Introduction to orbital welding

Creation of welding programs

ORBITALSERVICE®

THE FUTURE OF ORBITAL WELDING

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1. Explanation of the process

What is orbital welding?

The word "orbit" comes from Latin and originally referred to the moon's orbit around the Earth. Applied to welding, orbital technology refers to the production of circular welds on a fixed component. Here, the welding torch circles the pipe or container on a fixed circular path. This process is therefore a fully mechanized forced position circular weld.
And because the components welded in this way require reproducible results of high quality, the TIG process is used almost exclusively for this purpose. The tungsten inert arc burns calmly and stably under a protective gas bell formed by the noble gas argon.

The standard for equipment development in this field is now welding with pulsed direct current with and without the addition of filler material. An orbital welding system consists of two or three components:

- Welding power source with the option of setting different welding sectors or welding planes
- Orbital welding head that guides the tungsten inert gas welding torch around the component to be welded
- Cold wire unit that feeds filler material as needed.

Welding power source

To achieve optimum results, it is advisable to use power sources that are designed specifically for the orbital welding process. Only such devices usually have the required high reproducibility of parameters. The circular weld seam is usually divided into sectors with different setting data. This takes into account, for example, the different behavior caused by gravity in constrained positions and the increasing heating of the welding environment by adjusting the welding parameters. Attempts by various component manufacturers to offer only controllers that can be connected to conventional power sources for TIG welding for price reasons have not proven successful. It has been shown that this does not allow for optimal coordination of the welding process.

Thanks to inverter technology, compact devices are now available that can be used on construction sites due to their robust design and low weight. Depending on the task and ease of use, devices with analog adjustment of the

welding program and computer-controlled systems that allow parameters to be stored. With regard to use on construction sites, care should be taken with computer-controlled systems to ensure that programs can be stored not only in battery-buffered RAM. In addition, they   on   floppy disks   or   specially   for   the   construction site use   . This is the only way to permanently save the parameter sets, which are often laborious to create.

However, in addition to data backup, it is also advisable to print out the parameters. In the course of quality assurance (ISO 9000), there is often a requirement to print out the actual parameters for high-quality tasks or at the customer's request. Some devices on the market have integrated printers, but only print out the entered setpoint value.
In addition, hardware and software must be purchased for these systems. In order to avoid false economies, it is better to opt for a high-quality analog-controlled system if the investment budget is limited. The individual parameter sets are then taken from prepared data sheets for each weld and entered manually into the system. This effort is comparatively small in relation to the bad experiences that can be had with cheap versions of computer-controlled systems. It would be a shame if this were to cast doubt on the sensible use of orbital welding technology.

Complete assembly unit, computer-controlled
(Manufacturer ORBITEC, year of manufacture 2000)
Orbital welding head

Analog power source
(manufacturer
ORBIMATIC)

At   the   orbital welding heads   are   three different   designs   : closed cassette welding heads, welding tongs, and chassis heads.

There are also a number of welding tools for special applications. Particularly noteworthy is the pipe-in-bottom welding head. This diversity is by no means a gimmick or the result of different equipment manufacturers developing their own unique designs. Each specific design has its advantages and disadvantages, so the user must decide which design best meets the requirements of their production.

Cassette welding head

The cassette welding head is filled with the shielding gas used. Since the welding process takes place in a chamber that is closed on all sides, there is no need for additional coverage of the tungsten electrode by a gas nozzle. This allows for a compact design. The pipe sections to be joined are centered and clamped using special clamping inserts, which must be changed for each pipe diameter or each modified component geometry. This effort is offset by the great advantage that the parts to be welded are held and centered on both sides in the head. Since the entire welding area is covered by shielding gas, there is hardly any risk of discoloration on the outside of the pipes. There are various designs of cassette welding heads. Care should be taken to ensure that both clamping sides can be closed separately from each other. This is the only way to ensure that the parts to be welded are centered precisely. Cassette welding heads do not allow for cold wire feeding. For this reason, they are used almost exclusively for welding pipes with a maximum wall thickness of 3.5 mm.
Additional material could then only be added using molded parts (e.g., cajon angles with collars) or insert rings.
These were originally designed for the ultra-pure gas supply in chip manufacturing. Various heads cover the diameter range from 3.18 mm to 190.5 mm.

Cassette welding heads 9 and 8 (Arc Machines Inc.)

Welding tongs

The orbital welding tongs can be continuously adjusted and clamped to different pipe dimensions within the specified diameter range. However, as they are only attached to one side of the parts to be welded, additional

fixing by centering units or tack welding is required. Compared to the cassette head, the space requirement is also greater.

With this design, mechanical or electronic arc distance control makes it possible to keep the arc at the same length even with slightly out-of-round pipes. To ensure that the welding tongs can be clamped firmly to the pipe, they should consist of a fixed clamping part and a rotation unit that is attached to it. For welding without filler material, the welding tongs are also available with a removable cold wire feed device.

Open precision welding guns (type OWH, Orbitalservice GmbH)

This type of tongs is available in 3 sizes. It covers an outer diameter range from DA 10.0 mm to DA 168.3 mm. A major advantage is the simple design with separate clamping and drive systems and the possibility of adjusting the angle of the electrode position to the pipe.

Welding head pipe in bottom

This type of welding head was developed for welding pipe-in-pipe bottoms. With these welding heads, it is possible to weld flush, recessed, and protruding pipe ends to the pipe plate.
The arc distance is controlled by a sensor or a voltage-dependent control (AVC).
Precise centering of the heads is possible by means of centering pipe spindles and mandrels. These mandrels, which serve as holding and centering devices, can also be operated pneumatically. There is also the option of feeding cold wire.
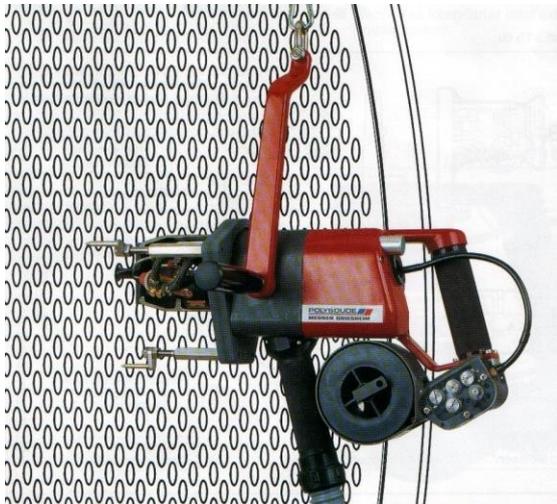
Welding head Pipe in base (type TS 60, Polysoude) Chassis head

Chassis heads are used for welding thick-walled pipes and for pipe diameters from approx. 150 mm. The chassis is clamped onto a guide unit that has been attached to the workpiece beforehand. Simple systems, rollers, chains, etc. have proven to be disadvantageous. Especially with a vertical pipe axis, precise seam guidance cannot be achieved.
Suitable guide rings must be available for each diameter. This type of head can be used for a wide range of applications, e.g., mounted on a rail for longitudinal seam welding, coating, etc.
As a rule, these heads have arc voltage control (AVC), motorized cross slides for torch oscillation, integrated wire feed, etc.
Various parameters can synchronized synchronized with with e.g. wire speed to current pulse, current pulse to oscillation, etc.
A modular system design enables the attachment of two-sided wire feed, video surveillance system, and TIG hot wire welding.
TIG hot wire welding enables increased performance, especially with thick-walled pipes.

An additional power source is connected to the welding wire. This heats up the wire by resistance heating before it enters the weld pool. This allows me to save a number of layers by increasing the amount of weld metal deposited, and the higher welding speeds result in time savings of up to 2/3 compared to cold wire welding.
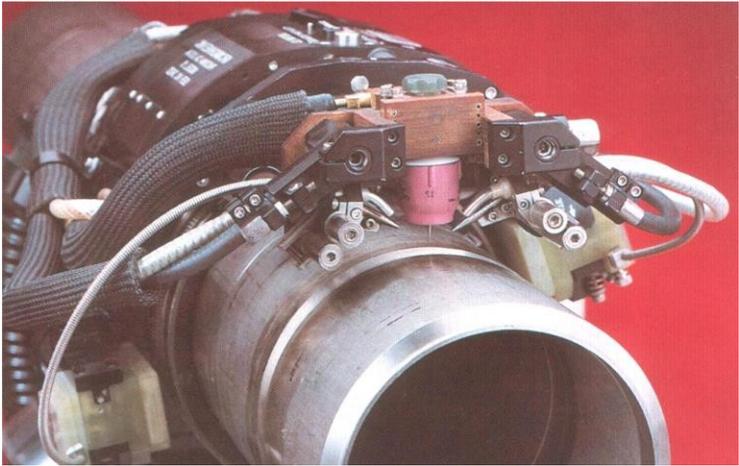

Welding carriage (Type 15, ARC MACHINES

INC) Cold wire feed device

For numerous applications, filler material is required for TIG orbital welding. A wire feed unit mounted directly on the welding head has proven to be advantageous, as the short feed path allows the wire feed to be synchronized with the pulsating welding current.

Cold wire is mostly used when welding ferritic steels. Cold wire is good for bridging welding gaps and controlling heat input. When orbital welding with pulsed direct current, it is possible, for example, to add material only during the high-current phase.
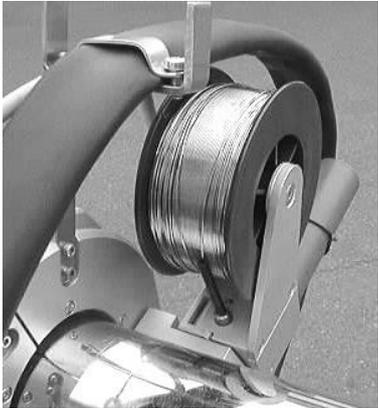
Cold wire device mounted on tongs

CWF-5 cold wire device (Orbitalservice)

2. Positioning accuracy

Before deciding on a particular orbital welding system, the question of the tolerances it can compensate for is often asked. However, since all systems available on the market ultimately work on the same principle of the rotating TIG welding torch, this type of question is not correct. It is much more important to consider the conditions that must be met for the systems. Before deciding on orbital welding technology, users must therefore ask themselves whether they are prepared to provide the precision and cleanliness required for this technology when preparing their components.

The often-cited "suitability for construction sites" therefore depends less on the system and more on the type of construction site and, above all, on the personnel assigned to the welding work. The fact that orbital welding is possible on construction sites with well-trained operating personnel who are willing to work with care is evident from the large number of systems used for such purposes.

And this is by no means limited to a few welds that could not be welded in the workshop. For example, around a thousand connections on the cooling pipes in the Amberg ice rink were welded on site with great success.

Orbital welding has become indispensable in the supply of high-purity media to the semiconductor industry.

The quality of the pipes used plays an important role in achieving a satisfactory result. Pipe manufacturers are primarily responsible for supplying pipes with greater dimensional accuracy. It may also be necessary to instruct your own purchasers to specify more precise tolerances for dimensions. The tolerance of 10% of the nominal wall thickness permitted for pipes in the standards is too high for reproducible welding results with wall thicknesses greater than 2 mm. Good results are achieved with tolerances of no more than 0.2 mm, regardless of the wall thickness. With such pipes, it is then entirely possible to weld a well-formed root with a butt joint without an air gap for wall thicknesses up to 4 mm. Here, too, careful seam preparation and precise positioning are essential.

The weld depends on precise seam preparation, taking into account the semi-finished product tolerances.

For pipes with greater wall thicknesses and thus greater permissible tolerances, it is sometimes possible to achieve good results by creating a program (step mode).

3. Seam preparation

Joint preparation in orbital welding is basically divided into two main groups: - I-joint
- Contour milling

The most common joint shape used for mechanized TIG welding is the I-joint, as this not only improves the quality of the weld seam but also saves a considerable amount of time compared to manual welding in most cases. This means that only the ends of the pipes are face-milled and the edges on the inside of the pipe are slightly deburred if necessary. For pipe diameters of 30 mm or more, it may be sufficient to use special pipe saws, which completely encircle the pipe using a special guide device. It is important to maintain a precise pipe joint angle of 90° to the pipe axis. For this reason, band saw or hacksaw cuts (and especially hand saw cuts!) are unsuitable for precise joint preparation. Butt joints can be used without hesitation for pipe wall thicknesses up to 3 mm. For wall thicknesses above 3 to max. 4.5 mm, a satisfactory result depends on the pipe quality and the dimensional accuracy of the wall thicknesses.
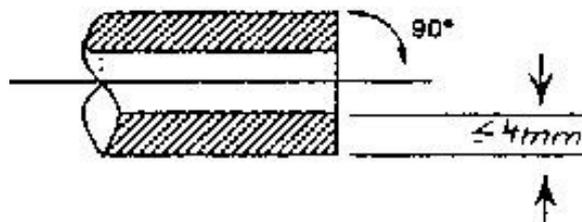

In order to achieve a small weld pool that can be controlled in all welding positions for thicker-walled pipes, it is necessary to reduce the pipe wall thickness in the seam area. This is done using pipe edge milling cutters, which form the desired pipe edge contour depending on the milling tool used. In many cases, the tulip contour has proven to be optimal in practice. First, a web approximately 1.5 mm wide and 1.5 mm high is machined on both sides of the pipe. This is followed by a radius of approximately 1.5 mm and a flank with an angle of inclination between 8 and 20°.
The V-seam shape without a web, which is familiar from manual welding, is not recommended, as the opening angle in the root area is too small due to the elimination of the air gap that is common in orbital welding. This would melt away too much base material from the seam flanks, resulting in an undesirable enlargement of the molten pool in the root.

Other seam preparations must be carried out for welds on thick-walled pipes.
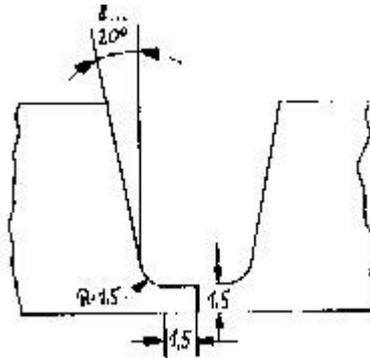

Geometric example of a tulip seam

For TIG narrow gap welding, a modified tulip seam is prepared. Depending on the pipe wall thickness, the flank angles are between 1° and 5°. This angle depends on the shrinkage of the material to be welded, so that jamming of the TIG torch is avoided. The narrow gap welding technique and the associated reduction in seam volume compensate for the disadvantage of inefficiency when welding thick-walled pipes. In individual cases, this can result in significant qualitative advantages, e.g., reduction of tensile stresses and sensitization of the austenitic base material.
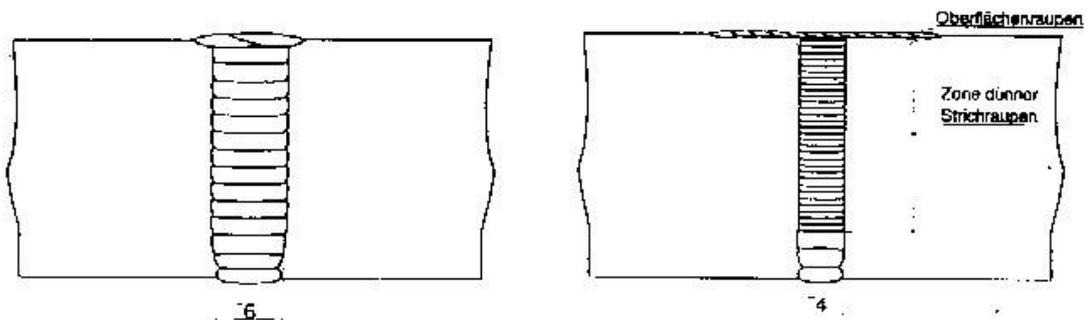
Narrow gap weld

Optimized narrow gap weld with bead grooves
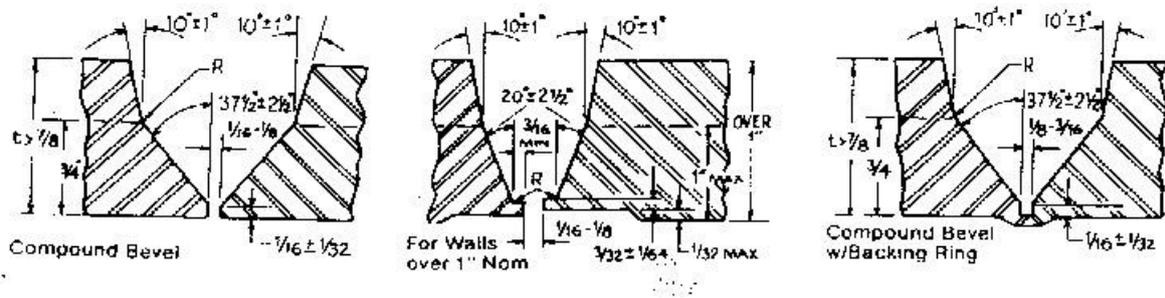
Various examples of seam preparation in the thick-walled area, with and without insert rings.

Seam preparation equipment

The required tight tolerances cannot be achieved during joint preparation with hand-held grinding machines. Therefore, centering pipe edge milling cutters are used to machine the joint flanks on the outside or inside of the pipe.
These are available in various designs—electrically, hydraulically, or pneumatically driven—not only for the workshop, but also for the precise adjustment of the joining parts on the construction site.

Pipe saw type GF 4 (Orbitalum Tools GmbH - formerly G+F) mounted on a saw trolley with removable chip tray (Orbitalservice)

Weld-in rings and fittings with collar

When solving alloy problems in welded joints (e.g., achieving a low ferrite content or welding different materials), it is possible to work with weld-in rings. An identical or higher alloyed filler material is added via these rings.

They allow complete root fusion without sagging. The perfect joint can be verified by X-ray.

The T-shape used offers the advantage of better centering of the pipes.

It is also possible to use a cassette welding head, which was previously only possible with open welding tongs and cold wire.

The cross-section of the weld security rings is designed so that the flow is not affected and the ring edges press firmly against the inner wall of the pipe.

Of course, the use of molded parts with collars and weld-in rings must be specified in the LV.
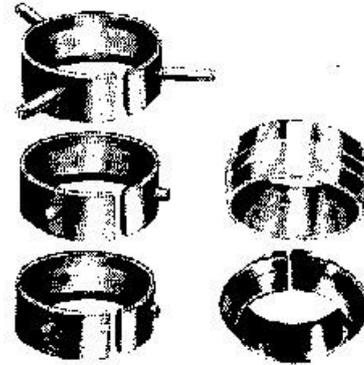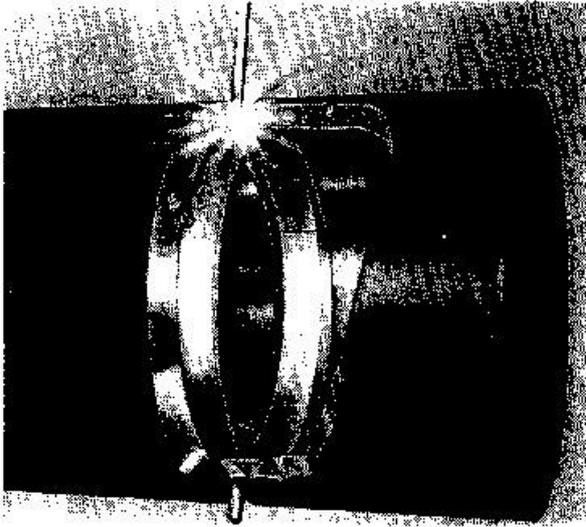
Fusible welding rings (Robvon, USA)
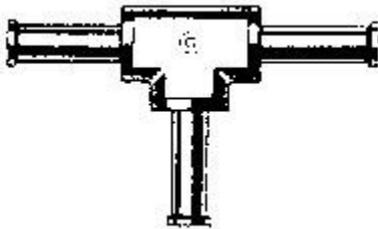
Fittings with collars were used in ultra-pure media technology, today without collars (Cajon brand)

Optimal preparation for welding in the I-joint

1. The pipe ends must be at right angles.
2. The pipe ends must be free of burrs.
3. The pipe ends may max. wall thickness tolerance of +5 % of the nominal value.
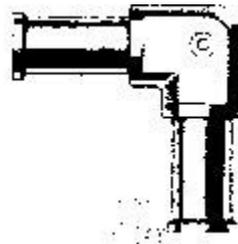4. The pipe ends must free free rust, grease, oil, paint or other surface contaminants.

Smaller dimensions (up to approx. 1") can be cut with a pipe cutter. Afterwards, they must be finished with a pipe end finishing tool.
The pipe is clamped on the outside. An off-center cutting steel circles the pipe end. Using an expander or a spindle, the steel is guided to the pipe end, where it planes the end.

4. Forming

The TIG process is primarily used to weld ferritic and austenitic steel materials. While it is essential to form the inside of the seam when manually welding austenitic steels, this is not considered necessary for ferritic steels. However, this is not the case with orbital welding. Unlike manual TIG welding, there is no air gap through which the protective gas flowing out of the gas nozzle slightly covers the weld pool from the inside, meaning that the weld pool remains completely unprotected during orbital welding. If no forming is carried out, this can lead to complaints about scale or other inclusions in the seam. In the case of oxygen-sensitive materials, it is even essential that the weld joint flanks do not oxidize before welding. Therefore, welding should be carried out as soon as possible after preparing the joint.

In order to remove air, and in particular the oxygen responsible for oxidation, from the welding area, the pipeline must be pre-flushed for a sufficient length of time before welding. The frequently asked question of how much forming gas is required for flushing is actually misguided, as this depends largely on the volume to be formed. Once the purity of the atmosphere to be formed has been achieved, the forming gas supply can theoretically even be shut off completely, as the forming gas is not consumed. In practice, however, a slight gas flow of about 2 l/min should be maintained in order to prevent oxygen from penetrating through the weld joint that is not yet closed by means of slight overpressure. The duration of forming for different pipe volumes can only be determined accurately through individual practical trials. Exact values can be obtained using commercially available oxygen analyzers, which accurately determine the residual oxygen content of the escaping forming gas and thus create consistent forming conditions. Additional devices are commonly used for protective gas supply
that reduce forming gas consumption.
They are available on the market in various sizes and are guided into the correct position by chains
or ropes. With flexible center pieces, they can also be pulled through pipe bends.

Forming gas chambers
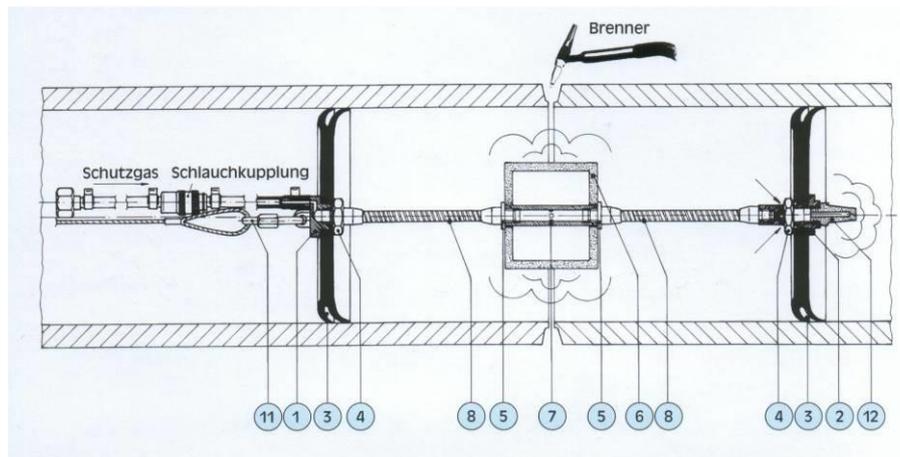
For orbital welding, it has proven particularly advantageous when welding with cassette welding heads to form with the same gas that is used for welding. Otherwise, there is a risk that the forming gas escaping from the weld joint will mix with the shielding gas of the welding head. This can significantly alter the welding results.

In the high-purity media industry, it is not common practice to "flush" with internal forming devices, press pistons, or similar. External forming devices (e.g., Swagelok fittings with Teflon cutting rings) must be used, as no particles may be introduced into the pipe.

If plastic hose lines are used for welding shielding and forming gases, considerable amounts of moisture and oxygen can be absorbed
(see diagram).
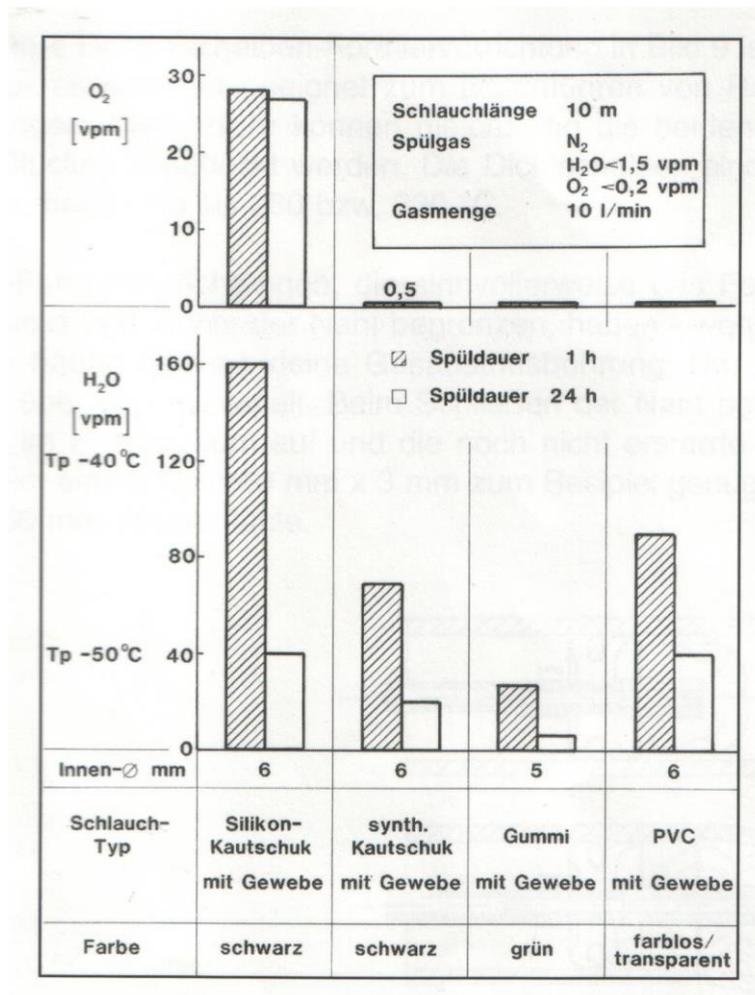
Silicone rubber has a very high permeability to H2O and O2.
The PVC hose shows particularly high moisture absorption, with the dew point only just reaching -50°C even after 24 hours of purging. With correspondingly long purging intervals, all hoses show a significant increase in the dew point above the permissible minimum of -50°C. The oxygen content in silicone rubber could also cause problems. With the metal pipe being practically completely impermeable, the moisture content of the flushing gas is reached after approx. 1 hour.

Plastic pipes should be avoided for higher welding qualities. Pre-flushing or welding the system is therefore always recommended.

Rohrlänge: 6 m
Rohr : 60,3 x 2,9 mm, CrNi–Stahl

O_2–Gehalt Luft: 21 %
Spülgas : Argon 4.8

Einströmung über quer-schnittsgleiche Sintermetall – fläche

0,4 m Plastikschlauch
30,0 m Cu– bzw. CrNi–Rohr ab Bündel

	Gasstrom l/min	Ström.geschw. m/min
○	4	1,7
●	8	3,4
□	12	5,0
■	16	6,8
▲	20	8,5
▽	30	12,8
▼	40	17,0

O_2 [vpm]

Reduzierung des Spülgradienten durch Rückvermischung
Messung 30 s nach 1 % O_2

Beginn unsichtbarer Oxidschichten

Spülzeit [s]

Influence of different forming gases

N2 and N2/H2 mixtures lead to golden yellow coatings even with very low Ti contents in the pipe material (e.g., 1.4571). These are extremely thin, firmly adhering, and wear-resistant titanium nitride layers.

Although N2 reacts chemically at temperatures above approximately 1000°C, no nitriding occurs outside the melting range. This is most likely due to the passive chromium oxide layer, which acts as a barrier.
The severe flaking under N2 can be attributed to lower surface tension.
Ar and Ar/H2 mixtures result in bright seam surfaces. Due to the high surface tension, coarser scaling occurs under 100% Ar. The light deposits next to the weld seams are condensed vapors.

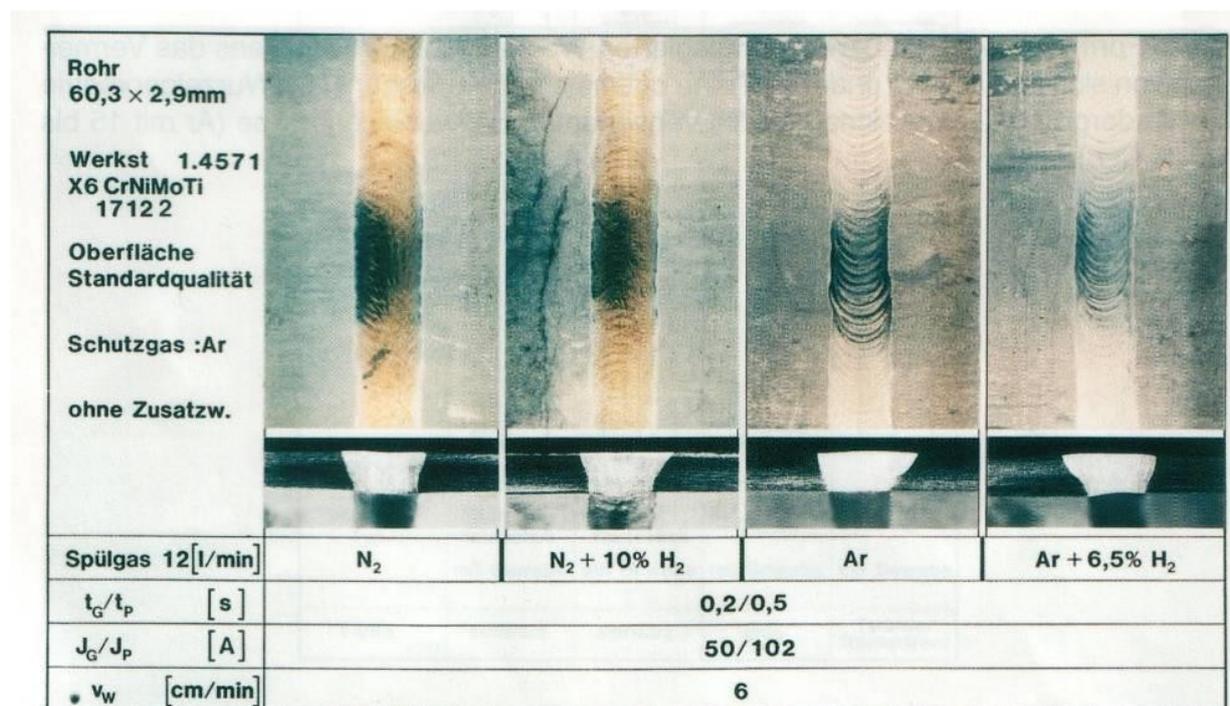| Rohr 60,3 × 2,9mm Werkst 1.4571 X6 CrNiMoTi 1712 2 Oberfläche Standardqualität Schutzgas :Ar ohne Zusatzw.				
Spülgas 12 [l/min]	N_2	N_2 + 10% H_2	Ar	Ar + 6,5% H_2
t_G/t_P [s]	0,2/0,5			
J_G/J_P [A]	50/102			
v_W [cm/min]	6			

Bild 5: Einfluß verschiedener Gase auf die Nahtwurzel

Die Gase sind in EN 439
– Gruppe R (Ar/H$_2$-Gemische)
– Gruppe I (Ar + Ar/He-Gemische) und
– Gruppe F (N$_2$ + N$_2$/H$_2$-Gemische)
genormt.

Aus sicherheitstechnischen Gründen empfiehlt das DVS-Merkblatt 0937 das Abfackeln bei H$_2$-Anteilen über 10 Vol.-%.

Um Anlauf-Farben sicher zu vermeiden, muß das Einbringen der Formiergase bis zur Abkühlung der Bauteile auf ca. 220 °C erfolgen.

Um Oxidation beim Schweißen von Rohrleitungen sicher auszuschließen, sind bestimmte Vorspülzeiten einzuhalten, die von der jeweiligen Spülmenge und der Geometrie des Bauteils abhängig sind.

Vor Beginn des Schweißens an Rohrleitungen muß vorgespült werden, um die Luft zu entfernen. Als Richtwert für das benötigte Schutzgasvolumen gilt das 2,5 – 3,0fache geometrische Rohrvolumen, gerechnet von der Einspeisung bis zur Schweißstelle. Je nach Rohrdurchmesser wird eine Durchflußmenge von ca. 5 – 12 l/min empfohlen.

Bei Titan-stabilisierten CrNi-Stählen verursachen N$_2$-haltige Gase eine Gelbfärbung der Nahtwurzel. Für stickstoffhaltige Grundwerkstoffe, z.B. Superduplexstähle, können Formiergase mit ca. 3 Vol.-% N$_2$ vorteilhaft sein, z.B. Steuerung des Ferritgehaltes.


Schweißen unter Formiergasschutz

Schutzgas	Werkstoff
Argon	alle Werkstoffe
Ar/H$_2$-Gemische	austenitische Stähle, Ni und Ni-Basis-Werkstoffe
N$_2$/H$_2$-Gemische	Stähle mit Ausnahme hochfester Feinkorn-Baustähle, austenitische Stähle (nicht Ti stabilisiert)
N$_2$ Ar/N$_2$-Gemische	austenitische CrNi-Stähle, Duplex- und Super-Duplex-Stähle

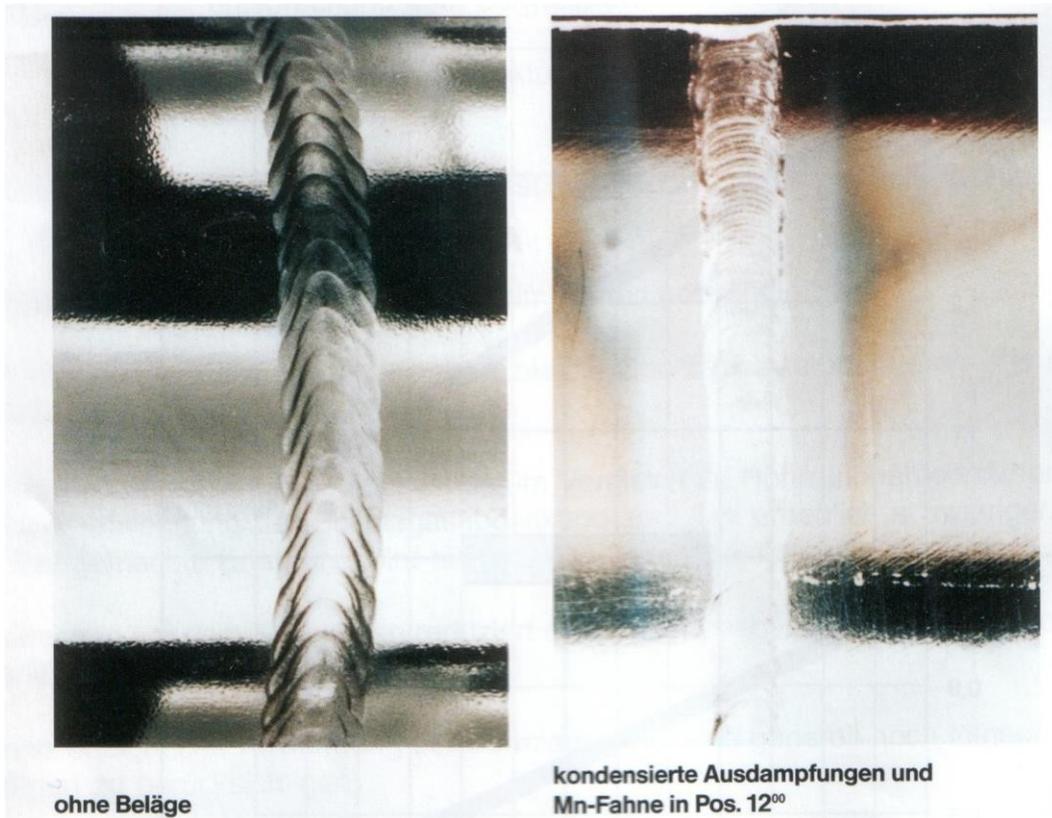Typische Gelbfärbung: Titan-stabilisierter CrNi-Stahl formiert mit Stickstoff
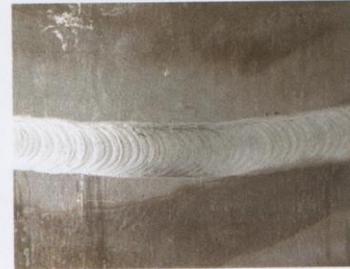
Keine Färbung: Titan-stabilisierter CrNi-Stahl formiert mit Argon/Wasserstoff

Preferably on chrome-nickel steels, deposits form next to the weld seam during the welding of pipe circumferential seams despite forming. Oxygen oxidation is not responsible for this. Rather, it is a matter of relatively early evaporating phases that condense at a certain distance from the weld seam root in order to settle there.

This often results in a finger-shaped precipitation strip up to 20 cm long. Due to its higher manganese content, it is also referred to as a manganese flag. Measurements of manganese content on the polished surface of the sample in the manganese flag have yielded a ratio of 1:33.

The heaviest coating formation usually occurs when welding over the 12 o'clock position. This is where the most favorable condensation conditions arise due to the direct contact of the rising metal vapors with the cool pipe wall.

The influence of the deposits on the corrosion resistance of the component has not yet been investigated, but the forming gas qualities have practically no influence on deposit formation.

Orbital welding training manual

ohne Beläge

kondensierte Ausdampfungen und
Mn-Fahne in Pos. 12⁰⁰

Seam produced in "stepping mode"   Visible manganese flag

If such coatings must be avoided, it is advisable to switch to other alloys. Changing the energy input during welding can also help to counteract the disruptive condensation. Otherwise, the only option is to swirl the fumes using flow torpedoes or to intercept them using an electrostatic probe.

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The main factors influencing coating formation are the poor thermal conductivity of chromium-nickel steels, the high heat input during welding, and the geometric relationship between pipe wall thickness and pipe diameter. Larger pipe diameters with thin walls are more likely to produce coating-free welds.

One option for thermally favorable heat input is the use of the step technique. Here, overlapping molten cylinders are created using a high pulse current and the longest possible base current times. The energy introduced can dissipate more effectively during the low-energy, long base current time. The pulse frequency for this is usually below 1Hz.

Another way to prevent these tarnish colors (evaporation) is to use very high quantities. In the semiconductor industry, purging gas quantities of up to 40 l/min are therefore used. It is important, of course, to allow the purging gas to escape freely "extraction" of the purge gas – avoiding pressure build-up.

Occupational safety during forming

Hydrogen-containing root protection gases form flammable, i.e., explosive, mixtures with oxygen. The ignition limit for nitrogen-hydrogen mixtures is in the range of 4% hydrogen and 5% oxygen. Under argon-hydrogen mixtures   is   the ignition limit   to even low   oxygen levels   .

In contrast to the previous standard DIN 32526, EN 439 "Shielding gases for arc welding and cutting" no longer states that root shielding gases containing more than 10% hydrogen must be flared. This statement was often misunderstood. It only referred to the mixing of hydrogen-containing root shielding gas escaping from a container with atmospheric oxygen.

However, some users of forming technology have already concluded from this that they have taken the necessary safety precautions by using hydrogen-containing root shielding gases.

Before welding, it must therefore be ensured that the mixture is non-flammable.

If the oxygen contents suitable for proper forming – approximately 100 vpm = 0.01% – are maintained, there is no risk of explosion. Oxygen contents of 0.5% already cause significant discoloration.
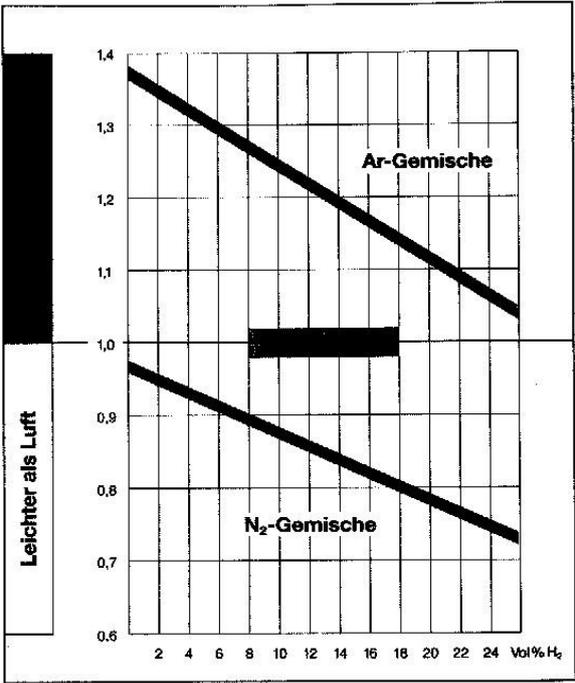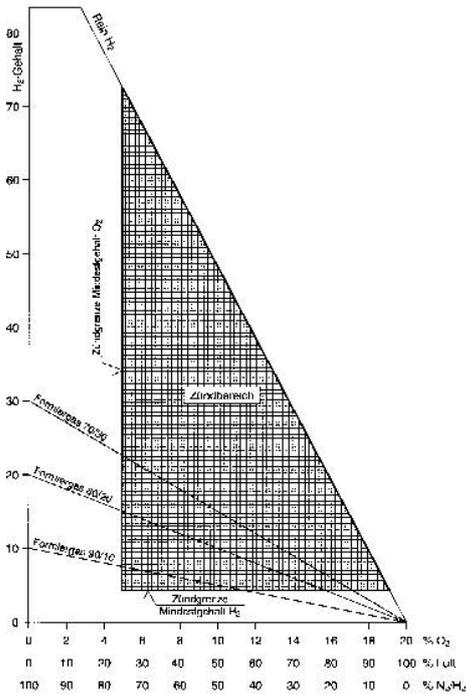
Ignition limits of H2/N2 mixtures in air

Relative density of root protection gases

Equipment for determining the residual oxygen content

It is possible to measure the residual oxygen content in the pipe before starting welding.
As mentioned above, oxide layers are no longer visible at a content of
< 30 ppm. This value is usually sufficient for welding to begin. In some areas of industry, e.g., supply lines for ultra-pure gases for semiconductor manufacturing, gases with qualities of > 6.0 are used for forming, where 30 ppm is of course not an issue. We are now talking about the ppb and ppt range. Hose lines, plugs, and silicone chambers are not sufficient for this. Forming is carried out with solid pipe coils and a metal chamber is pushed over the outside of the pipe to seal it to the outer wall of the pipe.
Zirconia cells are very accurate and also easy to maintain. These cells usually measure up to 10 ppm or 1 ppm.
Percentage cells, 0.1% or 0.01%, are not recommended. These measuring devices are intended for determining flue gases, oxygen content in food packaging, etc. If you consider that the measuring ranges end at 0.1 or 0.01%, this means 1000 ppm and 100 ppm. We only start welding at < 30 ppm. So what does such a device tell us?
You should save yourself the approx. $500 to $1000.

Residual oxygen measuring device PRO2 plus (smallest measuring range 1 ppm) and PRO2 mobile (smallest measuring range 10 ppm). The devices have interfaces for documentation.

With the latest device series from Orbitalservice GmbH, it is possible to print out a report immediately after measurement without an orbital welding machine by connecting a serial printer.
Last but not least, Bluetooth transmission of measurement data to a cell phone, multi-range power supply, update capability, integrated horn, date and time, multilingualism, and much more round off the measuring device. Administrators save themselves the annual calibration by the manufacturer and can carry this out independently on the air oxygen.

5. The tungsten electrode

The correct electrode length and geometry are very important for successful TIG orbital welding.

Electrodes with a diameter that is too large for the welding current strength lead to a reduction in arc pressure. This causes the penetration depth to decrease to an unacceptable level. The more pointed the electrode is ground, the greater the arc pressure generated. However, the tungsten electrode cannot be loaded arbitrarily.

Therefore, the guideline values for diameter listed in the table have proven to be helpful for the different current ranges.

Current in A	Diameter in mm
below 20	1.0
20 - 100	1.6
100-200	2.4
200 - 300	3.2
300 - 400	3.2

Only machine-manufactured electrodes with correct dimensions provide reproducible welding results.

The manufacturing process for tungsten electrodes results in a molecular structure that is formed in the longitudinal direction.

The defined roughness depth of the electrode tip is important. Electrodes that are manufactured transversely and have a high roughness depth have a negative effect on the electrode tip due to the notch effect.

It is well established that electrons flow in greater density at the surface of an electrical conductor. The tungsten electrode is the decisive carrier in a welding process.

If the roughness of the electrode is too high, the electrical energy jumps over the grooves. The arc starts in front of the tip, is widely scattered, and flickers. The electrode becomes excessively heated and burns out prematurely. The service life is significantly reduced. With a low roughness depth, electrons are guided evenly and smoothly to the outer tip of the electrode. The arc is narrow, bell-shaped, concentrated, and stable. High-frequency ignition is linear and precise. The electrode is subjected to significantly less thermal stress and therefore has a very long service life.

Tungsten electrodes are subject to high demands in terms of ignition capability, service life, arc stability, and burn-off tendency.

Thoriated electrodes can be subjected to higher welding currents than pure tungsten electrodes.

This results in a more stable arc, better penetration, and a longer service life.
Since thorium is a radioactive element, non-radioactive substitutes are used. However, the only danger to the welder arises from grinding the thoriated tungsten electrode.
The oxides of the elements cerium and lanthanum have proven particularly effective.
We recommend WC 20 (gray). Welding can also be carried out
with other tungsten/rare earth electrodes.
In the foreseeable future, thoriated electrodes will soon disappear from the German market for environmental reasons.
The new thorium-free electrodes are an equivalent replacement.
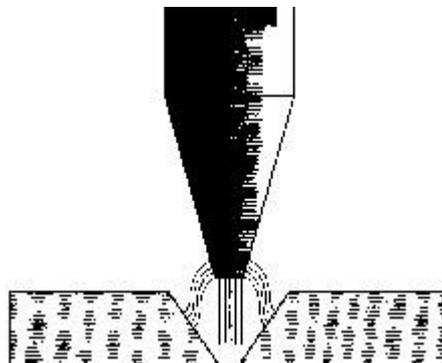

2% thorium oxide   2% cerium oxide

Oxide distribution in tungsten electrodes cut lengthwise along the electrode axis (photos: Metallwerk Plansee, Reutte)

Bell-shaped overall arc, cylindrical core arc Recommended

electrode geometry from various manufacturers:

The ideal geometry for TIG orbital welding of steels and stainless steels is between 15° and 30°. Depending on the current strength, the end is provided with a tip surface (flat surface).

The electrode distance and geometry vary depending on the application. These values are guidelines.

Wall thickness of the workpieces to be welded	Electrode diameter D	Electrode tip d	Arc gap
0.5 - 1.0 mm	1.0 mm	0.2 mm	0.5 mm
0.8 - 1.5 mm	1.6 mm	0.2 mm	0.8 mm
1.2 - 2.4 mm	1.6 mm	0.2 mm	1.2 mm
2.0 - 3.6 mm	2.4 mm	0.4 mm	1.6 mm

Calculating different electrode lengths for closed cassette welding heads

$$\text{Electrode length} = \frac{\text{Rotor outer diameter - Pipe outer diameter}}{2} - \text{Arc gap}$$
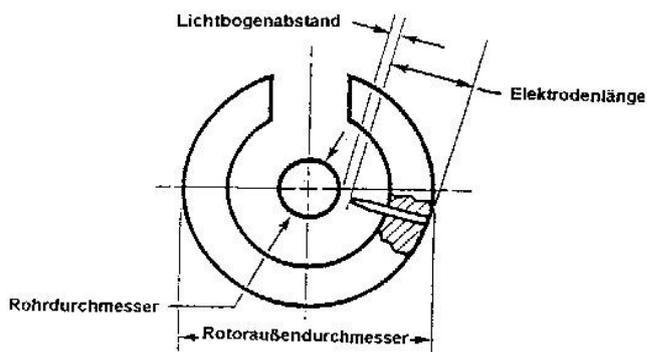
The electrode must be replaced if the arc ignition or welding quality deteriorates or after a specified number of welds.

Conversion table inches / mm

| Inches	MM	Inch	MM	Inches	MM
0.010	0.25	0.125	3.12	1.000	25.4
0.020	0.50	0.250	6.35	1.050	26.7
0.030	0.75	0.375	9.53	1.250	31.8
0.040	1.00	0.405	10.3	1.315	33.4
0.050	1.25	0.500	12.7	1.500	38.1
0.060	1.5	0.540	13.7	1.660	42.2
0.070	1.80	0.625	15.8	1,900	48.3
0.080	2.00	0.750	19.05	2.000	50.8
0.090	2.25	0.840	21.34	2.375	60.3
		0.875	22.3	3.000	76.1

6. Considerations regarding sulfur

Austenitic materials require special material behavior to be mastered. With the same parameters, good welding behavior with narrow seam formation and good penetration can be observed on the one hand, while on the other hand, the seam formation is wide with low penetration.
The elements sulfur and oxygen have a significant influence on welding behavior. A high sulfur and oxygen content has a positive effect on penetration. A flow forms in the molten pool towards the center of the molten pool and from there in the direction of the workpiece thickness.
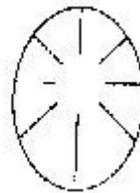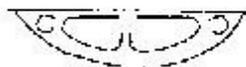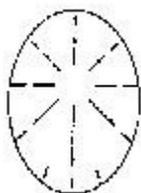
Low sulfur and oxygen content   High sulfur and oxygen content

With low sulfur and oxygen content, it spreads out and is flat. This makes welding more difficult, especially with larger wall thicknesses. (Burkhardt and Heiple, 1986)

When welding two austenitic workpieces, one of which has a low sulfur content and the other a "normal" sulfur content, deflection of the arc occurs. In this case, the arc deviates to the melt with the low sulfur content. This can lead to inadequate penetration of the weld joint. Especially with pipe-fitting connections, it is advisable to ensure that the correct penetration depth is achieved. (Fithey and Simoneau, 1982)
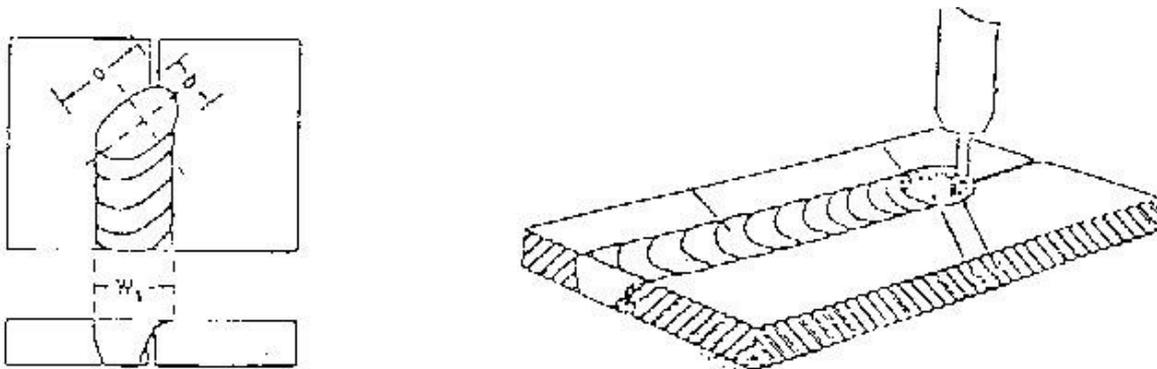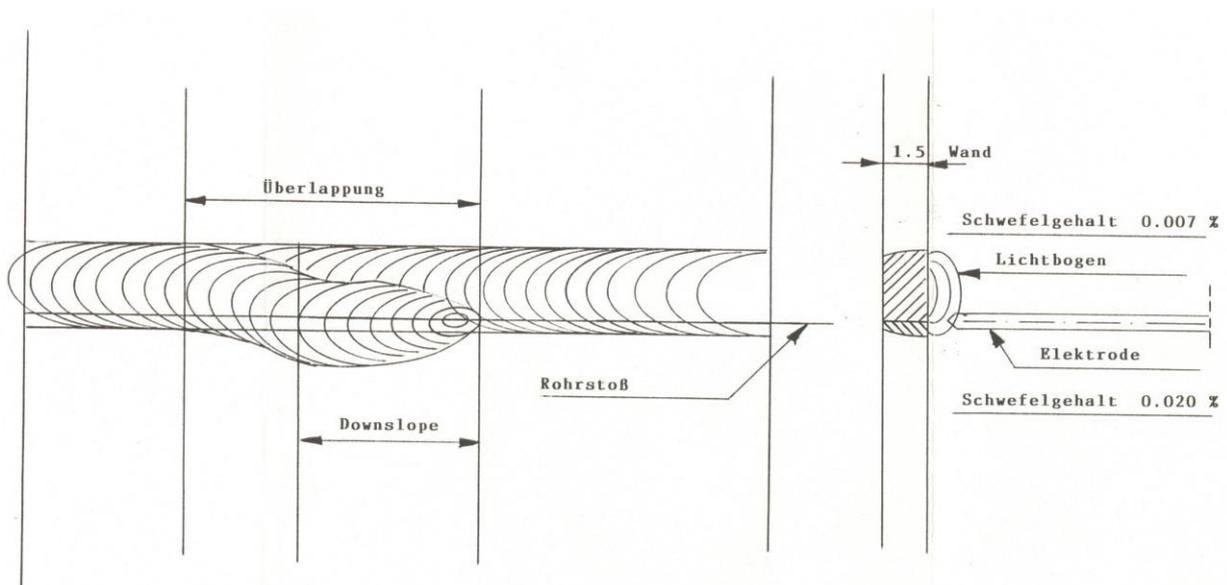

Illustration of the flow of the molten pool towards low sulfur and oxygen content

Case study from practice

Due to the widely differing sulfur contents of the two melts (0.007% and 0.021%), this arc deflection occurs, resulting in low sulfur. Examination under a microscope showed that one edge of the low-sulfur pipe is melted, while the vast majority of the seam is on the high-sulfur side. This defect continues until the beginning of the overlap.

At this point, the electrode hits the mixed melt, so that the characteristics of different sulfur contents can hardly influence the weld. The arc is no longer deflected here, so that the downslope ends very precisely at the center of the joint.

The physical and chemical explanation for this is the Marangoni effect described above (moderate S content = narrow, well-welded seam; low S content = wide, possibly not fully welded seam).

One way to solve these irregularities would be to use pipes and fittings from the same melts. However, this is rarely feasible from a technical standpoint, as pipes, fittings, and valves are purchased from different manufacturers.

Another option would be to weld twice using special parameters. This is also done in practice and has proven itself. However, the heat input must be precisely controlled.

Furthermore, the step mode could be programmed. In this case, the rotary movement is in the high-current phase and the arc can burn in a targeted manner without deflection.

In the case shown below, the electrode is placed next to the I-joint (approx. 1 mm) on the pipe with the higher sulfur content. The elemental composition of the melts should be known.

The use of argon/hydrogen mixtures increases the arc voltage, allowing the heat input to be reduced. This results in a higher welding speed, increased penetration, and the best possible oxidation-free seam.
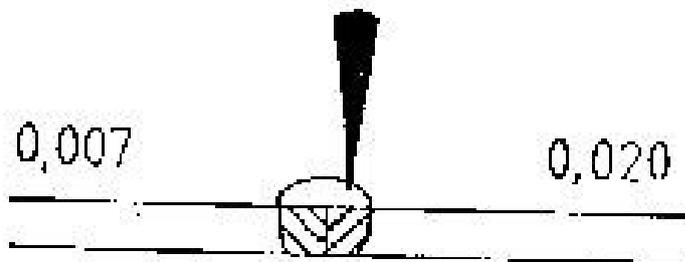
Same or similar sulfur contents
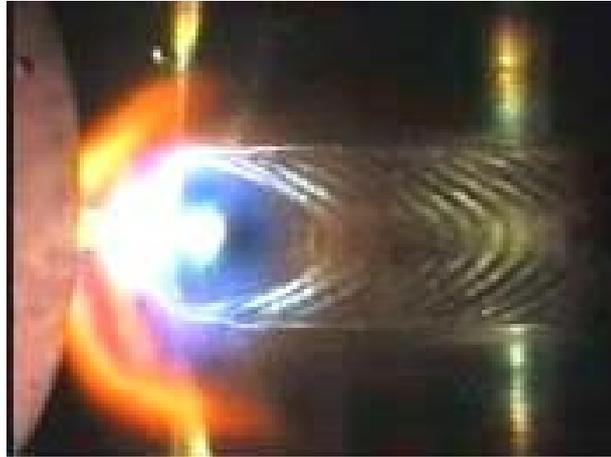
Different sulfur contents
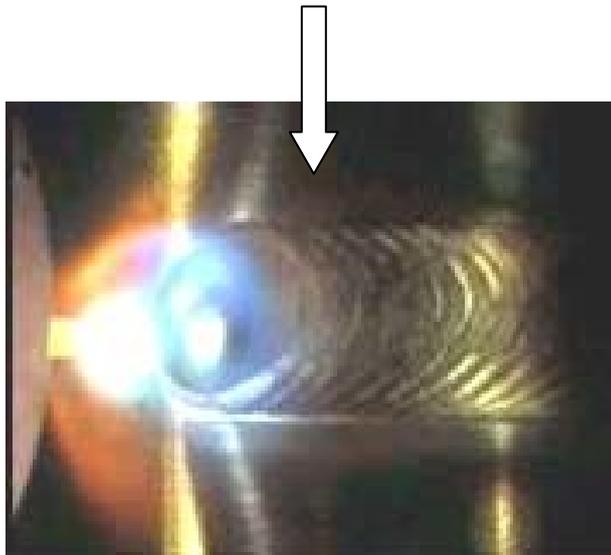
The marked component has less sulfur. The arc is "drawn" there.
The irregular scaling of the weld seam and the burn-in notch on the side with the higher sulfur content are also clearly visible.

7. Considerations regarding the delta ferrite content Basler Norm 2 (BN 2)

In order to better meet the requirements of the pharmaceutical industry, especially for the installation of ultrapure water and WFI systems, Roche has created a factory standard called Basel Standard 2.

This recommendation further restricts the requirements of DIN. For example, sulfur can be up to 300 ppm according to DIN, but only 150 ppm according to BN 2.

Pipeline construction companies working for customers in this Basel area are confronted with this standard in almost all tenders.

Structure formation

Steel solidifies at a composition of 18% chromium and 8% nickel delta-ferritic. During cooling, the delta ferrite first partially and then completely transforms into austenite. However, this formation of an austenitic microstructure only occurs if there is enough time for the delta ferrite to transform into austenite (e.g., when rolling or forging a steel block). During casting and especially in weld metal, the cooling time is not sufficient for the transformation. Therefore, there is usually always a certain amount of delta ferrite present in the weld metal.
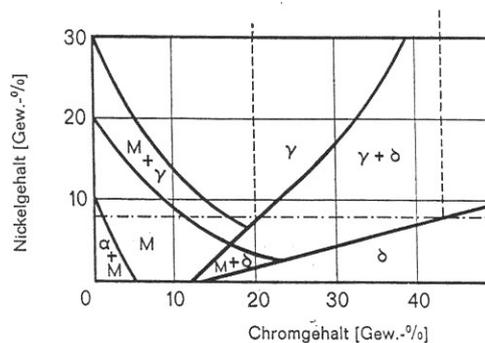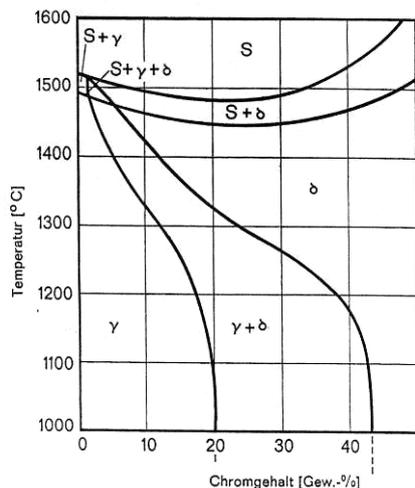
α = Alpha-Ferrit; δ = Delta-Ferrit; γ = Austenit; S = Schmelze; M = Martensit

Abb. 5: Schnitt durch das Dreistoffsystem Fe-Cr-Ni nach PUGH und NISBET bei 8 % Ni (oben) und Gefügeausbildung der Chrom-Nickelstähle mit 0,1 % C nach Abschrecken von 1050 °C auf Raumtemperatur nach BAIN und ABORN (unten).

Below a temperature of 900 degrees Celsius, no further structural changes occur.

Legierungsanreicherung an den Zellgrenzen

ferritische Erstarrung mit Umwandlung δ → γ   austenitische Erstarrung mit δ-Ferrit
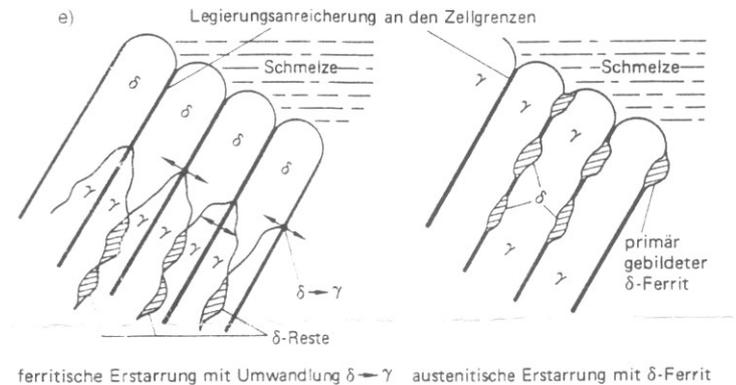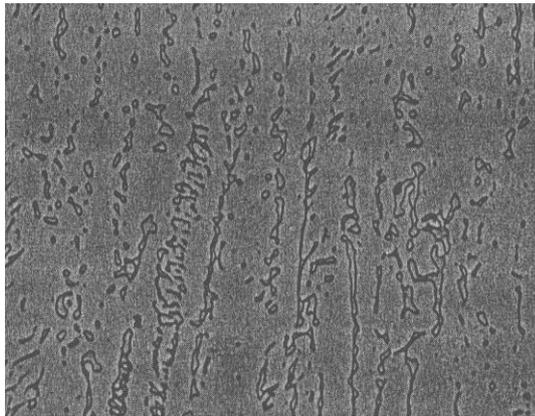
Grinding with visible delta ferrite deposits   Ferritic   and   austenitic solidification

at the grain boundaries

When processing steels, a delta ferrite content between 5 FN and 10 FN (ferrite number) is usually aimed for in order to avoid hot cracks. In the pharmaceutical industry (WFI – water, aggressive substances for cleaning piping or killing germs), the delta ferrite content in the weld seam must be limited to 1 FN to 2 FN from a corrosion perspective, as otherwise

"ferrite path corrosion" can occur.

High-alloy austenitic alloys of the 1.44xx group (non-transforming austenitic Cr-Ni-Mo steels) are used as materials, whose corrosion resistance is based on the most homogeneous possible distribution of chromium, which should never be < 12% locally. This achieves very good corrosion resistance in oxidizing media and, through the addition of molybdenum, significantly better resistance to chlorides and halides.

Some time ago, stabilized steels (1.4571 – stabilized with Ti) were used to improve corrosion behavior. This had the disadvantage that during polishing, the carbides formed during the process broke off and left surface defects on these areas.

The delta ferrite content of an austenitic weld metal can be determined in three ways in accordance with the applicable regulations set out in DVS Merkblatt 1005 (6/1988):

- Physical determination
- Metallographic determination
- Calculated determination using the Schäffler or De Long diagram

The accuracy of the individual methods varies greatly, and the comparability of the determined values depends heavily on the respective measuring device. A ferrite number (formerly delta ferrite content in %) is only meaningful if the method or measuring principle (measuring device) used is also specified.

For all physical measurement methods, the devices must be calibrated with calibrated SECONDARY STANDARDS before each measurement.

Physical determination

The magnetic measurement of the delta ferrite content can be carried out in accordance with DVS data sheet 1005 using the Magne-Gage method, e.g., Ferritscope MP 30 from Fischer. The aforementioned calibration bodies in accordance with the standard are required for this. These are usually reference bodies with a multi-layer welded strip plating. These reference bodies are calibrated in FN using a magnetic balance (magnetic gauge), whereby the adhesive force of soft iron samples with copper coatings of varying thicknesses serves as a reference standard for the respective ferrite numbers (FN). The dispersion is approximately ±1 FN (±1%).

The importance of device calibration in FN is demonstrated by the representations of the device-specific measured value deviation as a function of the delta ferrite content. If SECONDARY STANDARDS are not used, it is not possible to compare the measured values determined with different devices. The differences that occur can be in the range of up to 2 FN or more than 40

% of the measured value.

In addition to device calibration, the following influencing factors must also be taken into account:

- Surface quality of the measuring range
- Influence of pipe curvature
- Influence of the pipe wall thickness

The resulting measurement deviations can be up to 15% for the application.

MP 30 with test piece and printer
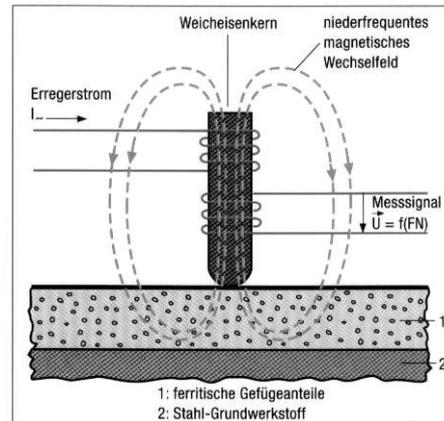
Prinzipielle Wirkungsweise der magnetinduktiven Messmethode am Beispiel einer austenitischen Plattierung.

Functionality of the magnetic-inductive measurement method

Metallographic evaluation

The sample, which is usually ground and polished for metallographic examination, is etched according to Murakami to determine the delta ferrite content. For welded materials, an overview image of the entire cross-section of the weld seam and micrographs at 1000x magnification of the areas representative of the delta ferrite content (three areas are recommended) must be taken.

The location of these areas must be marked on the overview image. The usual dispersion is approximately ± 2%. To determine the delta ferrite content, the respective microstructure image is compared with the corresponding delta ferrite reference series (IIW Reference Atlas) and classified, or counted using the line intersection method based on the ground section documentation.
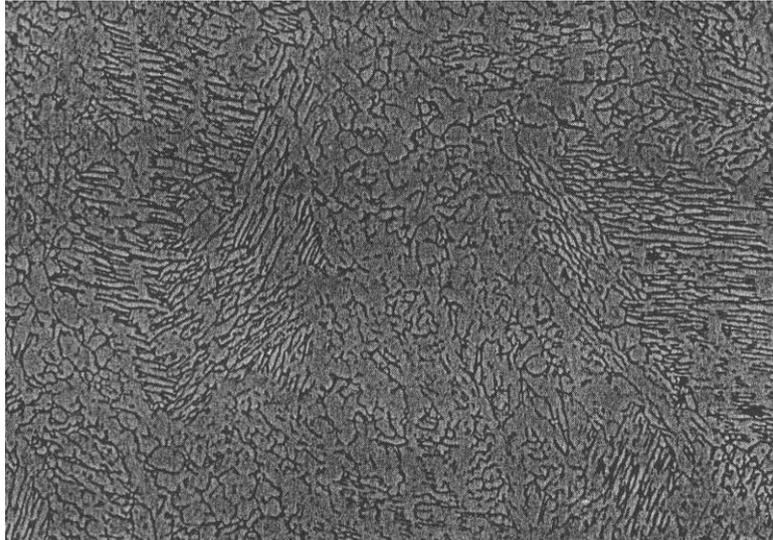
Example of a micro section

Calculated delta ferrite determination

Delta ferrite is determined using the De Long diagram for the base material and weld metal, whereby the base material must be determined in accordance with the specification. Alternatively, the Schäffler diagram can be used, whereby in both cases the chromium and nickel equivalent values must be calculated according to the actual chemical composition (melt or piece analysis).
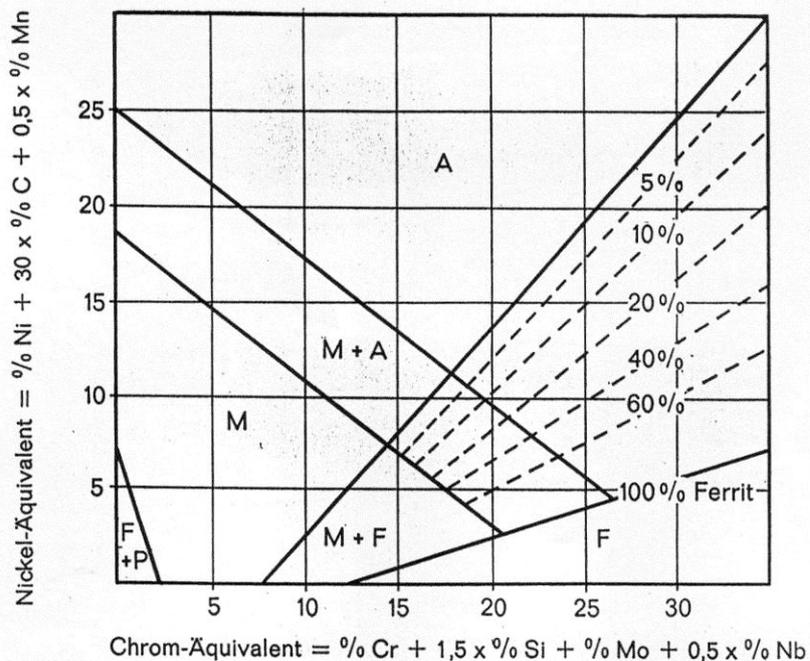
Diagram according to Schäffler

Comparison between WRC FN – numbers with the percentage values of the delta ferrite content
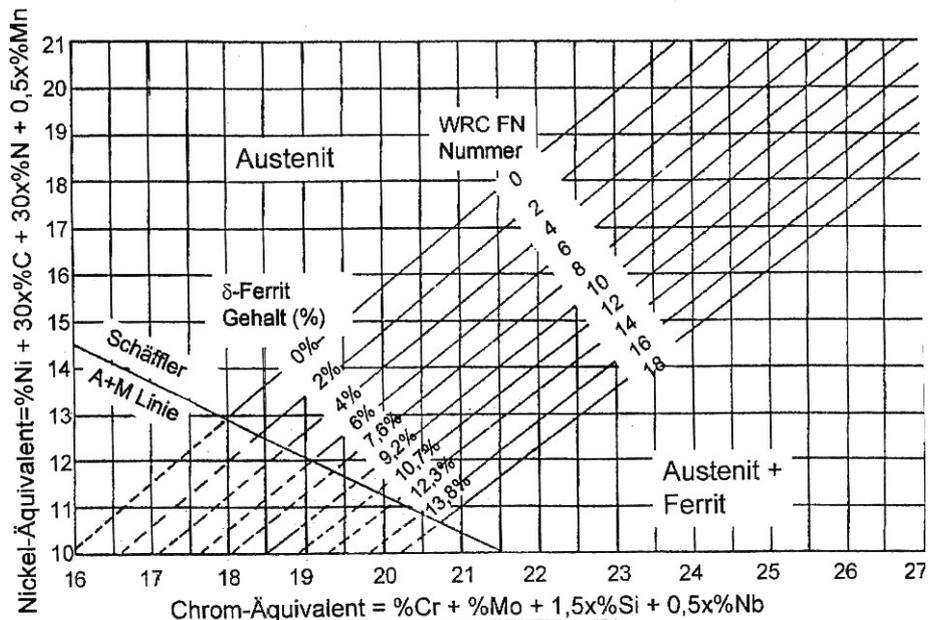
Ferrite formers

- Chromium (Cr)
- Aluminum (Al)
- Titanium (Ti)
- Tantalum (Ta)
- Silicon (Si)
- Molybdenum (Mo)
- Vanadium (V)
- Tungsten (W)

Austenite formers

- Nickel (Ni)
- Carbon (C)
- Cobalt (Co)
- Manganese (Mn)
- Nitrogen (N)

Comments

Based on the many years of experience of an engineering firm from Austria, it can be said that theoretical considerations, which clearly demonstrate the need for the lowest possible delta ferrite content, must be supplemented by factors that can be observed in operational practice and which also have an influence on the corrosion resistance of the system, in order to then create a basis in the form of a priority list.

As a rule, there are usually several, often even systematically justified errors, as can be seen from the following list:

- Incorrect dimensioning of the pipeline
- Use of unsuitable components (fittings)
- Inadequate flow through individual areas
- Non-emptiable "bags" in pipelines
- Use of different materials
- Use of longitudinally welded pipes and fittings
- Use of different pipe qualities
- Use of different dimensions
- Inadmissible weld edge preparation
- Tacking without root protection
- Inappropriate welding technique
- Material damage due to inadequate root protection
- Damage to the surface due to inadequate cleanliness
- Inadequate cleaning before commissioning

Standard description Stainless steel according to BN2

1 Purpose of the standard

This standard describes the material requirements for products made of austenitic stainless steel based on steel W-No. 1.4435 (X2CrNiMo18-14-3) according to EN 10088, prEN 10028-7 or DIN 17440 or 316L (AISI),
but with tighter analysis limits and a defined ferrite content. This is to ensure that consistent corrosion resistance can be expected even when using products from different sources and batches.

2 Area of application

This standard applies to sheet metal, strip, wire, steel bars, forgings, tubes, and semi-finished products. For complete equipment, the customer's technical documentation also applies.

3 Specifications

3.1 Heat treatment, surface treatment

The products must be solution annealed at 1020 to 1100°C, quenched and pickled, or solution annealed (bright annealed) under protective gas at 1020 to 1100°C and quenched. During processing, any measures that lead to carburization must be avoided (e.g., heat with a reducing flame).

3.2 Welded semi-finished products

Orbital welding training manual	ORBITALSERVICE® THE FUTURE OF ORBITAL WELDING

The composition of the weld metal must at least correspond to that of the base material. As a rule, slightly higher-alloyed filler materials should be used (e.g., W-No. 1.4439, 1.4440, 1.4443). The weld seam must allow the same thermal post-treatment as the base material.

3.3   Material certificates

The content of the alloying elements C, Si, Mn, P, S, N, Cr, Mo, Ni, and Ti mentioned in the analysis limits, as well as the ferrite content, must be stated.
- 0.2% yield strength (Rp 0.2)
- 1.0% yield strength (Rp 1.0)
- Tensile strength (Rm)
- Elongation at break (A5)

3.4   Analysis limits of the products in %

C	Si	Mn	P	S	N	Cr	Mo	Ni	Other
<= 0.030	<=1.0	<=2.0	≤0.045	<=0.015(1)	<=0.11	17.0 to 19.0	2.5 to 3.0	12.5 to 15.0	Ti<=0.05

1) For bars, wire rod, profiles, and the corresponding semi-finished products, a maximum content of 0.030% S applies.

Revision 1997-06-19:   - Section 3.1 supplemented (protective gas): individual values of EN 10088 adjusted
        - Explanations on page 3 deleted: this concerned the former parts 1 to 3 of BN 2

3.5   Ferrite content

The analysis must meet the following condition

$$X-0.91Y <= 7.70$$

X= %Cr + 1.5(%Si) + %Mo +2(%Ti) (chromium equivalent)
Y= %Ni + 0.5(%Mn) + 30(%C) + 30(%N - 0.02) (nickel equivalent)

The following measured iron contents are permitted:
Sheet metal (except cut edges), seamless tubes <= 0.2% Welded tubes <= 0.5%
Forgings (unless otherwise agreed) no limit

Ferrite is defined here as all phases detectable with a magnetic-inductive ferrite measuring device (e.g.

page Page
39

Fischer Ferritoscope) in the austenitic base structure, whereby a measurement depth of 3 mm must be recorded.

3.6   Mechanical properties

Temperature °C	20	100	15	20	25	300	350	400
Tensile strength Rm N/mm2	500 to 700 (1)	-	-	-	-	-	-	-
0.2% Yield strength Rp0.2 N/mm2	min. 200 (1)	165	150	137	127	119	113	108
1.0 Yield strength Rp1.0 N/mm2	min. 235(1)	200	180	165	153	145	139	135

Minimum elongation at break according to DIN 17440:1996 ("2)							Average minimum notch impact energy					
Flat products		Bars and forgings					Bars and forgings				Flat products
< 3 mm thickness (A80mm)		>= 3 <= 100 Thickness (A5)	Decisive dimension	A5			Relevant dimension				<= 75 mm Thickness
longitudinal %	crosswise %	longitudinal transverse %	DIN 17440 Image 3 mm	Longitudinal	transverse	tang(3)	DIN 17440 Image 3	longitudinal J	transverse J	tang (3)	transverse J
35	40	40	<= 160	35	-	30	<= 160	85	55(4)	65	55
			>160 <= 250	-	30	30	>160 <=250	-	55	60	

1) For sheet metal and strip, slightly higher values apply at 20°C, see EN 10088-2
2) The specifications according to EN 10088-2 and -3 differ in part from those according to DIN 17440:1996; the values according to EN 10088 are also permissible for BN 2 steel.
3) Applies only to forgings
4) This value applies only to rods with a diameter > 100 mm

3.7   Physical properties (reference values), value according to EN 10088-1

Density	Modulus of elasticity at °C						Average coefficient of thermal expansion between 20°C and °C					Thermal conductivity	Specific. Heat capacity	Electrical resistance
	20	100	20	30	40	500	100	200	300	400	500	at 20°C	at 20°C	at 20°C
kg/dm3	kN/mm2						10-6xm/(mxK)					W/(mxK)	J (kgxK)	Ωxmm2/m
8.0	200	194	186	179	172	165	16.0	16.5	17.0	17.5	18.0	15	500	0.75

8. Welding process

It has become clear that orbital welding is largely dependent on the
"boundary conditions." Of course, everything must also be right during the actual welding process itself in order to achieve the desired seam formation. Welding current, arc length, welding speed, tungsten electrode dimensions, and shielding gas composition are the key factors here.

Welding current and arc length

There is a direct correlation between welding current, arc length, and welding speed on the one hand, and penetration depth on the other. The most important requirement for a power source for TIG welding in orbital technology is therefore that the current is kept constant within narrow limits. Deviations of 1% from the set value can be tolerated at most.

When guiding the welding torch by hand, the welder can compensate for current fluctuations in a larger range by changing the welding speed or making small changes to the arc length. Since the arc length influences the arc power and thus also the penetration depth via the electrical resistance, orbital welding systems have devices that prevent changes in the arc length.
This device can be mechanical (distance wheel) or voltage-dependent (AVC).

The set rotation speed must remain constant over the entire seam length, because even small fluctuations have a significant effect on the
This precise speed control is particularly important in view of the high frictional resistance inherent in cassette welding heads or in larger welding guns due to weight shift in the raised or lowered position, and can only be guaranteed by using controlled drives. The speed is kept constant by using tachogenerators or incremental encoders.

A tachometer-controlled system constantly compares the actual and target values and adjusts for any voltage deviations.

Another type of control is position control (pulse position control).

With this type of control, the welding head constantly informs the control system of its exact position. The accuracy is better than one degree of angle, i.e., < 0.2 mm for a pipe with an outer diameter of 25 mm.

The presence of such a control system should therefore be taken into account when selecting welding systems.

Some high-quality computer-controlled systems also offer the option of setting different wire feed speeds in the individual welding planes (sectors). This is particularly useful when welding ferritic steels with the typical low-viscosity weld pool is a partitioning of the arc circulation into different planes (in horizontal pipe axis).

Factors influencing weld seam quality

In TIG orbital welding, there are over 80 parameters that determine the weld formation and quality. Around 20 of these parameters define 95% of the weld properties.

Main factors influencing weld quality (welder)

- Welding parameters
- Base material
- Temperature
- Tungsten electrode
- Welding filler material
- Shielding gas

- Welding equipment technology
- Seam preparation
- Seam geometry
- Welding position
- Assembly tolerances
- Root shielding gas

Due to the wide range of programming options available for power sources, processors initially face a number of difficulties when selecting parameters. Variations in pulse current, base current, pulse voltage, base voltage, welding speed, wire feed, frequencies, duty cycle, etc., result in many possibilities for influencing bead formation and ensuring error-free welding. For this reason, it is necessary to carry out a parameter study before each new welding task. The scope of this study depends on experience with the pipe dimensions, materials, and component requirements at hand. One of the main areas of interest is the penetration behavior and thus the root formation. Experience has shown that the base current has the greatest influence on the penetration depth on average.

The second most important factor is the base voltage, followed by the duty cycle and the pulse current.

Tests have shown that the maximum penetration is reached earlier with austenite. Due to the low thermal conductivity of austenite, heat accumulation occurs during welding, which leads to higher penetration even at low speeds. It is important to mention to mention that all welding parameters and the general conditions of the test welds should be recorded on welding data sheets.

The weld seams shown in cross-section illustrate how the various parameters influence the shape of the weld seam.

Geringe
Nahtüberhöhung,
kerbfreier
Übergang

Außenseite

Schweißzone

Innenseite

Wurzel gut
ausgebildet,
kerbfreier
Übergang
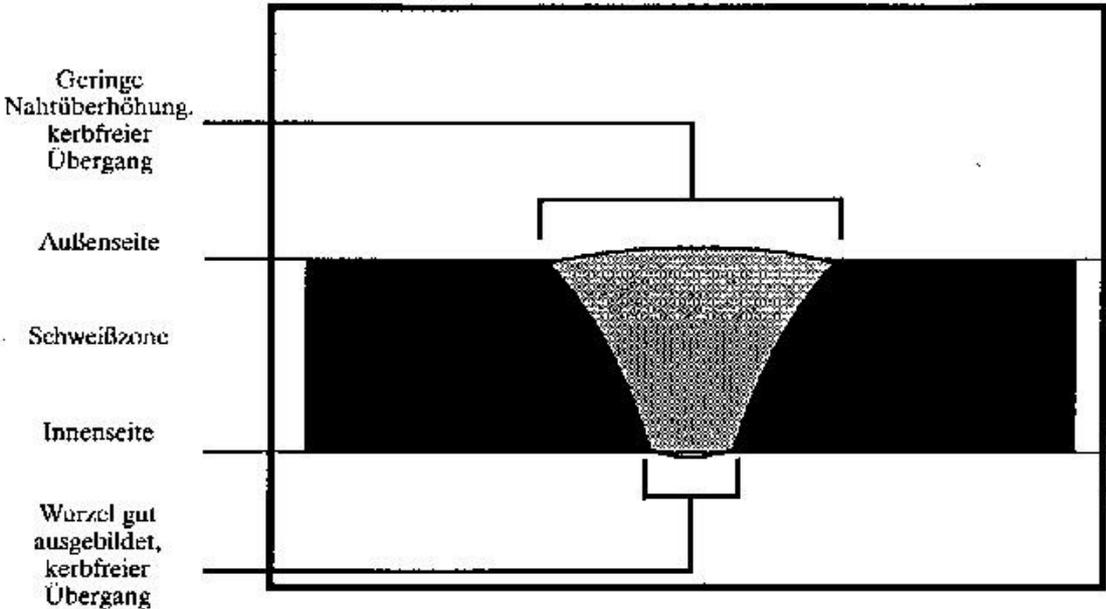
Cross-section of a correct weld seam
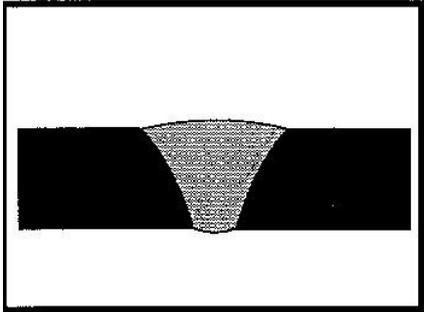
Correct illustration
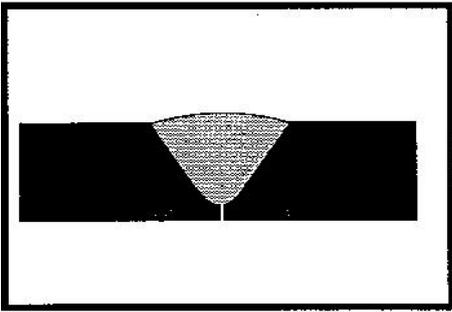
Low pulse current, no penetration of the root
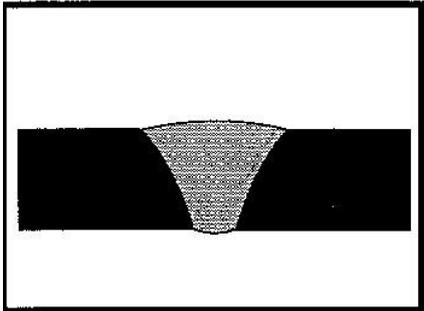
Correct illustration
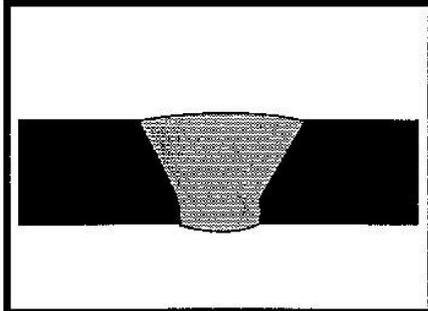
High pulse current, enlarged root formation and weld seam width
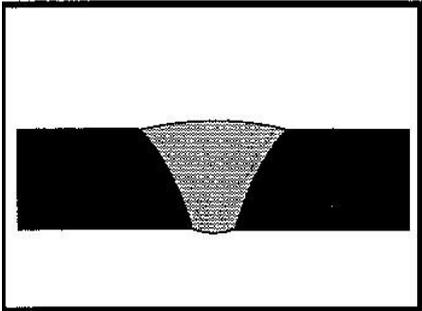
Correct illustration
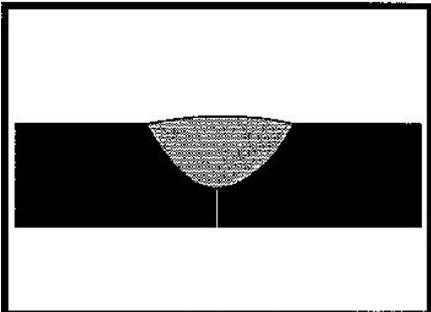
Low base current, no root burn-through
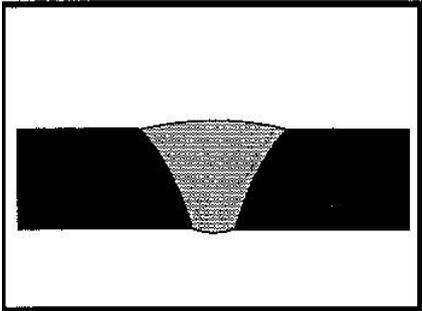
Correct illustration
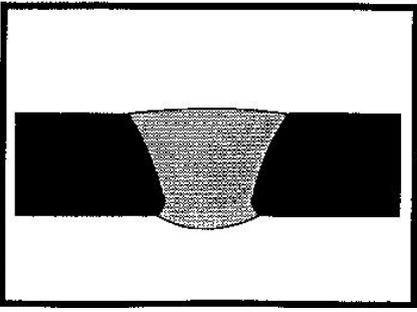
High base current, increased root formation, and weld seam width
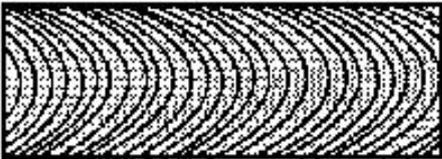
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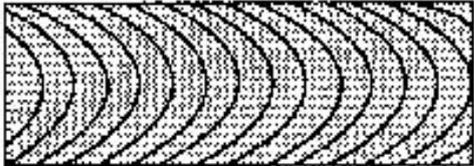
Low frequency, coarse-scaled seam (long pulse time)
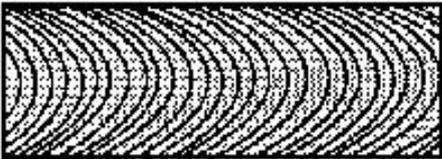
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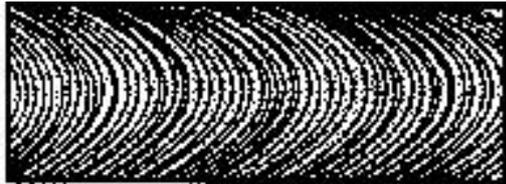
High frequency, fine-scaled seam (short pulse time)
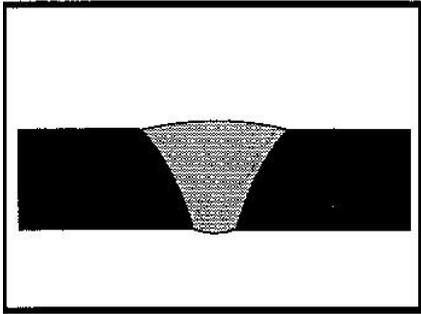
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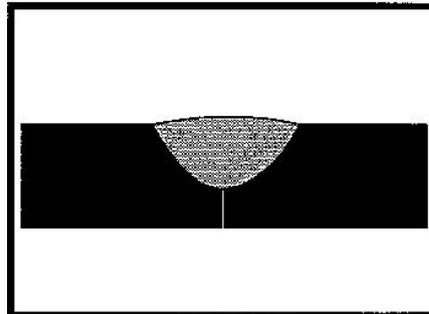
Short pulse duration, no penetration of the root
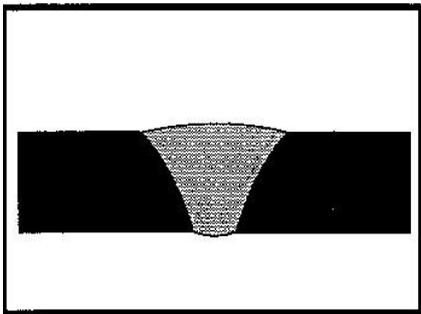
Correct illustration
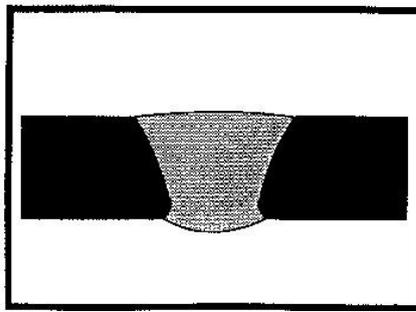
Long pulse duration, enlarged root formation and weld seam width
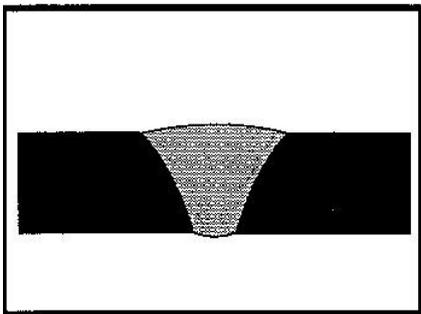
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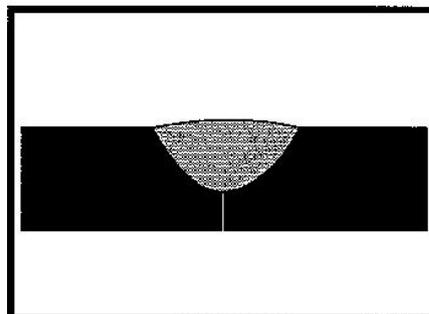
High welding speed, no burn-through due to reduced heat input
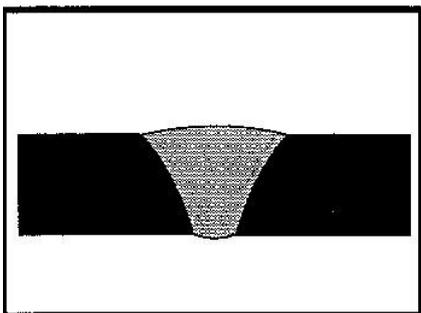
Correct illustration
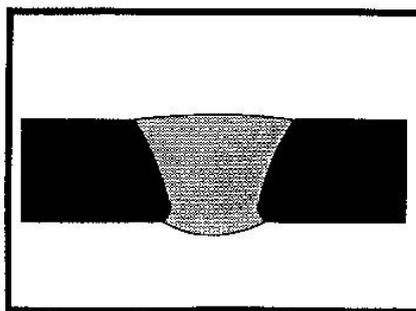
Low welding speed, increased root formation and weld seam width

9. Calibration of the welding head

For flawless welds, the speed must match the setpoint value entered on the device. To do this, a calibration program must be used to adjust the connected welding head. Digitally controlled machines calibrate the head automatically, while analog machines must be calibrated manually.
The calibration of the welding head is largely based on the rule 1 RPM =
60 sec./revolution (360°).
The machine sends out a voltage, after which the welding head must perform a complete revolution. If it does not do so, the calibration potentiometer must be adjusted until the setpoint and actual values match.
The motors are speed-controlled.
They send a voltage signal back to the welding system (motor control card). The machine compares the target and actual values and supplies the welding head with the voltage it needs to perform the specified parameters,
e.g., when welding in a constrained position and the weight of the tongs is also a factor, or when various gear parts in a cassette welding head are worn.
Companies such as ORBIMATIC, AMI, ESAB, and in some cases Tesch Orbital
use tachogenerators.

Pulse generator-controlled motors do not need to be calibrated. Here, a pulse generator mounted behind the motor for the rotary movement of the welding torch provides information about the exact position of the electrode and the welding progress.
Convenient machines obtain all the information required for welding (pulses per revolution, speed of the tongs, etc.) by entering a tong number.
With less convenient equipment, various reference numbers must be entered with the dividers and the speed must be calculated using a gear ratio.
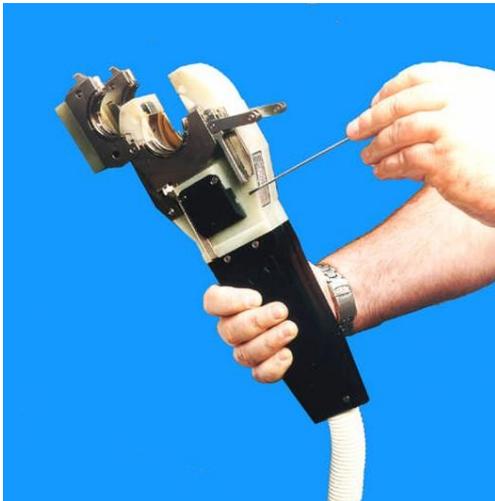
Manual calibration of a closed welding tongs 9 – 1500 (AMI)

10. Welding data at continuous rotation (time control)

1. Welding speed   120 mm/min (2 mm/sec.)

2. Pipe circumference, seam length   3.14 x diameter

3. Rotation speed   120 mm/min : 3.14 x diameter

4. Time per revolution (in sec.)   60 sec. : Rotational speed

5. Rotation delay, preheating
    thickness Bath exposure time (in sec.)   2 - 3 x wall

6. Overlap (in sec.)   2 - 3 x wall thickness

7. Wall thickness (in mm)

8. Pulse times (in sec.)   Wall thickness: 8

9. Downslope, settling time (in sec.)   Wall thickness x 4

10. Calculation of welding times
    sectors   <u>60 sec.: Rotation speed</u> in the 4 sectors

11. Welding current value

    Sector 1 = 40 A per mm wall thickness

    Sector 2 = 95% of sector 1

    Sector 3 = 95% of sector 2

    Sector 4 = 95% of sector 3

    (reduction per sector 5%) or   Sector 1 = 40 A per mm wall thickness
           Sector 4 = 80% of sector 1
           Sectors 2 and 3 must decrease evenly.

    When welding with 6 sectors, the reduction is approx. 3.5%.

12. Base current   approx. 30% of sector 1
           but can also be 25% - 50%

13. Note
    For pipes smaller than 20 mm, the welding current must be less than 40 A.

    Current sector 1 = (24 A x wall thickness) + outer diameter of the pipe Example:
    Pipe 6 x 1.0 mm = (24 A x 1.0) + 6.0 = 30 A

14. Pre- and post-flow times and purge gas quantities depend on the size of the
    cassette welding heads (from 20-60 sec, 4-20 l/min).
    The purge gas volumes of the open tongs are similar to those used in manual TIG
    welding. For more detailed information, please refer to the manufacturer's
    documentation.

10.1. Welding data for continuous rotation (time control) Option 2, ∅ > 20 mm

1. Welding speed   90 mm/min (1.5 mm/sec.)

2. Pipe circumference, seam length   3.14 x diameter

3. Rotation speed   90 mm/min : (3.14 x diameter)

4. Time per revolution (in sec.)   60 sec. : Rotation speed

5. Rotation delay, preheating thickness Bath exposure time (in sec.)   2 - 3 x wall

6. Overlap (in sec.)   2 - 3 x wall thickness

7. Wall thickness (in mm)

8. Pulse times (in sec.)   High current phase: 0.1 sec Base current phase: 0.3 sec – 0.4 sec

9. Downslope, decay time (in sec.)   Wall thickness x 4

10. Welding current values   High current value: 55 A / mm wall thickness Basic current value: 10 A / mm wall thickness

11. Pre- and post-flow times and purge gas quantities depend on the size of the cassette welding heads (from 20-60 sec, 4-20 l/min).
The purge gas volumes of the open tongs are similar to those used in manual TIG welding. For more detailed information, please refer to the manufacturer's documentation.

Note:
The values suggested are guidelines. These depend on the material, the batches, the gas, etc.

Welding speed: 60–120 mm/min
Pulse ratio unalloyed: 0.1/0.1 sec 0.1/0.3 sec (root for V and U seams) High
               alloyed: 0.1/0.1 sec   0.1/0.3 sec   0.1/0.4 sec
Degree of overlap: approx. 70%

10.2. Welding data for continuous rotation
∅ > 20 mm (path control)

1. Welding speed   90 mm/min (1.5 mm/sec.)

2. Pipe circumference, seam length   360

3. Rotation speed $\frac{\text{Welding speed x coefficient C}}{\text{Pipe outer diameter}}$

4. Pulse divider   R 30 (see device technical documentation)

5. Rotation delay, preheating thickness Bath formation time, pre-melting time (in sec.)   2 - 3 x wall

> **I 21 = I 22**
> Current during pre-melting time
> = High current sector 1!

6. Overlap (in sec.)   5

7. Pulse times (in sec.)

    High current phase: 100 ms
    Basic current phase: 300–400 ms

8. Downslope, decay time (in seconds) Wall thickness x 4

9. Welding current value   High current phase: 55 A / mm wall thickness Basic current phase: 10 A / mm wall thickness

10. Note

If the heat build-up becomes too great, e.g. with austenitic steels and smaller pipe diameters, it is possible to insert additional sectors at any time to minimize the heat input.

11. Pre- and post-flow times and purge gas quantities depend on the size of the cassette welding heads (from 20-60 sec, 4-20 l/min).
The purge gas volumes of the open tongs are similar to those used in manual TIG welding. For more detailed information, please refer to the manufacturer's documentation.

Note:
The values suggested are guidelines. These depend on the material, the batches, the gas, etc.

Welding speed: 60–120 mm/min
Duty cycle unalloyed: 100/100 ms 150/300 ms (root for V and U seams) High alloyed: 100/100 ms 100/300 ms   100/400 ms Degree of overlap: approx. 70%

10.3. Welding data for continuous rotation
Ø < 20 mm (path control)

1. Welding speed   120 mm/min (2 mm/sec.)

2. Pipe circumference, seam length   360

3. Rotation speed $\frac{\text{Welding speed x coefficient C}}{\text{Pipe outer diameter}}$

4. Pulse divider   R 30 (see device documentation)

5. Rotation delay, preheating   2 - 3 x wall
   thickness Bath exposure time (in sec.)

6. Overlap (in sec.)   5

7. Pulse times (in sec.)   Wall thickness: 8

8. Downslope, descent time (in sec.)   Wall thickness x 4

9. Welding current value High current in A

   1. Sector = (24 A x wall thickness) + outer pipe diameter
   2. Sector = 95% of sector 1
   3. Sector = 95% of sector 2
   4. Sector = 95% of sector 3

If the pipe is quartered, the second sector starts at 90°, the third at 180° and the fourth at 270°.

10. Base current   Approximately 30% of sector 1 (all 4 sectors
    are the same), but can also be 25% - 50%.

11. Pre- and post-flow times and purge gas quantities depend on the size of the cassette welding heads (from 20-60 sec, 4-20 l/min).
    The purge gas volumes of the open tongs are similar to those used in manual TIG welding. For more detailed information, please refer to the manufacturer's documentation.

Note:
The values suggested are guidelines. These depend on the material, the batches, the gas, etc.
For pipes > 20 mm, this framework can also be used for programming.
For the high current value in sector 1, 40 A/mm wall thickness should then be used.

10.4. Welding data for continuous rotation
∅ > 20 mm (Tigtronic)

As described in the previous calculations (tachometer control or path control), the control system calculates a welding program using the values. This calculation is performed with the help of the quick start guide.

- Welding speed continuous 90 mm/min

- Current High-current pulse current (55 A x mm wall thickness)
- Current Basic current (10 A x mm wall thickness)

- Pulse time High-current pulse current (0.1 sec)
- Pulse time base current (0.3 sec – 0.4 sec)

- Pool formation time (2 x wall thickness in sec)

- Lowering time (4 x wall thickness in sec)

Open or closed welding tongs for the following parameters:
- Gas flow times (before and after welding)
- End switch query after welding for return
- Option of wire addition
- Scope of application of welding tools
- Direction of rotation
- Gear calculation
- Impulses per revolution
- Ohmic resistance of the hose package

10.5. Welding data for continuous rotation
∅ < 20 mm (Tigtronic)

As described in the previous calculations (tachometer control or distance control), the control system calculates a welding program using the values. This calculation is performed with the help of the quick start guide.

- Welding speed continuous 120 mm/min

- Current High-current pulse current in A Sector 1:
  (24 A x wall thickness) + outer pipe diameter Sector 2:
  95% of sector 1
  Sector 3:
  95% of sector 2
  Sector 4:
  95% of sector 3

- Current Basic current in A (1/3 x high current sector 1)

- Pulse time High-current pulse current and base current (1/8 x wall thickness)

- Weld pool formation time (2 x wall thickness in sec)

- Lowering time (4 x wall thickness in sec)

Open or closed welding gun for the following parameters:

- Gas flow times (before and after welding)

- End switch query after welding for return

- Option of wire addition

- Scope of application of welding tools

- Direction of rotation

- Gear calculation

- Impulses per revolution

- Ohmic resistance of the hose package

10.6. Welding data for synchronous operation (torch step mode, step mode) Tigtronic Mod. 1999

The control system **does not** calculate a program for step mode.
Proceed as follows:

- Automatic program creation as described in the quick start guide

- In the menu item "Frame parameters" (☐, double the lowering time and activate the pulsed rotary movement

- In the menu item "[MAX/MIN]," set the rotation monitoring to "Zero." Use the arrow key to go to "Rotation," press "[ENT]" and enter the number 0. Use the P key and "[↵]" to return to the welding screen

- The calculated program of the control system is freely overwritten with the parameters listed below (see also the Tigtronic Orbital operating instructions).

- Welding speed only in basic current (100 mm/min)

- Current High-current pulse current in A
  Sector 1:
  35 A x wall thickness
  Sector 2:
  95% of sector 1
  Sector 3:
  95% of sector 2
  Sector 4:
  95% of sector 3 Current Basic

- current in A (1/3 x high current sector 1)

- Pulse time High-current pulse current and base current (1/4 x wall thickness)

- Bath formation time (2 x wall thickness in sec)

- Lowering time (8 x wall thickness in sec)

Open or closed welding tongs for the following parameters:
- Gas flow times (before and after welding)
- Query limit switch after welding for return
- Option of wire addition
- Scope of application of the welding tools
- Direction of rotation
- Gear calculation
- Impulses per revolution
- Ohmic resistance of the hose package

10.7. Welding data during (torch step mode, step mode) synchronous (path control) operation

1. Welding speed   100 mm/min (2 mm/sec.) (only in base current)

2. Pipe circumference, seam length   360

3. Rotation speed $\dfrac{\text{Welding speed x coefficient C}}{\text{Pipe outer diameter}}$

                                              Only in base current!

4. Pulse divider   R 30 (see device technical documentation)

5. Rotation delay, preheating   2 - 3 x wall
thickness Bath formation time (in sec.)

6. Overlap (in sec.)   5

7. Pulse times (in sec.)   Wall thickness: 4

8. Downslope, descent time (in sec.)   Wall thickness x 8

9. Welding current value High current in A

      5. Sector = 35 A per mm wall thickness
      6. Sector = 95% of sector 1
      7. Sector = 95% of sector 2
      8. Sector = 95% of sector 3

When the pipe is quartered, the second sector begins at 90°, the third at 180°, and the fourth at 270°.

10. Basic current   Approx. 30% of sector 1 (all 4 sectors are the same), but can also be 25% - 50%.

11. Pre- and post-flow times and purge gas quantities depend on the size of the cassette welding heads (from 20-60 sec, 4-20 l/min).
The purge gas volumes of the open tongs are similar to those used in manual TIG welding. For more detailed information, please refer to the manufacturer's documentation.

Note:
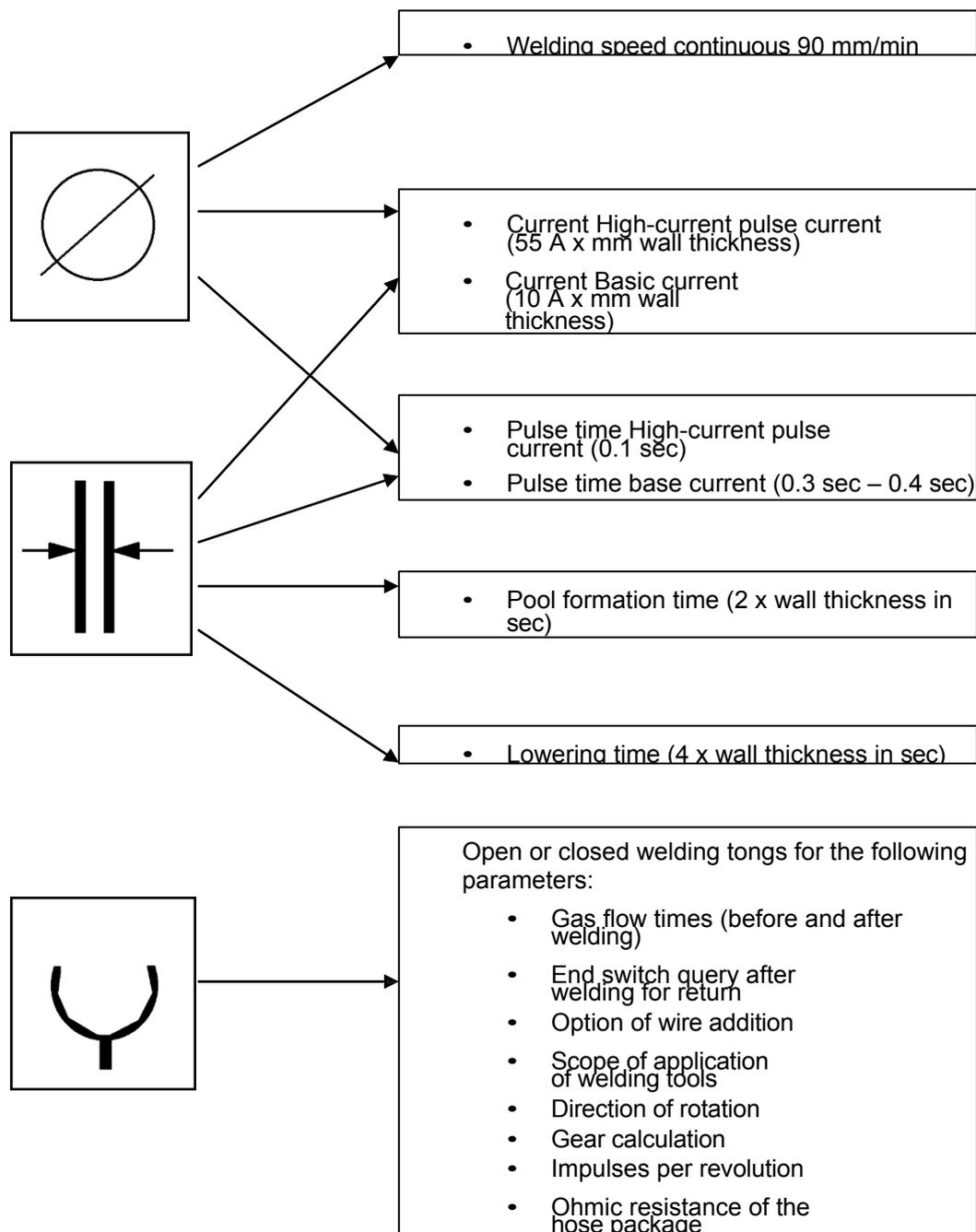The values suggested are guidelines. These depend on the material, the batches, the gas, etc.

10. 8 Welding data for synchronous operation/step mode (time control)

1. Welding speed — 100 mm/min (1.5 mm/sec.)

2. Pipe circumference, seam length — 3.14 x diameter

3. Rotational speed — 100 mm/min : 3.14 x diameter (only in basic current)

4. Time per revolution (in sec.) — 120 sec. : Rotational speed

5. Rotation delay, preheating thickness Bath formation time (in sec.) — 2 - 3 x wall

6. Overlap (in sec.) — 2 - 3 x wall thickness (10% of total welding time)

7. Wall thickness (in mm)

8. Pulse times (in sec.) — Wall thickness: 4

9. Downslope, descent time (in seconds) — Wall thickness x 8

10. Calculation of welding times the sectors — 120 sec.: Rotational speed in 4 sectors

11. Welding current value

   Sector 1 = 33 A per mm wall thickness

   Sector 2 = 95% of Sector 1

   Sector 3 = 95% of Sector 2

   Sector 4 = 95% of sector 3

   (reduction per sector 5%) or

   Sector 1 = 33 A per mm wall thickness
   Sector 4 = 80% of sector 1
   Sectors 2 and 3 must decrease evenly.

When welding with 6 sectors, the reduction is approx. 3.5%.

12. Basic current   approx. 30% of sector 1
                                           but can also be 25% - 50%

13. Pre- and post-flow times and purge gas quantities depend on the size of the cassette welding heads (from 20-60 sec, 4-20 l/min).
The purge gas volumes for open tongs are similar to those for manual TIG welding. For more detailed information, please refer to the manufacturer's documentation.

10. 9. Welding data for continuous rotation ⌀ < 20 mm (OWC plus-Orbitalservice GmbH)

As described in the previous calculations (tachometer control or path control), the control system calculates a welding program using the values. This calculation is performed with the help of the quick start guide.

- Continuous welding speed 125 mm/min

- High-current pulse current in A Sector 1:
  (24 A x wall thickness) + outer pipe diameter Sector 2:
  95% of sector 1
  Sector 3:
  95% of sector 2
  Sector 4:
  95% of sector 3

- Current Basic current in A
  (1/3 x high current sector 1)

- Pulse times for high-current pulse current and base current
  (1/8 of wall thickness in sec.)

- Pool formation time (2.5 x wall thickness in seconds)

- Lowering time (5 x wall thickness in sec)

Open or closed welding gun for the following parameters:

- Gas flow times (before and after welding)
- End switch query after welding for return
- Option of wire addition
- Scope of application of welding tools
- Direction of rotation
- Gear calculation
- Impulses per revolution
- Ohmic resistance of the hose package

10. 10. Welding data for continuous rotation ∅ > 20 mm (OWC plus-Orbitalservice GmbH)

As described in the previous calculations (tachometer control or path control), the control system calculates a welding program using the values. This calculation is performed with the help of the quick start guide.

- Welding speed continuous 125 mm/min

- High-current pulse current in A Sector 1:
  40 A x wall thickness
  Sector 2:
  95% of Sector 1
  Sector 3:
  95% of Sector 2
  Sector 4:
  95% of sector 3

- Current Basic current in A
  (1/3 x high current sector 1)

- Pulse times for high-current pulse current and base current
  (1/8 of wall thickness in sec.)

- Pool formation time (2.5 x wall thickness in seconds)

- Lowering time (5 x wall thickness in sec)

Open or closed welding gun for the following parameters:

- Gas flow times (before and after welding)
- End switch query after welding for return flow
- Option of wire addition
- Scope of application of welding tools
- Direction of rotation
- Gear calculation
- Impulses per revolution
- Ohmic resistance of the hose package

10.11. Welding data for synchronous operation (torch step mode, step mode) OWC plus (Orbitalservice GmbH)

- Welding speed only in base current (100 mm/min)

- Current High-current pulse current in A
  Sector 1:
  35 A x wall thickness
  Sector 2:
  95% of sector 1
  Sector 3:
  95% of sector 2
  Sector 4:
  95% of sector 3 Current Basic
- current in A (1/3 x high current
  sector 1)

- Pulse time High-current pulse current and base current (1/4 x wall thickness)

- Bath formation time (2.5 x wall thickness in sec)

- Lowering time (10 x wall thickness in sec)

Open or closed welding tongs for the following parameters:
- Gas flow times (before and after welding)
- End switch query after welding for return flow
- Option of wire addition
- Scope of application of the welding tools
- Direction of rotation
- Gear calculation
- Impulses per revolution
- Ohmic resistance of the hose package

12. Control overview

Pipe AD	Speed RPM	Time 1 rev.	0.9	AMPS for wall thickness mm 1.0	1.1	1.2	
16 mm	2.4	25 sec.		36	40	44	48
-							
-							
-	2.5	24					
15				35	39	43	47
-	2.6	23					
-							
-							
14				34	38	42	46
-							
-							
-							
-							
13	2.7	22		33	37	41	45
-	3	20					
-							
12	3.2	19		32	36	40	44
-							
-	3.3	18					
-							
11	3.5	17		31	35	39	43
-							
-							
-							
10	3.8	16		30	34	38	42
-	4	15					
-							
-							
9	4.3	14		29	33	37	41
-	4.6	13					
-							
-							
8				28	32	36	40
-	5	12					
-							
7	5.5	11		27	31	35	39
-							
-							
-	6	10					
-							
6				26	30	34	38
					27		

13. Operating personnel

The selection of persons who are eligible to operate orbital welding systems should be based primarily on technical evaluation criteria. It is certainly an advantage if the operator has training as a gas-shielded welder. Based on experience to date, this requirement should be imposed as a matter of principle. In addition to knowledge as a TIG welder, the focus is naturally on equipment technology.

The complexity of the orbital welding system requires intensive training in equipment technology. This includes:

- Proper preparation of the components to be welded

- programming the system and/or correctly setting the specified program parameters
- setting the welding parameters on the device
  correct attachment of the tongs or welding heads

During welding, the operator monitors the system and watches for irregularities. Each weld seam should be inspected visually.

If the welding result is unsatisfactory, the operator must make the necessary corrections. It is advantageous if the operator is a certified welder, especially when working on construction sites.

The practical part of the training can be carried out both as part of process and work tests, but also by means of test welds and separately welded test pieces.

Test for operators

Practical	theoretical
Procedure/work test	TIG process
Test welds	Accident prevention
Test pieces	Weld seam preparation
	Weld seam defects

Evaluation of test pieces Test piece

Non-destructive testing	Destructive testing
Visual inspection	Macro sections
Surface crack testing	
Radiographic testing	

Tests for operators in the regulations

Unlike the testing of manual welders, the testing of operators is not yet regulated in standards. For operators of orbital welding systems used in steam boiler and pressure vessel construction, regulations have been drawn up in the VdTÜV Welding Technology Data Sheet 1163, Edition 3. 90 "Procedure test for orbital welds" as an appendix. Due to the increased complexity of the systems, it is necessary to revise these regulations.

Testing regulations at European level are currently being prepared. A draft standard, EN 1418 "Testing of operators for fully mechanical and automatic welding of metallic materials," already exists for this purpose.

According to this draft standard, the practical test is carried out either as part of a procedure qualification test in accordance with EN 288-3/4 or EN 288-8. The welding conditions must be described in a WPS.

14. List of sources

- Economical orbital welding with the TIG process (SFI W: Fanschen)

- Orbital welding in areas subject to monitoring and the qualification of operating personnel (F. J. Steinborn)

- TIG orbital welding, welding data, quality assurance, and cost-effectiveness (G. Engelhard, D. Pelkhofer, K. S. Schuchardt)

- Orbital welding – practical solutions (U. Dahms)

- Application criteria for TIG orbital welding of high-alloy electropolished pipes (Ing. H. Geipl)

- Experience with orbital welding in power plants (D. Pellkofer, G. Engelhard)

- Orbital welding from a processor's perspective (Dipl.-Ing. W. Höschen,

- Dipl.-Ing Klaus Lange)

- Considerations regarding sulfur (R. Heidrich, Dockweiler)

15. Conversion tables / data sheets