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A METHODOLOGY FOR PARAMETERIZATION OF THE MIG / MAG CA AND ITS APPLICATION IN SERVICE REPAIR OF PIPELINES OF OIL AND GAS

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Abstract. *The AC MIG/MAG process presents remarkable application potential, since it allows join the characteristics of the conventional MIG/MAG process with the ones obtained when negative current is applied in MIG/MAG welding. However, the current wave shape demands a criterions selection of its innumerous setting parameters, fact that limits the development and application of this process version. The objective of this work was to propose and evaluate a methodology able to estimate the setting parameters of the AC MIG/MAG welding process, in such a way to result in welds with arc length stability and adequate bead geometry. A step-a-step description of the input parameter definitions and of the way to experimentally obtain some parameter values needed to estimate other setting parameters. The estimation equations are presented and discussed. A demonstration of the methodology application is carried out, with validation through actual welds. Hus, were then made of carbon steel with welding parameters and raised with the proposed methodology, it was then realized a study of metal transfer through filming with Shadowgrafia. Concomitantly, temperature measurements were made on the opposite side of the plate via infrared camera, checking temperature values reached underneath the plate is below the critical tempertura established for pipe in service repair secured with lower input of heat the material soldier as studies of the Batelle Institute and other researchers on subject.*

Keywords: *AC MIG/MAG, Alternate Current, negative polarity, parameter selection.*

1. INTRODUCTION

The MIG / MAG welding process is the most important metal joining processes today. This is due to its high capacity, feature constantly coveted by industries in their manufacturing processes. The CA MIG / MAG welding process is a variant of the MIG / MAG process, in which seeks to combine the advantages typical of MIG / MAG conventional (electrode operating in positive polarity DC +) with increased deposition rate and reduced heat input that occurs when the MIG / MAG process is operated with the Electrode Negative Polarity (CC-). In CC +, there is still the possibility of welding with different metal transfer modes (short circuit pulsed droplet). According to (Ueyama *et al* 2005) a featured application for this process is the welding of thin plates.

One of the main benefits of DC welding-would reverse the balance of the heat generated in the arc. According Talkington (1998) in MIG / MAG welding DC + using as a gas shield a mixture of argon and less than 5% O_2 or CO_2, about 30% of the heat generated in the arc is concentrated in the electrode and the remaining part (about 70%). In this welding process is otherwise approximately 30% of the heat generated by the arc is transferred to the base metal and about 70% of the electrode. (Souza et al., 2009) and (Farias et al., 2005), have confirmed that there is a higher fusion rate, DC, but the results indicate that this was due more to the rise in arc along the walls of the wire in search of oxides (for field emission) increasing the thermal efficiency by greater than heat generated in the cathode connection. However, Talkington (1998) shows that DC-welding is limited, typically to the type of globular transfer, are hardly used in practice for registering large arc instability and undesirable amount of spatter produced. These results are partially at odds with Souza et al. (2009), which demonstrate that the metal transfer mode DC-is dependent on the type of shielding gas used and it is possible to obtain transfer without repulsive droplets (droplet and globular) this polarity.

There are some types of waves used in this version of the MIG / MAG welding process, and the pulsed DC + combined with constant current DC-, represented in Fig. 1, the most accepted. This waveform has been studied by some authors as (Harwig et al 2006) and Nascimento et al (2009), for which the period starts at the negative pole to form the drop and after reversal of current, there is a period of current Based on the positive pole (pre-pulse) to stabilize the drop before the pulse step in which the drop is released. Before the new reversal, after the detachment of the drop, there is a further based on the positive pole.

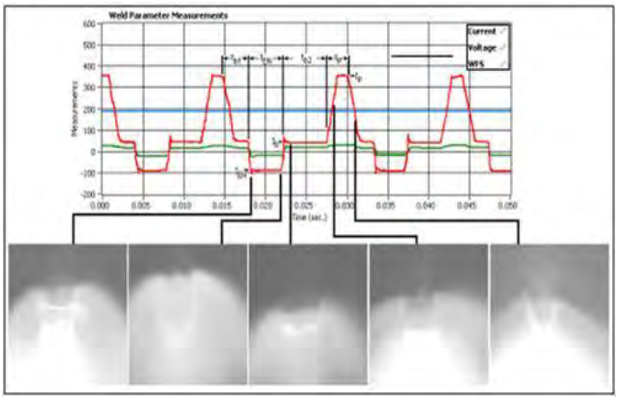

Figure 1 - Typical Waveform CA MIG / MAG and its correlation with the stages of growth and detachment of the drop (Harwig adapted from 2006)

There are also various other waveforms of current that can be used for AC MIG / MAG, it is not clear yet what benefits of each. But what is common between them is the large number of variables of the wave to be regulated. Combines to this limitation the need to try to keep the arc length as constant as possible between the inversions, the fact that it can regulate the current in the negative pole to give the same fusion rate than in the positive polarity. Thus, the same feed speed setting is used in both polarities. As seen, the number of parameters to be regulated is greater than in the conventional P - MIG As seen, the number of parameters to be regulated is greater than in conventional pulse MIG according (Quentin and Allum, 1984; Scotti Vilarinho, 2000), and even that the MIG / MAG double pulse (Silva et al 2008). Thus, the aim of this paper is to present a methodology to select the parameters for welding with AC MIG / MAG and its application in service repair of pipelines of oil and gas.

2. A METHODOLOGY FOR DEFINING PARAMETERS FOR AC MIG / MAG WELDING

In this process, there is a transition periodic polarity, but one should ensure that there is only metal transfer in positive polarity by one pulse. Thus, the stability of metal transfer is subject to the posting of a single drop with a diameter close to the wire electrode during the pulse time (ODPP). Furthermore, one should look to maintain the same length of arc in both polarities to ensure regular weld beads in size and shape. However, there is a negative polarity at an increased rate of melting. Thus, to maintain the same wire feed speed in both polarities, one option is to vary the average current for each polarity in order to maintain the same arc length.

It was developed a methodology to find parameters for welding CA MIG / MAG that resulted in good stability transfer and weld beads with good looks and geometric features within the standards of acceptability. The application of this method starts with the current waveform, for example, as in Figure 1 (base-pulse-base). Then be defined input parameters for adjusting the welding in AC MIG, or desired the following values:

- The average current in the desired positive polarity (Im +);
- The rate of the electrode negative (EN%);
- The shielding gas;
- The chemical composition of the wire diameter and

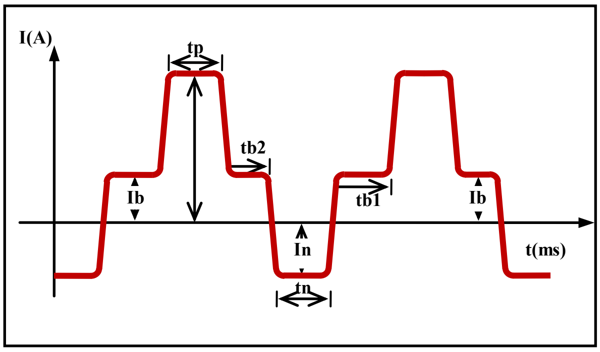

Figure 1 - Waveform (base-pulse-base) I_p= Peak current; I_{b1}= Background current before of detachment; t_{b1}= Background time before the peak detachment; I_{b2}= Background current after peak of detachment; t_{b2}= Background time after the peak detachment; I_n= Negative current in the; t_n= Negative Time.

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Importantly, it is not possible to input directly the current global average desired (I_{mg}), that why she is a dependent variable of variables to be determined. Therefore, the input must be desired by the average current in the positive polarity (I_m +). This current will be close to the average current end but through recursive calculations can be reached overall desired average current. The average current in the positive polarity should be adjusted to be typical average current pulse for the given condition (the base material, type and diameter electrode, shielding gas and CTWD). For example, for carbon steel electrode AWS70S-6 with a diameter of 1.2 mm, and shielding gas mixture of Ar + 2% O_2, the average current values should vary between 90 and 210 A.

The percentage of the negative electrode is described as the ratio between the time at which the electrode operates at negative polarity (t_{EN}) and period. The period in turn corresponds to the total time spent in both polarities, i.e. in the negative time (t_{EN}) over time in the positive (t_{EP}) as shown in equation 1.

$$\%EN = \frac{t_{EN}}{t_{EN}+t_{EP}} \tag{1}$$

Where, EN% = percentage of the negative electrode, t_{EN} = time that the electrode operates in negative polarity and t_{EP} = time that the electrode positive polarity. A operates in choosing the type of shielding gas depends on the type of electrode wire, which in turn depends upon the material being welded. In the case of welding of structural steels, should favor a gas with low CO_2 or O_2 in mixtures with argon, for facilitating the transfer metal droplet during the pulses. In this case, the diameter of the wire electrode used is more than 1.2 mm.

As output, we expect an average arc length of about 5 mm, steadily, and the condition of One Drop Per Pulse (ODPP) in positive polarity without metal transfer in the negative polarity, with average current (I_m) which may be a little different than (I_m +) set, and% EN close to desired values. To achieve these conditions, some settings need to be taken, they are:

a) Definition of values parameters which are invariable for a particular condition:

- Peak current (I_p);
- Background current (I_b);
- Contact tip Distance Workpiece (CTWD);
- Free length of wire energized (L);
- The constants of the equation of the overall consumption α and β in both polarities;

The peak current (I_p) is defined according to its application. If the goal is greater penetration, one must adopt their value much larger than the transition current set on tables or determined experimentally for gas and wire chosen in other words,: (I_p) >> ($I_{transição}$). In case you want to finish, you must choose a value (I_p) slightly larger than ($I_{transição}$). The background current (I_b), in practice (I_{b1}) and (I_{b2}) should also be selected according to desired average current. The value of the background current recommended should be above 40 and 60 A. For CTWD, seeks to focus on what is normally charged for Pulsed MIG, one should try to achieve greater value for high feed rate using low values of average current (below the transition current), with a confidence up to 25 mm for the electrode wire of 1.2 mm diameter, for reasons of rigidity of the free end of the wire. The free length of the electrode is usually remains the CTWD subtracted from the length of the arc, which in practice is adopted for this case 5 mm. Ultimately, the constants α^-, β^- and α^+, β^+ consumption of the general equation are determined experimentally for the entire gas-wire polarity. If the user does not have them tabulated, should seek to determine them or request a specialized laboratory that determination, according to procedures described in Section 2.1.

b) Definition of values all other parameters through the user:

- Peak time (t_p);
- Time background (t_b);
- Feed speed in positive polarity (F_{speed}+)
- Feed speed in negative polarity (F_{speed}¯)
- RMS current in the positive polarity (IRMS);
- The negative current (I_n);
- Negative time (t_n);
- Global average current (I_{mg});

The peak time (tp) is calculated by interpolation curve (Im^+ x t_p) for the condition ODPP, found over experimentally for the conditions in MIG Pulsed (if the user does not have this curve, should seek to determine it or ask a specialized

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laboratory this determination, according to the procedures described in Section 2.2). The background time (t_b) is calculated by the equation current exponential average for MIG pulsed, or isolating time based on equation 2, and by entering the values of the other parameters, where (I_m^{+}) is an input value and λ_1 and λ_2 are the exponential time constant of the exponential waveform (Figure 2), chosen because of the characteristics of the font used. For this purpose, a program is used by using the Matlab to find the solution of the equation.

$$I_{m+} = \frac{I_p.t_p - \frac{(I_p-I_b)}{\lambda_1}\left(1-e^{\lambda_1.t_p}\right) + I_b.t_{b} - \frac{(I_b-I_p)}{\lambda_2}\left(1-e^{-\lambda_2.t_b}\right)}{t_p+t_b} \quad (2)$$

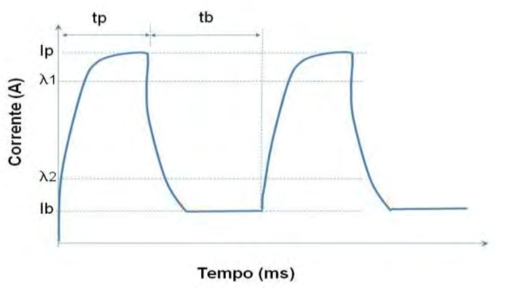

Figure 2 - Waveform for pulsed current of type Exponential, typical equipment capable of pulsed current

The RMS current ($I_{RMS}+$) is calculated by equation 3 from the exponential waveform on condition ODPP;

$$I_{RMS} = \left\{I_p^2.t_p + I_b^2.t_b - \frac{(I_p-I_b}{e^{\lambda_1 t_p}.\lambda_1}\left(\frac{(I_p-I_b)}{2e^{\lambda_1.t_p}.\lambda_1} + 2.I_p\right) - \frac{(I_b-I_p)}{e^{\lambda_2.t_p}\lambda_2}\left(\frac{(I_b-I_p)}{2e^{\lambda_2.t_b}.\lambda_1} - 2I_b\right) - \frac{(I_p-I_b)}{e^{\lambda_1.t_p}.\lambda_1}(3.I_p + I_b - \frac{(I_b-I_p)}{2.\lambda_2}(3.I_p + I_p\right\} \quad (3)$$

The current in the negative (In) is calculated by equating the values of fusion rate in both polarities expressed by equations 4 and 5.

$$V_{alim}^{\ +} = \alpha^{+}I_{m+} + \beta^{+}LI_{RMS+}^{2} \quad (4)$$

$$V_{alim}^{\ -} = \alpha^{-}I_{m-} + \beta^{-}LI_{RMS-}^{2} \quad (5)$$

Where, (I_m^{+}) is an input parameter (average current required at the positive pole) ($I_{RMS}+$) calculated according to equation 3 I_{RMS}, is by definition (In), since the negative current is constant, and α-, β- and α+ β+ are constants calculated experimentally.

Equating feed rate in both polarities, we have:

$$V_{alim}^{\ -} - V_{alim}^{\ +} = 0 \quad (6)$$

Substituting equation 4 and 5 6 have:

$$\alpha^{-}I_n + \beta^{-}LI_n^2 - V_{alim}^{\ +} = 0 \quad (7)$$

it has reordered in the form of equation 8

$$\beta^{-}LI_n^2 + \alpha^{-}I_n - V_{alim}^{\ +} = 0 \quad (8)$$

Thus, the current value in the negative (I_n) is calculated by solving the equation 8. Already the value of time the negative is calculated from equation 9:

$$t_n = \frac{\%EN\ t_{pp}}{1-\%EN} \quad (9)$$

Where, t_n = time at which the electrode operates at negative polarity and t_{pp} = total time of positive polarity.

Finally, the overall average current (I_{mg}) corresponding to the weighted average of the currents in the various phases of the pulse, defined by equation 10;

$$I_{m_g} = \frac{I_p t_p + I_b t_b + |I_n| t_n}{t_p + t_b + t_n} \tag{10}$$

Where,

I_p=Peak current;
I_b=Background current; (I_{b1}) ou (I_{b2});
t_p =peak time;
t_b=background time ;
I_n=negative current;
t_n=negative time

In case the overall average current (I_{mg}) after the calculation does not reach the desired value, in a recursive way one can increase or decrease the average current in the positive pole (I_m^+) and restart the convergence calculations to the value of desired (I_{mg}).

2.1 Experimental determination constants equation of consumption in the two polarities (CC^-) and (CC^+)

The fusion rate in positive and negative polarities is expressed by Equations 4 and 5, respectively. To determine the constants and α^+ β^+, α^- and β^- these equations, a series of experiments have to be done, sweeping across up a range of current applied to the wire and shielding gas (strictly speaking, this should also scan be given for the (CTWD), but it can take an average value of 20 mm as representative range for this technique to be used, namely 15 to 25 mm). During welding, the arc attempt to maintain approximately 5 mm, length most used for this type of process. This is possible if the device has adaptive control of the arc length by adjusting the reference voltage until it reaches the desired arc length. If not, the feed rate should be adjusted to more and less until it reaches the desired value.

In the case of the positive polarity should adjust the power of constant current welding mode, with pulse. If the source has a control for synergic pulsed current, use it for each desired average current as a function of shielding gas and wire chosen. Otherwise, should adjust all pulse parameters, taking as a basis the values of current pulse and the pulse time to be used at work. Anyway, it is important to ensure the detachment condition of one drop per pulse for every desired current level, for example, using the optical monitor according (Miranda et al 2007) or Shadowgraph technique according (Balsamo et al 2000). In the case of negative polarity due to regulate the supply of constant current welding mode, no pulse (if the font does not allow put in the pulsed mode, but making $I_p = I_b$).

During the welding, the feed rate monitor (F_s^+ and F_s^-) and the current for each experiment and determine the values I_m^+ and I_{rms}^+ or I_m^- and I_{rms}^-. Thus, through regression analysis, available in commercial computer programs, it is possible selectors let you determine the constants, based on Equation 4 or 5.

2.2 Experimental determination of peak times (t_p) in positive polarity (CC+)

The experimental procedure for determining the peak time (t_p) for a given pulse current (I_p) consists in making several weld seams, steeply varying the pulse time (t_p) for each current average for that parameter which shall be regulated (sweeping the average current within the range of applicability). Feeding speed (F_s) should be consistent with each average current, looking up an arc of approximately 5 mm (starting up welding with a high value of (F_s) and lowers gradually until this regulation is able to open the bow and keep it to the desired length). The value of I_b should be chosen beforehand, similar to I_p. Thus, for each adjustment of pulse time (t_p), it is necessary to adjust the time background (t_b), keeping the average current, as indicated by equation 11. There will also be a need to adjust the length of the arc through the Feed speed.

$$t_b = \frac{t_p(I_m + I_p)}{I_b + I_m} \tag{11}$$

There will be a range of pulse times will be reached in which the condition of one drop per pulse for each desired average current level for a given current pulse wire, shielding gas. To measure whether there would be the condition of one drop per pulse can be used, for example, optical monitor (Miranda et al 2007) or high-speed film (Balsamo et al 2000). Thus, from the values of the regulated and monitored values is constructed a graph of the relationship average current and average pulse time range in which the condition is one drop per pulse, as illustrated in Figure 3.

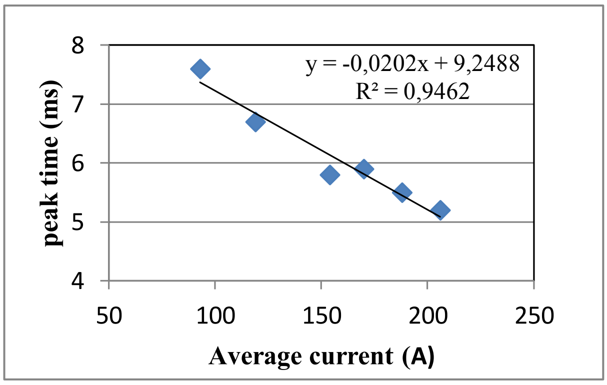

Figure 3 - Relationship between average current and peak time raised for I_p = 250 A, wire AWS ER70S-6 and protection with using a mixture of Ar + 2% O_2

2.3 Application of the methodology

To illustrate the application of the described methodology, the waveform was set shown in Figure 4 (base-pulse base), which has the base before and after a positive pulse, and it is beneficial to avoid sudden changes polarity, the metal base was used the carbon structural steel, alloyed. Thus, the deposition material as the electrode was specified class AWS ER70S-6 with a diameter of 1.2 mm, maintaining a CTWD 25 mm. A mixture of argon + 2% oxygen was used, aiming at a condition of 50% EN. Initially set the following values of the input parameters of the average current in the positive polarity (I_m +) = 90 A, 120 A, 150 A, 165 A, 180 A and 210 A. Others were also defined input parameters are invariant, ie:

- I_p = 250 A;
- Background curent 1 (I_{b1}) ou Background curent 2 (I_{b2}) = 40 A;
- CTWD = 25 mm, and L_{arc} = 5 mm;
- Values of the constants of the equation of the consumption in both polarities (experimentally obtained):
  - Na polaridade negativa: $\alpha^- = 6{,}19 \times 10^{-4}\, m/_{s.A}$; $\beta^- = 2{,}9 \times 10^{-5} s^{-1} A^{-2}$;
  - Na polaridade positiva: $\alpha^+ = 1{,}19 \times 10^{-4}\, m/_{s.A}$; $\beta^+ = 8{,}9 \times 10^{-5} s^{-1} A^{-2}$

Then were defined set of estimated parameters:

- The values of peak time (t_p), calculated by interpolation curve Im + x tp raised experimentally to all current averages in positive pole, as defined;
- The time base (t_b); isolating the time based on equation 2 and coming up with the values of other parameters ($I_m + I_p$, I_b, t_p, λ_1 and λ_2, these latter assumed to 2 and 3 respectively depending on the welding equipment);
- The values of the Feeding speed of positive polarity for each value of the input average current calculated by the equation 4;
- The values of the feed rate of negative polarity for each value of the input average current calculated by equation 5;
- The values of the negative current (I_n), for each value of the input average current calculated using Equation 8;
- The values in the negative time (t_n) calculated by making use of the equation 9;
- Finally, the overall average current values (I_{mg}) using equation 10.

The Table 1 shows the input values and estimated by the proposed methodology for the current range 90-210 A and EN = 50%. It can be noticed that the current global average was slightly lower than the average current in the positive pole. Thus, if one desire was to increase this figure, it would only be by trial and error correct the input value for the average current in the positive pole (I_m+). Using the input values (I_p, I_{b1} and I_{b2}) and the estimates (t_p, t_{b1}, t_{b2}, F_s, I_n and t_n) of Table 1 for regulating equipment, welds were made to validate the method. Table 2 shows the parameter validation, where the overall average current (I_{mg}), since it was estimated and can be monitored. One can notice the good performance of the methodology.

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Table 1 - Parameters estimated for AC MIG / MAG welding current range for a positive electrode in the 90-210 A and EN = 50%

Input Parameters					Estimated Parameters							
I_m^+ (A)	EN %	I_p (A)	I_{b1} (A)	I_{b2} (A)	t_p (ms)	t_{b1} (ms)	t_{b2} (ms)	V_{alim} (m/min)	I_n (A)	t_n (ms)	I_{mg} (A)	T (ms)
90	0,5	250	40	40	7,4	22,30	1	2,5	63	30,7	77	61,5
120	0,5	250	40	40	6,8	9,60	1	3,4	80	17,4	101	34,8
150	0,5	250	40	40	6,2	4,23	1	4,7	100	11,4	127	22,8
165	0,5	250	40	40	5,9	2,73	1	5,1	126	9,6	147	19,2
180	0,5	250	40	40	5,6	1,55	1	6,1	134	8,1	159	16,2
210	0,5	250	40	40	4,9	-0,05	1	6,7	166	5,9	191	11,8

I_m^+= Average current in the positive polarity; %EN= Percentage of on the negative electrode; I_p= peak current; I_{b1}= background current before pulse; I_{b2}= background current after pulse; t_p=peak time; t_{b1}= Background time before the pulse; t_{b2}= Background time after the pulse; F_s=Feed speed; I_n= Negative current; t_n= negative time; $I_{(mg)}$ = Global average current; T=Period

Table 2 - Comparison between the values of Average Current Average Current and Estimated Global Global Monitored, with the corresponding percentage error for welds performed in AC MIG / MAG welding using control parameters as input values and estimates shown in Table 2

I_{mg} (Estimated) (A)	I_{mg} (measured) (A)	Percentage error (%)
78	76	2,7
99	101	-2,2
125	122	2,7
146	144	1,1
161	156	3,4
186	187	-0,7

2.3 The effect of the Percentage of negative electrode (EN %) on the welded material by AC MIG / MAG process

Based on the definition these parameters and a value of average current input on the positive (I_m +) equal to 165 A, because with the current value was verified by high-speed camera with the condition of posting ODPP. So then we used two approaches to:

Approach A;

Determine the value of time on the negative (t_n) for a range of values in a 0% to 90%, by keeping the time base 1 (t_{b1}) and the second base time (t_{b2}) constant (varying as a result the period (T));

Approach B;

Determine the value of time the negative (t_n) for a range of values in a 0% to 90%, keeping the period (T) and the second base time (t_{b2}) set (as a result of varying the time of base 1 (t_{b1})).

Expectations:

I) By using the approach A, can happen t_n influence metal transference, losing condition ODPP. For example, a very long time in the negative, is subject to escalation of the arc condition, causing the droplet acquires a larger diameter than the wire electrode, which is undesirable.

II) In approach B, by reducing t_{b1} and maintaining and t_{b2} constant, there is little scope to change t_n arithmetic.

Table 3 and Table 4 show results of calculations with the parameters of the pulse approaches to for A and B to a current average of 165 A and varying in a 0% to 90%.

Table 3 - Parameter for AC MIG / MAG for different values of EN% using approach A

I_m (A)	EN (%)	t_p (ms)	t_{b1} (ms)	t_{b2} (ms)	t_n (ms)	Período (ms)
165	0	5,90	2,73	1,00	0	9,63
	10	5,90	2,73	1,00	1,07	10,70
	20	5,90	2,73	1,00	2,40	12,03
	30	5,90	2,73	1,00	4,12	13,75
	40	5,90	2,73	1,00	6,42	16,05
	50	5,90	2,73	1,00	9,63	19,26
	60	5,90	2,73	1,00	14,45	24,07
	70	5,90	2,73	1,00	22,47	32,10
	80	5,90	2,73	1,00	38,52	48,15
	90	5,90	2,73	1,00	86,67	96,30

I_m= Average current required; %EN= Percentage of on the negative electrode; t_p=Peak time; t_{b1}= background current before pulse; t_{b2}= Background time after the pulse; t_n= negative time; T=Period; CTWD =25 mm

Table 4 - Parameter for AC MIG / MAG for different values of EN% using approach B

I_m (A)	EN (%)	t_p (ms)	t_{b1} (ms)	t_{b2} (ms)	t_n (ms)	Período (ms)
165	0	5,90	12,10	1,00	0,00	19,00
	10	5,90	10,20	1,00	1,90	19,00
	20	5,90	8,30	1,00	3,80	19,00
	30	5,90	6,40	1,00	5,70	19,00
	40	5,90	4,50	1,00	7,60	19,00
	50	5,90	2,60	1,00	9,50	19,00
	60	5,90	0,70	1,00	11,40	19,00
	70	5,90	-1,20	1,00	13,30	19,00
	80	5,90	-3,10	1,00	15,20	19,00
	90	5,90	-5,00	1,00	17,10	19,00

I_m=Average current required; %EN=Percentage of on the negative electrode; t_p=Peak time; t_{b1}= background current before pulse; t_{b2}=Background time after the pulse; t_n=negative time;; CTWD=25 mm

3.3 Study of metal transfer through filming with high speed camera

For visualization of metal transfer and related phenomena, was used a digital camera capable of shooting 2000 fps (frames per second) using the technique filming direct arc welding. For the experiments was then used as a workbench schematically in Figure 5 which is basically a table for the displacement of the specimens, which allows the torch, and consequently the arch remain stationary relative to the camera, a protective glass to prevent any spillover damage the camera and / or the game of lenses and filters neutral, and finally, the high speed camera.

Once the parameters have been raised CA MIG / MAG through the methodology presented were made then filming with camera high speed. Initially made in the form shooting conditions shown in Table 1 for values of the input average current positive polarity ranging from 90, 120, 150, 165 and 180 A.

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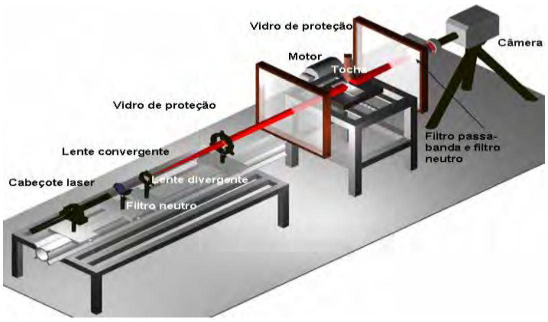

Figure 5 - Arrangement drawing of the equipment for filming, especially the high-speed camera(Balsamo et al 2000) and table displacement of the specimen

The filming was synchronized with the aid of two computational tools necessary to perform this step, the program Matlab and Origin 8.5. Thus then each graph was constructed for the average current value entry already described and the results show the instant position and detachment of the drop. Figure 6 illustrates metal transfer with the parameters calculated for a value of the input average current positive polarity equal to 165 A, an average current value corresponding global equal to 147 A, and a value of the percentage Negative Electrode 50% . The choice of this value chain is due to meet the requirement of posting ODPP

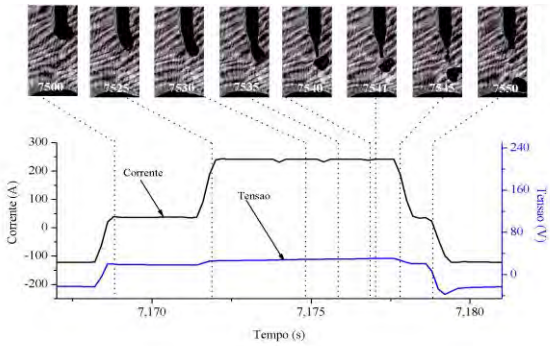

Figure 6 – Graphic of metal transfer AC MIG/MAG process, showing a parameter regulation that produces "ODPP the end of the pulse"; (50%EN: I_m^+= 165A; I_p= 250A; I_{b1}=I_{b2}=40 A; t_p=5,2ms; t_{b1}=2,73ms; t_{b2}=1ms; F_s=5,0m/min; I_n=126A; t_n=9,6ms; $I_{(mg)}$=147A; T=22,8ms); CTWD=25mm

Then were done filming metal transfer welding of the weld bead table 3 that corresponds to the approach, with percentage values at the negative electrode (EN%) ranging from 0%, 10%, 30%, 50% and 70%. The sequence of some image frames is shown in Figure 7 for a percentage value equal to the negative electrode of 50%.

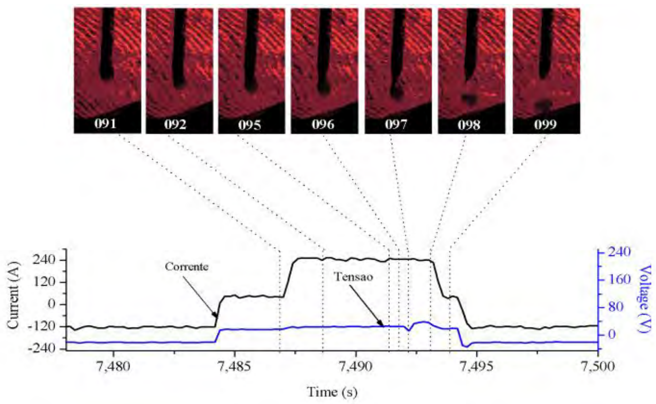

Figure 7 – Graphic of metal transfer AC MIG/MAG process, showing a parameter regulation that produces "ODPP the end of the pulse". Approach A com 50%EN: I_m^+= 165A; I_p= 250A; I_{b1}=I_{b2}=40A; t_p=5,9ms; t_{b1}=4,5ms; t_{b2}=1ms; F_s = 4,7m/min; I_n=126A; t_n=7,6ms; $I_{(mg)}$=147A; T=19ms; CTWD =25mm

Were also made, filming metal transfer welding of the weld bead table 4 that corresponds to the approach B with values in percentages of electrode negative (EN%) ranging from 10%, 30% and 50%. The sequence of some image frames is shown in Figure 8 for a percentage value equal to the negative electrode of 50%.

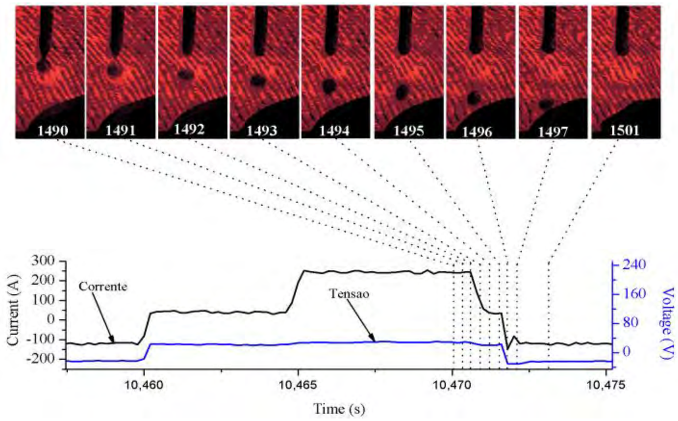

Figure 8 – Graphic of metal transfer AC MIG/MAG process, showing a parameter regulation that produces "ODPP the end of the pulse. Approach B com 50%EN: I_m^+= 165A; I_p= 250A; I_{b1}=I_{b2}=40A; t_p=5,9ms; t_{b1}=6,4ms; t_{b2}=1ms; F_s= 4,7m/min; I_n=126A; t_n=7,6ms; I $_{(mg)}$)=147A; T=19ms; CTWD =25mm

3.4 The performance assessment AC MIG / MAG welding process tax in terms of

In this step we sought to investigate the phenomenology of MIG / MAG CA and its potential for application in welding of pipelines in service recovery, making an assessment of the influence of the variation in the percentage of Electrode Negative (EN%) in training weld bead and heat on the opposite face of the sheet, measuring the temperature variation with a thermographic camera.

The infrared temperature measurement is a method that does not require the direct contact of the sensor with the part being analyzed, this being one of the advantages of this equipment. However, the main advantage of this equipment with regard to making temperature measurements with thermocouples during welding, is that the camera does the measurement of a temperature field, ie, makes multiple measurements in the same instant, while the thermocouples are only a measurement every time.

Infrared cameras are sensors that transform the intensity of infrared radiation temperature signal. Equipment are modern, but still fairly high cost. Its use requires a good knowledge in the area of radiation, because its handling is not as simple as the analysis of the results.

Infrared cameras are sensors that transform the intensity of infrared radiation temperature signal. Equipment are modern, but still fairly high cost. Its use requires a good knowledge in the area of radiation, because its handling is not as simple as the analysis of the results. Thus, at this stage of the work consisted in the analysis of the two approaches addressed in the previous studies based on the proposed waveform and different rates of negative electrode. To perform the temperature measurements at the rear of the plate during the welding process in this work, we used an infrared camera FLIR A325 shown in Figure 9 the type microbolometer that can analyze a range of spectrum from 7.5 to 13 µ m (long infrared). This camera has a resolution of 320 x 420 pixels, a rate de aquisição de até 60 Hz e uma acuracidade de ±2°C. Sua análise é dividida em três níveis de temperatura: (-20°C 120 °C; 0° C a 350° C e 300 °C a 2000 °C).

Figure 9 - Infrared Camera FLIR A325 series

The technique for measurement on the opposite side of the plate is to position the camera underneath the part to be welded and direct focus on where want to measure the temperature during the course of welding as shown in Figure 10.

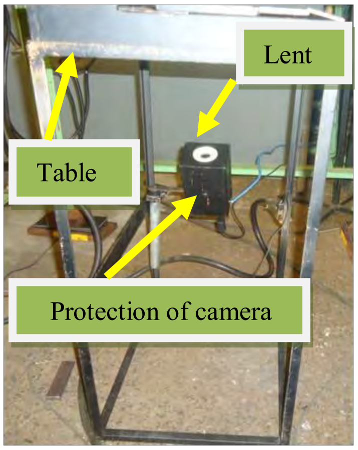

Figure 10 - Infrared Camera FLIR A325 series in its enclosure positioned to shoot infrared

The methodology for making temperature measurements was to monitor every 5 seconds of arc stabilization temperature values, taking three measurements for each condition in the percentage of negative electrode approaches A and B. In figure 10 is shown the software interface Thermocam research 2.9 for the first condition of 50% EN, the approach in the instant 20s after the arc has been stabilized. It can be seen from the graph that the maximum temperature (Tmax) achieved at this moment corresponds to 689.7 ° C.

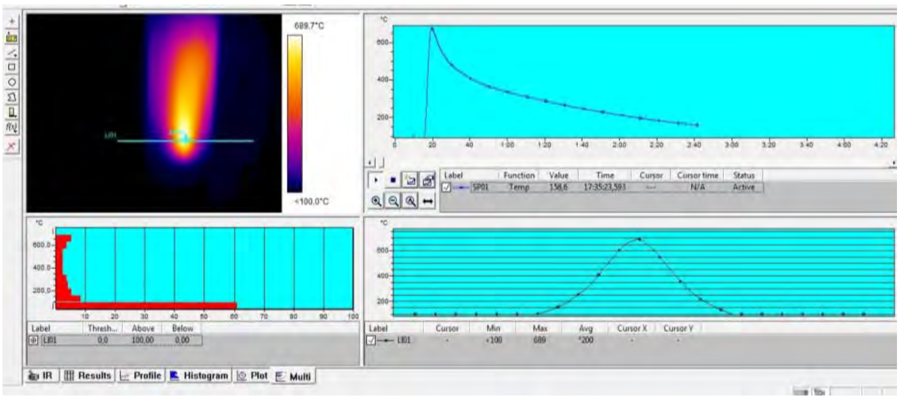

Figure 10-Graphical Interface Software 2.9 Thermocam research, Approach A (EN=50% I_m^+=165A; I_p=250A; I_{b1}=I_{b2}=40 A; t_p=5,9ms; t_{b1}=2,73ms; t_{b2}=1ms; F_s=4,8m/min; t_n=9,6ms; T=19,3ms; t_n=9,6ms; t_2 = 689,7 °C; t_{time}=20s)

In the same way in figure 11 is shown the graphic to the condition EN=50%, B approach the instant 20s after the arc is stabilized recording a maximum temperature of 695.3.

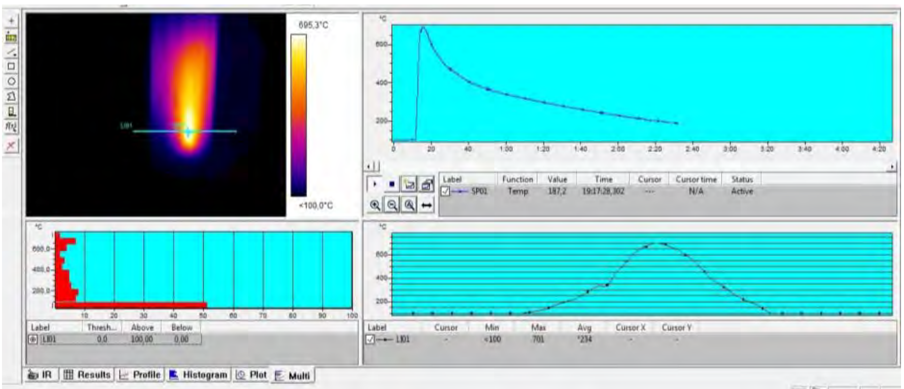

Figure 10 - Graphical Interface Software 2.9 Thermocam research, approach B (EN = **5**0% I_m^+=165A; I_p=250A; I_{b1}=I_{b2}=40 A; t_p=5,9ms; t_{b1}=2,60ms; t_{b2}=1ms; F_s=5,2m/min; t_n=9,50ms; T=19; t_n= 9,508ms; t_2 = 689, 7 °C; t_{time}=20s

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Made after all welds made with the temperature in instants desired, table 5 shows the results for the approach A.

Table 5 - The Approach A: Increasing the value of the time in the negative, varying the period (T). Maximum temperature (Tmax) at the rear side of the plate

I_m (A)	$I_{(mg)}$ (A)	EN (%)	I_p (A)	I_{b1} (A)	I_{b2} (A)	I_n (A)	t_p (ms)	t_{b1} (ms)	t_{b2} (ms)	t_n ms	T (ms)	t_1 (°C)	t_2 (°C)	t_3 (°C)	t_{avg} (°C)
165	146	0	250	40	40	123	5,90	2,73	1	0,00	9,63	747	756	804	797
		10								1,07	32,10	736	740	735	737
		30								4,12	13,76	714	718	715	716
		50								9,63	19,26	691	690	693	691
		70								86,70	10,70	628	660	655	648

I_m^+= Average current on the positive; $I_{(mg)}$= Current global average; %EN=Percent electrode on the; I_p=peak current; I_{b1}=base current before the peak; I_{b2}=background current after the peak; I_n= Negative current; t_p = peak time; t_{b1}=background time before the peak; t_{b2}=background time after peak; tn=time on the negative; T=Period; t_{avg}= average temperature of the plate opposite

Similarly in Table 6 shows the results for approach B.

Table 6- Approach B: the ten to compensate decreasing t_{b1} and t_{b2} keeping constant, there is little room for change t_n.

I_m (A)	$I_{(mg)}$ (A)	EN (%)	I_p (A)	I_{b1} (A)	I_{b2} (A)	I_n (A)	t_p (ms)	t_{b1} (ms)	t_{b2} (ms)	t_n ms	T (ms)	t_1 (°C)	t_2 (°C)	t_3 (°C)	T_{avg} (°C)
165	146	0	250	40	40	123	5,90	2,73	1	0,00	9,63	746	759	797	767
		10								1,07	32,10	740	749	729	739
		30								4,12	13,76	707	695	696	699
		50								9,63	19,26	563	584	616	588

I_m^+= Average current on the positive; I(mg)= Current global average; %EN=Percent electrode on the; I_p=peak current; I_{b1}=base current before the peak; I_{b2}=background current after the peak; I_n=Negative current; t_p=peak time; t_{b1}=background time before the peak; t_{b2}=background time after peak; tn=time on the negative; T=Period; t_{avg}=average temperature of the plate opposite

3.5 Study on the effect of the percentage of the negative electrode in relation to the geometrical parameters of the weld in AC welding process MIG / MAG

It was then performed an analysis of the samples Macrograph the welded material with the aim of verifying through the Heat Affected Zone (HAZ), the effect of varying the EN% of the heat contributed to the plate. For this weld beads were sectioned in the transverse direction of the plate, because the aim is to analyze the weld profile with respect to its geometrical and thermal characteristics. The samples after working were subjected to metallographic etching technique by using a wetting solution using a Nital reagent 10%. The samples were split, photographed and subjected to analysis by computational tool ImageJ 1.43u.

Measurements were made of the Width (W), Depth (P), Reinforcement (R), Fused Area (A_F) and the Heat Affected Zone (HAZ). For each condition, three measures were then made and the average taken for analysis of results. Figure 12 illustrates the cross section of a bead on plate done with AC MIG / MAG and regulation of the parameter values estimated by the methodology presented in this work, showing the geometric quality of the cord produced.

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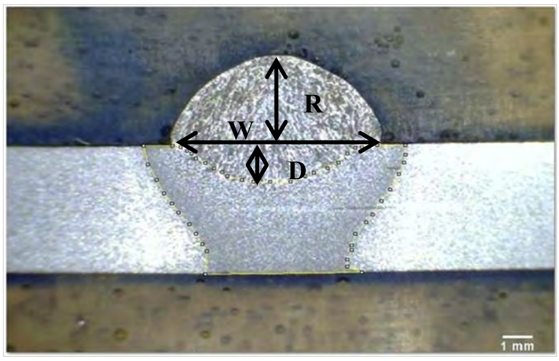

Figure 12 - Cross section of a weld bead simple deposition on the plate using AC MIG / MAG process, the Approach A; (EN =50%; I_p=250A; I_b =40A; I_n =126A; t_p =5,9 ms; t_{b1} =2,7 ms; t_{b2} =1 ms; t_n=2,73 ms; T=19,26 ms; W=6,8 mm; D = 1,3 mm; R = 3,4 mm.)

In Table 7 shows the measured values of the geometrical parameters of the weld beads according to the percentage variation of the negative electrode to the conditions set out in approach A.

Table 7 - Change the width (W), penetration (D), Reinforcement (R) area and the heat affected (HAZ) with the variation of the percentage of negative electrode in% EN (approach A)

EN (%)	*W (mm)*	*W_{avg} (mm)*	*D (mm)*	*D_{avg} (mm)*	*R (mm)*	*R_{avg} (mm)*	*A_{HAZ} (mm^2)*	*A_{HAZavg} (mm^2)*
0	8.36	8.38	2.23	2.26	2.98	2.97	36.55	36.78
	8.41		2.24		2.93		37.22	
	8.36		2.32		3.01		36.59	
10	7.44	7.46	2.29	2.35	3.15	3.10	31.12	32.28
	7.45		2.38		3.12		32.78	
	7.48		2.38		3.02		32.93	
30	7.22	7.24	1.36	1.43	3.20	3.24	30.06	30.40
	7.24		1.47		3.25		30.15	
	7.27		1.46		3.28		30.99	
50	7.01	6.98	1.37	1.39	3.43	3.43	26.73	26.79
	6.96		1.36		3.47		26.84	
	6.96		1.42		3.40		26.82	
70	6.55	6.60	0.70	0.71	3.47	3.40	23.08	22.98
	6.61		0.73		3.36		23.82	
	6.65		0.70		3.37		22.03	

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Figure 13 illustrates the cross section of a bead on plate done with AC MIG / MAG, approach B and setting parameter values estimated by the methodology presented in this work, showing the geometric quality of the cord

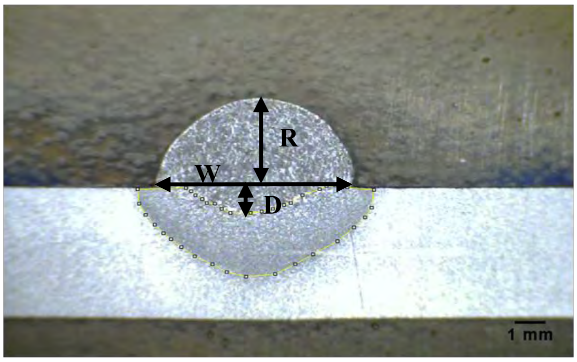

Figure 13 - Cross section of a weld bead simple deposition on the plate using AC MIG / MAG process, the Approach B; (EN = 50%; I_p = 250A; I_b = 40A; I_n = 126A; t_p = 5,9 ms; t_{b1} = 2.60 ms; t_{b2} = 1 ms; t_{EN} = 9.50 ms; T=19 ms; W=6.56 mm; D=0.94 mm; R=3.30 mm)

In Table 8 shows the measured values of the geometrical parameters of the weld beads according to the percentage variation of the negative electrode to the conditions set out in approach B.

Table 8 - Variation of width (W), penetration (D), Reinforcement (R) area and the heat affected (HAZ) with the variation of the percentage of negative electrode in% EN (approach B)

EN (%)	*W (mm)*	*W_{med} (mm)*	*D (mm)*	*D_{med} (mm)*	*R (mm)*	*R_{med} (mm)*	*A_{HAz} (mm^2)*
10	7.20	7.23	1.82	1.80	3.61	3.65	29.61
	7.24		1.82		3.69		28.99
	7.26		1.77		3.66		29.18
30	6.58	6.61	1.30	1.23	3.42	3.36	26.47
	6.63		1.20		3.36		27.83
	6.61		1.19		3.31		28.28
40	6.70	6.77	1.27	1.32	3.23	3.20	23.03
	6.72		1.29		3.15		22.58
	6.89		1.41		3.24		24.42
50	6.94	6.56	0.95	0.94	3.30	3.30	16.74
	6.37		0.94		3.26		16.64
	6.38		0.94		3.35		17.51

From the results shown it can be seen that there is a decrease in the heat contributed to the base metal to the extent that it increases the percentage of the negative electrode (%EN). This is evidenced by the values of temperature measured on the opposite side of the plate, that is, when there is a decrease decreases the value of (%EN). Consequently there is less penetration, width and area of the HAZ with a possible increase in the reinforcement when increasing the value of the percentage of the electrode negative (EN%).

3.6 Conclusions

With the proposed methodology can be calculated with great precision values to be used in regulating equipment for welding with AC MIG / MAG welding process, overcoming one of the limitations of this version of the MIG / MAG. Survey demanding lifting of some experimental parameters, the preparation of a database over time will become more popular and easy application process for ease of selection of its control parameters.

By the method presented can use the process of AC MIG / MAG welding in the coating of pipelines in service in view of the temperature values reached at the rear of the base metal to be below the values obtained with welds using other welding processes coating such as, for example, GTAW and SMAW.

There is a substantial decrease of temperature with increasing% EN due to the reduced heat input, allowing application in welding thin sheet and welding of coatings.

Consequently with increasing% EN, there is a reduction in penetration and width of the weld bead, reducing the dimensions of the HAZ. There is also an increase in reinforcement.

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