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FEASIBILITY STUDY OF NON CONVENTIONAL PARAMETERS FOR DISTURBANCES MONITORING AND DETECTING IN SHORT CIRCUIT GAS METAL ARC WELDING

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Abstract. *The welding is one of the manufacture processes most used in the metallic construction industry. When the welding reached industrial scales, the demands and quality requirements also were multiplying. To guarantee the welding quality, certain cares are taken, as visual inspections, non-destructive testing and destructive testing. These inspections and tests are made after the welding process. That increases the final production cost, because they are necessary qualified technicians, sophisticated equipment and working hours. During the welding, the electric arc generates physical phenomenons as the infrared emission, electromagnetic fields, luminosity, acoustic pressure, among others phenomenons. Some those phenomenons are noticed by experienced operators to monitor and to control the welding operations. Based on that fact, in the present work was made a study of feasibility to use the sensing some of these phenomenons to monitoring and detection of disturbances welding that could be interpreted as defects. With a preset optimal welding parameters setting on the power source, were made two bead on plate welding experiments groups. The first experiments group was welds free of the interferences in the weld trajectory on the plate. In the second group the welds were made with induced interferences in the weld trajectory on the plate. In both experiment groups were acquired luminosity intermitence, infrared radiation and acoustic pressure signals generated by the electric arc in the GMAW process. After multiple analyses based on sensorial fusion and statistical techniques it was ended that is possible monitoring and to detect disturbances in welding starting from sensing of some phenomenons produced during the welding.*

Keywords*: GMAW, Parameters, Monitoriment, Disturbances, Detection.*

1. INTRODUCTION

Gas Metal Arc Welding (GMAW) is widely used in industry because of its high metal deposition rate, flexibility and low cost. It is attractive for high-productivity manufacturing application and is well suited to automatic or robotic welding (Bingul, 1999). To maintain the high-productivity followed from a high weld quality, the process monitoriment is indispensable. The quality welding is a function of many factors: selecting satisfactory welding parameters, maintaining the same parameters in production, monitoring internal and external changes in the process and correcting them (Bingul, 1999). Therefore the monitoring of the weld quality is very important to avoid time-consuming, post-weld and repair (Wu, 2007). Many sensing systems have been designed to monitoriment the weld quality. However the arc voltage and welding current monitoriment has been the on-line quality meter most used because these parameters are inherent process parameter and also responsible for the stability in the welding process. The curves of transient values over time of these two parameters reflect many peculiarities of the welding process in their shape. Each kind of arc welding process is characterized by certain transient variations of the welding voltage and current typical of the process (Adolfsson, 1998). Any disturbances or occurrences of faults during welding inevitably result in the variation of the transient values to some extent and therefore the sensing and examining the welding voltage and current can be used to welding quality monitoriment (Wu, 2007). In the present work is approached the study of any non-conventional welding parameters that can be used to welding quality evaluation.

1.1. Welding Parameters Monitoring for the Quality Evaluation

They are many welding process parameters classifications. “Cook, 1997” separates this into two categories: direct weld parameters (bead width, penetration, porosity, etc.) and indirect weld parameters (current, voltage, travel speed, etc.) but this author does not mention the welding phenomenons produced by the electric arc (WPA). The American Welding Society (AWS) separates the welding parameters into input weld parameters (IWP) and feedback weld parameters (FWP). In the AWS classification the WPA are not clearly represented in the FWP. A modified welding parameters classification is showed in the Figure 1. In the IWP the fix parameter and adjustable parameter are setting before the start of the welding process. Some adjustable parameter as current and voltage waveform, contact distance tip to work piece (CTWD), wire feed speed and travel speed can be varied on-line during the process. The FWP is separate into direct weld parameters (DWP) and WPA. DWP are those relating to the weld reinforcement, fusion zone geometry, weld mechanical properties, weld microstructure, and discontinuities. IWP are those input variables that collectively control the DWP, such as welding equipment set-point variables, such as voltage and current waveform, torch travel speed, wire-feed speed, travel angle, electrode extension (stick-out), focused spot zone, and beam power

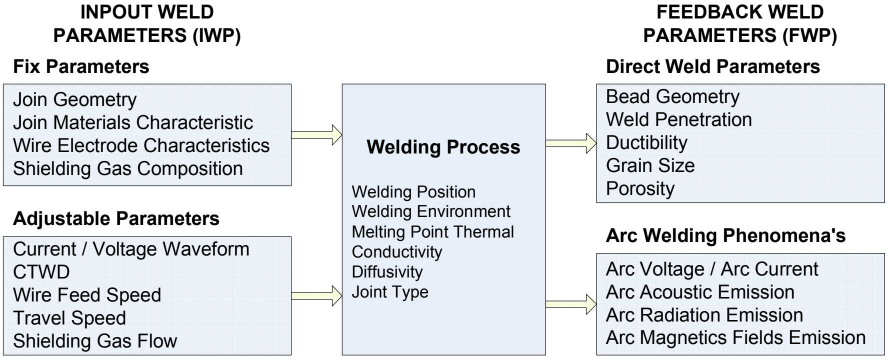


Figure 1. Input and feedback welding process parameters

The welding quality will be high when the DWP fulfills with the quality standards established. Therefore is important to determine a set of IWP that will produce the desired DWP. Classically is measured the arc voltage and arc current to disturbances and instabilities detection to ensure the weld quality, (Cook 1997, Adolfsson, 1998, Hermans, 1999, Quinn, 1999, Di, 2000, Wu, 2001, Xiaoqing, 2005, Luksa, 2006, Wu, 2007). Also are measured weld parameters as wire feed speed, travel speed, etc. These measured parameters are kneed as conventional parameters. During the welding process apart from arc voltage and arc current are produced the WPA's as acoustical, radiation and magnetic fields emission. These last WPA set is kneed as non conventional parameters. Some non conventional parameters are used by experienced human welders to welding stability monitoring and evaluating. It is a well established fact that experienced human welders are able to maintain and direct the welding arc using a combination of their visual and auditory senses (kral, 1968).

1.2. Sensors for Quality Control

There are some metallurgical properties, such as porosity and cracking that need to be monitored and controlled on-line to ensure proper weld quality. Some of the visual indications characterizing the weld quality are cracks, porosity, undercuts, micro fissures, etc. (Anderson, 1993). Three levels of on-line quality control have been articulated by the industry (see Fig. 2).

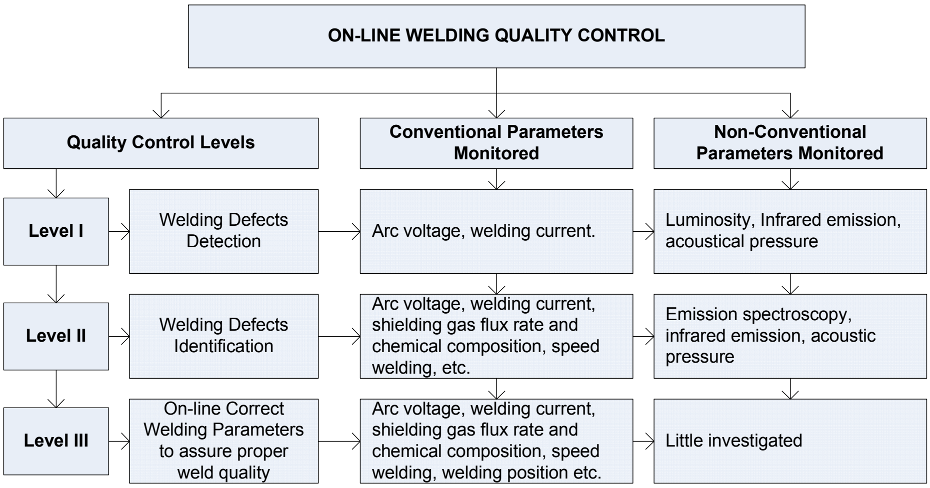


Figure 2. *On-line* welding quality control levels

In the first level one should be able to automatically on line detect production of bad welds. In the second level one should be able to locate type of fault and reasons for faulty weld production like changes in welding process induced by disturbances in shielding gas delivery, changes in wire feed rate and welding geometry, etc. in the third level one should be able to correct welding parameters during the welding process to assure proper weld quality (Grad, 2004). To detect defects, identification and welding parameter corrects are broadly used conventional parameters as voltage and current welding, shield gas flux rate, speed welding, etc. The non conventional parameters are still little used for the welding quality evaluation. They are some non contact methods to welding process monitoriment developed as acoustical sensing (Drouet 1979, Drouet 1982, Mansoor, 1997, Mansoor, 1999, Polajnar, 2007, Poopat, 2006, Cayo, 2007), Cayo, 2008a, Cayo, 2008b, Yaowen 2000), spectroscopy emission (Alfaro, 2005, Alfaro, 2006a, Lacroix, 1999, Mirapeix, 2006, Mirapeix, 2007, Li, 2000, Sforza, 2002, Szymansky, 1997), infrared emission (Fan, 2003, Nagarajan, 1992, Nagarajan, 1989, Wikle III, 2001, Wikle III, 1999) and some that consist in the sensors combination (Alfarob, 2006 and Bonss, 2004).

2. EXPERIMENTAL PROCEDURE

2.1. Data Acquisition Equipments

Virtual instrumentation software (BKSV, 2008), data acquisition card (EAGLE, 2008), welding source (IMC, 2008) and an equipment set up as shown in the Figure 3 was used for acquisition and processing data based on the arc voltage, welding current, sound pressure, luminous intermittence and infrared radiation of the arc welding at sampling of 20 kHz. The sound pressure was measured using the analogical output decibelimeter (NI, 2008) which use a microphone 4189 (Sensor 1) with - 26 dB ±1.5 dB, 50 mV/Pa sensitivity. The luminous intermittence was measured using the voltage output from monolithic photodiode with on-chip transimpedance amplifier (Sensor 2); this sensor uses an optical filter with 380 a 430 nm wavelength band pass. The sensors 1 and 2 were one beside of other and located to 200 mm from the pool fusion. The infrared radiation was measured using the TL-S-25 Calex pyrometer (Sensor 3). This sensor has a lens array that regulates the focal distance to 600 mm and works on the 800 a 1000 nm wavelength. The sensor 2 and 3 measure the radiation emissions produced by the electric arc. The sensor 2 operates on the ultraviolet region and the sensor 3 operates on the infrared region. The pyrometer was located to 600 mm from the pool fusion due to focal distance. The output pyrometer source a current signal from 4 to 20 mA. As data acquisition card does not has loop current inputs, was used the CC-E/STD ABB current loop to voltage converter.

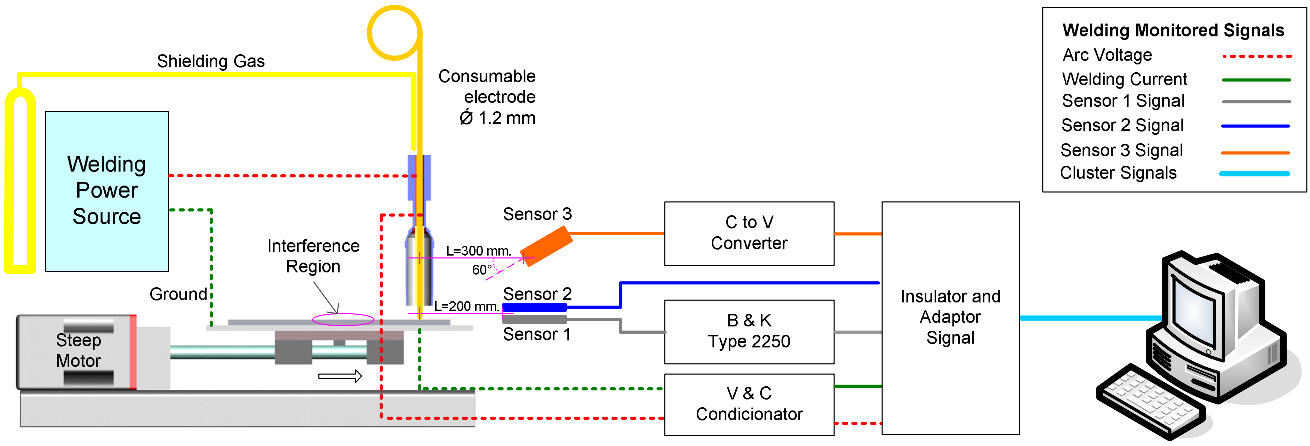


Figure 3. Experimental Setup

2.2. Data Acquisiton Parameters

The welding parameters using in the present work is showing in Table 1.The welds were carried on 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 was the mixture of argon and carbonic anhydride M21 (ATAL 5A/Ar 82% + CO2 18%). The induced interferences were located in the center of the welding path and it is called weld interference region [Figure 3].

Table 1. Set of Welding Parameters

Arc Voltage [V]	Wire Speed [m/min]	Travel Speed [mm/s]	CTWD [mm]	Shield Gas flow [l/min]
20	6	10	12	15

Five welding run, as shown in table 2, were choosing to deposit welds in a flat position following a rectilinear trajectory of 180 mm.

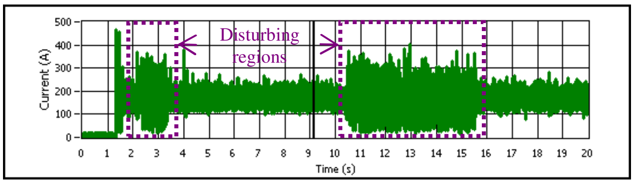
Table 2: Set of Welding Experiments

Weld experiment	
1	Shield Gas absence
2	Paint presence

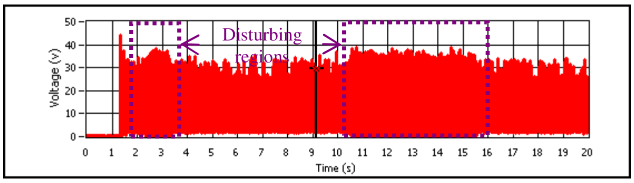
3. EXPERIMENTAL RESULTS

3.1. Welding Parameters Monitored

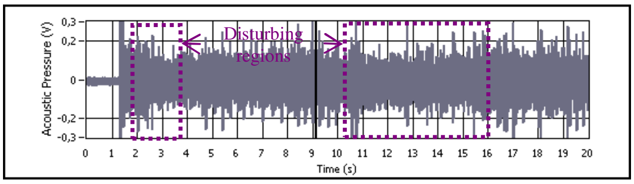
The Figure 4 shows the sequential charts of the current welding (a), arc voltage (b), sound pressure (c), luminous intermittence (d) and infrared radiation (e) monitored simultaneously.



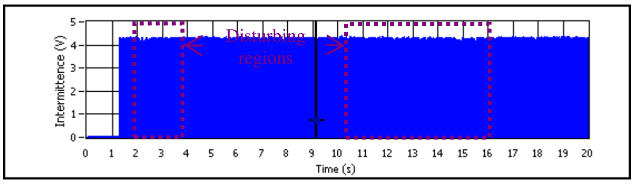
a. Welding Current



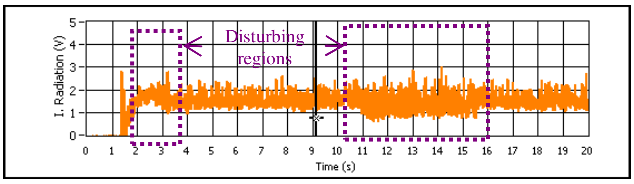
b. Arc Voltage



c. Sound Pressure (sensor 1)

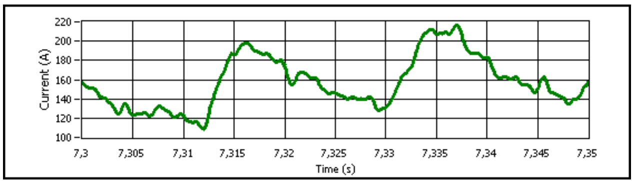


d. Luminous Intermittence (sensor 2)

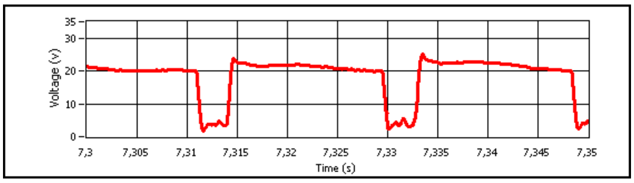


e. Infrared Radiation (sensor 3)

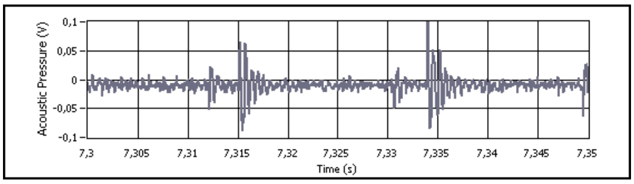
Figure 4. Welding Parameters Monitored



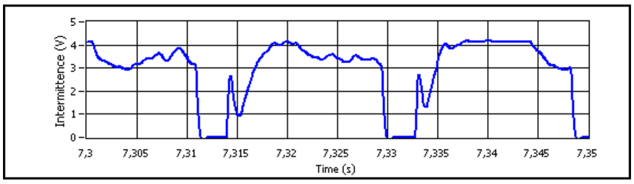
a. Welding Current window



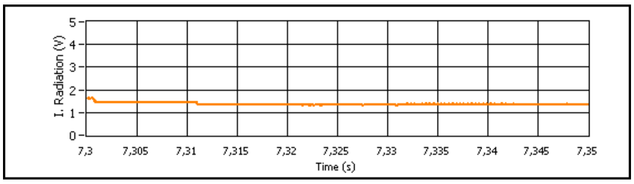
b. Arc Voltage window



c. Sound Pressure window



d. Luminous Intermittence window



e. Infrared Radiation window

Figure 5. Relation between Welding Parameters Monitored

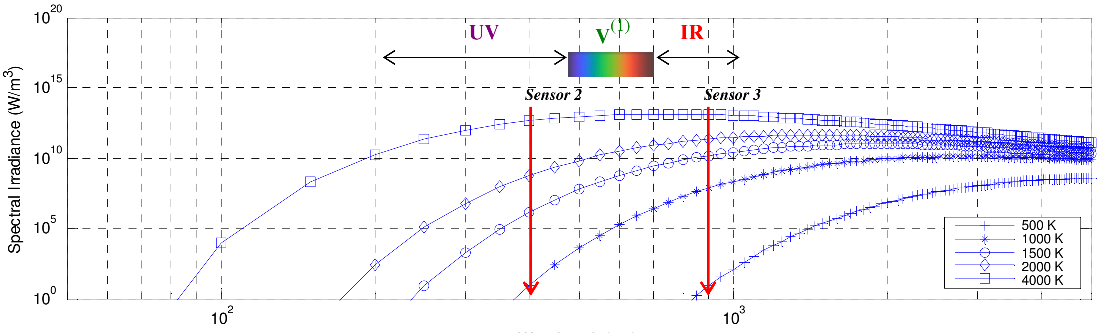
It can be seen that when the welding torch enters the disturbing region of the workpiece (see figure 3), all measurement parameters varies suddenly. From the three non conventional parameters monitored, the pressure sound and luminous intermittence amplitude seemingly do not vary in comparison with the infrared radiation amplitude. But when is observed a 50 ms data window of each parameter described above, is possible notice that so much the sound pressure as the luminous intermittence can follow the welding current and arc voltage behavior that represents the metallic transference dynamic on the GMA welding process (see Fig. 5-a,b,c,d).The fist non-conventional parameter monitored is the sound signal produced by the electric arc. The sound pressure is a longitudinal mechanical wave, produced by the difference of pressure in a medium that can be solid, liquid or gaseous; in this work the transport medium is the air. The metallic transference in the welding process produces changes in the air volume of the electric arc environment. This air volume changes produces pressure variations that are airborne transported and perceived by the sensor 1. The sound pressure from electric arc is a consequence of amplitude modulation of arc voltage and welding current (Drouet, 1979). This relation is expressed by the equation (1).

$$S_a(t) = \frac{d(k.V(t).I(t))}{dt} \tag{1}$$

Where: $S_a(t)$ is the amplitude of the sound signal at time t measured in (V), $V(t)$ is the voltage across the arc at time t (V), $I(t)$ is the current flowing through the arc at time t (A), k is a constant of proportionality. It can be seen that they are relationship between the conventional parameters behavior (welding current and arc voltage) and the arc sound pressure. The airborne nature of the sound pressure generates a pronounced delay representing the metallic transference behavior respect to arc voltage, welding current and luminous intermittence sensors (see Fig. 5). Studies in psychoacoustic has determined if the electric arc sound signal does not exceed 400 ms, this will be a good indicator of the behavior weld process (Tam and Huissoon, 2005), (Tam, 2006). A 400 ms delay can to occur if the microphone is installed to more than 100 meters of the weld process, fact that do not occurs in the presents work and therefore the sound pressure signal acquired is a good indicator of the arc welding behavior. The second and third non-conventional parameters are the luminous intermittence and infrared radiation respectively; both parameters are manifestations of the radiation emissions. These emission radiations are originated by the electromagnetic energy emitted for the welding electric arc. The radiation emission occurs at visible (V), ultraviolet (UV), and infrared (IR) wavelengths. Intensity and wavelength of energy produced depend on the welding parameters, electrode and base metal composition, fluxes, and any workpiece material. Visible brightness (luminance) of the arc increases at a much lower rate, but the ultraviolet radiation increases approximately as the square of the welding current [MED]. This electromagnetic phenomenon is expressed by the Planck's black body radiation law (Eq. 2).

$$L(\lambda,T) = \frac{2\pi c_1}{\lambda^5}\frac{1}{\exp\{c_2/(\lambda T)\}-1} \tag{2}$$

Where constants $c1$, $c2$ are defined as: $c1 = 5.9548 \times 10^{-17}$ (W. m^2), c2 = 0.014377 (m K) and variable L is defined as $L(\lambda,T)$ (W m^{-3} sr^{-1}) as a luminance temperature, $T(K)$ as a true temperature of objects, and $\lambda(m)$ as wavelength of radiation. In the Figure 6 is showed the spectral irradiance to different wavelengths and temperatures calculated using the equation 2. In this figure is can be seem that the on ultraviolet region the radiation emission varies suddenly when the temperature varies but on the infrared region the emission radiation varies very lower. It is the reason for which the sensor 2 that works on the ultraviolet region (see Fig. 6) can represents the extinction and ignition sequence (see Fig. 5 – d) and the sensor 3 that works on the infrared region (see Fig. 6) can not represents this transference metallic behavior (see Fig. 5 – e), but its amplitude decrease when the weld run enters the disturbing region of the workpiece and this is lingering (see Fig. 4-e).



(1) : Visible Radiation (light)

Figure 6. Spectral Electromagnetic Emissions

3.2. Perturbances Detection through Non Conventional Parameters

The quality control in the welding processes is subject of many researches. The task of weld quality evaluation is not trivial, even for the experienced quality inspector. This is particularly true when it comes to specifying in quantitative terms what attributes of the weld affect its quality and to what extent. Different types of discontinuities have been categorized for this purpose, such as cracks, porosity, undercuts, microfissures, etc. (Cook, 1997). Generally, good quality GMA welds are uniform and contain little or no artifacts on the bead surface. Furthermore, the bead width is relatively uniform along the length of the bead [Cook, 1995]. To reaches the standard weld quality is fundamental maintain continuity on the welding stability. The stability of the short circuit gas metal arc welding process is directly related to weld pool oscillations (Hermans, 1999). Optimal process stability corresponds to maximum short-circuit rate (Number/s), minimum standard deviation of the short-circuit rate, a minimum mass transferred per short circuit and minimum spatter loss, “Cook et al, (1992)”, “Adolfsson et al, (1999)” and “Wu et al, (2001)”. As the sound pressure and luminous intermittence follows the arc ignition and extinction sequence (see Fig. 5 - c, d) and the infrared radiation follow the amplitude variations of the arc voltage and welding current is expected also that through these signals can be evaluated the welding stability. For the welding stability evaluation using the three non-conventional parameters measured, were calculated the acoustic ignition frequency (AIF) through the arc sound pressure and the luminous intermittence frequency (LIF) through arc luminous intermittence. As the infrared radiation signal information is in its amplitude was made and noise canceling treatment to use it signal also the welding stability evaluation.

3.2.1 Acoustic Ignition Frequency (AIF)

The AIF was calculated counting the acoustic pulses produced every time that an extinction or ignition of the electric arc. The pulses produced were counted to each 250 ms data window of sound pressure. For reach this objective was made a pre-processing treatment of the acoustic signal. As the acoustic amplitude pulses produced by the arc ignitions are greater than acoustic amplitude pulse produced for the short circuits, consequently, the arc ignitions counting are easier than the short circuits counting. For this in the first place the envelopment sound pressure signal was determined using a quadratic demodulator. Squaring the signal effectively demodulates the input by using itself as the carrier wave. This means that half the energy of the signal is pushed up to higher frequencies and half is shifted towards DC. The envelope can then be extracted by keeping all the DC low-frequency energy and eliminating the high-frequency energy. Nevertheless, due to the sound pressure have a stochastic behavior [eber], it can be concluded that were needed low-pass filters with an elevated order; a filter with an elevated order produce a pronounced delay and deformation in the envelopment signal. Due to these characteristics of the acoustic signal and the low-pass conventional filter, was used a statistical filter: the “kalman filter”. This statistical filter instead of letting pass low frequencies follows the statistical tendency of the squared signal obtaining in the envelopment sound pressure (Cayo, 2008b). In the Figure 7 is showed the 150 ms moving window data extracted from the sound pressure signal (as also show in figure 5 – c) and can also be observed the sound pressure signal and its envelopment sound pressure. Starting from envelopment sound pressure signal is calculated the arc ignitions for each moving window data. An ignition takes place whenever the envelopment sound pressure signal surpasses the ignition threshold established (k = 0,1).

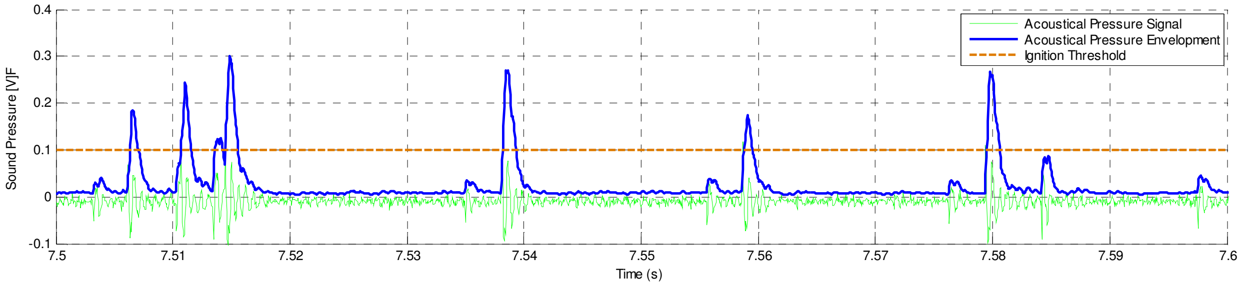


Figure 7. Acoustic Pressure Frequency Parameter

3.2.2 Luminous Intermittence Frequency (LIF)

Contrary to the sound pressure signal, the luminous intermittence signal does not require pre-processing treatment because the original signal can represents clearly the pool fusion dynamic (see Fig. 4 a, b and d). The luminous intermittence and the arc voltage have a similar behavior. When the arc extinction is produced the luminous intermittence signal amplitude is nearly to 0 volts and when the arc ignition is produced the luminous intermittence amplitude signal change suddenly and oscillates around of the 4 volts (see Fig. 8). These sudden changes on the amplitude intermittence signal are counting to obtain the luminous intermittence frequency. As well as in the AIF case, the LIF was counted to each 250 ms data window of luminous intermittence.

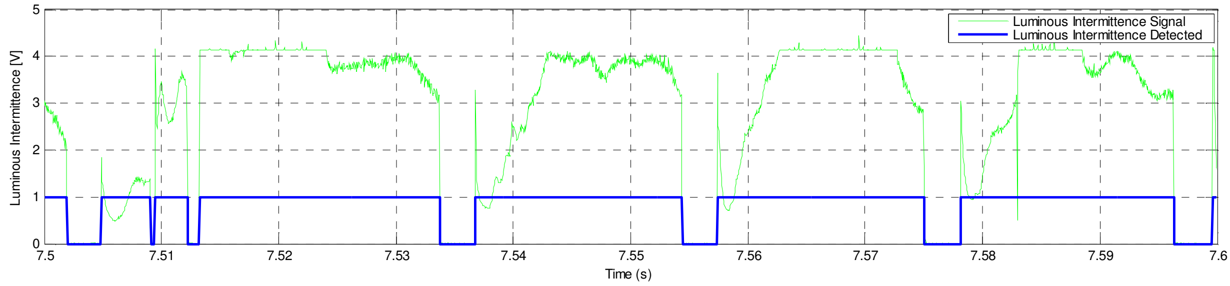


Figure 8. Luminous Intermittence Frequency Parameter

3.2.2 Infrared Radiation

As was explaining in the 3.1 section, the infrared radiation does not follow the short circuit and ignition sequence from the electric arc behavior. Nevertheless behavior, after welding experimental was noticed that they are perturbations that produce imperceptible variations on the welding current and arc voltage. In the Figure 9 is shown the root mean square – RMS of the arc voltage and the infrared radiation. In this figure can be see two perturbation detected clearly by the infrared radiation sensor, but these perturbations are imperceptibles o the RMS arc voltage.

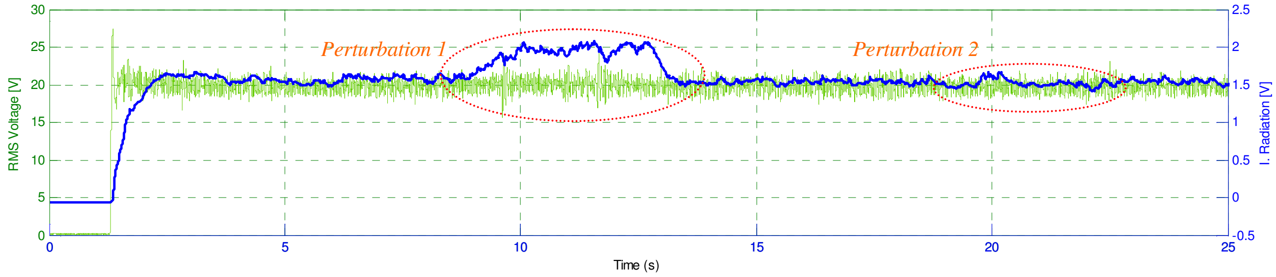
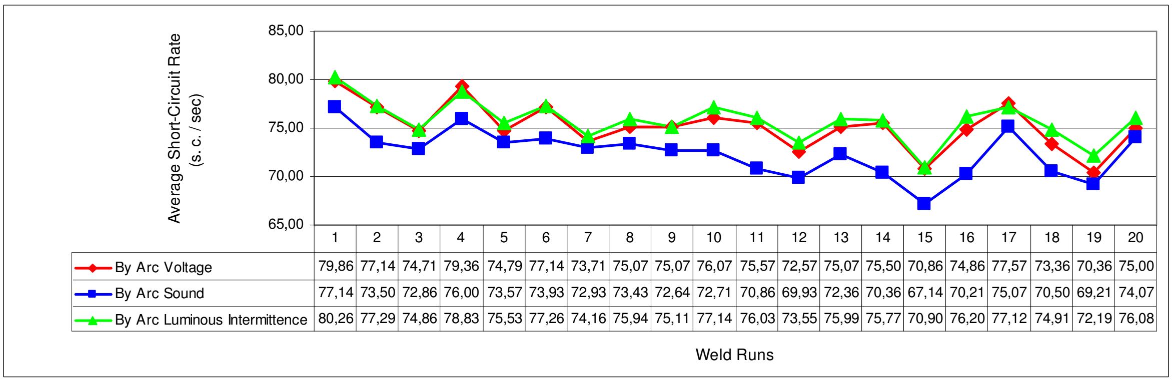


Figure 9. Infrared Radiation and RMS arc Voltage

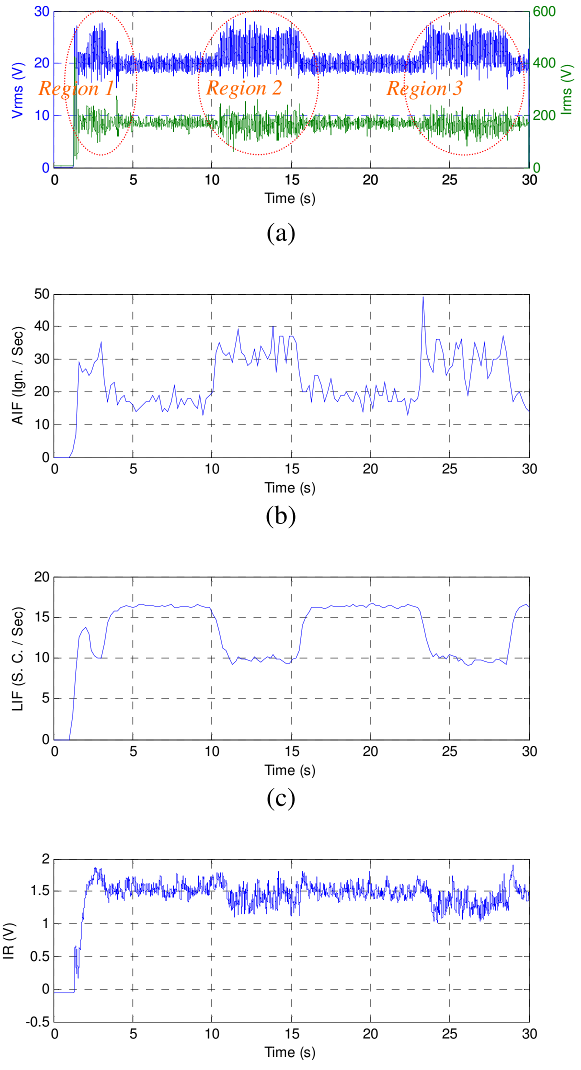
4. DISCUSION

The information extracted from the sound pressure and the luminous intermittence produced by the electric arc is the AIF and LIF that represents the short circuit and ignitions sequence produced during the welding operation. In the Figure 10 is showed comparatives estimations of the average short circuits per second through the arc voltage, sound pressure and the luminous intermittence to 20 weld runs experiments. In this figure is possible to notice that they are approximately similar results for each welding experiment but the average short circuits calculates through the luminous intermittence are nearer to the average short circuits calculates through the arc voltage in comparison with the average short circuits calculates through sound pressure. Nevertheless little difference both non-conventional parameters can be represents the dynamic of the metallic transference. In the figures 11, 12, 13 and 14 are showed the parameters behavior for the set weld run experiments described in the table 2.



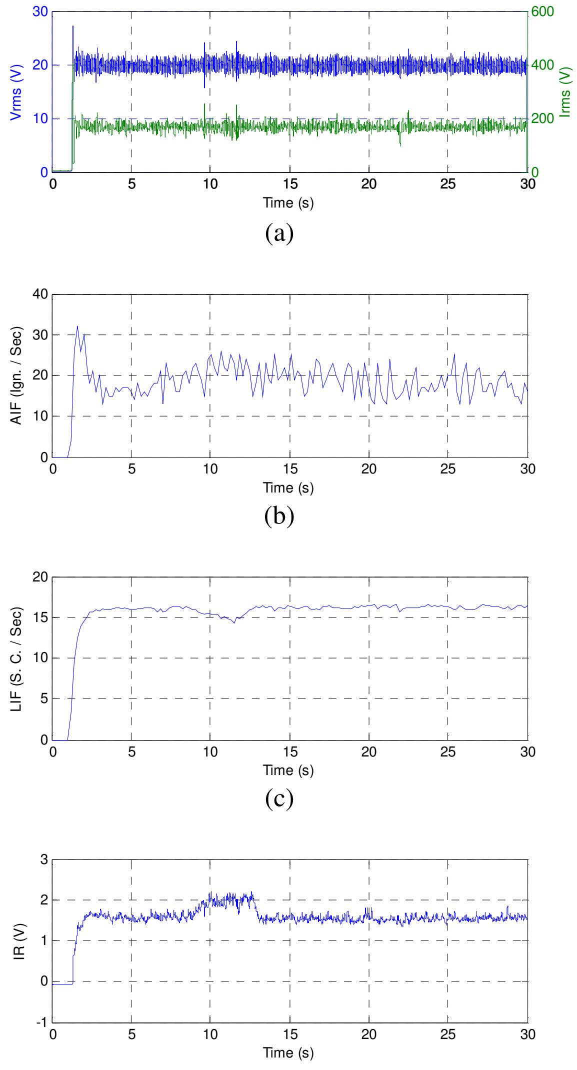
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
By Arc Voltage	79,86	77,14	74,71	79,36	74,79	77,14	73,71	75,07	75,07	76,07	75,57	72,57	75,07	75,50	70,86	74,86	77,57	73,36	70,36	75,00
By Arc Sound	77,14	73,50	72,86	76,00	73,57	73,93	72,93	73,43	72,64	72,71	70,86	69,93	72,36	70,36	67,14	70,21	75,07	70,50	69,21	74,07
By Arc Luminous Intermittence	80,26	77,29	74,86	78,83	75,53	77,26	74,16	75,94	75,11	77,14	76,03	73,55	75,99	75,77	70,90	76,20	77,12	74,91	72,19	76,08

Figure 10. Average Short Circuit rate measured using simultaneously the Arc Voltage, Arc Sound Pressure and the Arc Luminous Intermittence



(a) (b) (c) (d)

Figure 11. Shield Gas absence Experiment



(a) (b) (c) (d)

Figure 12. Paint presence Experiment

The Figure 11 (a), (b), (c) and (d) show the RMS arc voltage and RMS welding current, AIF, LIF and infrared radiation respectively. To simulate the interference due to absence shield gas protection of the electric arc was closed the source valve welding gas cylinder in three regions (see Fig. 11-a). These interferences have lead to porosities formation and higher spatter level. When the weld enter on the interference region the RMS welding current has incremented suddenly and RMS arc voltage and oscillates chaotically; the AIF parameter has incremented suddenly whereas the LIF has decremented suddenly on the three interference regions. The infrared radiation also has varies chaotically during the interferences. These parameters were varied because the absence of the shield gas causes contamination in the arc welding environment originating the incomplete metallic transference, increasing the short circuit and ignitions rate.

The Figure 12 (a), (b), (c) and (d) show the RMS arc voltage and RMS welding current, AIF, LIF and infrared radiation respectively to one bead when the weld enter on the interference region simulated taking paint on the plate. For it induced perturbation the RMS welding current and RMS arc voltage variation are practically invariants. The AIF parameter has incremented slightly whereas the LIF has decremented also very slightly, but the infrared radiation has incremented suddenly during whole interference. The paint presence on the plate generates temperature variation on the pool fusion when the torch welding enters the interfered region. These temperature variations don't vary significantly the short circuit and ignitions sequence and therefore the AIF and the LIF parameters don't indicate clearly the interference presence on the weld trajectory. The infrared radiation sensor has could to detect the disturbance when the weld enter on this interference region.

5. CONCLUSIONS

Signals of the arc voltage, welding current, sound pressure, luminous intermittence and infrared radiation were tested to monitor the welding process. Each non-conventional parameter signal has a characteristic behavior when they are anomalous interferences on the welding trajectory and, therefore can be concluded that the three non-conventional parameters monitored can be used for welding monitoriment. From sound pressure were calculated the AIF, from sound pressure were calculated LIF, the infrared radiation signal was used directly to monitoring the welding process. The monitoring of the GMAW-S process by digital analysis of this three non-conventional welding parameters enable to detect disturbances related to phenomena that take place in welding arc and can influence the welding arc stability. This fact shows that the three non-conventional welding parameters are a non-intrusive potential tool that could be used for the weld quality evaluation.

The gas shielding absence together with paint presence affects the whole protection of the welding pool. The paint presence and the lack of shielding gas affect the gas shield of welding arc. Oxygen, nitrogen and hydrogen as components of the air or the products of decomposition of paint change the welding arc shield properties as ionization potential, the surface tension of molten metal, the condition of welding arc ignition and other essential conditions of arc burning. The instability profiles make possible the identification of each type of induced disturbance. The instabilities and disturbance identification in real time based on the three non-conventional welding parameters could become good control tool for the GMA welding process.

6. ACKNOWLEDGEMENTS

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