WELDING QUALITY MEASUREMENT BASED ON ACOUSTIC SENSING

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Abstract: *The quality control in the welding processes is subject of many researches, mainly the ones that relate the weld quality and the choice of the best welding parameters. The GMAW weld process, among others technical characteristics, a bigger deposition, facilitates the control improving significantly the production and the weld quality with relation to the traditional processes. In the present work a welding cell was used with open loop control. This allows the selection of electric input and output parameters (current, voltage, wire speed, welds speed, bead geometry and others). The present work has the objective to determine quantitatively the acoustic behavior in the audible bands (20 Hz the 20 kHz) which is characteristic in each transfer mode. Then it will obtain an aero - acoustic model that relates acoustic behavior to the weld quality.*

Words key: *Sensing, Aero - acoustic, weld Quality, GMAW.*

1. INTRODUCTION

The welding process, since its origin, was the manufacture process most used. The gas metal arc welding process (GMAW) Due to its high productivity is the predominant process in industry. The final process result evaluation, the weld, determines if it presents or not acceptable quality levels to fulfill market requirements. In the GMAW process, many physical and metallurgic variables are involved, such as voltage, current, magnetic fields, luminosity, temperature, sound pressure, shielding gas composition, among others, which can be used as weld quality indicators.

The phenomenon that makes possible the success of a welding process is the Metallic Transference. The GMAW process presents three transference modes: Short circuit, Drop and Spray. The choice of adequate weld parameters (voltage and current) provides each transfer mode and the sound is a good indicator of that choice. It is known that the welders use a visual – auditive combination for the monitor and control to obtain a weld of good quality. The knowledge of the sound pressure origin and its correlation with electric parameters to get a good quality in the weld are an interesting alternative to the automation and optimization of the welding process.

1.1. Sound Pressure Origin

The sound 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 pressure variation produces in the air a change in the volume ΔV . Consider the deformation of one volume element that it is initially at position x, and its displacement (v) Ψ (figure 1):

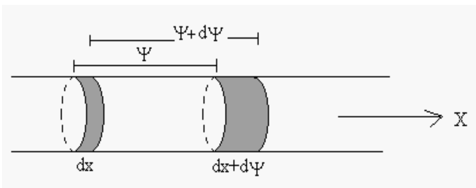

Figure - 1 Volume Deformation

The mass of the gas contained in the volume element is the same before and after the deformation. If ρ_o it is the gas density before passing the disturbance, the density of the perturbated element:

$$\rho S(dx + d\Psi) = \rho_o S dx \tag{1}$$

$$\rho = \frac{\rho_o}{1 + \partial\Psi / \partial x} \tag{2}$$

$$\rho - \rho_o \approx -\rho_o \frac{\partial \Psi}{\partial x} \quad (3)$$

The difference pressure p in respect to equilibrium p_o is defined as:

$$p = p_o - \frac{\partial \Psi}{\partial x} \gamma . p_o \quad (4)$$

The pressure is a function of the density (figure 2). The difference between the pressure p in respect to equilibrium p_o is very small is possible to make a approximation:

$$p \approx p_o + (\rho - \rho_o) \left(\frac{\partial p}{\partial \rho} \right)_o \quad (5)$$

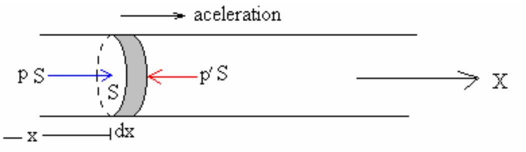

Figure - 2 Volume Displacements

The relation between elementary volume displacement and mass (density per volume), ρ0·*S.dx is:*

$$dF = (p - p')S = -S.dp = S\gamma . p_o \frac{\partial^2 \Psi}{\partial x^2} dx \quad (6)$$

By the second law of Newton $F = m.\frac{d^2 x}{dt^2}$:

$$dF = (\rho_o S dx) \frac{\partial^2 \Psi}{\partial t^2} \quad (7)$$

From equations (6) and (7), becomes the wave differential equation:

$$\frac{\partial^2 \Psi}{\partial t^2} = \frac{\gamma . p_o}{\rho_o} \frac{\partial^2 \Psi}{\partial x^2} \quad (8)$$

Where:

p	Pressure
t	Time
S	Superficies
ρ	Density
Ψ	Displacement

The metallic transference model in GMAW process, based on the method of volume of fluid – VOF, (F. Wang, W. K. Hou, S. J. Hu, and Kannatey - Asibu, W. W. Schultz and P C Wang, 2003 and H G Fan and R Kovacevic, 1998,), describes behavior of temperature, drop speed, current density, magnetic field and the pressure on air. They divided the welding process in three parts: drop formation, undetached droplet and detached droplet (figure 3)

The sound pressure of the electric arc is proportional to the arc electrical potency variation (Drouet *et al*, 1981):

$$S_a(t) = k\frac{d(V(t)I(t))}{dt} \quad (9)$$

$$k = \alpha\frac{(\gamma - 1)}{c^2} \quad (10)$$

Where:

$S_a(t)$	Sound signal time
$V(t)$	Arc Voltage
$I(t)$	Arc Current
α	Geometric factor
γ	Adiabatic air expansion coefficient
c	Sound speed in the air

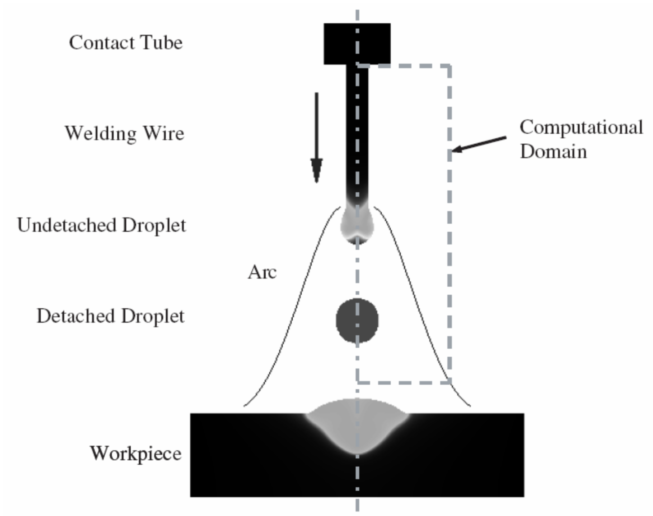

Figure - 3 Schematic of the metal transfer process in GMAW

Later, Drouet *et al*, 1981 proceeded to refine this relationship when they made experiments using graphite electrodes. They discovered that the acoustic signal is specifically attributed to the instantaneous change in electrical power of the arc column and not of the whole arc. In other words, there are no acoustic emissions due to the cathode and anode fall regions. But in their experiment the electrodes were fixed.

The GMAW process presents different forms of metal transfer to the melted pool. In the globular and short circuit transfer's modes, besides the presence of the arc sound, the impact sound of the drop in the melted pool is characteristic. In the spray transfer mode the sound of the electric arc has predominance on the sound of the drop impact in the melted pool.

2. EXPERIMENTAL PROCEDURE

2.1. Data Acquisition Equipments

The equipement involved are:

- Power Source: IMC Inversal 450.
- Linear displacement table to move the workpiece. The torch is fixed.
- Sound level measurement Hand Held Analyzer Type 2250.
- PC to monitor, control and measure weld process variables.
- Data acquisition Board: Eagle Technologies 703S. With 400 kHz sampling frequency.

- Analogical signals connector PC 452A5.
- Digital signals connector PC 43A4.
- Power control Drive IDS91 for linear displacement table.

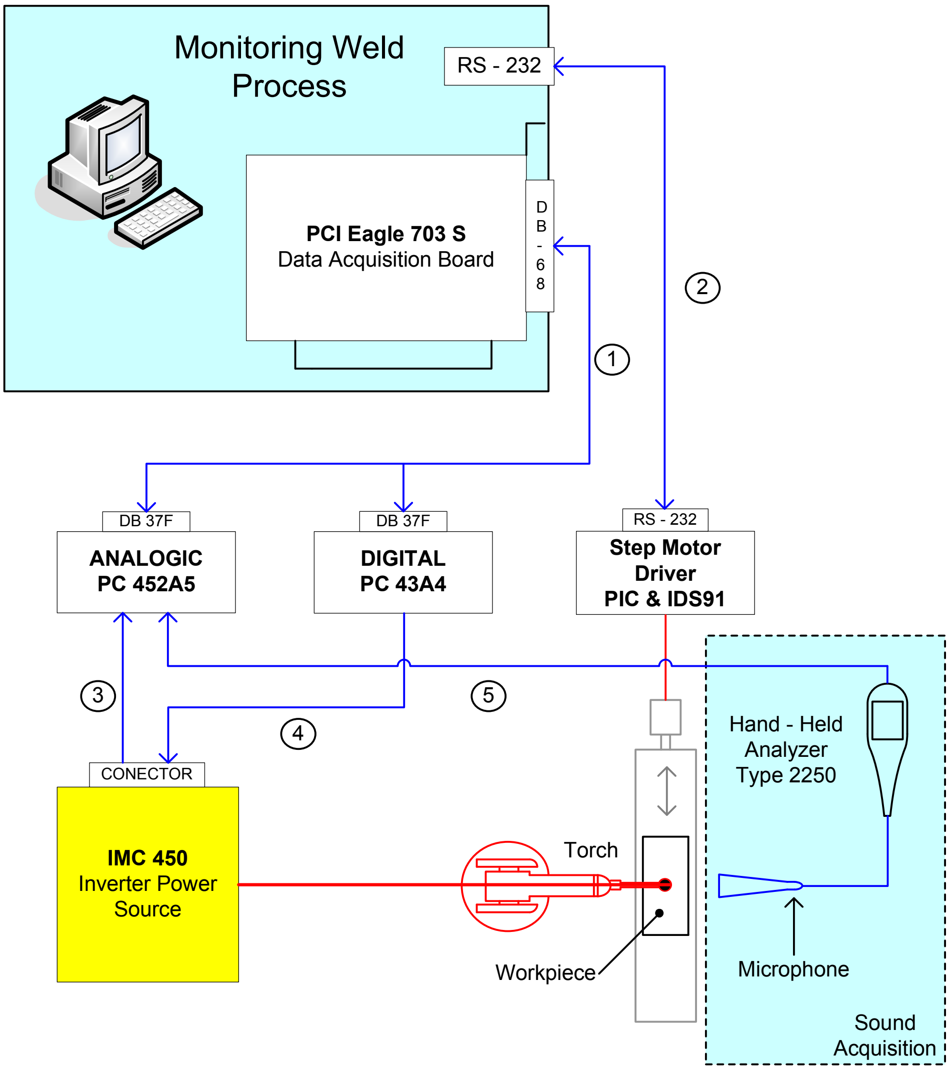

Figure - 4 Environment acquisitions of dates

2.2. Conectivity between data acquisition equipament

Figure 4 presents the equipment used in data acquisition in the welding process and table 1 show the types of signals involved. The computer has installed the data acquisition board: PCI Eagle 703S. This board was responsible for the communication between computer and weld power source. It starts the welding process and makes the acquisition of weld current, voltage and sound pressure. The power drives IDS91 with the microcontroller 18F485 have communication with the computer by serial port RS-232. They control the displacement of the workpiece.

Table 1. Types of signals of the data acquisition process.

Control and Measurement Signals	
1	Analogical and Digital signals
2	Send and receive signals for driver motor control
3	Voltage and Current measurement signals
4	Ignition, gas and wire feed signals
5	Voltage signals from pressure sound

2.3. Data Acquisiton Parameters:

Table 2. Data Acquisition Parameters

	Transfers modes		
Parameters	Short Circuit	Globular	Spray
Shielding gas	Argon		
Gas Pressure	15 l/min	15 l/min.	15 l/min.
Stand Off	15 mm.	15 mm.	20 mm.
Wire diameter	1 mm.	1 mm.	1 mm.
Wire speed	5 mm/s		
Weld speed (table speed)	5 mm/s	5 mm/s	5 mm/s
Sampling frequency	48000 samples/s		
Peak record level	110.6 dB		
Microphone sensibility	90.2 mV/Pa		
Bandwidth	1/3 octave		

3. DATA ANALISYS

It was made the record of the sound pressure for each transfer mode at 48000 samples per second.

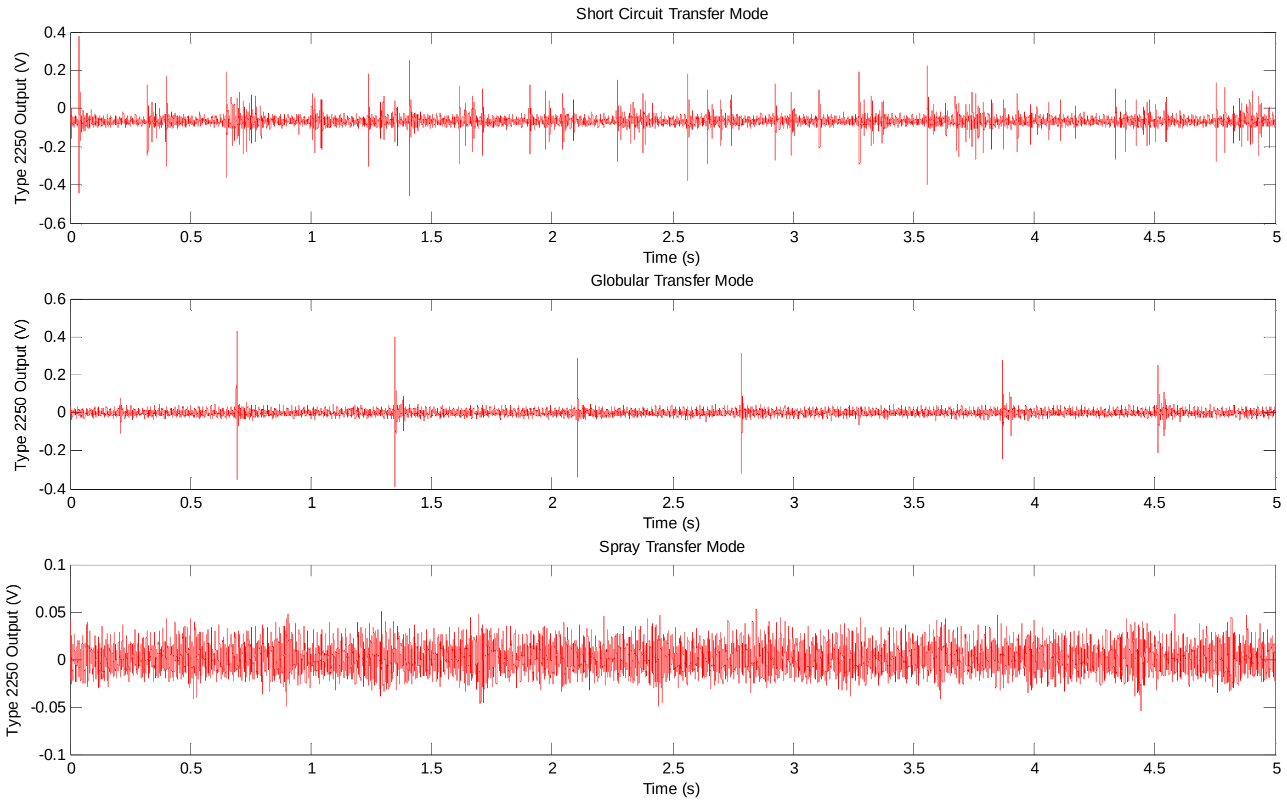

Figure - 5 Sound Signals for each Metallic Transfer

The voltage and current involved in the welding process are considered as stationary random processes and satisfy the ergodic hypothesis (S. C. Absi, 2006). There is a characteristic sound for each transfer mode due to the number of impulses per second (Mansoor, and Huissoon, JP, 1997). With this information it was made a distribution of the number of impulses per second of the sound pressure. The results are presented in the following table:

Table 3. Sound Peak Distribution

	Weld Parameters					Number of Sound Impulses per Second					
	Time (s)	Voltage (v)	WFR (m/s)	T. Mode	Stand Off (mm)	second 3	second 4	second 5	second 6	second 7	second 8
Test 1	24	21.4	6	cc	15	48	44	34	21	32	37
Test 2	20	21.4	6	cc	15	44	38	41	47	35	31
Test 3	20	18.0	3.5	cc	15	27	25	33	24	35	36
Test 4	20	18.0	3.5	cc	15	31	34	31	33	25	25
Test 5	20	26.6	3.5	gb	15	3	3	2	3	3	3
Test 6	20	26.6	3.5	gb	15	2	3	4	2	2	4
Test 7	20	26.6	4.0	gb	15	6	5	4	3	4	4
Test 8	20	27.5	4.5	gb	15	5	4	6	3	5	3
Test 9	20	36.8	7.0	sp	20	2	2	1	2	1	2
Test 10	20	36.8	7.0	sp	20	2	1	1	2	1	2
Test 11	20	36.1	6.5	sp	20	1	0	1	1	0	1
Test 12	20	36.1	6.5	sp	20	0	1	1	0	1	1

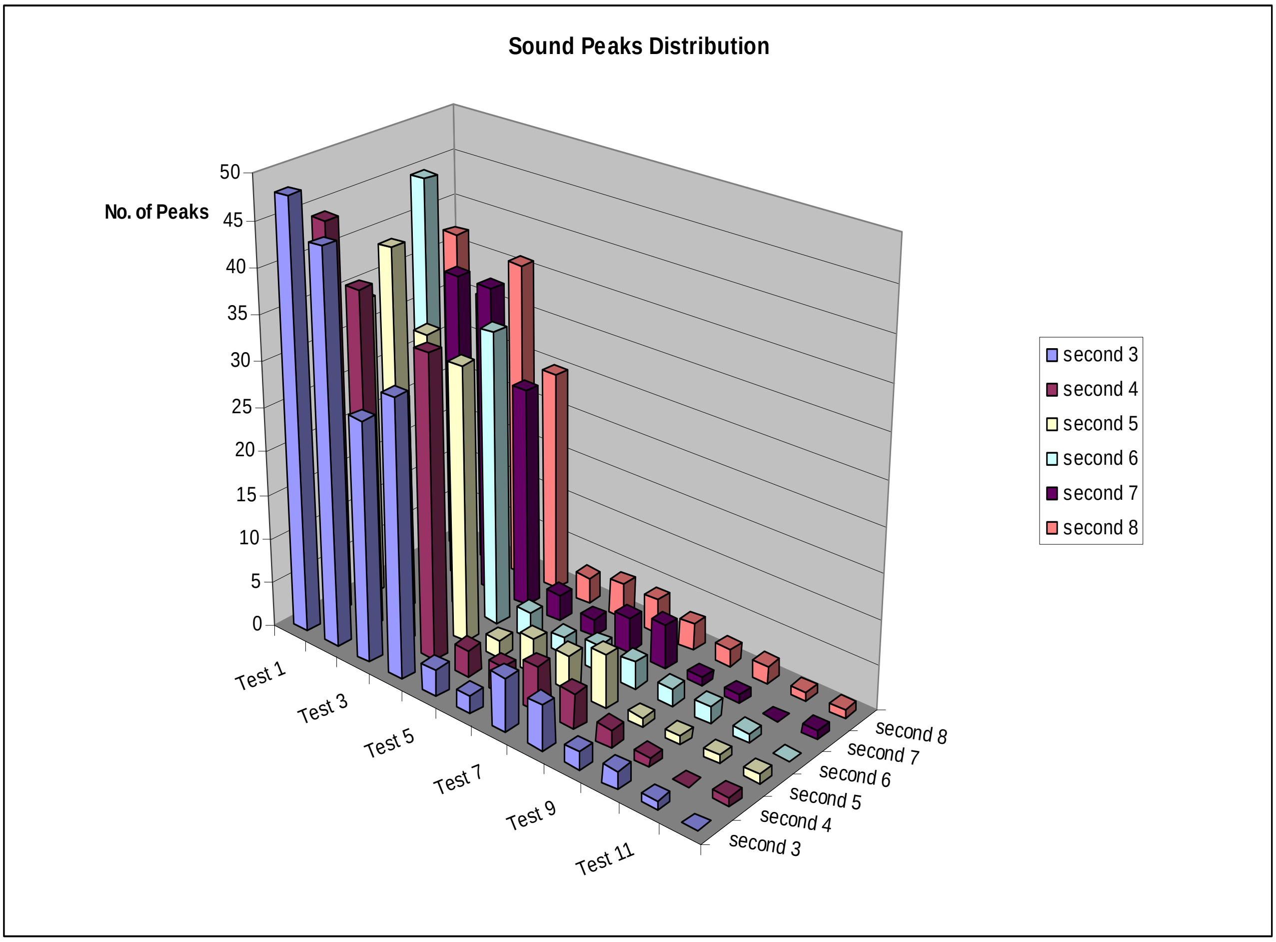

Figure – 6 Sound Peak Distributions

Figure 6 presents the graphical results of table 3. Tests 1 to 4 correspond to short circuit mode. Tests 5 to 8 are drop transfer mode and tests 9 to 12 correspond to spray transfer mode.

4. RESULTS AND DICCUTIONS

The sound pressure is a good indicator of variations and/or changes in voltage and current in the welding process for short circuit and drop transfers modes. Figures 7, 8, 9 show the variation of the electric signals as well as the sound variations.

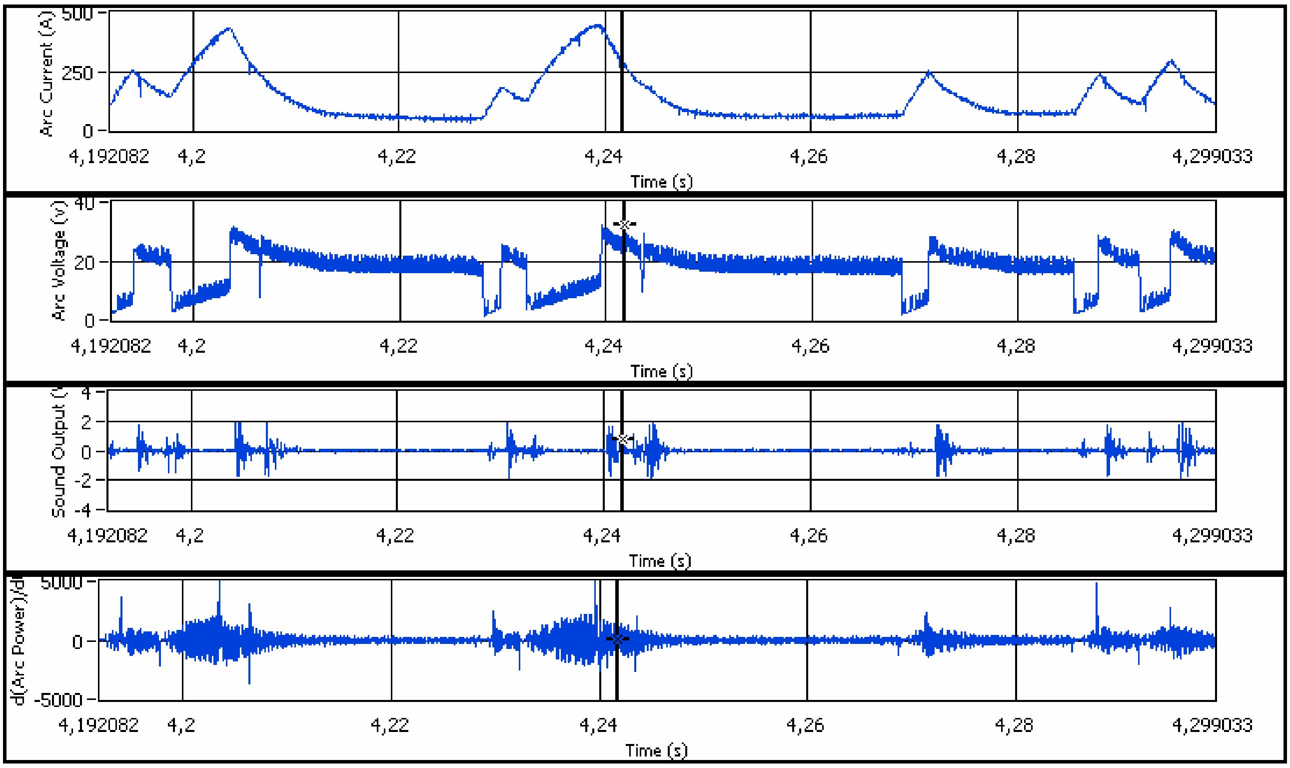

Figure – 7 Short Circuit Mode signals (Test 1)

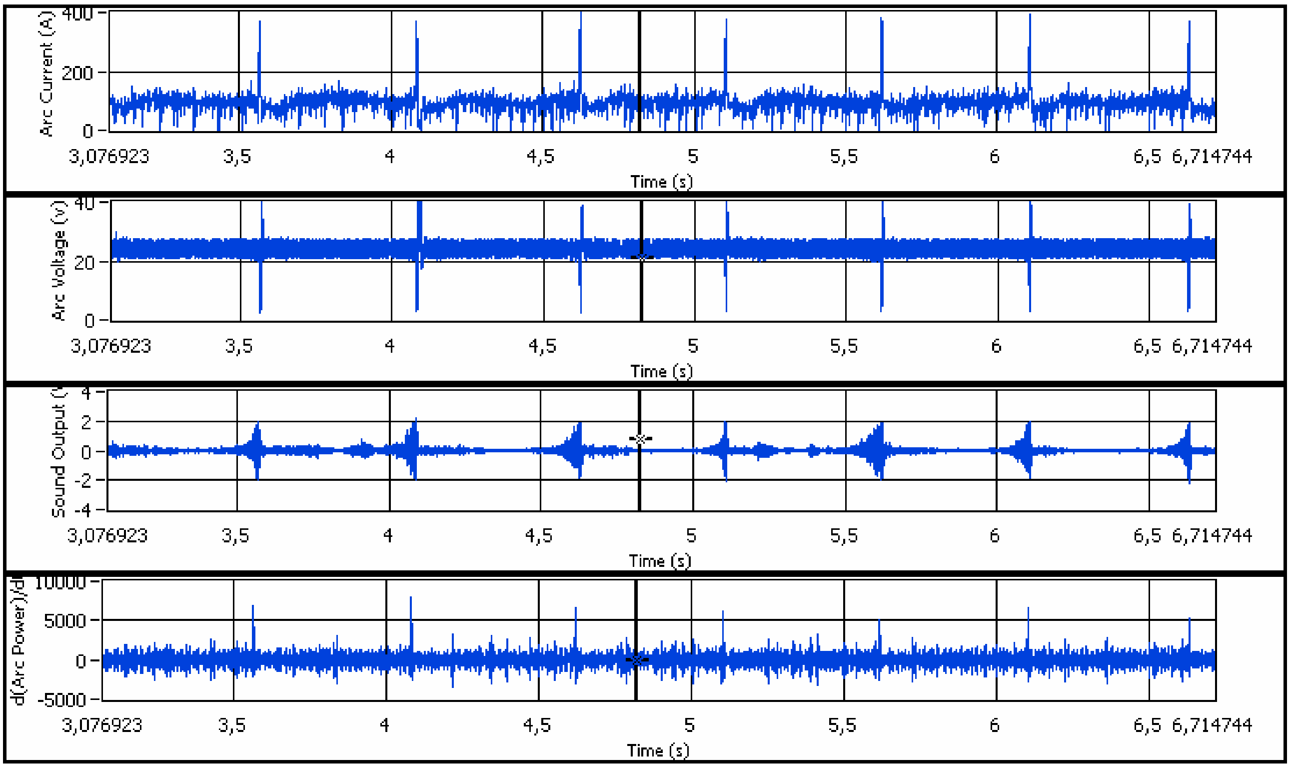

Figure – 8 Globular Mode signals (Test 8)

The difference between the short circuit and drop transfers modes is found in the behavior of electrical parameters amplitude as well as the sound. In both modes the sound is originated by the impact of the drops and the sound of the electric arc. In the spray mode the sound caused by the impact is imperceptible since the drops are very small. Thus, the sound of drop an short circuit modes are easily perceptible, but for spray mode it becomes hard to capture. (see figure 9).

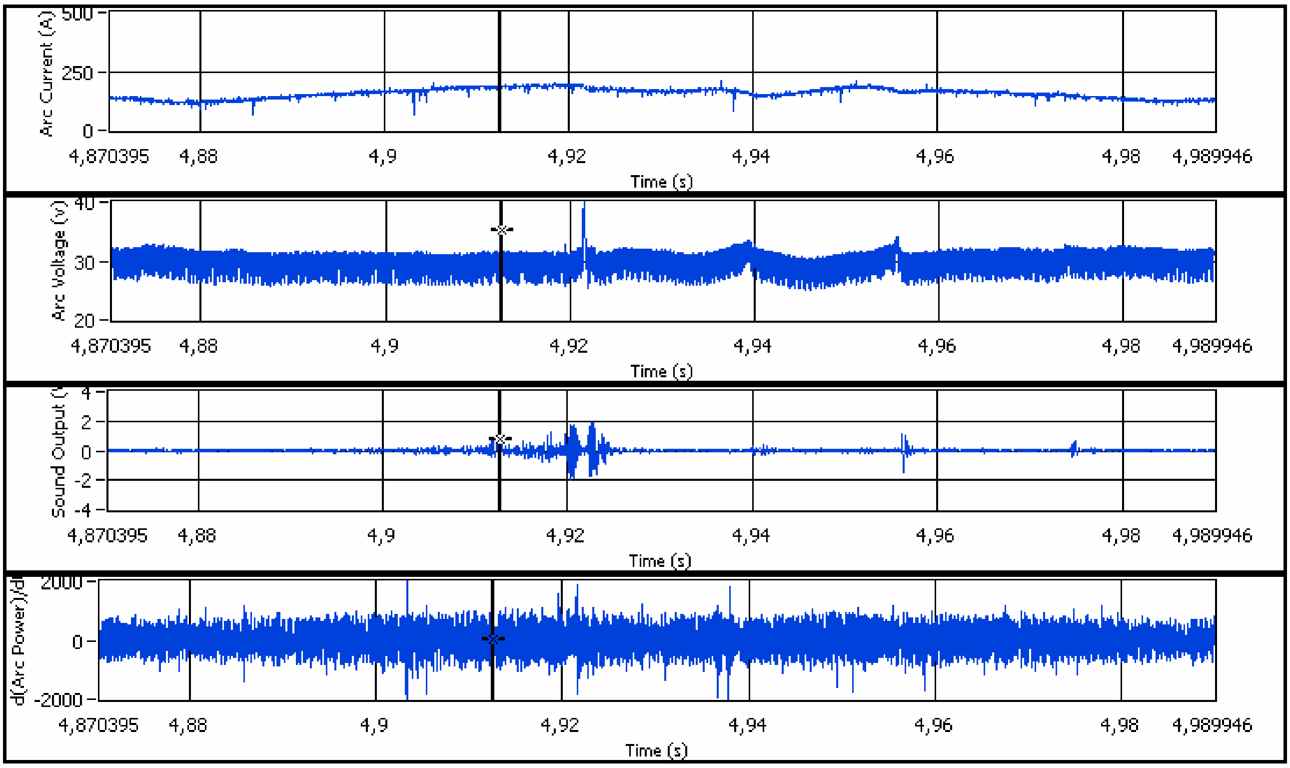

Figure – 9 Spray Mode signals (Test 15)

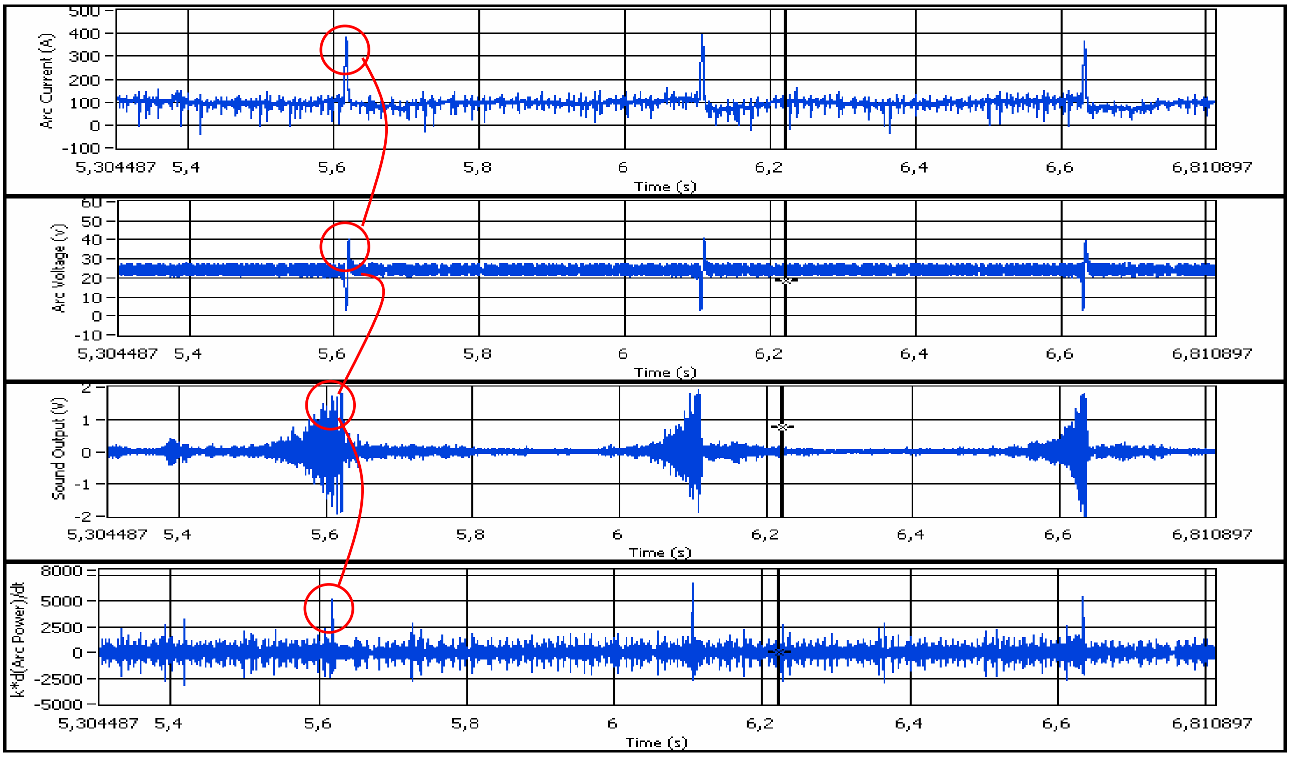

Figure – 10 Correlation between voltage, current, sound and power (Test 8)

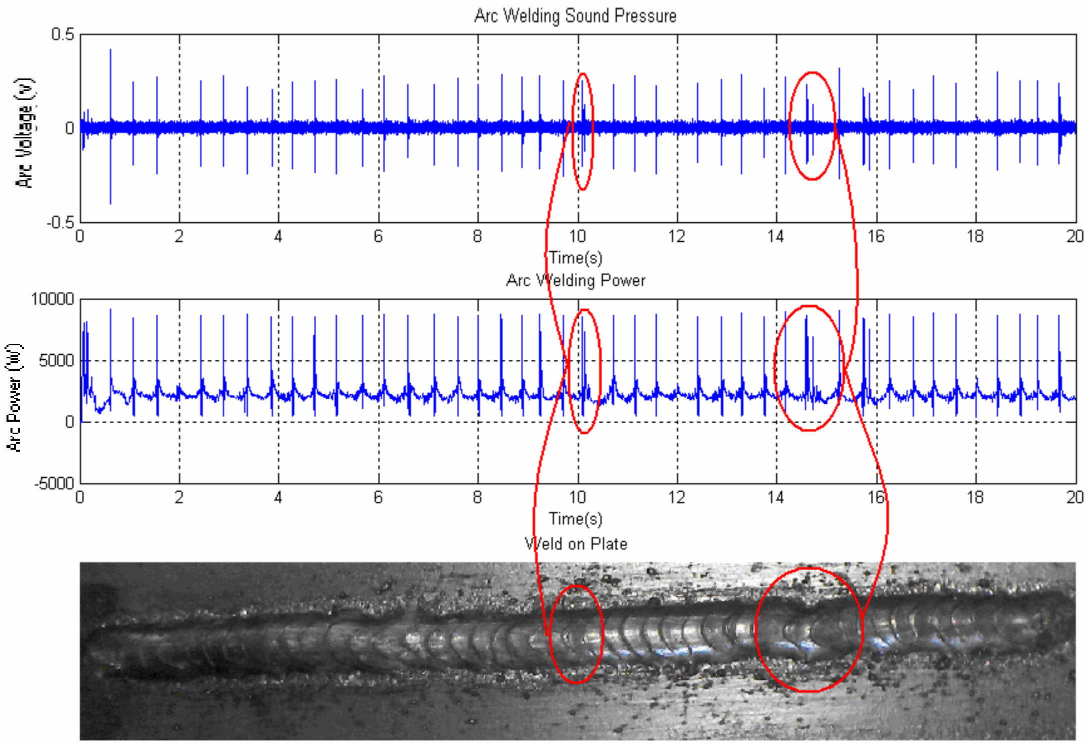

Figure – 11 Weld Defect Identification of power and sound pressure (Test 8)

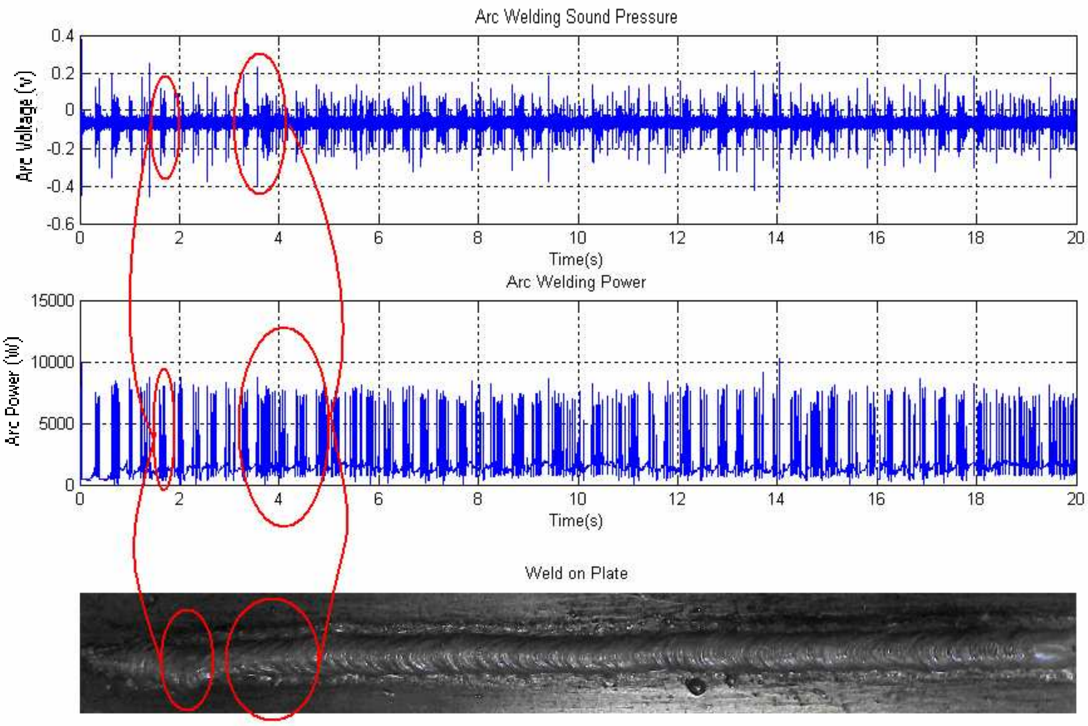

Figure – 12 Weld Defect Identification of power and sound pressure (Test 1)

Figures 11 and 12 show the weld for the drop and short circuit modes in this order. The drop transfer mode presents two evident defects on the weld. The sound pressure and the electrical power also presents variations of de same position. But for the short circuit mode the variations are not so clear which can be seen in figure 12.

After observing the pressure sound behavior in the different transfers modes, one can affirm that the sound pressure is a good indicator of the weld quality, but presents limitations for the spray transfer mode.

5.CONCLUSIONS

The sound is correlated to the behavior of the tension. It is evident in the short circuit transfer mode. The extinguish of the arc produces a sound of lesser amplitude than the re-ignition. The arc re-ignition in this transfer mode goes after the wire explosion. Therefore, a bigger sound amplitude is produced.

In the experimentations for the acoustics measurement of the electric arc, for Drouet *et al*, there is not metallic transference being the electrodes. Even so the relation found for (equation 9) is valid for the measurement of eletric arc tension in GMAW process. But it has additional contributions for each way of transfer mode.

Each transfer mode depends on the chosen electric parameters. Their changes will indicate that some error has occurred at the change moment. It is demonstrated that the eletrical potency derivate behavior is correlated with the sound signal amplitude behavior. Therefore, the sound characterization can be used as a tool for welding quality inspection.

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