Facts about plasma technology and plasma cutting
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Introduction

Plasma cutting was developed at the end of the 1950s for cutting high-alloy steels and aluminum. It was designed to be used on all metals that, due to their chemical composition, could not be subjected to oxy-fuel cutting. Owing to its extremely high cutting speeds (especially with thin materials) and narrow heat-affected zone, the technique is also used today for cutting non-alloy and low-alloy steels.

Metal cutting today is characterised by higher quality demands and increasing cost pressures. The edges of cut parts should not require any further processing and are expected to exhibit maximum dimensional accuracy. As a result, the ability of traditional cutting techniques to meet these demands is being increasingly questioned.

Plasma fusion cutting is in direct competition with other techniques such as oxy-fuel cutting, laser cutting and water jet cutting. However, it can also be an alternative to the mechanical processing techniques such as nibbling, punching, drilling.
Plasma cutting can be used to cut all electrically conductive materials, such as structural steels, high-alloy steels, nonferrous metals such as aluminum and copper, and clad metal plates. Depending on the plasma cutting technology, cutting system capacity and material type, sheet metal between about 0.5 and 180 mm in thickness can be cut.

Plasma cutting is unrivaled when it comes to cutting medium to thick sheets of high-alloy steel and aluminum. It is also used for cutting normal structural steel up to about 40 mm in thickness and results in very little distortion, particularly in the case of thin workpieces. Owing to its low heat input, it is also especially suitable for cutting high-strength fine-grained structural steels. The high cutting speeds are especially important in the preliminary fabricating process: in comparison to oxy-fuel, cutting speeds of 5 to 6 times greater can be achieved.

The cutting process can be easily automated. Through the use of different plasma cutter guidance systems, both flat and three-dimensional components with different contours can be produced. There are also a number of modern peripheral devices and accessories available for manual cutting, which allow for easier handling of parts during processing, and simplify assembly and repair work. Modern plasma cutting technology is becoming increasingly important. Especially when it comes to cutting thin, high-alloy steels, plasma cutting allows vertical cuts to be produced on multiple sheets simultaneously in laser-quality without the need for further machining.

Figure 2: Comparison of maximum cutting speeds for form cutting of structural steel
Plasma cutting

Plasma – more than just a state of matter?

Plasma is a high-temperature, electrically conductive gas, comprised of positively and negatively charged particles as well as excited and neutral atoms and molecules.

A dynamic balance exists between the dissociation, ionisation and recombination processes that occur in the plasma state. Thus, the plasma behaves electrically neutral. In physics, plasma is often referred to as the fourth state of matter. Plasma naturally occurs in the interior of the sun and other stars due to the high temperatures. Lightning is also a natural form of plasma, caused by high electrical field strengths.

To produce a technical plasma, a gas is either greatly heated using a heat source or is subjected to a strong electrical field in order to transform it into an ionised state.

Figure 3: Plasma – the fourth state of matter
**Principle of plasma cutting**

Plasma cutting is a thermal cutting process in which a plasma arc is constricted through a nozzle. The transferred arc, which occurs when electricity flows from the non-melting electrode (cathode) to the workpiece (anode), is used to cut electrically conductive materials. This is the most commonly used form of plasma cutting. In the non-transferred mode, the arc occurs between the electrode and the nozzle. Even when using a cutting gas that contains oxygen, the heat effect of the plasma arc prevails. Thus, this method is not considered an oxy-fuel process, but rather a melt cutting method.

The plasma gases are partially dissociated and ionised in the arc, thereby making them electrically conductive. Owing to the high energy density and temperature, the plasma expands and moves towards the workpiece at up to three times the speed of sound.

Through the recombination of the atoms and molecules on the surface of the workpiece, the energy absorbed is instantly released and intensifies the thermal effect of the plasma arc on the workpiece. Temperatures up to 30,000 K are produced in the plasma arc. Together with the high kinetic energy of the plasma gas, these temperatures permit extremely high-speed cutting of all electrically conductive materials, depending on material thickness.

To initiate the cutting process, a pilot arc is first lit between the nozzle and electrode by applying a high voltage. This low-energy pilot arc prepares the space between the plasma burner and the workpiece by causing partial ionisation. When the pilot arc contacts the workpiece (flying cutting), the main plasma arc lights through an automatic increase in power.

The metal material melts and partially vapourises due to the thermal energy of the arc and plasma gas. The melt is forced out of the kerf by the kinetic energy of the plasma gas. In contrast to oxy-fuel cutting, in which about 70% of the thermal energy is produced through iron combustion, in plasma fusion cutting the energy required for melting the material in the kerf is produced only electrically.

Which plasma gases are used depends on the material to be cut. For example, the monatomic gas argon and/or diatomic gases, such as hydrogen, nitrogen, oxygen, and combinations thereof as well as purified air are used as the plasma gas and also as the cutting gas.

Burners can either be water-cooled or gas-cooled. Plasma cutting processes are broken down according to where they are used (above and on the water and under the surface of water).

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**Figure 4: Principle of plasma cutting with transferred arc**

- **Electrode (cathode)**
- **Nozzle**
- **Plasma gas**
- **Coolant**
- **Nozzle cap**
- **Plasma arc**
- **Workpiece (anode)**
- **Kerf**
- **Cutting direction**
- **Ignition system**
- **Pilot arc resistor**
- **Cutting power source**
**Equipment for plasma cutting**

**Plasma power source**

The plasma power source supplies the operating voltage and the cutting current for the main and auxiliary arc. The no-load voltage of plasma cutting power sources ranges from between 240 and 400 V. The power source contains a pilot arc (auxiliary plasma arc) ignition system, responsible for lighting the main plasma arc. This is generally done by first lighting a non-transferred plasma arc using high-voltage pulses. This arc is responsible for ionising the space between the nozzle and the workpiece, thus permitting the main plasma arc to be produced.

Plasma cutting power sources either have a characteristic steeply decreasing voltage current curve (Fig. 6), or a constant current characteristic (Fig. 7), which results in little or no cutting power changes as the arc gets longer.

**Plasma burner electrode and nozzle**

Enhancing plasma cutting depends greatly on the design of the plasma burner. The more tightly the plasma arc is constricted, the higher the cutting speed and cut-edge quality.

Key plasma burner components are the plasma nozzle and electrode. Both the plasma nozzle and the electrode are components with a limited service life time. The wrong choice or incorrect use of a nozzle, or an electrode, can significantly shorten their life time and damage the burner.

Electrode life is greatly determined by the intensity of the cutting current, number of ignitions and the type of plasma gas used. Furthermore, gas and power management at the beginning and end of the cut, as well as heat dissipation from the electrode also play a key role. Rod-shaped tungsten electrodes and pin-shaped zirconium or hafnium electrodes, which can be transformed into pointed or flat electrodes, are generally used. Due to its tendency to erode, tungsten electrodes can only be used with inert plasma gases and mixtures thereof, as well as with low reactivity and reducing plasma gases. When using pure oxygen, or plasma gases that contain oxygen, a significant increase in electrode life can be achieved by using electrodes made of zirconium or hafnium. These materials naturally form a protective layer that melts at higher temperatures (Table 1) and, in addition, they are embedded in a very thermally-conductive, intensively-cooled main shell. When plasma cutting with oxygen, an increase in electrode life can be achieved by supplying two gases: the ignition process is conducted using a low oxidising gas and the actual cutting process with oxygen.

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**Figure 5: Example setup for plasma cutting**

![Figure 5: Example setup for plasma cutting](image)

**Figure 6: Plasma power source with steeply decreasing voltage current curve**

![Figure 6: Plasma power source with steeply decreasing voltage current curve](image)

**Figure 7: Plasma power source with constant current characteristic (vertical drop)**

![Figure 7: Plasma power source with constant current characteristic (vertical drop)](image)
Workpiece
In plasma cutting with transferred plasma arc, the material to be cut has to be electrically conductive since the workpiece is a part of an electric circuit. The ground of the connected workpiece must be designed to permit a continuous flow of current.

Gas supply
Plasma cutting systems operate with the following gases: inert, reduced-reactivity, low-reactivity, active, and mixtures of any of these. See page 16 for a comprehensive description of gas supply systems and for information on selecting gases, and what gas qualities should be used.

Coolant circulation system
Due to high thermal loads, plasma cutting requires effective cooling. A distinction is made between integrated and external water circulation cooling and gas cooling. Burners of approx. 100 amps or more are generally water-cooled.

Cutting bench and exhaust system
Cutting benches serve as a stable device for positioning metal sheet to be cut. The dimensions of the bench depend on the size, thickness and weight of the metal plate. Emissions released during the cutting process can be significantly reduced by using a plasma cutter in combination with an exhaust system for smoke and dust or with a water basin.

Table 1: Characteristic values of consummable parts used with plasma burners

<table>
<thead>
<tr>
<th>Material</th>
<th>Symbol</th>
<th>Melting temperature (°C)</th>
<th>Gases used</th>
<th>Thermal conductivity at 20 °C (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tungsten</td>
<td>W</td>
<td>≈ 3400</td>
<td>Ar</td>
<td>≈ 174</td>
</tr>
<tr>
<td>Tungsten oxide</td>
<td>WO₃</td>
<td>≈ 1473</td>
<td>Ar/H₂</td>
<td></td>
</tr>
<tr>
<td>Zirconium</td>
<td>Zr</td>
<td>≈ 1852</td>
<td>O₂</td>
<td>≈ 22</td>
</tr>
<tr>
<td>Zirconium oxide</td>
<td>ZrO₂</td>
<td>≈ 2700</td>
<td>Air</td>
<td>≈ 2.5</td>
</tr>
<tr>
<td>Zirconium nitride</td>
<td>ZrN</td>
<td>≈ 2982</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hafnium</td>
<td>Hf</td>
<td>≈ 2227</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hafnium oxide</td>
<td>HfO₂</td>
<td>1700</td>
<td>O₂</td>
<td></td>
</tr>
<tr>
<td>Hafnium nitride</td>
<td>HfN</td>
<td>3305</td>
<td>Air</td>
<td>≈ 29</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>1083</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper oxide</td>
<td>Cu₂O</td>
<td>1235</td>
<td>All</td>
<td>≈ 400</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>961</td>
<td>All</td>
<td>≈ 429</td>
</tr>
</tbody>
</table>

Source: DVS leaflet 2107
Plasma cutting techniques are constantly being improved. The main aim of these enhancements is to reduce environmental pollution, increase cutting capacity, and improve cut-edge quality. The ultimate goal is to produce two plane-parallel, even cut surfaces, which require little to no finishing before they are sent on for further processing.

Depending on the type of material to be cut, its thickness and power source output, a number of plasma cutting variations are available.

The variations mainly differ through their plasma burner design, the material feed system and the electrode material. Figure 6 provides an overview of the various options possible in the design of a plasma burner.

The following types of plasma burners based on the type of constriction:
- Conventional plasma cutting/standard plasma cutting
- Plasma cutting with secondary medium
- Plasma cutting with secondary gas
- Plasma cutting with secondary water
- Water injection plasma cutting
- Plasma cutting with increased constriction

Figure 8: Design options for plasma burners

Plasma burning systems

- Burner cooling
  - Water direct
  - Water indirect
  - Gas-cooled

- Plasma type
  - Dry
  - With secondary gas
  - With water injection
  - Under water

- Plasma gas
  - Inert
  - Oxidising
  - Reducing
  - Monatomic
  - Multiatomic

- Electrode type
  - Needle electrode
  - Plate electrode
  - Electrode material
    - Tungsten
    - Zirconium
    - Hafnium
Conventional plasma cutting

In standard plasma cutting machines, the burner is relatively simple and designed for only one gas, the cutting gas. Cutting gases used are generally nitrogen, oxygen or argon-hydrogen mixtures (Argoplas®) (Fig. 9). The plasma arc is only constricted by the interior diameter of the nozzle, producing the beveled cut surfaces typical to this method. In general, the plasma gas moves tangentially around the electrode. Depending on the cutting speed, the burner is cooled by either air or water. Conventional plasma cutting systems are available for cutting metals up to 160 mm in thickness.

Plasma cutting with secondary medium

A secondary medium is fed around the plasma arc in order to create a specific atmosphere around it. The secondary medium can either be water or a certain gas (Fig. 10).

Plasma cutting with secondary gas

Feeding a secondary gas around the plasma arc further constricts the arc and creates a specific atmosphere around it. This increases the power density, cutting quality and cutting speed. Through special positioning of the shield cap, damage to the system through shorting and double arcing can be avoided, thus extending the life of consumable parts. Generally these secondary media are also referred to as “secondary gas,” “shielding gas,” “protective gas” or “swirl gas”. Machines based on this technique are currently available for cutting metal plates up to 75 mm in thickness (Fig. 11).

Water-shielded plasma cutting

Plasma cutting with water as secondary shield is another variation of plasma cutting with a secondary medium. The water shield is discharged as spray and broken down by the plasma arc. Owing to its reducing effect, the hydrogen formed in the process results in a shiny, metal surface. Therefore, plasma cutting with a water shield is the preferred method for cutting aluminum and high-alloy steels up to 50 mm in thickness (Fig. 10).
Water injection plasma cutting

In this method, the plasma arc is further constricted by radially injecting water around it. Only a small portion of the water evaporates. The rest cools the nozzle and the workpiece. Cooling of the workpiece through the injected water and the high cutting speed permit distortion-free cutting, little burr formation, and extends the life of consumable parts. There are two types of water injection plasma cutting methods based on how the water is injected: radial injection and vortex injection. With vortex injection, one of the cut-edges is nearly vertical while the other is off by about 5 to 8° (Fig. 12).

When using a water injection plasma cutter, it is important to cut the workpiece so that the side with the beveled edge is on the side of the scrap material. Flat electrodes are preferred for water injection plasma cutting. This method is exclusively used with underwater cutting machines. Metal plates between 3 and 75 mm can be cut using this technique.

Plasma cutting with increased constriction

This variation involves increasing arc density by using nozzles with greater constriction. Different companies use different methods (some are patented), for constricting the arc. Gas rotation (Fig. 13) and adjustable nozzles (Fig. 14) have generally proven to be effective. The plasma arc created with this system allows high-precision vertical cuts to be produced when cutting metal sheets 0.5 to 25 mm in thickness. Plasma cutting with increased constriction is the method of choice when secondary gas is used.
In addition to the above described basic plasma cutting methods, the literature also describes many companies’ propriety techniques, some of which are protected by patents.

Table 2 provides an overview of company designations for the basic plasma cutting variations.

Other plasma cutting variations

Underwater plasma cutting

This variation of plasma cutting significantly increases operating safety. Cutting is done about 60 to 100 mm below the water surface (Fig. 15), significantly reducing noise, dust and aerosol pollution in the environment. The noise level is well below 85 dB (A). The water also reduces the amount of ultraviolet radiation produced in the cutting process. Cut parts exhibit little distortion.

Since underwater plasma cutting requires more energy than cutting in the atmosphere, the cutting speeds that can be achieved are lower than comparable cuts in an atmospheric environment.

Structural steels of approximately 15 mm in thickness and high-alloy steels of approximately 20 mm in thickness are generally economical to cut under water.

Plasma gouging

Plasma gouging (Fig. 16) is the process of removing surface material using a plasma arc. The heat provided by the plasma arc permits continuous melting of the material. Through the force in the plasma arc the melt is expelled out of the area.

As a clean alternative to carbon arc gouging, plasma gouging is used for eliminating defects in welds, or surface defects on structural steel and high-alloy steels. Owing to the smooth finish of the base of the joint, grinding is not necessary. Heat input is low and there is practically no distortion. The operator can easily see what he/she is doing. The noise and smoke that accompanies plasma gouging is significantly lower than with carbon arc gouging.

Plasma marking

Used for marking cut components. When marking a workpiece with a plasma jet, the workpiece is subjected to heat, which can cause discolouration of the surface through heat tinting. (The plasma machine does not independently switch to a higher cutting current, thus initiating cutting.) The arc current is a maximum of 10 amps. Argon, nitrogen or air are generally used as plasma gases.

<table>
<thead>
<tr>
<th>Company designation</th>
<th>Conventional</th>
<th>w/secondary gas</th>
<th>w/water shield</th>
<th>w/water injection</th>
<th>w/increased constriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual flow technology</td>
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<tr>
<td>Finefocus plasma technology</td>
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<tr>
<td>HiFocus plasma technology</td>
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<tr>
<td>High plasma technology</td>
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<tr>
<td>High current plasma cutting</td>
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<tr>
<td>HyDefinition plasma technology</td>
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<tr>
<td>Longlife plasma technology</td>
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<tr>
<td>Precision plasma cutting</td>
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<tr>
<td>Water vortex</td>
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<tr>
<td>WIPC plasma technology</td>
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<tr>
<td>Swirling-gas plasma technology</td>
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<tr>
<td>WIRS process</td>
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<td></td>
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<tr>
<td>XLife-Time technology</td>
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</tr>
</tbody>
</table>

Source: DVS leaflet 2107
Plasma notching

Used for defining the position of subsequent components.

When notching a workpiece with a plasma jet, the workpiece is subjected to a slight mechanical load, which results in notches on the surface. (The plasma machine does not independently switch to a higher cutting current, thus initiating the cutting process.) The arc current is a maximum of 25 amps. Argon or air are generally used as the plasma gas.

Plasma punching

Used for defining the position of subsequent components.

When punching a workpiece with a plasma jet, the workpiece is subjected to a slight mechanical load. However, the plasma burner does not move over the workpiece and the plasma jet is only directed at the surface of the workpiece for a short period of time (about 1 sec.). (The plasma machine does not independently switch to a higher cutting current, thus initiating cutting.) The arc current is a maximum of 25 amps. Argon or air are generally used as the plasma gas.
Gases used for plasma cutting

Definition of a plasma gas

Plasma gas
Refers to all gases or gas mixtures that can be used for creating a plasma and for the cutting process itself. The plasma arc involves two main phases, the ignition phase and the cutting phase. Thus, plasma gas is broken down into the ignition gas and cutting gas, which can differ both in terms of gas type and volume flow.

Ignition gas
This gas is used for igniting the plasma arc. It is responsible for facilitating the ignition process and/or increasing electrode life.

Cutting gas
This gas is required for cutting the workpiece with the plasma arc. It is responsible for achieving an optimal cutting quality with different materials.

Secondary gas – swirl gas – auxiliary gas
This gas encloses the plasma jet, thus cooling and constricting it. In this way, it improves cut-edge quality and protects the nozzle when penetrating the workpiece and when cutting under water.

Impact of plasma gases on the quality of the plasma cutting process

Which plasma gas is used plays a decisive role in the quality and economic efficiency of the plasma cutting process. Different materials and different material thickness require different plasma-producing media. These media can be gases, gas mixtures and water. The following section addresses the selection criteria, focusing primarily on gases.

In order to avoid further processing after plasma cutting, the right plasma gas should be used for the given material. The physical and mechanical properties of the gases should be taken into account when selecting a gas. In order to achieve a high cutting speed and good cut-edge quality, the plasma jet must have a high energy content and good conductive properties for transferring heat to the metal, as well as possess high kinetic energy.

The chemical properties – reducing, neutral, oxidising – have a great impact on the shape of the cut-edges and, thus, on any subsequent finishing costs. Since the plasma gas interacts with the molten metal, it can also have a significant effect on cut-edge quality.

The following quality factors are affected:
—cut squareness
—roughness
—rounding of top edge
—burr formation
—weldability (pores)

The following physical properties must always be taken into account when selecting a plasma gas:
—ionisation energy of monatomic gases
—dissociation energy of multiatomic gases
—thermal conductivity
—atOMIC weight and molecular weight
—specific gravity
—chemical reactivity

Table 3 provides a comparison of the main physical properties of the gases generally used for plasma cutting.

<table>
<thead>
<tr>
<th>Property</th>
<th>N, (N)</th>
<th>H, (H)</th>
<th>O, (O)</th>
<th>Ar</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionisation energy [eV]</td>
<td>15.5 (14.5)</td>
<td>15.6 (13.5)</td>
<td>12.5 (13.6)</td>
<td>15.8</td>
<td>34</td>
</tr>
<tr>
<td>Dissociation energy [eV]</td>
<td>9.8</td>
<td>4.4</td>
<td>5.1</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Atomic weight [u]</td>
<td>14</td>
<td>1</td>
<td>16</td>
<td>40</td>
<td>14.4</td>
</tr>
<tr>
<td>Thermal conductivity at 0 °C [W/mK]</td>
<td>24.5</td>
<td>168</td>
<td>24.7</td>
<td>16.6</td>
<td>24.5</td>
</tr>
</tbody>
</table>
Selecting a plasma gas based on the material and method to be used

Inert and active gases and mixtures thereof are generally suitable as plasma gases. Plasma cutting gases comply with Australian standard AS 4882 and ISO 14175 in terms of their designation, mixing precision and purity. These standards refer to shielding gases but the purity and percentage fill tolerances are important to understand.

Plasma gases that can be used are argon, hydrogen, nitrogen, oxygen, mixtures thereof, and air. In terms of their advantages and disadvantages, none of the plasma gases described below is an optimal plasma medium. Therefore, in most instances, a mixture of these gases is used.

Before using any certain gas mixture, the manufacturer should be consulted to find out whether the mixture is suitable for the system. Unsuitable mixtures may lead to a reduction in the life of consumable parts or to damage or destruction of the burner.

Argon

With a volume of 0.9325%, argon is the only inert gas that can be produced commercially using air separation technology. As an inert gas it is chemically neutral. Owing to its high atomic weight (39.95), argon promotes expulsion of the molten material from the kerf through the high impulse density of the plasma jet produced.

With a low ionisation energy of 15.76 eV, argon is relatively easy to ionise. For this reason, pure argon is often used for igniting the plasma arc. Once the transferred plasma arc is ignited, the actual plasma gas is supplied in order to begin the cutting process. Due to its relatively poor thermal conductivity and enthalpy, argon is not completely ideal as a plasma cutting gas, since it only permits a relatively low cutting speed and leads to blunt, scaly surfaces.

Hydrogen

In comparison to argon, hydrogen has a very low atomic weight and exhibits relatively high thermal conductivity. Hydrogen’s extremely high maximum thermal conductivity is in the dissociation temperature range and is the result of the dissociation and recombination processes. The dissociation of hydrogen begins at a temperature of 2,000 K and is fully completed at 6,000 K. Full ionisation of hydrogen occurs at temperatures around 25,000 K. Recombining and ionising the diatomic hydrogen initially draws a great deal of energy from the arc. This leads to constriction of the arc stream. When the arc impacts the material surface, the charged particles recombine and release energy as recombination heat, which contributes to the increase in temperature in the melted material. Tenacious chromium and aluminum oxides are reduced when hydrogen is added, thus making the melt more fluid. Due to the above described physical properties, hydrogen alone is just as unsuitable as a plasma medium as argon. However, if hydrogen’s positive thermal properties (high energy content and enthalpy) are combined with argon’s high atomic weight, the resulting gas mixture offers fast transfer of high kinetic energy (atomic weight) as well as sufficient thermal energy to the material to be cut.

Figure 17: Impact of temperature on thermal conductivity of gases
Argon-hydrogen mixtures (Argoplas®)

Argon-hydrogen mixtures are often used for cutting high-alloy steels and aluminum. Even adding only a few percentages of hydrogen to argon permits a significant improvement in cutting speed and cut-edge quality. Furthermore, the reducing effect of hydrogen results in smooth, oxide-free cut metal surfaces. The mixtures are often used to cut thick plates up to 150 mm.

The hydrogen portion amounts to as much as 35% (Argoplas® 35) by volume and depends on the thickness of the material. Increasing the percentage of hydrogen beyond this leads to no significant increase in cutting speed. In fact, hydrogen portions of over 40% by volume, can lead to bulging recesses of the cut surfaces and increased burr formation on the bottom edge of the workpiece. BOC stocks three standard Argoplas® mixtures – Argoplas® 5, 20, 35.

Nitrogen-hydrogen mixtures

Nitrogen-hydrogen mixtures are often used for cutting high-alloy steels and aluminum. They permit cuts with parallel edges to be produced at considerably higher cutting speeds than argon. Oxidation on the cut surfaces is also less than when pure nitrogen is used. These mixtures, referred to as forming gases, contain up to 20% hydrogen.

Argon-hydrogen-nitrogen mixtures

Argon-hydrogen-nitrogen mixtures are used for cutting high-alloy steels and aluminum. They offer good cut-edge quality and pose fewer problems with burr formation than argon-hydrogen mixtures. The most commonly used mixtures are made up of 50 to 60% argon and 40 to 50% nitrogen and hydrogen. The percentage of hydrogen is usually as much as 30%. The amount of hydrogen depends on the thickness of the workpiece: the thicker the material, the more hydrogen that should be used. By adding nitrogen to argon-hydrogen mixtures when cutting high-alloy steels and structural steels, burr-free edges and high cutting speeds can be achieved.

Oxygen

Oxygen is used as a plasma gas for cutting non-alloy and low-alloy steels. When oxygen mixes with the melt, the viscosity of the melt decreases, causing it to become more fluid. This generally permits burr-free edges and top edges that are not rounded. Higher cutting speeds are possible than with nitrogen or air. In contrast to nitrogen or air, oxygen does not cause a nitrogen content of the cut surface and minimise the danger of pores developing during subsequent welding.

Owing to the high cutting speed, the width of the heat affected zone is very small and the mechanical properties of the cut metal do not deteriorate. The high cutting speed is due to the chemical reaction of the oxygen with the material.

Nitrogen

In terms of its physical properties, nitrogen falls somewhere between argon and hydrogen. With an atomic weight of 14, nitrogen far exceeds hydrogen, but is well below argon. Nitrogen’s thermal conductivity and enthalpy are higher than argon’s and below hydrogen’s. Nitrogen behaves similar to hydrogen in terms of its ability to constrict the arc and how its recombination heat produces fluid melts. For this reason, nitrogen can be used alone as a plasma gas. Nitrogen as a plasma gas permits quick and oxide-free cutting of workpieces with thin walls. The disadvantage is that the number of draglines is relatively high. Cuts with perfectly parallel sides are hardly ever achieved. The angle of the bevel produced greatly depends on the set gas volume and the cutting speed. The absorption of nitrogen on the cut surface has an unfavourable effect on weldability. The increased nitrogen concentration on the cut surfaces is responsible for the porosity in the weld metal.

Nitrogen-hydrogen mixtures

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Carbon dioxide

Carbon dioxide is generally not used as a plasma gas in plasma cutting; in rare cases, it is used as the secondary gas or cooling gas.

Air

Air basically consists of nitrogen (78.18% by volume) and oxygen (20.8% by volume). The combination of these two gases provides a very energy-rich gas mixture. Air is used as a plasma gas for cutting non-alloy, low-alloy steel and high-alloy steel and aluminum. Air is generally used for manual cutting and for cutting thin sheets. Using air as a plasma gas when cutting non-alloy steel generally results in square and relatively smooth edges. However, as a cutting gas, air increases the nitrogen content of the cut surface. If these cut-edges are not mechanically finished afterwards, pores may form in the weld. When cutting aluminum, the cut-edges may become discoloured.

Water (steam)

At a certain temperature, water is broken down into its components hydrogen and oxygen. If more energy is added, water dissociates and ionises. In the case of water injection plasma cutting and plasma cutting with a water shield, a part of the water is used for transferring heat, while the other part helps constrict the plasma arc and cool the nozzle.

Table 4: Recommended gas combinations and their impact on cut-edge quality

<table>
<thead>
<tr>
<th>Material/thickness</th>
<th>Plasma gas</th>
<th>Secondary gas</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural steel</td>
<td>Oxygen</td>
<td>Oxygen or oxygen/nitrogen or nitrogen</td>
<td>—Squareness tolerance similar to laser</td>
</tr>
<tr>
<td>0.5 to 8 mm</td>
<td></td>
<td></td>
<td>—Smooth, burr-free edges</td>
</tr>
<tr>
<td>Structural steel</td>
<td>Oxygen</td>
<td>Oxygen/nitrogen or air or nitrogen</td>
<td>—Up to 25 mm squareness tolerance, similar to laser</td>
</tr>
<tr>
<td>4 to 50 mm</td>
<td></td>
<td></td>
<td>—Smooth cut surfaces</td>
</tr>
<tr>
<td></td>
<td>Nitrogen</td>
<td>Nitrogen or nitrogen/hydrogen</td>
<td>—Low squareness tolerance</td>
</tr>
<tr>
<td>High-alloy steel</td>
<td>Nitrogen</td>
<td></td>
<td>—Smooth, burr-free edges (1.4301)</td>
</tr>
<tr>
<td>1 to 6 mm</td>
<td>Argon/hydrogen/nitrogen</td>
<td>Nitrogen or nitrogen/hydrogen</td>
<td>—Low squareness tolerance</td>
</tr>
<tr>
<td>High-alloy steel</td>
<td>Air</td>
<td>Nitrogen or nitrogen/hydrogen</td>
<td>—Smooth cuts</td>
</tr>
<tr>
<td>5 to 45 mm</td>
<td></td>
<td></td>
<td>—Burr-free up to 20 mm (1.4301)</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Argon/hydrogen/nitrogen</td>
<td>Nitrogen or nitrogen/hydrogen</td>
<td>—Nearly vertical cuts</td>
</tr>
<tr>
<td>1 to 6 mm</td>
<td></td>
<td></td>
<td>—Burr-free cuts (AlMg3)</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Argon/hydrogen/nitrogen</td>
<td>Nitrogen or nitrogen/hydrogen</td>
<td>—Roughness, grainy</td>
</tr>
<tr>
<td>5 to 40 mm</td>
<td></td>
<td></td>
<td>—Nearly vertical cuts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>—Burr-free up to 20 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>—Roughness, grainy</td>
</tr>
</tbody>
</table>
Gas supply for plasma cutting machines

Plasma cutting machines operate with one or several different gases. The required supply pressure and throughput depend on the type of equipment being used. The manufacturer’s specifications should always be complied with. The gas can be supplied in various forms, such as in cylinders, in cylinder packs or in liquid state in tanks.

The form in which the required gases are delivered – in gaseous or liquefied state – primarily depends on how much of the gases is needed. The same holds true for the size and type of the gas storage unit. However, economic factors also have to be considered in terms of the design of the gas supply system for plasma cutting. The amount of plasma and secondary gases required depends on various factors such as the plasma nozzle diameter, gas pressure and cutting current and can lie anywhere between 20–100 l/min. Under these conditions, depending on the job(s) at hand, anything from individual gas cylinders to stationary tanks may be required to supply sufficient gas.

If gas utilisation is 200–300 m3/week, the gas is delivered in its gaseous form; for quantities above that amount, it comes in liquid state.

If the gas flow in a plasma cutting system falls below the value specified by the manufacturer, the burner can be seriously damaged. To avoid this, it is paramount that the pressure be set to the value specified by the manufacturer. At least 12 bars of pressure should be available.

Table 5 shows the minimum purity requirements for gases used in plasma cutting of non-alloy, low-alloy and high-alloy steels and aluminum. Non-compliance with these values can jeopardise quality and economic efficiency due to a reduction in cutting speed.

Note: When air is supplied using a compressor instead of technical air in cylinders or packs, it is absolutely essential that the requirements specified in Table 5 regarding maximum particle size, residual oil content and dew point be maintained since increased oil and moisture content can reduce the life of consumable parts and increase the chances of ruining the burner.

<table>
<thead>
<tr>
<th></th>
<th>Oxygen</th>
<th>Argon</th>
<th>Hydrogen</th>
<th>Nitrogen</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purity</td>
<td>99.5%</td>
<td>99.99% (4.5)</td>
<td>99.5%</td>
<td>99.99% (5.0) for plasma gas or 99.99% (4.0) for swirl gas</td>
<td>Dry, free of dirt, oil and water, max. particle size: 0.1 μm, class 1 in accord. with ISO 8573, max. residual oil content: 0.1 mg/m³, class 2 in accord. with ISO 8573, max. dew point: +3 °C, class 4 in accord. with ISO 8573</td>
</tr>
<tr>
<td>(2.5)</td>
<td>(2.5)</td>
<td>(4.5)</td>
<td>(2.5)</td>
<td>(2.5)</td>
<td></td>
</tr>
</tbody>
</table>
European standard EN ISO 9013 “Thermal Cutting” defines the classification of thermal cuts, geometric product specifications and quality.

The standard applies to materials suitable for oxy-fuel cutting, plasma cutting and laser cutting and should be used for oxy-fuel cuts from 3 to 300 mm, plasma cuts from 1 to 150 mm, and laser cuts from 0.5 to 40 mm. This standard contains the geometric product specifications and dimensional (quality) tolerances.

It is important to determine the correct quality for every product to be cut. This section explains the most important quality parameters.

Quality parameters

- Squareness and angularity tolerance (u)
- Average peak-to-valley height (Rz5)
- Dragline lag (n)
- Melting of the top edge (r)
- Possible formation of burrs or drops of molten metal on the bottom of the cut-edge

In order to determine u, the value Δ a should be offset from the top and bottom cut-edge.

Δ a depends on the thickness of the plate.
**Designation and definition**

The cut-edge quality of materials subject to plasma cutting is defined by the following values:

—Squareness (see Fig. 19) and angularity tolerance (see Fig. 20)
—Average peak-to-valley height (Rz5) (see Fig. 21)

The following values can be also used to visually assess quality:

—Dragline lag (n) (see Fig. 22)
—Melting of the top edge (r) (see bottom of Fig. 22)

**Other quality criteria**

Dross (burr formation on the bottom of the kerf and spatter on the top of the kerf) Burr refers to resolidified metal and metal oxide that adheres to the bottom of the plasma-cut surface. Spatter can also form on the top edge of the plasma cut-surface. Burr formation depends on a number of process variables, such as the cutting speed, burner distance, current intensity, voltage, the plasma gas and the plasma technology. It is also affected by variables such as the material itself, its thickness, surface condition and temperature changes in the material during cutting. Burrs can also form if the cutting speed is too high or too low. Generally there is a middle range between these two extremes in which a burr-free cut can be achieved. The plasma cutting technique and gas used are important factors in avoiding the formation of burrs.

**Angle deviation**

During plasma cutting, the cut surface generally runs at a slight angle due to the temperature gradient in the plasma arc. The greatest energy input occurs at the top of the kerf, causing more material to melt there than at the bottom. The more the arc is constricted, the smaller the resulting cut angle. The cut angle is also influenced by the distance of the burner and the cutting speed. In conventional plasma cutting, the cutting angle on both sides is normally 4 to 8°. When using plasma technology with greater constriction, the cut angle can be reduced to less than 1 degree so that cutting parts possess common cutting edges.
Kerf width
A rule of thumb is that the kerf width in plasma cutting is about one and a half to two times greater than the diameter of the nozzle outlet. Kerf width is influenced by the cutting speed. If the cutting speed is reduced, the kerf is wider.

Metallurgical effect (heat-affected zone)
In comparison to oxy-fuel cutting, the heat affected zone is about one-third smaller when using plasma cutting on non-alloy steel. When plasma cutting other materials, the heat-affected zone varies depending on the material.

Nitrogen absorption
When plasma cutting with air or nitrogen an increased nitrogen content occurs on the cut surface. As a result, porosity may occur in the weld. By using oxygen, the development of pores can be significantly reduced.

Plasma cutting with increased constriction permits an extremely good cut quality and high precision to be achieved. This technology guarantees a component tolerance of ± 0.2 mm and a high repeating accuracy, thus permitting almost laser-quality cuts to be attained.

Achievable cut qualities
If the specified technical cutting parameters are maintained, standard-conform cut qualities can be achieved with the most popular types of structural and high-grade steels. Although aluminum materials can also be cut according to standards, their peak-to-valley height is greater than with steel. The qualities that can be achieved generally depend on the material being cut. Depending on the alloy, cut-edges of parts made of titanium, magnesium and their alloys, as well as of brass and copper exhibit a grainy surface with an average peak-to-valley height that cannot be calculated nor assessed based on standard EN ISO 9013.

Plasma cutting with increase constriction permits good results to be achieved (see Figs. 23 and 24):
—No or little burr formation
—High contour accuracy at sharp corners and edges
—Low squareness tolerance of the cut surfaces
—High fit accuracy (e.g. of plug connectors)
—Narrow heat-affected zone, little distortion
—Minimal peak-to-valley height, smooth cut surface
—Possible to cut holes with small diameters
Troubleshooting

Process variables that can impact cut quality include cutting speed, burner distance (distance to the workpiece), type of plasma and secondary gas, nozzle size, and cutting current. Table 6 offers suggestions for troubleshooting.

Table 6: Typical quality problems related to plasma cutting and ways of eliminating them [1]

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Problem</th>
<th>Possible causes</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle deviation</td>
<td>too great.</td>
<td>1. Burner not at a right angle</td>
<td>1. Position burner at right angle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Distance too great</td>
<td>2. Reduce distance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Current too low</td>
<td>3. Increase current</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Speed too high</td>
<td>4. Adjust speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Direction of movement of burner</td>
<td>5. Change direction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Nozzle eroded</td>
<td>6. Replace nozzle</td>
</tr>
<tr>
<td>High-speed burr</td>
<td>Kerf too narrow, striation diagonal or s-shaped.</td>
<td>1. Speed too high</td>
<td>1. Adjust speed</td>
</tr>
<tr>
<td></td>
<td>Slight burr formation, burr is hard.</td>
<td>2. Current too low</td>
<td>2. Increase current</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Distance too great</td>
<td>3. Reduce distance</td>
</tr>
<tr>
<td>Low-speed burr</td>
<td>Kerf is wide, striations run vertically.</td>
<td>1. Speed too low</td>
<td>1. Adjust speed</td>
</tr>
<tr>
<td></td>
<td>Extensive burr formation, burr is blistered.</td>
<td>2. Current too high</td>
<td>2. Reduce current</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Distance too little</td>
<td>3. Increase distance</td>
</tr>
<tr>
<td>Rounded top edges</td>
<td></td>
<td>1. Unsuitable secondary gas</td>
<td>1. Use a different gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Distance too great</td>
<td>2. Reduce distance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Speed too high</td>
<td>3. Adjust speed</td>
</tr>
<tr>
<td>Spatter at the top</td>
<td></td>
<td>1. Speed too low</td>
<td>1. Adjust speed</td>
</tr>
<tr>
<td>edge.</td>
<td></td>
<td>2. Distance too great</td>
<td>2. Reduce distance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Replace nozzle</td>
<td>3. Replace nozzle</td>
</tr>
</tbody>
</table>
Plasma cutting safety

As with all welding and cutting techniques, plasma cutting also requires compliance with the basic industrial safety rules.

Each country sets its own safety regulations.

Special consideration should be made for the following factors that can occur during manual and machine plasma cutting:

— Electric current
— Smoke, dust and gases
— Noise
— Radiation
— Hot metal spatter
— Environmental influences

Electric current

Plasma cutting methods pose a special electrical danger due to the high no-load and cutting voltages involved in the process. This danger can be avoided through the safety features integrated in a machine’s design by the manufacturer and by having operators wear appropriate safety clothing.

In the case of a machine defect (insufficient insulation), electric current can flow through parts of the human body. Depending on current type, current intensity and current path as well as length of exposure and the high voltages typical to plasma cutting, the following physical effects can occur:

— Muscle cramps
— Heart palpitations
— Cardiac arrest or heart fluttering

In order to avoid these dangers, gloves should be worn on both hands during plasma cutting.

Smoke, dust and gases

Pollutants, including gases, that can occur during plasma cutting are nitrogen oxides, ozone and carbon monoxide. The amount of nitrogen oxide produced during plasma cutting depends on the current strength and the plasma gas used. Current intensity directly affects nitrogen oxide volume. In other words, the higher the current strength, the higher the nitrogen oxide level. Nitrogen oxide levels are highest when pure nitrogen is used as plasma gas. Therefore, pure nitrogen is hardly ever used as the plasma gas for manual plasma cutting.

The amount of ozone (O3) and carbon monoxide (CO) produced during plasma cutting is well below permissible limits.

The smoke and dust concentrations generated during plasma cutting depend on the material being cut, the plasma gas being used, and the condition of the metal surface (dirt, primer or oxidised surfaces).

The thinner the metal being cut, the less smoke and dust generated. Underwater plasma cutting also produces less smoke and dust. Special exhaust fans (either mobile or stationary) should also remove these pollutants from the air.

If no such exhaust systems are available, operators should wear a respiratory mask or helmet with a particle filter. The gases used in plasma cutting are not flammable. However when forming gases containing hydrogen with a percent by volume of 4% are used and/or processing is conducted at a temperature of 560°C, detonating gas can be produced. This type of gas can also be produced in underwater plasma cutting.

Noise

Since plasma emerges at very high speeds from the plasma nozzle, the amount of noise produced during the cutting process is very high. Its frequency can lie anywhere between 8 and 20 Hz. The noise level is affected by the shape of the nozzle, thickness of the material, gas throughput and current intensity. The amount of noise generated during manual plasma cutting is generally between 90 and 115 dB (A). Values below 80 dB (A) can only be achieved through manual cutting at a low current strength or through using an underwater plasma cutting machine. Wearing hearing protection is required.

Radiation

During plasma cutting, very strong visible and ultraviolet light is produced. In order to protect eyes and skin, the operator must wear appropriate full-body protective clothing and an appropriate protective screen and goggles. The light generated is reduced in underwater plasma cutting.

Hot metal spatter

Personal protection equipment, including safety shoes, gaiters, leather apron and gloves, is necessary for protecting against burning from liquid metal spatter. The danger of injury through metal spatter is reduced in underwater plasma cutting.

Environment

The burrs produced during plasma cutting and trapped dust must be disposed of in accordance with valid regulations.
Literature

Sources:

Other sources:
DVS leaflet 2107
DIN EN 2310-6
DIN EN ISO 9013
ISO 8573
ISO 8206
DIN 8580
DIN 8590
DIN EN 439

Documents supplied by the company Kjellberg Finsterwalde Elektroden und Maschinen GmbH.

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Pictures:
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