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# The orbital welding handbook

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# INDEX

# 1. Preface

Among industrial welding processes, orbital **TIG welding** has become a well-established method, although there is still a considerable lack of information about the various possibilities of this challenging technique. Aerospace industry, aviation, high speed trains, nuclear industry, pharmaceutical industry, food industry, tiny microelectronic devices - to name but a few of the most exciting implementations - rely on orbital welding, but the equipment to ensure our daily supply of electric current, oil and gas also depends on orbital welding techniques.

In this booklet, basic information is provided about the orbital weld process and the related equipment: technical approach, advantages, common and special applications, but also restrictions and limits. With regard to practical support the text is illustrated by numerous application examples.

Tables and designs can help engineers and welding experts, as well as project managers, to get quick answers as to whether orbital welding could offer solutions corresponding to their needs. To get specific answers for your questions, visit the Polysoude website (www.polysoude.com) and consult the customer service team.

# 2. What does orbital welding mean?

Whenever high quality results are required, orbital welding is the first choice for the joining of tubes. The welding torch - in most cases, the TIG welding (Tungsten Inert Gas) process is used - travels around the tubes to be joined, guided by a mechanical system. The name *orbital welding* comes from the circular movement of the welding tool around the workpiece.

Generally, orbital welding technique covers two main fields of application:

- Tube-to-tube / pipe-to-pipe joining
- Tube-to-tubesheet welding.

In the first group, all kinds of tube joinings are included: butt welding and welding of flanges, bends, T-fittings and valves, i. e. the entire tubing and piping requirements.

The second group concerns the manufacturing of boilers and heat exchangers and comprises the different welding tasks related to tube-to-tubesheet welding operations.

# 3. Recapitulation of the TIG (GTAW) process

An electric arc is maintained between the nonconsumable tungsten electrode and the workpiece. The electrode supports the heat of the arc; the metal of the workpiece melts and forms the weld puddle.

The molten metal of the workpiece and the electrode must be protected against oxygen in the atmosphere; an inert gas such as argon serves as shielding gas.

If the addition of filler metal becomes necessary, filler wire can be fed to the weld puddle, where it melts due to the energy delivered by the electric arc.

## 3.1. Advantages/Inconveniences of the TIG (GTAW) process

### 3.1.1. Advantages

**1 -** Nearly all metals can be joined.

**2 -** Different kinds of steel, stainless steel included, can be welded as well as refractory or wear-resistant metals like nickel, aluminium, copper, gold, magnesium, tantalum, titanium, zirconium, and their alloys; even brass and bronze can be welded in certain cases; if filler wire is applied, workpieces consisting of dissimilar alloys or batches can also be joined together.

**3 -** All welding positions are possible.

**4 -** The process is very stable and reliable; the occurrence of weld defects can be reduced to less than 1%.

**5 -** No slag or fumes are developed during welding.

**6 -** The affecting weld parameters can be adjusted in a wide range and mostly independent one of each other.

**7 -** TIG welding can be carried out with or without filler wire.

**8 -** The arc voltage, which is directly related to the arc length, and the corresponding weld current intensity are used for Automatic Arc Voltage Control AVC. The torch position is controlled by an electronic device which, together with a mechanic slide, keeps the arc length on a programmed value.

### 3.1.2. Inconveniences

**1 -** Compared to other arc welding processes, the deposition rate of the TIG process is relatively low.

**2 -** Time-intensive and costly development is necessary to determine the weld procedures WPS and the exact values of weld parameters which are necessary to control the process.

**3 -** The welding equipment is sophisticated; it requires much more capital investment cost than gear for manual welding.

## 3.2. Types of weld currents

Two kinds of current are applied in the TIG welding technique:

▶ Direct Current (DC) is most frequently used to weld nearly all types of materials.

▶ Alternating Current (AC) is preferred to weld aluminium and aluminium alloys.

If DC is applied, the electrode is connected as cathode to the negative terminal of the power source; this configuration is named **DCEN** or Direct Current Electrode Negative. In this case, the electrons of the electric arc flow from the electrode with negative polarity to the workpiece with positive polarity. Up to 70% of the released energy is considered to heat up the workpiece, which means an efficiency of 0.7 (useful energy/ released energy).

The configuration **DCEP** or Direct Current Electrode Positive is not used in the TIG process except of some very special applications in aluminium welding. In this mode however, most of the heat is transmitted to the tungsten electrode, so already at low weld current intensities, very large electrode diameters, compared to TIG DCEN, become necessary to carry off the heat.

In the AC mode, the electrode is switched periodically between positive and negative polarity. During the time of positive polarity the tungsten electrode acts as the anode, due to the cleaning effect produced, the oxide layer on the surface of the workpiece will be destroyed. .

During the time of negative polarity the tungsten electrode acts as cathode, the heat necessary to melt the aluminium is applied to the workpiece; in this period the electrode can cool down.

## 3.3. Tungsten electrodes

### 3.3.1. Types of electrodes

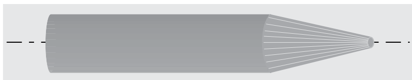
Tungsten is a highly refractory metal with a melting point of 3,410 °C. It withstands the heat of the electric arc and keeps its hardness even if it becomes red hot. In the past, thoriated tungsten electrodes have been widely used for TIG welding, but as thorium is a low-level radioactive element, special grinding equipment is required to ensure a safe disposal of the grinding particles.

Today, different alloyed tungsten electrodes are preferred, e. g. ceriated or lanthanated types, which are free of any radioactivity. In addition, their performance is comparable to that of thoriated tungsten electrodes.

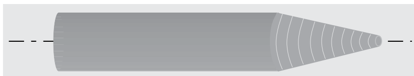
### 3.3.2. The Electrode grinder

To get the precise end preparation and sufficient repeat accuracy which is necessary to maintain a stable arc and a consistent level of weld penetration, a special electrode grinder should be used.

The design of the grinder must ensure that the grind marks on the tapered part run in correct alignment with the grain structure of the electrode: lengthwise. This ensures reliable ignition as well as improved arc stability, whereas collar formation can be avoided .



Correct: lengthwise grinding marks



Incorrect: circumferential grinding marks

## 3.4. Filler metals

The application of filler wire may become necessary under the following conditions:

**1 -** Fillet welding or special demands for the seam geometry.

**2 -** In case of a preparation of the tube ends, for example a J or V preparation.

**3 -** To prevent metallurgical failure if the tubes to be welded are made of dissimilar metals or alloys.

A well-known example is the welded connection between carbon steel and Stainless Steel 316, where a filler wire made of Stainless Steel 309 or nickel base alloy Inconel 82® is added.

**4 -** If the alloys change their composition or structure during welding.

## 3.5. Shielding gases

### 3.5.1. Welding gases

**Argon** is commonly used as shielding gas in the TIG process. It provides good arc striking characteristics and excellent arc stability even at low amperages, the energy of the arc is confined to a narrow area. Argon is also compatible with all types of base materials.

Shielding gas for standard TIG welding purposes should have a purity of 4.5, i. e. a purity level of 99.995 %. Metals which are classified as *delicate to weld*, for example titanium, tantalum, zirconium and their alloys, require a purity of at least 4.8, which means a purity level of 99.998 %.

To increase the weld energy, 2 % to 5 % hydrogen can be added to the argon. Besides a higher energy input of 10 % to 20 % resulting in a better penetration and faster welding speeds, argon/hydrogen mixtures have reducing properties helping to protect the molten metal against the influence of oxygen from the surrounding atmosphere. However, mild and carbon steels absorb hydrogen with the possible result of porosity and cold cracking, so the use of hydrogen containing gas mixtures is not recommended; for the welding of aluminium and titanium they are strictly forbidden.

The weld energy can also be increased by argon/helium mixtures with helium contents of 20 %, 50 % or 70 % or even pure helium. Helium has no detrimental effects on titanium, so it is used especially to weld the pure metal or titanium containing alloys.

Mixtures of argon, helium and nitrogen are used to weld Duplex and Super Duplex steels.

Unlike argon, **helium** is a good heat conductor. The arc voltage under helium is much higher than under argon, so the energy content of the arc is strongly increased. The arc column is wider and allows deeper penetration. Helium is applied for the welding of metals with high heat conductivity like copper, aluminium and light metal alloys. As helium is a lightweight gas, compared to argon its flow rate for identical gas coverage must be increased two to three times.

The following table indicates the qualification of different welding gases and mixtures according to the base materials to be joined:

| | Ar | Ar + $H_2$ | Ar + Hé | Ar + $N_2$ | He |
|---|---|---|---|---|---|
| Mild steel/ Carbon steel | *** | ** | ** | * | ** |
| Austenitic steel | *** | ** | ** | ** | ** |
| Duplex / Super duplex steel | ** | ** | ** | *** | ** |
| Copper | *** | x | *** | ** | *** |
| Aluminium | *** | x | *** | * | *** |
| Titanium | *** | x | *** | x | *** |

| | |
|---|---|
| Ar | Argon |
| $N_2$ | Nitrogen |
| $H_2$ | Hydrogen |
| He | Helium |
| *** | Recommended |
| ** | Possible |
| * | Not to be used |
| x | Prohibited |

### 3.5.2. Backing gases

Most applications of orbital welding require an outstanding quality to the inside of the root, as this is the part of the weld which will be in direct contact with the transported medium. To avoid any risk of oxidation, before, during and after the welding operation the hot metal at the inside of the tube must be prevented from coming in contact with oxygen of the atmosphere. Depending on the material to be welded, reducing components like $N_2$ or $H_2$ are added to the backing gas. The most typical backing gases and mixtures applicable for the different base metals are:

| | Ar | $N_2$ | Ar + $H_2$ ou $N_2$ + $H_2$ |
|---|---|---|---|
| Mild steel/ Carbon steel | *** | *** | * |
| Austenitic steel | *** | *** | *** |
| Duplex / Super duplex steel | ** | *** | ** |
| Copper | *** | ** | ** |
| Aluminium | *** | * | x |
| Titanium | *** | x | x |

| | |
|---|---|
| **Ar** | Argon |
| **$N_2$** | Nitrogen |
| **$H_2$** | Hydrogen |
| *** | Recommended |
| ** | Possible |
| * | Not to be used |
| x | Prohibited |

## 3.6. Weld energy

### 3.6.1. The Influence of heat input

The heat input cannot be measured, but only calculated; its quantity is used e. g. to compare different weld procedures for a given weld process. The heat input influences the cooling rate and the HAZ (Heat Affected Zone) of the weld. A lower heat input allows to obtain faster cooling rates and a smaller HAZ. With fast cooling rates, microstructure modifications of the base metal like grain growth or precipitations can be minimised, avoiding the loss of too much mechanical strength or corrosion-resistance. For many materials, e. g. sophisticated heat-treated and stainless steels, the heat input is limited by the specifications of the manufacturer.

In manual welding, to obtain a particular heat input, the welder must keep the arc length continuously at a specified level, by that the arc voltage remains constant at the desired weld current intensity. But additionally, as the heat input is influenced significantly by the travel speed, the manual welder must finish the weld within a fixed period of time. Only well-trained welding staff with excellent skills is able to meet these requirements.

In automatic Gas Tungsten Arc Welding, the process parameters arc voltage and weld current intensity, as well as travel speed and wire feed rates are controlled and kept constant by the microelectronic devices functioning within the power source, so the demand to respect a specified heat input does not cause any problems.

### 3.6.2. Formula to calculate the heat input

The energy per unit length of the weld (Heat Input) HI released by the electric arc during welding is calculated using the following equation:

HI = 60 x U x I/S

HI = heat input [J/mm or J/in]

U = arc voltage [V]

I = current intensity [A]

S = travel speed [mm/min or in/min]

Using the above cited equation for heat input calculation, the characteristics of the applied weld process are not taken into account. A weld process dependent efficiency coefficient "r" allows to calculate more comparable heat input values for different weld processes:

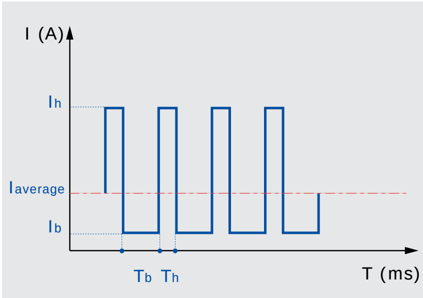
HI = 60 x U x I x r/S

In publications the coefficient "r" for TIG (GTAW) welding is expected to be in the range of 0.6 to 0.7, i. e. 60 % to 70 % of the energy released by the electric arc heats up the workpiece while 20% to 40% escape by radiation, heating up of the torch, the shielding gas etc.

**Expert information:**

To calculate the average weld current $I_{average}$ when using pulsed current for orbital welding applications, the following formula has to be applied:

$$I_{average} = (I_h \times T_h + I_b \times T_b)/(T_b + T_h)$$




$I_h$ Pulse current

$T_h$ Pulse time

$I_b$ Background current

$T_b$ Background time

# 4. Reasons to select orbital welding

The decision for the use of mechanised or automatic orbital TIG welding can be taken for different reasons: economic, technical, organisational, and others may be more or less important or even become the decisive factor. The orbital welding process offers a large range of benefits which qualifies it for industrial applications. The major advantages are:

## 4.1. Increased productivity compared to manual welding

Compared to manual TIG welding, the mechanised or automatic process leads to enhanced productivity. Repetitive work in the shop or complicated assembly jobs on site - orbital welding equipment guarantees that approved weld sequences are reliably repeated, hence time-consuming repair work will be reduced to a minimum.

## 4.2. Consistent excellent weld quality

Generally, the weld quality obtained by mechanised equipment is superior to that of manual welding. Once an adequate weld program has been developed, the weld cycle can be repeated as often as necessary, without deviations and virtually without weld defects. The quality level of manual welds is often lowered by fatigue symptoms of the welders, especially if extremely delicious tasks are required or boring jobs have to be executed.

## 4.3. Required skill levels of the operators

Certified welders are difficult to find and well remunerated. However, after appropriate training, skilled mechanics are able to operate orbital welding equipment perfectly and get excellent results. By using orbital welding equipment expenditure on personnel can be reduced.

## 4.4. Environment

Orbital welding can be executed even under harshest environmental conditions. Restricted space or barred access, lack of visibility, presence of radiation; once the welding head is positioned properly, the weld can be accomplished without problems from a safe distance; often supported by a video transmission.

## 4.5. Traceability – Quality Control

Modern orbital welding equipment is designed for real-time monitoring of the affecting weld parameters; a complete weld protocol can be generated and stored or output as a printed document. Sophisticated data acquisition systems operate in the background; if they are connected directly to a superior quality management system; automatic data transfer takes place without any interruptions to the weld procedure.

# 5. Industries which apply the orbital TIG welding process

## 5.1. Aircraft industry

In the aircraft industry, which was the first one to recognize the importance of orbital welding for their purposes, more than 1,500 welds are necessary to complete the high pressure system of one single plane. Manual welding of the small, thin-walled tubes is extremely difficult; finally the required consistent joint quality cannot be guaranteed. The only solution is to establish welding procedures using orbital equipment. In this way, the parameter values are reliably controlled by the equipment and the final welds meet the same quality level as the qualified test welds.

## 5.2. Food, diary and beverage industries

The food, diary and beverage industries need tube and pipe systems meeting delicate hygienic requirements. Full penetration of the welded joints is necessary; any pit, pore, crevice, crack or undercut can become a dead spot where the medium is trapped and pathogenic bacteria growth (Listeria etc.) can occur. Smooth surfaces everywhere inside the tubes enable successful cleaning and complete sterilisation of the system. The requested surface quality can only be ensured if orbital TIG equipment is used to weld these critical joints. Therefore, most standards and specifications oblige nowadays the manufacturers of hygienic installations to apply this process.

## 5.3. Pharmaceutical and biotechnology industries

Plants in pharmaceutical industries must be equipped with pipe systems for the transport and the treatment of the product and for the safe supply of clean steam and injection water. For injection water and its derivatives that are intended for injection into the human body, the purity requirements are particularly high. Any traces of corrosion are absolutely forbidden, the corrosion resistance of these welds must not be undermined, especially not by partial overheating of the base material. Joints made by orbital welding qualify for extended corrosion resistance. Additionally, to avoid any subsequent oxidation or corrosion, their smooth surface can be passivated.

## 5.4. Fabrication of semi-conductor devices

For the fabrication of semi-conductor devices, electropolished stainless steel tubes are installed as process gas lines, mostly with an OD of 6.3 mm and a wall thickness of 0.9 mm. The ultra-pure process gas must pass the tubes without picking up moisture, oxygen, particles or other contaminants. The acceptance criteria for these installations are very stringent: uniform welds with small weld beads to minimize the weld surface in the tubes, full penetration on the ID, absence of discoloration, etc. Only experienced operators working with reliable orbital welding equipment are able to perform this task, often even under adverse conditions on site.

## 5.5. Chemical industries

A considerable part of plant equipment for chemical industries is manufactured and installed by means of orbital welding. Chemical apparatuses are comprised of tubes, heat exchangers and converters which are made of corrosion-resistant or refractory metals or alloys of titanium, zirconium, nickel, chrome etc.; not to forget the whole range of different stainless steel types. As the service life of the installations depends directly on the quality level of the welded joints, strict control and traceability of the weld process are required by customers, inspection bodies and standards authorities. For the assembly of one heat exchanger, hundreds or even several thousand faultless welds have to be carried out, so here orbital welding becomes a must to ensure the expected results.

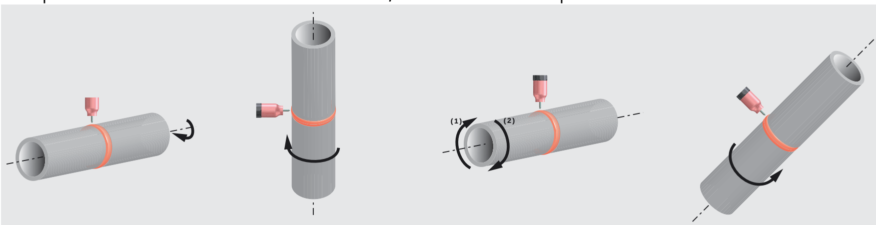
## 5.6. Fossil and nuclear power plants

For the safety of fossil fuel power stations and nuclear reactors the whole range of orbital joining techniques are applied: tubes with small diameters for sensing and control purposes must be connected, heat exchangers and other components are manufactured using orbital tube-to-tubesheet welding, and thick-walled tubes for operation under high pressure and temperature must be assembled on site. The welding procedures and the weld quality are generally under constant surveillance of the respective authorities and external organisations, the required complete documentation and traceability is ensured by the provision of orbital equipment with online data acquisition systems.

# 6. Specificities of the orbital weld process

## 6.1. Standardised welding positions

The denominations for pipe welding are specified by the ASME code, section IX, and the European Standards EN 287/EN ISO 6947, both refer to the position of the tube to be welded.




| AWS 1G<br>ISO PA<br>Rotating tube/<br>Horizontal axis | AWS 2G<br>ISO PC<br>Rotating tube &<br>fixed torch or fixed<br>tube & rotating<br>torch/Vertical axis | AWS 5G<br>ISO PG $_{(1)}$/PF $_{(2)}$<br>Fixed tube/<br>Horizontal axis | AWS 6G<br>ISO H-LO45<br>Rotating tube &<br>fixed torch or fixed<br>tube & rotating<br>torch/Inclined axis |
|---|---|---|---|

## 6.2. Pulsed current

The essential characteristic of successful orbital welding is the necessity to control the bath of molten metal during the whole weld cycle, taking into account the continuously changing situation in the process. An orbital weld of the PF/PG or 5G (fixed tube) type for example must meet at each moment the following conditions:

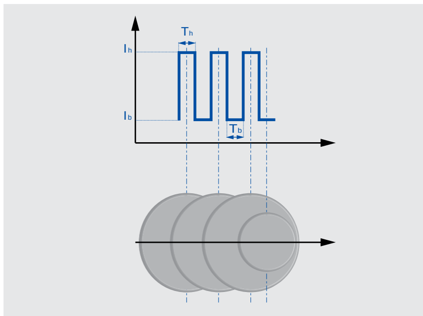
**1 -** Alteration of the weld position and hence of the influence of the force of gravity.

**2 -** Alteration of the thermal state of the workpiece.

The most effective measure to keep the control of all weld positions during the orbital weld cycle is to use a pulsed weld current.

Basically, a pulsed weld current toggles between two different levels of intensity:

- During a time period $T_h$ the weld current remains at a high level $I_h$; here the volume of the weld puddle increases to its maximum.
- During a time period $T_b$ the weld current remains at a lower level $I_b$, allowing the weld puddle to cool down and to decrease its volume to a minimum, which mitigates the awkward effects of the force of gravity.




Pulsed current is advantageous for a major part of orbital welding applications, making the determination of welding parameters easier and faster. However, if thick-walled tubes of significant diameters with wall-thickness over 10 mm and tube diameters above 114 mm are to be welded, the level of the low current intensity may approach that one of the high intensity, which results almost in an un-pulsed current.

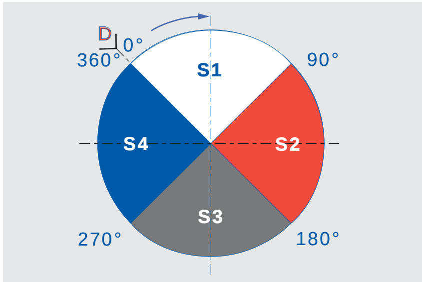
## 6.3. Programming of sectors

In many cases, the only use of a pulsed weld current is not sufficient to obtain acceptable orbital weld results. The parameters must be adapted with regard to the actual requirements of the weld. The course covered during the weld cycle is hence divided into different zones, which are called *sectors*. The weld parameters are modified if the border of one sector to the next is crossed.

To explain the sector layout, a circle of 360° as symbol of the cross-section of the tubes to be welded is divided into four sectors, each covering 90°. The first sector begins at the starting point D of the orbital weld, in this case at the 10.30 position, and ends at the 01.30 position.

Each sector corresponds to a specific welding position:

- Sector S1 from 0° to 90° *flat* position
- Sector S2 from 90° to 180° *vertically down* position
- Sector S3 from 180° to 270° *overhead* position
- Sector S4 from 270° to 360° *vertically up* position.




Depending on the weld position and the thermal conditions of the workpiece, which is heated up perpetually by the energy input of the electric arc, the parameter values are modified at the beginning of each sector.

In the orbital weld practice, most often the sectors are not divided as regularly as shown in the example. The number of sectors can also vary due to the different welding applications.

# 7. Hardware components of orbital welding equipment

Independently of the welding tasks to be carried out, orbital welding equipment is generally composed of the following components:

- A programmable power source and a remote control pendant, (distinct or as integrated part of the welding head)
- The welding head
- A wire feeding device, if required by the application.

In any case, the performance of the equipment depends on the design of the afore mentioned components.

# 8. Programmable power sources

## 8.1. Basic configuration

Any power source for orbital welding is composed of several integrated subunits with specific functions each:

- One Power Inverters to supply the welding current, and in case of hot wire welding a second one for the current to heat up the filler wire. Today, inverter sources are state of the art with POLYSOUDE's unique high performance transistor power source PC-TR is cutting edge.
- Programmable control unit which is generally based on an integrated or external PC.
- One or several shielding gas supplies.
- Cooling circuit for the torch and the welding and clamping tools.
- Data acquisition system recording each welding sequence.

The power sources for orbital welding can be divided in 3 categories with specific fields of application.

## 8.2. Portable power sources

The weight and volume of a portable power source has to be kept low, the machine must be carried to the job site by the operator himself and its size must be small enough to make it pass through the openings of a man hole.

The smallest power source with a weight of less than 17 kg delivers weld currents up to 140 A; it operates on a 230 V single phase supply. The programming and parameter development is carried out via an intuitive graphic user interface and a full function remote control pendant.

The Man-Machine-Interface MMI allows a comfortable management of weld cycles, programs and weld parameters, sector-programming is supported as well.

Power Sources of this type are equipped to handle three or four axes of control, i. e. up to four devices can be programmed and controlled: the shielding gas flow, the weld current intensities and pulse rates, the travel speed of the welding head, and if needed wire feeding operations. As integrated part or external unit a closed loop


Polysoude power source P3 UHP


Polysoude power source P4

cooling system can be used to operate water-cooled orbital welding heads and welding tools.

A recently launched power source allows to find matching weld programs (if the user specifies basic information about size and material of the tubes to be joined), using a wired or wireless tablet or PC. The system accesses its in-built database to find similar applications or suggests weld parameters determined by progressive calculations. The proposed welding procedure can be finally optimised by an expert help menu or the inbuilt Welding Assistant.

To relieve the operator from further error-prone tasks, the power source detects and recognises connected peripherals automatically (plug and play) and adapts itself automatically to available mains supply voltages.

## 8.3. Medium-sized mobile power sources

With their increased weight, medium-sized power sources for orbital welding are too heavy to be carried; they can be mounted on rubber wheels to get them mobile.

These power sources can be connected to three-phase 415 V outlets or feature a multi-voltage input, they generate welding currents up to 540 A. For the dialogue with the operator, the power sources are equipped with a convenient Man-Machine-Interface MMI and a full function remote control pendant.

Medium-sized power sources are designed to handle up to six axes, which can be programmed and controlled. Usually these axes are attributed to the shielding gas flow, the weld current intensities and pulse rates, the travel speed of the welding head, the wire feeding operations, and Arc Voltage Control AVC as well as Oscillation OSC.


Polysoude power source P6 CW


Polysoude power source P6 HW

## 8.4. Full-size power sources

Full-size power sources can be equipped to meet exactly the needs of the intended welding task: depending on the model, weld currents up to 550 A can be supplied; they are connected to a three phase 415 V outlet or can also offer a multi-voltage input. The programming is carried out via a Windows™ based PC and interactive welding software, a full function remote control pendant allows the operator to control the equipment. The programming can be carried out online or offline.

Full-size power sources are designed to handle six axes or more, which can be programmed and controlled. Basically, shielding gas flow, weld current intensities and pulses, travel speed of the welding head, wire feeding operations, Arc Voltage Control and oscillation devices are featured. A second power source can be installed to deliver a separate current for hot-wire applications.

The power sources are designed to control supplementary axes, which can be added later; the necessary electronic boards are installed to empty slots at the front of the machine.

Among the axes to control peripheral or external units are Control Boards for specific equipment (wire feeders, real time data acquisition systems, refrigerators, etc.); these extension boards are equipped with input and output ports which can be programmed entirely by the customer himself.

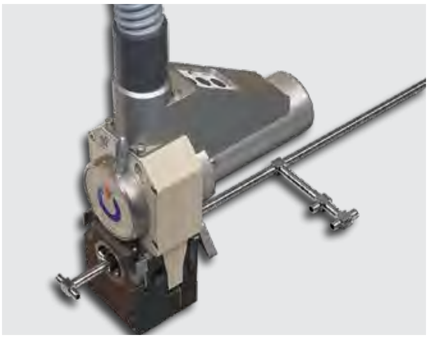

Polysoude power source PC-2

# 9. Orbital welding heads

## 9.1. Tube-to-tube welding heads

### 9.1.1. Closed chamber welding heads

Closed chamber welding heads are especially designed for autogenous welding of tubes without filler wire; their different sizes cover a range of diameters between 1.6 mm and 168 mm (ANSI 1/16" to 6"). Besides austenitic stainless steel, metals susceptible to oxidation like titanium or zirconium and their alloys can be welded with excellent results. Depending on the application, one or two pairs of clamping shells or TCIs (Tube Clamping Inserts) are needed to fix the closed chamber head on to the tubes to be welded.

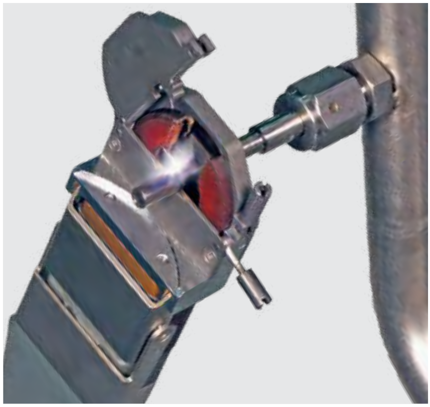


Polysoude welding head UHP 625

## UHP closed chamber welding heads

The UHP welding heads are specially designed to meet the requirements of high purity applications. Inside the welding head, the shielding gas is flowing separately through a high purity gas circuit and arrives directly at the weld zone without any contact to gears or rotating parts. Thus, the danger of particle contamination is significantly reduced.

Welding heads of the type UHP 250 and UHP 500 provide distinct reduced radial and axial dimensions; they are especially adapted to the welding of small diameter tubes. These welding heads are designed in a modular structure. The drive motor is integrated into a unique handle and can be combined with 3 gear modules: UHP 250 for tube sizes up to 6.35 mm (1/4"), UHP 500 for up to 12.7 mm (1/2"), and UHP 625 featuring fixture blocs for diameters up to 17.3 mm (5/8"). Interchangeable clamping cassettes for example allow preparation of the work pieces independently in advance. The handle with the motor is only attached during the time which is necessary to accomplish a weld. Clamping cassettes of the welding heads UHP 250 and



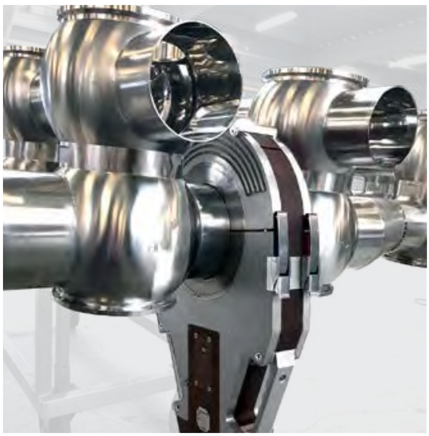
Polysoude welding head UHP 500

UHP 500 made from titanium and stainless steel tube collets of the UHP 625 are perfectly adapted to fit the typical standard outside diameters of tubing used in semiconductor applications or pure gas supplies. The asymmetric shape of the welding head allows the joining of fittings with a short stick-out, and fixture blocks ensure reliable centring, alignment and clamping of all kinds of common micro-fittings.

## MW closed chamber welding heads

The MW range of closed welding heads has been exclusively designed for autogenous welding without wire. They fit tube O.D. between 6 mm and 115 mm. In addition to the perfect weld quality which can be obtained with these kinds of welding heads, the inbuilt cooling circuit, together with the high-temperature resistant materials used in their construction, provide a considerable increase in productivity. Fast operation is ensured by the remote control buttons which are integrated comfortably into the handle.

Fittings and accessories with a short stick-out can be welded by means of an elbow-kit with off-set electrode holder.



Polysoude welding head MW

### 9.1.2. Open welding heads of the U-type

Open welding heads were conceived as a tool for orbital TIG welding with or without filler wire. The diameters of the tubes to be welded cover a range from 8 mm up to 275 mm (ANSI 5/16" to 11").

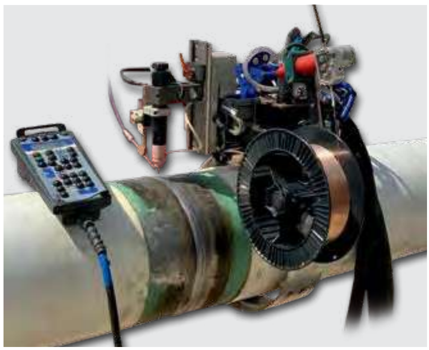
Open welding heads of the U-type are equipped with a TIG torch with gas diffuser. Sufficient gas protection is achieved only at a limited zone around the torch which is covered by the shielding gas streaming out of the gas lens. During the welding process, the arc and wire impact can be watched and controlled directly by the operator. The asymmetrical design of the open heads allows welding to be carried out at a very short distance to any wall or bend.

The positioning of the welding torch can be carried out manually or by means of motorised slides: Arc Voltage Control (AVC) and torch oscillation (OSC).

Open welding head Polysoude MU

### 9.1.3. Carriage-type welding heads

Open orbital welding heads of the carriage type travel around the tubes or pipes on appropriate rails or tracks, which can be mounted on any tube OD from 32 mm (1") upwards. The wall thickness of the tubes and pipes concerned always requires multi-pass welding, the robust design of the carriage welding heads enable them to carry the necessary equipment such as a heavy duty driving motor, a torch with an AVC and oscillation device and a wire feeder bearing spools with a weight of up to 15 kg. Additionally, video cameras can be mounted, allowing the operator to watch and safeguard the weld process.



Carriage-type welding head
Polysoude Polycar

Due to the application, these welding heads can be equipped with a standard TIG torch with gas lens, assuring the protection of the zone covered by the shielding gas; or with a narrow groove torch, which offers improved gas protection near to that of closed welding heads.

## 9.2. Tube-to-tubesheet welding heads

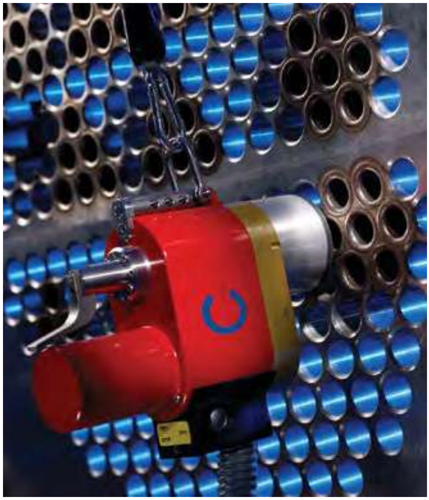
### 9.2.1. Closed orbital tube-to-tubesheet welding heads without filler wire

Closed welding heads are designed for TIG welding (GTAW) of tube-to-tubesheet applications, if they can be accomplished without filler wire. With these welding heads, flush or slightly protruding tubes with a minimum internal diameter of 9.5 mm (3/8") can be welded, the maximum diameter being 33.7 mm (1 1/3").

The weld is carried out in an inert atmosphere inside a welding gas chamber which provides very good protection against oxidation.

For clamping, a mandrel is inserted into the tube to be welded and expanded mechanically.

By means of a weld lance which is mounted at the front of the welding head, internal bore welding can be carried out at tube I.D. between 10 mm and 33.7 mm (13/32" and 1 1/3").



Polysoude tube-to-tubesheet welding head TS 34

### 9.2.2. Open tube-to-tubesheet welding heads with or without filler wire

Open orbital tube-to-tubesheet welding heads which can be used with filler wire cover the whole range of applications from tubes with an I.D. of 10 mm (13/32") up to tubes with a maximum O.D. of 60 mm.

Polysoude tube-to-tubesheet welding head TS 8/75

The TIG torch travels around the tubes, which can be protruding, flush or recessed.

The welding heads are equipped with a TIG-torch with gas diffuser. A sufficient gas protection is limited to the zone around the torch which is covered by the shielding gas streaming out of the gas lens. If oxygen sensitive materials need to be welded, the gas protection can be improved by installing an additional gas chamber.

The welding heads can be equipped with an integrated wire feeder. A pneumatic clamping device can be used to hold the welding head in working position on the tube plate, enabling several welding heads to be operated by just one person. Welding lances allow the operator to carry out internal bore welding with gapless joints behind a standard tubesheet or a double tubesheet.

# 10. **Wire feeders**

Generally, a wire feeding device can be integrated into the orbital welding head or used as an external unit. Above all the choice of the feeding device depends on the conditions of use, the constraints of the application, the requested mobility of the equipment and sometimes on the availability of filler wire on suitable spools.


Integrated wire feeder
on a Polysoude welding head TS 8/75


External wire feeder Polysoude POLYFIL-3

# 11. **Functionalities of orbital welding equipment**

## 11.1. Gas management


Gas control functions on the synoptic display of Polysoude P3-P6 series power sources

There are three possibilities when controlling the gas management of an orbital welding installation:

**1 -** A manually adjustable pressure reducer with flow meter, installed at the gas supply, (cylinder or network), completed by an integrated solenoid valve inside the power source which can be opened and closed.

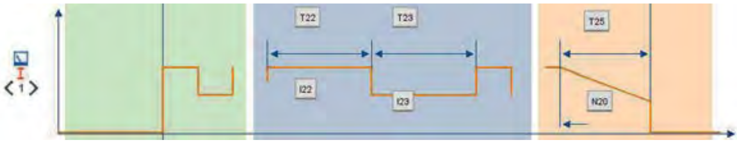
**2 -** An adjustable pressure reducer is installed at the gas supply (cylinder or network), an solenoid valve can be opened and closed by the control unit of the power source; a variable area flow meter is integrated in the power source.

**3 -** An adjustable pressure reducer is installed at the gas supply (cylinder or network), a programmable mass flowmeter inside the power source controls the gas flow rate.

Power sources for orbital welding are equipped to control up to four gases: two welding gases and two additional gases, e. g. backing and trailing gas. The so-called Bi-gas function of a power source allows the unit to change the type of welding gas after the electric arc is initiated, which is especially advantageous if helium is used as shielding gas. To avoid frequently occurring problems caused by ignition difficulties under helium, the ignition is initially carried out under argon and, after the arc has become stable, the welding gas supply is switched to helium.

Depending on the standard of the particular orbital welding equipment, the welding gas flow is continuously monitored. In case of an interruption of the welding gas supply, the ignition of the arc is blocked. If during welding the gas flow rate drops below a factory-adjusted value, the weld cycle will be aborted automatically. By this measure, severe damage of the workpiece and equipment can be avoided.

## 11.2. Current




Current control functions on the synoptic display of Polysoude P3-P6 series power sources

### 11.2.1. Arc ignition

The standard method of striking an arc is to apply high voltage surges with a tension of 10 kV during a time period of 2 microseconds at a frequency of 50 Hz. The column of shielding gas between the electrode and the workpiece becomes ionised and takes on conducting properties. As a consequence an arc is struck and the weld current begins to flow. This ignition method is the common standard for all types of orbital welding equipment.

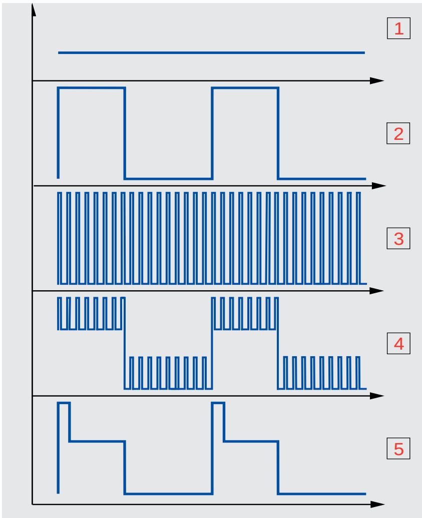
This ignition technique is limited by the cable length between the power source and the welding head, which, depending on the kind of application, must not exceed 30 m to 50 m. If the welding head is equipped with an AVC device, a so-called *Lift Arc* ignition can be carried out instead. The torch is moved towards the workpiece until the tungsten electrode touches its surface smoothly. Directly afterwards it is drawn back (lifted). The potential to initialise the weld current is applied in the same moment. Once the arc is struck the torch can be moved to the programmed arc length. The *Lift Arc* Ignition process has been developed by Polysoude, as result any tungsten inclusion in the weld seam is reliably excluded.

### 11.2.2. Welding current

The welding current is one of the affecting parameters of the TIG process, therefore its intensities must be controlled accurately by the power sources. A precision of ± 1 Ampere is guaranteed if the welding current intensity rests below 100 A, for intensities exceeding 100 A a precision of 1 % is ensured. To meet the requirements of the different applications, dissimilar current types can be supplied by the power sources:

- Unpulsed current (1): no variation of the current intensity.
- Thermal pulsation (2): this current is commonly used for standard orbital TIG welding (see chapter 6.2); the maximum frequency of thermal pulsations is 10 Hz.
- Fast pulsed current (3): the current is pulsed at increased frequencies between 500 Hz and 10,000 Hz. The fast pulsed current resembles an unpulsed current but forms an arc which is much more stable. The pulses are not visible but audible.
- Thermo-rapid pulsed current (4): this current form results of a combination of Thermal pulsation (2) and Fast pulsation (3).

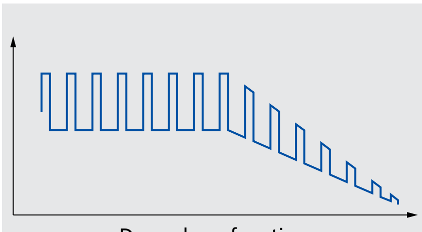
- Pulsed current with mono-pulses (5): the pulsed current is superposed by an intensity peak at the beginning of each pulse, which provokes an increased arc pressure on the weld puddle. This function is particularly helpful to get convex root geometry when welding in overhead position (the torch is situated below the workpiece), where the force of gravity primarily provokes a concave weld at the I.D. of the tube.



Types of welding current

### 11.2.3. Downslope

To avoid a crater occurring at the end of the weld, the welding current cannot be interrupted instantaneously. During a downslope, the weld current intensities are decreased linearly to values between 30 A and 4 A, afterwards the current is shut off. The higher intensities are adapted to tubes with a more significant wall thickness.


Downslope function

## 11.3. Torch rotation

Torch rotation control functions on the synoptic display of Polysoude P3-P6 series power sources

During welding the torch must rotate with the desired linear travel speed around the tube or pipe. Standard orbital welding applications require a linear travel speed range between 50 mm/min and 200 mm/min.

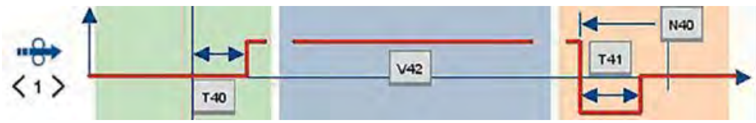
In most cases the travel speed remains unpulsed, but it can also become pulsed and synchronized to the weld current pulsations.

It is possible to program different speeds during base and pulse current. Usually, as in the case of step pulsed welding, rotation stops (V=0 mm/min) during the high current level, whereas during the base current period the torch moves forward.

The achieved speed precision is 1% of the programmed value. Polysoude standard welding equipment can be operated using impulse emitters or tachometer encoders on request.

The signals of the impulse emitter are also processed by the control system of the power source to identify the actual position of the torch relative to the start point, which means that the programming of a weld cycle can be carried out using angular degrees instead of time spans. Intuitive programming is possible because one tour of the torch always covers 360° per pass, independently of the linear welding speed and the tube or pipe diameter.

## 11.4. Wire feeding




Wire feeding control functions on the synoptic display of
Polysoude P3-P6 series power sources

Power sources for orbital welding are equipped to control different types of wire feeders; the attainable wire speeds range from 0 to 8,000 mm/min, a precision of about 1 % is attained.

Standard functions of wire feeding which are managed by all power sources are the control of wire start and stop as well as pulsed feeding rates. The wire feeding pulses can be synchronised to the pulses of the weld current; the wire speed is kept at a high level when the weld current is at its upper level, and is decreased during low level current. The independence between wire speed and weld current offered by the TIG process allows the reversal of synchronisation; the wire is fed at a high speed when the current intensity is low; thus the wire arrives at a small weld puddle and melts with a certain delay. The mechanical stability of the wire can be used to push the bath of molten metal to get a convex root pass surface at the inside of the workpiece.

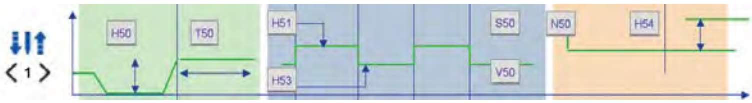
At the end of welding, a wire retract function allows the reversal of the feeding direction. The wire end is drawn back a few millimetres, avoiding the formation of a terminal wire ball or, even worse, the wire resting stuck in the weldment.

**Expert information:**

**1 -** Common diameters of wire for welding purposes range between 0.6 mm and 1.2 mm; the best choice for standard orbital welding is a quality wire with 0.8 mm diameter.

**2 -** The melting rate of the wire depends not only on the precision of the wire feed speed, but also on the precision of the wire geometry itself: a variation of 0.02 mm at a wire with a diameter of 0.8 mm represents a difference of already 5 % of added metal.

## 11.5. AVC (Arc Voltage Control)

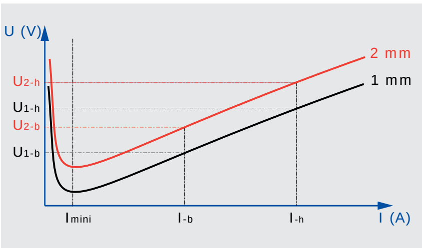



Arc voltage control functions on the synoptic display of Polysoude P3-P6 series power sources

### 11.5.1. Theoretical approach

During welding, it is important to keep the arc length constant, unfortunately there are no simple methods to measure it. In any case, if the welding conditions do not change, each particular arc length corresponds to a related arc voltage. This phenomenon is used to control the distance between the electrode and the workpiece during welding.

The characteristic of arc voltage at different arc lengths and welding current intensities are shown in the graph below:

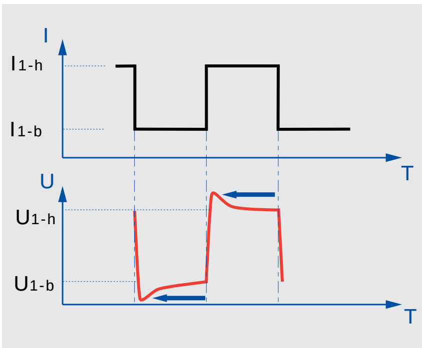



At an arc length of 1 mm, the arc voltage measured between the electrode and the workpiece at different welding current intensities is characterised by the black line.

The red line shows the result of the same measurement at an arc length of 2 mm.

**Expert information:** For welding currents below $I_{mini}$ the arc voltage control is not to be used. $I_{mini}$ is considered to be at a current intensity of 30 Ampere.

- Rule no. 1: at the same weld current ($I_{-b}$) an increase of the arc length provokes a higher arc voltage (increasing from $U_{1-b}$ to $U_{2-b}$).
- Rule no. 2: if the arc length is maintained (weld current intensity exceeds $I_{mini}$) and the weld current increases (from $I_{-b}$ to $I_{-h}$), the arc voltage also increases (from $U_{1-b}$ to $U_{1-h}$).
- Rule no. 3: if a different type of shielding gas is used (with other weld parameters remaining unchanged), the arc length will change: if the shielding gas is changed, e. g. from argon to an argon-hydrogen mixture, the arc becomes significantly shorter.
- Rule no. 4: if the geometry of the electrode differs (taper angle, tip diameter), the arc length at a given weld current changes or, at a constant arc length, the arc voltage changes.
- Rule no. 5: if a pulsed weld current is applied, the arc voltage pulsations are not proportional.




Each change of the weld current intensity provokes a peak of the arc voltage which is commonly known as *overshoot.*

### 11.5.2. AVC options

As for most orbital welding applications a pulsed current is applied, the rules 1 and 2 must be taken into account, making specific adjustments necessary to get a stable arc length.

▶ Restriction of the voltage measurement to the period of the low or of the high welding current. During the period without measurement the AVC slide is temporarily blocked, the electrode position does not change. The adjustment is simple, only one parameter value is requested to get a stable arc length.

▶ Extended arc voltage measurement during the period of the low and of the high welding current. This type of AVC control can be used if thermal pulsing (pulse frequency < 10 Hz) is applied.

▶ To get optimal results with minimised AVC-related torch movements, there are some more system parameters that can be set. These parameters are (beginning with the most important):

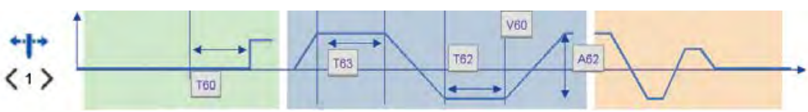
- Sensitivity of the control system
- Speed of the electrode movement
- Switch-off time at the beginning of each current pulse to eliminate the effect of overshoot (rule no. 5).

### 11.5.3. Programmable *distance between electrode and workpiece*

Besides the AVC control, the torch position can be determined by the "*Programmed distance between electrode and workpiece*" function. Here, starting from a reference value, the torch is moved by a motorised slide over the selected distance programmable in mm or inch to the desired height.

The mentioned function is often used to get the electrode in its proper position e. g. in case of tube-to-tubesheet applications or, if special welding tools are used, to follow the complex surface geometry of a workpiece in *piggyback position*.

## 11.6. Oscillation




**Oscillation control functions on the synoptic display of Polysoude P3-P6 series power sources**

If a weld preparation is applied to the tube ends, the groove to be filled becomes relatively wide, especially in the case of increased wall thicknesses. Differently to the stringer bead technique, where several passes are required to complete one layer, with torch oscillation the groove can be covered completely by one layer. In this case the torch is moving perpendicularly from one side to the other between the sidewalls of the weld prep. This movement is generated by a motorised slide and controlled by the oscillation system.

Parameters to be set for the correct oscillation are width and speed of the stroke as well as the dwell time, during which the torch remains next to the sidewalls of the groove at the end points of its movement.

It is possible to synchronise the torch oscillation with the pulsed current. For example, to increase the penetration at the sidewall, the high current intensity value is maintained continuously during the dwell time.

## 11.7. Remote control

The remote control pendant is a device to enable the communication between the welder or operator and the installation. All commands necessary to manage the welding equipment are directly accessible.

- Out of weld cycle

In this mode, all movements of the equipment can be controlled: torch rotation, torch movement away from or towards the workpiece as well as centring the torch above the weld seam (AVC and oscillation), etc.

- During weld cycle

During this mode adjusting of the welding parameters as necessary is possible (if enabled by the program), modifying of the torch position by means of AVC and oscillation functions can be practised. Additionally, most remote control pendants display actual welding information such as measured welding current intensities and arc voltage, travel and wire speed; angular torch position and time elapsed since the weld cycle start.


Remote control pendant of a Polysoude power source P6

## 11.8. Cooling Unit

With the exception of some devices designed for special applications, orbital welding heads are generally water-cooled. Most of the power sources provide integrated closed-loop water cooling circuits.

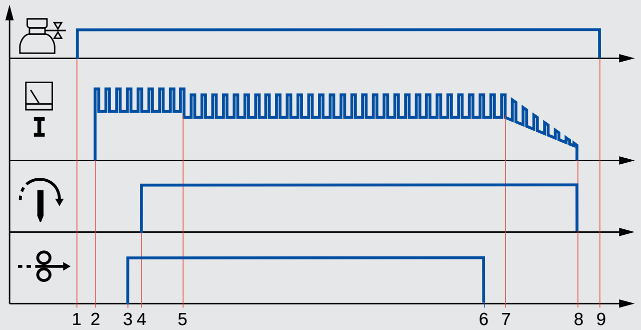
For heavy duty equipment (hot wire, plasma), an external regulated refrigerating water-cooling unit is necessary.

In all cases, the flow of the cooling liquid is continuously monitored to avoid damage to water cooled parts, the welding current e. g. will be switched off immediately if a failure occurs.

# 12. **Weld cycle programming**

## 12.1. Program structure of a weld cycle with 4 axes

Depending on the application and the type of orbital welding equipment, the programming of a weld cycle can be more or less complex. In all cases, the program structure is always built up following the same scheme of logical and chronological rules. As an example, the program of a standard weld cycle including filler wire, however without AVC and oscillation, is summarized.




| | |
|---|---|
| **1** | Start of the weld cycle (triggered by the Start button of the control pendant) |
| **1 to 2** | Shielding gas flow during the programmed preflow time span before the ignition of the arc |
| **2** | Ignition of the arc and beginning of the pulsed weld current. The clock is reset to zero |
| **2 to 3** | Delay of the wire feeding |
| **2 to 4** | Delay of the rotation |
| **3** | Start of the wire feeding* |
| **4** | Start of the torch rotation* (initial position of the torch is set to 0° position of the weld cycle) |
| **5** | Begin of a new sector where the weld current is modified |
| **6** | End of wire feeding* (and wire retract if programmed). Generally, the end of wire feeding is positioned at approximately 360° |
| **7** | Begin of the weld current downslope before the arc is finally switched off. Generally, the downslope is positioned at 360° + 5° to 10° of overlapping to re-melt the beginning of the weld seam and to ensure a perfect joint at the end of the weld |
| **7 to 8** | Time span of the weld current downslope to finish the weld without crack and crater formation |
| **8** | Extinguish of the arc and rotation stop |
| **8 to 9** | Time span of post-gas flow to protect the weld zone of the workpiece until a sufficiently low temperature has been reached and to protect the hot tungsten electrode against oxygen of the atmosphere |
| **9** | Shielding gas stop and end of the weld cycle. |

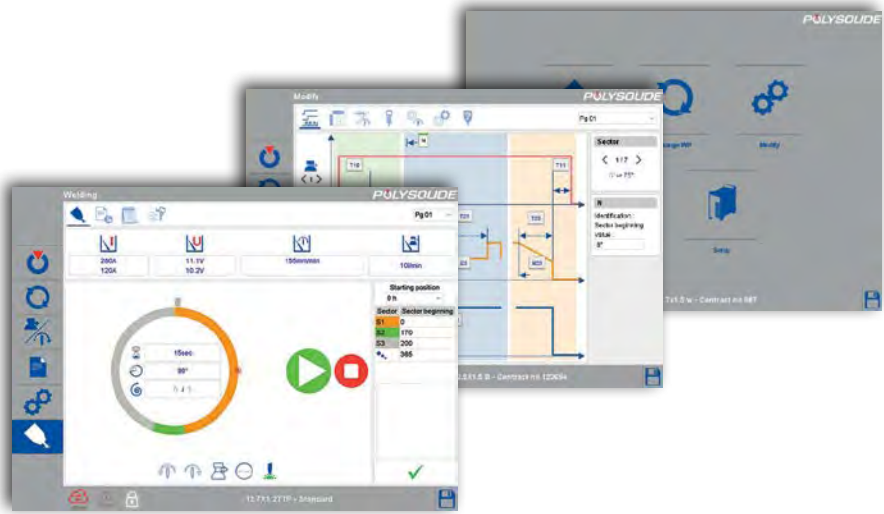
* Depending on the expected result the functions may be programmed in a different chronological order

## 12.2. Assisted programming of weld cycles

For a number of years most of the power sources on the market are equipped with assistance and support functions for the development of welding programs. The commonly used synoptic has been replaced by a virtual and evolutionary interface.

The related software can be implemented on a wired or wireless touchscreen (10.4") as well as on a desktop or laptop. Besides the program management the powerful Man-Machine-Interface MMI offers all function which are necessary to draw full benefit of the welding equipment.

- Complete documentation of the workpiece data with information about the equipment (type and serial no. of the power source, used shielding gas, badge of the operator, etc.). Quick and easy data input can be achieved by a barcode scanner. The documentation is stored in the memory of the power source and can be copied to a USB stick
- Creation of chained weld cycles to carry out complete multipass weld sequences
- Detailed description of boundary parameters, i. e. mechanical adjustments of devices, type and characteristics of welding and shielding gases, electrodes, filler wire etc. and comments concerning the correct execution of each welding pass
- An expert system with a search function which deals with up to 8 parameters and opens also access to tack welding programs
- Automatic recognition of connected welding heads
- Computer-aided optimization of welding parameters for standard tube-to-tube and tube-to-tubesheet applications
- Automatic generation of programs for autogenous welding without filler metal




Presentations on the synoptic display of a Polysoude power source P4

▶ Network connection of several power sources to become integrated part of a production line, also in conjunction with a super-vision system.

Programming can be executed offline or online via WIFI or Ethernet connection.

Power sources of the premium segment like P3 UHP, P4 and P6 are equipped with "intel-ligent" functions are introduced onto the market as "Smart Welding Stations".

Touchscreen of a Polysoude power source P4 for real time monitoring of the weld cycle in progress

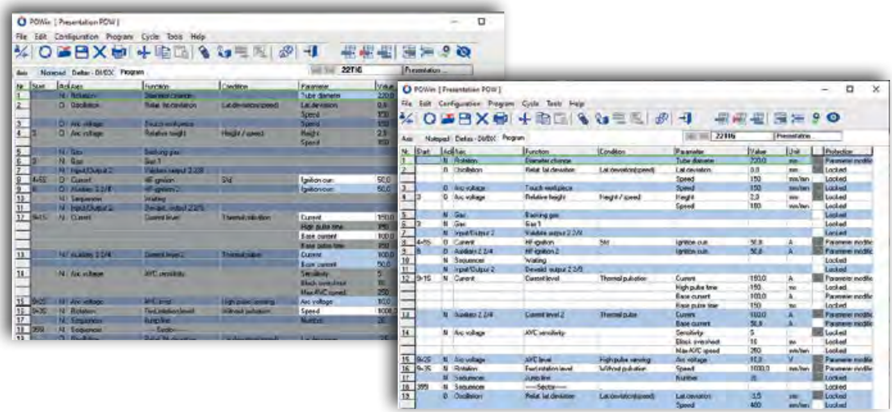
## 12.3. Open structure programming

Quite complex applications and research tasks are carried out by using a power source of the PC series. Programming takes place offline by means of a personal computer without connection to the power source. The sequences are created line after line. The procedure is similar to the programming of a numerical controlled machine tool, but here the commands are made available to the operator in his native language. After a short training period, each welder is able to understand these commands and to build up his own weld programs autonomously.

Anyhow, for security reasons the operator has not the same access possibilities as the administrator: selected functions can be hid-den behind a mask

The welding software is designed for a Windows® environment; the user surface is similar to an Excel® worksheet.

Due to the Windows® commonality, files of any format can be integrated, leading to complete documentation of the weld cycle and the attached parameters.



Programming of a weld cycle for a Polysoude power source of the PC series in operator mode (left sheet) and with administrator rights (right sheet)

# 13. **Real time data acquisition**

## 13.1. In summary

If a quality assurance system such as ISO 9000 has to be respected, only calibrated equipment can be used for the manufacturing of certain components.

The expression *calibration* is specified by regulating standards. It means that measuring instruments installed in the power source or within the connected devices of the welding equipment have to meet special requirements, they must be related to national or international standards or certified reference materials.

Calibration needs specific testing equipment and procedures and can only be carried out by an approved organisation, for example the manufacturer of the welding equipment, the quality assurance division of the user, or an agreed external company.

## 13.2. Integrated real-time data acquisition

During a weld cycle, the essential parameters values of weld current intensities, arc voltage, travel speed and wire feed speed are measured and memorised cyclically. To allow a complete documentation of the process, a weld cycle report including these measurements as well as the actual date and time can be printed whenever a weld cycle has been completed successfully or ended prematurely.

The weld cycle programs can be documented as well. The printouts may be used to verify that all parameters have been set correctly and provided as proof for quality assurance purposes. The printout contains the program name, the parameter values and the modifications made by the operator during the weld process by means of the remote control. Furthermore, the information stored in the section "Welding comments" are included in the document.

The data acquisition system and printer are available for Polysoude power sources P3 UHP, P4 and P6.

```
                AMO
               Pg 01
              Number 7

           U     I      V rot     V wir
          (V)   (A)   (mm/min)  ()

      5s  0.0   0.2                 0
          0.0   0.2
S01   1°  0.0   0.2         46      0
          0.0   0.2
|   422°  0.0   0.2        500      0
          0.0   0.2
    431°  0.0   0.3        500      0
          0.0   0.2
    442°  0.0   0.3        500      0
          0.0   0.2

>>>>>>>>>>>>>>> ! OK ! <<<<<<<<<<<<<<<<
Cycle start:   Fri 28 Feb 2020 15:02:42
Cycle time : 00:00:22   N =   448


>>>>>>>>>> ! Weld comments ! <<<<<<<<<<
Identifiant : A.GUERIZEC
002096589 Gaz Argon TSUL
P4-3 1949037
```

Weld cycle report

## 13.3. External real-time data acquisition

The Smart Welding Stations come with integrated real-time data acquisition system. As supplement, Polysoude has developed a device to measure, store and control the welding parameters separately in a real-time process: the DAQbox.

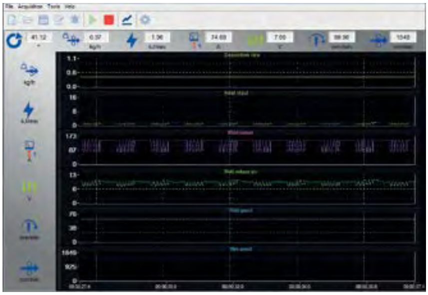
Parameters such as values for welding and hot wire current intensities, arc voltage, travel speed and wire feed speed are recorded at a frequency of up to 200 Hz. The parameter values can be set to trigger an alarm (limit, "all or nothing" or manual mode). When the weld cycle starts (arc ignition), the recording begins automatically; at the same moment, the data storage on the hard disk of the related PC is launched independently of the Smart Welding Station.

The progress of the weld cycle can be monitored, selected parameter occur as graphs on the display, completed by indications of temperature and angular or relative torch position and calculated energy input and deposition rate.

The data acquisition system allows the operator to set limits for the different weld parameters. In this case, the concerned parameter values are continually compared to those of a previously recorded defect-free sample weld. If the system is operated in the **passive mode**, a colour mark occurs as soon as a parameter limit is reached. Switched to the **active mode**, the data acquisition system aborts the weld cycle if one of the specified limits is exceeded and highlights the origin of the incident.

Once the recording has been finished a weld cycle protocol with at least the monitored parameters, the calculated data and the cause of the alarm is generated and memorized as PDF-file.

The synchronisation between the DAQbox and the Polysoude video system Polyview allows to read the parameter values of the different graphs at a given moment on a first monitor and to see at the same time the corresponding video section on a second one. This can be very helpful during the evaluation of finished welding operations.



Example of a weld cycle report
generated by the
Polysoude data acquisition system DAQbox

# 14. **Autogenous tube-to-tube welding without wire**

## 14.1. Applications

Autogenous welds of thin-walled tubes cover a wide range of applications. Clients include for example: semiconductor industry, biochemistry, instrumentation, food and beverage, pharmaceutical industry, chemical/sanitary industry, and aeronautics/aerospace. In most cases, the tubes are made of austenitic stainless steel, but nickel alloys as well as titanium and its alloys can also be found. The range covers diameters from 1.6 to 170 mm with wall thicknesses varying between 0.2 and 3.2 mm.

## 14.2. Equipment

Preferentially, fusion welds are carried out using machines such as the P3 UHP or P4 power sources, combined with closed or open orbital welding heads. Depending on the application, the closed welding heads can be categorized into 2 groups.


Smart Welding Station Polysoude P3 UHP with closed welding heads UHP 500 and UHP 625

## 14.3. Calculation of weld parameter values

Depending on the diameter and wall thickness of the tubes to be joined the parameter values for autogenous welding without wire can be calculated. The calculations are based on formulas developed for stainless steel of the 300 series (e. g. 316L), but the results can be applied to other materials as well. Recent power sources like the P4 are equipped with software to calculate weld parameter values automatically if the particular application cannot be found in their integrated library.


Mask to identify existing weld procedures or to initiate the calculation of parameters

In any case, the validity of the calculated results must be confirmed by test welds. Materials with the same designation, and of an equal nominal composition, may still have very different welding properties (see also chapter 14.7 - Chemical composition and repeatability of welds).

## 14.4. Joint preparation

Autogenous orbital welding requires a precise butt end preparation of the tubes. To obtain such precise square edges, the preparation should be carried out with a special bevelling machine. Burrs must be removed completely and the tube ends must fit exactly without any gap. No grease, moisture or other types of contaminations are allowed around the welding zone.

Before the welding process can be started, the tubes must be positioned without misalignment and in many cases fixed by tack welding. To avoid any discoloration or oxidation inside the tubes taking requires purging with backing gas. Due to the high melting temperature of chromium oxides blue or dark spots originated by tack welds can provoke a lack of fusion during the final weld operation.

The diameter of the tack welds must remain smaller that the width of the final weld seam. To ensure a complete re-melting of the tacking points during the welding process, tacking operations have to be carried out without filler wire.

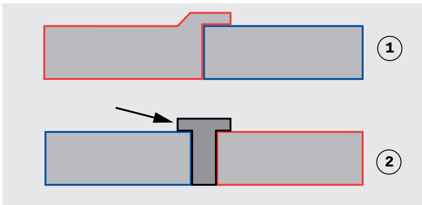
## 14.5. Electrode preparation

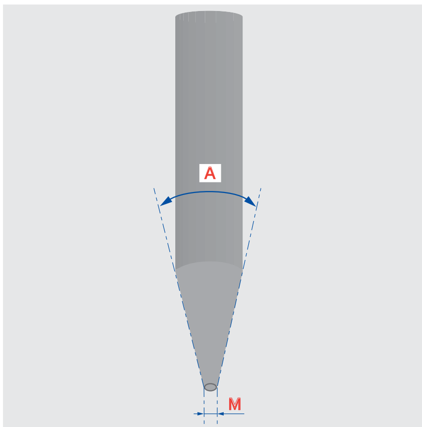
To maintain a constant and compact form of arc tungsten electrodes which will be used for mechanised or automatic welding should be prepared with a tapered end. The diameter of the electrode, the grinding angle "A" and the diameter "M" of the flattened tip depend on the weld current intensity. The grinding angle "A" should have a value between 18° and 30°, the flattened tip diameter should be prepared between 0.1 mm and 0.5 mm. Higher weld current intensities request larger grinding angles and greater flattened tip diameters.

The length of the electrode must be calculated and cut dependant on the type

Internal mechanical fixing devices can be helpful for positioning and welding of thin walled tubes, these devices are often connected to systems to control the backing gas flow rate; they are advantageously used if SMS-fittings have to be joined for applications of the food and beverage industry.

**Expert information:** To reinforce the mechanical strength of a seam manufactured by autogenous welding, additional material can be obtained by the preparation of one tube end with an overlapping collar ①. The collar also facilitates correct assembling of the tube ends. As further possibility a welding insert can be placed into the gap between the tubes ②. A thoroughly selection of the insert alloy allows welding dissimilar materials which otherwise cannot be joined by autogenous welding.




Preparation of the electrode

of welding head, the O.D. of the tubes to be welded and the specified arc length. Sometimes it is difficult to prepare the electrodes with the necessary precision on site even if an electrode grinder is used. In this case purchasing of ready-to-use electrodes on the market can be an efficient and economic solution.

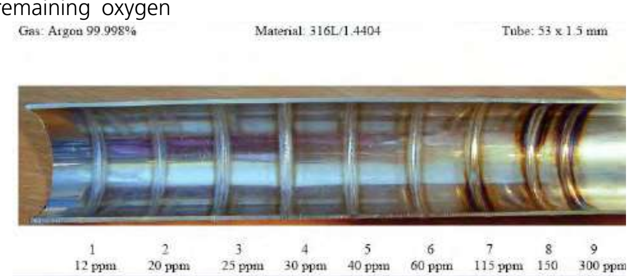
**Expert information:** The tungsten electrodes should always be changed preventively, thus a considerable number of welding problems (arc instabilities, ignition difficulties) and defects can be avoided. Delicate applications may require the electrode to be changed after each weld.

| | | Direct current [A] | | Alternating current [A] |
|---|---|---|---|---|
| **Electrode diameter** | | **Straight polarity DCEN** | **Reverse polarity DCEP** | **Balanced waves** |
| 0.020″ | 0.05 mm | 5-20 | | 10-20 |
| 0.04″ | 1.0 mm | 15-80 | | 20-30 |
| 1/16″ | 1.6 mm | 70-150 | 10-20 | 30-80 |
| 3/32″ | 2.4 mm | 150-250 | 15-30 | 60-130 |
| 1/8″ | 3.2 mm | 250-400 | 25-40 | 100-180 |
| 5/32″ | 4.0 mm | 400-500 | 40-55 | 160-240 |
| 3/16″ | 4.8 mm | 500-750 | 55-80 | 190-300 |
| 1/4″ | 6.4 mm | 750-1100 | 80-125 | 325-450 |

Recommended tungsten electrode diameters for different welding current intensities

## 14.6. Backing gas

During orbital welding, the inner surface of the tubes must be protected against oxidation. Therefore, the interior of the tube system is purged by backing gas. The purity of the backing gas depends on the required weld quality. Before the weld can be started, a sufficient purge time must elapse, allowing the backing gas to remove the oxygen out of the system. The remaining oxygen content of the backing gas can be analysed at the outlet; once it has decreased to an acceptable value, the welding operation can begin. Usually in the case of UHP applications (Ultra High Purity) the oxygen level of the exhausting backing gas must fall below 10 PPM (Parts per Million), i. e. must reach less than 0.001 %.




Colouration of the root weld due to the oxygen content of the backing gas

**Expert information:** The supply of ultra-pure process gas for manufacturing purposes requires that it passes through the tubes without being contaminated by moisture, oxygen, particles or other contaminants.

During welding, the specified values of flow rate and internal pressure of the backing gas must be precisely respected and kept constant. The internal pressure must be controlled continuously: excessive pressure will provoke a root weld with a concave surface or, even worse, cause an explosion of the molten metal sputtering to the outside.

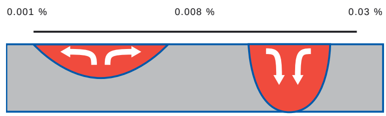
If tubes with small diameters below 9.52 mm (3/8") are welded, the internal pressure can be used to prevent probable excess of convexity or inside diameter reduction.

**Expert information:** A light heat tint, due to remaining oxygen in the backing gas, can be removed by passivation.

## 14.7. Chemical composition and repeatability of the welds

Certain difficulties occurring during the welding of stainless steel can be caused by low sulphur content of the base metal. The sulphur content influences the surface tension of the molten metal, high sulphur grades are characterized by a narrow deep weld profile. Low sulphur contents cause a very wide but shallow weld bead with drastically reduced penetration, which can be explained by a phenomena named the Marangoni effect.

If a workpiece with very low sulphur content should be joined to a second one with high sulphur content, the arc can be deflected completely to the part with the smaller sulphur content, thus excluding any acceptable standard weld operation. In some cases, a weld cycle with a double nonstop tour of the torch may solve the problem.




Influence of the sulphur content on the weld pool geometry

# 15. Orbital tube-to-tube or pipe-to-pipe welding with filler wire

## 15.1. Applications

For several reasons, it can become necessary to apply filler metal in orbital welding procedures:

- Wall thickness of the tubes requires a preparation of their ends
- Due to the base materials of one or both tubes, metallurgical causes require filler metal
- The specified weld geometry can only be obtained by added material
- Strength and/or corrosion resistance are compromised by autogenous welding.

Tube-to-tube welding applications with the addition of filler wire are often demanded in the field of energy production (power plants) and chemical or petrochemical industries.

A wide range of base materials are used:

- Mild steel
- Low-alloyed chromium or chromium molybdenum steel
- High-alloyed chromium nickel steel (austenitic or with austenitic-ferritic structure)
- Nickel and its alloys (like e. g. Inconel®-alloys or Hastelloy®-alloys)
- Titanium and its alloys.

## 15.2. Choice of the equipment

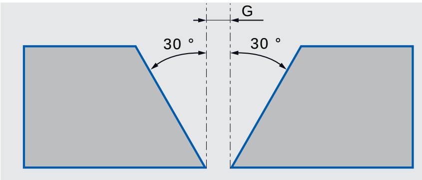
For orbital welding with additional filler wire, standard equipment with 4 controlled axes (shielding gas flow, weld current intensity, torch rotation speed and wire feeding speed) or with 6 axes (4 axes + AVC and oscillation) can be taken.

Independently from economic or other project-related considerations, the table below shows the technical requirements for 4 or 6 axes equipment to be used:

| | | Type of equipment | |
|---|---|---|---|
| Criterion | | **4 axes** | **6 axes** |
| **Wall thickness to be welded** | small (< 4 mm) | + | + |
| | medium and thick (> 4 mm) | - | + |
| **Accessibility** | reduced | + | - |
| | free | + | + |
| **Weld sequence** | simple | + | + |
| | difficult | - | + |
| **Level of automation** | low | + | + |
| | high | - | + |

## 15.3. Weld preparation

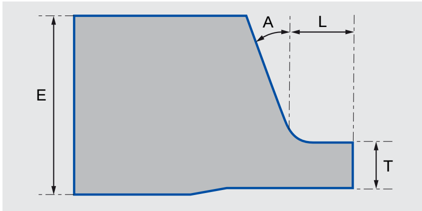
The standard preparation for manual welding of tubes, bends, T-pieces, and flanges is a V-joint with a gap. For different reasons, this type of preparation cannot be used for orbital TIG welding (uniform gap is impossible to be achieved, tack welding points cannot be ground off, backing gas protection is not obtainable, etc.).




Tube end preparation commonly used for manual tube welding

Preparations for orbital welding are always designed as a joint without any gap at the root face (G=0). In this case for accessibility reasons the angles of standard V-preparations have to be increased to 30° or even 37°. With this type of joint a regular penetration cannot be obtained; on the contrary, depending on the weld position significant concavities occur.

To avoid these problems and to get the desired uniform penetration a J-preparation with a collar of the width L and the thickness T has to be applied. Indications about the recommended geometry of the preparation with respect to the tube diameter and thickness are given in the table below:




Recommended tube end preparation for orbital TIG welding

| Tube range (mm) | Angle (°) | Collar (mm) | |
|---|---|---|---|
| Wall thickness (mm) | A | T | L |
| 3 ≤ E ≤ 6 | 30° | 1 | 2 |
| 6 ≤ E ≤ 10 | 30° or 20° | 1.5 | |
| 10 ≤ E ≤ 15 | 20° | | |

**Expert information:**

To ensure the necessary precision and repeatability of the weld preparation, machines for mechanical tube end preparation must be used. Two types of machines are available on the market:

- Stationary machines for the workshop
- Electric or pneumatic mobile machines which can be hand-carried to machine small batches or to be used on site.


Mobile tube end facing equipment

Machine to be used in the workshop

In case of some assemblies, e. g. certain tube-flange connections, it is impossible to obtain a correct J-preparation, so a mixed preparation of J and V becomes necessary. With the mixed preparation the occurrence of concavity during the downhill position and, even worse, in the overhead position can be minimized or avoided. For detailed information the Polysoude booklet "Orbital TIG welding of tubes and accessories" can be consulted.

To remove all traces of rust and calamine, the inside and the outside of tubes made from carbon steel must be ground.

**Expert information:** Metals which can be magnetised must be inspected: no residual magnetism or at least a very density (less than 3 gauss) are acceptable. Otherwise, welding problems or defects (lack of penetration, lateral sticking or porosity) can occur.

## 15.4. Positioning of the tubes

Before orbital welding can be started, the tubes must be positioned and tack welded; generally a maximum misalignment (high/low) of 75 % of the lip thickness T is tolerated. In order to avoid penetration faults during the laying of the root pass, tack welding must be carried out without, or at least with very low wire input. The prepared tube ends must perfectly fit together: no gap is permitted.

If stainless steel, nickel base alloys or titanium and its alloys have to be welded, a protection by backing gas is obligatory. In fact, carbon steel can be welded without backing gas, but a lower repeatability and an increasing repair rate of the welds must be accepted.

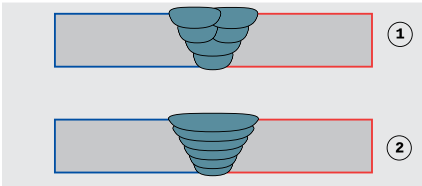
## 15.5. Multilayer welding

Two different methods can be applied to carry out multilayer welding. Which one is possible depends on the features of the available equipment:

**1 -** With four controlled axes, only the stringer bead technique with narrow weld seams first placed side by side and then super-positioned ① can be applied. In special cases, e. g. fillet welding (2G or PC) or still at 45° (6G or H L045), even if equipment with AVC and oscillation is available, the stringer bead technique is used.

**2 -** Equipment with six controlled axes allows laterally movement of the torch. Passes with torch oscillation OSC can be superimposed and/or laid side by side ② .

Multilayer welding with the stringer bead technique is quite complicated and time-consuming, as the process has to be interrupted after each pass and mechanical adjustments need to be adapted: the lateral position of the torch and the distance between the previous pass and the electrode must be corrected. These adjustments can only be executed if the setting elements of the welding head are accessible in its working position.



Multilayer welding methods

By welding equipment with six controlled axes the time required for manual interventions can be reduced significantly. With the AVC function the distance between electrode and workpiece is controlled, the oscillation allows coverage of the entire joint width or positioning of the torch laterally. Once the torch is situated above the joint, the electrode will be centred in the gap automatically. The different passes of a weld can be chained and the winding up of the hose and supply cables can also be executed automatically. Finally the operator will not be distracted by repetitive actions and can fully concentrate on supervising of the welding process

## 15.6. AVC requires precise electrode geometry

If tungsten electrodes are used for automatic orbital welding, it must be ensured that their geometry remains absolutely the same. Even small variations of the shape or dimension cause significant changes of the arc voltage, which is used as a base value by the AVC control (see chapter 11.5.1). Any difference of the arc voltage will be transformed by the AVC control to a differing arc length which provokes significant variances of the melting bath size.

**Expert information:** An increased arc length provokes the loss of the arc pressure and can cause poor penetration and a concave surface geometry. If the arc length is too short, the electrode will be rapidly deteriorated.

## 15.7. Backing gas

For manual welding of carbon steel a backing gas protection is not mandatory, the inside of the tubes is protected by the shielding gas passing through the gap at the bottom of the V joint.
In the case of orbital welding with a J-preparation without any gap between the tube ends, backing gas protection is strongly recommended. The formation of refractory calamine, which occurs distinctly if steel with higher manganese silicon content is welded, can be successfully suppressed. Thus a better repeatability of the weld will be achieved. The backing gas types to be used for different base metals are listed at chapter 3.5.2.

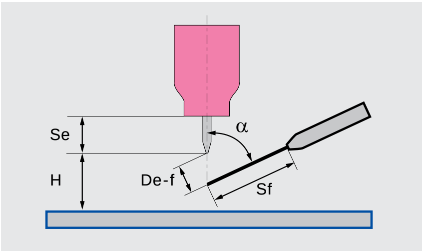
## 15.8. Boundary parameters

The importance of boundary parameters, i. e. parameters which are not directly programmed at the machine, is often underestimated in orbital welding. The consequences are poor repeatability of the welds and a decreased productivity. Some of the boundary parameters are listed below:

- Shielding gas: type, purity, flow rate
- Backing gas: type, purity, flow rate
- Gas lens: type and size
- Ceramic nozzle: size, diameter and length
- Electrode: type, diameter, end preparation and stick out
- Wire: grade and diameter; cast n°, entry angle, impact point
- Position of the start point of the weld
- Inter-pass temperature
- Ground cable position and connection.

## 15.9. Geometrical adjustments

For all applications the geometrical adjustments concerning the torch and the wire guide must be carried out thoroughly and documented clearly.




**1 -** The angle α between the tungsten and the arriving wire should be adjusted to a value between 50° to 80°.

**2 -** The wire distance De-f to the electrode should be adjusted between 1.5 mm and 3 mm. For the root pass the larger value is recommended: the rigidity of the wire can be used to push the weld bead through and obtain the required root convexity. For the filler and cap passes it is preferable to reduce the distance to 2 mm. By this, the wire is closer to the arc and melts easily. More wire can be fed and cold wire defects are avoided.

**3 -** The wire stick-out Sf should be adjusted between 8 and 12 mm. If this distance is too short the wire nozzle will burn or stick. If the distance is too great the wire can twist in any direction and, for example, contaminate the tungsten electrode.

**4 -** The arc gap H should be adjusted between 2 and 3 mm. In the case of 6 axes equipment the distance will be controlled by the AVC device. For a root pass weld the arc gap can be reduced to 1-2 mm (see chapter 11.5).

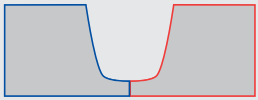
## 15.10. Possibilities to increase the performance of orbital TIG welding

Orbital TIG (GTAW) welding with cold wire is an adequate choice for standard applications which require high quality levels. Unfortunately, compared to other arc welding processes, the deposition rate of the TIG process is relatively low (0.15 to 0.5 kg/h). In order to boost the efficiency of the process it is possible to use a narrow groove preparation and/or the hot wire technique.

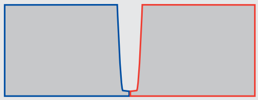
### 15.10.1. *Narrow Groove* welding

An important gain in productivity can be achieved by reducing the groove volume. The narrow groove technique deals with the shrinkage of the workpiece after each filler pass. The size of the gap at the root just allows the insertion a flat-profile narrow groove torch to deposit a stringer bead, e. g. one pass per layer. As a result of the shrinkage, the gap above each layer becomes a bit narrower after the weld, thus forming the borders for the next pass. This technique can offer economic advantages for workpieces with wall thicknesses of at least 25 mm; weld seams of unchanging width can be obtained on walls with a thickness of up to 250 mm.

**Expert information:** The narrow groove technique is not recommended for any base materials being sensitive to hot cracking.



Commonly used
J-preparation for orbital TIG

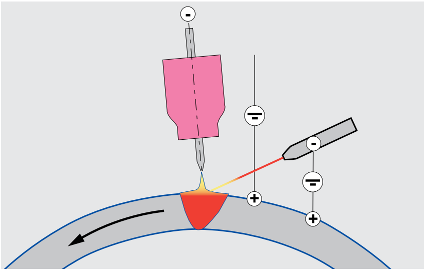


Preparation for
*Narrow Groove* welding

Macrographic section of
a *Narrow Groove* TIG weld

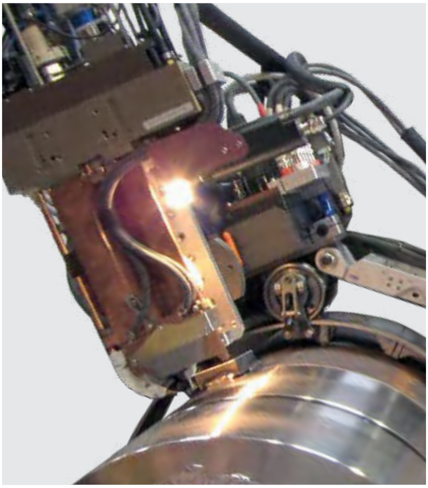
### 15.10.2. Hot wire TIG welding

Increasing productivity without quality losses can be achieved using the hot wire TIG process. In this case, the filler wire is heated up by an additional current. The necessary hot wire current is supplied by a second power source. The hot wire technique leads to appreciable higher deposition rates, i. e. 1 kg/h for orbital welding and much more for cladding applications.



Principle of hot wire TIG welding

### 15.10.3. Hot wire *Narrow Groove* welding



Of course the major efficiency is obtained combining the narrow groove technique and the hot wire process. This welding procedure is mainly used to weld the high pressure and high temperature pipes installed in fossil or nuclear power plants.

For detailed information about orbital welding of thick walled pipes, the Polysoude booklet "Guide of narrow gap TIG welding" can be consulted.

Joining of thick walled pipes with a
Polysoude *Narrow Groove* hot wire
TIG welding torch

# 16. **Orbital tube-to-tubesheet welding**

## 16.1. Range of materials and tube dimensions

Nearly all weldable metals and alloys are used in the field of tube-to-tubesheet applications, but the tube dimensions are relatively restricted. Their diameter range covers 12.7 mm to 101.6 mm, the wall thicknesses are between 0.5 mm and 5 mm. Most of the tube diameters measure between 19.05 mm (3/4") and 38.1 mm (1.5") with wall thicknesses between 1.65 mm and 3.4 mm.

Boilers and heat exchangers are used in all kinds of industries, whereas the heaviest equipment is found in the plants of the chemical or petrochemical industries and in electric power stations.

## 16.2. Welding equipment

In most cases, the welding equipment used for tube-to-tubesheet welding is strictly adapted to the kind of application and the desired level of automation:

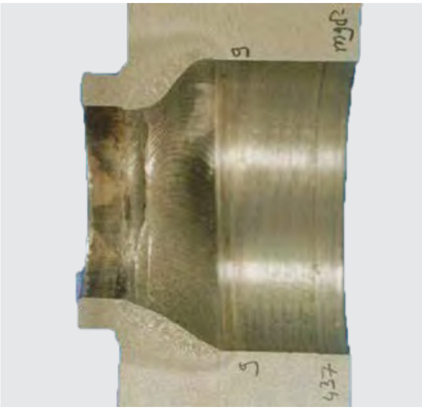
**1 -** Welding equipment featuring three controlled axes (welding gas, welding current, torch rotation) is composed of a stationary installed power source* and a closed chamber welding head. This equipment allows for the execution of fusion welding without addition of filler wire.

Example of a three axis application with a Polysoude welding head TS 34

**2 -** The welding equipment, including four controlled axes (welding gas, welding current, torch rotation, wire), is composed of a stationary installed power source* and an open welding head. The equipment is suitable for single pass welding; two passes must be welded in two separate steps.

**3 -** The welding equipment fitted with five controlled axes (welding gas, welding current, torch rotation, wire, AVC) is composed of a power source designed to control 6 axes and a welding head of the type TS 8/75 with AVC configuration. The equipment allows the use of several welding heads by one operator, the raising of the torch between passes can also be programmed and is carried out without interruption of the weld cycle.

* Portable power sources are rarely used for these applications: there is no need for the machines to be carried.



**4 -** Welding equipment furnished with six controlled axes, (welding gas, welding current, torch rotation, wire, AVC, torch offset) is composed of a power source with integrated weld controller and a welding head with AVC and motorised torch offset configuration. The equipment allows the chaining of multilayer welding operations (two or more layers). The torch height and gyration radius (offset) are programmable and automatically adjustable.

Macrographic section of a fully penetrated tube-to-tubesheet joint welded behind the tube plate

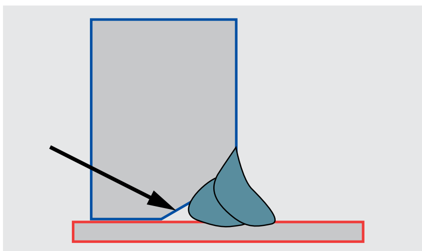
## 16.3. Specific requirements concerning tubes and weld preparations

Compared to manual welding, the planning of the orbital tube-to-tubesheet welding requires some more specific attention:

**1 -** The tubes have to be seamless (or with flattened weld); concentricity faults between the inner and the outer diameter must be limited to a minimum to allow the repeatability of the electrode positioning. With standard applications, (flush, protruding or recessed tubes) the torch is aligned at the inside of the tube whereas the welding is carried out at the external diameter. Concentricity faults would cause unacceptable variations of the distance between workpiece and electrode and thus directly alter the arc length.

**2 -** As with V-joints it is virtually impossible to ensure reliable melting of the base of the tube edge, especially in the vertically down position (fusion defects are to be seen on macrographic sections), these joints have to be replaced by J-preparations.

**3 -** In some cases, if a good thermal conduction is requested, the play between the tube and the bore must be eliminated by a slight expansion of the tube. Play is necessary for the assembly of the apparatus before the welds are carried out, but if clearances become too great, problems of repeatability may occur. However, it is difficult to specify a maximum amount of play; it depends on the demanded weld quality and the thickness of the tube.



Fusion defects occurring on the ground of a V-preparation

**Expert information:** To get optimized centring tools for the tube-to-tubesheet welding heads, each order must be accompanied by information about the depth of the expansion and the tube diameter at the expanded zone as well as the original diameter.

4 - The contact zone between the tube and the tubesheet must be clean. Grease, oil or other residues from the tube manufacturing or machining can cause the formation of unacceptable blowholes, with outlets on the surface or closed in the welds.

5 - A strong expansion of the tubes inside the tubesheet must never be carried out before automatic welding. A strong expansion (with or without longitudinal grooves in the bore) causes almost always explosive degassing effects which make automatic welding impossible.

## 16.4. Welding of flush tubes

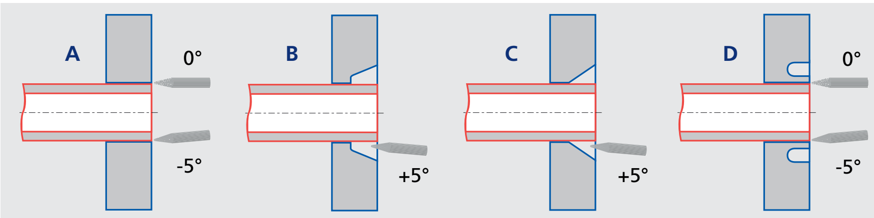
Depending on the application, orbital welding of flush tubes with or without filler metal is possible. Different joint designs are shown below:

A – Standard preparation

B – J-preparation

C – V-preparation

D – Relief groove

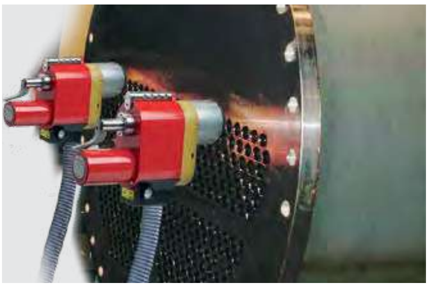



### 16.4.1. Welding of flush tubes without filler wire

Most often the type A preparation is carried out for the welding of flush tubes; rarely the type D is applied. In case of tube diameters between 10 mm and 32 mm the use of the especially developed welding heads for applications without filler wire is recommended.

It is the operator's task to position the welding head and to start the weld cycle. The complete sequence is carried out automatically; the operator is not needed any longer at this machine. Thus, one operator can work simultaneously with several welding heads.

Typical application: Condensers of thermal-electric power plants. Here, the tubes with a wall thickness of about 1 mm are made of titanium whereas the tubesheet is designed and manufactured as titanium-cladded steel plate.



Example of welding flush tubes to a tubesheet with two Polysoude welding heads TS 34

### 16.4.2. Welding of flush tubes with addition of filler wire

Welding equipment fitted with four or five controlled axes can be used for this application; the open tube-to-tubesheet welding head should be configured with devices adapted to the requirements:

- Integrated or external wire feeder
- With or without AVC
- With or without shielding gas chamber (for the welding of titanium or zirconium)
- Torch angle of 0° or 15°.

**Expert information:** The AVC function is recommended especially for the welding of flush tubes.

Generally, the tube end preparations are of the type A, B or C. If a preparation of the tubesheet is carried out, a V-joint should be avoided. With this type of preparation remains always the risk of incomplete penetration of the root. A J-preparation (with or without radius) has to be preferred; if the depth of the bevelled edge exceeds 1.5 mm, the tube end should be positioned at the half of it. The maximum value of the tube end to be recessed is 50 % of the tube thickness, the tube becomes finally flush by the weld.

Depending on the dimensions and the required weld thickness one or two passes are necessary. One tour of the torch is always applied in case of a pass for tightness; layers for mechanical resistance often require additional tours.

Example of welding flush tubes to a tubesheet with a Polysoude welding head TS 8/75

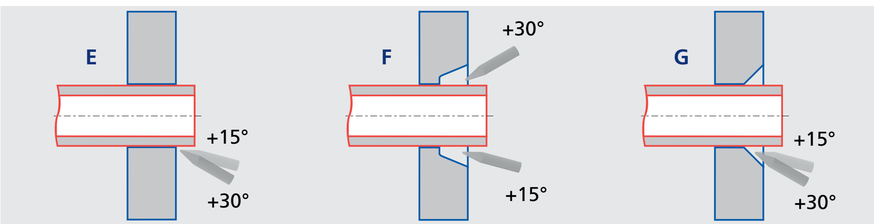
## 16.5. Welding of protruding tubes with addition of filler wire

Protruding tubes are always welded with addition of filler wire, but in some cases the weld is beginning with a fusion pass. As shown below, different joint designs are possible.

E - Standard preparation without groove

F – J-preparation

G – V-preparation

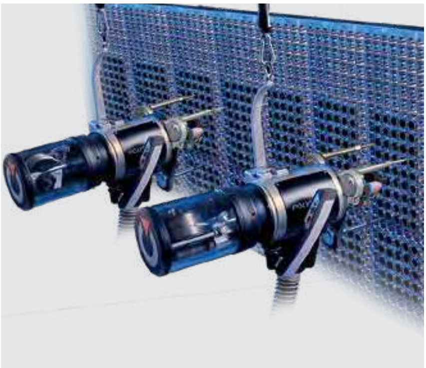


Welding equipment fitted with four or five controlled axes can be used for this application. Depending on the pitch and the protruding distance, the torch inclination may be varied. Standard torch angles are 15° or 30°:

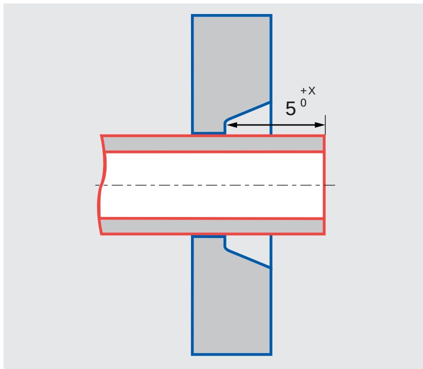
- Torches with an angle of 15° are preferentially used in case of thin-walled tubes (1.6 mm to 2.11 mm), thus melting of the inside can be avoided
- Torches with an angle of 30° are applied for thick-walled tubes (from 2.5 mm onwards) if there is sufficient space with regard to the tubes around (reduced pitch).

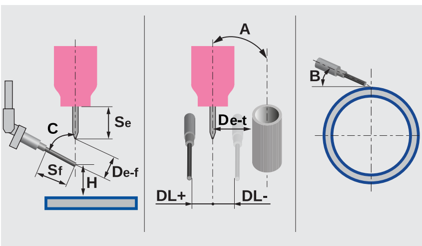
In any case, to avoid melting down the tube edge, the tube length measured from the ground of the groove must exceed at least 5 mm. In any way, with a torch and an AVC-slide, both inclined of 15°, slightly protruding tubes (3 mm) can be welded.

**Remark:** If equipment fitted with five controlled axes is used, the AVC has to be operated in the *Relative height* mode. Thus it is possible to adjust the distance between electrode and tube plate to get the best result; independently of the torch position.



Example of welding protruding tubes to a tube- sheet with a Polysoude welding head TS 8/75




Special attention must be paid to the training of the operators; differently to orbital tube-to-tube welding, where the mechanical adjustments of torch and wire guide are carried out in the same plane, tube-to-tubesheet welding requires three-dimensional operation.

## 16.6. Welding of recessed tubes

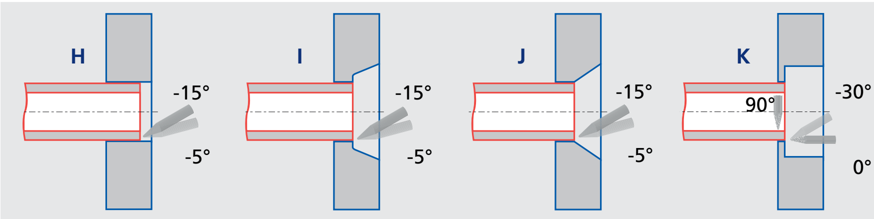
Different joint designs are shown below:

H: Standard preparation without groove

I: J-preparation

J: V-preparation

K: Welding behind the tube plate



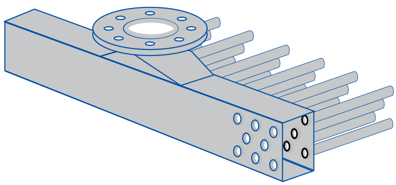

Welding equipment fitted with four or five controlled axes and an open tube-to-tubesheet welding head can be used for the application H, I and J.

The preparation of the type K is frequently used in the petrochemical industry; welding equipment with six controlled axes and a SPX compact welding head with separate clamping device have to be used. This type of application generally requires a specific project to study the best adaptation of clamping tools and welding procedures.

**Expert information:** Different to those applications with protruding tubes, in the case of recessed tubes a V-preparation of the tube plate is possible. If joint preparations of the type I or J are applied, the tubes may protrude slightly from the base of the groove.

Depending on the dimensions and the required weld thickness, one or two passes are necessary. One tour of the torch is always applied on the first pass for tightness; layers needed for mechanical strength and wear resistance will often require additional tours.

**Particular application:** Welding behind the tube plate of a double-walled collector for air-cooling or fluid condensation. The AVC operation is indispensable to make the weld in this application.



Welding behind the tube plate
of a double-walled collector

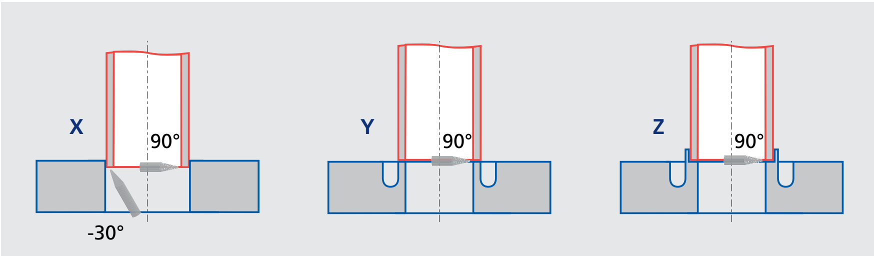
## 16.7. Internal bore welding behind the tubesheet

To avoid gap corrosion between the tube and the tubesheet, gapless joints are welded from the inside of the tubes at the backside of the plate. This type of application requires extended accuracy of the workpiece preparation and welding. Some possible joint designs are shown below:

X: Standard without groove

Y: Preparation with relief groove, without collar

Z: Preparation with relief groove, with collar




A joint preparation of the type X is not recommended: the important mass difference between the tube and the plate excludes the possibility to achieve sufficient penetration.

The joint preparation of the type Y overcomes the penetration problem by creating a welding zone with a better balanced mass distribution between tube and plate.

For three reasons the joint preparation of the type Z leads to weld conditions quite similar to those of a standard orbital tube-to-tube welding operation:

- By the collar the tube is aligned with the bore
- Melting down the collar offers some additional metal which increases the mechanical strength of the weld
- The concave form of the weld is reduced.

**Expert information:** Unlike classic tube-to-tubesheet applications, the internal bore welding operations behind the tubesheet require a gas protection of the root (at the outside of the tube). Only with a preparation of the type X, where the tube end is positioned sufficiently deep in the bore (e. g. half of the tube wall thickness), a root protection is not necessary. The protection can be provided by flooding the entire apparatus with inert gas or, if the backside of the plate is accessible, by a local protection applied tube after tube.

If the tube I.D. exceeds 35 mm, the use of welding tools with filler metal is possible.

Example of internal bore welding behind the tubesheet

If relatively thick walled tubes of 3 mm to 3.6 mm (depending on the base material), are to be welded, a horizontal weld position with the plate at the bottom and the welding head horizontally positioned as well is recommended.

The distance from the face of the plate to the welding joint must be precisely respected (close tolerance). The operator cannot see the torch position inside the tube, he has no possibility of adjustment and he cannot watch the welding process.

Generally, the weldability problems resemble those discussed in Chapter 1.4 for autogenous tube-to-tube welding without filler wire.

Welding equipment fitted with three or four controlled axes can be used for this application; in case of a joint preparation of the type X, five controlled axes are necessary. The welding heads must be equipped with a particular lance for internal bore welding

**Similar application:** If nipples have to be welded on a collector (this is a typical application in the field of power plant equipment construction), identical base materials are used, and the joint preparation and the precautions to be taken are similar to those of internal bore welding behind the tubesheet.

For power plant equipment nipples have to be welded on a collector

## 17. Conclusion

At the end of this booklet once again the importance of orbital TIG (GTAW) welding shall be underlined for sophisticated applications which require reliable outstanding joint quality. For several decades, the French company Polysoude has developed and manufactured appropriate gear and offers a wide range of standard machines or adapt it for specific demands. The modular design of the devices, i. e. welding heads and power sources, allows the proposal of tailor-made solutions to exigent customers, always respecting the special constraints of the particular project.

Due to the confidence of the clients and hence the shared experience of solving technical problems, Polysoude has become the unrivalled market leader when it comes to mechanised and automated TIG welding equipment. The sales department, the engineering and the application service are curious in regard to your project and would highly appreciate participating in your welding activities.

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# Notes

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