# ONGOING ACTIVITIES AND PROSPECTS RELATED TO WELDING TECHNOLOGY AT LAPROSOLDA–BRAZIL

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An overview of Laprosolda' activities in research, development and innovation of welding processes is presented within three main areas: fundamentals, instrumentation and application. Since the group philosophy aims to develop different welding processes, in this work three cases are presented to illustrate these areas. The first one deals with the measurement of heat input for derivative arc-welding processes. The second case shows embedded systems developed for arc-welding monitoring and control. The last one presents the evaluation of conventional and controlled short-circuit GMAW processes for pipe welding. The objective is to present the ongoing activities and prospects related to welding technology within Laprosolda group. 16 Ref., 3 Tables, 10 Figures.

**Keywords:** *heat input measurement, monitoring and control, pipe welding, ongoing activities, prospects*

Welding technology demands continuous research, development and innovation through the years. It is defined by ISO 3834 (2005) as a special manufacturing process, since quality assurance cannot be realized by final inspection only. The joining is totally dependent on personnel, equipment and facilities. Therefore, development and improvement of equipment and methods are needed for constant development.

In this context, the Brazilian group named Laprosolda (Center for Research and Development of Welding Processes) started its activities in research, development and innovation of welding processes in 1992. The group philosophy aims to develop different welding processes in three main areas (or work line) named: the Fundamentals of Welding (arc physics, metal transfer during derivative processes, corrosion in welded joints, derivative arc-welding processes and numerical simulation of heat transfer, residual stress and distortion correlated to welding processes), instrumentation for arc-welding processes (remote monitoring and controlling for arc welding, embedded wireless monitoring system, low-cost vision system, calorimeters, sound monitoring system, waveform synchronized weaving, development of dedicated experimental rigs and luminescence sensors for AVC and joint tracking) and Application (pipe welding of API steels and CRA, overlaying for wear and corrosion purposes, RSW for AHSS in MFDC and AC machines, stainless steel weldability and health and safety — fumes, radiation and electromagnetic fields).



The objective of this work is to summarize the activities that have been done and what is intend to do in the future in Laprosolda group within the scope of these three areas. In order to illustrate these activities, three following cases are presented. The first one deals with the measurement of heat input for derivative arc-welding processes. The second case shows embedded systems developed for arc-welding monitoring and control. The last one presents pipe welding with conventional and derivative GMAW processes.

**Heat input measurement for derivative processes.** One of the most influent parameter on the welding process is the heat delivered to the workpiece (heat input) due to its direct connection with changes in metallurgical characteristics and mechanical properties of the weld joint. In order to quantify the heat input, different methods have been developed, both theoretical (analytical and numerical ones) and experimental (calorimetry), with large dispersion of results.

Calorimeters used for thermal studies in welding include different methodologies and physics basis for their construction and with, technological advances, calorimeters increase in sophistication. The last trend is the use of liquid-nitrogen calorimeter (Pepe, 2010), which is based on the measurement of evaporated mass from a recipient with liquid nitrogen and this mass is correlated to the heat input. Although liquid-nitrogen (N2L) calorimeter is a powerful tool for heat input measurement, it was not found in literature any attempt in automatize or take external effects into account.

Therefore, a fully automatic N2L calorimeter (Figure 1) was developed at Laprosolda basing on pneumatic automation for measuring heat input during different arc-welding processes, with improvement from previous literature work, minimizing the influence of operator, environment, welding time and transfer time (from rig to N2L recipient). Very good repeatability was found with maximum data scattering of 3.0 %.

Due to the increase importance of derivative GMAW processes, their thermal efficiencies were measured. These processes are surface tension transfer (STT), regulated metal deposition (RMD), cold metal transfer (CMT), GMAW-P (Pulsed) and GMAW-VP (Variable Polarity). It must be pointed out that the correct nomenclature to designate such variants is GMAW process with controlled short-circuit metal transfer by using commercial RMD/STT/CMT power sources manufactured by Miller/Lincoln/Fronius». This nomenclature is usually summarized in the form of RMD/STT/CMT Process in order to simplify both oral and written communication.

Welding parameters were adopted from previous Laprosolda researches (Vilarinho et al., 2009 and Costa, 2011) and preliminaries runs were carried out to select proper parameters at two current levels of 115 and 155 A. ASTM A36 plates were used with 1.2 mm AWS ER70S-6 wire and Ar + 25 % $CO_2$ (short-circuit) and Ar + 5 % $O_2$ (spray) as shielding gases. Data acquisition was carried out for monitoring voltage, current, wire feed speed and mass (scale read out) at 2.0 kS/s. Welding energy calculation was performed by Equation 1. The heat input is calculated by latent heat of N2L and thermal efficiency is calculated by dividing heat input by welding energy.

$$P_{\text{inst}} = \frac{\sum_{i=1}^{n} U_i I_i}{n}, \qquad (1)$$

where Pinst is instantaneous power, W; $U_i$ is voltage for each i sample acquired by DAQ system, V; $I_i$ is current for each $I$ sample acquired by DAQ system, A; and $n$ is the number of samples. This power must be also divided by the travel speed.

The results are shown in Table 1. It must be pointed out that this table shows one replica for each condition to show repeatability. It is possible to observe the higher values of electric power (and therefore welding energy) for GMAW-P and GMAW-PV (Figure 2). This is due to the fact that these processes demands free-flight transfer mode, i.e, they demand high arc lengths and therefore higher voltages when compared to the other processes (STT, RMD and CMT), which uses controlled short-circuit transfer.

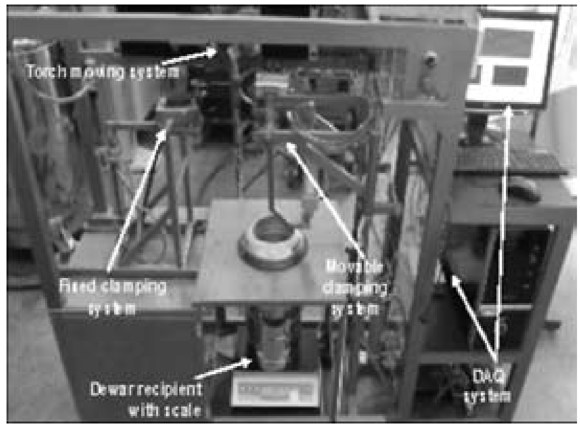


**Figure 1.** Experimental rig for N2L calorimeter

For STT process the measured values for thermal efficiency range from 74.0 to 78.7 %, when current arises from 115 A to 155 A. This shows an increase in heat losses by convection and radiation. The average thermal efficiency for STT is 76.4 %, which is low when compared to 85 % presented by other authors (Hsu and Soltis, 2003 and Pepe, 2010). For CMT process, Pepe (2010) presents average value of 86 %, which is also higher than the ones found in this work: 75.4 % for 115 A and 76.8 % for 155 A. The reason for this discrepancy is the range of parameters used here and other authors, and the fact that welding time for these authors are considerably lower (25 s for literature and 42 s in this work).

During RMD process, thermal efficiencies of 91.0 and 76.3 % were measured for 115 and 155 A, respectively, i.e., a similar behavior was found when compared to other processes. Measurements from other authors were not found in literature and since these results are close to the ones measured for STT and CMT, they are considered to be adequate. The main reason for such close measured values for thermal efficiency is due to the fact that the welding parameters were previously investigated (Costa, 2011) and represent an optimized condition for these three processes (STT,

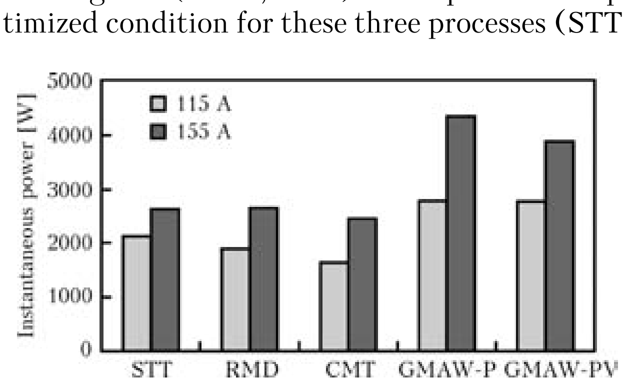


**Figure 2.** Instantaneous electric power for different GMAW processes

**Table 1.** Measurements by using the N2L calorimeter for derivative processes

| $I$, A | WFS, cm/min | $V_s$, cm/min | $L_c$, cm | $U_m$, V | $I_m$, A | $P_{inst}$, W | $E_{sold}$, J/mm | $E_{imp}$, J/mm | $R_{end}$, % |
|---|---|---|---|---|---|---|---|---|---|
| STT | | | | | | | | | |
| 115 | 2.3 | 12.3 | 15 | 18.4 | 119 | 2147 | 1055 | 774 | 73.4 |
| 115 | 2.3 | 12.3 | 15 | 18.4 | 119 | 2134 | 1045 | 780 | 74.7 |
| 155 | 3.3 | 17.6 | 15 | 16.6 | 154 | 2606 | 851 | 681 | 79.9 |
| 155 | 3.3 | 17.6 | 15 | 16.6 | 154 | 2629 | 892 | 692 | 77.5 |
| | | | | | | | | | 76.4 |
| RMD | | | | | | | | | |
| 115 | 2.3 | 12.3 | 15 | 17.5 | 118 | 1906 | 903 | 741 | 82.0 |
| 115 | 2.3 | 12.3 | 15 | 17.5 | 118 | 1917 | 902 | 722 | 80.1 |
| 155 | 3.3 | 17.6 | 15 | 17.5 | 156 | 2651 | 957 | 730 | 76.3 |
| 155 | 3.3 | 17.6 | 15 | 17.6 | 154 | 2645 | 944 | 720 | 76.2 |
| | | | | | | | | | 78.6 |
| CMT | | | | | | | | | |
| 115 | 2.2 | 11.2 | 15 | 10.7 | 114 | 1646 | 861 | 649 | 75.4 |
| 115 | 2.2 | 11.2 | 15 | 10.9 | 113 | 1658 | 863 | 652 | 75.6 |
| 155 | 3.3 | 17.0 | 15 | 12.0 | 156 | 2464 | 816 | 622 | 76.3 |
| 155 | 3.3 | 17.0 | 15 | 11.9 | 157 | 2465 | 851 | 657 | 77.2 |
| | | | | | | | | | 76.1 |
| GMAW-P | | | | | | | | | |
| 115 | 3.0 | 15.8 | 15 | 21.2 | 113 | 2773 | 1049 | 744 | 70.9 |
| 115 | 3.0 | 15.8 | 15 | 21.5 | 113 | 2816 | 1031 | 725 | 70.3 |
| 155 | 4.0 | 21.3 | 15 | 25.7 | 154 | 4368 | 1184 | 813 | 68.7 |
| 155 | 4.0 | 21.3 | 15 | 25.3 | 155 | 4360 | 1180 | 812 | 68.9 |
| | | | | | | | | | 69.7 |
| GMAW-PV | | | | | | | | | |
| 115 | 3.0 | 15.8 | 15 | 21.9 | 115 | 2775 | 1462 | 860 | 58.9 |
| 115 | 3.0 | 15.8 | 15 | 22.1 | 115 | 2793 | 1512 | 867 | 57.3 |
| 155 | 4.0 | 21.3 | 15 | 23.7 | 154 | 3898 | 1408 | 816 | 57.9 |
| 155 | 4.0 | 21.3 | 15 | 23.8 | 154 | 3922 | 1394 | 808 | 57.9 |
| | | | | | | | | | 58.0 |

RMD and CMT) for a given situation (welding of carbon-steel pipes in single pass).

GMAW-P process presented a decrease in thermal efficiency from 70.6 to 68.8 % when current decrease from 115 A to 155 A, which again indicates a higher heat loss for higher currents and a demand for higher arc voltage. The latter contributes to a higher heat input. The average value of thermal efficiency for GMAW-P found in literature (Joseph et al., 2003) varies from 62 to 73 %, against 69.7 % in this work and in Bosworth (1991), which reports values from 75 to 80 %.

Among the GMAW processes, GMAW-PV is the one that presented the lowest thermal efficiency with an average of 58.0 %, with no statistical variance between current levels (115 and 155 A). Harwig (2003) reports that the heat input by GMAW-PV is at least 25 % lower when compared to GMAW-P and almost half when compared to conventional spray transfer for a given wire feed speed.

**Embedded systems for monitoring and control.** Different devices from different manufacturers provide monitoring for welding process, with focus on specific parameters. Ongoing trend follows the creation of equipment for practical and simple use, with the elimination of adaptive circuits and greater flexibility. This is highlighted by the fact that the monitoring equipment must be adapted to the manufacturing environment and not otherwise. The demand for flexibility is

**Table 2.** Comparison of resolution for different resolutions of A/D converters

| Parameter | Range | Required resolution | A/D 10 bits | A/D 12 bits | A/D 14 bits |
|---|---|---|---|---|---|
| Voltage, V | ±100 | 0.1 | ±0.196 | ±0.048 | ±0.012 |
| Current, A | ±500 | 1 | ±0.978 | ±0.244 | ±0.061 |

accomplished by replacing traditional cabling system by wireless communication one, which is not readily available/applicable for welding monitoring.

The initial idea of an embedded device (complete and independent system prepared to perform a unique and determined task — Cunha, 2007) with wireless communication is originated in the dissemination of computer networks for manufacturing and technological development of communication products and portable data (notebooks and smartphones). This scenario indicates the integration of welding monitoring with wireless communication, which is an achievable reality and promising technology. Therefore, it is presented a series of independent embedded («autonomous») systems with specific features (proprietary technology, scalability, portability, autonomy, flexibility and low cost/simplicity of operation), namely:

- wireless signal monitoring;
- vision-based joint tracking;
- waveform synchronized weaving;
- sound monitoring for regularity index determination.

The first one is a system for wireless arc-welding signals monitoring (so-called MoSo — Welding Monitor in Portuguese, Machado, 2011), which consists of an independent embedded system, capable of monitoring arc-welding processes and communicating in a robust and flexible way to different devices, with a user-friendly system, using the state-of-the-art in communication technology. It employs an A/D converter resolution of 12-bit (Table 2) with the Microchip ZeroG ZG2100M for Wi-Fi communication module and the dsPIC33FJ256GP710 as the device to be used.

The human interface of MoSo system is based on web server technology and it is accessible by any equipment with a built-in web browser. The main page of the system has a configuration section, where the user selects among fixed acquisition time (0.5 to 4 s), finite and continuous acquisition, and the possibility for data saving.

Once initiated, MoSo receives the data from the embedded system and shows waveforms for voltage, current and wire feed speed. It also shows the rectified mean and RMS (root mean square) values of each parameter. The whole system was tested with GMAW short-circuit and spray, GMAW-Pulsed, GTAW-AC (alternating current) and GTAW-Pulsed. Using the statistical parameter knows as Pearson coefficient (r), the waveforms saved by MoSo where compared to a reference system (from a worldwide manufacturer of DAQ systems), and shows results above 0.7, indicating a strong correlation between the waveforms. The rectified mean and RMS values obtained show relative errors below 2.5 %, which is required by BS7570 (2000). As an example, Figure 3 presents a comparison between the results (waveforms) from MoSo system and reference one for GMAW with short-circuit transfer. The resemblance between the obtained signals from both developed and reference systems is evident. Therefore, the developed system met its objective and it is capable of performing the required tasks.

The second system is a low-cost vision system, which is based on the use of high-power (70 W) laser diodes with low cost. It can be used for man-assisted supervision, for joint tracking and for process parameter control, such as arc length and weaving amplitude. The developed vision system is so-called ViaSolda and consists of an analogic low-cost camera (CCD Costar SI-M331) with low exposure time (1.25 μs) and resolution of 768 × 494 pixels. Also ViaSolda system uses a developed near-infrared (905 nm) illumination set that consists of 19 high-power laser diodes (Osram SPL PL90_3). It also has a high power circuit and a programmable MCU (microcontroller) capable of generating enough power to the

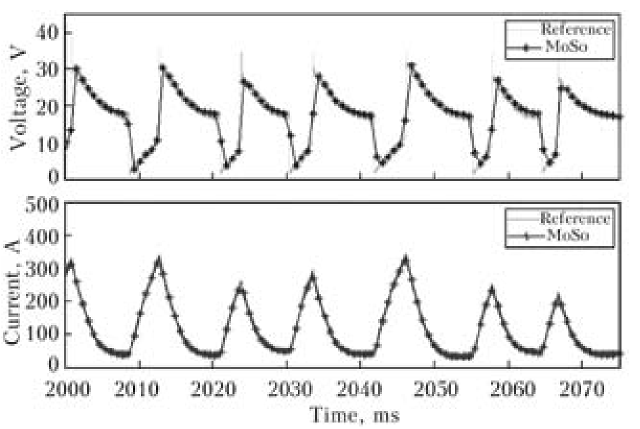


**Figure 3.** Current and voltage signal obtained by using MoSo and reference system: 19.0 V; 4 m/min, Ar + 25 % $CO_2$ and 1.0 mm ER70S-6 electrode

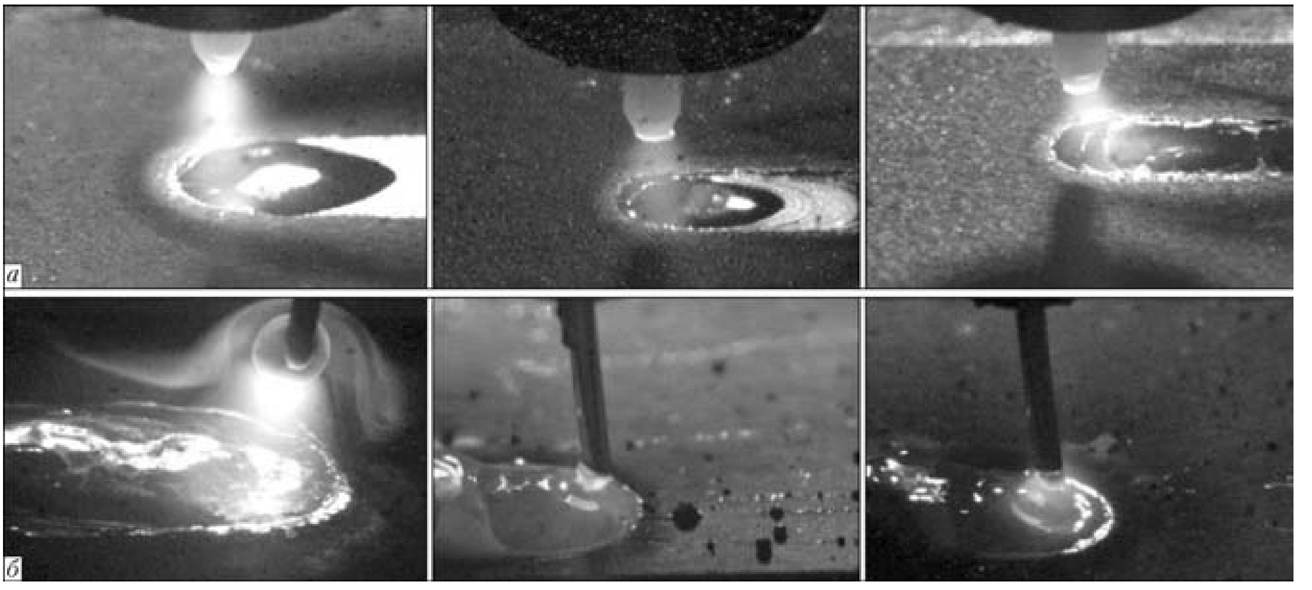

**Figure 4.** ViaSolda system images from left to right: *a* — GTAW at 250, 150 A (shorter exposure) and 150 A (longer exposure); *b* — GMAW at 150 A for globular transfer (30 V), short-circuit transfer during short-circuit (18 V) and short-circuit transfer during open arc (18 V)

diodes and an electronic trigger to turn the camera on (shuttering) and the illumination system at the same time. In this case a frequency of 30 Hz (frames per second) was selected (Mota, 2011).

The images obtained by ViaSolda are shown in Figure 4. It is possible to assert that the developed low-cost vision system is fully capable of viewing the weld pool and its surrounds and, therefore can be used as a vision-based joint tracking system.

The third proposed system is an embedded and dedicated system capable of monitoring the torch angles (attack and working angles) during torch movements (travel speed and weaving). By using the measurement of the torch angle, the system can control the power source and lead to different set of parameters (in the present version, three different sets are possible). This is underlined by the requirements of field joining, which involve variability in geometry, consumables, equipment, personnel skills, land site and weather. Among those, the tolerance of the groove itself is a major concerned when mechanized welding is performed. Therefore, it is important to develop strategies that can cope with poor geometric tolerances, which are estimated from 1.6 to 3.0 mm for both root opening and alignment of the groove. One possible strategy for overcoming this limitation is the use of synchronous waveforms with torch positioning during its weaving. The idea is to vary welding parameters, such as positive to negative polarities or high to low currents, dependently to the waving setup, as shown in Figure 5. Also different waveforms can use, since they are synchronized with weaving.

Therefore, it was developed and assessed a system Conparte (Parameter Control System by Weaving, in Portuguese), which is capable of monitoring the torch angles (attack and working angles) during torch movement (travel speed and weaving). During the weaving three regions are considered (as shown in Figure 5) and numbered 1–3. Once each of these regions is identified, the Conparte system commands a welding power source (IMC DIGIPlus A7) to select a specific welding program. The identification of each spatial region can be done by different sensors. In

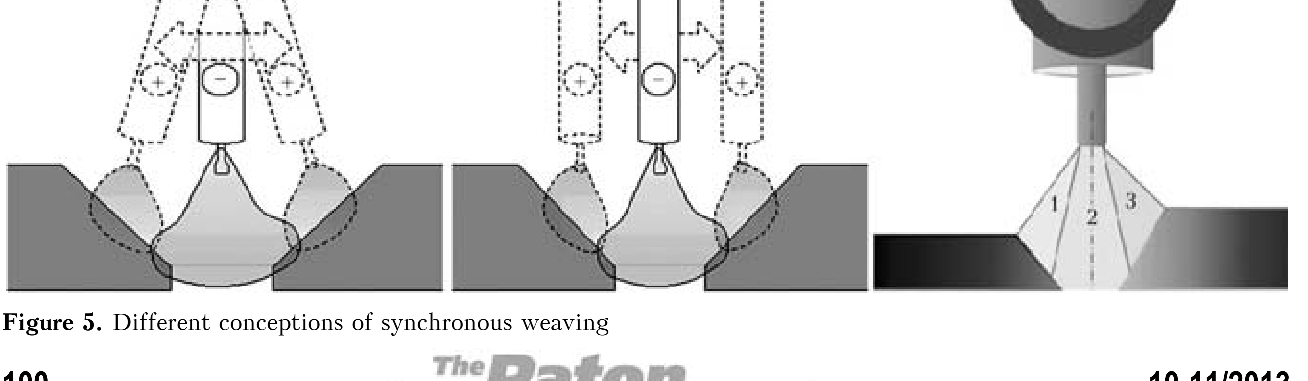


**Figure 5.** Different conceptions of synchronous weaving

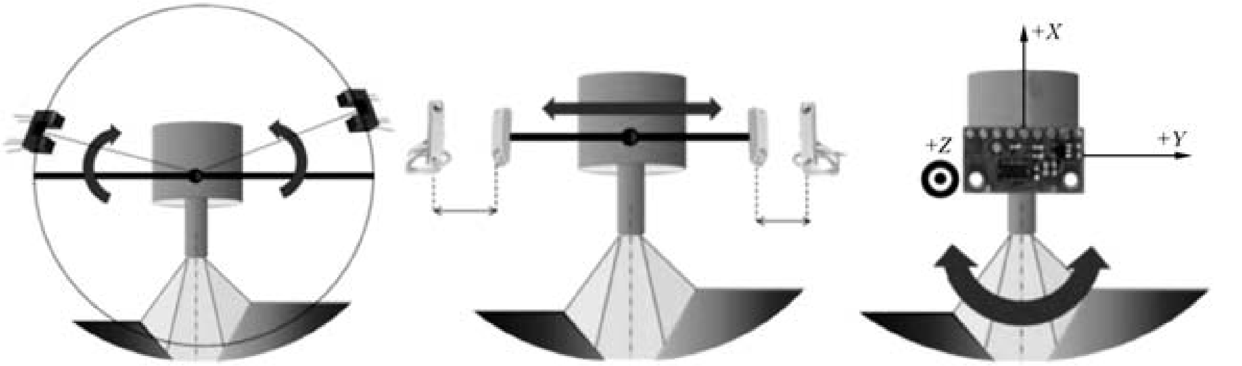


**Figure 6.** Sensors used in Conparte system: magnetic 9028PA (*left*), optic infrared receiver TCST1103 (*center*) and accelerometer MMA7361L (*right*)

this case, a three-axis accelerometer (MMA7361L), a magnetic-contact sensor (9028PA) and an optic infrared receiver (TCST1103) were used (Figure 6). As mentioned, it identifies three mentioned regions and set three different programs in the power source, accordingly to Table 3 for GMAW with ER70S-6 1.2 mm wire and Ar + 25 % $CO_2$.

The final acquired signals for the three sensors are shown in Figures 7, *a*–*c*, respectively for optic infrared receiver, magnetic-contact sensor and three-axis accelerometer sensors. These images show the synchronization between the program selection (P2 or P4) according to Table 3, with immediate response shown in current curves. Therefore, it is possible to state that Conparte system was capable for performing waveform synchronized weaving.

The fourth system is a sound monitoring system. The sound monitoring has been always treated as a possibility for welding control but with little application, justified by its low robustness by external noises interference. Sound monitoring is not new (Arata et al., 1979), but successful application has been possible by using modern instrumentation and processing (Cudina et al., 2008 and Cayo and Alfaro, 2009). Differently from these authors, instead of using the signal to identify a trend on its own, here it is propose to use the sound to calculate a regularity index, already established during the monitoring of electrical signals (voltage and current).

**Table 3.** Programs used for validating Conparte system

| Sensor | Program | Current, A | Wire feed speed, m/min |
|---|---|---|---|
| Optic infrared receiver | P2 | 150 | 3.0 |
| | P4 | 200 | 3.5 |
| Magnetic-contact sensor | P2 | 300 | 6.0 |
| | P4 | 260 | 8.0 |
| Three-axis accelerometer | P1 | 220 | 6.0 |
| | P2 | 260 | 8.0 |
| *Note*. In all cases, the pulse period was set as 18 ms for each program. | | | |

The study of metal transfer regularity in short-circuit welding processes has already been done by electrical signals monitoring. Different indexes for establishing suitable conditions, such as regularity in this transfer, have been proposed. One of them is so called Vilarinho's Regularity Index (IVcc), which is a methodology created by the group Laprosolda/UFU based on Equation 2.

$$\text{IVcc} = \frac{\sigma t_{cc}}{t_{cc}} + \frac{\sigma t_{ab}}{t_{ab}}, \quad (2)$$

where $\sigma t_{cc}$ is the standard deviation of short-circuit period (time); $\sigma t_{ab}$ is the standard deviation of open-arc period (time); $t_{cc}$ is the average of the short-circuit period (time); $t_{ab}$ is the average of open-arc period (time).

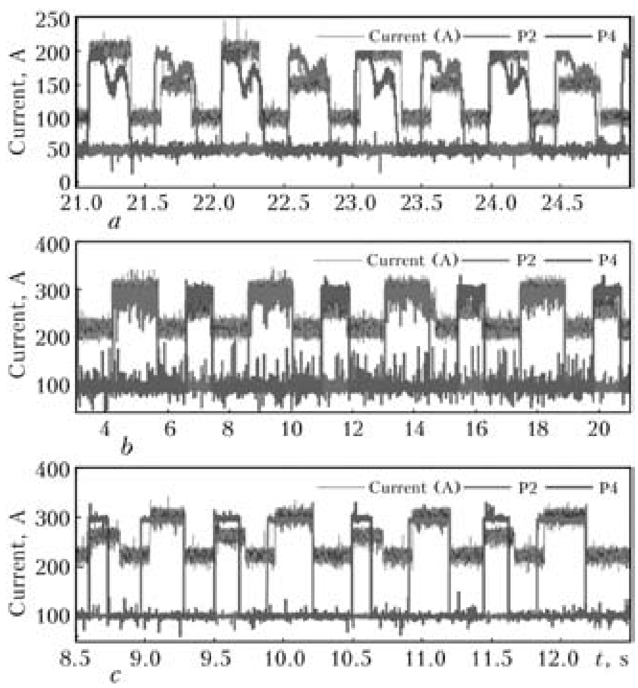


**Figure 7.** Signals obtained from Conparte system for different sensors: *a* — optic infrared receiver; *b* — magnetic-contact sensor; *c* — three-axis accelerometer

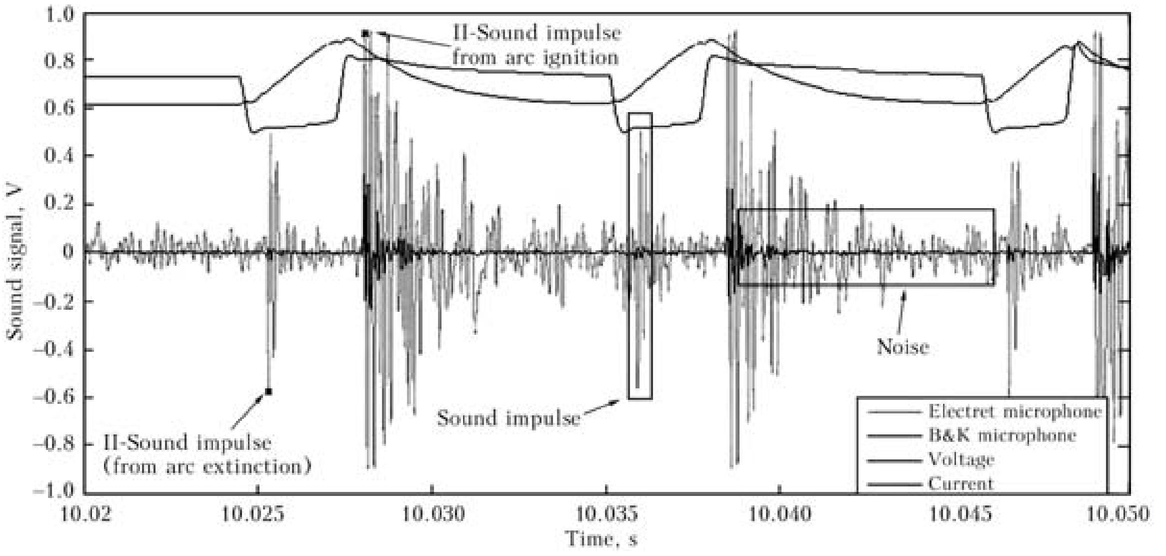


**Figure 8.** Relationship among current, voltage and sound signals

Therefore, it is presented the use of sound signal from conventional short-circuit GMAW process for IVcc determination and compare it with the one obtained by electrical signals. The use of conventional short-circuit is justified by the fact that besides it has been widely used, it is expected to its use in opposition to derivative processes, which demand high-cost equipment. The final goal is to verify the feasibility of sound monitoring to measure metal transfer regularity without electrical instrumentation or where sound monitoring is simpler and straightforward. Weldments were carried out and comparisons between the results provided by electrical and sound analysis have been carried out. Two types of microphones (electret and commercial ones) and three distances (200, 400 and 800 mm) from the process were employed.

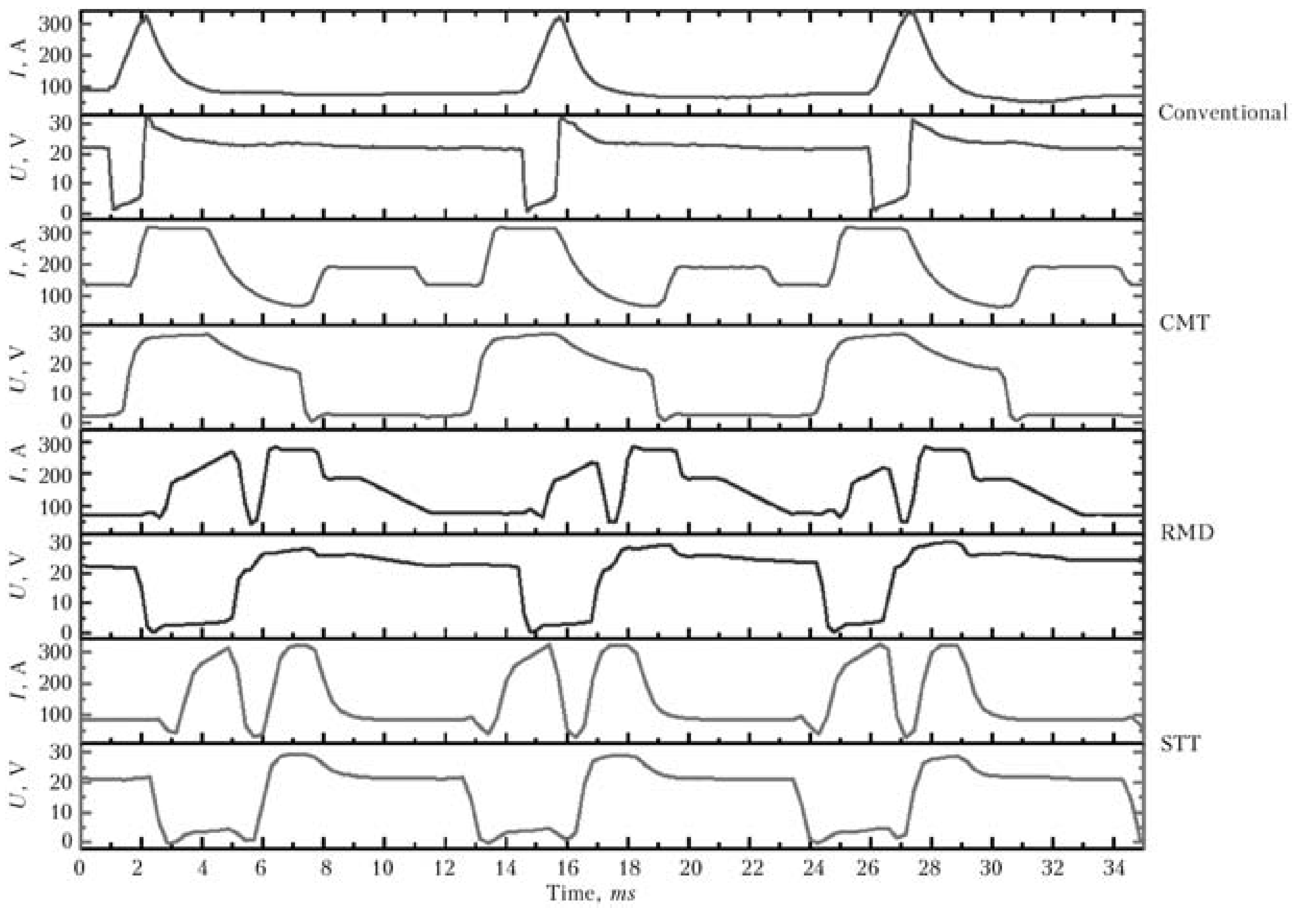


**Figure 9.** Example of obtained electrical signals

Figure 8 illustrates the obtained results when comparing electrical and sound signals, which after processing calculate the mentioned index with difference lower than 0.5 %. It is possible to conclude that the developed sound monitoring methodology is capable of measuring the regularity index similarly to the one calculated from electrical signals and the suitable distances between the microphones and the welding is from 200 to 400 mm, with a delay time of 0.7 and 1.1 ms, respectively. For 800 mm (2.1 ms delay) the signal-to-noise relationship is so low that calculation was not possible.

**Pipe welding with conventional and derivative GMAW.** Brazil's continental size and the increasing demand for oil and gas in new industrial areas outside Brazilian south-southeast axis have established a great challenge for fast and reliable expansion of pipelines. Such need requires the continuum development of joining technologies, which main trend has been the development of power sources capable of waveform control. This feature introduced the concept of GMAW derivative process and its version for short-circuit metal transfer (also known as controlled short-circuit) has become a trend in the search for high productivity and high quality weld beads, especially for pipe welding.

It is believed that the waveform control, achieved in such GMAW derivative processes, improves the metal transfer and reaches stability on both process and weld pool. Also the waveform control aggregates value to the power source, i.e., the conventional short-circuit GMAW process requires power sources with lower cost in comparison to the derivative ones. Therefore, it is presented the use of GMAW processes with conventional short-circuit transfer and derivatives (STT, RMD and CMT) for pipe welding, especially for the root pass in pipe welding, which is critical for the cadency of field welding.

The root pass was investigated using downhill progression, 1.2 mm ER70S-6 wire and both Ar + 25 % $CO_2$ and pure $CO_2$ as shielding gases. A V-butt joint was used with 15° bevel angle, 1 mm root face and 3 to 4 mm root opening preparation in 8-mm thickness on API 5L X-65 with 8″ pipe. Contact tip to work distance was 15 mm. Conventional short-circuit GMAW and RMD processes were carried out by using PipePro 450 RFC power source. PowerWave 450 power source were used for the STT process, whereas TPS 5000 were employed for CMT. The parameter set for each process was varied together with weaving technique and wire-feed speed, keeping the same amount of deposited material. Analyses of the

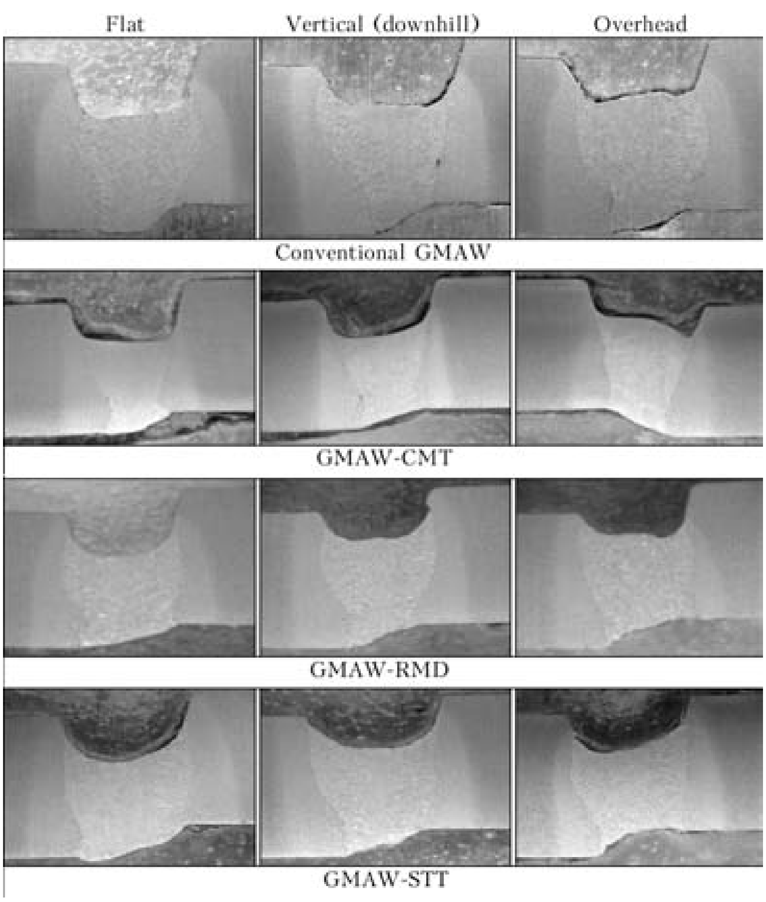


**Figure 10.** Examples of suitable weld beads (macrographs) obtained with up to 1.5 mm of Hi/Low (thickness 8 mm)

weld beads were carried out by visual inspection and metallographic analysis based on of API 1104 (2010).

Figure 9 presents an example of electrical signals (voltage and current) obtained during welding. The waveforms for the derivative process comprise two stages. The first one refers to the moment when the droplet and the electrode touch the weld pool and there is a control for reducing the increase in welding current. And a second one, when the current increase promoting the droplet detachment, followed by a maintenance of constant value for both voltage and current, which characterizes the open arc phase.

Concerning the bead quality, Figure 10 presents the macrographs with misalignments (Hi/Low) for each process at three positions: flat, vertical (downhill) and overhead. These results show that derivative and conventional short-circuit GMAW processes are capable of achieving sound welds even if misalignments are present. In this case, the correct setup of welding parameter is capable of handling up to 1.5 mm of misalignment in the root (Hi/Low). It indicates that derivative and conventional short-circuit GMAW processes present suitable operational envelopes for all investigated processes, even when misalignment (Hi/Low) up to 1.5 mm is presented in the root.

**Final considerations.** Different ongoing activities and prospects related to welding technology within Laprosolda group were presented. They indicate the group philosophy, which is aimed to develop different welding processes in three main areas (or work line): the Fundamentals of Welding, Instrumentation for Arc-welding Processes and Application. It is possible to conclude that the results and the techniques presented here are powerful tools for R&D&I in welding technology.

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