Real-time assessment of the stability of metal transfer in GMAW-S process based on arc emissions

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Introduction

The operational activities of welding processes can be divided in three stages: pre-welding, welding and post-welding [1]. In the first stage are contemplated the choice of materials, sequence of operations and choosing of optimal welding parameters. The second stage contemplates welding operations such as monitoring and control techniques for reaching uniformity on the welding bead shape for ensuring a good quality. The third stage is related to quality assessment operations of the welding beads resultants aiming to identify discontinuities for later to be re-worked. One way of asses the welding quality is throughout standard specifications, which lists the limits of discontinuities which are acceptable for a particular application. Quality specifications are not the same for all weld applications. The gas metal arc welding process in short circuit transference mode (GMAW-S), is the manufacture process most used in the metallic construction industry. Diverse advantages such as the high rate metallic transference, elevated penetration and facility to welding in diverse positions, makes this process become the most requested and the focus of the present work.

The choosing of optimal welding parameters is critical for reaching an acceptable welding quality. The setting of welding parameters was typically done by trial-and-error or based on experience of welder, which might not result in the best setting. Different researches were carried out aiming to find adequate methods for choosing of optimal welding parameters for diverse welding processes by monitoring of some welding parameters as arc voltage and welding current. Simple methods are based on analysis of data acquired during previous weld runs where the objective is to identify a set of parameters that produce a regular heat and mass transference. Advanced methods aim to find a steady state of the monitored parameters that assure regularity in the heat and mass transference. Although these methods show promising results, in many cases they are not applicable to real welding operations, due to the hard welding environment where the set of optimal welding parameters chosen previously, loses effectiveness in the case of simple methods and due to the complexity of acquisition and data processing system suggested by the advanced methods; in both cases the lack of qualified personnel for management these systems represents a great limitation. In addition, great part of these methods is based on off-line data processing, what implies additional work time. In the present work is proposed a methodology for find an optimal set of welding parameters for GMAW-S processes in real time based on monitoring of arc emissions processed by a PIC 18F452 microcontroller.

The electric arc is a current flowing between two electrodes through an ionized column of gas called plasma. The space between the two electrodes can be divided into three areas of heat generation: the anode, the cathode and the arc plasma [2]. In the welding arc the electrons flow from cathode to anode and the positive ions flow from anode to cathode. These have been accelerated through the plasma by the arc voltage and they give up their energy as heat. The heat is generated in the cathode area mostly by the positive ions striking the surface of the cathode as well as the heat is generated at the anode mostly by the electrons.

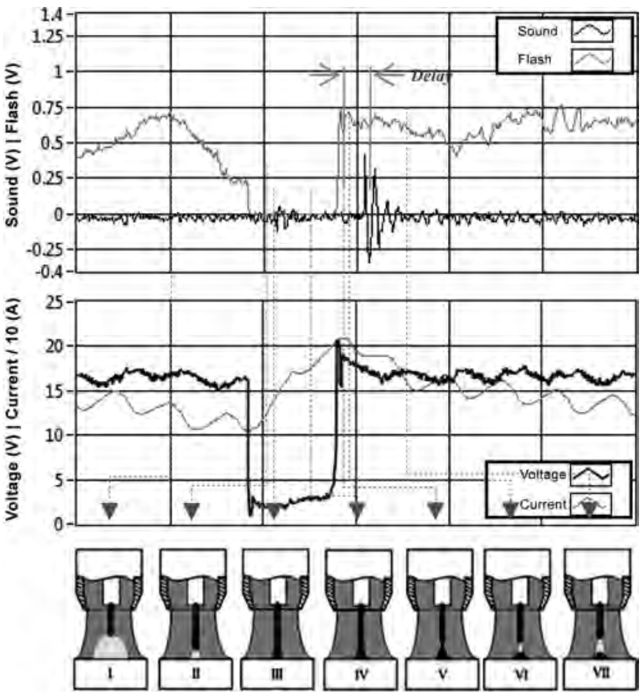

Figure 1. Short circuit transference mode.

These electrons, atoms and ions that are flowing along the plasma column are in accelerated motion and constantly colliding. This chaotic flow together with the heat and the electromagnetic fields of the welding arc produces the arc emissions of mechanical and electromagnetic nature manifested as sound and brightness respectively. These emissions are produced principally due to changes of the electric power in the arc column [3, 4]. Figure 1 shows the short circuit transference mode in seven stages and the behaviour of the monitored signals. The electrode wire is fed at a constant speed but burn-off during the arcing period is insufficient to maintain constant arc length (I, II). The arc gap closes and the wire eventually contacts the weld pool (III). In response to this short circuit, the welding current rises rapidly causing resistive heating in the thin filament of electrode wire which bridges the gap (IV). The bridge ruptures (V), a portion of the heated electrode is transferred to the weld pool and the arc is established (VI, VII). If the wire feed speed and power source values are carefully matched the short circuiting process is repeated at regular periods.

The first two graphs show the welding arc emissions (sound and flashing). Both signals matches the voltage and current signals (two last graphs), but notice that sound signal has a delay due to its airborne nature. The flashing signal does not shows a perceptible delay, matches the arc voltage and therefore from its behavior is possible to measure statistical parameters of the melting rate frequency and of the short circuiting time.

The metal transference rate is governed by the equation (1):

$$MR = \alpha I + \frac{\beta l I^2}{a} \qquad (1)$$

Where, **MR** is the melting rate expressed in [m s^{-1}], **I** is the current [A], **l** is the stick out [m], **a** is a cross sectional area of the electrode wire [m^2], α and β are constants; $\alpha \approx 3 \times 10^{-4}$ [m s^{-1} A^{-1}] and $\beta \approx 5 \times 10^{-5}$ [s^{-1} A^{-2}].

The first term of the equation (1) refers to arc heating effect whilst the second term to joule effect heating (resistive heating) [5]. Finding optimal welding parameters means remaining the melting rate constant. When the transference rate reaches this state, the welding process reaches stability. The steady state in GMAW-S process is reached when the pool fusion oscillation and short circuit frequency are same [6], when there is balance between wire feed speed and its melting rate [7]. There are four conditions for reach a high stability: maximum short circuits number, minimal standard deviation of the short circuits periods, minimal mass transfer in each short circuit and minimal spatter level [8]-[10]. The characteristics depicted before are the qualitative requirements of the melting rate for reaching a steady state in welding. In quantitative terms, there are diverse stability criteria that relate principally the mean and standard deviation of the arcing and short-circuiting time. In the present work will be used a criteria relating the melting rate frequency and the short circuiting time which will be explained in the next items.

Experimental Setup and Methodology

The data control, monitoring and acquisition was performed using the equipment set up as shown in the Figure 2.

The welding power source is the Fronius TS 5000; this power source has a control interface, the ROB 5000, which has inputs and outputs (analog and digital) that are linked to manual command and at the USB acquisition cards (DEV1 and DEV2). Signals of voltage, current, sound and flashing were acquired simultaneously sampled at 20 kHz by the PCI 703S acquisition card. The arc sound signal was acquired by the decibel meter B&K (sensor1). The flashing arc was acquired by a transimpedance sensor OPT 101 (sensor 2) in combination with an optic band-pass filter (380 – 430 nm). The arc voltage was acquired by a voltage shunt and optical insulator. The welding current was acquired by a Hall Effect sensor. Signals coming from stability sensor also were recorded by the PCI 703S acquisition card. The weld runs were carried out using steel plates AISI 1020 (30 mm x 200 x 6,50 mm), electrode wire AWS A5.18 ER70S-6 with 1 mm of diameter, shield gas

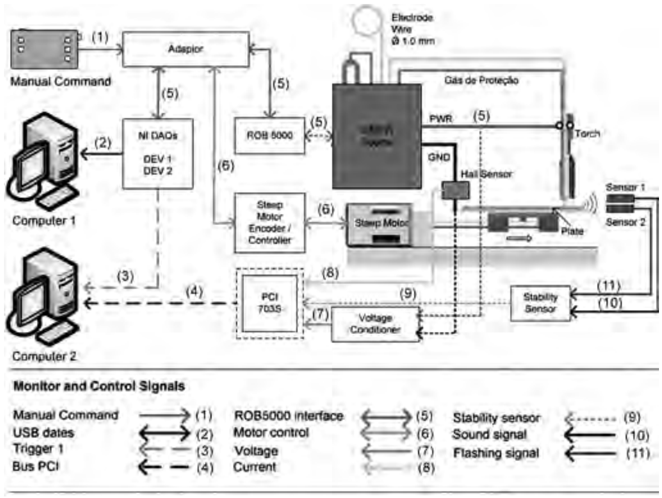

Figure 2. Experimental Setup.

was the mixture of argon and carbonic anhydride M21 (ATAL 5A/Ar 82% + CO_2 18%).

Results and Discussions

Stability Factor

Figure 3 shows the short circuiting monitored by the arc voltage and flashing. From both signals can be monitored the metal transfer period TP as well as the arcing time AT and the short circuiting time ScT. One stability criterion is the maximum short circuiting frequency ScF [6], but this criterion does not take in account the time of arcing and short circuiting. If in

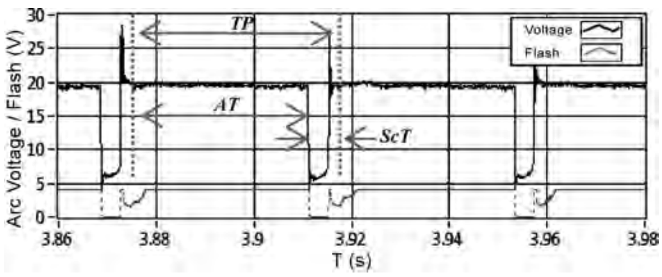

Figure 3. Arcing and Short circuiting times.

each transference cycle, the times of arcing and short circuiting vary, the welding process has not reached stability, although the frequency value is constant (Eq. 2). Short circuiting time represents the time during which the metal is transferred from tip of electrode wire to fusion pool. The uniformity of the time of this stage indicates that the transference is relatively uniform. The arcing time is responsible of heating the electrode wire tip which determines the quantity of mass that will be transferred in the next short circuit, therefore also this time has a strong influence over short circuiting time. The equation (3) relates the short circuiting time with transference period.

$$ScF = \frac{1}{(AT+ScT)} \qquad (2)$$

$$TC = \frac{ScT}{(AT+ScT)} * 100 \qquad (3)$$

Where ScF represents the short circuit frequency [Hz], TC the transference cycle [%], the short circuiting time [s], AT the arcing time [s].

The Sensor

For monitoring of the stability factors: transfer frequency and transfer cycle, has been performed a sensing system based on sensing of arc flashing. The stability factors could be monitored sensing directly the arc voltage, but for making it, it is necessary insert some circuits into the welding process what could generate loading effects over the process and that finally this situation could misrepresent the metal transference and even could reduce the quality of welding. Besides this, inserting of hardware on the welding process represents additional working time as well as qualified personnel. Flashing arc sensor does not need conventional electrical connections to welding process (Figure 4).

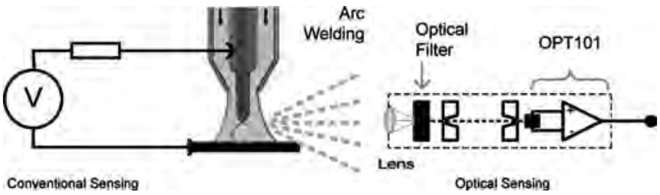

Figure 4. Flashing arc sensor

The Figure 5 shows the block diagram of the system circuit. The sensor output signal is pre-processed by a low-pass filter of fourth order and after by a threshold circuit, finally the resultant signal (pulses) is processed by the microcontroller. The result of this processing is shown in a display and also are generated two analogue signals representing the transference frequency and the transfer cycle.

modules are turned off and saved, after the TMR3 and CCP2 modules are turned on and now, the microcontroller is waiting for a rising edge. When this event occurs the TMR3 and CCP2 modules are turned off and saved, after the CCP1 and CCP2 saved values are processed according the equations (2) and (3). The resultant values are shown in a display. Also these values are

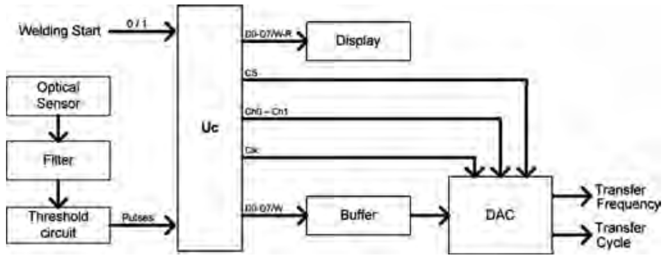

Figure 5. Sensor system.

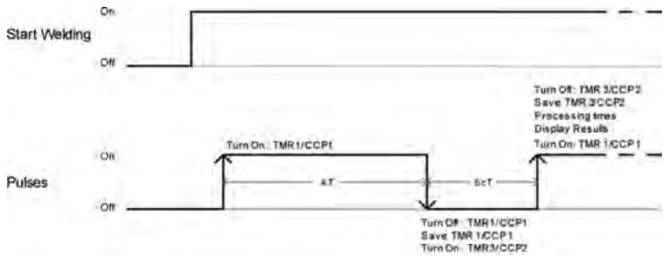

Figure 6. Sensor system.

converted to analogue signals by managing the DAC (Fig. 5). Finally the TMRs and CCPs modules are cleared and the TMR1 and CCP1 modules are turned on for continues the sequence depicted before. If the welding starting signal is turned off, the TMRs and CCPs modules are cleared, cero is displayed as final

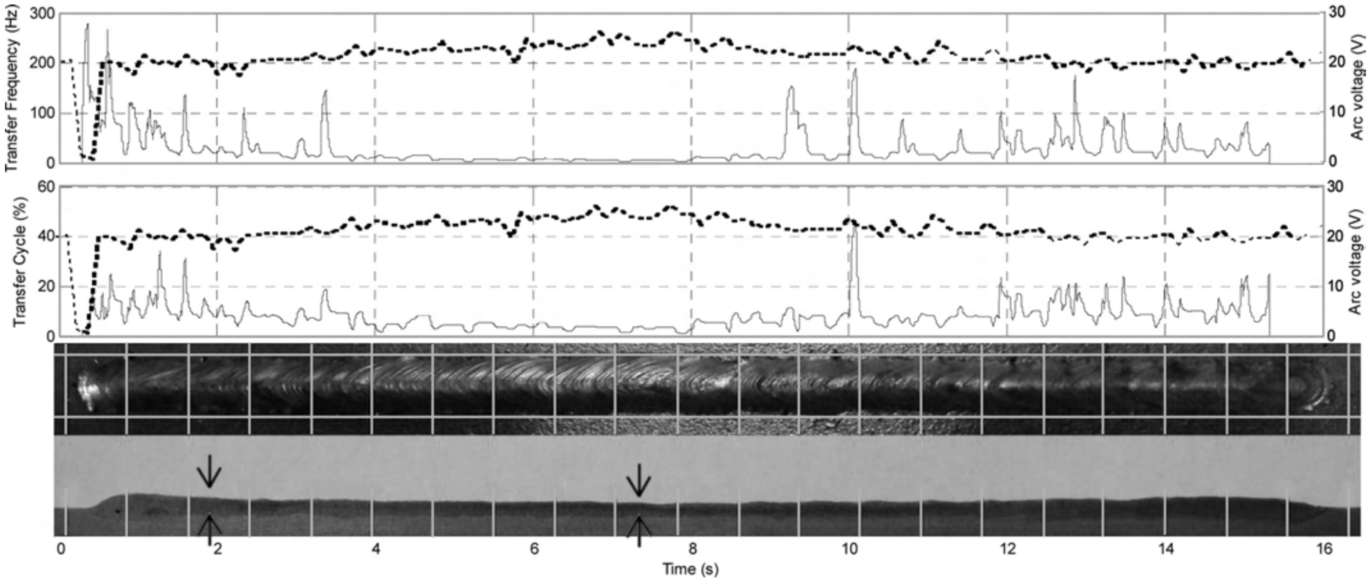

Figure 7. Stability Arcing and Short circuiting times.

For do it, the microcontroller manages a digital to analogue – DAC converter of 8 bits configured for 2 analogue voltage outputs (0-5V).

The firmware of the microcontroller uses two capture modules (CCP1 and CCP2) as well as two timers (TMR1 and TMR3). The Figure 6 shows a summarized chart of signals. After starting the welding process the microcontroller is waiting for a rising edge; when this event occurs, the TMR1 and CCP1 modules are turned on and now, the microcontroller is waiting for a falling edge. When this event occurs, the TMR1 and CCP1

values of the stability factors and the microcontroller is waiting starting the welding process again.

Performance

Figure 7 show the waveforms corresponding to transfer frequency (short circuit transference) and the transfer cycle. Both graphs are matched with the average arc voltage (dotted line). In the same figure, also is shown the resultant welding specimen detailing its top view and its penetration view.

The variation of both stability factors was induced by variation of the arc voltage (dotted line) commanded manually (Fig. 2). In the first graph is noticed some peaks of high frequency, but they do not remain constants, this fact indicates instability. As the arc voltage increases, the frequency of transfer decreases. In consequence, the weld bead measured of width increases and decreases the height and penetration. In this state, also is noticed that the transfer cycle and transfer frequency parameters remain almost constants. This behaviour represents a stability state in welding (in this experiment this steady state was reached from 22V to 25V). Note that weld bead geometry also remains constant. Varying carefully the wire feed speed and welding speed parameters also can be found other optimal welding parameters with other values of arc voltage provided that values of the transfer frequency and the transfer cycle remain constants.

Conclusion

By processing signals in real time coming from arc flashing was possible to monitor the transfer frequency and transfer cycle. The results show that a high frequency of short circuits does not necessarily represent a proper stability. The regular relation between short circuiting time and transfer period indicates the behaviour of the mass and heat transference. The welding bead has more geometric uniformity when the transfer cycle is constant than the transfer frequency is maximum. According to the welding applications, there are different requirements of the geometry of the weld bead (height, width and penetration), but in each case the uniform distribution of the short circuiting time in relation to transference period will be determinant to assuring a high uniformity of the mass and heat transference and therefore a high quality. By using the proposed sensor could be identify optimal welding parameters for different applications as well as its analogue outputs could be used as feedback signal for tracking the heat mass uniformity in automatic GMAW-S process.

References

[1]. Pharris T.C., Kolpa R.L., *Overview of the Design, Construction, and Operation of Interstate Liquid Petroleum Pipelines*, U.S. Department of Energy Office of Scientific and Technical Information, 2007.

[2]. Lincoln, T.J.F.A.W.F. The procedure handbook of arc welding. 40th ed.; The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio, USA, 2000.

[3]. Drouet M., Nadeau F., "Pressure waves due to arcing faults in a substation", *IEEE Trans. Power App. Sys.*, 5, pp. 98, 1979.

[4]. Cayo, E., Alfaro, S., "Non-Intrusive GMA Welding Process Quality Monitoring System Using Acoustic Sensing". *Sensors*. 2009, 9(9), 7150s-7166s.

[5]. J. Norrish, 1992, Advanced Welding Process. In: IOP Publishing Ltd., London.

[6]. Hermans M.J.M., Den O.G., "Process behavior and stability in short circuit gas metal arc welding". *Weld. J.*, 78, pp.137–141, 1999.

[7]. Bingul Z., Cook, G. E., "A real – time prediction model of electrode extension for GMAW", *IEEE/ASME Transactions on Mechatronics*, vol 11, no 1., 2006.

[8]. Adolfsson S., Bahrami A., Bolmsjö G., Claesson I., "On-line quality monitoring in short-circuit gas metal arc welding", *Welding Journal*, p. no2 pp.59–73 Feb. 1999.

[9]. Cook G.E., Maxwell J.E., Barnett R.J. and Strauss, A.M., "Statistical process control application to weld process". *IEEE Trans. Ind. Appl.*, 33, pp.454-463, 1997.

[10]. Wu C. S., Gao J. Q. and Hu J. K., "real-time sensing and monitoring in robotic gas metal arc welding", *Measurement Science and Technology, Institute for Materials joining, Shandong University, Jinan, 250061, People's Republic of China*, 18 pp.303-310, 2007.

Calendar of international and national events /

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2012			
Jul. 8-13	65th IIW Annual Assembly and International Conference	Denver, Colorado, USA	http://www.iiw2012.com
Sept. 12-15	30th European & 7th International Conference on Acoustic Emission Testing	Granada, Spain	http://www.2012.ewgae.eu/
Sept. 19-21	International Conference on Industrial Computed Tomography	Wels, Austria	http://www.3dct.at/cms
Sept. 24-26	10th International Seminar Numerical Analysis of Weldability	Graz-Seggau, Austria	http://www.iws.tugraz.at
Oct. 07-10	2012 IEEE International Ultrasonics Symposium in Dresden (IUS 2012)	Dresden, Germany	http://www.ewh.ieee.org/conf/ius_2012
Oct. 10-11	JOIN-EX - International Congress on Welding and Joining	Vienna, Austria	http://www.iiwelding.org
Dec. 2-5	International Conference on Nanojoining and Microjoining	Beijing, China	http://www.nmj2012.com/