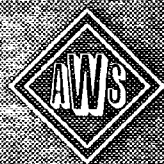


# **Recommended Practices For Plasma Arc Cutting**



AMERICAN WELDING SOCIETY

**AWS C5.2-83**

**Recommended  
Practices  
for  
Plasma Arc Cutting**

**Superseding  
AWS C5.2-73**

**Prepared by  
AWS C5 Committee on Arc Welding and Arc Cutting**

**Under the Direction of  
AWS Technical Activities Committee**

**Approved by  
AWS Board of Directors, August 15, 1981**

**AMERICAN WELDING SOCIETY, INC.**  
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These recommended practices are subject to revision at any time by the responsible technical committee. They must be reviewed every five years and if not revised, they must be either reapproved or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this document are requested and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the responsible technical committee and you will be informed of the committee's response. Guests are invited to attend all meetings of AWS Committees to express their comments verbally. Procedures for appeal of an adverse decision concerning your comments are provided in the Rules of Operation for AWS Technical Committees. A copy of these Rules can be obtained from the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126.

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## Foreword

These recommended practices, prepared by the AWS C5J Subcommittee on Plasma Arc Cutting of the AWS Committee on Arc Welding and Arc Cutting, are intended to guide cutting operators and supervisors in the use of plasma arc cutting equipment. They should be supplemented with the instructions provided by the equipment manufacturer.

Comments on the content and usefulness of this publication will be welcomed by Subcommittee. Communications should be addressed to the Secretary, AWS C5 Committee on Arc Welding and Arc Cutting, American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126.

# Recommended Practices for Plasma Arc Cutting

## 1. Introduction

### 1.1 Process Description

Plasma arc cutting is a process which severs metal by melting a localized area with the heat of a constricted arc and removes the molten material with a high velocity jet of hot, ionized gas issuing from the orifice.

In the early 1950's, it was discovered that the properties of the open arc, as used in gas tungsten arc welding, could be greatly altered. The arc was constricted by directing it through a water-cooled copper nozzle located between an electrode (cathode) and the work (anode). Instead of diverging into an open arc, such an arc is constricted by the nozzle into a small cross section. This action greatly increases the power density of the arc. Both the arc temperature and the voltage are raised. An arc passing through a constricting nozzle obtains a high velocity and becomes well collimated and intensely hot.

Figure 1 shows arcs operating in argon at 200A. The plasma jet is only moderately constricted by the

3/16 in. (4.8 mm) diameter nozzle, but operates at twice the voltage of the open arc and has a much hotter plasma.

Moreover, the plasma cutting arc is considerably hotter than the example described in Fig. 1. Greater temperatures are possible because of the high flow of gas. The flow forms a relatively cool boundary layer of non-ionized gas inside the nozzle bore. This, in turn, increases the amount of arc constriction. The thickness of this boundary layer can be increased by swirling the cutting gas. The swirling action forces the cool, non-ionized gas to move radially outward and form a thicker boundary layer.

The characteristics of the plasma jet can be altered greatly by changing the gas type, flow rate, arc current, and nozzle size. For example, if low gas flow rates are used, the jet momentum is reduced. Such a plasma jet forms a highly concentrated heat source that is ideal for welding. Conversely, if the gas flow rate is increased sufficiently, the momentum of the plasma jet will be high enough to expel the molten metal created by the heat of the plasma arc, resulting in gouging or cutting.

## 2/RECOMMENDED PRACTICES FOR PLASMA ARC CUTTING

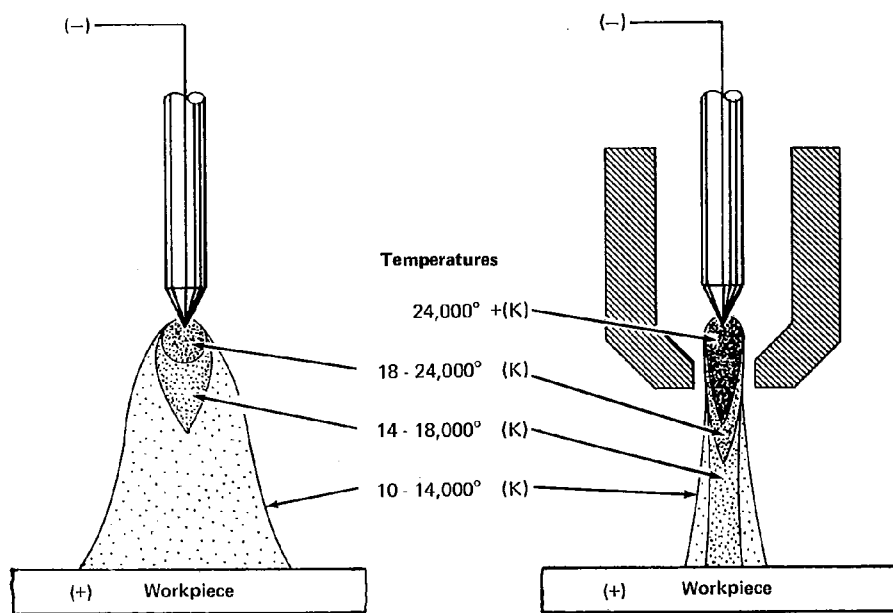


Fig. 1 — Temperature differences

**1.2 Safety**

The potential hazards associated with plasma arc cutting are similar to those of most arc welding and cutting processes. The obvious hazards such as fires, burns, etc., that are related to the heat of the arc are discussed briefly at the end of this section. Emphasis is placed on the less obvious hazard categories of electrical shock, fumes and gases, noise, and radiation.

The equipment should not be operated until the manufacturer's instructions have been read and understood. In addition, other potential physical hazards such as those due to the high pressure gas and water systems should be considered.

Some secondary, or orifice, gas mixtures contain hydrogen. Inadvertent release of such gases can result in explosion and fire hazards. Do not operate equipment where gas leaks are suspected. The manufacturer should be contacted if there is any question about the equipment operation.

**1.2.1 Electrical.** Voltages present in plasma arc cutting equipment generally range from 200 to 400V, direct current. Electric shock may be fatal. The equipment must be properly grounded as recommended by the manufacturer. Work practices should be followed as specified for the locality in which the equipment is installed.

Emergency first aid should be available. Prompt and trained emergency response may reduce the extent of injury due to an accidental electric shock. Untrained and unskilled personnel should not be permitted to

operate or maintain the equipment. In addition to the manufacturer's instructions, the following references may be of assistance:

- ANSI C2, *National Electrical Safety Code*<sup>1</sup>
- ANSI Z49.1, *Safety in Welding and Cutting*<sup>2</sup>
- 29 CFR 1910, *OSHA Safety and Health Standards*<sup>3</sup>
- American National Red Cross, *Advanced First Aid and Emergency Care*<sup>4</sup>
- NFPA Standard 51B, *Fire Prevention in the Use of Cutting and Welding Processes*<sup>5</sup>

Some additional safety reminders are listed below:

- (1) Keep all electrical circuits dry. Moisture may provide an unexpected path of current flow. Equipment cabinets that contain water and gas lines, as well as electrical circuits, should be checked periodically for leaks.

1. ANSI C2, *National Electrical Safety Code*, American National Standards Institute, 1430 Broadway, New York, NY 10018.
2. ANSI Z49.1, *Safety in Welding and Cutting*, American Welding Society, 550 NW LeJeune Road, Miami, Florida 33126.
3. 29 CFR 1910, *Safety and Health Standards*, U.S. Government Printing Office, Washington, D.C. 20402.
4. American Red Cross, *Advanced First Aid and Emergency Care*, Local office.
5. NFPA Standard 51B, *Fire Prevention in the Use of Cutting and Welding Processes*, National Fire Protection Association, 470 Atlantic Avenue, Boston, MA 02210.

(2) All electrical connections should be clean, dry, and tight. Poor electrical connections can generate heat.

(3) Use the proper high voltage cable and wire sizes. The cable should be rated at no less than 600V, dc. Keep cables and wires in good repair. Consult the manufacturer's instructions for proper cable and wire size.

(4) Do not touch live circuits. Keep equipment access doors closed.

(5) The risk of electrical shock is probably greatest when replacing torch parts. Operators must make certain the primary power to the power supplies and the power to the control circuitry are disconnected when replacing torch parts.

(6) Operators and maintenance personnel should be aware that plasma arc cutting equipment, due to the higher voltages, presents a greater hazard than typical welding equipment.

**1.2.2 Potential Hazard - Fumes and Gases.** Plasma arc cutting unavoidably produces by-product fumes and gases which can harm your health. The composition and the rate of generation of the fumes and gases depend on many factors. These factors include the arc current, cutting speed, plate material, orifice gas, etc. The fume and gas by-products will usually consist of the oxides of the elements in the metal being cut, ozone, and oxides of nitrogen.

These fumes must be removed from the work area or be eliminated at the source. Fumes may be removed from the work area by using an exhaust system. Local codes may require that the exhaust be cleaned before being vented into the atmosphere.

Several alternative fume removal systems are available for mechanized cutting applications. One system consists of two parts: a cutting table which maintains a bed of water that contacts the bottom surface of the workpiece, and an annular-shaped nozzle which generates a heavy shroud of water around the arc. This nozzle mounts on the torch body as shown in Fig. 2A. Water is pumped from the cutting table through the water shroud nozzle at a flow rate of 15 to 20 gal/min (56.8 to 75.7 L/min). Refer to Section 1.2.4 if this type of system is to be used on aluminum.

Another system also uses a water bed, but instead of the level of water contacting only the bottom surface of the workpiece, it totally submerges the workpiece so that the top surface is 2-1/2 in.-3 in. below the surface of the water (Fig. 2B). This system, which is referred to as underwater plasma cutting, does not require the use of the water shroud nozzle, but does require that the level of water be periodically lowered for loading and unloading plate and for initial positioning of the torch and plate. With this system, the operator cannot see the plate during cutting and, therefore, it is recommended for use with numerical control systems.

**1.2.3 Potential Hazard - Noise.** The amount of noise generated depends primarily on the current. For

example, one torch operating at 400A generates approximately 100 dBA, measured at a distance of 6 ft (1.8 m). At 750A, the noise level is about 100 dBA. Much of the noise is in the frequency range of 5000 to 20,000 Hz. Such noise levels can damage your hearing. Hearing protection must be worn where the noise level exceeds specified limits. These values may vary locally. They are specified by OSHA for most industrial environments.

The maximum acceptable noise level, according to 1978 OSHA regulations, is 90 dBA for eight hours continuous exposure; 95 dBA, 4 hours; and 100 dBA, 2 hours.

The water shroud technique described in Section 1.2.2 is a method commonly used for reducing noise for mechanized cutting applications. The shroud of water effectively acts as a sound-deadening enclosure around the torch nozzle. The water directly below the plate stops noise leakage through the kerf opening. Noise reduction is typically 20 dBA. This reduction will usually be sufficient to bring the operation to within OSHA limits.

This water shroud technique should not be confused with water injection or water shielding. Neither process uses a sufficient flow of water for noise reduction.

Underwater plasma cutting provides greater noise reduction than the water shroud because the entire working end of the torch and the arc are totally submerged in water.

**1.2.4 Potential Hazard - Radiation.** Like all welding arcs, the plasma arc emits intense visible and invisible (ultra-violet and infrared) radiation. In addition to the potential harm to the eyes and skin, the radiation may produce ozone and oxides of nitrogen.

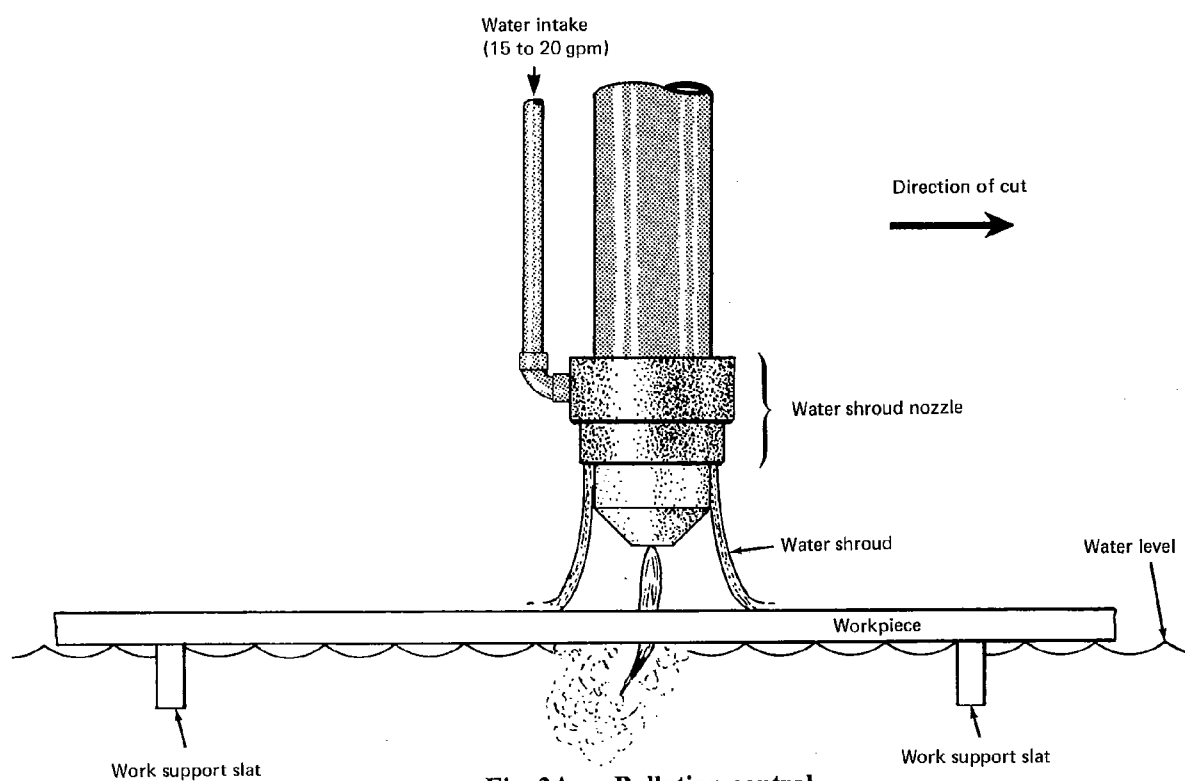
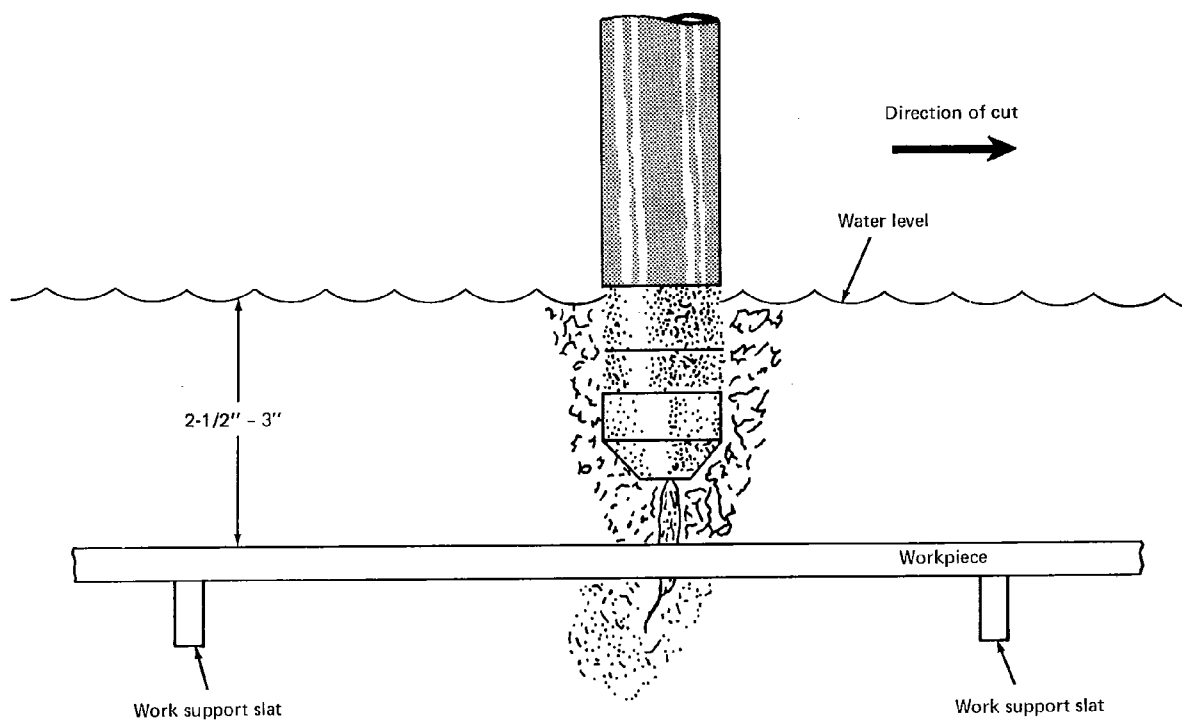
It is necessary to wear eye and skin protection when exposure to the radiation is unavoidable (see Table I). The likelihood of radiation exposure may be reduced by the use of mechanical barriers such as walls or welding curtains. The operator should wear eye protection designed to guard against radiation (see Table A1 in ANSI Z87.1-79).<sup>6</sup>

**Table 1**  
**Recommended shade densities for**  
**filter lenses**

| Current range A | Minimum shade | Comfortable shade |
|-----------------|---------------|-------------------|
| Less than 300   | 8             | 9                 |
| 300 to 400      | 9             | 12                |
| 400 plus        | 10            | 14                |

6. ANSI Z87.1-79, *Practice for Occupational and Educational Eye and Face Protection*. American National Standards Institute, 1430 Broadway, New York, NY 10018.

## 4/RECOMMENDED PRACTICES FOR PLASMA ARC CUTTING

**Fig. 2A — Pollution control****Fig. 2B — Underwater plasma cutting**

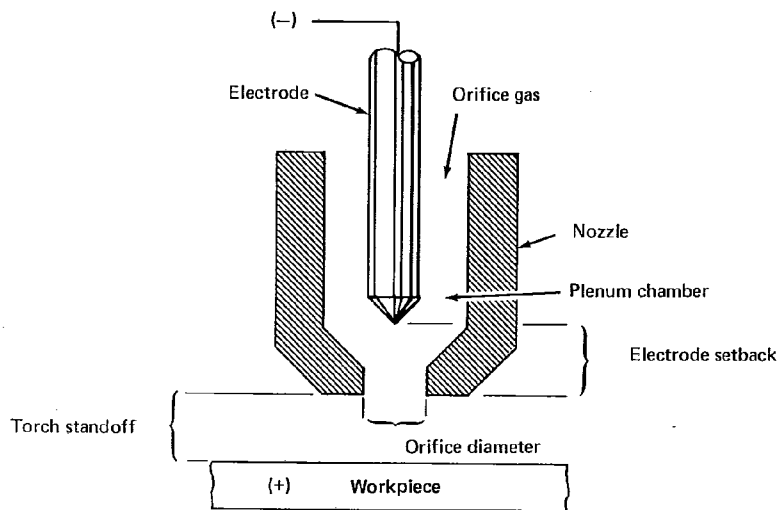


Fig. 3 — Conventional plasma arc terminology

The water shroud can also act as a light absorbing shield when dye is added to the water table. If the use of dye is contemplated, contact the equipment manufacturer for information on the type and concentration of dye to use. It is necessary to provide operator eye protection, even when using these dyes, due to the possibility of unexpected interruption of water flow through the water shroud.

Underwater plasma cutting reduces the amount of radiation because of the depth of water in which the arc is operated. Addition of dye is not required.

**1.2.5 Heat.** Plasma arc cutting produces a great deal of by-product heat, as well as metal sparks and hot spatter. Unless care is taken to protect the surrounding area, there is a good chance of starting fires. Personnel should use personal protective equipment to prevent burns. In addition to the fire hazard, there may be an explosion hazard when certain cutting gases are used; i.e., hydrogen mixtures. The National Fire Protection Association Standard 51B, *Fire Prevention in the Use of Cutting and Welding Processes*, should be referred to for advice regarding these hazards.

**1.2.6 Explosion Hazards When Cutting Aluminum.** There is a possibility of hydrogen detonation beneath the workpiece when cutting aluminum plate on a water table. The actual cause of these detonations is not fully understood, but it is believed to be due to hydrogen released by the interaction of molten aluminum and water. The hydrogen can accumulate in pockets under the workpiece and ignite when the cutting arc passes near or over a pocket.

When cutting aluminum, contact the equipment manufacturer for recommended practices.

### 1.3 Terminology

The plasma arc cutting process, having been derived from the gas tungsten arc welding process, uses some of the same terminology. Due to its greater complexity, however, some new terms have come into common usage. A familiarity with these terms will be an aid to making useful comparisons between the systems available and will provide a common language for operators, service personnel, and management. (Fig. 3)

**1.3.1 Conventional Plasma Arc Cutting.** Conventional plasma arc cutting refers to the basic process which has been in use since the early 1950's. Since that time, it has been refined considerably. Some critical adjustments, such as centering the electrode in the middle of the nozzle orifice, were eliminated. In most cases, such adjustments have been optimized by the manufacturers and are fixed. The terminology remains the same and also applies to the systems discussed later.

(1) **Electrode.** Just as in gas tungsten arc welding, electrodes in plasma arc torches are usually made of 2% thoriated tungsten. However, due to the heat of the high arc currents, these electrodes may be imbedded in a water-cooled copper body.

(2) **Nozzle.** The nozzle contains the orifice through which the arc passes. The nozzle orifice causes the arc current to be confined to a small cross section. It increases the current density within the orifice. The constriction results in increased heating and elongation of the arc. It produces a well collimated, intensely hot, stream of ionized gas.

Most nozzles are water cooled by *direct* passage of water through ports or grooves machined into the nozzle.

## 6/RECOMMENDED PRACTICES FOR PLASMA ARC CUTTING

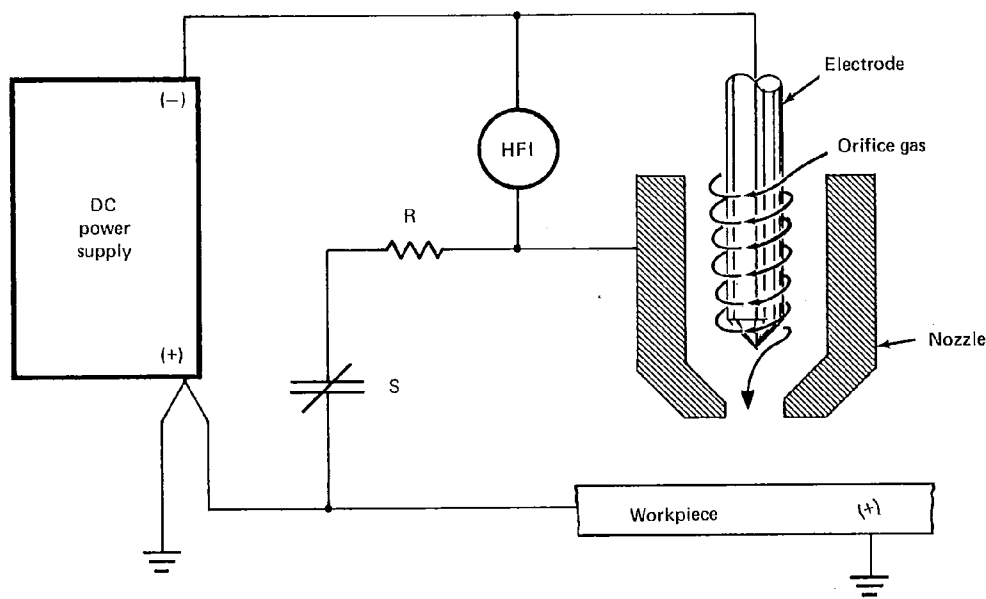


Fig. 4 — Plasma arc torch circuitry

zle. Some torches used for low current applications use *indirectly* cooled nozzles. They make good thermal contact with some other torch component which is water- or gas-cooled.

(3) Orifice Diameter. The orifice diameter is simply the diameter of the nozzle hole through which the arc and gas pass. Tapered orifice diameter is defined by the smallest diameter of the nozzle bore.

Maximum arc constriction is achieved by keeping the orifice diameter as small as possible for a given operating current. In practice, the nozzle will be rapidly destroyed if the orifice diameter is too small for the arc current.

(4) Orifice Gas. The orifice gas is the gas that is directed into the torch to surround the electrode. It becomes ionized in the arc to form the plasma, and issues from the orifice in the torch nozzle as the plasma jet.

(5) Secondary Gas. Unlike the orifice gas, the secondary gas does not pass through the nozzle. It is passed around the nozzle and forms a shield around the arc. Not all torches use a secondary gas, as will be explained later.

(6) Plenum. The plenum is the space between the inside wall of the constricting nozzle and the electrode. The orifice gas is initially directed into this area, then through the orifice to the work surface. In some equipment tangential velocity is imparted to the gas within the chamber, to swirl it as it passes around the electrode and through the orifice. In other equipment, axial flow is used to produce a uniform gas stream

similar to the high pressure stream in oxygen fuel gas cutting.

(7) Electrode Setback. Electrode setback is the distance the electrode is recessed behind the constricting orifice measured from the outer face of the nozzle.

(8) Standoff Distance. The standoff distance is the distance between the nozzle and the work surface. This variable is sometimes referred to as the torch-to-work or coupling distance.

In the following sections, additional definitions are given when they apply.

#### 1.4 Principle of Operation

Referring to Fig. 4, when the initial dc power is applied, no arc is generated because the orifice gas is nonconductive. To make the orifice gas conductive, it is necessary to apply a very strong electric field to the gas. The electric field must produce a spark between the electrode and nozzle to ionize the gas. Frequently this is done by applying a series of high voltage, high frequency pulses from a high frequency igniter, HFI.

The spark between the electrode and the nozzle provides a path for arc current from the dc power supply, through the electrode, the nozzle, the current limiting resistor (R), the relay contacts (S), and back to the power supply. Note that these contacts are closed during the starting sequence. This arc is called the *pilot arc*. Its current is limited to 15 to 60A.

The pilot arc significantly heats the orifice gas, thereby greatly increasing its ionization. The ionized gas then passes through the nozzle, and if it is close

enough to the work, usually 1 in. (25.4 mm) or less, it creates a path for the main cutting arc to strike. There is no current-limiting resistor in the main arc circuit. The current will be as high as the power supply resistance permits. The main arc current can reach 1000A on some mechanized torch installations.

After the main arc strikes between the electrode and workpiece, the pilot arc is no longer needed. Relay contacts (S) are opened to extinguish the pilot arc and remove its heat load from the nozzle.

## 2. Gas/Water Shielded Plasma Arc Cutting

### 2.1 Gas Shielded Plasma Arc Cutting

This method incorporates the same features as conventional plasma arc cutting, except that a secondary shielding gas is added around the nozzle (Fig. 5). Usually the cutting gas is nitrogen, and the secondary shielding gas is selected according to the metal to be cut. Secondary shield gases used are CO<sub>2</sub>, air, argon-hydrogen, argon, and oxygen.

### 2.2 Water Shielded Plasma Arc Cutting

Water shielded plasma arc cutting is similar to gas shielded, except that water is substituted for the shielding gas. Cut appearance and nozzle life are improved because of the cooling effect provided by the water.

## 3. Water-Injection Plasma Arc Cutting

In the water-injection plasma arc cutting process, water is injected around the arc. Generally, water is injected either as a high velocity radial spray or with tangential direction to impart swirl. This is illustrated in Fig. 6. The impingement of the water around the arc provides a higher arc constriction than can be achieved by conventional means. This improves cut squareness and increases cutting speeds. Nitrogen is used as the orifice gas with this technique, regardless of the type of metal being cut.

The cooling provided by the injection water permits the use of a ceramic piece between the nozzle and the work. This feature extends the nozzle life, improves the piercing capabilities of the torch, and protects against electrically shorting the nozzle to the workpiece.

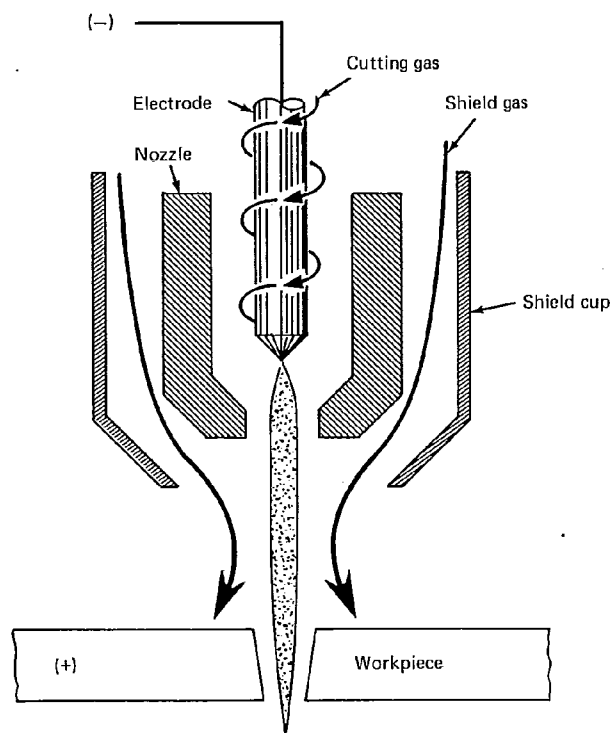


Fig. 5 — Gas/water shield plasma arc cutting

## 8/RECOMMENDED PRACTICES FOR PLASMA ARC CUTTING

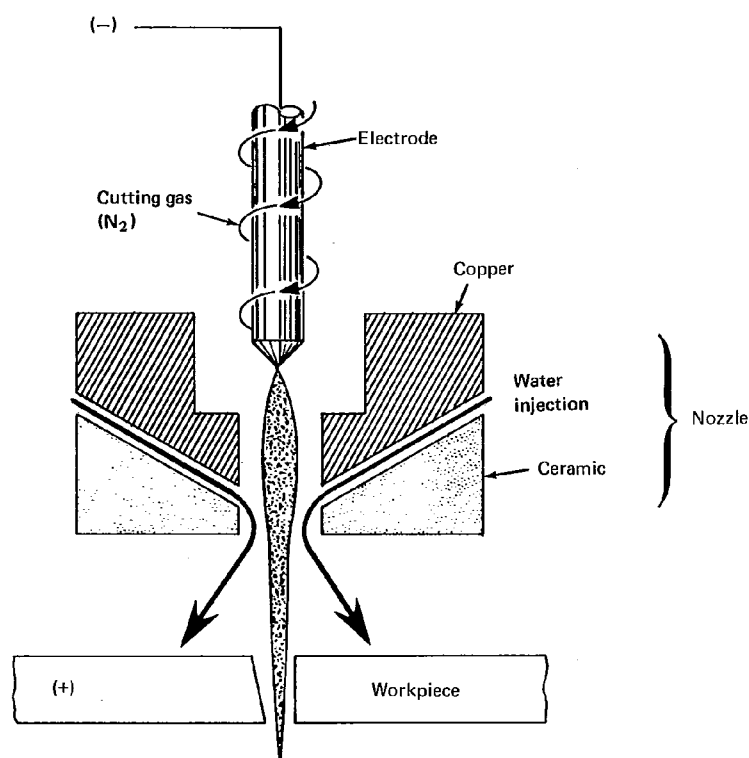


Fig. 6 — Water injection plasma arc cutting

#### 4. Process Capabilities

Selection of the plasma arc cutting technique should be based on the intended application. Proper consideration should be given to economics, equipment on hand, thickness and configuration of the workpieces, quality of cut, and production rate required. In general, most applications will fall into one of three categories. These are: mechanized high-speed cutting, mechanized low-speed cutting, and manual cutting; a few applications will fall into a fourth category, high current cutting.

##### 4.1 Mechanized High-Speed Cutting

**4.1.1 Mild Steel.** Prior to the 1980's, most mild steel plate was cut using oxyfuel processes. There were two reasons for this situation. The first was that, although conventional plasma arc cutting offered higher speeds, it also required some sacrifice in cut quality. The second, and perhaps more significant reason, was that many of the shape-tracing machines could not operate reliably at plasma arc cutting speeds. Fortunately, the quality of plasma arc cuts has been greatly improved. The introduction of numerically controlled shape cutting machines has made high-speed plasma cutting routine.

As a result, the most widespread application of plasma arc cutting has been multiple torch cutting of mild steel. The high cutting speed achievable with plasma arc cutting and the capabilities of numerically controlled cutting machines enable the user to increase productivity greatly. Cutting costs are typically one-half to one-quarter that of oxyfuel cutting for plates less than 1 in. (25.4 mm) thick.

**4.1.2 Stainless Steel and Aluminum.** Plasma arc cutting is preferred for cutting stainless steel and all nonferrous metals. There are, of course, many repetitive applications in thin materials where a high production rate can be achieved with shearing or nibbling machines. Applications requiring flexibility on heavier plate (1/16 to 6 in.) (1.6 to 152 mm) can be handled easily with plasma arc cutting.

**4.1.3 Cut Quality.** There are four factors to consider in evaluating the quality of cuts obtained by different processes. They are cut angle, dross, and metallurgical effects; occasionally, kerf width may also become a factor.

(1) **Cut Angle.** Plasma arc torches with water injection and clockwise orifice gas swirl, viewed from the torch toward the work, produce cuts whose right side of the kerf (in the direction of travel) is square, and the

left side slightly beveled. The swirling orifice gas is less disturbed at the right, where the swirl offsets the forward travel; at the left drag is encountered. This drives more arc energy to the right side of the kerf. In shape cutting applications, this means that the direction of cut must be properly selected to produce a square cut on the production part. Cut direction is not a factor in plasma torches that produce square cuts without using gas swirl.

On the annularly shaped part shown in Fig. 7, the outside cut is made in a clockwise direction to place the saved piece on the right side of the kerf. Similarly, the inside cut must be in a counterclockwise direction to maintain a square inside edge. In most applications, like the one shown in Fig. 7, the beveled side of the cut is disregarded when evaluating squareness. Nozzles that produce counterclockwise orifice gas swirl are available for applications such as mirror image cutting where the high quality side must be on the left.

Another aspect, often overlooked, is the necessity of keeping the torch perpendicular to the workpiece. Even if the torch is perpendicular to the cutting bed, it may not be perpendicular to the workpiece. Scrap pieces must be removed from the cutting table, and the table should be kept in good repair. Hoses and cables that are pulled tight when the cutting machine carriages are extended to their travel limits are also a cause of off-square torches.

(2) Dross. Dross is resolidified, oxidized metal that adheres to the bottom edge of a cut. The tendency to form dross depends on metallurgical composition, surface condition, orifice diameter, cutting speed, and arc current. The two major cutting variables that influence dross formation are cutting speed and arc current.

There are actually two types of dross: low-speed dross, and high-speed dross. As the names imply, dross

is formed if the torch travel speed is either too low or too high. Most material, therefore, has a range of cutting speed which will produce dross-free cuts. This range is broadened as the arc current is increased. If the arc current is too low, the dross-free range may be nonexistent. If a dross-free range cannot be found, it is usually best to stay in the low speed range since that type of dross is easier to remove.

Stainless steel is very tolerant in terms of dross formation. Its dross-free operating range is relatively wide. Aluminum is also easy to cut dross-free. Ni-Cu, Ni-Cr-Fe, and copper alloys, by contrast, tend to form dross more readily. Mild steel falls somewhere in the middle.

When cutting plate over 1/8 in. (3.2 mm) thick, the dross-free operating ranges diminish with increasing plate thickness. In some cases, it might not be possible to produce a dross-free cut. This problem can be minimized by stacking the plates. Dross, if formed, is usually confined to the lower plates. Stack cutting requires close contact between the plates. If the cut crosses an area where the gap between the plates exceeds 0.010 in. (0.25 mm), the plates will stick together. In most applications, this requirement is not easy to satisfy.

(3) Metallurgical Effects. The heat-affected zone of plasma arc cuts is much narrower than in oxyfuel cutting. This may be a significant factor where the metal must be subsequently welded or finished.

The thickness of the heat-affected zone is typically 0.010 in. (0.25 mm) for austenitic stainless steel and 0.020 in. (0.50 mm) for cold rolled or low carbon steel. Carbon steels generally exhibit heat-affected zones from 0.015 to 0.30 in. (0.4 to 0.8 mm) thick. Aluminum cuts exhibit heat-affected zones in the range of 0.040 to 0.100 in. (1.1 to 2.7 mm) thick.

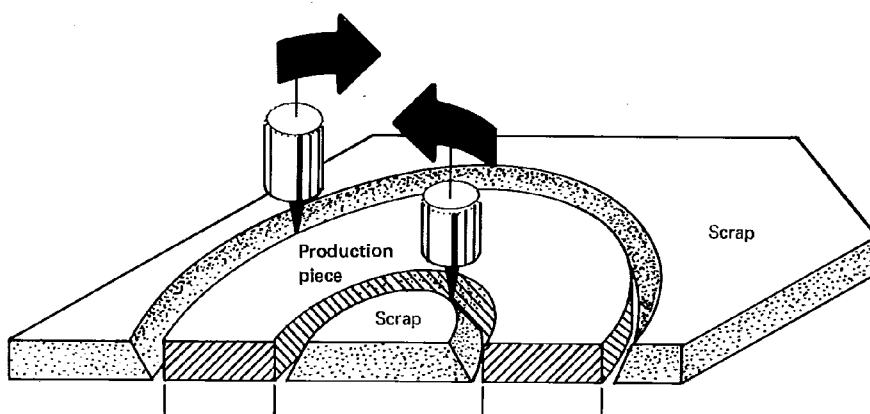


Fig. 7 — Direction of cut with water injection and clockwise orifice swirl

## 10/RECOMMENDED PRACTICES FOR PLASMA ARC CUTTING

When cutting austenitic stainless steels, the high cutting speed and the quenching effect of the base plate, cause the cut face to pass rapidly through the metallurgical critical temperature of about 1500° to 1200° F (650° C). Thus, there is virtually no chromium carbide precipitation along the grain boundaries and reduction in corrosion resistance. Measurements of the magnetic properties of Type 304 stainless steel made on base metal and on plasma arc cut samples also indicate that magnetic permeability is unaffected by arc cutting.

Heat treatable aluminum alloys, such as Types 2014 and 7075, are crack sensitive, and increased cutting speed and plate thickness increase the tendency to cracking. Strain-hardenable alloys, such as 5456, do not tend to crack during cutting.

Hardening will occur in the heat-affected zone of a plasma arc cut in a high carbon steel. The degree of hardening can be reduced by preheating the workpiece. Preheating reduces the quench effect of the mass of metal immediately behind the cut face.

When forming plasma arc cut steel parts, it is recommended that the top edge of the cut be on the tension side of the bend. The slight top edge rounding of the plasma cut improves the ease of forming in this direction. Cracks may occur in some alloys if the sharp bottom edge is on the tension side of the bend. Grinding a radius on the bottom edge will also alleviate forming difficulties.

(4) Kerf Width. The width of a plasma arc cut is greater than cuts made with oxyfuel processes, by one and one-half to as much as four times. Therefore, just as with other cutting methods, there must be a kerf allowance applied to the templates or programs generating the desired shape. In many cases, the kerf allowance is automatically applied by the tracing machine according to a preset kerf allowance of half the kerf width.

The allowance required is difficult to quantify in general terms. Every variable in a plasma cutting system has some effect on kerf width. Each installation will be unique, due to the way it is operated. The most influential factor affecting kerf width is plate thickness, with wider kerfs being cut in thicker plates. Table 2 is intended as a rough guide. Actual results may be different.

Table 2

| Plate thickness |               | Kerf allowance |       |
|-----------------|---------------|----------------|-------|
| in.             | mm            | in.            | mm    |
| 1/8 to 1        | 3.2 to 25.4   | + 3/32         | + 2.4 |
| 1 to 2          | 25.4 to 51.0  | + 3/16         | + 4.8 |
| 2 to 5          | 51.0 to 127.0 | + 5/16         | + 8.0 |

## 5. Economics

The greatest variable cost factor in a cutting operation is labor. Other factors such as power, gas, and nozzle and electrode consumption typically account for 15 to 25% of the total cutting costs. Any increase in productivity (speed, duty cycle, additional torches, etc.) can reduce the cost per foot of cut. A rough estimate of the cutting costs per torch can be obtained by dividing the average length of plate cut per hour into the cost of labor and overhead. For example, 1/2 in. (12.7 mm) steel can be cut at 90 in./min (450 ft/hour). Assuming that the cost for labor and overhead is \$15/hour and the duty cycle is 50% (0.5 arc hours/hr), the approximate cutting cost is calculated as follows:

$$\begin{aligned}\text{Length cut/hour} &= (450 \text{ ft/hr}) \times (0.5 \text{ arc hours/hr}) = 225 \text{ ft/hr} \\ \text{Cutting cost} &= \frac{\$15/\text{hr}}{225 \text{ ft/hr}} = .066 \$/\text{ft} \text{ or } 6.6 \text{ ¢/ft}\end{aligned}$$

For thin material (when power and consumable costs are low), the actual cut cost will be no greater than 15% higher than this estimate. For heavier plate, the increase can be as much as 25% since the power consumed is considerably greater.

A more exact estimate of cutting cost can be obtained by applying the following formula:

$$W = \frac{20}{S} (100 \frac{L}{N} + G + H + J + K)$$

where:

- W = cutting costs (¢/ft) per torch
- N = number of torches
- S = cutting speed (in./min)
- L = labor and overhead (\$/hr)
- D = duty cycle (%)
- G = gas cost per torch (\$/hr)
- H = nozzle cost per torch (\$/hr)
- J = electrode cost per torch (\$/hr)
- K = power cost per torch (\$/hr)

A "typical" cutting cost is impossible to estimate since the cost factors previously discussed greatly depend on location. It is possible, however, to make a relative cost comparison with oxyfuel cutting for a hypothetical user as shown in Fig. 8. Costs were calculated using a rate of \$15 per hour for labor and overhead, and a 50% duty cycle. In the case of mild steel cutting, the cost advantage of plasma over oxyfuel is four to one on 1/4 in. (6.4 mm) plate and two to one on 1-1/2 in. (38.7 mm) plate. Changing the ratio of plasma and oxyfuel torches can have significant effects on operating costs.

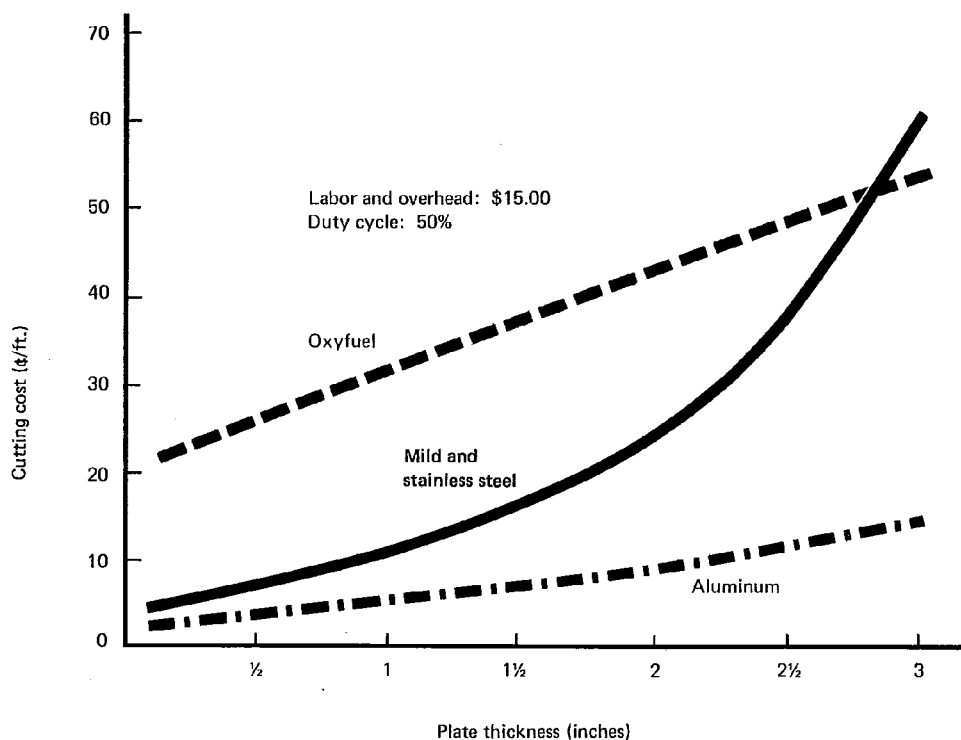


Fig. 8 — Typical cutting costs

## 6. Mechanized Low-Current Low-Speed Cutting

The high speed capability of the plasma arc cutting process can be a drawback when used on some shape-tracing machines. The problem is that the optimum plasma cutting speed for a given application may exceed the speed capability of the machine. In this case, a low current plasma cutting process should be used.

Low current plasma cutting will cut most nonferrous metals up to one in. (25.4 mm). Low current torches usually operate between 50 and 100A; some have capacity up to 400A.

Low current plasma cutting orifice gases are usually nitrogen, mixtures of argon and nitrogen, or argon and hydrogen. Orifice gases depend upon equipment used and applications. Some equipment uses a secondary gas, normally carbon dioxide or compressed air, to blow the molten metal away from the kerf. This also reduces spatter buildup on the working end of the torch, cools down the torch, and is said to boost the piercing capability of the process.

An orifice gas mixture of argon and hydrogen can be used on stainless and nonferrous metals, 1/2 to 3 in.

(12.7 and 76.2 mm) thick. The combination gives a sharper top edge and cleaner cut surfaces at a slight sacrifice in speed.

Low-current low-speed plasma arc cuts in metals up to 2 in. (51 mm) thick tend to have smooth surfaces with a kerf width approximately 1/8 in. (3.2 mm). Heavier thicknesses are generally rough although clean. Dross can usually be eliminated, or minimized, by readjusting cutting speed and torch standoff.

## 7. Manual Cutting

Hand-held plasma cutting torches are frequently used on stainless steel and nonferrous metals. They may be used for the same kinds of work that would be done with a hand-held oxyfuel torch on mild steel applications. The major difference between manual plasma cutting equipment and mechanized equipment is that the torch is designed to be held in the hand. Also, the power supply uses 300 open circuit volts, or less, rather than 400V as in mechanized cutting. This limitation is made to reduce the electrical hazard. The arc current is usually 400A, or less, because higher arc currents produce too much radiated heat for the operator.

## 12/RECOMMENDED PRACTICES FOR PLASMA ARC CUTTING

Manual plasma cutting systems produce cut quality every bit as good as manual oxyfuel cuts and usually at slightly higher speeds. In most instances, the quality of cut is influenced as much by the skill of the operator as by the capabilities of the equipment.

## 8. High Current Cutting

Most high-speed plasma arc cutting machines use either water injection or water-shield type plasma arc cutting systems. They handle the common cutting applications for plate less than 3 in. (76 mm) in thickness. High current cutting is used when it is necessary to cut heavier plate.

The high current cutting mode is generally done in the 800 to 1000A arc current range. It is intended for cutting plate 3 to 6 in. (76 to 152 mm) thick. A mixture of 65% argon - 35% hydrogen is the orifice gas commonly used. This mixture provides two benefits: first, at high currents, electrode life is much better with argon-hydrogen mixtures than with nitrogen, and second, the ability of the arc to penetrate thick material is greatly improved.

The use of argon-hydrogen gas mixtures creates a fire and explosion hazard if there happens to be a gas leak inside the control console. Be sure to follow the equipment manufacturer's recommendation for proper operation.

The cut quality in the high current mode is good on most materials less than 4 in. and fair on most materials 4 to 6 in. (100 to 150 mm) thick. In all cases, the cuts are quite square. However, for material thicknesses above 4 in., the cut face becomes increasingly rough, and heavy dross is common. Kerf width is generally 1/2 to 5/8 in. (13 to 16 mm).

## 9. Equipment for High-Speed Mechanized Cutting

### 9.1 Plasma Arc Cutting System

**9.1.1 Torch.** Several similar torch models are available for high-speed cutting. They have direct water-cooled nozzles and electrodes. The arc current is brought into these torches by means of the water supply and return hoses which have a copper conductor inside. In addition, there is another hose for orifice gas and one for injection or shield water. The one remaining conductor is a high voltage wire which serves as a return path for the high frequency and pilot arc currents.

**9.1.2 Control.** The control circuitry for a plasma arc cutting torch provides for proper sequence of the gas, water, and power. The circuitry is more complex than that found in most welding controls, but it can be serviced properly by a trained technician.

Usually, the control is fabricated in two separate units. One unit is located near the torch and contains the high frequency generator and the gas and water solenoid valves. The other unit is located at the operator's position. It contains the switches necessary for operating the system.

If more than one torch is to be used, it is necessary to have a separate control for each. The controls must be properly interfaced to avoid situations such as having travel commence after the first torch fires, but prior to the second torch firing.

### 9.2 Power Supply

**9.2.1 Type.** Due to the electrical characteristics of constricted arcs, only power supplies specifically designed for plasma arc cutting can be used. These power supplies are of the constant current (drooping) VA-curve type.

High-speed torches require an open circuit voltage of approximately 400V, direct current (see 11.2). While these torches actually operate at approximately 150 to 225V, stable operation is not obtained without the higher open circuit voltage. Ordinary gas tungsten arc welding power sources cannot be used since they do not meet the above criteria.

**9.2.2 Capacity.** Plasma cutting power sources are manufactured in various current capacities; typically, 250A, 350A, 400A, 500A, and 600A. They may be used in parallel, when recommended by the manufacturer, to obtain a desired capacity.

The plate thicknesses to be cut determine the current capacity required. However, it should be noted that many power supplies rated to supply a given current at 100% duty cycle can supply a greater current at a lesser duty cycle. For example, a 600A at 100% duty cycle power supply might be capable of 750A at 60% duty cycle. Therefore, if 600A are required to cut 2 in. (51 mm) thick plate, and 750A are required to cut 3 in. (76 mm) plate, this power supply would be adequate. Most of the cutting should be done in the 2 in. (51 mm) range with occasional use for cutting 3 in. (76 mm) material for short periods, provided the manufacturer permits the overloading. The key factor is the length of cut required. Power supply duty cycles are usually based on ten minute periods. This means that if the power supply is rated at 600A 100% duty cycle, and 750A at 60% duty cycle, it can be operated at 600A continuously, or at 750A for a total of 6 minutes out of each 10 minute period. There is little chance of damaging a power supply when it is used as recommended by the manufacturer.

**9.2.3 Paralleling.** In some cases when cutting is to be done beyond the continuous rating of one power supply, another power supply may be paralleled to increase the available current. This requires connecting the DC output connections and contactors in parallel. This last step is generally a simple matter since receptacles are usually provided for connecting the contactors in parallel.

*Do not connect power supplies in parallel unless authorized by the manufacturer. Do not parallel rectifier transformer units with generators. Only similar power supplies may be paralalled.*

The number of power supplies required for each torch is simple to determine. First, determine the greatest thickness to be cut most frequently. Then, from the cutting conditions, determine the current required for this thickness. Any combination of similar power supplies whose 100% duty cycle ratings add up to this current is suitable provided it is done with the manufacturer's permission. Now consider the occasional need to cut thicker-than-usual materials. Determine if this occasional work can be handled using the power supplies at the permissible 60% duty cycle rating. If not, can an additional power supply be justified economically, or should occasional heavy work be done some other way?

It is important to note that each torch requires its own power supply or bank of power supplies connected in parallel. More than one torch cannot be operated from the same secondary power supply circuit.

### 9.3 Standoff Distance

Accurate control of standoff distance is necessary to obtain optimum cut quality. If the standoff distance is too high, the cut angle will be beveled; if the standoff distance is too low, the cut angle will be undercut.

Plasma arc cutting may be done without automatic height sensing. In most shops, however, the workpiece does not always lie flat due to an uneven work table and the warped condition of most plate. Since a small change in torch height will greatly alter the position of the hottest part of the arc with respect to the plate, cut quality is greatly improved by controlling torch height.

The most widely accepted means of automatically controlling standoff distance is by maintaining a predetermined arc voltage setting. There are several types of these "arc voltage" height controls available from the various equipment manufacturers.

### 9.4 Water Cooling

Previously it was stated that most plasma arc cutting torches are water cooled. It is extremely important that users of plasma equipment follow exactly the recommendations of the manufacturer regarding proper hose sizes and water pressures. Any restriction in the cooling system, or inadequacy in the water supply, can result in damage to the equipment.

Cooling water requirements for high-speed mechanized torches are generally about 2 gal/min at pressures ranging from 80 to 175 psi (0.5 to 1.2 MPa), depending on the manufacturer. This is not an operating range. If the manufacturer specifies 175 psi (1.2 MPa), it is unsafe to operate below that pressure. Inlet water temperature is also an important factor. Consult the manufacturer's operating instructions for specific details.

The most common cause of insufficient cooling is the use of hose with too small a diameter. This kind of installation error is most likely to happen when two or more torches supply cooling water to the same return or drain line. In this case, it is necessary to use a larger diameter hose for the drain line. Even in single torch installations, it may be necessary to increase the hose diameter if unusually long water lines are necessary. The safest approach is to measure the flow rate at each new installation.

Some equipment manufacturers prefer to use tap water for cooling, allowing the used water to be discarded through the drain. Others prefer the use of water recirculators wherein the water is cooled by a fan and radiator arrangement similar to an automobile cooling system. Water chillers employing refrigeration systems are also available.

### 9.5 Pollution Control

The generation of excessive noise and fumes by plasma cutting torches was discussed in 1.2.2 and 1.2.3. One widely accepted approach to reduce noise and fumes is to cut over a bed of water and surround the arc with a thick water shroud. This method requires a cutting table filled with water up to the work support surface, a water shroud nozzle, and a recirculating pump to draw water from the cutting table and pump it through the water shroud nozzle. Water flow is typically 15 to 20 gal/min. Another method, under-water plasma cutting, was also discussed. This method submerges the working end of the torch and the plate beneath 2-1/2 to 3 in. of water.

The primary requirements in water table design are adequate strength for supporting the work, sufficient scrap capacity, and ability to maintain the water level in contact with the work. If the table is used for under-water plasma cutting or for both plasma and oxyfuel cutting, it is usually desirable to provide a rapid means of lowering and raising the water level. This can be accomplished by pumping in and out of a holding tank.

## 10. Equipment for Low-Current Low-Speed Cutting

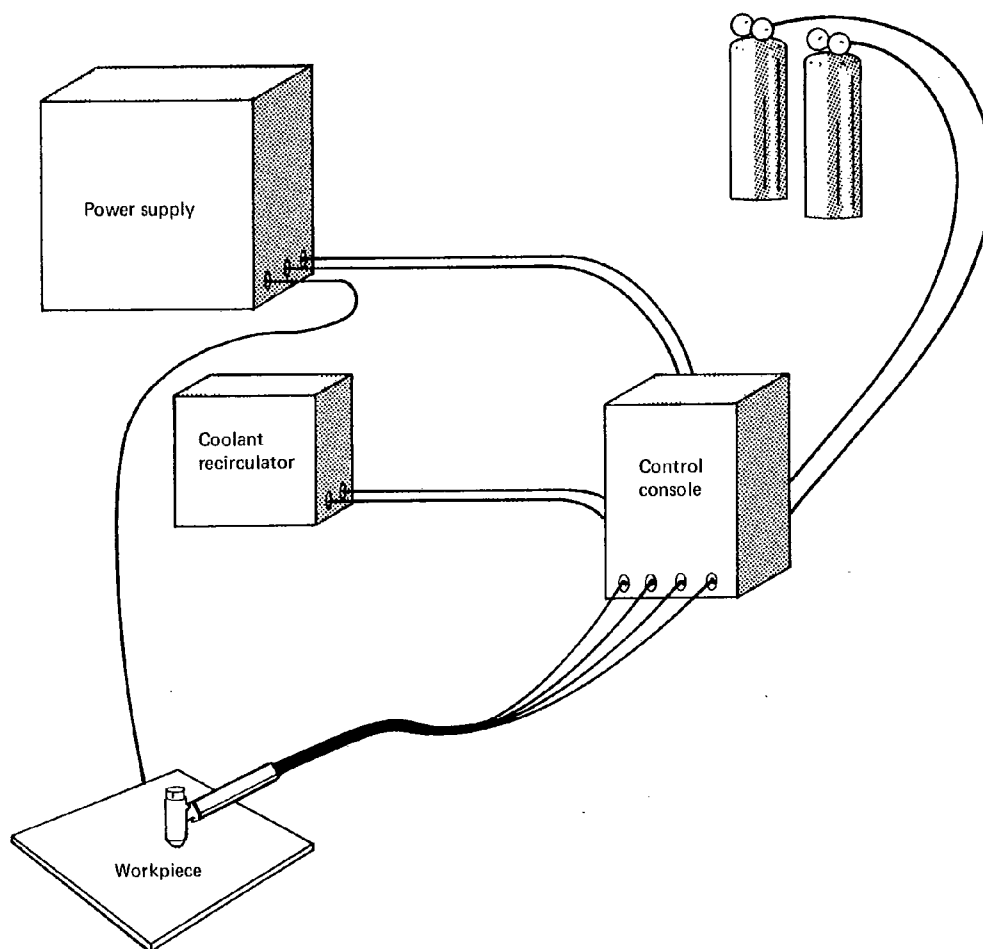
### 10.1 Plasma Arc Cutting System

Low-current low-speed plasma arc cutting requires a torch, control console, power supply, coolant recirculator, source of orifice gas, and secondary gas. The power supply should have a nominal 300V open circuit voltage or less and a drooping volt-ampere characteristic. A typical system layout is shown in Fig. 9.

Some manufacturers provide a single enclosure design for the power supply, recirculator, and control. This arrangement has the advantage of easy portability.

Torches for use with the low-current low-speed process are available for both manual and mechanized

## 14/RECOMMENDED PRACTICES FOR PLASMA ARC CUTTING



**Fig. 9 — Equipment for low-current low-speed plasma arc cutting system**

cutting. They may be either water or gas cooled, depending upon the manufacturer's design.

#### 10.2 Hazard Control

Manual cutting installations pose a more difficult problem in reducing noise and fumes. Water muffles underwater plasma cutting, but water tables cannot be used because the water increases the risk of electric shock to the manual operator.

Area ventilation should be adequate to remove all visible smoke and metal fumes during cutting. Chlorinated hydrocarbon solvents and degreasers should not be used near the cutting operation. Arc radiation can act on the solvent fumes and create toxic phosgene gas.

The high noise level from most plasma cutting requires the use of some form of ear protection if noise cannot be attenuated. Sound pressure levels over 105 decibels can occur. Ear protection may be required for nearby exposed personnel.

Refer to 1.2, Safety, for additional information on safety precautions.

## 11. Installation Requirements

### 11.1 Site Selection

A clean, dry location should be selected for plasma cutting equipment. Adequate space must be left around all units to provide access for maintenance and proper air flow for cooling. Most equipment is air cooled; so, an important maintenance requirement is cleaning the air passages on a routine basis. Attention must be paid to material handling requirements. Material handling equipment is often a major element in the total cost of a cutting installation.

### 11.2 Input Power

A source of three-phase power with either a fuse disconnect switch or circuit breaker at the cutting

location is required. The size of the electrical service depends on the power requirements of the unit. The equipment manufacturer's specifications should be consulted for specific recommendations. Table 3 provides typical fuse requirements, but it should not be used as a substitute for the actual manufacturer's specifications.

**Table 3**  
**Typical fuse requirements**

| Output 100% duty cycle | Fuse for line voltage |        |
|------------------------|-----------------------|--------|
|                        | 230V30                | 460V30 |
| A, dc                  |                       |        |
| 100                    | 60                    | 30     |
| 400                    | 400                   | 200    |
| 600                    | 700                   | 350    |

Most equipment can be ordered for input voltages other than those shown in the above table. It should also be noted that power factor correction capacitors are available for most power supplies.

### 11.3 Gas Supply

One or two cutting gases are required for the plasma cutting system. The delivery pressure and flow rate required will depend on the type of equipment used. The gas may be obtained from a single cylinder, several manifolded high-pressure cylinders, or a liquid bulk system. When liquid systems are used, particular attention should be paid to the evaporation rate of the system. Be certain that pressure and flow rate can be maintained at the required levels for extended operating periods.

Loss of sufficient gas flow in a plasma arc cutting system can cause serious damage to the torch. Be sure delivery pressure is set according to the manufacturer's specifications, and periodically monitor gas supply levels. Some plasma arc equipment is provided with a pressure switch to shut off the system if the pressure drops too low. These circuits, however, are not completely fail-safe.

### 11.4 Cutting Machine

The best mechanized cutting system is no better than the machine that provides its movement. The machine must accurately and reliably follow the

intended path. It must be sturdy enough to be free of vibrations.

Most cutting is done on one or another of three types of cutting machines:

**11.4.1 Portable Carriage.** This type of machine is a device which is capable of moving the torch in a straight path on a track, or for hand or otherwise guided curves. It is used primarily for cut-off, trimming and squaring operations, and for manually controlled cutting of large layout work.

**11.4.2 Optical Tracing Machines.** These machines are commonly used in metal service centers and other locations where it is desirable to trace part shapes from a template or line drawing. They are available with low-or high-speed optical tracing heads.

The low-speed optical heads have a maximum speed of about 60 in./min (25 mm/s) (40 in./min [17 mm/s] on older ones). These low speed machines are mainly intended for oxyfuel cutting. They are not suitable for most high-speed mechanized cutting. The low-speed low-current plasma cutting systems, however, are compatible with this type of cutting machine.

Coordinate drive cutting machines equipped with high-speed optical tracers are suitable for high-speed plasma arc cutting. These machines can operate successfully at speeds up to 150 in./min (64 mm/s), which gives good coverage of the plasma cutting speed range.

**11.4.3 NC/CNC Machines.** Developments in high-speed plasma arc cutting have been paralleled by improvements in cutting machines. Present cutting machine control systems rely heavily on computer technology. Almost all of the cutting machine direction is generated via computer rather than by hardware. The computer numerical controls (CNC) have advantages over the older NC controls in terms of greater reliability, expanded capability, lower cost, and the ease of connecting several units to a central processor as a direct numerical control (DNC) system.

This dual evolution of plasma process and machine allowed the plasma arc cutting process to develop into a high-speed production tool capable of significant productivity gains in cutting virtually any metal. The most common application, however, is cutting mild steel up to 1 in. (25.4 mm) thick. When material handling can keep up with the cutting, productivity is typically three to five times that of the oxyfuel process. It is not uncommon to have as many as four plasma torches on this type of cutting machine.