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WHITE PAPER

Orbital TIG welding: tubes and fittings

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FR EWE 00388

2020 - First issue - Polysoude S.A.S. Nantes, France

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Printed in France.

Published by Polysoude, Nantes, France.

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TABLE DES MATIÈRES

1. Intention of the study

A substantial element of applications of all-position TIG welding concerns the joining of tubes and fittings such as flanges, elbows, reductions, Tees etc.

Apart from the necessity of having to clamp the orbital welding heads, there is no one systematic approach to the joining of tubes and fittings, as there is in connecting tube segments.

Within this project the state-of-the-art technique of orbital TIG welding of tubes in 5G position is explained, together with the particular problems which may arise with applications other than tube to tube connections. Furthermore, based on the study of different welding applications appropriate solutions are proposed.

The presented welding tasks are examined to develop a systematical approach to determining all conditions and welding parameters which must be specified and respected, if tubes and fittings are to be welded together successfully.

In the first part of the document, the conditions which have to be ensured or avoided in the case of tube-to-fitting welding will be discussed.

The examples presented in the second part of the document can be used to develop appropriate welding procedure specifications (WPS). It should be noted that a comprehensive collection of welding procedure specifications WPS for common applications is stored in the database of the power sources P6 and P6 HW.

2. State-of-the-art technique in manual TIG welding

Without going into detail as to the numerous conditions which must be taken into consideration when all-position welding of tubes has to be carried out, TIG welding is the best solution regarding different alloys and high-quality requirements of joints.

However, enhanced quality levels can only be achieved by procuring specialist knowledge and expertise and taking incisive measures.

Depending on the dimensions of the workpieces to be joined (diameter and wall thickness), manual TIG welding is used exclusively for the root pass or for the root and hot pass, whereas filler passes pose less difficulties and can be carried out using other processes. For example, if high quality joints are to be obtained by manual welding, then using MMA with coated electrodes is often the simplest solution.

The brake-even point which has to be reached by manual TIG welding or by manual TIG welding combined with another filling process depends on the application, on the structure of the company, on the materials to be joined, on the required quality level, and, last but not least, on the availability of skilled welders.

In the following chapter the possibilities and advantages of automatic welding will be presented, but first, the state-of-the-art conditions of manual TIG welding will be described.

In the case of delicate alloys and metals (alloyed steel, stainless steel, nickel base alloys, titanium and others), backing gas must be used for manual as well as for automatic TIG welding.

The most important advantage of manual TIG welding is the weld preparation of the tube ends to be joined, which can virtually remain the same regardless of the workpiece dimensions.

In cases of extreme wall thicknesses (thin or crucially important) the preparation of the groove may have to be slightly adapted.

A characteristic feature of manual TIG welding is that, for the root pass, a weld preparation with a certain gap between the pieces to be joined is acceptable.

Tack welding (executed by TIG welding) must be carried out, so that a uniform distance (generally 3 to 4 mm, or slightly less in cases of smaller wall thicknesses) between the walls of the preparation is maintained by the spots.

A sufficient number of sound spots with additional material are made in order to suppress the effect of shrinkage during root pass welding, which tends to produce a continuous decrease of the gap.

Commonly, the welder uses wedges to maintain the gap between the walls of the workpiece and sets the spots one by one, taking care not to block the wedges by the force generated from shrinkage.

Sometimes, depending on the skills of the welder and the joint type, the

shrinkage effect can be compensated for by a weld preparation with widening gap.

Depending on the workpiece dimensions and the type of application the desired gap between the edges of the preparation, which is usually guaranteed by tack welds, can also be produced with wedges of appropriate thickness welded between the workpiece extremities. This solution ensures that the edges remain untouched during the joint preparation, so that a uniform penetration of the root pass can be achieved.

In most cases, the root pass is welded in several steps (often as vertical-up seam). By this technique the effects of shrinking can be compensated for and a better repartition of the tack welds becomes possible (evenly distributed around the circumference).

Unfortunately, if this technique is applied, in order to ensure a uniform profile of the root pass, the welding operation must be interrupted in front of every tack weld, so that the spot can be removed, either partially or entirely, by grinding.

The obtained result depends to a large extent on the skills of the welder; an experienced welder will adapt his actions to avoid extensive shrinkage or, if this is not possible, will refinish the gap by grinding. Perfect grinding of tack welds is also part of the craftsmanship of a qualified welder.

The profile of the weld seam is also the result of the welder’s manual ability, he can increase or decrease the size of the molten pool and adapt the penetration with respect to the walls of the groove and the welding position.

Another difficulty of manual welding is the management of the shielding gas stream; its laminar flow is severely disturbed by the gap between the workpieces.

As a universal weld preparation, a V-groove with an opening angle of 37.5° and an edge thickness between 1.5 and 2 mm can be applied.

The thickness of the edges is very important and helps the welder managing the imperfections and irregularities of the weld preparation. With an appropriate edge geometry, the welder can compensate for misalignments of several millimetres without changing his technique.

Manual TIG welding is characterised by the following advantages:

- The certainty of achieving a sufficient result, if the welder is well-trained
- A universal weld preparation for almost all applications
- Relatively simple equipment
- A correct weld seam profile, if a skilled welder has carried out the work
- The possibility of interrupting the process and reworking the weld seam at any time
- The application of a predictable and simple welding procedure

Ultimately, the quality of the obtainable results depends entirely on the skills and craftsmanship of the particular welder, however in many cases talented candidates for all-position manual TIG welding are extremely difficult to recruit and to train.

If the company does not succeed in employing a suitable number of experienced welders, the weld quality may become inconsistent, deadlines for delivery times may be extended and a sufficient workload may be difficult to maintain.

If sophisticated alloys are joined, already small variations of the welding speed can provoke severe deteriorations of the characteristics of the assembly.

3. State-of-the-art technique in orbital TIG welding

The difficulty of recruiting qualified manual TIG welders for delicate joining tasks and the necessity of guaranteeing a stable brand integrity leads companies to look for other suitable solutions. Industries must solve the problems of employing sufficient skilled personnel, reducing reliance on the human factor and shortening production time.

The often harsh conditions of the welding environment (accessibility, thermal load, radiation exposure) must also be taken into consideration in the effort to ensure the safety of personnel in hazardous and stressful work.

In the course of several decades the working conditions in the field of TIG welding have been substantially improved.

Firstly, different types of equipment have been developed to meet the specific requirements of the numerous applications. Today, tailor-made power sources and orbital welding heads for any joining task are available on the market.

A similar development has taken place concerning the machining possibilities of the workpieces, which make the required precise weld preparations possible.

To eliminate dependance on the manual dexterity of welders, the welding technique has been modified to a gapless weld preparation.

The aim was to move away from the concept of weld preparations with gap (more or less variable) and to establish constant conditions in which there is no longer the need for the welder to adapt his manner of welding to particular constraints.

This approach is based on some essential features:

- The use of pulsed welding current
- Software-controlled power sources with synchronised axes for orbital welding purposes
- Management of concavity when laying the root pass on tubes in 5G position
- Precise specification of the weld groove geometry
- Defined tolerances concerning the alignment of workpieces
- Appropriate welding techniques.

Not all of the presented features are discussed in this paper, only the important facts for successful tube to fitting assembly will be explained.

To compare manual and automatic TIG welding of tube to fitting joints the advantages and weaknesses of the process are listed below:

Advantages of automatic TIG welding:

- Repeatability of welding results. The essential welding parameters are kept constant and repeated reliably by the software-control of the power sources.
- Unlike manual welding, the thermal conditions remain unchanged, thus a better quality of the joint (compactness, mechanical characteristics) can be achieved.
- Productivity is independent of the human factor and stays at a high level.

However, to reach this level of productivity the following conditions must be fulfilled:

- Precise tolerances must be specified for the geometry of the weld
- Preparation.
- Perfect alignment of the workpieces (gap and deviations) must be ensured.
- Scrupulous management of the entire welding process (careful adjustment of the welding heads, accurate cleaning of the weld preparations, regular maintenance of the equipment) must be organised.
- Systematic application of a J-preparation, which has to be adapted to the particular materials and applications, must be enforced.

4. Problems regarding orbital welding of accessories

If joining without gap is to be executed, only a J-preparation can be applied. Due to this geometry, the manufacturing specifications of tube-to-tube connections concerning the inside profile of the root pass laid by all-position welding can be met, however difficulties frequently occur if a tube must be joined with accessories such as elbows.

These difficulties are commonly caused by particular problems:

- In many cases the elbows are delivered with ready-to-use weld preparations which have been designed for manual welding. In most cases a V-preparation with an opening angle of 37.5° and an edge with a thickness of 1.5 mm can be found, if no trimming of the internal diameter is executed its thickness may vary between 1.5 to 2.5 mm
- The straight lengths of the elbow extremities are too short. A sufficient length is necessary to machine a proper J-preparation with respect to the longitudinal axis of the elbow
- There are not many reliable industrial solutions which allow a mobile machine to be clamped onto an existing elbow (the same problem exists if trimming of the internal diameter is required.

Finally, these problems only occur if elbows have to be machined. They do not arise on accessories which have sufficient straight lengths to enable clamping, such as Tes, reduction parts, flanges etc. In any event, whenever a sufficient straight length for clamping is available and appropriate equipment can be used a J-preparation at the extremities of the elbows should be executed. Thus, the joint between tube and elbow can be realised as a usual tube/tube butt weld. Attention must be paid, however, as to the method in which the elbow has been manufactured (casting, centrifugal casting etc.) as this can cause unsymmetrical fusion of the lips.

If a V-preparation for manual welding already exists on the workpieces and the straight length of the elbow is not sufficient for further machining, a J-prep should be realised at least on the tube extremity, so that a mixed J/V-preparation will be obtained.

The details of how to execute successful welds on such a mixed preparation is the topic of this study.

The technical challenges of tube/elbow joints manufactured by TIG welding, as opposed to tube/tube connections are as follows:

Due to the fact that in many cases difficulties occur when machining a J-preparation on the extremity of the accessories, the V-preparation will be situated on the side of the elbow.

Some experience already exists when it comes to welding mixed J/V-preparations, but a solution to re-machining commercially available tubes with extremities where a V-preparation has already been realised, or to treating raw elbow pieces in the same manner, was prerequisite for this study.

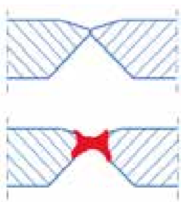
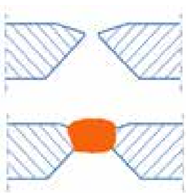
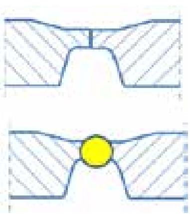
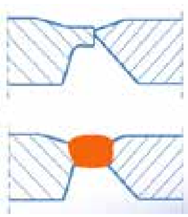
The concavity and penetration problems of the root pass geometry caused by a ½ V-preparation occur preferentially in the vertical down and in the overhead position. Generally, any V-preparation is quite disadvantageous for automatic welding of tube-tube and tube-elbow connections; the welding operation itself becomes very difficult and, together with the forces generated by the surface tension, the effect of gravity may cause insufficient penetration or concavity of the welding seam geometry.

Only with a mixed preparation composed of a J and a V can the occurrence of concavity in the vertical down position and, even more pronounced in the overhead position, be minimised or avoided. As a matter of principle, the opening angle of the V should be 45° (which is the most universal solution in regard to the different materials to be welded) with a mating face as small as possible (between 0.1 and 0.5 mm). Within this range a proper trimming operation of the inside diameter can be executed and a sufficient surface for the contact with the lip of the J-preparation be created.

An important aim of the project is to find the conditions which lead to reliable connections, produced by orbital welding, if a mixed layout composed of a J and a V-preparation is used.

5. State-of-the-art preparations for orbital welding. Concavity in overhead position

Four different scenarios can be distinguished in case of orbital welding of mixed layouts composed of a ½ J and a ½ V-preparation, but there is only one possibility to improve the result.

Profile of the root pass produced by orbital TIG welding in overhead position with a gapless V-preparation	This type of preparation is unsuitable for orbital TIG welding. With such configuration reliable results are impossible		**Together with the effects of gravity the forces generated by surface tensions cause concavity**
Profile of the root pass produced by manual TIG welding in overhead position with a V-preparation with gap	This type of preparation is unsuitable for orbital TIG welding		**The interventions of the welder prevent the occurrence of concavity**
Profile of the root pass produced by orbital TIG welding in overhead position with a gapless J-preparation	To guarantee the absence of concavity only this type of preparation is suitable for orbital TIG welding. Unfortunately, in many cases proper machining is impossible		**A proper design of the joint geometry and correct welding parameters lead to perfect results**
Profile of the root pass produced by orbital TIG welding in overhead position with a gapless J/V-preparation	This type of preparation is the only compromise which can be applied for orbital TIG welding if a ½ V-preparation exists at the elbow. The results are not reliable.		**Is it possible to obtain sufficient results if the thickness of the lip at the J-preparation, the mating face at the V-preparation and the welding parameters are correctly specified?**

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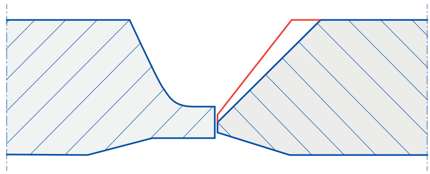
Similar to the specification of conditions which have to be respected if a tube/ tube connection with a J-preparation shall be welded in the following the elements necessary to establish a welding procedure specification for a tube/ elbow connection with a mixed J/V-preparation will be brought together

At first the theoretical approach of the preparations is presented.



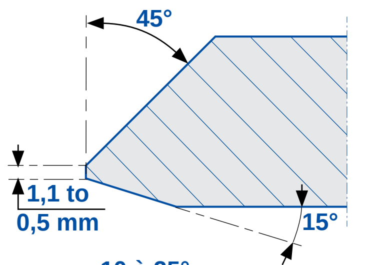
At the tube side, a J-preparation similar to that one used for a tube/ tube connection shall be applied, only the dimensions have to be adapted

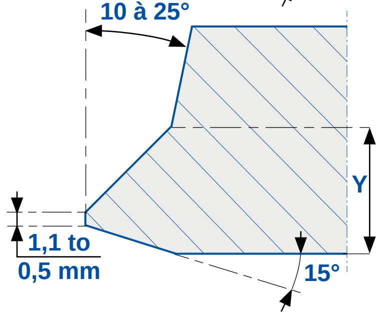
For the required assembly with mixed preparation the original design (edge thickness of 1.5 mm + V 37°) has to be modified.

The necessity to modify the inside trimming depends on the quality of the original preparation (principally on the concentricity of the edge and the inside geometry)

In the following, the ½ J-preparation will be specified with regard to the particular application whereas all ½ V-preparations will be machined at 45° (identical preparation for all applications with a mating surface tolerated between 0.1 and 0.5 mm).

Obviously, an opening angle of 45° can be disadvantageous in case of medium wall thickness, therefore a preparation with a double angle of inclination can be applied if the dimension y (see adjacent drawing) approaches 10 to 12 mm.





Assemblies composed of mixed preparations are also delicate to weld because of the different geometries of tube and elbow extremities. Finally, an accumulation of form defects can appear at the elbow side (elliptical as shown in the adjacent scheme), additionally distinctive differences of thickness may occur.

These differences can be caused by aligning problems due to diameter fluctuations or just positioning variances (as can be seen in tube/tube assemblies).

The limits of the diameter D1 (inside diameter of the mating surface at the V-preparation made on the elbow extremity) are decreased by the tolerances of form and thickness at the elbow side. Ideally the diameters D1 and D2 (inside diameter of the lip at the J-preparation made on the tube extremity) should be the same.

The most critical cases occur if the preparation is machined by means of a sensor system thus becoming elliptic (leading to a variable diameter causing an evolutionary misalignment).

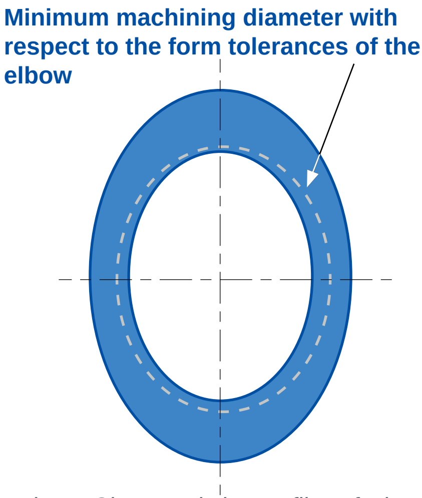
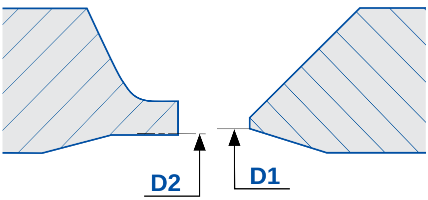
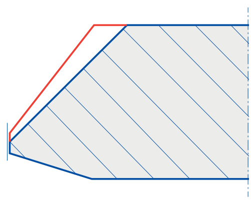


Fig. 1 - Characteristic profile of the extremity of elbows showing an elliptic geometry with differing wall thicknesses



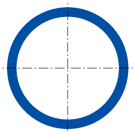
For an assembly with a mixed preparation the original geometry of the V has to be re-machined (mating surface of 1.5 mm + V 37°). The necessity of re-machining the internal trimming has to be examined separately.



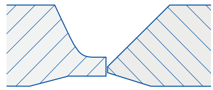
6. Different alignment conditions in the case of mixed tube/ elbow assemblies

6.1. Theoretical approach

$D1_{tube} = D2_{accessory} +$ concentricity



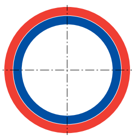
Ideal welding configuration



6.2. Alignment limits

$D1_{tube} \neq D2_{accessory}$

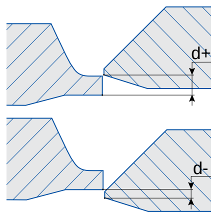
D1 and D2 are concentric with slightly differing dimensions; the transition is regular on an ongoing basis (if the alignment has been perfectly controlled)



One of both cases will occur

Risk to loose contact

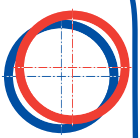
The preparation has to be modified if the extremities do not match



$D1_{tube} = D2_{accessory}$

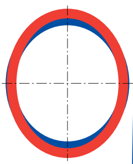
+ concentricity defect

Due to imperfect alignment D1 and D2 are not concentric: a crosswise misalignment occurs (inversion between d+ and d- at ½ circumference with impact on the welding position)



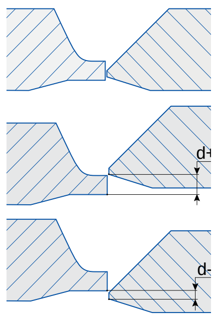
Elliptic geometry of the V-preparation.

This can be caused e.g. by use of a copy system during machining. Even a well-executed alignment causes variable conditions.



Common situation in case of tube/elbow welding

During welding, all situations arise one after the other without any possibility of adaption

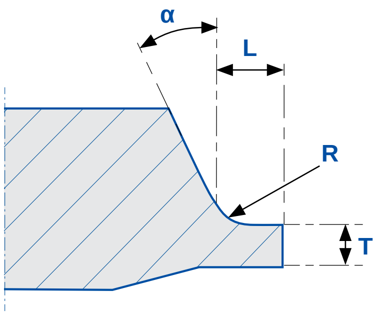


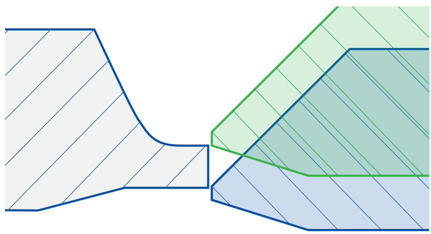
Correct dimensioning of the preparation at the tube side is essential for successful welding of mixed assemblies.

The first dimension to specify is the lip thickness. Its value depends on the elbow quality, the precision of the piece, the diameters to be welded, and the material nuances.

As shown before, the allowable tolerances of the alignment are by a few tenth of a millimetre close to the thickness of the lip. If the mating surface of the V-preparation is beyond the lip diameter of the J-preparation the forces generated by shrinking effects can cause a loss of contact which generally prevents a correct assembly (probably due to lack of fusion).

Generally, the greatest possible thickness for the lip should be specified to allow the widest tolerances for the alignment.





α = opening angle

L = length of the lip - essential variable

R = connecting radius

T = thickness of lip - essential variable

Fig. 2 - The thickness of the lip limits the allowable alignment tolerance

Note: Generally the play between the lip of the J-preparation and the mating surface of the V-preparation cannot exceed some 1/10 mm except it occurs quite locally (0.3 to 0.5 mm maximum).

However, for each batch of material an ideal proportionality exists between the lip thickness and its length. Commonly, this proportionality is named P/L and can be used as an indicator for the behaviour of different material nuances concerning fusion, heat conduction, generation of surface tension forces, viscosity, etc.

Later, it will be shown that T and L should be specified according to the material nuances to be welded together, but first, how they influence the design of the preparation should be explained.

To ensure constant penetration T and L have to be adapted to the material characteristics; afterwards, the proportionality P/L can be used to optimise the design of the preparation.

The elbow quality and its dimensions are also essential for the specification of the value T. For example an assembly should be carried out with pieces of small diameters (2 to 4 inches) and small wall thicknesses (4 to 5 mm) using

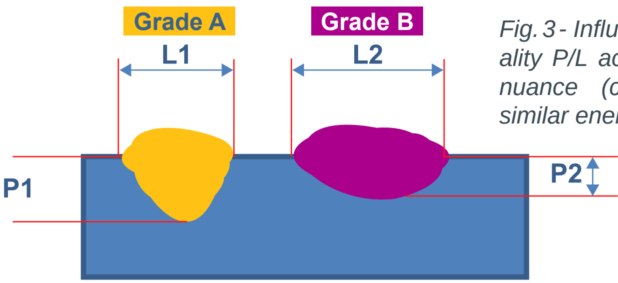


Fig. 3 - Influence of the proportionality P/L according to the material nuance (comparison based on similar energy input)

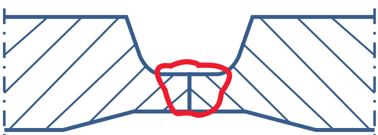


Fig. 4 - Increased lip thickness and decreased length ⇨ easier to weld

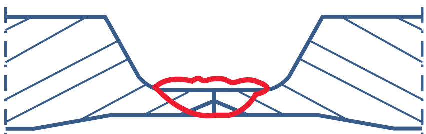


Fig. 5 - Decreased lip thickness and increased length ⇨ more difficult to weld

elbows of excellent quality (CAD machined with precise concentricity between internal and external diameter). In this case, alignment of the pieces is easy to obtain and allows for optimisation of the value of T. By the optimised T value, the length L decreases and the width of the gap is reduced, which leads to a shortened welding time, less filler material added and reduced shrinking effects. If a similar assembly has to be welded with the same material but a diameter of 31 inches with wall thicknesses between 20 and 25 mm a perfect alignment is hard to obtain, so a tolerance of several millimetres must be allowed in comparison to the geometry of the elbow preparation. Hence, the lip thickness of the J-preparation must be specified as great as possible, in order to enable an alignment which meets the requirements of automatic welding.

Usage of the proportion P/L

In order to solve individual problems, for a given material nuance different welding gap designs may be chosen.

For example, with a maximum thickness of the lip an acceptable alignment of the pieces can be obtained more easily. The proportions of the gap geometry finally remain similar, in any case they are limited by the behaviour of the pool of molten metal in the different welding positions. Finally an advantageous choice of parameters is possible within the limits of reasonable conditions.

This case must in no way be confused with the previously presented adaption to different material nuances.

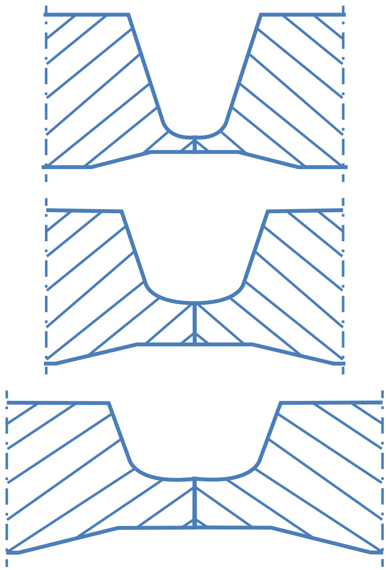


Fig. 6 - Different welding gap designs with constant proportion P/L
The proportions P/L of the three designs are similar, but their weldability is different.

7. Organisation of tests due to the type of welding pass

The aim of the approach is to establish applicable rules of practise and to verify under varying conditions like different material nuances and several diameters whether acceptable results can be obtained and where the difficulties begin.

These rules of practise can be improved over the course of the years, different applications can be added, and the technical conditions or essential parameters may be adapted, and even recommended values can be modified.

The following assemblies with mixed preparations have been examined:

Nuance	Dimensions
Unalloyed steel	168.3 x 13
Unalloyed steel	168.3 x 8.8
Stainless steel type 304 L	168.3 x 7.11
Stainless steel type 304 L	60.3 x 5.5
Stainless steel type 304 L	76 x 3.6
Stainless steel type 304 L	88.9 x 5.5
Stainless steel type duplex	88.9 x 3.3

After a first welding practise had been developed it has been applied to further tasks in order to establish a procedure for certain diameter ranges which can be welded with orbital welding heads of the type MU AVC/OSC and POLYCAR. The idea was to find out whether similar conditions exist for a given range of assemblies.

In all these cases, use of a similar gap design and the same welding technique for each pass have been tried out

To remain close to the topic of producing a joint pass after pass, the gained experience has been arranged following the different stages of a welding process.

Beginning with the programming details and the essential variables of the weld, finally the specific parameters values are introduced.

A distinction has to be made between two different welding techniques:

- Cold wire orbital TIG welding is applied for small diameters of less than 4 inches and wall thicknesses of up to 5 or 6 mm
- Hot wire orbital TIG welding is beneficial in cases of more crucial tube diameters and increased wall thickness.

It should be mentioned that the limits of 4 inch diameters and 5 to 6 mm wall thicknesses are just a fictive approach, finally all diameters can be joined by cold wire orbital TIG welding. However, beyond these limits the gain of productivity in case of hot wire orbital TIG welding begins to become advantageous.

The information concerning the filler passes and the cap pass is given merely as a reminder. The welding conditions and parameters are usually quite similar to those of common tube/tube welding, i.e. 20° (or similar) J-preparations and oscillated filler passes.

Nevertheless, the root passes of these assemblies are quite special. It is the technique of the root pass, based on the gap design and particular welding parameters, which opens up the possibility of producing mixed assemblies.

Supported by matching welding parameters, the following preparation which is being presented, leads to universally applicable tube/elbow joining methods.

Each of the following chapters focuses on a particular type of welding pass (root, penetration, filler and cap pass) and will be structured in the same manner:

- Functions and axis conditions according to the type of pass
- Selection of essential variables and parameters according to the type of pass
- Typical synoptic of the type of pass
- Pictorial representation (principally of the type of pass and complete weld structure)
- Notes and commentaries.

The study has been carried out by means of the following equipment:

- Power source P6 HW + open orbital welding heads MU 195 AVC/OSC HW (Hot Wire)
- Power source P6 HW + orbital carriage-type welding heads POLYCAR 60 and POLYCAR MP. It should be noted that the settings concerning functions and axes can be applied to the entire range of power sources for TIG welding.

The access to the functions and parameters of the power sources P6 and P6 HW is described on the following page.

Basically, the results are a combination of mechanical settings of the welding head, the gap preparation, the alignment (quality of tack welding), and the additional shielding gas measures, associated with the applied welding program.

Strict adherence to the recommendations about the functions concerning the axes conditions is essential.

When it comes to welding parameters, a clear distinction is made in the following between four different categories:

	Essential parameters	*(to be kept constant at always the same values or within narrow limits)*
	Influencing parameters	*(has to be varied in accordance with the particular application)*
	Parameters of secondary importance	*(still important, these parameters are usually modified to compensate the consequences of optimising an influencing parameter. Frequently concerned are the arc voltage which has to be adjusted in accordance to the welding current intensity to obtain a proper arc length or the hot wire current intensity which must be adapted to different wire feeding speeds)*
	Parameters without influence	*(their value is not taken into account but important for the progress of the weld cycle. In case of synchronisation between welding current and oscillation e.g. the value of the pulse frequency remains without effect but is necessary for carrying out the function)*

Note: not all of the parameters are mentioned. Some of the values such as time settings, AVC sensibility, gas stream etc. are indeed important, but are not of special note in the welding of mixed assemblies.

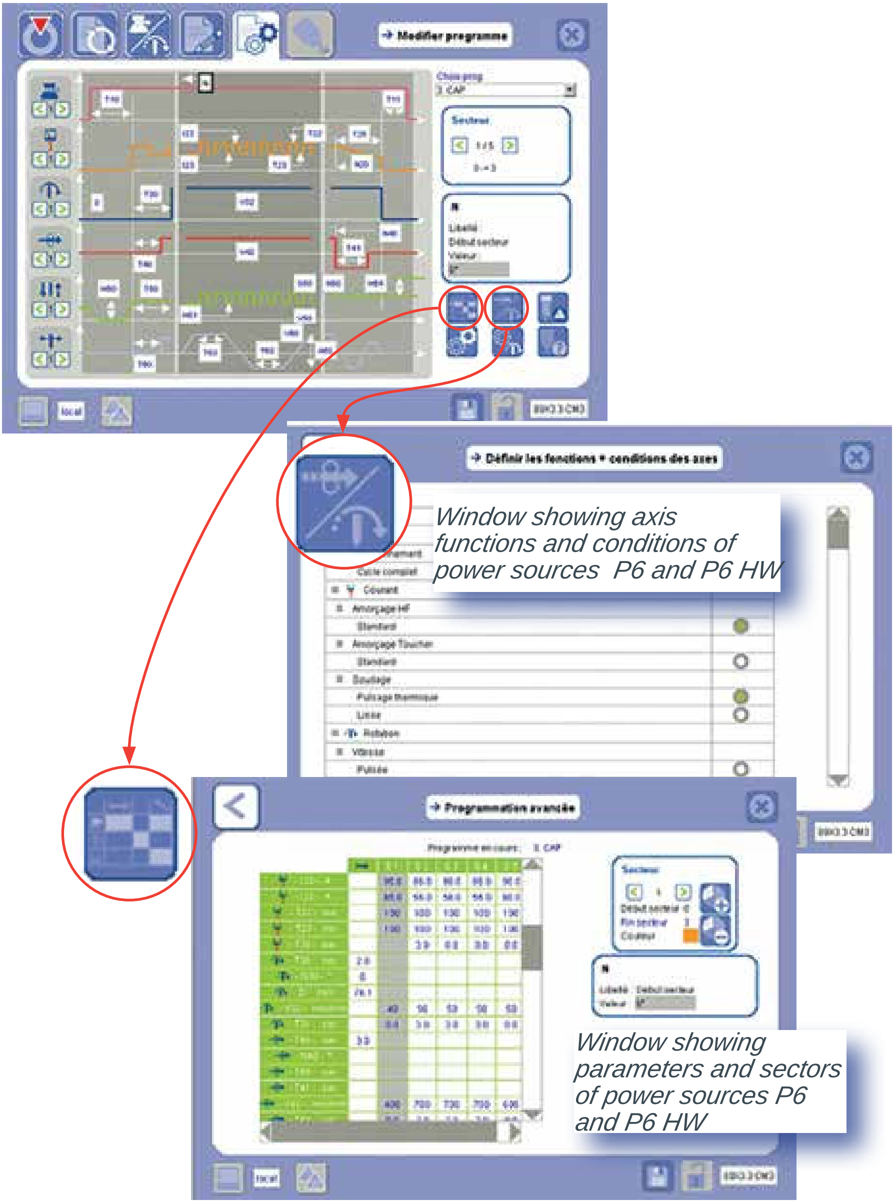
Within the presented examples of WPS (Welding Procedure Specifications) sector programming has been abandoned. Creation of sectors has to be carried out as a result of the particular comportment of the weld pool. So far the welding comportment of tube/tube assemblies with J-preparation and welding of mixed preparations is similar. Mechanical settings are documented in the preliminary WPS.

Welding conditions common to all MOS:

- Electrode sharpening at 30°.
- Point of impact of the electrode on the J at 3 mm from the end of the electrode.
- Electrode / Wire distance :
  - 2.5 mm for the root / test from 15.05 with 2.0 mm + U adjustment if possible / To be tested on 76 X 3.6 and 88.9 X 5.5
  - 2.0 for hot pass and filling

Interpass temperatures: for stainless steel and duplex / air cooling between passes / inter-passes 80°C max.

The access to the function conditions at the power sources of the type P6 or P6 HW is shown by the following screenshots.

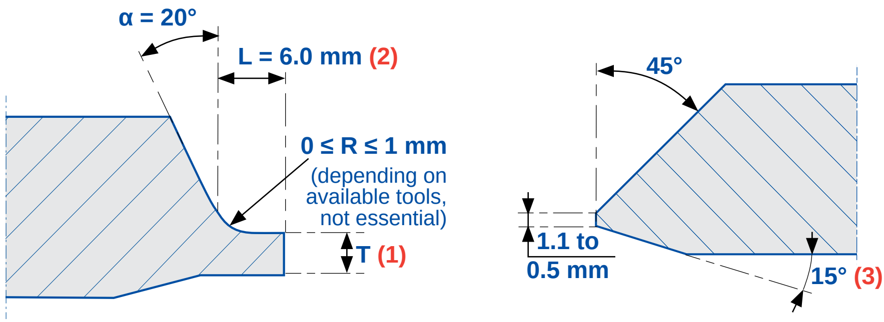


8. Mixed preparation J/V

In 80 to 90 % of applications only the lip thickness of the J-preparation has to be adapted, occasionally, in the case of small diameters, the slope of the J must be revised.Proposed geometry for a mixed preparation:

Tube preparation

Elbow preparation



(1) T = lip thickness is the only variable to be adjusted according to the material nuances which should be welded:

- T = 2.5 mm for unalloyed steel (without backing gas)
- T = 2.0 mm for alloyed steel or fine grain steel with backing gas protection
- T = 1.2 mm for "difficult to weld" alloys and metals (Duplex, Super Duplex, Titan, etc.).

(2) The default value of the length is set to 6.0 mm (practicable for 80 to 90 % of the applications)

(3) Depending on the workpiece quality, the 15° angle can be optimised.

9. Machining technology and equipment

Joining tubes to tubes and tubes to accessories requires high quality machining operations (regarding surface finish and tolerances).

Precise geometry and maintained tolerances of the workpieces lead to a good level of reproducibility, since there is no way of adapting the welding conditions as manual welders can do. This is the reason why an excellent workpiece preparation is so important for automated welding.

Generally, joining of tubes by orbital welding is carried out without any passes being laid from the inside. Therefore, the machining operations must include the internal profile of the tube or accessory. This operation is called 'trimming', it enables the inner diameter at the tube extremity to be made exactly round. Properly executed trimming is an essential prerequisite, in order to maintain uniform thickness of the lip.

For perfect bevelling the following instructions should be observed thoroughly.

9.1. The different faces of joint preparation

Below are the different faces that make up the ½ V-bevel on the bend (or other accessories) as well as the J-preparation on the pipe.

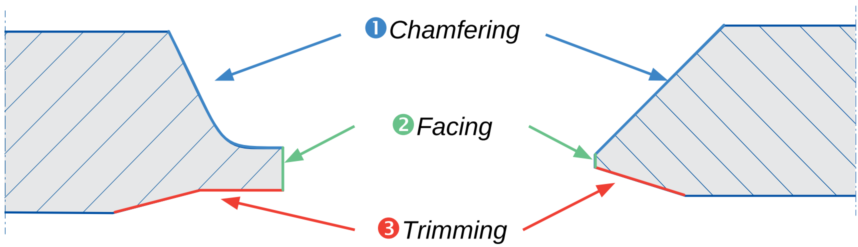


Fig. 7 - Schematic of two end preparations for orbital welding purposes. Each ½ preparation is composed of a chamfering, facing and trimming operation

Chamfering

Chamfering is carried out to get a flattened surface of the tube end so that the torch can reach the complete thickness of the tube. Due to the applied welding technique (stringer bead technique or oscillation) and the particular welding position, the opening angle of the weld groove (composed of simple or multiple faces) improves the correct superposition of welding layers to a uniform joint, ensuring the mechanical strength of the assembly. A root pass is laid at the ground of the weld groove; it constitutes the base of the joint. The hot pass, which ensures the correct fusion of the walls, is the most delicate operation of automatic welding and isvery important. One or more filler passes are welded into it, before the weld is finished by the cap pass forming a perfect cover between both workpiece surfaces.

Facing

Facing is carried out in order to create the frontal area of the lip: the spot face of the tube must be smooth and angular. Suitable facing helps to align the tube ends in a correct manner; above all it contributes to avoiding

any play between the spot faces of the tubes to be joined. Gap-free positioning of the workpieces is a mandatory requirement to avoid burn through of the root pass.

Trimming

Due to the manufacturing tolerances of tubes and elbows (generally 12 % of the wall thickness) the wall thickness may differ along their circumference. These differences cause discrepancies between the inner and outer diameters of the workpieces to be welded. On the outside, the connection is made by a cap pass which is in most cases made by oscillated welding; this ensures a continuous profile, provided that during the positioning of the workpieces, a concentration of variances has been avoided. However, welding of the root is a much more delicate operation, as a uniform wetting between the weld metal deposited by the root pass and the walls of the groove must be obtained (where the form of the weld bead should remain even to avoid any problems). Concerning the trimming operation, two important items must be taken into consideration: the choice of a proper profile (flat and a chamfer or simply flat) and the positioning of the blank in the machine tool. A trimming operation is recommended for automatic welding of workpieces with medium or high

wall thicknesses, where at least two or three passes are required. When it comes to the preparation of tube ends, external clamping is preferable, whereas elbows and accessories without plane surfaces are fixed from the inside. The centring of the workpiece should be carried out in such a way that a minimum of material has to be removed in order to reach the specified inner diameter. To obtain the required uniform thickness of the lip, some material must be removed at 360° of the circumference at the inside of the wall. The constant thickness of the lip is necessary so as to ensure sufficient reproducibility of the root pass.

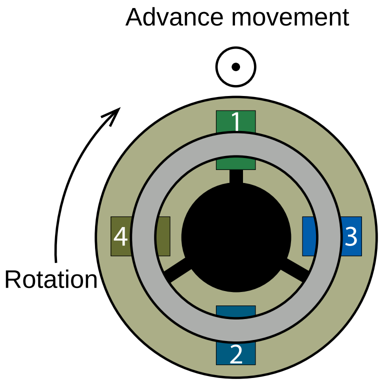
Principle of the tube end preparation machining

For the tube end preparation a cold machining process is applied by means of a particular bevelling machine which is the only way to ensure the perfect geometry of the preparation without altering the tube material; at the same time a sufficient level of reproducibility can be reached.

These machines are equipped with a chuck, which is moved in the direction of the tube axis. The cutting tools are fixed in a position which allows for getting the required tube end geometry to be achieved. If a complex bevel has to be carried out, a cutting tool with an identical shape can be used; otherwise several tools, each with a simple geometry, each can be mounted. The most performing effectivemachines have the capacity to allow working with 4 cutting tools at the same time. Thus, chamfering, facing and trimming takes place within one single operation.

The composed chamfer is cut by tool 1 and 2 (these two tools can be replaced by a single one), the lip is formed by tool 3 and the trimming of the inside of the wall is done by tool 4.

The chuck with the clamped tools is moved in thedirection of the tube axis. Therefore this type of bevelling machines is only suitable for tube end preparation and cannot be used to cut a tube into two separate pieces.



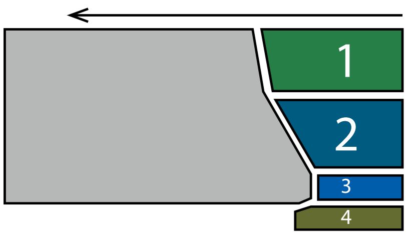


Fig. 8 - Bevelling example: weld preparation at the end of a tube segment which had been cut previously to the proper length

Bevelling of a J-preparation at the end of a tube

Protem bevelling machines of the type US25CH or US 40 are suitable for a J-preparation at the end of tubes made of mild steel, stainless or Duplex types with outer diameters between 60.3 and 168.8 mm.

Similar machines can be used for different tooling and dimensions.

These mobile machines can be equipped with a pneumatic or electric drive.

Before the machining operation is carried out the inner diameter must be measured, so that the correct clamping jaws can be selected. Due to the required chamfer fitting, cutting tools have to be mounted. For a J-preparation a special tool with the particular shape has to be used. Facing of the lip is carried out by another cutting tool, which must be mounted opposite. The third tool is adjusted to the required inner diameter of the workpiece for the trimming.

After the set-up, the machine is introduced into the tube and the clamping is carried out by means of a ratchet. Next, a connection to the energy supply must be established. The rotation speed must be chosen with respect to the tube material, its diameter and wall thickness. Finally, a perfect J-preparation of the tube end can be realised.

Fig. 9 - Tube end preparation with a bevelling machine US40

Fig. 10 - Tube end preparation with a bevelling machine US25CH

Bevelling of a ½ V-preparation at the end of an elbow

Protem bevelling machines of the type FBB are designed to carry out the ½ V-preparation at the spot face of a 45° elbow with a lip thickness between 0.1 and 0.5 mm and a 15° trim.

This stationary machine is designed for the end preparation of elbows with outside diameters between 60.3 mm and 168.3 mm.

It allows chamfering, facing and trimming to be carried out simultaneously. The main spindle is equipped with 4 tool holders where the insert holders can be fixed at the required angles.

The height of the main spindle can be adjusted exactly to the axis of the elbow (+/- 2 mm, 0.078‘‘).

The elbow itself can be reliably clamped and positioned on the machine as well. Equipped with a cross-slide the axes can be adjusted precisely (+/-5 mm, 0.19’’). Fixing of the workpiece is carried out manually. Therefore a small table with a clamping system is mounted on the cross-slide. This table adjusts itself automatically with respect to the spot face of the elbow (90° rotation). V-shaped jaws guarantee efficient clamping of any diameter.

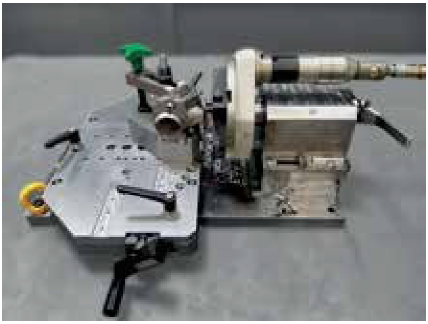


Fig. 11 - Bevelling machine for elbows

Fig. 12 - Machining of an elbow with a diameter of 60.3 mm (2’’) to realise a 45° V-preparation with a lip and a 15° trim at the inside of the wall

9.2. How to make a perfect weld preparation

- Use a suitable machine. The cold machining process is the only way to get a perfect weld preparation. The product range of Protem includes bevelling machines for all workpiece diameters, wall thicknesses and materials.
- Use appropriate tools. After a suitable machine has been selected it must be equipped with appropriate tools. Cutting inserts must be well sharpened, they must have the right geometry and the coating must match with the workpiece material.

The cutting speed of the PROTEM bevelling machines of the types US25CH and US40 for tubes as well as of the bank for elbows varies between approximately 10 and 15 m/min. It is recommended to use cutting tools made of HSS or inserts of similar material.

Tools made of HSS (8 % cobalt) are manufactured from solid block material. Used, dull tools can be re-sharpened.

HSS inserts are available with different coatings (TiN, TiALN or TiSiN). Due to these coatings an extended service life can be obtained and chips are prevented from adhering to the cutting tool. Inserts usually come with two cutting edges.

Fig. 13 - Protem bevelling machine US25CH with insert holders at 30° and at 90°

Fig. 14 - To obtain the required thickness of the lip the position of the particular insert holder must be adjusted

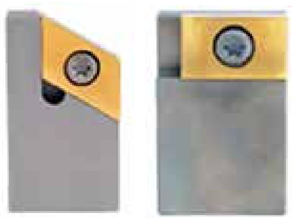


Fig. 15 - Insert holders for chamfering and trimming

Fig. 16 - Reliable fixing between the tool holders and the insert holders is guaranteed by wedges

- Carry out the adjustments thoroughly. Precisely adjusted tools result in well-machined tube ends and weld preparations which remain within the limits of tolerances. The use of insert holders is recommended, so the proper positions of the chamfering, facing and trimming tools are not altered. The inserts can be changed without touching the tool holder, their original adjustments remain preserved. The tool holders of Protem bevelling machines are designed for 4 cutting tools / insert holders to be mounted simultaneously.
- Control the cutting speed. Properly set cutting speeds are very important to obtain a good quality of weld preparation.

  The appropriate choice of the cutting speed depends on:

  - the base material of the workpiece
  - the cut depth
  - the geometry of the groove
  - etc.

When machining stainless steel, the cutting speed of the PROTEM bevelling machines of the types US25CH and US40 for tubes as well as of the bank for elbows should be set to approximately 8 till 10 m/min whereas mild steel requires cutting speeds of approximately 9 to 15 m/min.

If equipped with an electric drive, the cutting speed of the PROTEM bevelling machines of the types US25CH and US40 for tubes as well as of the bank for elbows can be adjusted by means of a speed regulator. Depending on the base material to be bevelled, the diameter of the tube and the cut depth the operator can adapt the speed of the machine.

Fig. 17 - Surrounded by a red circle: Speed regulator of a Protem bevelling machine US40 with electric drive

Fig. 18 - Surrounded by a red circle: Speed regulator of a Protem bevelling machine US40 with pneumatic drive

To set the speed of the PROTEM bevelling machines with pneumatic drive the operator can regulate the air flow at the entrance to the motor (pneumatic valve). The rotation speed must be adjusted with respect to the diameter of the tube, its wall thickness, the hardness of the base material and the geometry of the groove.

- Example of rotation speed for machining a chamfer and lip on a tube 60.3 mm x 5 mm made of mild steel, with an electrically driven Protem bevelling machine US25CH: approximately 50 to 60 tr/min
- Example of rotation speed for machining a chamfer and lip on a tube 114.3 mm x 8 mm made of mild steel, with an electrically driven Protem bevelling machine US40: approximately 25 to 80 tr/min
- If pneumatically driven machines are used, abnormal noise and vibrations generated by the machining operation may indicate that the rotational speed or the progression needs to be modified
- The colour and shape of the chips can also be used as indicators. The recommended thickness of the chips is between 0.1 and 0.2 mm. If the chips seem to be torn off, this may indicate that the advance speed should be reduced or that the tool has become dull and must be changed. Blue coloured chips are produced if the machining speed is too high.The use of carbon tool tips allows very high machining speeds. In this case, the occurrence of blue coloured chips is normal (the Protem machines of the type PFM, BB, CTA, TNO, and OHSB are designed for high speed machining).
- Use adequate lubrication. Appropriate lubrication helps in carrying out perfect machining, resulting in high quality weld preparations. The lubricant prevents the cutting tools from becoming dull, ensures a good surface finish and absorbs the released heat.

10. Welding of the root pass

In conjunction with the design of the preparation, the root pass guarantees the success of the proposed method of welding tubes and elbows together.

As an exception, the root pass may be executed with pulsed welding current of 100/ 500 ms with inverted wire pulsation. In order to generate a mechanical impact of the wire on the pool of molten metal during the low time period, a very high value for the wire speed is set (just as a manual welder might push the weld pool by means of his rod, when joining workpieces with a preparation with gap).

As this method is considered an exception, the described parameters of inverted wire feeding should not be used for other types of passes, where poor of molten metal during the time period of cooling down may cause porosity.

10.1. Welding conditions - Functions and axis conditions according to the type

Nuance		Dimensions (mm)	WPS	Pass	Curant
Stainless steel	DUPLEX	88.9 x 3.3	89X3.3CM3	Root	Pulsed
	type 304 L	76.3 x 3.6	76x3.6CM3	Root	Pulsed
		60.3 x 5.5	60X5.5CM2	Root	Pulsed
		88.9 x 5.5	89X5.5-JV	Root	Pulsed
		168.3 x 7.11	168X7.1-JV	Root	Pulsed
Unalloyed steel		168.3 x 8.8	168X8.8-JV	Root	Pulsed
		168.3 x 13	168X13-JV	Root	Pulsed

10.2. Recommendations – Welding parameters according to the type of pass

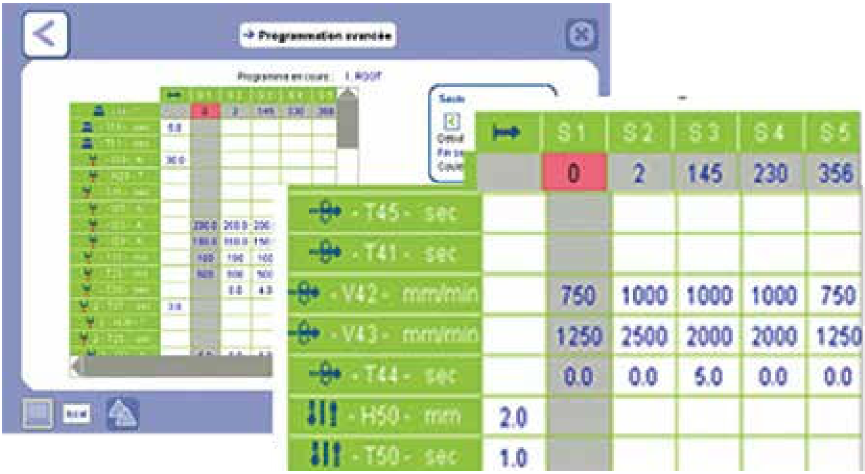
Nuance		Dimensions (mm)	WPS	Pass	Frequency (ms)		I (A)
					Th/ T22	Tb/ T23	Ih/ I22
Stainless steel	DUPLEX	88.9 x 3.3	89X3.3CM3	Root	100	500	80
	type 304 L	76.3 x 3.6	76x3.6CM3	Root	100	500	105
		60.3 x 5.5	60X5.5CM2	Root	100	500	130
		88.9 x 5.5	89X5.5-JV	Root	100	500	120/ 100
		168.3 x 7.11	168X7.1-JV	Root	100	500	145/ 152
Unalloyed steel		168.3 x 8.8	168X8.8-JV	Root	100	500	195/ 180
		168.3 x 13	168X13-JV	Root	100	500	200

of pass

Rotation	Wire	Hot Wire	AVC	Oscillation	Cycle start
Unpulsed	Pulsed	-	Low	-	3h
Unpulsed	Pulsed	-	Low	-	3h
Unpulsed	Pulsed	-	Low	-	3h
Unpulsed	Pulsed	-	Low	-	3h
Unpulsed	Pulsed	Pulsed	Low	-	3h
Unpulsed	Pulsed	Pulsed	Low	-	3h
Unpulsed	Pulsed	Pulsed	Low	-	3h

Axis1	Welding speed (mm/min)	Wire speed (mm/min)		I Hot Wire (A) - Axis 2		Oscillation			Voltage (V)	
Ib/ I23	V32	Vfh/ V42	Vfb/ V43	Ifh/ I22	Ifb/ I23	LB (mm)/ A62	VB (mm/min)/ V60	Tb(s)/ T62-63	Uh/ H51	Ub/ H53
55	50	600	600							8.0
68	50	400/ 0	750/ 900							7.4
85	50	400	1150							7.4
72/75	50	400	900/ 1200							7.4
80/85	60	600	1800/ 1200	5	30/ 40				8.6	
145/ 130	70	1000	2000/ 2500	5	50				10	
160/ 145	70	1000	2500/ 2000	5	30/ 60				9,4/ 10.2	

Together with the inversion of the values of high and low speed wire feeding, the pulse frequency of wire pulsing allows for the wire to be pushed mechanically into the pool of molten metal. The convex shape of the root pass is proportional to the low speed value of wire feeding.



The detail of the root program for the tube with a diameter of 168.3 x 13 mm indicates that in the first sector S2 (between 0° and 145°, i.e. approximately between 3h and 8h if rotating clockwise) the wire feeding speed V_{fb} is used to push the root and avoid concavity.

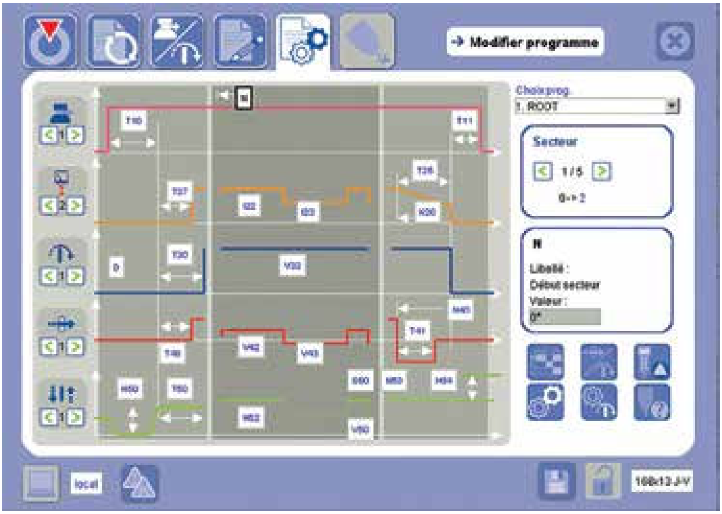
However, a possible meltdown in the welding upwards and plate positions is limited by a reduced wire feeding speed V_{fb}.

In accordance with the acceptance criteria or particular specifications of the customer the form of the bead can be modified by reducing the wire speed during the period of low welding current.

Fig. 19 - Root profile of a tube with a diameter of 168.3 mm at 6h (overhead position; welded without backing gas)

Note: the geometry of most of the internal profiles is intentionally quite pronounced, as it can be very easily diminished around the overhead position.

10.3. Typical synoptic of a root pass



The effect of mechanical pushing can be obtained if the value V43 exceeds the value V42.

10.4. Conditions for successful welding of the root pass

- It is essential to adapt the profile of the groove to the material to be welded (choice of T while keeping L and the opening angle in accordance with the wall thickness).
- Pulsing of the welding current should be of the type 100/500 ms
- Instead of the welding current pulsing, the wire speeds are inverted (fast wire feeding during the low welding current intensity period).
- The AVC regulation should be active during the low welding current intensity period.
- The inside profile of the hot pass can be modified by changing of wire speed during the low welding current intensity period.
- The welding speed remains low (approximately 50 mm/min)

- The parameters of inverted wire feeding should not be used for other types of passes, where poor degassing of the pool of molten metal during the time period of cooling down may cause porosity
- Possible application of hot wire TIG welding in case of more important wall thicknesses
- In the case of pronounced misalignment of the workpieces a small offset of the electrode to the tube side can solve the problem
- Recommended start position at 3h to weld the first quarter of the circumference as cold as possible, thus the occurrence of concavity in the overhead position can be limited.

10.5. Pictorial representation of tube/elbow assemblies - root pass

Tube Ø 60.3 x 5.5 mm, stainless steel 304 L

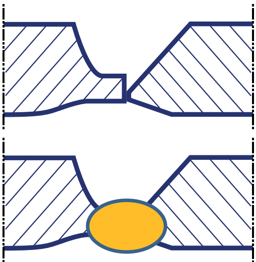
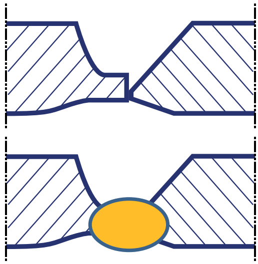
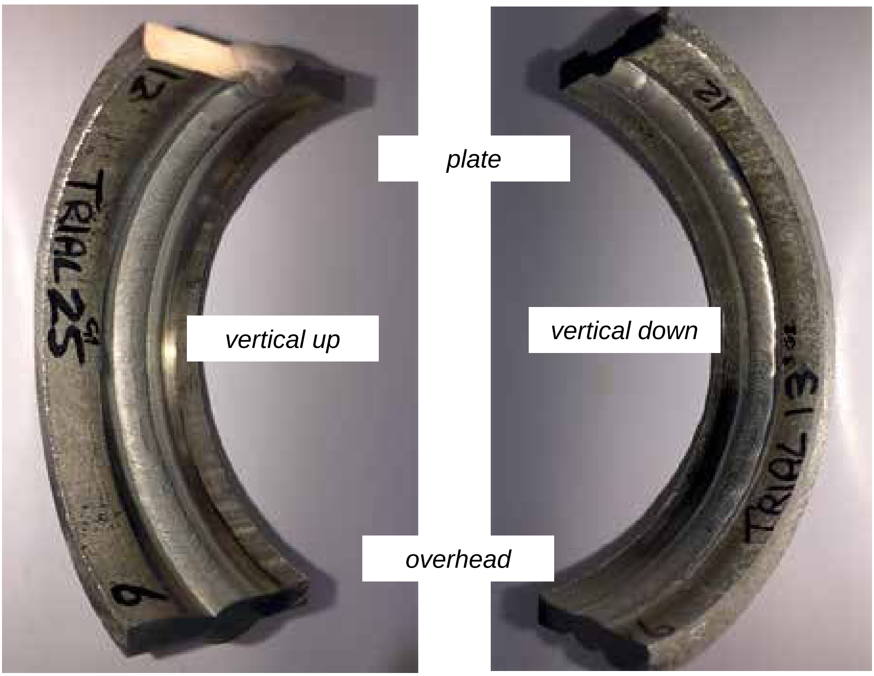


Fig. 20 - Weld bead in flat position (left side) and in overhead position (right side)

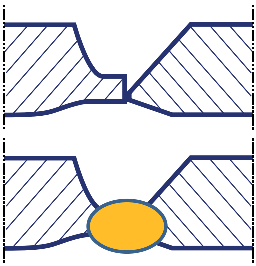
Fig. 21 - Weld bead in vertical up position (left side) and in vertical down position (right side)

Tube Ø 76 x 3.6 mm, stainless steel 304 L





Tube Ø 88.9 x 3.3 mm, stainless steel Duplex



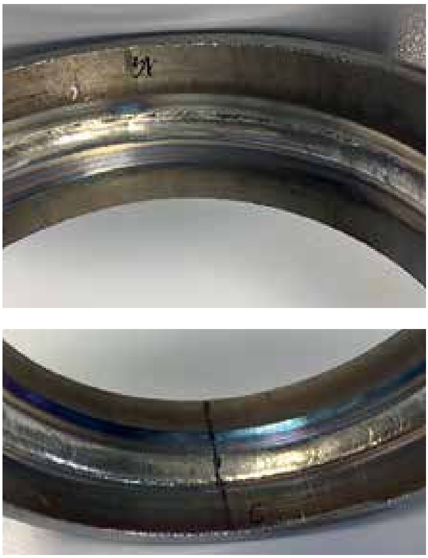
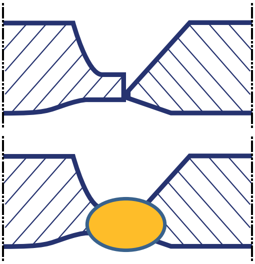


Fig. 22 - Weld bead in plate position (on top) and in overhead position (bottom)

Fig. 23 - Weld bead in vertical up position (left side) and in vertical down position (right side)

__Tube Ø 168.3 x 13 mm, unalloyed steel__



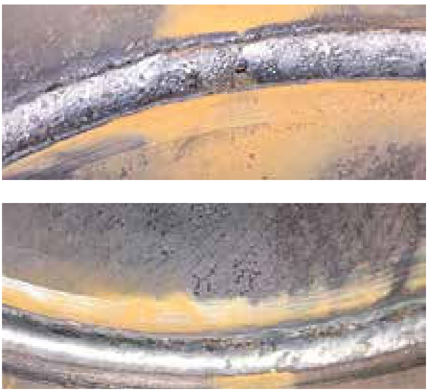
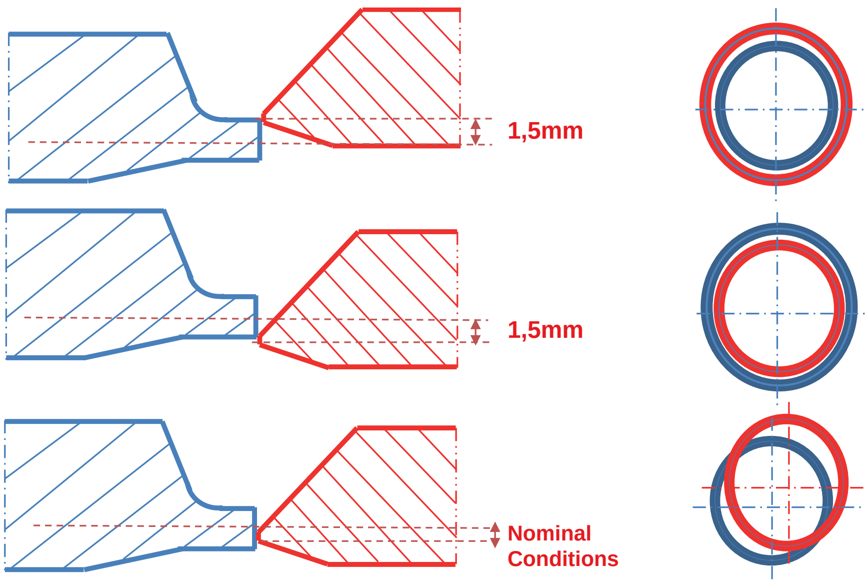


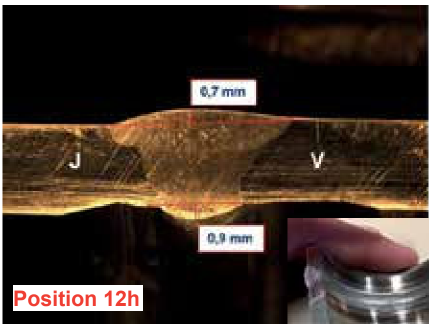
Fig. 24 - Weld bead in plate position (on top) and in overhead position (bottom)

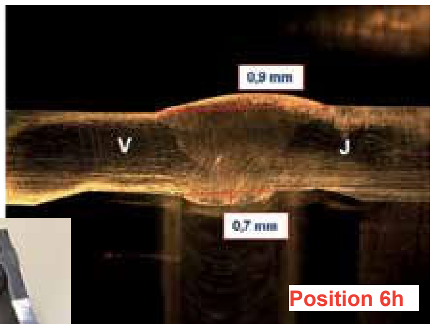
Fig. 25 - Weld bead in vertical up position (left side) and in vertical down position (right side)

10.6. Possibilities of WPS adaption to compensate misalignment

The alignment limits, which must be respected in order to apply the proposed WPS, have been specified during the welding tests. The first two tests allow for approaching the position, validating the alignments.







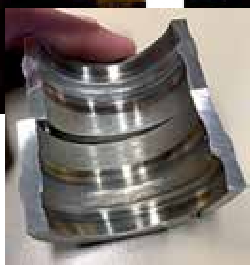


Fig. 26 - Result of the optimisation of the WPS 60X5,5CM2 intended for a mixed preparation assembly with a tube 60.3 X 5.5 mm made of stainless steel 304L

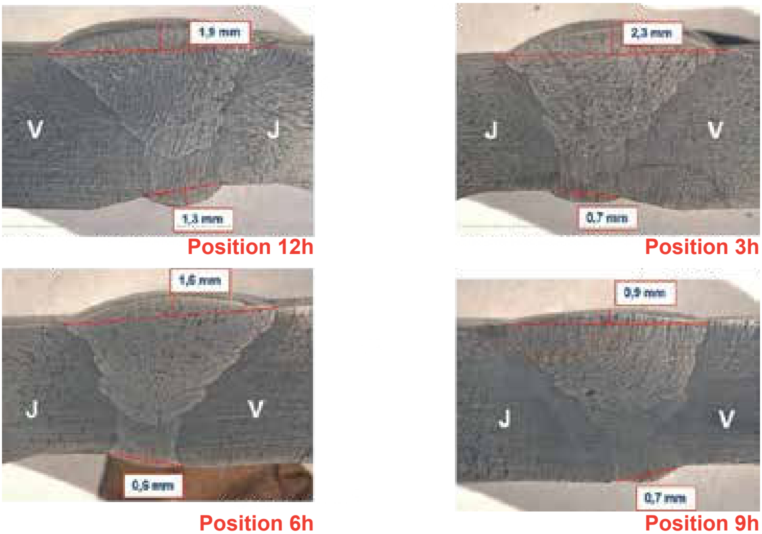


Fig. 27 - Result of the optimization of the WPS 168X13-JV intended for a mixed preparation assembly with a 168.3 mm tube made of unalloyed steel

11. Welding of the hot pass

Generally, the hot pass is a delicate orbital welding operation because any re-penetration, even if occurring only locally, can destroy the inside profile (meltdown, local concavity or undercut at the edges of the welding bead of the root pass).

In case of mixed J/V-assemblies the ½ V increases the heat dissipation considerably so the realization of the weld becomes easier to be executed. Attention is needed about remelting of the edges at the side of the J-preparation, the profile of the weld bead has to be regenerated to enable the following realization of filler passes.

The technical approach remains the same for all applications, only the variables have to be adapted to the differing dimensions and materials.

11.1. Welding conditions - Functions and axis conditions according to the type

Nuance		Dimensions (mm)	WPS	Pass	Curant
Stainless steel	DUPLEX	88.9 x 3.3	89X3.3CM3	Hot pass	Pulsed
	type 304 L	76.3 x 3.6	76x3.6CM3	Hot pass	Pulsed
		60.3 x 5.5	60X5.5CM2	Hot pass	Pulsed
		88.9 x 5.5	89X5.5-JV	Hot pass	Pulsed
		168.3 x 7.11	168X7.1-JV	Hot pass	Pulsed
Unalloyed steel		168.3 x 8.8	168X8.8-JV	Hot pass	Pulsed
		168.3 x 13	168X13-JV	Hot pass	Pulsed

11.2. Recommendations – Welding parameters according to the type of pass

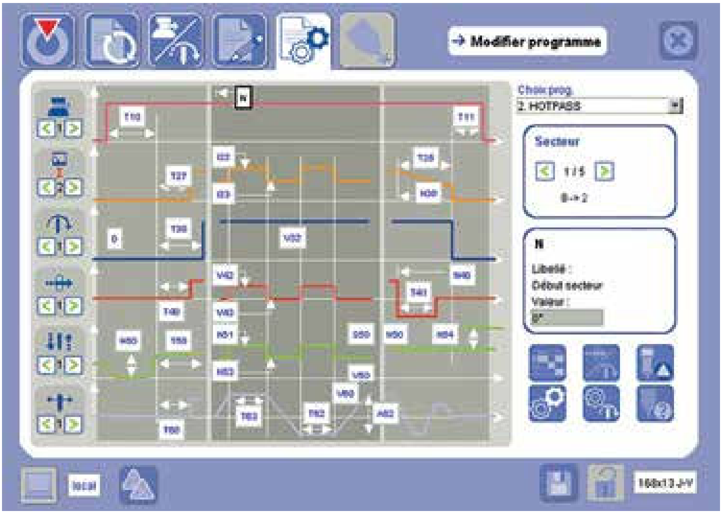
Nuance		Dimensions (mm)	WPS	Pass	Frequency (ms)		I (A Axis
					Th/ T22	Tb/ T23	Ih/ I22
Stainless steel	DUPLEX	88.9 x 3.3	89X3.3CM3	Hot pass	100	100	80
	type 304 L	76.3 x 3.6	76x3.6CM3	Hot pass	100	100	92
		60.3 x 5.5	60X5.5CM2	Hot pass	100	100	100
		88.9 x 5.5	89X5.5-JV	Hot pass	100	100	100
		168.3 x 7.11	168X7.1-JV	Hot pass	100	100	220
Unalloyed steel		168.3 x 8.8	168X8.8-JV	Hot pass	100	100	250
		168.3 x 13	168X13-JV	Hot pass	100	100	250

of pass

Rotation	Wire	Hot Wire	AVC	Oscillation	Cycle start
Unpulsed	Pulsed	-	Hight/Low	Synchro 2 sides - traverse unpulsed	1h
Unpulsed	Pulsed	-	Hight/Low	Synchro 2 sides - traverse unpulsed	1h
Unpulsed	Pulsed	-	Hight/Low	Synchro 2 sides - traverse unpulsed	1h
Unpulsed	Pulsed	-	Hight/Low	Synchro 2 sides - traverse unpulsed	1h
Unpulsed	Pulsed	Pulsed	Hight/Low	Synchro 2 sides - traverse unpulsed	1h
Unpulsed	Pulsed	Pulsed	Hight/Low	Synchro 2 sides - traverse unpulsed	1h
Unpulsed	Pulsed	Pulsed	Hight/Low	Synchro 2 sides - traverse unpulsed	1h

) s1	Welding speed (mm/min)	Wire speed (mm/min)		I Hot Wire (A) - Axis 2		Oscillation			Voltage (V)	
Ib/ I23	V32	Vfh/ V42	Vfb/ V43	Ifh/ I22	Ifb/ I23	LB (mm)/ A62	VB (mm/min)/ V60	Tb(s)/ T62-63	Uh/ H51	Ub/ H53
60	60	600	600			5.5	550	0.4	8.8	8.4
62	40/50	1500/ 1000	400/ 900			4.4	650	0.5	8.8	8.0
70/80	50	900	400			5.8	550	0.4	8.8	8.4
70/80	50	900	400			5.8	550	0.4	8.8	8.4
90	75	2800/ 3000	1800	40	30	7.2	700	0.4	10.4	8.8
130	80	3500	2500	80	70	7.2	700	0.3	10.2	8.6
140	80	3500	2500	65/ 40	65	6.0	700	0.3	9.8	8.5

11.3. Typical synoptic of a hot pass



As the synoptic shows, most of the axes except the rotation are working in the pulsed mode,what is of importance is the synchronisation between welding current and oscillation. It is, therefore, the delay on the edge of the welding groove that determines the high current; the amplitude and the oscillation speed set the pulse time low. .

11.4. Conditions for successful welding of the hot pass

- Generally, root passes with acceptable profile are characterised by insufficient wetting between the welding bead and the walls. In these cases the pulsed welding current has to be synchronized with the oscillation, so the melting of the sides can be reinforced
- The wire feeding speed at the sides must be set low enough to allow the arc sufficient melting of the walls
- The synchronisation of the welding current intensity with the oscillation at the sides ensures sufficient penetration of the root pass. The length of the period of suspension time at the sides should be set to values between 0.3 and 0.4 s
- The rotation speed can be relatively slow

(between 45 and 50 mm/min), so there is enough time for the melting process. Furthermore, a higher recovery rate is obtained (i.e. the distance travelled by the electrode between two pulses of the welding current at the side of the groove is quite short).

- The amplitude of the oscillation has to be set in a manner so that the electrode remains as near as possible at the walls, but a low oscillation speed when the electrode is moving from one side to the opposite one is important as well. To provide a sufficient period of time for the weld pool to cool down it is recommended that the length of time for the electrode to cross the groove should be at least longer or equal to the time period of remaining at the sides.
- If a mixed J/V-preparation is applied, there is virtually no risk of remelting at the elbow side.
- The arc voltage is not considered as an essential parameter, but attention
- should be paid to keeping the arc length short.
- To prevent the occurrence of porosity, pulsed wire feeding speed according to the welding current intensities should be applied (unpulsed wire feeding speed must be avoided).

In cases of hot wire TIG welding:

- Weld pool volumes and welding current intensity become more important, the welding speed increases from 45 to 50 mm/min at cold wire TIG welding to about 80 mm/min at hot wire TIG welding. The remaining parameters have to be increased proportionally.

12. Welding of filler passes

In case of small wall thicknesses of the workpieces the filler passes are often skipped and the weld is solely composed of a root pass, a hot pass and a cap pass.

However, for workpieces with important wall thickness the filler passes become very interesting, finally the productivity of the entire welding operation depends on their performance.

12.1. Weldingconditions-Functionsandaxisconditionsaccordingtothe

type of pass

Nuance	Dimensions (mm)	WPS	Pass	Curant
Stainless steel type 304 L	60.3 x 5.5	60X5,5CM2	Filler	Pulsed
	88.9 x 5.5	89X5.5-JV	Filler	Pulsed
	168.3 x 7.11	168X7.1-JV	Filler	Pulsed
Unalloyed steel	168.3 x 8.8	168X8.8-JV	Filler	Pulsed
	168.3 x 13	168X13-JV	Filler 1	Pulsed
			Filler 2	Pulsed
			Filler 3	Pulsed

12.2. Recommendations – Welding parameters according to the type of pass

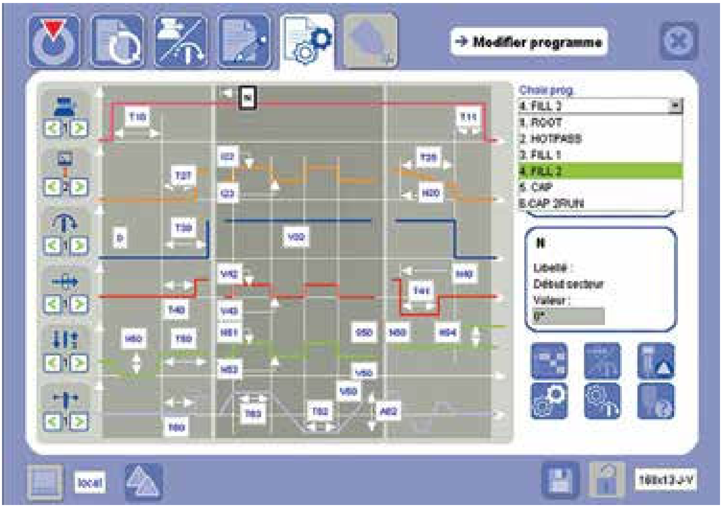
Nuance	Dimensions (mm)	WPS	Pass	Frequency (ms)		I (A)
				Th/ T22	Tb/ T23	Ih/ I22
Stainless steel type 304 L	60.3 x 5.5	60X5.5CM2	Filler	100	100	110
	88.9 x 5.5	89X5.5-JV	Filler	100	100	110
	168.3 x 7.11	168X7.1-JV	Filler	100	100	195/ 190
Unalloyed steel	168.3 x 8.8	168X8.8-JV	Filler	100	100	280
	168.3 x 13	168X13-JV	Filler 1	100	100	280
			Filler 2	100	100	300

Rotation	Wire	Hot Wire	AVC	Oscillation	Cycle start
Unpulsed	Pulsed	-	High / Low	Synchro 2 sides - traverse unpulsed	11h
Unpulsed	Pulsed	-	High / Low	Synchro 2 sides - traverse unpulsed	11h
Unpulsed	Pulsed	Pulsed	High / Low	Synchro 2 sides - traverse unpulsed	11h
Unpulsed	Pulsed	Pulsed	High / Low	Synchro 2 sides - traverse unpulsed	11h
Unpulsed	Pulsed	Pulsed	High / Low	Synchro 2 sides - traverse unpulsed	11h
Unpulsed	Pulsed	Pulsed	High / Low	Synchro 2 sides - traverse unpulsed	12h
Unpulsed	Pulsed	Pulsed	High / Low	Synchro 2 sides - traverse unpulsed	1h

Axis1	Welding speed (mm/min)	Wire speed (mm/min)		I Hot Wire (A) - Axis2		Oscillation			Voltage (V)	
Ib/ I23	V32	Vfh/ V42	Vfb/ V43	Ifh/ I22	Ifb/ I23	LB (mm)/ A62	VB (mm/min)/ V60	Tb(s)/ T62-63	Uh/ H51	Ub/ H53
88	40/45	1000/ 1200	1000/ 1200			7.0	550	0.4	9.0	8.6
88	40/45	1000/ 1200	1000/ 1200			6.0	550	0.4	9.0	8.6
115/ 100	75	4500	2500	45	45	9.4	800	0.4	10.6	9
170	85	6500	4800	105	95	10	1000	0.3	10.6	9
170	85	6000	4500	80	80	7.6	900	0.3	10.6	9.0
176	75	6000	4500	90/ 85	80	9.8	1200	0.3	11.0	8.8

12.3. Typical synoptic of a filler pass

The synoptic of a filler pass is broadly similar to that one of a hot pass, mainly the parameter values are increased to improve the productivity of welding joints of workpieces with medium and important wall thickness.



12.4. Conditions for successful welding of the filler passes

- The pulsed welding current is always synchronised with the motion of the oscillation.
- The wire feeding speed and the AVC are also set in pulsed mode (i.e two different speed levels are programmed).
- Only the rotation (linear welding speed) remains unpulsed.
- The pulse values of welding current intensity, wire feeding speed and AVC are synchronised with the time periods of oscillation when the electrode remains at the sides of the groove. Except at the very beginning of the welding cycle when the oscillation is not yet activated it is the motion of the oscillation (time period of remaining at the sides and start of crossing) which controls the movements of the other axes.
- In case of cold wire TIG welding, the welding speeds are set between 40 and 50 mm/min, whereas hot wire TIG welding can be carried out at welding speeds of about 75 to 90 mm/min (the maximum will be reached at about 120 mm/min).

- In the case of cold wire TIG welding, the pass thickness may be set between 1 and 1.5 mm, whereas hot wire TIG welding allows pass thicknesses of up to 2 mm.
- The length of the time periods of the oscillation remaining at the right and left side are virtually always set to 0.3 s (veritable reference value). Improved wetting can be obtained by increasing the pulse current intensity, the oscillation amplitude, the pulse speed of wire feeding, and adjustment of the pulse value of the AVC. In cold wire TIG welding with low rotation speed the pause time period of oscillation can be set to 0.4 s (all cold wire TIG welding applications).
- The length of time of the low pulse current intensity depends on the programmed amplitude and speed of the oscillation. The acceleration during the start at the sides and the deceleration before the arrival at the opposite side, makes a determination of the length of the cross time difficult.

The easiest way for the adjustment of the oscillation is to assume a proportionality between the set amplitude and welding speed. The following example is based on a constant ratio between oscillation amplitude and speed, so the welding speed remains virtually constant even if the width of the groove becomes increased. It should be mentioned that the effect of the ratio in question can be observed by watching the recovery rate (space between two successive waves on the surface of the weld).

Oscillation width (mm)	Oscillation speed (mm/min)
2 to 3	450 to 600
3 to 5	500 to 750
5 to 8	550 to 950
8 to 10	800 to 1000
Between 10 to 12	750 to 1200

Note:

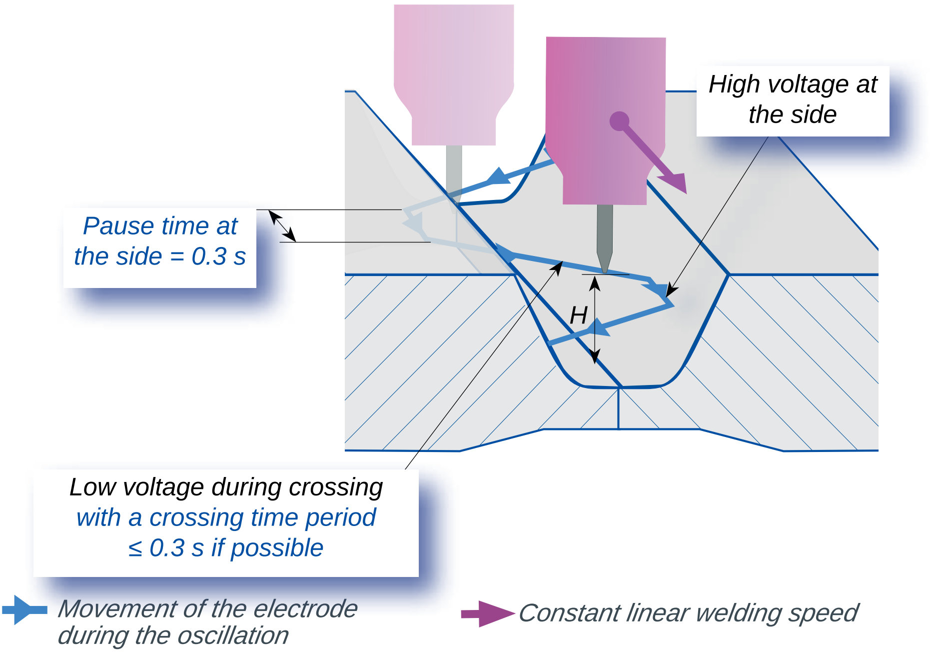
Based on oscillation pause times at the sides of the groove between 0.3 and 0.4 s at welding speeds between 50 and 100 mm/min the presented values can be used as reference.

Depending on the particular materials to be welded together the AVC adjustment can be carried out in three different manners. The difference of the arc behaviour is provoked by the disproportional relation between the welding current intensity and the reference voltage of the arc (adjustment of the AVC voltage values of current synchronisation and side voltages).

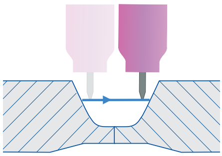
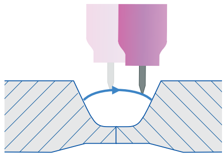
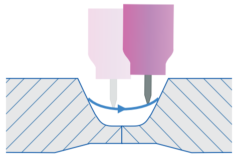
12.5. Adjustment of the AVC voltage values of current synchronisation and side voltages

During the low welding current intensity the low voltage (Tb) corresponds to the desired arc length H (about 1.5 to 2 mm) between electrode and workpiece.

During the high welding current intensity the high voltage (Th) corresponds to the desired arc length H (about 1.5 to 2 mm) between electrode and workpiece.



There are three parameter combinations which can be programmed:

Straight horizontal movement	Movement descending at the sides	Movement climbing at the sides
		
For the AVC control, **identical** values are set for the high and low arc voltage	For the AVC control, the value set for the low arc voltage is **greater** than that one set for the high voltage	For the AVC control, the value set for the low arc voltage is **smaller** than that one set for the high voltage

Note: The right choice of one of the three possibilities depends on the materials to be welded together, the gravity effects, the design of the welding preparation, and the desired wetting at the sides, which can be improved in places by exploiting the arc pressure.

13. Welding of the cap pass

Welding of the cap pass is used when there is a substantial difference between tubes with small diameters and others.

This difference (see detailed explication on the following pages) is provoked by the reduced heat dissipation of smaller workpieces, the behaviour of the weld pool can only be controlled if pulsed welding current is applied.

Cap passes are considered to be welded properly if filling has been completely finished by the preceding passes (i.e. the sides have already been entirely covered). The oscillation amplitude has to be increased and the pauses at the sides become very short without synchronisation with the welding current pulses at the sides. The important amplitude, the fast oscillation speed, the short pauses at the sides, and the absence of synchronisation between oscillation and welding current allow a more substantial weld pool without undercut in vertical upl position. Due to a pause time of 0.2 s and an optimised recovery rate a very smooth transition between workpiece surface and weld bead can be obtained.

13.1. Welding conditions - Functions and axis conditions according to the type

Nuance		Dimensions (mm)	WPS	Pass	Curant
Stainless steel	DUPLEX	88.9 x 3.3	89X3,3CM3	Cap	Pulsed
	type 304 L	76.3 x 3.6	76x3.6CM3	Cap	Pulsed
		60.3 x 5.5	60X5.5CM2	Cap	Pulsed
		88.9 x 5.5	89X5.5-JV	Cap	Pulsed
		168.3 x 7.11	168X7.1-JV	Cap	Pulsed
Unalloyed steel		168.3 x 8.8	168X8.8-JV	Cap	Unpulsed
		168.3 x 13	168X13-JV	Cap 1+2	Unpulsed

13.2. Recommendations – Welding parameters according to the type of pass

Nuance		Dimensions (mm)	WPS	Pass	Frequency (ms)		I (A)
					Th/ T22	Tb/ T23	Ih/ I22
Stainless steel	DUPLEX	88.9 x 3.3	89X3.3CM3	Cap	100	100	86
		76.3 x 3.6	76x3.6CM3	Cap	100	100	86
	type 304 L	60.3 x 5.5	60X5.5CM2	Cap			
		88.9 x 5.5	89X5.5-JV	Cap	100	100	110
		168.3 x 7.11	168X7.1-JV	Cap	100	100	110
		168.3 x 8.8	168X8.8-JV	Cap	100	100	160
Unalloyed steel		168.3 x 13	168X13-JV	Cap 1+2	100	100	2
		168.3 x 13	168X13-JV	Cap 1+2	100	100	1

of pass

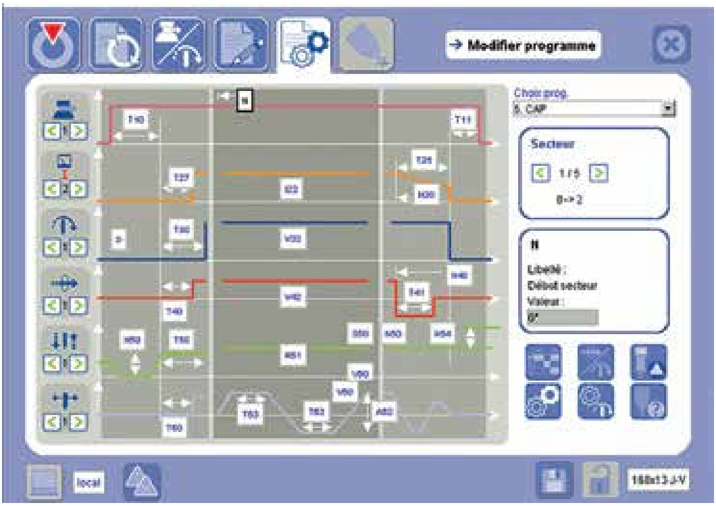
Rotation	Wire	Hot Wire	AVC	Oscillation	Cycle start
Unpulsed	Unpulsed	-	Low	Without synchro	12h
Unpulsed	Unpulsed	-	Low	Without synchro	12h
Unpulsed	Unpulsed	-	Low	Without synchro	12h
Unpulsed	Unpulsed	-	Low	Without synchro	12h
Unpulsed	Unpulsed	Unpulsed	High/Low	Without synchro	12h
Unpulsed	Unpulsed	Unpulsed	Unpulsed	Without synchro	12h
Unpulsed	Unpulsed	Unpulsed	Unpulsed	Without synchro	12h

Axis1	Welding speed (mm/min)	Wire speed (mm/min)		I Hot wire (A) - Axis 2		Oscillation			Voltage (V)	
Ib/ I23	V32	Vfh/ V42	Vfb/ V43	Ifh/ I22	Ifb/ I23	LB (mm)/ A62	VB (mm/min)/ V60	Tb(s)/ T62-63	Uh/ H51	Ub/ H53
56	50	700				7.6	600	0.2		8.4
56	50	500				7.8	600	0.2		8.2
70/ 90	40/45	700/900				9.0	600	0.2		9.0
70/ 90	40/45	500/900				8.7	600	0.2		9.0
95/ 100	65	3200		50		14.4	1000	0.2	9.8	8.8
10	80	4200/4500		80		12.5	1200	0.2	10.5	
75	80	2000		35		7.2	1200	0.2	10.0	

13.3. Typical synoptic of a cap pass

WPS 168 X 13 –JV / Hot wire TIG welding of cap passes.

When tube welding in a 5G position from workpieces of this size upwards, the application of unpulsed welding current becomes possible. The synoptic becomes simpler and the choice of unpulsed AVC parameters allows increased alignment tolerances..



13.4. Conditions for successful welding of the cap pass

- In cases of small workpiece dimensions pulsed welding current without synchronisation is applied, however, if the heat dissipation permits, then unpulsed welding current is preferrable, which generally can be used if hot wire TIG welding is possible.
- If unpulsed welding current causes problems pulse times of 50/50 or better 100/100 ms can be applied; setting of the low AVC voltage is not very efficient because of the fast oscillation speed and the very short regulation time during a pulse period.
- The rotational speed (welding speed) should be unpulsed. Generally the speed in case of cold wire TIG welding should be selected between 45 and 80 mm/min.
- The amplitude of the oscillation must be significantenough to remelt the entire surface of the preceding pass, an addition of 1 or 2 mm helps to avoid.

- The oscillation speed should be increased (600 to 800 mm in case of small dimensions and up to 1,000 or 1,200 mm/min maximum if more important wall thicknesses have to be joined).
- The cap pass should only be applied after the filling has been entirely completed. Filling and cap pass should not be mixed together, the inevitable parameters necessary for a filler pass would provoke undercut in vertical up position and convex or concave weld bead profiles at the central part.
- The pause times at the sides (right and left) are almost always set to 0.2 s. Improved wetting, augmented uniformity or increased thickness can be achieved by higher welding current intensities or lower welding speed.

If hot wire TIG welding is applied:

- Together with unpulsed wire feeding and AVC unpulsed welding current should be preferred. Due to these settings the profile can be managed even if different wall thicknesses occur (misalignment of the outside of the walls)
- In cases of medium wall thicknesses, usual settings of the oscillation amplitude vary between 8 and 10 mm. Above a wall thickness of 12 mm the possibility of welding two passes, one beside the other, should be considered. This is the classic solution for mixed J/V-preparations at diameters exceeding 10 mm (with the groove broadened by a 45° V-preparation).

13.5. Pictorial representation of tube/elbow assemblies - cap pass

In case of small wall thickness the gravity effects can be managed by use of pulsed welding current.

Smooth transition at the sides of the weld is achieved by pause times of 0.2 s.

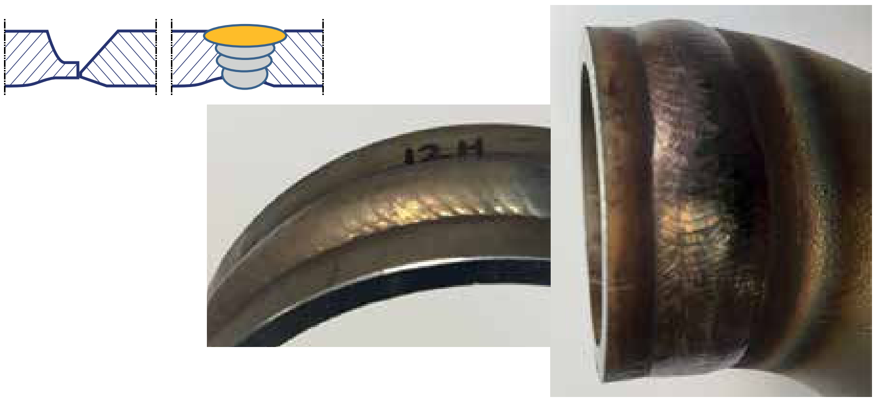


Fig. 28 - Examples of cap passes at workpiece assemblies with small wall thickness

If workpieces with more crucial wall thickness need to be welded (generally if hot wire TIG welding can be applied) the required profile is obtained by fast welding speeds, which become possible by the use of unpulsed welding current, and increased oscillation amplitudes.

The finish of broad joints is easier to accomplish if several cap passes are welded one besides the other.

Fig. 29 - Cap pass on a tube/elbow assembly with important wall thickness, hot wire TIG welding has been applied

Fig. 30 - Finish with cap passes one besides the other on a tube/elbow assembly with important wall thickness

14. Special cases of a V/V preparation

As initially proposed, a commonly applicable method of joining tube/elbow assemblies with a V-preparation on both extremities should be developed.

Such a type of preparation, which could have been applied for both manual and automatic welding operations would have been a perfect solution.

Within this project relevant tests on such complete V-preparations have been carried out.

A WPS for a V-preparation on both extremities of a tube/elbow joint with tube dimensions of 168 x 13 mm has been established successfully (the positive results are documented on the following page).

However, the results of further test welds carried out on other tubes of stainless steel confirm that the previously gained experience in the field of orbital welding is still applicable.

Thus, the exception shows that whilst it is possible to realise tube/elbow assemblies with V-preparations on both extremities, the success is not reliably guaranteed and can be hindered by small deviations of dimensions already present, material nuances of filler wire or other imperfections.

Even if some exceptions may occur, the general application of V-preparations on both extremities of tube/elbow assemblies cannot be advised, mixed J/V-preparations as proposed at the beginning of this document should be preferred.

An important portion of the welding energy is already consumed by the V-groove. Thus, sufficient penetration and furthermore a satisfying profile cannot be obtained.

The difficulties of joining V-preparations on both extremities of tube/elbow assemblies, become still more aggravated by the specific problems related to welding operations of stainless steel.

Welding of the root pass of a tube/elbow assembly made of stainless steel with dimensions of 88.9 x 5 mm has proved impossible, independently of the tried parameter combinations (low or high energy input). Furthermore, the observations have shown that no misalignment could be tolerated.

Root pass of a tube/elbow assembly with ½ V-preparation on both extremities

Dimensions 168.3 x 13 mm, unalloyed steel

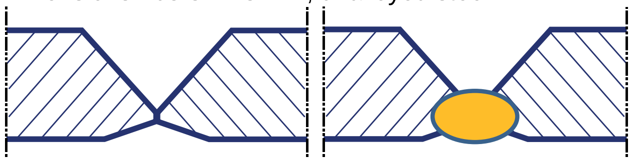


Fig. 31 - Special case of a successfully welded tube/elbow assembly with ½ V-preparation on both extremities

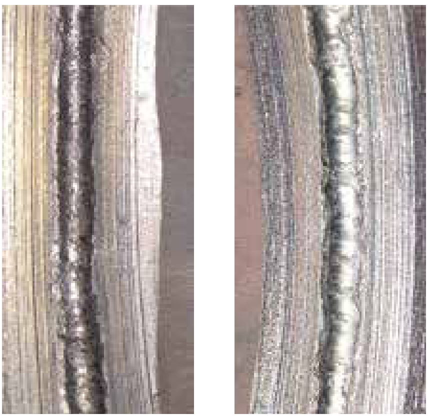


Fig. 32 - Weld bead in vertical up position (left side) and in vertical down position (right side)

Fig. 33 - Weld bead in overhead position (on top) and in flat position (bottom)

Dimensions 88.9 x 5 mm, stainless steel 304L

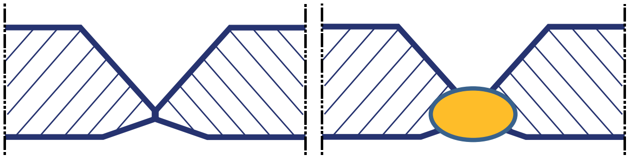


Fig. 34 - Examples of welding defects due to the problems related to welding operations of stainless steel, amplified by V-preparations on both extremities of the tube/ elbow assemblies

15. Summary and methodology

The approach of this project has been focused on the necessity of acquiring suitable knowledge and expertise, combined with the classic methods of orbital TIG welding of tube/tube assemblies in 5G position.

The questions concerning the weldability of different materials have been taken into account implicitly and the proposed designs of the extremity preparations are in line with the particular behaviour of these alloys.

As an initial step the ½ V-preparation at the elbow extremity has to be specified with respect to the materials to be welded together:

- The value of T must be fixed, within a first approach a value of L of 6.0 mm should be taken.
- To start with, an opening angle of 20° would be a good choice

The admissible diameter deviations of the elbow depend on the specified thickness of the mating surface, whereas the local misalignments could not exceed a few tenths of the inside or outside mating surface diameters.

The precision of the machining equipment for the elbows and the elbow quality itself are quite important (verification of the mating surface diameters at the elbow extremity, a roundness tolerance between 0.1 and 0.5 mm has to be respected).

As second step, a corresponding program with functions and axis conditions according to the type of pass must be selected or created. Within these conditions the acquired knowledge concerning the specific characteristics of each pass can be applied (e.g. the mentioned AVC voltage adjustment during the low pulse time for the root pass, the described proper synchronization for the filler passes, etc.).

During the last step appropriate parameter values must be specified.

The colour codes in the presented examples are used to distinguish the essential values which remain virtually unchanged (frequency of the pulsation of the root pass as the value of the high and low time of the pulsation, pause times at the sides if passes with oscillation are programmed) from the other parameters, which are also important, but which have to be adapted to each particular application.

15.1. Exemplary WPS

As explained at the beginning, the presented practice is based on a certain number of application examples.

The database of the WPS for tube/elbow assemblies with mixed welding preparation (compatible P6 HW) can be extended by complementary studies. If a new application is to be welded, a WPS from the database should be selected which satisfies the following parameters as much as possible:

- Wall thickness
- Workpiece diameter
- Material nuance.

If none of the WPS fits the envisaged application, then the one dealing with the most similar diameter should be chosen.

The following list shows the available WPS in version 00:

Nuance	Dimensions	WPS
Unalloyed steel	168.3 x 13	168X13-JV
	168.3 x 8.8	168X8.8-JV
Stainless steel type 304 L	168.3 x 7.11	168X7.1-JV
	88,9 x 5,5	89x5.5CM3
	76.3 x 3.6	76x3.6CM3
	60.3 x 5.5	60X5.5CM2
Stainless steel type Duplex	88.9 x 3.3	89X3.3CM3

15.2. Recommendations

The present document is intended to support the development of WPS for tube/elbow assemblies with mixed J/V-preparation of the extremities.

Even if this type of assembly is not yet very popular, it can be used in many cases of tube/elbow connections in 5G position, in which until now only manual welding has been considered to be applicable.

The same preparation can be used for welds in 2G position. Here identical parameters must be set for the root pass, programming of sectors is not necessary; all subsequent passes have to be welded, preferably in stringer bead technique, without oscillation.

Generally, the given parameters are valid for tubes from 1.5 to 2 inches with wall thicknesses of around 3.5 mm, which have to be welded with filler wire. These applications require an even more careful preparation than joints of tubes with diameters exceeding 4 inches and wall thicknesses of 5 to 6 mm.

In cases of assemblies with exceeding dimensions, it must first be clarified: whether the different components fit together, whether sufficient machining equipment is available, and whether the alignment conditions allow for the requirements of orbital TIG welding to be met.

Besides the proposed approach, the successful application of other parameters is possible. However, the presented practice allows for saving time when particular WPS are to be established, as only the variable parameters need to be adapted in the majority of cases.

An additional advantage of the proposed approach is that tasks which are not autonomously solvable are easy to identify, so that a competent expert can be consulted immediately.

Assemblies of parts with wall thicknesses of approximately 3.5 mm, which should be welded without filler wire have not been taken into consideration within this study, as it cannot be guaranteed that all materials with diameters up to 3.5 mm are weldable without filler wire. Successfully welded joints can be prevented by metallurgical requirements, but often the varying behaviour due to the weldability of different material nuances is the cause of failure.

Not to be concealed is the fact that the tube assembly with dimensions of 114 x 3.6 mm, which has been selected within this study, could not be welded together completely successfully with the related WPS.

In such situations it may become necessary to activate additional axes functions

and to program specific parameter values.

Before the creation of any WPS for special applications it should be taken into account as well that the quality and nuance of the used filler wire may be very important for the behaviour and result of orbital TIG welding operations.

Comparing tests of the influence of different filler wire nuances, can show whether due to their comportment, which could produce a reduced weld pool viscosity all position orbital TIG welding is hindered.

Due to such circumstances the creation of a reliable WPS can become even more delicate.

In the vast majority of cases an approach based on the proposed WPS gives the advantage of knowing the exact parameters to be modified and the ability to act within state-of-the-art criteria, thus helping to avoid the appearance of welding defects.

The recommendations concerning the groove design related to particular pulse programming of the root pass are essential for successful joining of tubes and accessories. The suggested settings of axes conditions and other parameter values as well as the proposed WPS make the fine tuning of the weld cycles easier and help to avoid classic errors, which often cause porosity in the joints.

Each specification of welding parameters must be based on the knowledge of the weld pool behaviour and the equipment characteristics, thus the best compromise between process stability and easy usage can be found.The present study will be continued, to propose further WPS concerning additional applications of tube accessory assemblies.

TABLE OF FIGURES

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