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GMAW process stability evaluation through acoustic emission by time and frequency domain analysis

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ABSTRACT

Purpose: In the present work was made the comparative analysis in time domain and frequency domain to the acoustical pressure generate by the electric arc to determinate which of the two analysis methods is better to evaluates the stability in GMAW process.
Design/methodology/approach: Welds had been made with the parameters adjusted to get the highest stability. In these conditions, were simulated instabilities that had been generated by the grease presence in the weld trajectory. In both experimental groups was acquired the acoustical pressure signal produced by electric arc to made analysis based in time domain and frequency domain.
Findings: After this comparative study we conclude that the acoustical evaluation of the stability on the GMAW process presents more clarity for the analysis based in the time domain that the frequency domain.
Research limitations/implications: In the gotten results, the time domain analysis method could represent adequately the stability and the instability of the process. The stability characterizes for the continuity and minim variation of the statistical parameters, but in the presence of instabilities, these parameters present chaotic changes. In the frequency domain method the variations are imperceptible for steady and unstable regions, but it presents little definite variations in the amplitude of determined bands of frequencies.
Originality/value: The stability evaluation in welding is crucial because it is responsible in the weld quality. The non contact methods as the acoustical method have a potentiality extraordinary to monitoring and detect instabilities in welding. The acoustical sensing has the capacity to make an on-line monitoring of the weld process.
Keywords: GMAW; Acoustic pressure; Time domain; Frequency domain; Weld stability

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1. Introduction

The welding is the production process most used in the metallic construction industry. They are several welding processes, but the Gas Metal Arc Welding - GMAW is the process most used due to advantages such as high rate of metallic transference, high penetration and easiness of welding in different positions [23]. When the use of the GMAW process grew up to industrial scales, the quality requisites of welding is also

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multiplied. The welding must fulfil with the requirements enough structural and geometrical to be classified as good quality. To achieve these requisites, it has to maintain continuity in the stability of the process; this happens when the heat flow and mass from wire electrode to the melt pool through the arc is uniformity in the transference [1]. Some discontinuities and disturbances can originate weld defects. During the welding process besides the voltage and current, the electric arc produce other phenomena's as the luminosity, infrared radiation, electromagnetic fields and acoustic pressure. It is known that the specialized welders use an acoustic and visual information combination to monitoring and control in the welding process, with these he also can identify the transfer mode, instabilities in the process, determine errors and evaluate the weld quality along the weld bead [2].

The sound produced by the electric arc is a consequence of the amplitude modulation in the current by the arc voltage [3], [4]. The voltage and current in the GMAW process are stochastic nature [5]. This implicates that the sound produced by the electric arc have also a stochastic nature [6]. The behaviour of voltage and current has a direct relationship with the behaviour of stability of the metallic transfer. Studies and researches about the acoustic sensing in welding process, makes approaches of analyzed in the time and frequency domain [7-17], but which of these two approaches is the better to welding sensing by acoustic emission?. In the present work was made a comparative study in the time and frequency domain for the evaluation GMAW process stability starting from acoustic electric arc using a statistics analysis of the sound pressure, statistics analysis of the acoustic pressure level and the octave frequency analysis of sound for cover a frequency range. The objective this paper is determinate which analysis suggested is better to stability evaluation and sensing in GMAW process starting from arc acoustic behaviour.

1.1. Acoustic pressure

The relationship between the acoustic behaviour and the voltage and current arc is represented by Equation 1, (Drouet and Nadeau, 1982).

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

Where *Sa(t)* is the acoustic pressure signal, *V(t)* the voltage arc, *I(t)* the welding current in the arc and *K* is the geometrical factor.

1.2. Frequency octaves

For the acoustic pressure analysis in the frequency domain is used the continuous Fourier transforms; it through a linear transformation converts the acoustic pressure signal from time domain to frequency domain. The continuous Fourier transform is defined by:

$$S(f) = \int_{-\infty}^{\infty} s(t)e^{-j2\pi ft}dt \tag{2}$$

Where *S(f)* is the acoustic pressure signal en the frequency domain, *s(t)* is the acoustic pressure signal en the time domain; starting from frequency domain is identified the dominant components and characteristics originates by the acoustic pressure variations in the time domain. Due to the integration in the continuous Fourier transform is done on an infinite time strip (see Equation 2), in the practices this is makes by a discreet integration on **N** data points and *k* bands of finite frequencies. This technique is known as Discrete Fourier Transform - DFT and it is expressed by the Equation 4.

$$S(k) = \frac{1}{N}\sum_{n=0}^{N-1} s(n)e^{-j2\pi kn/N} \tag{3}$$

The analysis in octave frequency fractions allows to evaluate the frequency strips behaviour instead of some frequency. An frequency octave is defined as an interval among two frequencies where one of them is the double of the other. The octave band limits are calculated by Equation 4, 5 and 6. After obtaining the acoustic pressure spectra *S(f)*, is obtained the octave frequency strips *G(n)* starting from Equation (7).

$$f_{C_{n+1}} = 2^m f_{C_n} \tag{4}$$

$$f_{L_n} = \frac{f_{C_n}}{2^{m/2}} \tag{5}$$

$$f_{U_n} = 2^{m/2} f_{C_n} \tag{6}$$

$$G(n) = \sqrt{\frac{1}{(f_{U_n} - f_{L_n})}\sum_{f(k)=f_{L_n}}^{f_{U_n}}[S(f)]^2} \tag{7}$$

Where *m* is the octave band fraction, f_{Cn+1} the central frequency of the *n* band, f_{Ln} the inferior limit of the *n* band and f_{Un} the superior limit of the *n* band.

2. Experimental procedure

In Table 1 shows the electrical parameters set adjusted to welding experiments. , which were applied to the short circuit transfer mode

The experiments was made adjusting the following: voltage to 20 V, wire feed speed 6 m/min., speed welding 10 mm/s., contact tip to work distance 12 mm. and gas flow 15 l/min.

Table 1
Electrical parameters for tests

Welding Voltage (V)	Wire Feed Speed (m/min)	Speed Welding (mm/s)	Contact Tip to Work Distance (mm)	Protection Gas Flow (lt/min)
20	6	10	12	15

The experiments are divided in two groups; the first group consists in welds without disturbances presence on the plate. The second group consist in weld with disturbances presence on the plate. The disturbance induced is generated placing grease in the weld trajectory; this area is called as interference region. During the pass of the weld for the interference region, it is produced instabilities in the arc ignitions originating dramatic changes in the metallic transfer cycles and as consequence they were originated structural discontinuities in the bead. In all weld experiments were acquired acoustic pressure signal generated by the electric arc. For it was used the virtual instrumentation software LabVIEW 8.2 and the data acquisition card PCI Eagle 703S. These experiments were made following the distribution shown in the Fig. 1. To acoustic pressure measurement was used the analogical output of decibelimeter Brüel & Kjær - Type 2250, it uses the 4189 microphone, the sensibility is -26 dB ±1.5 dB, 50 mV/Pa.

3. Results and discussions

3.1. General remarks

The sound signal was captured simultaneously with the arc voltage and current signals; it was sampling with a 20 KHz rate. Studies in psychoacoustic determined that while the acoustic signal of GMAW process does not exceed 400 ms of delay, this will be a good indicator of the behavior from welding process. In several works of weld acoustic monitoring, each author put the microphone in different distances from the weld pool; 85 mm Druet et al [3, 4], 200 mm Warinsiriruk et al [16], 35 mm Čudina et al [9]. The Fig. 1 shows as were located the microphone for the acustical measurement of GMAW process taking into account the protection of the microphone against the spaters from weld and the excess thermal radiation that can alter the stability, repeatability and time response from microphone.

3.2. Scope

Materials and properties

These tests were made with a wire electrode AWS A5.18 ER70S-6 with 1 mm diameter. The different metallic transfer modes tests were made on steel work piece AISI 1020 of 6.50 mm. The shielding gas used was a mixture of argon and carbonic gas M21 (ATAL 5A/Ar 82% + CO2 18%).

Methodology of research

In the Fig. 2 is showed acoustic pressure signal generated by the electric arc. Starting from this sign is determined the average and the standard deviation for window statistical parameters making use of the equations 8 and 9.

$$\overline{x_i} = \frac{1}{n}\sum_{j=1}^{n} x_i = \frac{1}{n}(x_1 + ... + x_n) \tag{8}$$

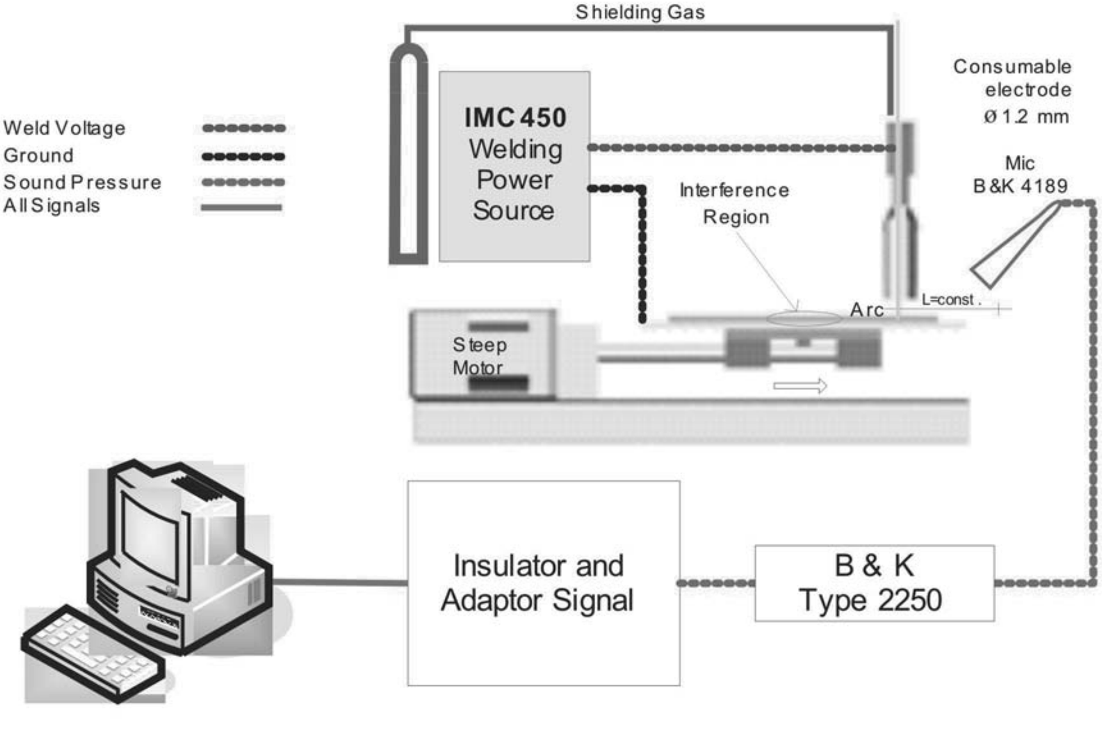

Fig. 1. Experimental set-up

$$S_i = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(x_j - \overline{x_i})^2} \qquad (9)$$

Where $\overline{x_i}$ is the date average of the window i, x_i is the component i of the analysis window, n is the data number components of the window, S_i is the standard deviation for the window i and x_j is the window component j.

In the Fig. 3 is possible notice an inserted sequence of acoustic pulses with big amplitude and pulses with small amplitudes. The pulses with big amplitude are produced by the arc ignitions while small amplitudes are produced by short circuits [Cayo 2008]. Therefore, starting from the acoustic pressure produces by electric arc, it results less complex to count the ignitions pulses that short circuits pulse. For to count the acoustic ignition pulses per window is necessary obtains the envelope of the acoustic pressure signal. So that is used a quadratic demodulator. This demodulator is based in the squaring of the acoustic pressure signal. After it, the squaring signal has high and low frequency components. For obtains the envelope signal normally is used a conventional low pass filter. But as the acoustic pressure signal has stochastic nature and also after analyses multiple was showed that low pass filter have to be high order; it originates a delay and pronounced deformation in the envelope signal. Due to the stochastic characteristics of the acoustic signal and limits presented by the low pass conventional filter, a kalman filter was used. It filter follows the tendency of squaring acoustic signal. The output signal of the kalman filter is just the envelope of the acoustic pressure signal. In Fig. 3 is showed a window of the acoustic pressure signal and the signal envelope obtained. This window that has 150 ms duration is extracted from the acoustic pressure signal (Fig. 2). Starting from envelope signal is counted the acoustic ignitions for window. An acoustic ignition is produced when envelope signal overcomes the established ignition level (k = 0.1). Then it's made an ignitions count by window, the average and standard deviation using the equations (9) and (10). The short circuit transfers mode in the GMAW process is characterized for be a sequence of the short circuits and ignitions arc. Therefore in a weld operation the short circuits number is approximately some to arc ignitions. The Eq. (1) indicates the relationship between the acoustic pressure, the voltage arc and welding current.

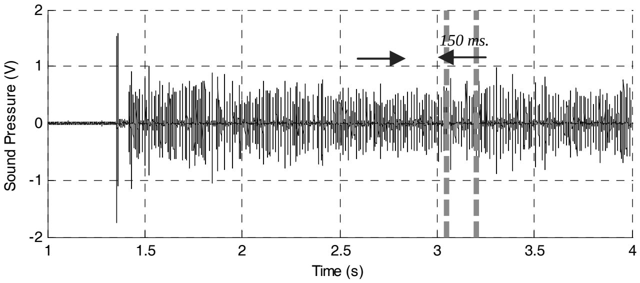

Fig. 2. Acoustic Pressure produced by Electric Arc

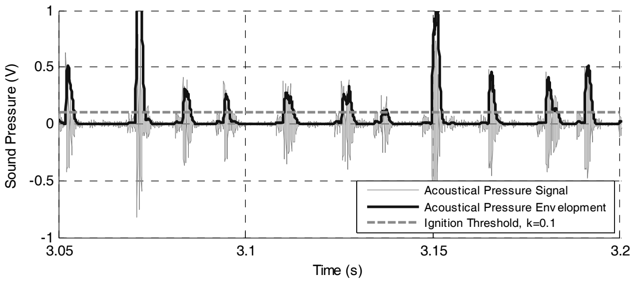

Fig. 3. Acoustical Pressure Window (150 ms.)

The Fig. 4 shows the final aspect of the welds with the induced perturbation that generates a defect. It perturbation was generated put grease on the weld trajectory. The Fig. 5 shows the acoustic ignitions frequency; in this figure is possible see that the acoustic ignitions frequency decreased when the weld pass on the interference region. It decreasing because the electric arc suffered openings and/or discontinuities that generate instabilities in the arc ignition, increasing the arc voltage at the same time in that the current suffers chaotic falls, therefore the acoustic pressure decreased in width and periodicity of the pulses. As a consequence of that I number him/it of ignitions it decreased. The Fig. 6 shows the standard deviation for the ignitions periods. In that graph is possible appreciate that were produced few pronounced abrupt changes during the defect. In the Figs. 5 and 6 are possible to see the Simulated Defects Region - SDR. In these regions is showed a pronounced decreasing of acoustical ignitions frequency and that has a similar behaviour with the short circuits frequency that also decreased.

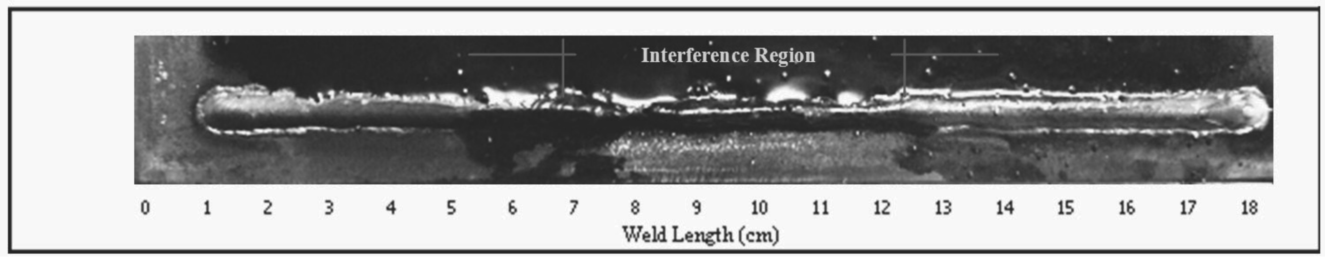

Fig. 4. Weld Experiment 1 with Disturbance

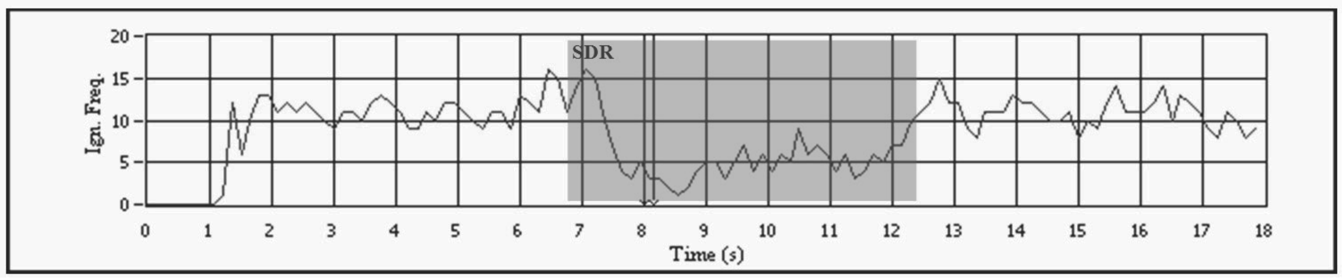

Fig. 5. Acoustic Ignition Average for 150 ms window

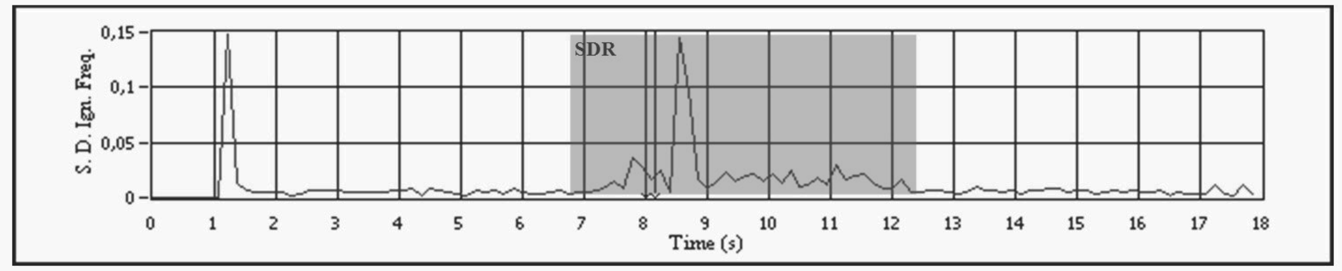

Fig. 6. Acoustic Ignition standard deviation for 150 ms window

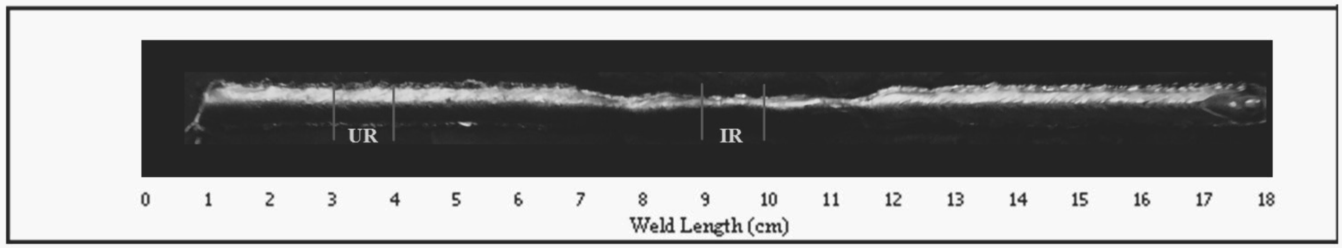

Fig. 7. Weld Experiment 2 with Disturbance

In the Fig. 7 is showed the final aspect of the weld with an interference simulated on the plate. In this weld is possible to notice two regions (un-interfered region - UR and interfered region - IR). The UR represents an equivalent portion to one second of the welds without interferences presence. IR represents the equivalent portion to one second of the welds with the presence of interferences. Starting from those regions there were octave frequency analysis through acoustical emission produced by electric arc. The Fig. 8 presents the frequencies distribution for both regions. In the frequency distribution for the un-interfered region can be noticed that the dominant frequency component is approximately 2 kHz. In the Fig. 9, 10 and 11 are showed the band frequency distribution for the 1/3, 1/10 and 1/12 octave frequency. Its distributions are to two analysis regions. In these frequency distributions to uninterfered welds region confirms that the dominant frequency (2 kHz) is inside on the dominant band. The frequencies distribution to interfered region is manifested how a decrease in the amplitude of the dominant frequency (see IR in the Figs. 9, 10 and 11), but it doesn't produce a change of the dominant frequency. In the octave frequency distributions either is not possible appreciate changes in the bands frequencies.

Analysis and modelling

Cook et al, (1992) [18], Adolfsson et al, (1999) [19] and Wu et al, (2001) [20], had determined that the maximum stability of the process to assure the best quality of the weld is produced when in the metallic transference happen the maximum number of short-circuits for second, when it has a shunting line minimum standard in the times of the short-circuits, when the mass transference is minimum during the short-circuit and when the spatter level is minimum. Hermans and Den Ouden, (1999) [21] revealed that they are three causes of the instability: the instantaneous short-circuits produced when the electrode leans in the pool fusion for short periods and the metal not transfer; a failure in re-ignition of the arc and the variations of speed of the wire. The author concludes that the maximum stability of the arc happens when the oscillation of the welding fusion pool and the frequency short-circuits are equal.

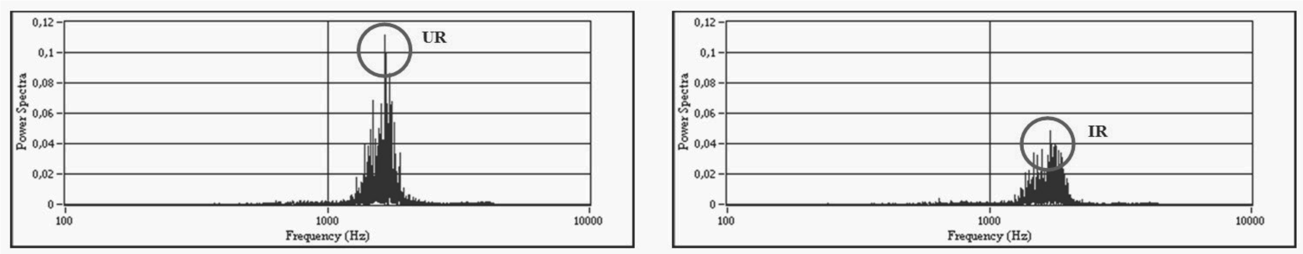

Fig. 8. Acoustic Signals in Time Domain

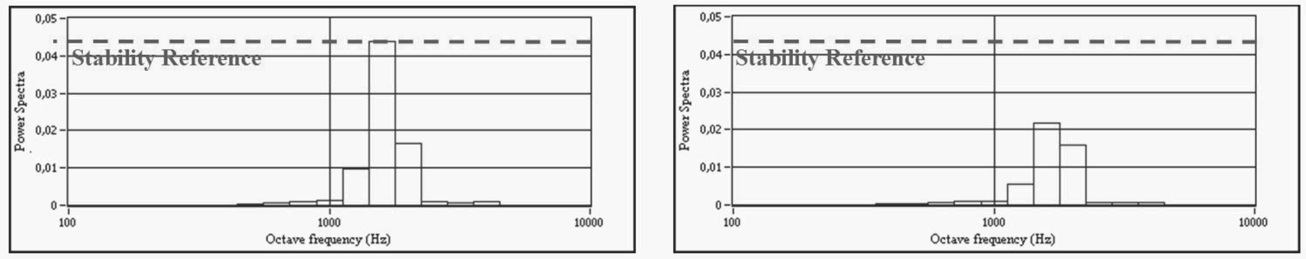

Fig. 9. Acoustic Signals in Time Domain

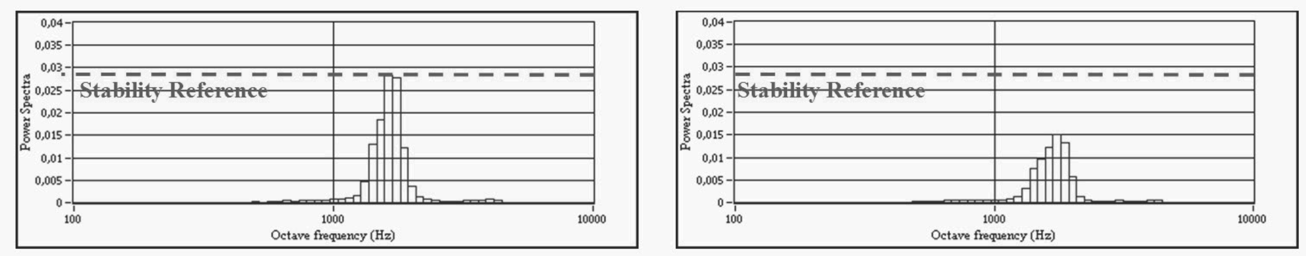

Fig. 10. Acoustic Signals in Time Domain

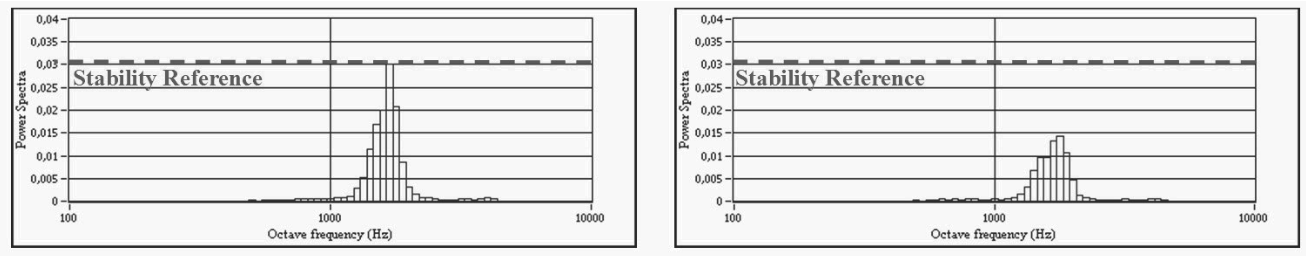

Fig. 11. Acoustic Signals in Time Domain

Cook et al (1997) [22] he detached the potentiality of the statistics for the application in the monitoring and analysis of the stability of the process of welding GMAW; an analysis statistics of the involved signals in the welding process results adequate for be these signals of random nature. In Fig. 5 we can observe the statistical behaviour of parameters of stability obtained from electric acoustics arc. We can notice that the statistical behaviour of the parameters in stability conditions (with the adjusted parameters according to Table 1) is characterized by continuities around of one determined value. When the weld passes for disturbance region it’s produced a variation in the electric acoustics arc. This variation is manifested in the statistical parameters as abrupt variations that allow identifying instabilities of the process. About research of Drouet et al (1982) [4], Mansoor and Huissoon (1999) [11] they made a work related to the identification acoustics of process GMAW. The data of arc sound had been processed in the time and the frequency domain to obtained describers. The results obtained will indicate that the sound of the arc shows distinct characteristics for each transference mode. It was concluded that analysis of sound of the arc made in the frequency domain does not allow distinguish between one and another transference mode, but in the time domain the possibility distinguish between one and another mode is bigger. In Fig. 5 F and G it is presented the behaviour of the acoustic parameters of the average SPL and its standard deviation; we can observe that the behaviour of this parameter also presents different behaviours for the region without presence of instabilities and unstable region. The behaviour of this parameter in normal conditions is characterized for be continues and with small variations. This continuity is interrupted when the presence of instabilities exists. Grad et al (2004) [10], on-line of process GMAW-S made a study of the possibility of the use of the acoustic signals of the electric arc for the monitoring. As s result of this work the sound of the electric arc of process GMAW contains information about the activity of the column of arc, the molten fusion pool beside to drop transference. In this work it made an analysis in the time and frequency domain. It was determined that the sound of the process is produced by the short circuit and the re-ignition of arc. Besides it was concluded that the frequency analysis is not reliable because the frequency of short-circuits in the welding process is of random nature. Fig. 6 also presents the behaviour of the frequency of sound of the electric arc for the regions in normal conditions and without the presence of instabilities as well as too the behaviour of the frequency whit the presence of instabilities. A analyzes comparative and qualitative sample that not exist variations even presence of the octave frequencies when the process remain unstable, but the instability is manifested with an amplitude reduction of the octave frequencies more pronounced(2 kHz.). These results are similar for an analysis of the acoustic signal FFT as well as for the analysis octaves frequency. In 2006, Warinsiriruk and Poopat [16] they made an inquiry of the variations current welding and stand off its repercussion in the activity acoustics. For its validation, was made variations in welding current and stand off distance. The acoustic signal of the process in the time domain was used to count the number of drops unfastened of the electrode until the molten fusion, obtaining itself to differentiate it enters a transference modes and another one. In a posterior work Poopat and Warinsiriruk (2006) [12], was supported in the acoustic signal to classify the transference modes in GMAW process. Quadratic average value behavior of the acoustic and the spectra frequencies was used to identify each transference mode. In this work the method of identification in the time domain presented greater clarity in the final results. The advantage of the method of analyzes in the time domain is that it allows to visualize the evolution of welding process and the acoustic behaviour; the evaluation of octaves of frequencies only allow to identify the instant of the variations regarding the presence of new components of frequencies is lowest. The statistical parameters of the evaluation of stability in the time domain of the weld that showing more clearly are those generated from the acoustics pressure. The behaviour of the statistical parameters of the SPL presents variations little pronounced front the presence of disturbances that represent instabilities in the weld due to it needs an interval Δt that is the integration time (to see Eq. 2) for its calculates, so that it lost fidelity in the representation of the acoustics arc.

4. Conclusions

As a result of this comparative study we can deduce that the acoustic evaluation of the stability of the GMAW process presents more clarity and representativeness in the analysis of acoustic pressure of the electric arc in the time domain analyzing the acoustic parameters as well as the number of ignitions and the standard deviation of the ignitions period, in the frequency domain.

The statistical analysis of SPL gets to represent the behaviour of the acoustics in the time domain, but the answer is little expressive front the variations originated by instabilities in comparison with the analysis of the acoustic pressure.

The analysis of the acoustic pressure in the frequency domain also presents variations. These variations only are showed in the decrease of the amplitude of the dominant frequencies, but there is not a change of component of dominant frequencies.

The analysis of the acoustics of the arc in the time domain, besides presenting more perceptibility for the detection of instabilities, presents a possible potential of locating defects on the welded foil.

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