason Start

Electrode wear in air, oxygen plasma

How to tell good electrode wear from bad to improve system performance



Electrodes for high-powered plasma cutting systems are highly engineered, consumable parts, similar in design, material, and function to an automotive spark plug. Like spark plugs, electrodes emit high-voltage electricity in a high-temperature environment.

The materials in electrodes must withstand the temperatures of plasma arc emissions; endure swirling, high-velocity gas jets; and provide an airtight seal for high-pressure gases and fluids. The electrode, like a spark plug, is the hardest-working component in the system.

A good mechanic can tell a lot about the health of a combustion engine by looking at the spark plugs. A trained plasma technician can do the same for a plasma system by learning how to inspect the electrode, understanding normal wear patterns, and knowing how to spot signs of trouble.

The electrode carries DC power from the plasma power supply to the metal plate. Typically, it comprises a copper or copper-silver composite holder that contains an emissive element of hafnium—a high-melting-point metal that can sustain an arc in air and oxygen cutting environments. The emitting element is eroded away slowly by the heat of the arc and the high-velocity plasma

gas stream. Most of this wear occurs at the start and stop of a cut, when the molten hafnium material quickly heats up and cools down, melting and then resolidifying.

During normal wear, a small, concave pit forms in the end of the part that wears away steadily, a few thousandths of an inch at a time, to a depth of 0.040 to 0.125 inch, depending on the torch and consumable design and materials (see **Figure 1**).

When the pit becomes too deep, the arc attaches to the holder material and melts it. The electrode fails when it no longer initiates and sustains an arc. If molten material from the electrode is deposited downstream into the bore of the nozzle, it causes a blowout—catastrophic failure of both the electrode and nozzle.

Normal electrode life for oxygen plasma systems is one to two hours of arc-on time and 200 to 300 pierces. Air systems typically can achieve twice this life, 400 to 600 starts, because the nitrogen component of air makes it less reactive with the electrode. Oxygen plasma systems with inert start gases and current ramping can reach 1,000 or more starts before an electrode change is necessary.

Plasma Arc Cutting (PAC) System	Copper Electrodes	Copper-Silver Composites
	Inches of Wear	Inches of Wear
High Precision (Oxygen Plasma)	0.030 - 0.050	0.060 - 0.080
Water Injection (Oxygen Plasma)	0.040 - 0.080	0.100 - 0.140
Conventional Dual Gas (Oxygen Plasma)	0.040 - 0.080	0.100 - 0.140
Conventional Dual Gas (Air Plasma)	0.090 - 0.120	0.100 - 0.140

Figure 1

During normal wear, a few thousandths of an inch of an electrode wears away each time it's used, depending on the torch, consumable design, and materials.

Figure 2

New Condition



Figure 3

Normal Wear



Figure 4

Normal Wear Half-life



Figure 5

Off-center Burn



Electrode Examples

Knowing the difference between good and bad electrode wear can help you improve your system's performance.

New Condition. **Figure 2** shows a picture of a new electrode. This electrode is a welded copper-silver composite with silver on the front and copper on the back.

Normal Wear. **Figure 3** shows an electrode with a normal wear pattern. The hafnium pit is well-centered and uniform in shape, indicating good alignment of consumables and a proper plasma gas swirl. The depth of the pit is approximately 0.100 in. The front edges of the electrode are sharp and distinct, and the silver has no severe discoloration. Some grayish-colored oxides

Figure 6

Moisture on Start



Figure 7

Coolant Leak



Figure 8

Low Pre-flow



Figure 9

Blowout



Figure 10

Low Plasma Gas (Snuffing)



Figure 11

High Gas Flow



on the front surface of the part are normal.

Normal Wear Half-life. The electrode in Figure 4 shows a normal wear pattern that has been pulled prematurely for another reason, such as the torch riding the plate; torch crash; voltage change (when the voltage rises as the distance between the torch tip and plate increases); or a change in cut quality, such as slagging or excessive beveling. The pit depth is 0.078 in. Although this part looks consumed, it may burn another 100 starts or more and proceed to a depth of 0.100 or 0.140 in. before approaching failure.

Off-center Burn. Figure 5 exhibits an off-center burn. This problem can be easy to spot. It usually indicates a severe gas flow problem—such as a broken or clogged swirl ring—or a torch part misalignment caused by assembly errors or fit-up problems. If completely changing torch parts doesn't correct the problem, the torch probably is damaged.

Moisture on Start. Figure 6 shows that moisture was present during the arc start. This electrode has a rough swirling arc track from the wrench flats—the side of the part where the wrench fits—down to the face of the electrode. Pre-flow gas moisture can cause the high frequency to attack the silver material. The front edges of the silver aren't sharp; instead, they're smoothed over with a sandblasted surface condition.

Check pre-flow gas for signs of moisture. One quick check is the paper towel test: Hold a clean paper towel under the torch with gas flowing through the system (in the test or gas check mode only). No sign of moisture or contamination should be present.

Coolant Leak. As shown in Figure 7, coolant leaks produce severe arcing of the electrode face and sides, characterized by pitting and pocks in the electrode surface. The front surface is rough and black with shiny melted spots of holder material.

This problem often is caused by cut O-rings, insufficient O-ring lubrication, or loose or misaligned parts. The paper towel test can detect a coolant leak, as can a mirror, on which mist will form.

Low Pre-flow. Figure 8 illustrates how insufficient gas during arc initiation produces a "lazy start"—the arc takes too long to travel from the start point, usually a sharp corner like a wrench flat, to the emitting element. These parts have a fairly uniform ring of molten holder material surrounding the pit. The surface may look like a solder splash or weld puddle has formed along the front of the part.

Blowout. Figure 9 shows an electrode that has been run to catastrophic failure. Because the electrode is upstream, it will damage the nozzle when molten material is blown out of the end of the part and deposited into the nozzle interior.

Low Plasma Gas (Snuffing). Low gas flow is indicated if the electrode has small pockmarks all over its end and there is corresponding damage to the interior of the nozzle (see Figure 10). Low gas flow produces uncontrolled arcing between the nozzle and electrode.

Check the gas flow rates to the torch. The best way to do this is with a flowmeter (0 to 400 cubic feet per hour) and a hose placed on the outlet of the torch with the system in test mode.

If a flowmeter isn't available, a quick check is to feel the gas flow at the outlet of the torch with only plasma gas turned on. You should feel a swirling flow of gas that actually has a suction force.

High Gas Flow. If the nozzle is in good condition but the electrode has a deep, concentric pit, the plasma gas flow rate may be too high (see Figure 11). If the plasma gas swirl is too intense, the element erodes quickly. This can cause a rapid, deep wear pattern. Check the volumetric flow rate of the plasma gas.

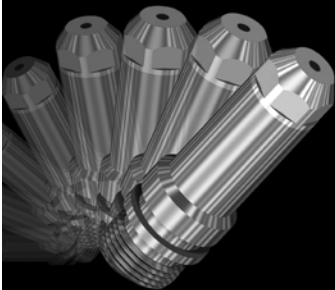
Learning how to identify different types of electrode wear can help you anticipate failure, save money on parts, and improve system performance.

David Cook is technical services director, Kirk Ferland is technical service team leader, and Jason Start is field service technician of Centricut LLC, Two Technology Drive, West Lebanon, NH 03784, phone 800-752-7623, fax 800-317-0438, e-mail djcook@centricut.com, Web site www.centricut.com. Centricut is a manufacturer of consumables for thermal cutting torches.

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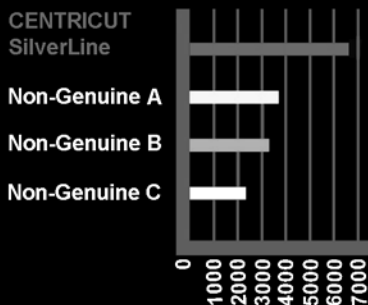
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CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

What to know before selecting a manual plasma unit

Understanding size, power, components, cost

The first plasma arc cutting (PAC) systems, developed in the '60s, were 1,000-amp monsters designed to blast through 6-inch stainless steel. Their mechanized torches were moved by X-Y cutting machines and powered by DC units the size of refrigerators. Surprisingly, the PAC industry evolved from high- to low-amp systems, water- to gas-cooled, and from gas- to air-cooled.

Today's hand-held air PAC systems are lightweight, portable, and relatively powerful for their size. They are used for cutting everything from thin-gauge metals to 1-inch plate. More traditional console PAC systems also are available to handle cutting tasks up to 2 inches and more. Hand-held PAC systems are now the fastest-growing segment of the PAC market because they offer a fast, efficient, and affordable way to cut.

This article offers an overview of manual PAC technology from the early days to the present, including an explanation of different power supplies, recommendations for selecting and sizing a system, and other functions and features to look for in a hand-held system.

Regardless of the size, all PAC systems contain the same basic components, including a gas supply, DC power supply, and plasma torch. The torch requires a circuit to initiate an arc and a cooling system.

Gas Supply

Most older plasma systems used nitrogen as the plasma gas and air or CO₂ as the secondary gas, which required expensive bottles or bulk containers. Now, most hand-held systems use clean, dry shop air to cool the torch and provide the necessary plasma gas.



Shop air currently is the most affordable and versatile plasma gas. It is readily available and provides good cut edge quality on mild and stainless steel and aluminum. With the exception of special applications, such as thick stainless steel and aluminum cutting or plasma gouging, almost all hand-held systems today use air plasma. Several manufacturers even have developed air plasma systems with small, onboard air compressors.

Power Supplies

PAC power supplies are direct current electrode negative (DCEN). The process requires a constant source of DC and a high open circuit voltage (OCV) to initiate the arc (typically at least twice the operating voltage). The following is a summary of some basic differences among PAC power supply types.

DC Droopers. Early plasma systems included "drooper" power supplies, named for their drooping output power curves. These units provided a high OCV and relatively stable current and operating voltage.

Metal Thickness	Minimum Recommended System Size	Approximate Cutting Speed*
18 ga.	12 amps	35-100 IPM
1/8 in.	12 amps	10-20 IPM
1/4 in.	25 amps	15-20 IPM
3/8 in.	40 amps	25-35 IPM
1/2 in.	55 amps	25-40 IPM
3/4 in.	80 amps	10-25 IPM
1 in.	100 amps	10-15 IPM

*Ranges shown are based on claims of several manufacturers. Speeds are based on carbon steel cutting. Actual cutting speeds vary, depending on torch and power supply design.

Figure 1 Material thickness determines the system size.

They used a fixed-output DC rectifier bridge consisting of a series of diodes to convert AC power from a transformer into usable DC for the cutting process.

These simple systems created a lot of power but wasted energy and had too much "ripple" in their output power. (Ripple is fluctuations in DC output that cause a rough cut and short part life.) To further regulate power output, multiple transformers could be used, each providing a higher level of output current.

Reactors. Reactor power supplies were the next step in power regulation. These used a reactor device to control the amount of AC voltage supplied to the bridge rectifier. The reactor consisted of a group of AC coils with a DC winding around it. The current in the DC winding controlled the amount of AC that passed through the reactor, which created an adjustable transformer that allowed variable DC output from the bridge.

SCRs. Silicon-controlled rectifiers (SCRs) are another type of continuously variable output power supply.

SCRs convert three-phase AC power from a transformer directly to DC. They require huge capacitor banks and large transformers. SCR systems are large and powerful and are used for high-amp PAC systems but are not well-suited to hand-held applications.

Switch-mode. Switch-mode power supplies use transistors to modulate DC power after the rectifier. **Choppers** are a type of switch-mode power supply that use power semiconductor devices such as isolated gate bipolar transistors (IGBTs)—which take raw DC with ripple and chop it up, rapidly switching the power on and off to smooth the output characteristics. IGBTs can be fired much faster than old reactor-type power supplies. The result is a very smooth output power curve.

Inverters are another type of switch-mode power supply. They use devices such as transistors on the input side of the power train to raise the frequency of the AC into the

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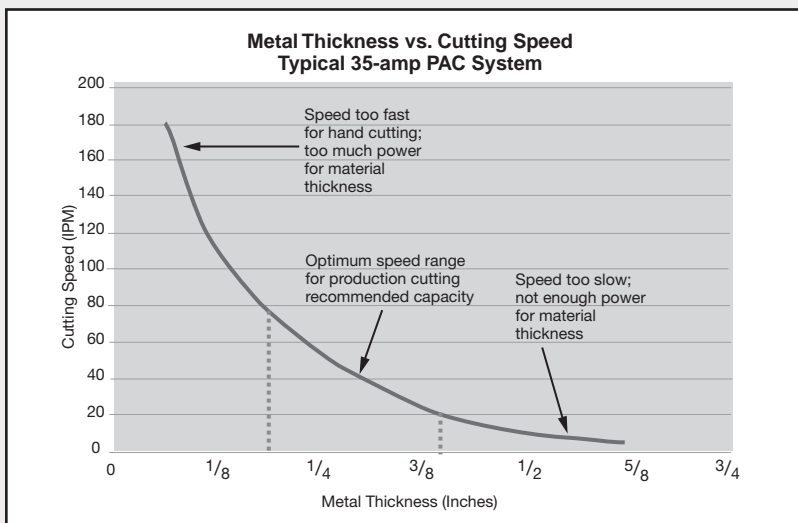
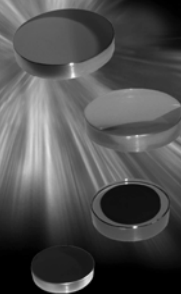


Figure 2

If the system doesn't have a recommended capacity rating, an analysis can be made by referencing the cut charts or a cut speed curve.

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What to know *Continued*

transformer. Higher frequency input allows a much smaller transformer to be used. Because a smaller transformer is used, inverters are much lighter and more portable than conventional power supplies, making them ideal for hand-held applications.

Early inverter power supplies were limited by low output current and complicated design and poor reliability. When problems occurred, sophisticated techniques and troubleshooting were required to solve them.

Today's inverters are more reliable, robust, and powerful. Most manual PAC systems now use inverter or switch-mode technology. These sophisticated, electronically or microprocessor-controlled devices are better able to tolerate variations in line voltage, take more abuse in the field, and deliver better cutting performance while consuming less power.

Torches

All plasma torches contain the same basic elements, including:

1. an electrode to carry the negative charge from the power supply.
2. a gas distributor, or swirl ring, to spin the plasma gas into a stable, swirling vortex.
3. a nozzle to constrict and focus the plasma jet.

The torch is primarily a holder for the consumable parts. Torch improvements have been aimed at optimizing the torch and consumable designs to improve cooling, enhance starting characteristics, and increase cutting capacity. Improvements also have been made in material selection for consumables and torches to improve durability, such as using high-temperature durable plastics in place of ceramics.

Ergonomics have improved with features such as trigger torches, better handle designs, and options for torch angle or adjustable torch heads. Safety improvements include parts-in-place (PIP) circuits and switches or triggers to prevent the torch from firing without the parts properly installed and the operator ready.

Most hand-held systems on the market today use one of two methods

to initiate the plasma arc. The tried-and-true method is a high-frequency (HF) starting circuit built into the power supply. This system uses a high-voltage transformer (similar to a bug zapper), capacitors, and spark-gap assembly to generate a high-voltage spark at the torch.

The spark ionizes the plasma gas, enabling current to flow across the air gap between the nozzle and electrode. The resulting arc is called the pilot arc. High-frequency starting systems are simple, relatively dependable, and require no moving parts in the torch. However, they do need periodic maintenance to prevent hard-starting problems. Another potential problem is that high frequency radiates from the system, creating electrical noise that may interfere with sensitive electronic equipment.

Contact start torches use a moving electrode or nozzle to create the initial spark that enables the pilot arc. When the torch is fired, the electrode and nozzle are in contact in a "dead short," or short circuit. But as the gas enters the plasma chamber, it blows the electrode back (or the nozzle forward), creating a spark. This process is similar to the spark created when a household electrical plug is pulled quickly from a receptacle.

Contact start torches produce much less electrical noise than HF systems. These also are "instant-on" torches, which reduce cycle time because of the lack of preflow.

Sizing a System

The machine should have sufficient power to handle typical cutting tasks with ease, and it should be able to cut the material at about 20 inches per minute (IPM) or faster. When an operator becomes accustomed to the speed of PAC, it is possible to hold the line profiling at 70 to 80 IPM. Even faster speeds are possible with template cutting or cutting accessories such as circle cutters and rolling plate followers.

Before purchasing a system, the three material considerations are:

- Types of materials to be cut
- Thickest and thinnest materials to be cut
- Most commonly cut material thickness

The third consideration is the most important when selecting a plasma system. Often, errors are made in sizing a system for an application, and too little or too much power is acquired for the most common cutting task.

Underpowering, or trying to cut at the high end or over the system's cutting capacity, will lead to poor cut quality, low cut speeds, and high torch and part consumption. Overpowering can lead to cut quality problems, such as heat distortion, wide kerf, and low-speed dross. Generally, more power is better, especially because most systems now allow variable output so that the power can be dialed down for thinner materials. **Figure 1** includes some basic cutting capabilities for a range of different amperages.

Equipment manufacturers rate the cutting power of a PAC system with a thickness or capacity rating. These ratings are based on carbon steel and list the thickest metal that the system will cut with reasonable speed and cut quality, from an edge start. In an **edge start**, the operator fires the torch with the nozzle just over the edge of the plate, then begins cutting.

For a **pierce start**, the operator fires the torch over the plate and blows a hole through the material before cutting. Piercing through material requires more power and operator skill than edge starting. For these reasons, the pierce rating, or piercing capacity, usually is half the cutting capacity. For example, most 100-amp systems will cut 1-inch plate from an edge start, but the thickest they will pierce is ½-inch plate.

Some manufacturers also offer a recommended capacity, which is a more useful specification than maximum capacity. The **recommended capacity** is the optimum thickness for the machine in terms of quality, parts life, cut speed, duty cycle, overall productivity, and cost of operation.

If the system doesn't have a recommended capacity rating, an analysis can be made by referencing the cut charts or a cut speed curve (see Figure 2). The regularly cut material should fall somewhere in the middle of the cut chart, and the corresponding speed should be at least 20 IPM.

Cost of Operation

Many variables contribute to the overall cost of operation for PAC, including labor, power, duty cycle, gas, shop air maintenance, consum-

ables, consumables life, speed of cut, amount of cleanup, or secondary operations required.

The two most important factors to consider when purchasing new equipment are consumable cost and consumable life. Because the part life of different systems varies, consumable cost alone is not the best measure of a system's cost of operation.

Consumable cost, or the total consumable cost divided by the consumable life in hours of arc-on time per hour, is the most useful measurement. For example, if the cost of a nozzle is \$4, the cost of the electrode is \$6, and together a set lasts 2.5 arc hours, then the cost per hour, or CPH, is $(\$4 + \$6)/2.5 = \$4$.

Just the nozzle and electrode are used for this calculation because the other consumable parts are designed to last much longer. To calculate CPH for all torch components, a weighted average should be used based on usage ratios. Typically, shields, swirl rings, and caps outlast nozzles and electrodes in a minimum 20-to-1 ratio.

Before purchasing a new handheld system, a company should do its homework by:

- Knowing what kind of power supply technology is used and understanding the system's capacity.
- Not skimping on power by purchasing enough power to do the job with ease.
- Calculating the cost of operation.
- Looking for an ergonomic and safe torch design.
- Testing the sales claims with a real-world cut test.
- Making sure the system is backed up by a good warranty.
- Adding technical support after the warranty expires.

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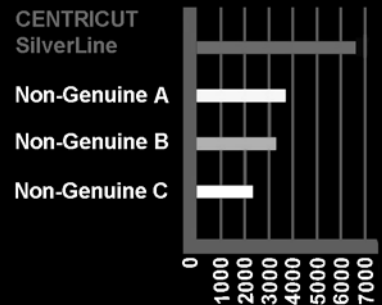
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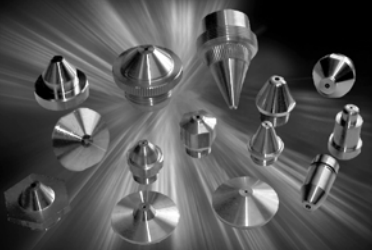
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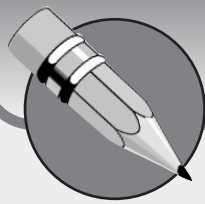
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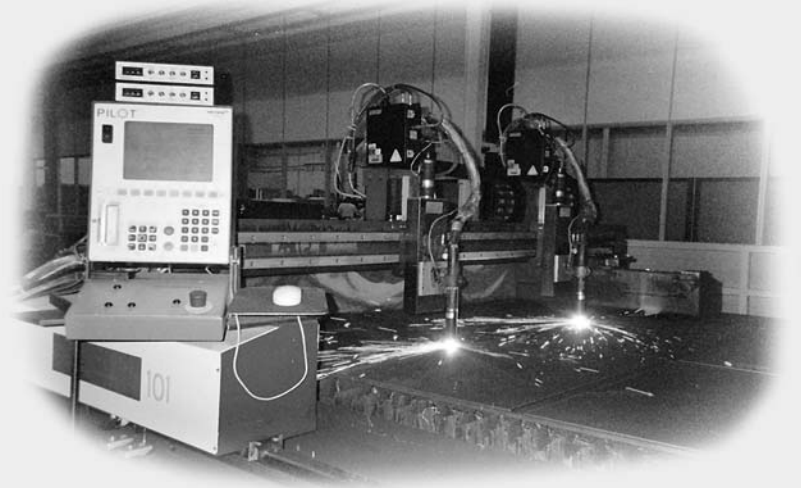


CLASSROOM

Written By: David J. Cook
Centricut Technical Services Director

CNCs form mechanized shape

What you need to know before you buy your next control



The computer numerical control, or CNC, is the most critical component in a mechanized shape cutting system. This article provides an overview of CNC technology, including the function of the CNC in a motion control system, a short history of CNCs for mechanized shape cutting, common control features, and a glimpse at the future of CNCs and related motion control technology. A basic understanding of the technology will prepare fabricators to spec out a control that meets the needs of their cutting operation as well as their financial requirements.

Motion Control Systems

A motion control system converts input commands into mechanical motion. Figure 1 shows the four main components of a typical motion control system:

1. CNC
2. Driver
3. Mechanical tool positioner
4. Feedback devices

The **CNC** is the "brain" of the motion control system. It controls the human machine interface (HMI), where the machine operator enters input commands. It processes the

input commands into output signals that will actuate the driver and responds to feedback loops to track position and speed correctly.

CNCs for mechanized shape cutters usually consist of a processor, some amount of internal memory, a keypad, an alphanumeric display screen, and a communications link. The operator loads CAD-generated part programs into the control either by disk or by downloading from a host computer. The CNC generates a path profile by making a series of calculations or cutting algorithms and then sends the path profile commands to the driver.

The **driver** provides the "muscle" in a motion control system. It translates commands from the "brain" (the CNC) into physical motion. In a shape cutting system, the driver is a drive amplifier/motor combination. Pulse width modulation (PWM) DC servomotors typically are used on shape cutters because of their high efficiency and response.

The **mechanical tool positioner** is the shape cutting machine. It acts as "bones" that support the movement of the system. **Figure 2** shows a typical gantry-style cutting machine. Rack-

and-pinion drives are the most commonly used method of motion transmission.

Bearings support the moving elements of the machine in the X, or longitudinal (the bridge moving along the rails), and Y, or transverse (the carriage moving along the bridge), axes. The cutting tool moves up and down in the Z axis. This function often is controlled by a separate motion control system—the automatic torch height control.

The **feedback devices** are sensors used to relay information back to the control. Shape cutters usually use encoders and tachometers for feedback loops. Encoders track the cutting tool's position. Tachometers measure velocity and acceleration. **Figure 3** shows a typical velocity and position loop.

Most current systems close the position and velocity loop. This means that the position and speed of the cutting tool are monitored constantly and relayed back to the CNC. The CNC compares actual speed and position with commanded speed and position, making constant adjustments to keep the cutter on path and at the correct speed. The faster this information is updated and exchanged, the more accurate the cut path will be.

Original Technology

In the 1970s and early '80s, several companies introduced programmable general-purpose automation tools. These early CNCs were fairly primitive devices with little programmability. They were based on microcontroller technology and used eight-bit microprocessors with peripheral devices such as serial ports, chip select circuits, and parallel ports.

Later on, these controls were upgraded to 16-bit microprocessors. After 16 bit came the 32-bit digital signal processor (DSP). Each of these new processors doubled the speed of the operating system.

Still, all of these systems used embedded CNC microcontrollers and thus relied on EPROMs (electrically programmable read only memory), which were physical chips that contained the software. The programming language was machine code or assembly language. Any change to the software in the EPROM necessitated installation of a new chip.

In the mid-'80s, the personal computer became the predominant technology used in development stations. With the PC came motion control cards (MCCs). This meant that the operator could use a PC for the "front end"—the HMI, including the keypad,

screen, joystick, etc.— and offload the motion control algorithms to the MCC. The feedback loops, such as velocity and position, also were controlled by the MCC.

This led to a dramatic change in CNC technology. Computer chipmakers made continuous improvements to their processors to increase computation speed. With faster processing speeds, bigger hard drives, and more memory to work with, CNC manufacturers were able to add more functions and features to the controls.

New Technology

Most CNC manufacturers now use PC-based controls in one form or another. They use DOS-based, Windows®, or Windows NT platforms, bringing the power of Microsoft and Intel® to the cutting machine. These economies of scale keep the prices of off-the-shelf computer component parts affordable.

In addition to handling the HMI, PCs now can use a graphical user interface (GUI). Graphics make the CNC more intuitive and easy to use. The higher-level programming languages such as C++ are more powerful and allow CNC manufacturers to acquire the engineering resources to develop better products.

CNC original equipment manufacturers (OEMs) are divided into two schools that are as much philosophical as technical. One group uses the PC platform to handle the HMI and offloads the motion control algorithms and feedback loops to an MCC or DSP. This method of distributed processing allows additional MCCs to be added without slowing down the user interface. It is also a stable platform. However, as much as 30 percent of the processing speed is wasted on communications between the processor and the MCC.

The other group of CNC developers uses the PC to control all functions; one processor handles all the HMI, path profiles, cutting algorithms, position and velocity loops, and file storage. This approach can result in increased speed and tight coupling of the output commands and the feedback loops. It also limits the hardware necessary and allows changes and updates to be added through software. However, adding more devices to be controlled theoretically could slow down the processing speed, causing the graphics and user interface to slow down as well.

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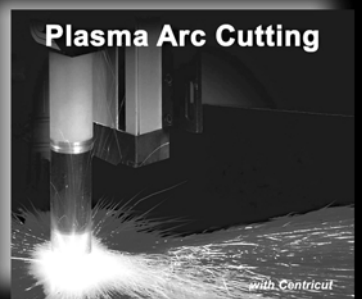
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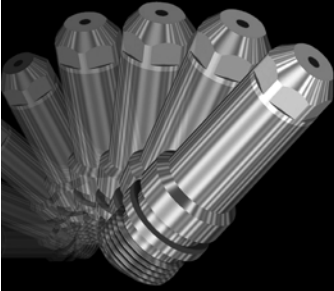
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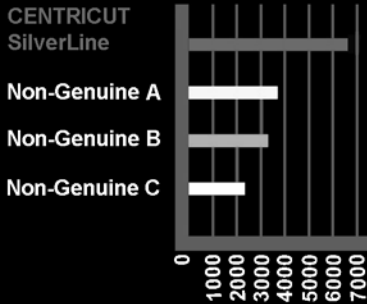
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CNC form mechanized shape *Continued*

Functions and Features

Here is a list of functions and features to consider when purchasing a new CNC.

1. Ease of use. Many CNCs are intuitive and as easy to use as a Windows-based program. Features such as good graphics, clear and bright screens, touchscreens or tactile

softkeys, and online help screens help to make the CNC easier to use and may reduce expensive training time and errors. These features aren't just bells and whistles—they help to reduce operator training time and expensive errors.

2. Processing speed. The speed of the CNC's processor is important.

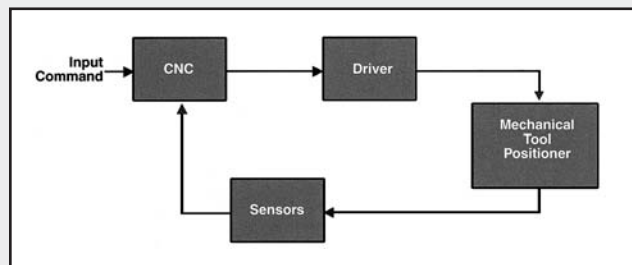


Figure 1

This motion control system flow chart shows how input commands are converted to mechanical motion.

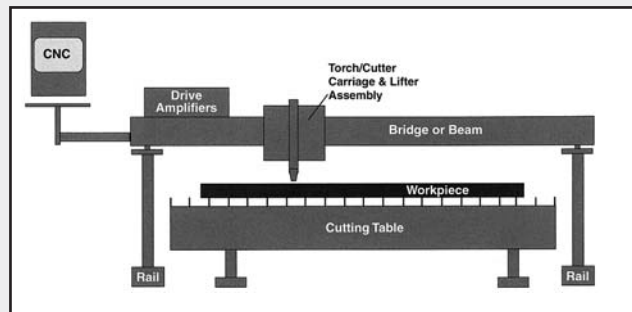


Figure 2

This is a typical gantry-style cutting machine. Bearings support the moving elements of the machine.

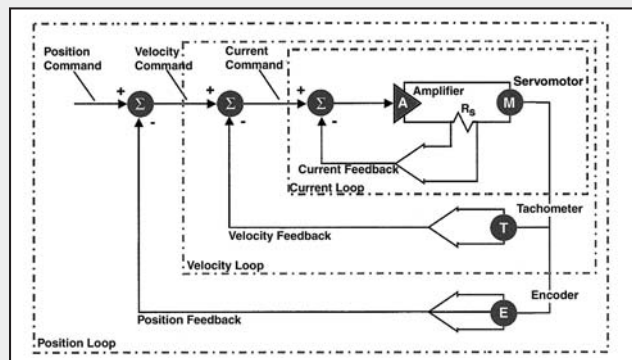


Figure 3

By using a system with velocity and position loop, the position and speed of the cutting tool are monitored and relayed back to the CNC.

PC-based controls now offer speeds up to 266 megahertz. It is possible (but not necessary yet) to use the 600-megahertz Pentium® chip in a PC-based control. Faster processing speed means faster download times for large nests of parts, faster kerf compensation, and better resolution on feedback devices. However, there is a point of diminishing returns in which the added performance does not justify the cost.

3. Accuracy. Closed-position and velocity loops help to maintain smooth motion and accuracy in the path profile throughout the range of possible velocities. Real-time motion displays allow the operator to verify visually that the cut path is accurate.

4. Communications. Speed of communications is important. If part programs are downloaded from a host computer, a fast modem is helpful. Serial ports with 115 to 230K baud rates are available.

5. Noise suppression. Sensitive components in the CNC must be isolated from electrical noise or electromagnetic interference (EMI) that radiates from plasma cutters, welding equipment, and other sources. The input and output ports to the CNC should be protected by adequate shielding and/or optical-isolation ports.

6. Data management. CNCs need sufficient hard drive space to store commonly used data files. This speeds upload times and simplifies operation. One- to three-gigabyte hard drives are available from several manufacturers. This hard disk space also can be used to store online help files, digital cut charts, parts life records, and inventory control systems.

7. Open architecture. Open architecture means that the CNC is built with industry-standard software and hardware components, which reduces the manufacturer's costs and, in turn, lowers the end user's initial capital cost. Replacement parts for open architecture CNCs also are significantly lower than proprietary components. If a part in the control such as the CRT or a disk drive breaks, replacements are readily available from computer parts suppliers.

8. Technical support. Despite the sales claims, no product is perfect. Technical support always is required. CNC manufacturers should back up their products with service, which means fast turnaround on factory repairs, access to well-trained technicians and engineers, and a strong commitment to customer satisfaction.

Future Technology

Several manufacturers are working on ways to collapse some of the distributed processes used on cutting machines. This could eliminate a lot of duplicated hardware and software effort, lowering the system's cost and making it easier to use.

For example, the automatic torch height controls used in plasma arc cutting usually have a separate motion control system. This system can be bundled into the CNC. Power supplies and gas consoles for plasma systems are also laden with duplicated automation hardware and software that can be collapsed into the CNC.

The goal of new-product development will be to provide more accurate positioning, better cut quality, and, most of all, simplicity and ease of use. With a centralized system, the cutting machine can be fully automated and the cutting process reduced to just a few steps.

The machine operator will load the plate and punch in the material type and thickness. The CNC will adjust all parameters for the cutting process automatically and provide the operator with a digital cut chart showing these parameters and the required parts to be used in the cutting device. When the operator hits start, the CNC will be in "autopilot"—all parameters will be adjusted dynamically to provide the best cut quality, parts life, and speed. When the cutting operation is complete, the operator will unload a full nest of near-perfect cut pieces.

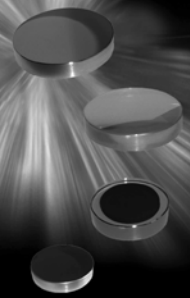
Conclusion

CNC technology has come a long way in the past 25 years. If you are a fabricator shopping for a new shape cutting machine or upgrading an older one for improved reliability and functionality, you will need to take a close look at current CNCs.

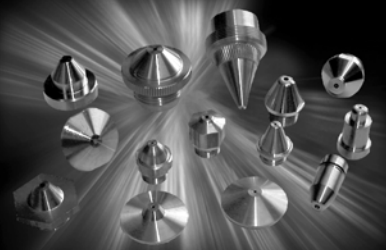
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