WELDING BASICS SERIES

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PLASMA WELDING BASICS 2

Plasma Welding Basics 2

PLASMA ARC FUNDAMENTALS

- HISTORY
- ARC FUNDAMENTALS
- ARC STARTING FUNDAMENTALS

Plasma Welding Basics 2

FUNDAMENTALS OF PLASMARC WELDING AND CUTTING

History

Plasma may be defined as a mass consisting of free electrons and positively charged particles. Lightning is an example of a plasma, as are a neon sign and the initial spark struck by ordinary electric arc welding rods. However, these lack the duration and/or charge density which characterize modern industrial plasma torches.

All plasma torch equipment utilizes an arc which is made to jump from one electrode through a confining space to another electrode. The process begins when a voltage difference causes the first few electrons to leave the cathode and increase in kinetic energy as they move toward the anode. When an electron collides with a molecule of the carrier gas, a portion of the kinetic energy is imparted to the molecule. If the molecule absorbs enough energy, dissociation and ionization will occur, thus creating additional electrons in the arc. This process takes place in the initial spark of ordinary electric arc welding and is the first step in the formation of a plasma "flame."

In plasma torches, this spark and the plasma-forming gas are forced to flow through an orifice or tube, which increases the electron and gas densities, and their probability of interaction. More and more kinetic energy is imparted to the gas, causing additional ionization and temperature increase until the condition recognized as the plasma state is achieved.

The heat content developed in the plasma is great enough to liquefy whatever material may be used to construct the orifice, and so the development of the plasma torch was retarded until the discovery of the thermal pinch effect.

If the orifice or tube through which an electron arc flows is cooled sufficiently, the arc will constrict from the container walls, because the cooling effect decreases the degree of ionization and lowers conductivity in the plasma-gas adjacent to the container walls. The current will tend to concentrate in the hotter, more conductive, central region of the flow, causing further ionization and temperature increase. When the developed plasma arc flame comes in contact with the metal which is to be worked, this tremendous store of energy is released to the work surface. For example, the heat transfer rate for the transferred arc plasma torch can be twenty times that of oxy-acetylene flame (10 BTU/in.^{2}/sec).

History and Applications in Industry

The earliest mention of a plasma-like device dates back to 1908, when researchers discussed the use of a plasma in iron ore treatment. Other plasma arc-type devices include a high-intensity arc developed in 1910. The use of plasma as a heat source in high-temperature furnaces was outlined by E. Mathers in a 1911 patent. Irving Langmuir worked on the development of the plasma theory in the 1920's and gave the name "plasma" to the phenomenon.

This early work was successful in proving the theory of plasma generation, but the duration of each run was limited by the lack of highly refractory materials necessary for fabrication of the critical parts. Another retardant to the development of plasma-forming devices was the lack of general interest in extreme temperature piror to World War II. The development of jet and rocket engines, with the accompanying necessity for heat-resistant materials and knowledge of high-temperature processes, stimulated interest in high-temperature technology. This interest, and the development of refractory materials, resulted in renewed plasma studies.

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INTRODUCTION

The term "plasma" is used to describe a gas which is electrically conductive.* In welding, a good example of a plasma is the gas tungsten arc or open arc. In this case, the shielding gas is heated to the extent that some of the atoms become ionized.

In the early 1950's, it was discovered that the properties of the open arc could be greatly altered by directing the arc through a nozzle located between an electrode (cathode) and the work (anode). This action greatly increases the arc temperature and voltage and results in a highly constricted jet capable of cutting or welding metals depending on the velocity of the jet.

This paper discusses the fundamental principles of the process and its application for the industrial working of metals. Mr. R. M. Gage discovered the constricting (plasma) arc while doing research at the Union Carbide laboratories in the early 1950s.*

Plasma arc welding and cutting are mainly used on austenitic chromium-nickel steels, but the economically more important unalloyed and low-alloyed structural steels are presently being fabricated using the plasma arc process.

Welding is done on materials in the thickness range of 0.002 to 0.300 inches with currents of 0.5 to 300 amps. Cutting is done on materials up to 6 inches thick although most plasma arc cutting is done in the range of 1/4-1 inch thick on carbon steels, 1/4-3 inches on nonferrous metals and alloys.

It is possible to alter the characteristics of the plasma jet by changing the current, nozzle size, gas type or flow rate. With low gas flow rates, the jet is suitable for welding. Conversely, if gas flow rate is increased dramatically, the plasma jet will cut through metal, since the velocity of the plasma jet will be high enough to blast away the molten metal created by the arc. This ability to vary the gas type and flow rate in addition to the degree of arc constriction enables us to optimize welding and cutting parameters.

ARC FUNDAMENTALS

Physics of the Arcs

When an arc is established through a gaseous column separating two electrodes, some of the gas becomes ionized. This ionized material, called plasma, is kept hot by the resistance heating effect of the current passing through it. Plasma is present in all arcs. If a constriction containing an orifice (nozzle) is placed around the arc, the amount of ionization, or plasma is greatly increased. This results in higher arc temperature, a more concentrated heat pattern and higher arc voltage than can be obtained with a nonconstricted arc.

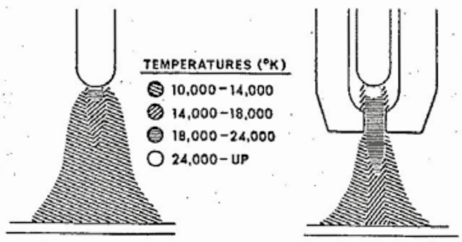

Figure 1

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The constricted arc used in plasma arc welding and cutting offers several advantages over the nonconstricted arc used in gas tungsten - arc welding:

1. Electrode contamination is eliminated.
2. Arc stability is improved, particularly at low current levels.
3. Energy concentration is greater.
4. Heat content is higher.
5. The plasma has higher velocity.
6. Arc length becomes less sensitive.
7. Reduced operator skill is necessary for welding .
8. Autogenous welding is possible up to 0.250 inches thick.

One of the classic explanations of why a DCSP - GTAW arc is hotter than DCRP is that the electron flow is toward the work piece. The electrons, since they are much lighter in mass than the positive ions, gain and carry energy more efficiently.

STRAIGHT POLARITY DCSP   REVERSE POLARITY DCRP

FIGURE 2

This explanation is not accurate since the opposite is true in GMAW (MIG) welding.

DCRP - Highest penetration, lowest burnoff

DCSP - Lowest penetration, highest burnoff

A more accurate explanation of how heat is transferred to the work can be obtained by a study of the arc which can be divided into three regions as shown on next page.

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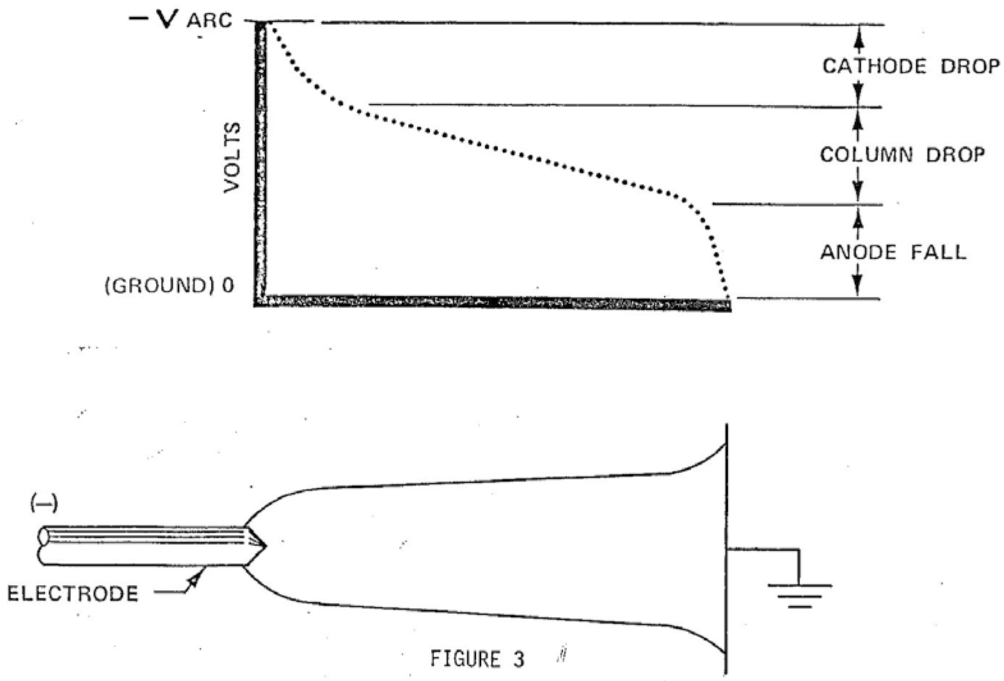

FIGURE 3

DCSP is "hottest" in GTAW and DCRP is "hottest" in GMAW.

GTAW and Plasma Arc Welding

The use of tungsten as the cathode in an electrical circuit provides the unique characteristic of good thermionic emission. Vcath is relatively low since tungsten, especially 2 percent thoriated tungsten, liberates electrons easily.

Therefore:

$$V_{cath} < V_{anode}$$

Where:

Vcath = Cathode drop
Vanode = Anode fall
Ia = Arc current
Va = Arc voltage
Vcol = Column drop
Q = Heat supplied by radiation and convection

Then:

(I) Total power consumed by the arc = Ia X Va
(II) Energy dissipated in arc column = Ia X Vcol
(III) Energy consumed by electrode = Ia X Vcath
(IV) Energy provided to work = Ia X Vanode + Q

Most of the energy in the arc column is wasted in the form of radiation. A small portion of this heat does heat the work piece.

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The addition of thoruim to tungsten effectively lowers the work function because it aids electrons to escape. A thoriated tungsten cathode has an effective work function of 2.6 eV compared with 4.5 eV for pure tungsten.

Since the power to the work piece is approximately Vanode X Ia (Q is relatively small), the maximum heat will be developed at the anode.

GMAW

Vcath is higher in comparison with Vanode since other metals do not have the same cathode emission properties as tungsten.

Therefore:

$$V_{cath} > V_{anode}$$

Thus the maximum heat will be developed at the cathode (DCRP) with GMAW.

Plasma arc is closest to GTAW since a thoriated tungsten is used. In the case of plasma arc, however, there are four regions instead of three. The fourth region is created by the arc constriction. Note that the column drop is much steeper because the plasma jet is smaller in diameter.

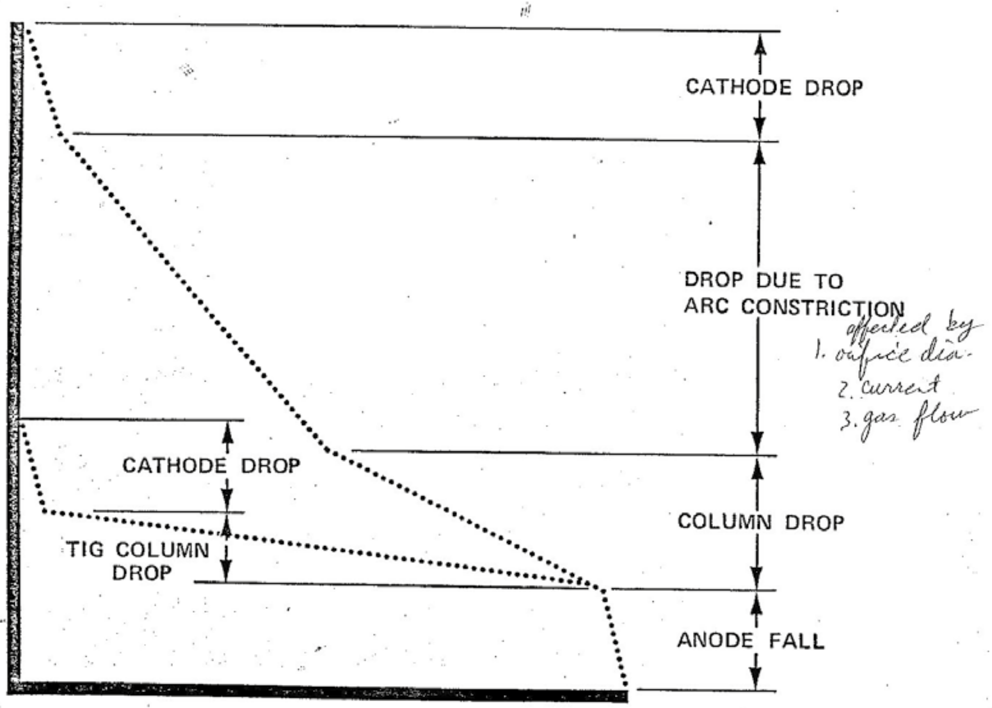

FIGURE 4

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A plasma arc is a converter of electric energy into heat. Therefore, on the one hand, as an electric circuit element, it is characterized by electric parameters (current, voltage), and on the other hand, as a heat source, it is characterized by thermal parameters (temperature, heat content). There is a complex interrelation between the parameters of the first and of the second group. This is graphically represented by the four zones (figure 4). consisting of a cathode region, pre-, intra - and after nozzle sections of the column and an anode region which is on the work piece. The arc voltage is the sum of the drops of voltages across the section.

In both plasma arc processes, gas stabilization may be both axial and vortical. In the first case, the gas passes along the cathode, cooling the nozzle and coming out of the nozzle orifice. In the second case, gas is admitted into the chamber through tangential holes and flows spirally, enveloping the arc column in the vortex flow.

The use of high enthalpy molecular-forming gases is more efficient since they have equal thermal efficiencies as monatomic gases at lower temperatures.

ARC STARTING FUNDAMENTALS

Physics of Arc Starting

The energy requirement to start an arc from the "zero" current condition is best described by a voltage-current curve or a discharge characteristic. Each gas has its own discharge characteristic and is similar in shape to the one shown in figure 5. Physical parameters such as gas pressure, electrode material, electrode separation, and electrode geometry will influence the shape of this curve.

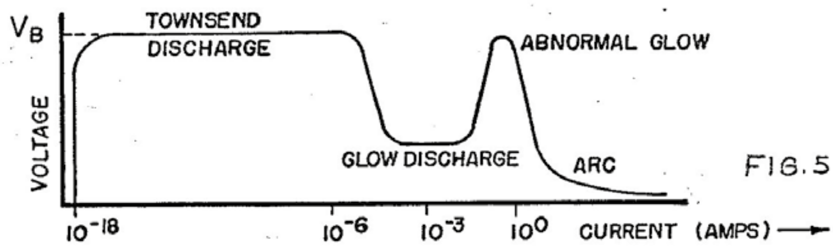
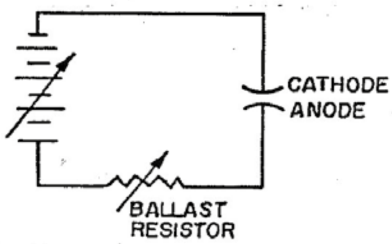


FIG.5

The discharge characteristic of a particular gas (constant pressure and electrode configuration) is determined by connecting a high voltage power supply with an adjustable voltage output in series with a ballast resistor across the cathode (electrode) and anode (work piece) as shown in figure 6. As the voltage



is increased from zero, a miniscule current known as the "dark current" begins to flow and remains relatively constant until the breakdown potential is reached.

Plasma Welding Basics 2

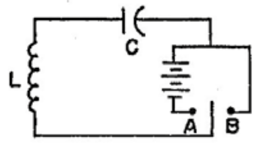
This dark current is dependent upon a source of primary electrons and ions already present in the gas. They were created from external sources such as radiation and/or thermal agitation. Upon reaching breakdown potential (V_B), secondary emission and electron multiplication occurs, creating a source of electrons independent of the primary source.

The breakdown potential for nitrogen is quite high in comparison with other gases. For example, it takes 30KV to breakdown 1 cm gas in nitrogen at one atmosphere of pressure. Argon, by comparison, would require approximately half this voltage. In general, the breakdown voltage is directly proportional to the separation between the cathode and anode and the gas pressure. Therefore, the voltage needed to breakdown a 1/4 cm gas in nitrogen at 1 atmosphere is 7.5KV. If the pressure was increased to 2 atmospheres, the breakdown potential would be 15KV. Water injection plasma cutting, since it uses nitrogen cutting gas, will be relatively difficult to start.

It is important to realize that achieving breakdown between the cathode and anode does not start the arc because the current is a small, small, fraction of a microamp. The high voltage source that initiates breakdown must also have sufficient power to supply a current great enough for the arc, or high current, power source to "follow through." Therefore, in order to start an arc, the breakdown must be very intense - at least .1 amp or more. This means that the high voltage source must have a current output in the lethal range if the source is DC. High frequency eliminates this problem because of a phenomenon known at the skin effect. At frequencies in the .5 MHz range and over, the high frequency current will pass around the outside of a conductor rather than through the conductor. This reason, along with the fact that high frequency is easy to isolate from the arc power source, are the major reasons that high frequency is used in arc cutting and welding equipment today.

The High Frequency Generator

1. Principles of Operation



Placing the switch in the "A" position charges the capacitor (C) to a voltage (V) determined by the power source. The amount of energy (E) contained in "C" is given by the relationship:

$$E = 1/2\ CV^2$$

When the switch is placed in the "B" position, it produces an oscillatory discharge which quickly damps out. The frequency (F) of the oscillation is determined by L and C:

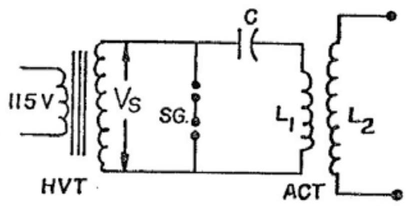
$$F = 1/2\pi\sqrt{LC}$$

The conversion of the energy ($1/2\ CV^2$) into high frequency is on the order of 50 percent.

Plasma Welding Basics 2

II. The Spark Gap Oscillator

The high frequency (HF) unit used to start a plasma cutting torch is often referred to as a "spark gap oscillator." It works in exactly the same way as the previous example except that the switch is replaced by a pair of spark gaps. This circuit used in the PCC-8 control is described in the schematic below:



Component

HVT, High voltage transformer - 400V, 30 Ma rating
SG, Spark gaps - double gap set at .025"
C, Tank capacitor, .003 MFD, 12.5 KV
L_1 Primary of air core transformer (ACT)
L_2 Secondary of ACT. Turns ratio is 7 to 14.

The sequence of operation is as follows:

a. As V_s voltage builds up, it charges "C". Energy in "C" equals $1/2\ CV^2$.

b. When V_s builds up to a high enough voltage, the spark gaps ionize and become essentially a short circuit.

c. The capacitor (C) discharges through the spark gaps and L_1.

d. Because of the energy stored in L_1, the current continues to flow even after the capacitor is discharged. This charges "C" in the opposite direction until the energy in L_1 is dissipated. This process keeps reversing itself but also decays because of circuit losses.

e. As the high frequency circuit decays, it soon reaches a value which will not maintain ionization of the spark gaps and they go to open circuit again.

f. As soon as this occurs, the capacitor (C) starts charging up, thus loading the V_s of HVT down to below the ionization voltage of the spark gaps.

g. It takes an appreciable time for voltage V_s to build up to the breakdown voltage of the spark gaps. When this occurs, another series of damped HF is generated.

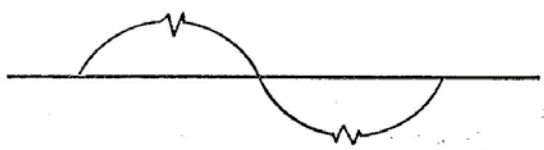
h. This cycle keeps repeating itself, delivering a series of damped wave pulses with a time space between pulses. A typical number of pulses is 5-10 pulses per half cycle of 60 Hz.

Plasma Welding Basics 2

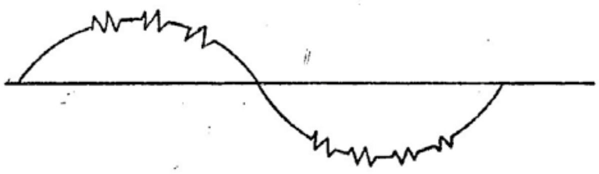
i. The spark gas setting has a direct influence on the output of the generator:

(1) If the spark gaps are set too wide they will not break down at all because there is insufficient voltage to ionize the large gap.

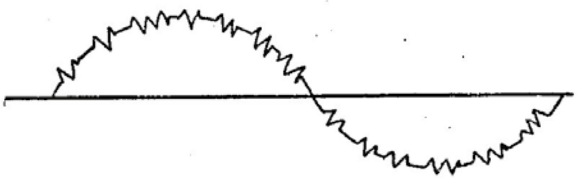
(2) If the spark gap setting is gradually reduced, a setting will be reached where the gaps will break down at peak voltage only.



(3) If gap is further reduced, the gaps will jump before peak voltage is reached and several pulses will be produced each half cycle.



(4) Still further reducing the gap setting will produce an almost continuous series of pulses.



(5) The high frequency voltage which is generated is a direct function of the breakdown voltage of the spark gaps. The wider the gap settings, the greater the breakdown voltage, and the greater the high frequency voltage. The greater the HF voltage, the larger the electrode to work distance.

Starting a Plasma Torch

A plasma cutting system consists of a control, power supply and torch. The only part of the control that we will be concerned with here is the HF unit. Schematically the starting circuit, in its basic form, is shown below:

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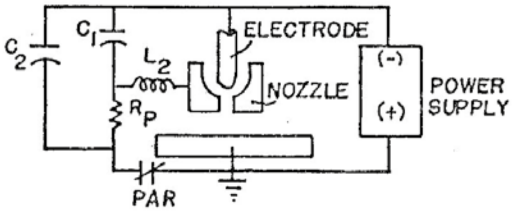


NOTE:

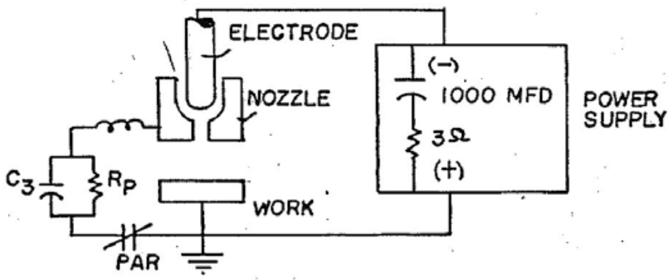
Coupling capacitors C_1 and C_2 eliminated to simplify schematic. In this figure, L_2 is the secondary of the air core transformer, i.e., the generator output. Since L_2 is isolated, the nozzle side is at high voltage and the ground side is coupled via C_1 and C_2 to the electrode. This is a very important feature from a design standpoint - a relatively small and simple air core transformer can be used to isolate and sustain high voltages. A much larger inductor would be required to block a low frequency pulse, say in the KH_Z range. The voltage difference across L_2 is on the order of 10KV. Secondly, the coupling capacitors C_1 and C_2 provide a simple, reliable means of providing a HF connection between the ground side of L_2 and the electrode.

Once the nitrogen flowing between the electrode and nozzle is ionized, the power supply (OCV = 400V) will conduct through the discharge and rapidly increase the current to a level determined by the pilot arc resistor R_P. The resulting discharge is a very intense arc called a pilot arc. This arc blows through the nozzle and ionizes the region between the electrode and the work piece. If the pilot arc current is sufficiently high and the torch is close enough to the work piece, the arc will "transfer" and form a main arc. The current level of this arc is generally, at least, 300 amps and is limited by the power supply setting. In order to get reliable transfer of the main arc, the value of the pilot arc resistor must be low so that a high current pilot arc is formed. This presents problems. First, the resistor must dissipate the heat; second, the pilot arc relay (PAR) must be able to open at this current level and withstand the arcing that occurs.

A few years ago a better approach was developed. A capacitor (800 MFD, 450V) was added around the pilot arc resistor. In addition, the plasma cutting power supply was made to respond faster by adding a RC circuit across the output. This circuit, shown schematically below,

NOTE:

Coupling capacitor C_1 and C_2 eliminated for simplicity



provides an instantaneous burst of energy which is bypassed by C_3 until C_3 charges up to some voltage less than OCV (OCV minus pilot arc voltage).

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Generally, the arc will start on this initial burst because the pilot arc is most intense at that time. If, however, the arc doesn't start, R_p will bleed down C_3 when it reaches its maximum charged potential so that the process can be repeated again. The net result is a series of audible, intense "pops." This type of pilot arc circuit will provide a positive arc start and will increase the maximum torch-to-work-distance by about 50 percent. This circuit will not work well without the RC circuit in the power supply since, without it, the power supply output is too inductive.

Beware of starting problems in installations that use power supplies not manufactured by Linde. It is very likely that the lack of this RC circuit (often called a "suppressor circuit") is the cause.

The function of the pilot arc relay PAR is to provide continuity to ground for the pilot arc resistor during the start. When the main arc is established, PAR is opened to minimize heat load on the nozzle.

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ANY QUESTIONS? CONTACT US!

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