DIGITAL CONTROL OF AUTOMATIZED WELDING MACHINE WITH PULSED CURRENT USING IGBT

Petronio Vieira Junior, João Antonio C. Pinto, Aldo C. Pereira, Denis Bolhosa
DEEC-CT-UFPA, Rua Augusto Correa, 01 – C.P. 8619, 66075-970, Belém – PA - Brasil
petronio@ufpa.br, j.pinto@cfetpa.br, aldoczsar@ufpa.br, bulhosa@ufpa.br

***Abstract* – This work presents the development of a welding machine MIG/MAG (Metal Gás Inerte/Metal Active Gás) whose exit current is pulsed, the control was developed starting from a simplified mathematical model, what allowed the elaboration of a program of simpler digital control. The mathematical model was based on equivalent circuits of the components of the process. These equivalent circuits allowed to characterize a variable of the process denominated stick out, this was modeled as being a variable resistance, allowing the control of the welding as being function just of that resistance. The circuits were simulated in MATLAB/SIMULINK and their data were compared with experimental results, allowing to validate the proposed model. The digital control was developed with base in the acquisition of current data and voltage through sensor, and digital processed using the microcontroller PIC16F877. The project of the potency circuit was elaborated with characteristics similar to the welding machines conventional and commercially available. An implementation was developed in the form of a prototype in real scale with use of power structures and IGBT, with capacity of up to 300 amperes. The experimental results are compared with the theoretical data, the one that allows do one analyzes comparative and of acting of the system.**

***Keywords* – Digital Control, IGB, PIC16F877, Machine Welding, MIG/MAG.**

I. INTRODUCTION

In the industrial installations the electric solder is used for assembly and maintenance of metallic structures, as any electric equipment, this possesses a source of responsible power for the correct and efficient use of the electric energy. In the industrial atmosphere the appropriate use of that energy is highly desirable since the imperative of the competitiveness makes it for they be obtained smaller production costs. On the other hand to the quality and speed of the assembly they depend partly on the welder and of the equipment. Being the welder a human operator an uncertainty factor the quality of the solder is imposed. The attempt of eliminating this factor, ally to the development of an equipment to reduce the consumption of energy, it can be gotten by the application of automated welding. A welding technique that can be automated is MIG/MAG (Metal Inert Gas/Metal Active Gás). This possibility is due to the feeding of the solder wire to be motorized (Motor CC) and to the type of chosen potency converter to be used in the process (Conversor BUCK). on the other hand the current pulsed in the exit of the potency source is that joins better conditions to the welding process, because, through this, it is possible to weld in all of the positions and to guarantee a better metallic transfer of the coalition pool. For the non linear of the welding the automation of the process is not trivial. A model suggestion simplified for the control is presented, and proven in an experimental way using techniques of digital control with the use of the microcontrolador PIC16F877.

II. DESCRIPTION OF THE PROCESS OF ELECTRIC WELDING MIG

The process of welding MIG, uses a wire consumable, naked massive electrode, continuously feeding the fusing zone and a system of protection, for inert/active gas, to the voltaic arc. The control of the process can be carried through by the manipulation of the speed of the feeding of the wire and/or by the adjustment of the parameters of pulse of the source of power, illustrated in Figure 1. It is verified, therefore, the necessity to control the electric speed do motor and the tension or the current of source of power The basic principle for the attainment of the stability of the voltaic arc in an operation of welding is that the speed of consumption and the speed of feeding of the consumable electrode are equal, in way that the length of the arc remains relatively constant. This is, also, the principle to establish strategies to any type of control in this process.

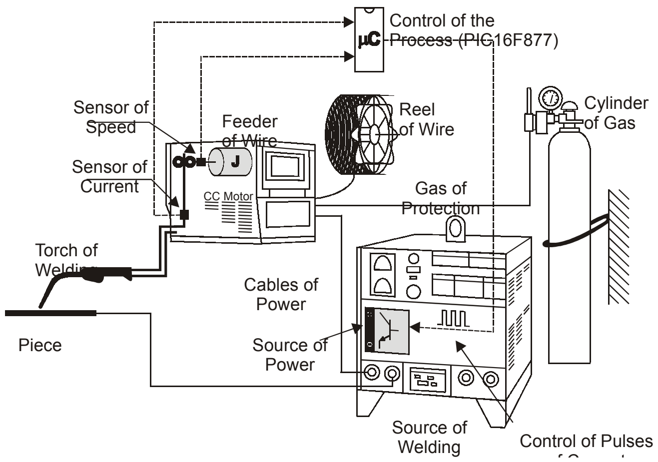


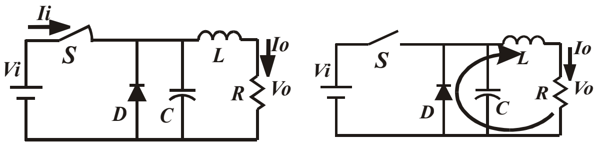
Figure 1. Esquematic of the welding process MIG.

III. MATHEMATICAL MODELLING OF THE PROCESS OF WELDING PULSED MIG-MAG

The model was developed to operate the welding in pulsed current, ideally square. The motor is of continuous current (motor CC) with speed controlled through a converter CC-CC. The models of the welding source and of the motor they are developed separately and together they represent the welding process mathematically

Mathematical model of the Source of Welding:

The used converter is of the step-Down type (Buck) that allows to condition the current CC in pré-established levels. By this reason it is adjusted to produce currents pulsed in the welding process. The mathematical model is, therefore based in this principle of functioning that can be represented by two circuits, with two operation stages, as illustraded in figure 2. A stage is defined with closed key *S* when the power is supplied by the source CC. The other operation stage occurs in the opening of the key S when the current settles down for the capacitor *C*. The resistance *R* and the Indutância *L* represent the characteristics of calorific energy and the inductive effect of the electric arc. Thus, the increase of the *stick out* corresponds to the increase of the value of *R*.



(a) Stage 1 of operation. b) Stage 2 of operation.

Fig. 2. Stages of operation of the Buck converter.

Mathematical Equation of the Stage 1 (Key closed S):

$$\frac{di_O}{dt} = \frac{1}{L}.[(E - Vs) - i_O.R] \qquad (1)$$

Mathematical Equation of the Stage 2 (Key open S):

$$\frac{di_O}{dt} = \frac{1}{L}.[i_O.R - \frac{1}{C}\int i_O dt] \qquad (2)$$

To implement the functioning of the opening commands and closing of the key of the Buck converter it is used of a signal PWM (Pulse Width Modulation).

Mathematical model of the Feeder of Wire

The drive of the feeder of the wire is accomplished by an electric motor. This way it can be considered that the model of the Feeder of the Wire understands exclusively the drive of motor CC.

Integration of the Models of the Source and of the Feeder of the Wire for Modelling of the Process of Welding

The representative model of the welding process is constituted of the Source of Power (Inverting) and of the feeder of wire (Motor CC),), enclosed the control of the process, show in block-type in figure 3.

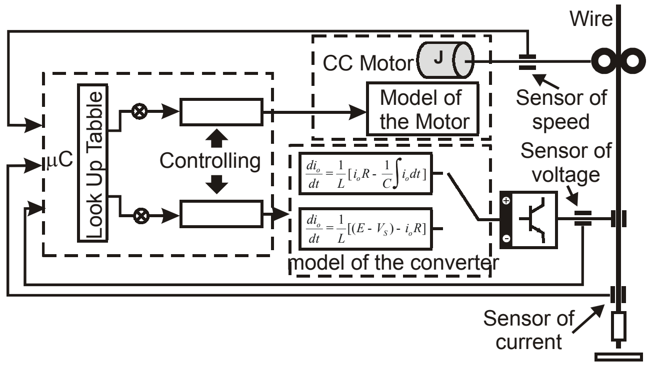


Figure 3. Diagram of blocks of the model of the control of the welding process.

IV. SIMULATION

Experimentally they were obtained instantaneous data of current for welding pulsed MIG/MAG, according to Table 1.

Table 1. Data obtained experimentally.

D	*w*	t_p	V_p	*T*	V_b	I_m	I_b	I_p	V_g
(mm)	(m/min)	(ms)	(Volts)	(ms)	(Volts)	(A)	(A)	(A)	(mm3)
1,2	5	4,4	28,38	9,60	5,20	118,17	32,40	219,68	0,90
1,2	6	4,2	29,05	8,00	3,80	134,75	35,32	224,85	0,90
1,2	7	3,8	30,54	6,86	3,06	151,32	45,77	236,38	0,90
1,2	8	3,3	32,77	6,00	2,70	167,90	63,26	253,66	0,90
1,2	9	3,1	33,81	5,33	2,23	184,48	77,46	261,72	0,90
1,2	10	2,8	35,58	4,80	2,00	201,06	97,19	275,38	0,90

Where:
D - Diameter of the Wire;
w – Speed of the Wire;
tp – Time of Pick;
Vp – Voltage of Pick
T – Timer;
Vb – Voltage of Base;
Im – Medium current of Adjustment;
Ib – Current of Base;
Ip – Current of Pick;
Vg – Volume of the Drop;

The model was developed in MATLAB/SIMULINK, figure 4, to verify its consistence. The result of the simulation is illustrated in the figure 5 (a) and (b). In this figure they are presented current of base and of peak and the speed of advanced of the wire respectively. The increase of the current characterizes the implicit inductance to the process. The resistance used in the equivalent circuit represents the *stick out* and has a direct relationship with the values of the currents and, therefore speeds of the wire. This relationship has a lineal approach, as it can be verified by the curves in the figure 6 (a) and (b). The figure 5 illustrates the answer in closed loop of the current and speed respectively to a step in the variation of the *stick out*.

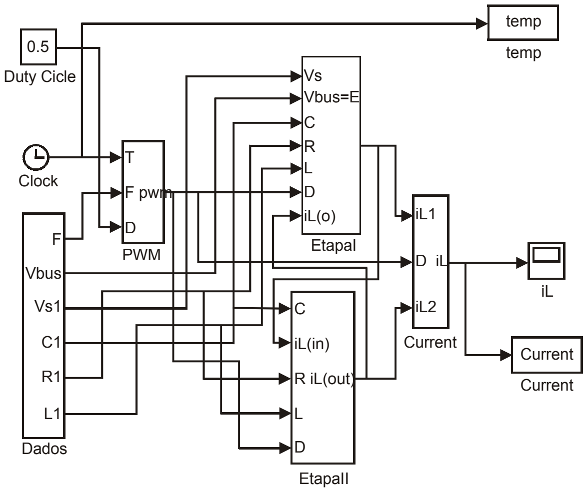
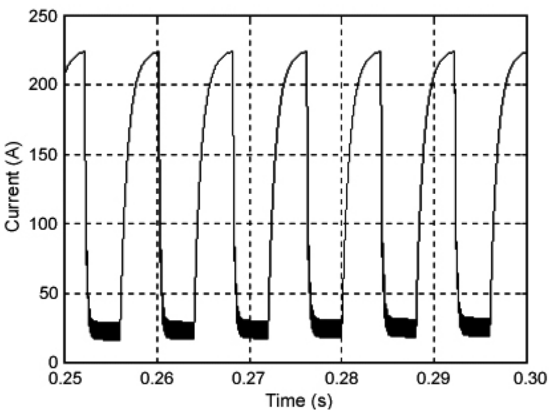
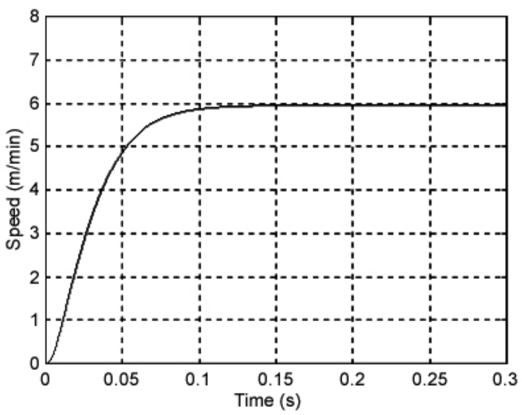


Figure 4. Esquematic in MATLAB of the convert CC-CC.



(a) Wave form of the Current.



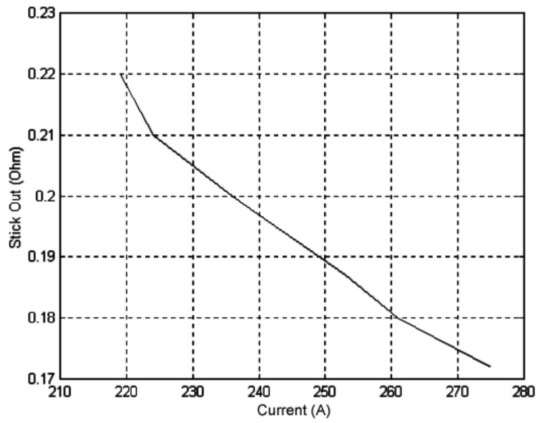
(b) Speed of the Progress of the Wire.

Figure 5 - Behavior of the Current for a Stick Out of the 0,21.

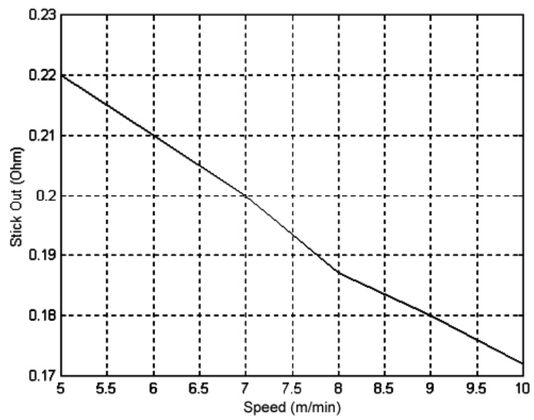
Another important point for a good operation of the machine is the choice of your operation point for the operator, with the help of the simulations it was possible to determine the representative resistance of the "stick out" for each current pick or speed, with those data the table 2 was built with values of those variables in a stable state of welding.

Table 2. Table fixes of values of R obtained by simulation

Nr. Of the measure	*R* (*stick-out*)	Current of pick (A)	Speed of the wire feeder (m/min)
1	0,220	219	5
2	0,210	224	6
3	0,200	236	7
4	0,187	253	8
5	0,180	261	9
6	0,172	275	10



(a) Determination using the peak current.



(b) Determination using the speed of the wire feeder.

Figure 6 – Linearity of *Stick out*.

V. DIGITAL CONTROL

The automated process consists of doing the automatic control of the current supplied by the power source. In this process the correct control of the key should produce the current pulsed in the exit of the converter, this control is accomplished for a very popular microcontroller and of easy acquisition, PIC16F877 - of the Microchip, this controller should generate a sign appropriate PWM to the key. A sensor of current is put in the mesh of the converter to indicate possible variations of the exit current, these variations go by a conditioning circuit and then they are converted by a converter analogic-digital (converter A/D) and processed through a control algorithm by the microcontrolador that must sends a sign appropriate PWM to the key so that the same supplies only the necessary current at a given moment of the welding process.

When the process is initiate should be established an operation point, This point of reference can be configured through a sign appropriate correspondent for one of the controller's gate. In the moment of the welding if there is some imperfection or relief in the work surface the characteristics of the current and *stick out* they change, that changes are "feeling" by the sensor of current put in the mesh of the converter and for the sensor of speed put in the motor that it feeds the wire electrode. As for each reference current a reference speed exists selected by the operator of the machine, the program will execute a consultation routine to a table (look up Table) obtained experimentally and described in the table II, then the control will act to return to the operation point, for e exemple if there is a projection in the work surface the current it will increase and it will happen imperfections in the welding, as illustrated in the figure 7. THE flowchart shown in the figure 8 describes the routines of the digital control.

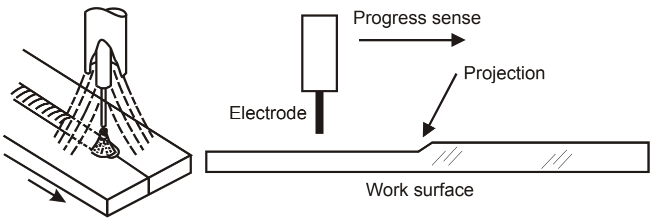


Figure 7 - Welding process with a projection in the work surface.

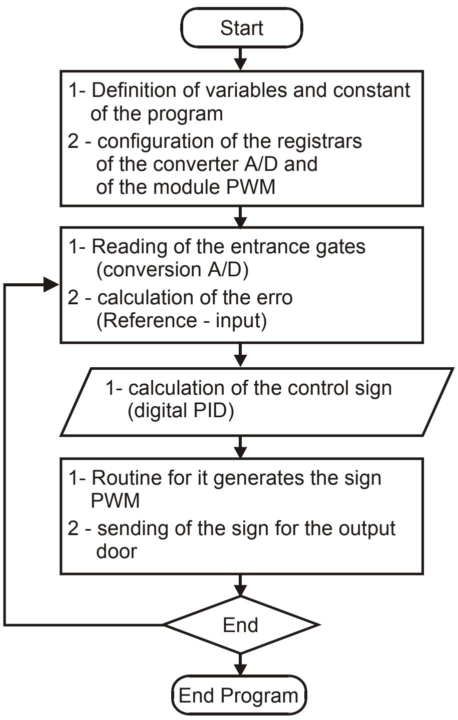


Figure 8 - Flowchart of digital control

VI. IMPLEMENTATION AND EXPERIMENTAL VERIFICATION

The implementation of the prototype can be seen in the figure 8. All the experimental results were obtained starting from this prototype, where the digital program is being validated. Experimentally it was obtained the behavior of the pulsed current shown in the figures 9 and 10 (a) and (b). Theoretical results presented in the figures 4 and 5 could be validated by the comparison with the experimental ones, proving the model.

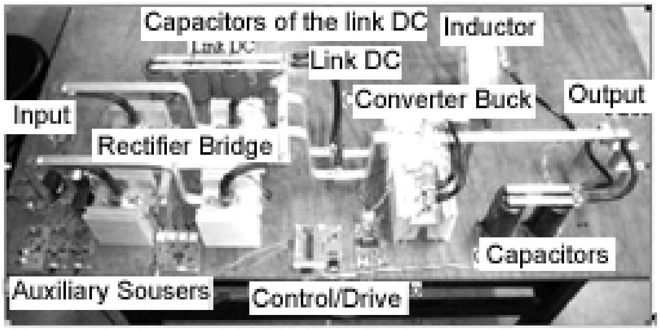


Figure 8 - Implementation of the welding source MIG

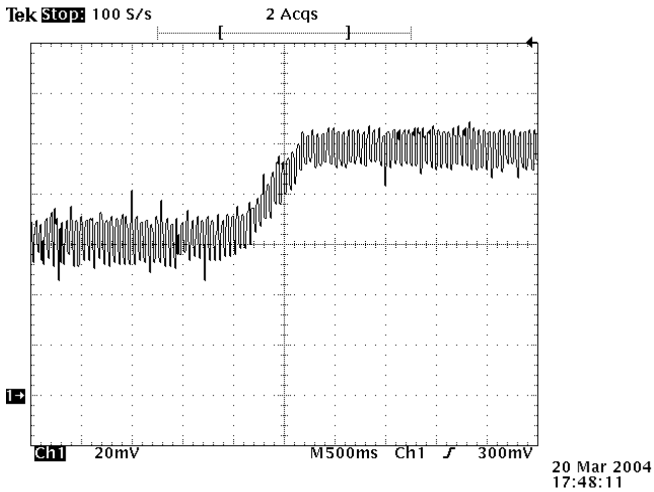
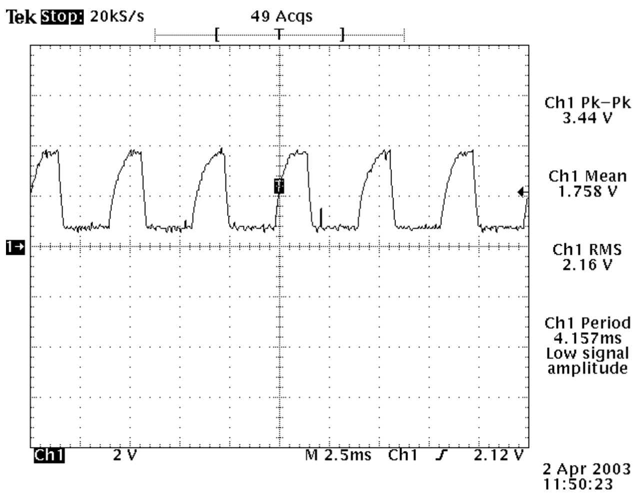
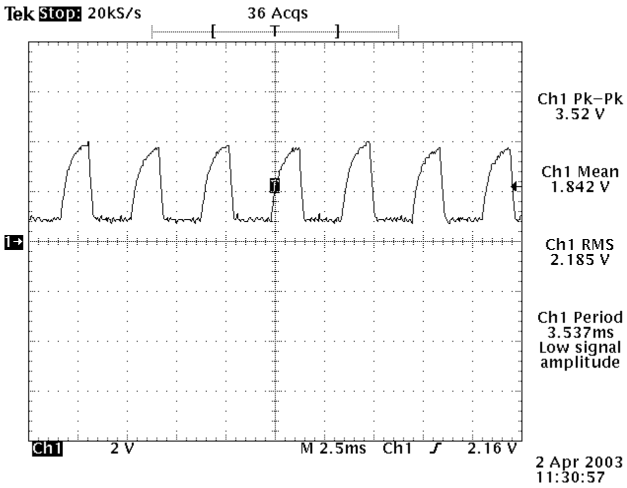


Figure 9 - Answer in closed loop



(a) - Wave form for speed of 6m/min



(b) - Wave form for speed of 7m/min

Figure 10 - Acquisition of the wave forma of the of the arch of the solder MIG.

VII. CONCLUSION

A simplified mathematical model of the welding machine pressed MIG was developed. Experimental results were presented validating the model simplified proposed. The implementation of this model simplified is only possible through digital control. This simplified model allows an efficient control and smaller costs, what represents a contribution to the development of machines MIG of pulsed current. A digital board was developed and its programming is being validated using the proposed mathematical model. The work also made possible the verification of the most efficient use of the process, as well as a reduction in the consumption of energy.

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