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Oscillation – Polarity Synchronized MIG/MAG Welding Process for Enhanced Performance in Automated Joining and Coating

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ABSTRACT

Most equipment in the Oil and Gas sector operates in harsh environments. Together with productivity needs that demand automation, special materials and high quality construction processes are required. Welding challenges in the case of large and complex equipment lie in positioning, tolerances and dissimilar thicknesses to be joined; regarding coating, issues are dilution and seam geometry. In order to address these problems a welding system able to determine the position of the torch along its oscillation and constantly adjust the welding parameters for consistent results, the Oscillation – Polarity Synchronized MIG/MAG Welding (MIG/MAG O-PS) was developed, as well as welding procedures for some specific applications.

KEY WORDS: GMAW, Negative Electrode, Mechanization, Oil Rigs, Bridgebility, Torch Weaving, Reliability.

INTRODUCTION

The Oil and Gas sector is characterized by equipment of high dimensions, operating in harsh environments and/or which are responsible for processing / transporting aggressive media. Some examples are ships, refineries, pipelines and oil rigs installed or operating in extreme temperatures, which process or transport corroding and eroding fluids with abrasive particles, under impact loading and constantly increasing work pressure (Huang, 1998; Matsuda, 1990; Yaedu, e D'Oliveira, 2005). Together with productivity needs that lead to automation, such conditions require not only the employing of special materials resistant to wear and mechanical loading, but also the application of construction processes that provide structures integrity, avoiding failures as leakage and fracture.

Welding challenges in the case of large and complex geometry equipment lie in the difficult joint alignment and positioning as well as the dissimilar thicknesses to be joined. These conditions set the need of welding processes robust enough to simultaneously assure high quality weld geometry (seam dimensions, bridgebility, wettability, consistent penetration) and avoidance of burn-through and lack of penetration when the pieces thicknesses are different, the welding gap varies or both factors at the same time. In the case of coating applications, the challenge is ensuring both metallurgical and geometrical surface quality. For that, low dilution (mixture) of the high resistant and high cost material with the base material by consistent metallurgical joining and good wettability for defect free overlapping of adjacent seams must be provided.

The required welding properties for both joining and coating (bridgebility, consistent penetration, burn-through freedom; low dilution, wettability) are not concurrent in respect to welding parameterization. In order to produce the required characteristics over the same welding task, a technological option is the variation of welding parameters during the operation, in dependence of the current welding torch position over the joint.

Thus the objective of this work was to develop an automated welding system able to determine the position of the torch in its oscillating movement (transversal or longitudinal to the joint) and constantly adjust the welding parameters. For this, dedicated software was developed, that synchronizes the oscillation movement with the welding parameters previously set for better results in each position of the torch trajectory to make the weld seam. The corresponding hardware for automation, human-machine-interface and communication was also developed. Finally, welding procedures were set for some specific applications regarding type of application (joining or coating) and materials (chemical composition, thicknesses).

NEGATIVE ELECTRODE MIG/MAG WELDING

The MIG/MAG welding process has since its industrial introduction and over the years proven to be one of the most productive and reliable joining and coating process. The high energy density provided by the low wire-electrode diameter yields a high melting rate, at the same time that the automatic material feeding contributes for adequacy for automation (Killing and Killing, 2002; Dilthey, 2005). Also, the innumerous possibilities of precise metal transfer, weld pool dynamics and heat control make the process highly versatile and adaptable for a profusion of conditions and applications. This flexibility arises from different combinations of gas mixtures, torch displacement characteristics and energy control (current and voltage waveforms). Developments in electronics and software make it not only more versatile, but also way more stable than other processes, as coated electrode (SMAW) (Silva and Dutra, 2009). Semi-automatic applications, where welding torch is displaced manually by a welder, also benefit from these characteristics.

Nevertheless the MIG/MAG process has its technological edges and the expanding of these edges are the focus of constant R&D efforts. That is accomplished by deepening the understanding of the welding arc physics, which supports adequate manipulation of the parameters to obtain distinct process response and the pushing of the technological edges. In this context, the present work deals with an unconventional MIG/MAG mode.

Normally, the process is used in the indirect polarity (CC+), which means that the wire-electrode is the positive electrode. This configuration ensures a coupling arc-wire on the droplet at the tip of the wire-electrode, suitable for stable droplet transfer in either short-circuiting or short-circuiting free modes. On the other hand, the direct polarity configuration (CC-), whereby the wire-electrode is the negative electrode, originates a coupling arc-wire above the tip of the wire-electrode, over the surface of the wire and not over the formed droplet (Tong et al, 2001; Ueyama et al, 2005; Cirino, 2009). Fig. 1 shows both situations.

The arc-wire coupling properties of the direct polarity has two major implications. Firstly the pinch forces, which would help impel the transferring droplets towards the molten pool, are not acting on the droplet. Thus there is a tendency for unstable material transfer, with poor formation and directioning of the droplets (Lancaster, 1986; Talkington, 1998). However results from Souza et. al. (2009) show satisfactory metal transfer characteristics and quality welds under CC- by applying an adequate gas mixture of Ar and O_2. Secondly the arc heat is more effectively consumed to direct melting of the wire-electode, and not to superheat the molten droplet (Tong et al, 2001; Ueyama et al, 2005), resulting in higher melting rate for the same arc energy. This yields as subimplication a lower heating, higher viscosity and lower wettability of the weld seam, as well as lower workpiece heating and lower penetration as found by Schwedersky (2007). These effects can be seen in Fig. 2. The welds were made with a 250 A welding current at a 15.0mm contact tip to work distance (CTWD). The other corresponding welding parameters are in Table 1.

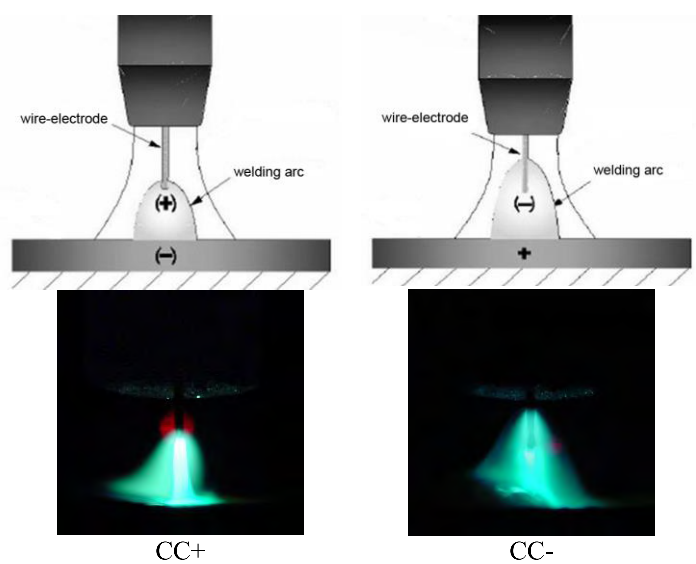

Figure 1. Arc-wire coupling for indirect polarity (CC+) and direct polarity (CC-) MIG/MAG welding (adapted from Cirino, 2009).

One can see that substantial geometrical differences are attainable with the negative electrode mode (CC-). Such features can be beneficial for determined applications, provided that the attached difficulties are properly dealt with and overcome. One technique in this direction is the AC MIG/MAG welding, covering mainly small thickness and aluminum applications (Tong et al, 2001; Ueyama et al, 2005; Puschner, 2007).

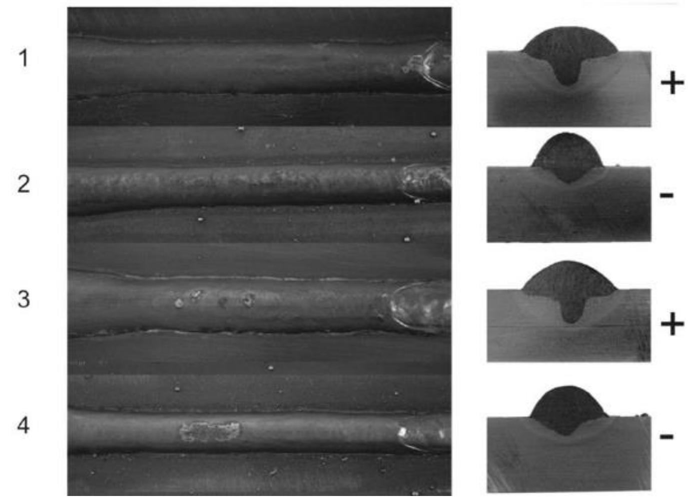

Figure 2. Effects of negative polarity MIG/MAG welding over weld seam geometrical profile (Schwedersky, 2007).

Table 1. Welding parameters for the samples in Fig. 1 (Schwedersky, 2007).

Test no.	Polarity	Shielding gas	Wire feed speed (m/min)	Welding speed (cm/min)
1	CC+	98%Ar+2%O2	8.0	30
2	CC-	98%Ar+2%O2	12.4	46
3	CC+	92%Ar+8%CO2	8.0	30
4	CC-	92%Ar+8%CO2	11.4	43

MIG/MAG O-PS FOR COATING APPLICATIONS

As stated, MIG/MAG CC- delivers a higher melting rate, which from the point of view of productivity is absolutely desired. Additionally it has lower penetration, which, in parallel to more material deposited, results in low dilution (relationship between volumes of substrate molten material and overall molten material). Such feature is highly sought after by coating weld applications, because low dilution means low mixture of the substrate material (lower resistance properties, lower cost) with the coating layer material (high resistance properties, higher cost) (Matsuda, 1990; Lai, 2004; Yaedu, e D'Oliveira, 2005). In this way the final chemical composition of the resulting coating can be kept more similar to the added material chemical composition, providing higher resistance (for example against corrosion, abrasion and erosion).

On the other hand the individual weld seams resulting from MIG/MAG CC- have a convex geometry due to poor wettability. This characteristic is detrimental for coating applications since such operations are mostly carried out by overlapping several adjacent seams, in order to cover large surfaces. When a next seam overlaps the previous one, the convex geometry impairs the accessibility of the arc and of the impinging droplets to properly melt the base of the weld, thus resulting in linear lack of fusion, longitudinally to the coating direction. Such a resulting coating layer can be seen in Fig. 3. In these tests, in an attempt to overcome the lack of fusion the torch was tilted and torch weaving was applied, ineffectively. Table 2 describes the welding parameters used.

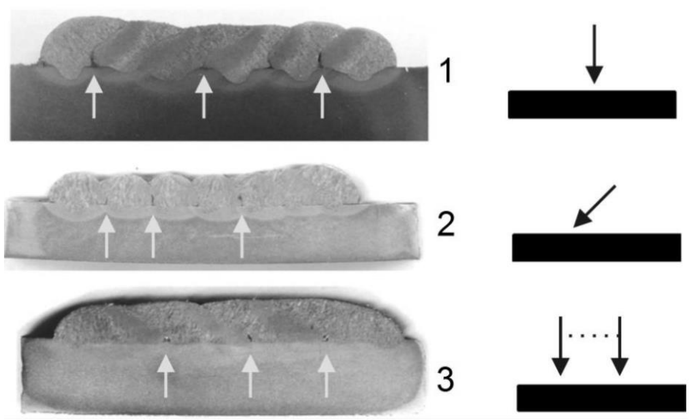

Figure 3. Coating layer deposited with MIG/MAG CC-.

Table 2. Welding parameters for the samples in Fig. 3.

Test no.	Voltage (V)	Resulting mean current (A)	Wire feed speed (m/min)	Welding speed (cm/min)	Tilt angle	Weaving frequency/ Amplitude
1	-32	-250	11.7	22.0	0°	0/0
2	-32	-250	11.7	22.0	45°	0/0
3	-32	-250	11.7	22.0	0°	2.5 Hz/ 12.0mm

Thus the challenge was assuring productivity and low dilution and at the same time good wetting properties and adequate weld bead side geometry. These desired properties are achievable by CC- and CC+ respectively. The developed technique then synchronizes the polarity of the MIG/MAG process with the oscillation movement of the torch in a way that, when the torch is in the center of the weaving, CC- is delivered and when the torch is at the sides of the weaving, CC+ is delivered. The technique, for its functioning, is only applicable to mechanized operations with a minimum of 2 degrees of freedom (2 axes, X and Y). The expected weld bead geometry is depicted in Fig 4..
The task of synchronizing the polarities with the oscillation trajectory of the torch is carried out via a digital synchronization signal generated in the manipulator controller and recognized at the welding source. The correspondent technique for oscillation-polarity synchronization is depicted in Fig 5.. As the torch in its weaving movement reaches and remains at a Y position higher than the set Y transition point (Yt), the manipulator switches the output signal to the power source to logic level 1, imposing CC+. In between, for Y positions lower than Yt, i.e. center of the weaving, the output signal is switched to logic level 0, imposing CC-.
The welding current values set in the power source must correspond to the non-changing wire feed speed, because of the differing melting rate capacities of CC+ and CC-.

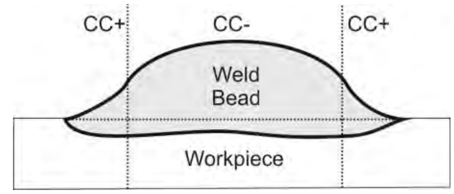

Figure 4. Appropriate bead geometry for weld coating and functioning of the oscillation-polarity synchronization.

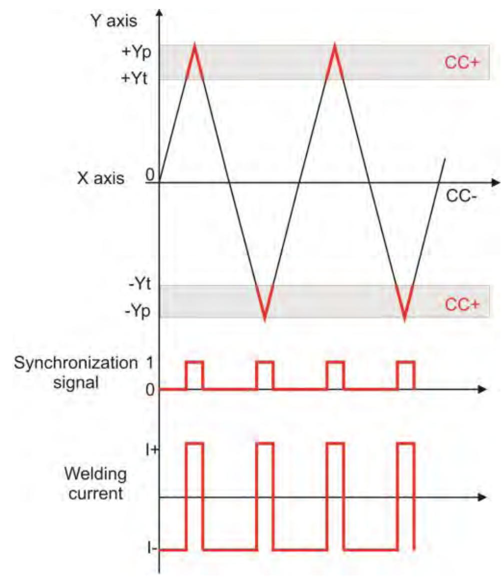

Figure 5. Synchronization logic of MIG/MAG O-PS.

The output synchronization signal from the manipulator is sent to the CPU that runs the human-machine-interface (HMI) software (called SAC - Advanced Control System, in Portuguese), whose interface screen is seen in Fig. 6. These CPU is also responsible for the joining of the signals from the manipulator together with the welding current settings, which are performed in the interface screen shown in Fig. 6. After composing the welding current command signal, the CPU, via USB communication, sends it to the microprocessor that commands the power unit of the power source, which delivers the welding current in either CC+ or CC- at the due moments.

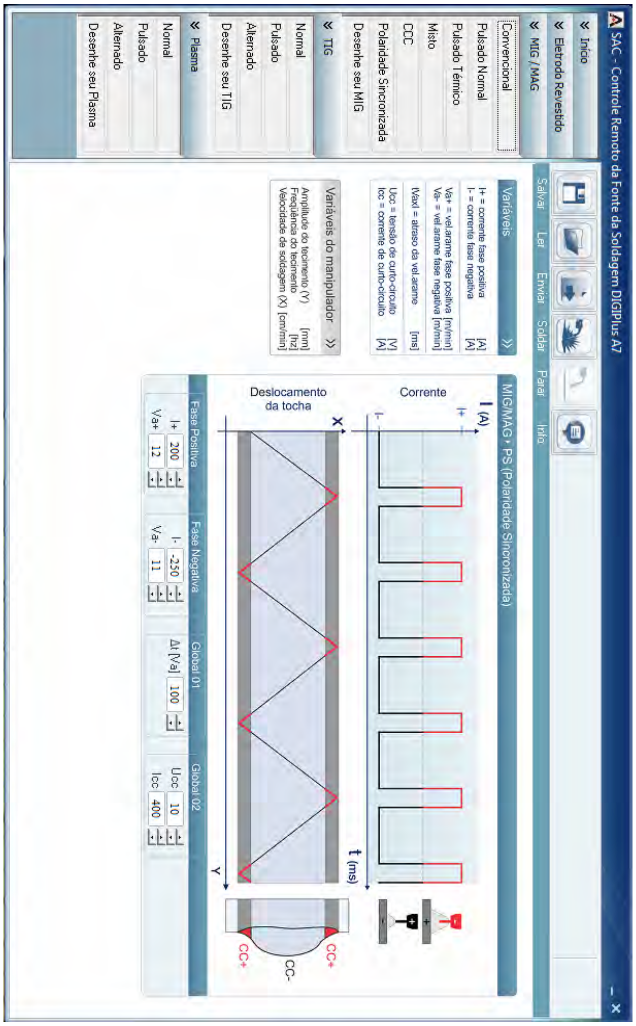

Figure 6. Graphical interface of the MIG/MAG O-PS in the SAC software.

The complete welding test rig for the welding tests is shown in Fig. 7. Procedures development activities lead to the coating result of Fig. 8. A 1.2mm diameter ER70S-6 wire-electrode and a Ar+ 2,0 % O_2 shielding gas mixture at 13.0 l/min were utilized. Welding source and manipulator used were developed in-house and have open architecture, enabling integrations and adaptations. The welding took place in the flat position. Table 3 describes the parameters of the welded coating shown in Fig. 8, with shallow penetration, quality surface with no excessive spattering and defect free. The welding speed difference between both procedures (CC- and MIG/MAG OP-S) lies in the fact that for CC- no higher speeds than 22.0 cm/min were feasible, since the pool becomes unstable and discontinuous because of higher metal pool viscosity.

Table 3. Welding parameters for the sample in Fig. 8.

Welding speed	43.6 cm/min
Oscillation frequency (Hz)	1.5 Hz
Oscillation amplitude, 2.Yp (mm)	12.0 mm
Polarity amplitude CC-, 2.Yt (mm)	8.0 mm
Wire feed speed (m/min)	11.5 m/min
Welding current in CC+ polarity, I+	270 (A)
Welding current in CC- polarity, I-	- 250 (A)

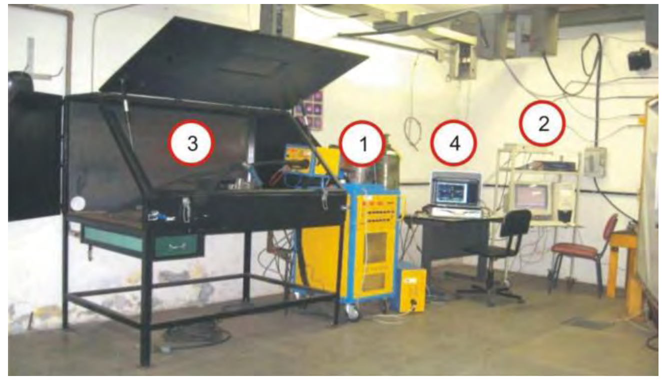

Figure 7. Welding tests rig: 1: power source; 2: CPU running SAC; 3: manipulator; 4: portable data monitoring system.

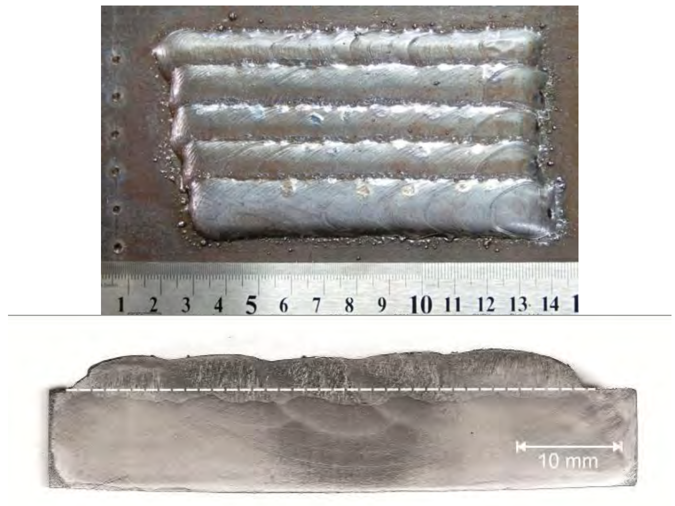

Figure 8. MIG/MAG O-PS produced weld coating.

The resulting oscillograms of the process can be seen in Fig 9, as well as the monitored wire speed.

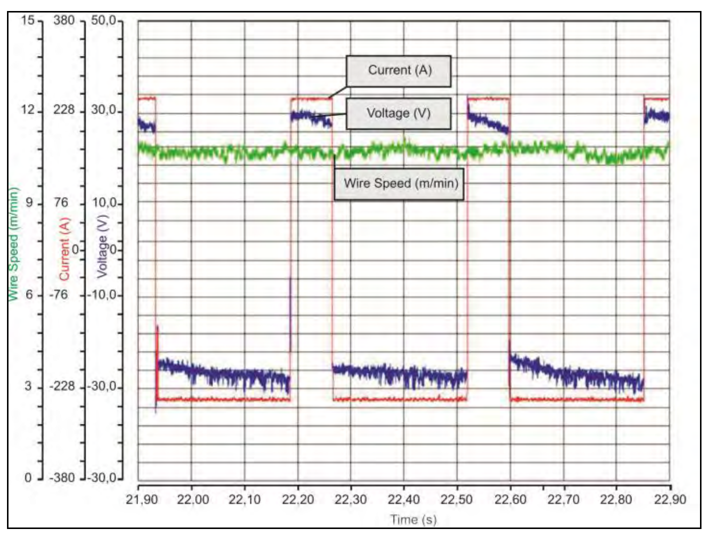

Figure 9. Oscillograms of MIG/MAG O-PS coating welding parameters.

Not only coating operations can benefit from the presented combined features of the indirect (CC+) and direct polarity (CC-) in MIG/MAG, but also joining application under complex, variable conditions.
Particularly in the case of large structures, as the ones found in the Oil and Gas industry including Shipbuilding, tolerances are high not only in the fabrication of parts to be welded, but also in the positioning of these parts for welding, often groove joints. Such conditions result in variable welding gaps, which normally can be dealt with only by experienced welders, or by means of sensors, incurring in further costs and equipment complexity. Another frequent complicating situation is the need for joining of parts of dissimilar thicknesses, which can be present together with varying gap conditions.
One way of providing more robustness to the MIG/MAG welding process is the use of a technique called switch-back welding. In this technique, depicted in Fig. 10, the torch oscillation is longitudinal to the joint, instead of transversal. In this way the final welding speed is a composition of the forward speed and the backward speed of the manipulator, whereby the forwards movement is always longer than the backwards one. The sought effect is a better distributing of the heat over the joint, avoiding burn-through, and main applications are thin sheets and root passes.
Switch-back welding has been investigated for root pass, attaining higher weld pool controllability and process robustness (Kaneko et al, 2007; Yamane et al, 2007; Yamane et al, 2008). Also higher welding speeds are reported (Bruecker, 2007).
In this case the synchronization signals management are a bit different from the case of transversal oscillation for coating. As described in Fig. 11, as the manipulator moving in the x axis with a preset speed va reaches a preset x position (in this example, 2d), it changes its direction and returns a preset length (in this example, d) with a preset speed vr. The welding torch is moved forwards with CC-, reducing heat input to the base material, thus avoiding burn-though. Then it is driven backwards with CC+, assuring good wetting and bridgebility. There is also a better overall heat distribution as consequence of the arc weaving over the welding pool.

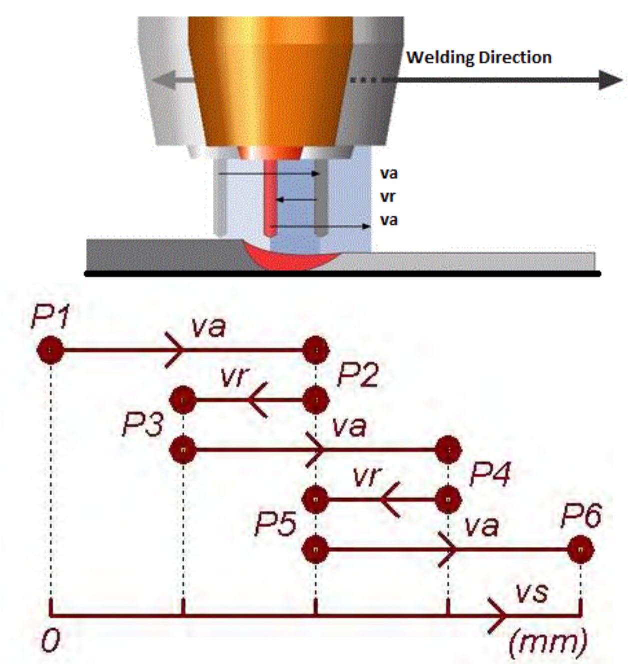

Figure 10. Switch-back oscillation technique: va: forwards movement; vr: backwards movement

The direction change is provided by the inversion of the direction command signal (DIR) of the controller to the manipulator's x axis motor. Parallel to DIR inversion an output synchronization signal (SS) from the manipulator controller is sent to the welding source's power unit controller, commanding the inversion of polarity. The current values for CC+ and CC- are preset in the welding source's HMI.

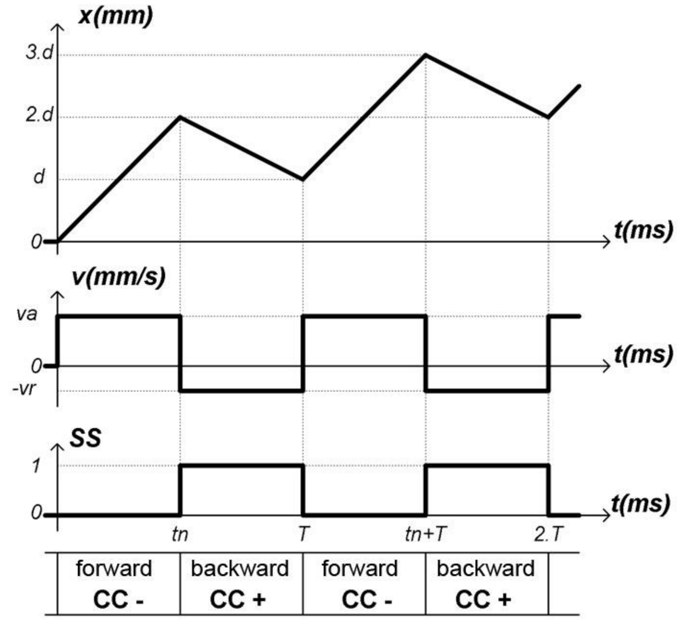

Figure 11. MIG/MAG O-PS switch-back oscillation technique.

Welding tests were carried out to verify the MIG/MAG O-PS's joining performance in a joint with dissimilar thickness sheets. A thin sheet of 2.25mm thickness was to be welded to a thick sheet of 6.35mm with varying gap (0.0 to 2.0mm) in a fillet joint. As seen in Fig. 12, a consistent weld was achieved, even at critical joint gap conditions. The correspondent MIG/MAG O-PS parameters are described in Table 4, with a 1.2mm diameter ER70S-6 wire-electrode and a Ar+ 2,0 % O_2 shielding gas mixture at 20.0 l/min. For comparison, the figure also shows the same jont performed with constant polarity (CC+) switch-back MIG/MAG welding. One can see a less prominent, but still consistent weld root, as well as better wetting on the weld face.

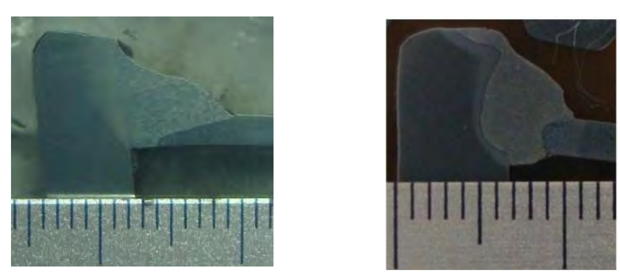

Figure 12. Left: Switch-back MIG/MAG O-PS produced weld; right: constant polarity (CC+) switch-back MIG/MAG. (scale in mm).

Table 4. Welding parameters for the sample in Fig. 12.

Welding speed forward,va (CC-)	3.2 m/min
Welding current CC-	- 220 A
Forward length	5.0mm
Welding speed backward,vr (CC+)	2.0 m/min
Welding current CC+	280 A
Backward length	3.0mm
Wire-electrode feed speed	Constant at 11.0 m/min

CONCLUSIONS

The mechanized MIG/MAG welding technique developed was able to achieve optimizations in weld coating and joining applications further than conventional, market available MIG/MAG solutions. At first, higher process robustness and weld reliability can be reached with the MIG/MAG O-PS. In critical applications, like large structures of the Oil and Gas and Shipbuilding industry operating in extreme environments (temperature, corrosion, abrasion, fatigue) these are key factors. The possibility of a wider control of heat input to the welded parts is also of relevance in these sectors, as special, heat sensitive materials are increasingly being employed. Furthermore, overall welding productivity (higher melting rates, higher welding speed, less rework) are also significant benefits.

Besides the presented examples other applications can benefit from the properties of the technique, like repair of in-service pipelines and thin-sheet welding.

The presented work was highly interdisciplinary and the performed innovations in software, hardware, automation and welding technology grant a wider application spectrum for MIG/MAG. Nevertheless, the focus at this first stage was the development and evaluation of the technique. For specific industrial applications, special materials, joint designs and higher misalignments than the ones tested further work has to be carried out for dedicated parameterization (development of welding procedures). Current R&D efforts are being undertaken at LABSOLDA aiming at enhancing the performance of the MIG/MAG O-PS by adding adaptive features to the system (online monitoring and correction of parameters like oscillation amplitude, welding speed and wire electrode feed speed).

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