A computational tool for the control of arc welding processes

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This study describes the development of a control and monitoring platform for arc welding processes which provides versatility and efficiency in the scientific study of welding technology. The implemented system is capable of executing different welding modalities as well as effecting substantial changes in their function logic in a simple and didactic manner. One of the innovations promoted by the development of this system is the possibility of drawing wave forms of the welding current for the MIG/MAG process, thus allowing a deepening of the studies related to the metal transfer and, as a consequence, presenting technological innovations for this process. The control and monitoring platform developed was structured in such a way as to be able to incorporate new technologies, allowing its updating together with the evolution of welding processes. In this context, this system is presented as an alternative with significant potential for welding studies in teaching and research institutions both in Brazil and abroad.

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1 Introduction

Arc welding processes have been consolidated for over half a century; however, at the time of the original process it was considered impossible that many of the modern versions currently in commercial use could be made viable. This is the case of variable-polarity MIG/MAG. The existence of such a version of the MIG/MAG was considered impossible because the arc is extinguished with polarity changes. Even if this extinguishing problem was resolved, by means of peak voltage systems (called high-frequency systems) the process would only be possible with the metal transfer in free flight. This is due to the fact that short-circuit transfer requires current peaks at the time of physical contact between the drop and the weld pool. Obviously it would be impossible to avoid the coincidence of the current going to zero during the polarity changes with the need for the current peaks mentioned. However, the advent of new welding technologies, allowed by the advances in power and control electronics, led to controlled metal transfer in which the drops are transferred in a synchronised manner with the wave forms adjusted in the welding equipment. This then enabled the development of the above-mentioned AC welding modality.

Also, controlled metal transfers resulted in the Surface Tension Transfer (STT) process [1, 2] for root passes which is a commercial solution, presented by the manufacturer of welding sources Lincoln Electric. This process is derived from the consolidated conventional MIG/MAG with short-circuit metal transfer, presenting, as a fundamental difference in its working principle, the imposition of a current wave format pre-established by the equipment. The imposition of the current in the STT process, together with the monitoring of the voltage between the contact tip and the piece in real time, makes the welding source control the metal transfer in a synchronised way, besides guaranteeing, up to a certain point, a constant drop diameter and a significant reduction in the quantity of spattering. As in the AC MIG/MAG process, the STT technology only became possible with advances in control and power systems which made the acquisition of signals, data processing and the performance of welding source output circuits at very high speed viable.

As can be observed, as power electronics and control and monitoring systems of signals evolve, new possibilities for innovation in welding processes appear, inducing the research institutes to diversify their activities in an ever more intense rhythm. However, university laboratories and technological centres which study welding technology are often limited to the use of commercial equipment which is totally aimed at industry and does not allow significant manipulation of its working principles. The closed

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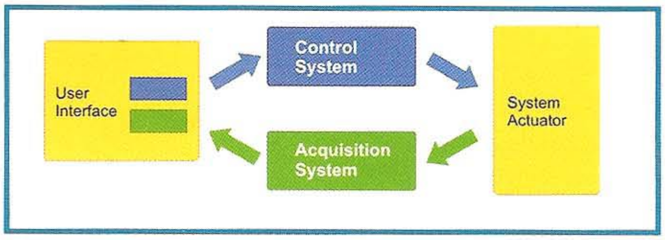

Fig. 1. Conceptual layout of the "Advanced Control System".

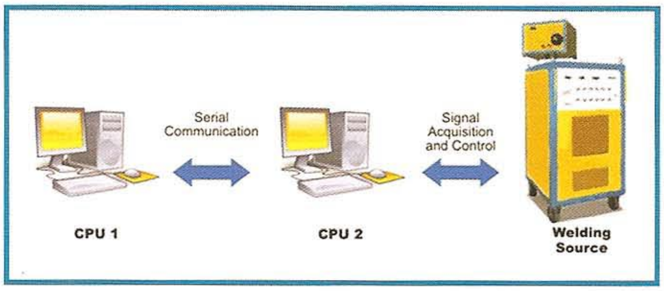

Fig. 2. Physical layout of the "Advanced Control System".

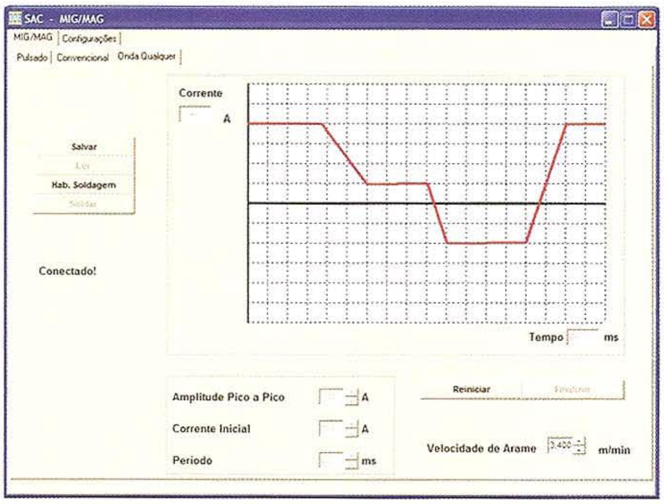

Fig. 3. Interface for the drawing of current wave forms of the "ACS".

architecture of this equipment inhibits significant scientific advances or limits them to concepts pre-established by the manufacturers.

Furthermore, a research institution needs to invest a considerable sum of financial resources in order to procure some variants of the welding processes since each one requires specific equipment. As a way to solve this drawback a control platform for arc welding processes was developed and is described herein.

2 Development of a research platform for new arc welding techniques

The platform developed, called the "Advanced Control System" (ACS), was implemented with the aim of facilitating communication with the user and at the same time achieving a high degree of flexibility in terms of operation, allowing the researcher to carry out relatively complex interventions in different welding processes in a fast and efficient way. The "ACS" was also structured to be capable of incorporating new technologies, thus allowing its continued evolution according to the needs of each research and development centre [3].

In order to ensure such characteristics the platform was structured as shown on Fig. 1.

The user interface, besides having the function of configuring the different welding modalities, also has the role of exhibiting the signal acquisition in real time.

The commands provided by the operator, mediated by the user interface, are decoded by the control system of the platform which, in turn, acts on the system actuator, the welding source. On the other hand, the acquisition system takes the readings of the welding variables and displays them again for the user by way of the same interface.

Although different technological solutions can be used for the conception of this system, the first generation, Fig. 2, used two microcomputers which communicate through their serial ports. CPU 1 is responsible for the user interface and CPU 2 is responsible for the signal acquisition and control. The system actuator is the "Inversal 450" welding source, entirely developed at Labsolda and, therefore, well-known to all of the laboratory team.

The use of two CPUs for the conception of the "ACS" originates from the fact that two different operating systems are required for the current platform, MS-Windows and MS-DOS. The MS-DOS operating system, despite being outdated in relation to personal computers, has highly functional tools for data treatment in real time and until today has been used in embedded systems. However, the user interface offered by MS-DOS lacks flexibility and agility in its handling which inhibits the implementation of functions for the manipulation of welding processes and system navigation as a whole.

In order to compensate for the restrictions of the interface with the operator imposed by the MS-DOS platform, this interface was implemented in the MS-Windows system, widely known to PC users, which provides significant support of programs for the conception of units of data management and manipulation of variables. However, MS-Windows presents significant difficulties in terms of hardware intervention, that is, this operating system does

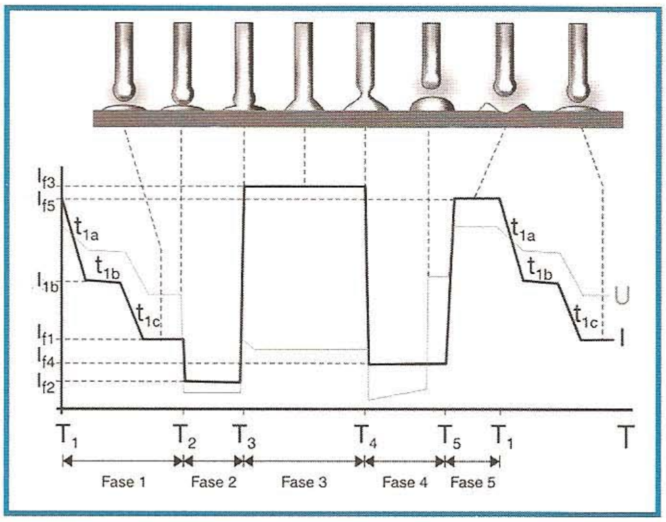

Fig. 4. *Wave form of the controlled short-circuit process.*

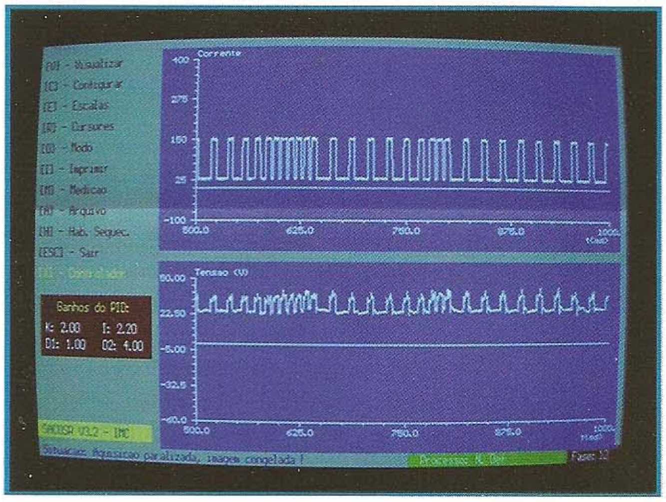

Fig. 5. *Sample of signal acquisition carried out in "ACS".*

not offer, in a relatively simple way, tools to aid the programming and implementation of systems in real time, an aspect which is absolutely necessary for the effective control of welding processes.

Thus, the alternative adopted to combine the benefits of both operating systems, as well as to facilitate the development of the "Advanced control system", was the use of two processing units, as mentioned above. The unit managed by MS-Windows, responsible for the user interface and manipulation of variables of the welding processes, and the CPU which uses the operating system MS-DOS, with the functions of managing control routines and signal acquisition.

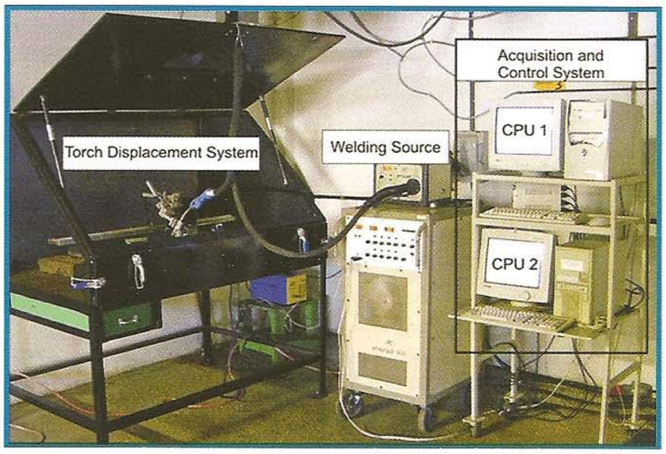

Fig. 6. *Complete rig of the "Advanced Control System".*

2.1 User interface (CPU 1)

The software responsible for the interface with the user was implemented on a structure offered by "Borland C++ Builder" which provides a layout for the construction of control platforms suitable for the purposes of "ACS".

The interface with the user was conceived with two operation modes, conventional manipulation of the variables of the welding modalities and the intervention in the working principles of the processes by way of drawings of wave forms.

The conventional interface for the manipulation of the variables of each process allows access to the parameters of the welding modalities in a way similar to that in panels of equipment found commercially.

The second mode of "ACS" operation, that is, the interface developed for the drawing of wave forms, Fig. 3, allows the operators to freely manipulate the welding current totally according to their criteria, making it viable to study the behaviour of processes according to significant variations in their wave forms.

Systems which provide the operator with the aforesaid freedom in welding wave form development have already been commercially available for some time like "Wave designer" [4], devel-

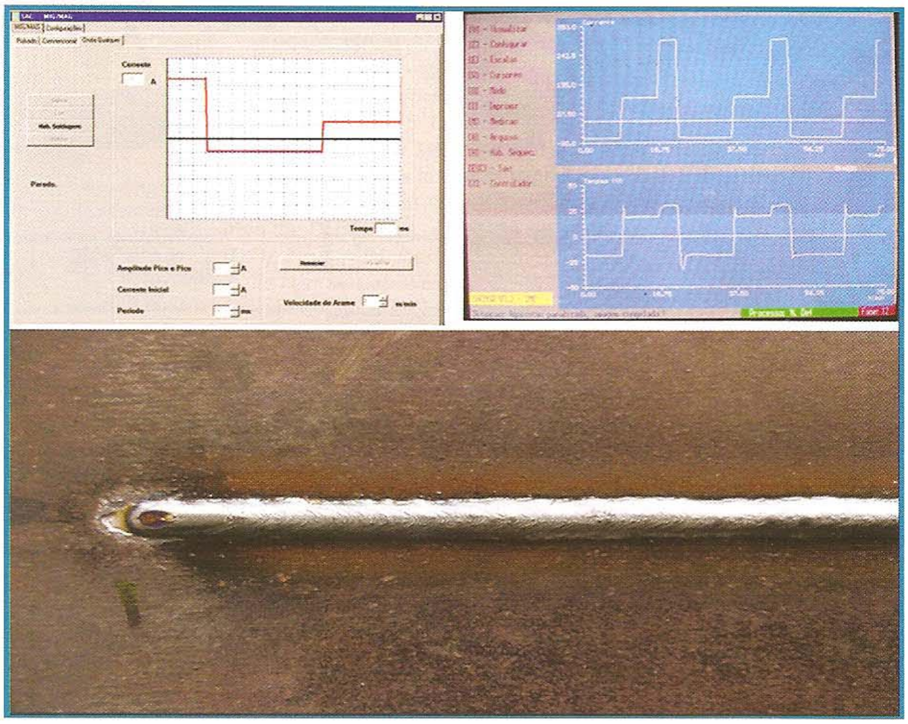

Fig. 7. AC MIG/MAG welding in steel.

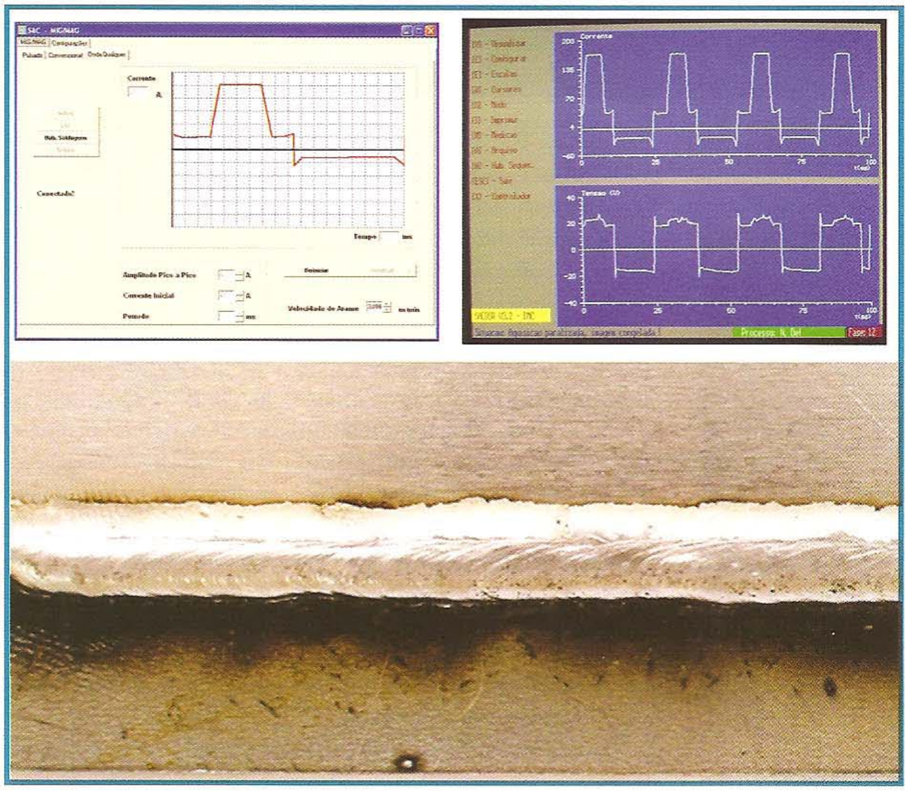

Fig. 8. Joining of aluminium plates with galvanised steel.

oped by Lincoln Electric. However these systems generally limit the user to certain adjustments, not allowing significant variations of the procedure's operation principles. In many cases, for example, polarity changes during welding are not allowed. Due to these limitations the "ACS" differs significantly from its commercially available counterparts since complete wave shaping freedom is provided. It enables the user to draw any wave form through mouse dragging, as in an image editor software.

On the other hand, the free drawing of current wave forms allows the operator to impose non-factual working conditions on a certain welding process. The versatility offered by "ACS", when not used coherently, may lead to an unstable process, or even to non-operation. Thus, the welding source, developed to operate as the system actuator, has circuits which monitor the welding process in real time, with the aim of verifying possible arc extinction, promoting its reigniting from appropriate circuits. It is known, however, that arc extinction is not the only problem which can be caused by poorly dimensioned current wave forms. However, it is expected that, for a powerful tool such as "ACS", the users have some knowledge of welding technology to enable them to edit the wave forms coherently with the requirements of each process.

For both of the operation modes of "ACS", the software responsible for the control routines imposes on the system actuator the wave forms for each process, whether conventional or created according to the criteria of the user. Apart from auxiliary control logic, such as the detection of short circuits and the actuation of trigger relays, the code implemented by these processes does not receive any other type of feedback from the welding source, being able to be identified almost as a command system only.

However, in the welding modalities with controlled metal transfer there is generally the need to monitor the process variables throughout the period. The dependence which exists between the welding parameters and the instantaneous conditions of the process leads to a need for a permanent feedback channel between the welding source and the control software of the system.

The signal of the feedback system comes from the arc voltage or from the arc current. It is derived from the data already stored and processed by the monitoring system, thus allowing easy implementation of different operating and control characteristics on the system. Among the developments which were made possible by these special features, there is the "CSC" (Controlled Short Circuit) which uses voltage feedback and has similar characteristics to the STT which was already mentioned.

The CSC welding process was developed, in principle, as an alternative for root-pass welds. The attempt to develop a specific welding process for this application originates from the fact that the conventional MIG/MAG modality, by voltage command, does not allow the operator to act directly on the welding current, that is, the parameters available for the process manipulation (voltage, wire-electrode speed and inductances) make this current a consequence of the arrangement of these variables. It should also be mentioned that the current is dependent on the conditions under which the welding is being carried out, that is, the contact-tip-to-work distance (CTWD), welding speed, frequency and form of weaving, among others. The concern regarding the welding current is due to the fact that it is the main factor responsible for the wire/electrode fusion and, as a direct consequence, a determinant variable of the process [5]. The lack of alternatives for direct action over its amplitude inhibits the control of the deposit in the root which can generate failures and even make certain applications non-viable.

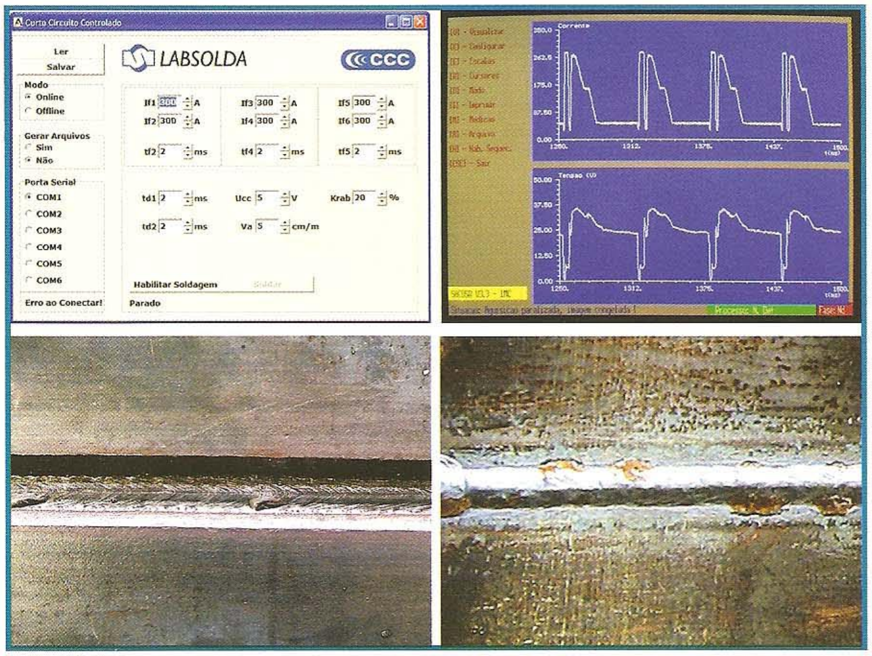

Fig. 9. Welding of root carried out with the CSC process.

In this context the "CSC" was developed as a process for current command, that is, despite the metal transfer still occurring due to phenomena similar to those which promote the detachment of the drops in the conventional MIG/MAG process, the welding source imposes differential current levels over a period, Fig. 4. These current levels are synchronised with the metal transfer stages, from the formation of the drop, passing through its constriction, up to its detachment. In this wave form, there is also a reduction in the quantity of spattering, a requirement which is fulfilled due to the low current levels imposed at the time of the establishment of the short circuit and the restriking of the arc [6].

In the "Advanced Control System" the interface developed for the "CSC" enables the manipulation of all of the current levels of the wave form shown on Fig. 4, as well as the temporisation and auxiliary variables for the working of the "CSC". The "ACS", from the parametrisation provided by the user, reproduces the current wave form at the actuator output (welding source), being responsible for all of the process control and signal acquisitions.

2.2 Control and Acquisition of Signals (CPU 2)

By way of a communication protocol, CPU 1 sends all of the parametrisation of the welding processes, via the serial port, to CPU 2 which, from the storage of the variable provided by the operator, starts the welding operation.

All welding processes control logic was implemented in the CPU 2, as well as the necessary software routines for the acquisition of signals. Both the sampling rates, as the response in frequency of the system, were adjusted to 10 kHz which was assumed to be sufficient for the applications implemented in the laboratory so far. In this CPU, as previously described, the operating system used is MS-DOS since it allows, in a more simple way, access to the hardware components of the PC. Thus, it is expected that this processing unit contains the device for the conversion of digital signals (used by the microprocessing unit) to analog signals (recognised by the welding source). The device for the signal conversion is a board also developed at Labsolda which carries out both the control and the acquisition of the welding source signals. Denominated "Interdata", this acquisition and control board comprises: a 16-channel A/D converter, an 8-channel D/A converter, a frequency meter and a digital port with 8 inputs and 8 outputs.

In the interface created for the signal acquisition, Fig. 5, traces of the current and arc voltage are available, enabling the adjustment of sampling times as well as the synchronising of the acquisition from the events (trigger) and also the storage of traces obtained in files of points which can be plotted later on electronic worksheets.

2.3 Welding Source

As previously mentioned, the "Advanced Control System" uses the "Inversal 450" welding source, completely designed by Labsolda, as an actuator. The equipment is configured in such a way that it receives external signals and it is able, from these signals, to command the welding process in a way predetermined by the user. This system, in its complete configuration, can be observed on Fig. 6.

3 Results and Discussion

The "Advanced Control System", in its current configuration, is being used as a support tool in different lines of research at Labsolda and also at other research institutions in Brazil and one in Chile. The results presented here relate to different tests carried out in different situations in which the "ACS" provides differentiated support to studies, such as the possibility to draw wave forms and simulation of innovative welding processes such as controlled short circuit. In the studies related to the AC MIG/MAG welding process the "Advanced Control System" was used for the drawing of differentiated wave forms for the modality, varying the percentage values in each polarity, in order to analyse the stability, penetration profiles and fusion rates, Fig. 7. Through simply redrawing the current wave form it is possible to vary the duration of each polarity, allowing, due to its simplicity, batteries of tests to be performed, with the aim of carrying out different analysis with velocity, flexibility and efficiency which are rarely found in other development rigs. In the specific case of the AC MIG/MAG, it was possible to carry out conclusive analysis using "ACS" due to the real effectiveness of this modality, as well as to verify the applicability of the process in different situations.

In a different line of development at Labsolda, AC MIG/MAG welding is also used for the joining of aluminium plates with galvanised steel. Due to the low currents used in this joining, adaptations need to be made to the wave forms of the process [7], as can be seen on Fig. 8.

The increase in the current levels before and after passing through zero improves the stability of the process, thus demonstrating the great efficiency of this system which makes the respective welding modes viable due to the very detailed design of the wave form in the polarity transitions.

For studies related to the CSC process, the objective of which is to obtain high-quality root passes, as also proposed by the STT, the system provides a platform for the complete manipulation of the CSC variables, from current levels and temporisations up to fine adjustment of the drop detachment conditions of the process.

Fig. 9 shows an example of a welding procedure with a screen of the command data, the form of the trace of the current and voltage and the weld obtained with the surface aspect and the root.

4 Conclusions

The "Advanced Control System" was consolidated as a research platform at Labsolda. Currently it is being used for different lines of development in the laboratory, it being a fundamental support tool for academic and technological studies.

The flexibility of the "ACS" makes it a versatile and polyvalent tool for teaching and training support since it gathers, on the same rig, different welding processes, each with their different particularities, dealt with by the platform in a simple and practical way.

Essentially, the "ACS" offers technological and economic advantages and replaces, on a single platform, different pieces of welding equipment which, if acquired individually, would require substantial budgets.

Besides the features mentioned and welding processes which the "ACS" is able to command, the platform has a great potential for adaptation to the different needs of each research line, enabling easy evolution for the control of more complex welding modalities, as well as it being suitable for the specific requirements of each line of development, with reduced costs and significant advantages.

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