Study and Implementation of the Drive for Dynamic Wire Feeding System for Arc Welding Processes

Régis Henrique Gonçalves e Silva, Cleber Marques, Arthur Gondim Rodrigues, Fernando Costenaro Silva, Jair Carlos Dutra

Federal University of Santa Catarina, Mechanical Engineering Department /LABSOLDA - Welding and Mechatronics Institute, Florianópolis, SC, Brazil

Abstract:

Modern versions of GMAW and GTAW welding processes have presented solutions using the forward and reverse movement of the wire to obtain different welding results. The obstacle associated with this movement, here called dynamic wire feed, mainly arises in the case of GMAW welding, which is required to use frequencies compatible with a short-circuiting transfer. As a tool to assess the real influence of the dynamic movement of the wire on the weld results, this work has the main objective to present the study and implementation of a wire feed system that allows performing welding tests using this philosophy. Some types of drive systems were surveyed, assembling a prototype based on a high dynamic servomotor. With the implementation of logic control integrated with the welding source, it was possible to make deposits with good visual appearance and good stability in the metal transfer.

1. Introduction

In general, the results obtained by arc welding processes are influenced by a series of different factors such as voltage, current, type of shielding gas, regularity of torch movement, surface finish of the piece, among others. In this scenario, several authors present the welding current as the parameter that plays the more important role in the final weld joint configuration [1]. Variations in the current during the execution of the weld can cause, for example, inhomogeneous levels of penetration. And this, in the case of thin sheet joining or root passes, may be what will define the success or failure of the welding procedure. For this reason, the control of the current imposed by the process is, in fact, paramount and has originated a profusion of MIG/MAG versions, along with advances in power electronics.

Low energy levels welding operations mean choosing a parameter setting that results in short-circuit metal transfer. In conventional welding power sources, which run under a voltage command mode, the short-circuit metal transfer happens due to and according to events that are naturally associated. In these cases, the welding current is free to vary and reacts directly to the contact events of the wire with the metal puddle [2]. As a result, the welding process is subjected to the higher levels of spatter and fumes generation.

Controlling the welding current in a short-circuit transfer condition requires that the equipment be provided with strategies for proper maintenance and stability of the electric arc. Process versions that exclusively operate with current control for this purpose (STT, CCC, RMD, ...), use a specific waveform that promotes a constriction of the metal bridge under the direct action of the related electromagnetic forces with the *pinch* effect [1]. According to the electrical parameters in this phase of the droplet transfer, the closed loop control system reduces the current in anticipation of the moment of arc reignition. This contributes, mainly, to the reduction of spatter and fumes. However, the arc reopening prediction may not occur properly and in that case the process will be subjected to some instability. In addition, for materials such as aluminum, which has a low electrical resistivity value, this difficulty is even more pronounced, making this type of control unfeasible.

Hence, versions of the process that use the feature of pulling the wire backward, in order to facilitate the transfer of material, emerge on the market. In this way, the instant that the arc should reopen is strongly connected to the recoil movement of the wire, which is controlled by the source itself. The predictability of the arc restriking is independent of the reading, treatment and interpretation of electrical parameters and the process is able to operate with different materials. The difficulty associated herein is closely linked with the drive system responsible for controlling the movement of the wire, in view of the high frequency inversion values that is required. Available commercial systems´ results are knowingly very good in terms of process stability and spatter and fumes reduction. By adding such a movement to the wire, the entire molten puddle and transferring droplet are subjected to a dynamic condition different from the conventional one, and this behavior and related phenomena still need to be further investigated. The need to evaluate the effects of the dynamic wire movement, as opposed to a movement under a static constant speed regime, is also present in the case of the TIG processes with this type of feed.

In this context, as a way of obtaining a study tool for the analysis of the phenomena involved with dynamic wire feed, the present work aims to study and evaluate different drive technologies, through the implementation of a prototype wire feeder for welding with dynamic movement of the wire.

2. Dynamic wire feed welding processes

The use of a feeding system that allows the control of the forward and backward motion of the wire has different purposes and requirements for the MIG / MAG and TIG welding processes.

In the MIG / MAG process, this movement is directly related to the control of the metal transfer and the arc length. For this reason, the movement inversion frequencies must hereby be compatible with those observed in a conventional process operating in a short circuit. Figure 1 presents data obtained in aluminum welding at a wire feeding speed (Va) of 6 m / min. For this configuration, the welding showed good transfer stability at a frequency of approximately 54 Hz. Different manufacturers today have versions of the MIG / MAG process that use some drive mechanism for the dynamic feed [3-6]. The values reported on the maximum frequency of motion inversion vary from 70 Hz [7] to 130 Hz [8].

The operation of the system depends on the correct synchronism between the movement of the wire and the electrical parameters of the process. They are basically two main phases: the arc phase and the short-circuit phase. The control system monitors the arc voltage and compares it with predefined reference limits that correspond, respectively, to the arc phase and short-circuit phase limits. During the arc phase the energy required to form the drop and the puddle is supplied. The drop is deposited in the short-circuit phase, with the contact of the wire tip to the puddle. When the voltage falls below the set reference, the control classifies the state as a short circuit and the wire begins to be retracted. When the measured voltage is above the reference, the control identifies as the arc phase and the wire is retracted to maximum distance defined as arc length reference [4]. Figure 2 represents the MIG / MAG process with dynamic wire feed. Because there is a need for synchronization between the movement of the wire and the current, all the control is executed by the motor of the feed unit directly actuating in the advance and retreat.

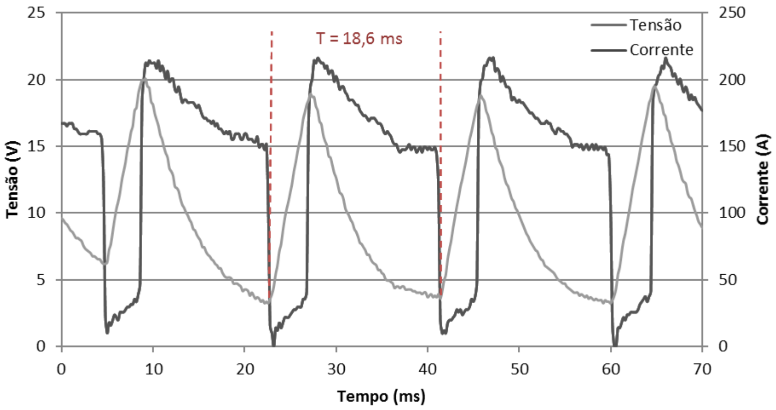
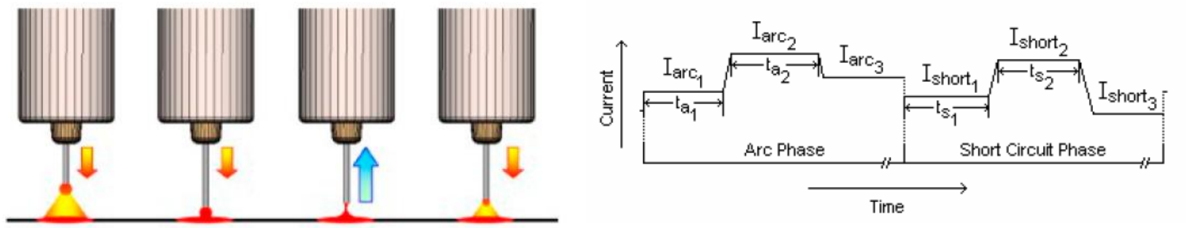


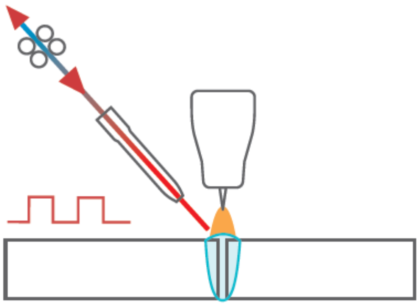
Figure 1. Voltage and current oscillograms for conventional MIG (short circuit) in aluminum welding ER5183 1.2 mm, Va = 6 m / min, droplet transfer frequency of approximately 54 Hz



A B

Figure 2. MIG / MAG process with dynamic wire feed; In A - Representation of the movement of the wire [6]; In B - Schematic diagram of the current cycle [9]

Unlike the MIG / MAG process, the true reasons for the use of the forward and backward motion of the wire in the TIG are not yet very clear and are object of study at the institute where the present work was carried out. The few information found in the current literature, for the most part, correspond to much more commercial than scientific data. According to data from a manufacturer [10], the mechanical action of the wire moving in the puddle, associated with the preheating of the wire, creates a more fluid melting pool that allows a better wettability of the sides, with a significant increase in melting rate. In addition, associated with the vibration effect there would be a greater ease of expelling of gases retained in the puddle, which contributes in the porosity reduction. Figure 3A provides a representative model of advance and retreat of the filler wire of the TIG process. No synchronism is used with the welding current, so that the commercial devices perform the movement of the wire by introducing an oscillatory motion of the wire traction mechanism, the rollers unit (Figure 3B). In these cases, the frequencies used can reach up to 16 Hz [11], thus being much smaller than the values required for the MIG / MAG. There are also versions that synchronize the wire and the current for TIG [12]. In these cases, the inversion frequency is quite low and, just as in the MIG / MAG, the movement is performed directly by reversing the rotation direction of the motor of the rollers.

A


B


Figure 3. TIG process with dynamic wire feed - A- Schematics of the wire movement (adapted from [11]); B - Oscillatory movement of the traction mechanism [13]

The success in conducting a welding procedure depends, among many factors, on the choice of the correct welding parameters. The development of complex control systems greatly increases the number of input variables, making parameter setting an increasingly difficult task. For this reason, most commercial welding source models provide a list of preconfigured programs for each type of adding material and shielding gas. These are the so-called synergistic modes, which simplify parameter setting by the operator. Taking the MIG / MAG as a reference, the general rule is to select in the source the type of addition material, the wire diameter and the shielding gas, within the welding modes programs available. Once the program selection is complete, the adjustment is done by means of a single input parameter, for example the wire speed. All other parameters required for welding are set automatically. In this way, the operator ends up being restricted to the values selected by the source that, for specific applications, may not offer the ideal condition. In this case, the use of synergetic programs in research activities also ends up limiting the possibilities of process study by researchers interested in investigating related phenomena of arc and pool physics.

Aiming at the total control of each parameter and consequently of the process as a whole, the present work focuses on the development of a prototype for MIG / MAG welding with dynamic wire feed. Considering that the development of the technique for the MIG/MAG process is the one that requires greater complexity in terms of the mechatronic actuation and control of the wire movement, future developments for the TIG process would also be contemplated, and will benefit from the MIG/MAG results.

3. Materials and Methods

The work can be divided into two stages. The first one comprises the studies and tests carried out with different types of motors with the objective of evaluating which model is best suited to the frequency requirements of the MIG / MAG. Tests were carried out with different reversion frequencies of the rotation direction, with the observation of the maximum amplitudes obtained in each case.

With the selection of the most appropriate motor model, the second stage comprised the assembly of the prototype to define control strategies and the conduction of the welding tests.

3.1. Methodology for Motor Testing

Tests were performed with three different drive systems: DC motor with brushes, CA stepper motor and servo motor, each with its respective power driver with input signals of the type step / dir (step / direction). The AC servomotor was further tested in two power versions, 100 W and 200 W. For all tests, the reversion frequencies tested were 40 Hz, 50 Hz and 60 Hz, with signals imposed by function generators and sources compatible with the power drivers.

The first step in analyzing engine performance consisted of an unloaded test, ie with the engine free to rotate its shaft without any type of coupling. Under these conditions the motors should not have limitations on operation, except for their own constructive limitations. The purpose of this test was to verify the maximum angular displacement that each drive technology is able to offer for the different controlled frequency inversion conditions. High speed videography was used for monitoring and subsequent measurement of motor shaft movement with the aid of an image processing software. Acquisitions were made at a rate of 4000 frames per second.

The strategy adopted for the measurement of the movements was based on the use of the frames that indicated the inversion of the movement of the motor axis. These images were separated and, through *software*, the initial and final shift angles were measured. In Figure 4 one can see an example of the methodology used. Each of the images in the figure indicates one end of the motor movement, the starting position is indicated by the image A, while the image B indicates the final position of displacement of a given cycle. For each frequency condition the mean value of the measurand was calculated based on a repetition of three samples.

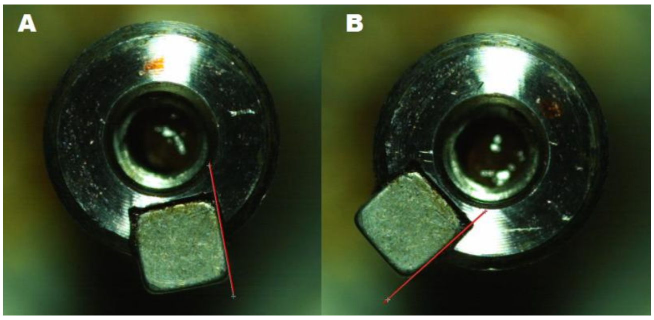


Figure 4. Example of measuring the angular variation of a servomotor with direction reversing frequency of 50 Hz. A - Initial position; B - Final position

In the second stage the motors were subjected to loading, traction of a welding wire in a similar way to the welding application. To perform this test the motors were attached to a wire feeder unit, with the motor shaft attached directly to the roller. The monitoring and measurement has now been based on the wire displacement, also using the high-speed filming feature and subsequent data processing in imaging software, similar to the no - load test.

3.2. Methodology for Welding Tests

The welding torch prototype was built on the same feeder unit used in the tests of the previous test. In order to reduce the influence of a long path from the wire to the contact tip, a MIG / MAG torch neck was adapted directly to the feeder outlet.

The source used was the DIGIPlus model from IMC. This equipment has a 32-bit ARM processor, in which a control strategy was developed for this work. With the integration of the prototype to the source, the driver's command signals are now generated by the same ARM processor. A secondary wire feed unit was used to store and supply wire for the process, and was also controlled by the same welding source. Due to the size of the experimental torch, it was decided to carry out the relative movement by moving the part to be welded, instead of the torch. For this, a cartesian manipulator model Tartílope V2, from SPS, was used. Process data monitoring and treatment was done with the IMC SAP (Portable Acquisition System) and IDT Y4S2 high-speed camera. The experimental set up is shown in Figure 5.

Figure 5. Test rig layout with : welding power source; Manipulator for piece displacement; Prototype torch for dynamic wire feed

In order to verify the suitability of the developed system, bead on plate welding tests were carried out on aluminum and carbon steel. The aluminum deposits were made in 3 mm thickness sheets, argon as shielding gas at a flow rate of 15 l / min. As adding material the ER4043 and ER5183 wires, both 1.2 mm in diameter, were used. The steel deposits were made on a 4 mm thick sheet and the 1.2 mm diameter ER70S-6 wire with a 75% Ar25%CO2 gas shielding at a flow rate 15 l / min.

All tests were performed in the flat position, with a welding speed that varied between 30 and 45 cm / min and contact tip to work distance (DBCP) of 18 mm. The main parameters involved in the process are entered directly by the user into the welding source through its interface. These parameters include: pulse, base and short-circuit currents, pulse time, forward and backward speeds and reference voltages.

4. Results and Discussion

4.1. Motor Testing

The first test to be performed was the no-load test. The analysis of the images resulted in the maximum rotation angles each engine model was able to provide as a function of the required inversion frequency. The values are presented in Table 1. To estimate the linear displacement of wire corresponding to the angular variations, the diameter of a wire traction roller of a commercial feeder model was considered and a direct ratio relation between angular and linear displacement was made. Values displayed in the last column of the table.

Table 1. Results of the no-load test of the motors

Motor	Oscillation Frequency (Hz)	Angular Variation (º)		Linear displacement(mm)
		Average	Stand. Dev.	
Servomotor CA 100 W	40	83,25	0,07	21,64
	50	60,83	2,20	15,81
	60	46,00	2,72	11,96
Servomotor CA 200 W	40	84,97	2,66	22,09
	50	59,13	0,55	15,37
	60	46,70	0,17	12,14
DC brushes	40	55,55	1,20	14,44
	50	28,93	5,47	7,52
	60	20,60	1,35	5,36
Stepper motor	40	23,15	0,45	6,02
	50	15,37	0,45	3,99
	60	8,73	0,57	2,27

Based on the high-speed filming of a commercial version of the MIG / MAG process with dynamic feed, it was drawn that the minimum linear displacement required was 5 mm. By analyzing Table 1, it is possible to observe the superior performance of the AC servo motors in relation to the other motors tested, especially in higher inversion frequency, in which they reach displacements superior to twice the established minimum displacement. The stepper motor has been able to achieve the desired minimum displacement only at low frequencies, which makes its use unfeasible for the construction of the prototype. With regard to the DC motor, although the average displacement has exceeded the minimum established in all frequencies tested, the results of 50 and 60 Hz presented a value of standard deviation that questions the control capacity for these frequencies. Thus, the load test proceeded with the evaluation of only the AC servomotors. The objective was provide results that are closer to the behavior of the drive system when subjected to the actual welding process. The test results are shown in Table 2.

The table shows that both engines exceeded the minimum limit of previously established wire displacement, with a very similar behavior. Thus, the selection of the model for the assembly in the prototype of the torch consisted in the comparison of two technical characteristics of the motors. The first one was the size, considering that a future evolution of the prototype should require smaller models. The second specification evaluated was in relation to the lowest moment of inertia of the rotor, which directly affects the effort that the motor must perform in each reversal of direction. The tendency is that for higher frequencies of inversion, smaller moment of inertia result in smaller response time (deceleration and acceleration) of the engine. With this, the selected model was the one of 100 W of power.

Table 2. Load test results

Motor	Oscillation Frequency (Hz)	Linear speed (m/min)	Displacement (mm)	
			Average	Stand. Dev
Servomotor CA 100 W	30	77,00	21,13	0,33
	40	64,54	13,54	0,39
	50	60,84	10,27	0,11
	60	51,48	6,86	0,14
Servomotor CA 200 W	30	87,59	24,23	0,53
	40	71,39	14,67	0,13
	50	60,48	10,22	2,11
	60	38,93	5,28	0,03

4.2. Welding Tests

The difficulties encountered in the development of control strategies defined the division of the work into three distinct stages, being the arc opening stage, welding stage and finishing stage. The behavior of the system in each step is presented as follows.

Figure 6 showcases an oscillogram highlighting the arc opening stage. At this stage the source commands the advancement of the wire over the part until the event of the short circuit. At this instant an increasing current curve is imposed for a predetermined time in order to promote the heating of the contact region to facilitate the opening of the arc as a function of the short return of the wire. The figure shows two current profiles before the pulse step. It is also observed that the beginning of the current increase occurs after the voltage drops, indicating the event of the contact of the wire with the part (short circuit).

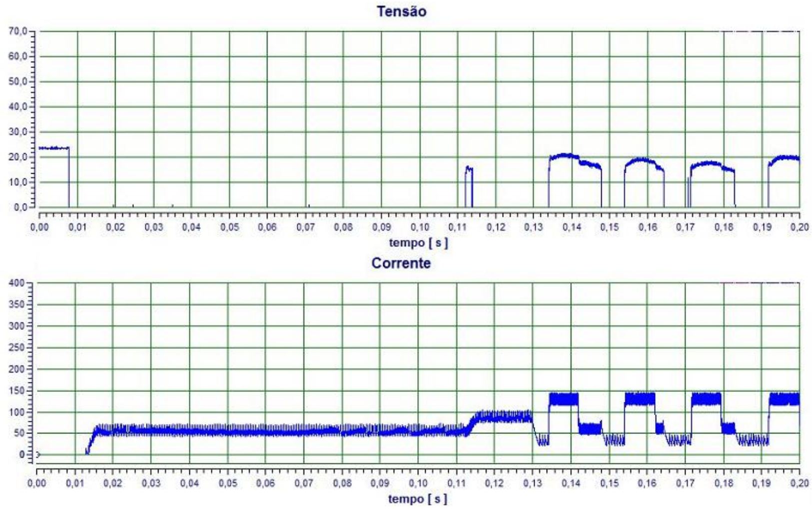


Figure 6 - Voltage and current oscillograms with highlight for the opening step

Figure 7 is representative of the result of the control strategy in the welding stage. This is the process steady stage regime, which controls the advancement and retreat of the wire, as well as the current levels that are supplied by the source. In the figure it can be observed that there are three well-defined current levels, one for each stage of the welding process. First, the pulse current provides the formation of the metal droplet. The current is then reduced to the so-called base current when, as a function of the continuity of the wire advance, the short circuit occurs. Once the control identifies that the measured voltage is less than the short-circuit reference value, the control reduces the current to the short-circuit value and commands the motor for the backward movement. The arc restriking identification is also given based on the reading of the voltage and its comparison with a predefined reference. After this moment, the system commands the advancement of the wire with the application of a new current pulse. The good repeatability of the pulses is also observed in the figure, and is fundamental for uniform results of the welding process, which, in this case, is totally dependent on the stability in the control of the advance and recoil of the wire.

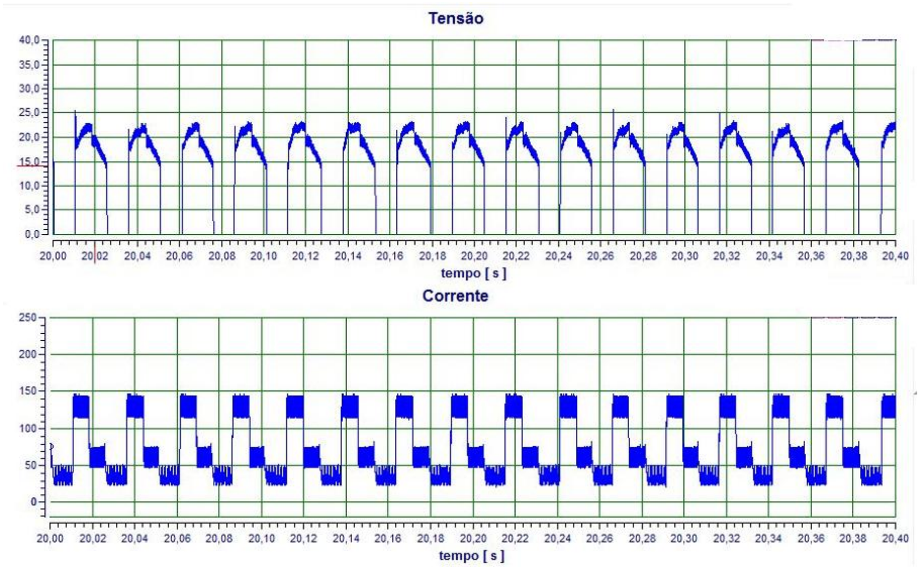


Figure 7 - Voltage and current oscillograms with highlight to the welding steady state stage, in weld made with ER5183 aluminum wire with Ø = 1,2 mm

In Figure 8 one can see the oscillogram with highlight of the finishing stage. The main function of the finishing stage is ensure the wire does not stick to the part at the end of the weld. For this, it is necessary to ensure the process never ends in a short-circuit phase. If the weld termination signal matches that instant, the source applies a current pulse to avoid the problem. Then, the control commands the off powering of the source and the torch motor. The result can be checked by the high voltage value after the final pulse, indicating that the wire is not in contact with the part. Success in each stage results in stability of the process as a whole, as well as the repeatability and robustness of the deposits made.

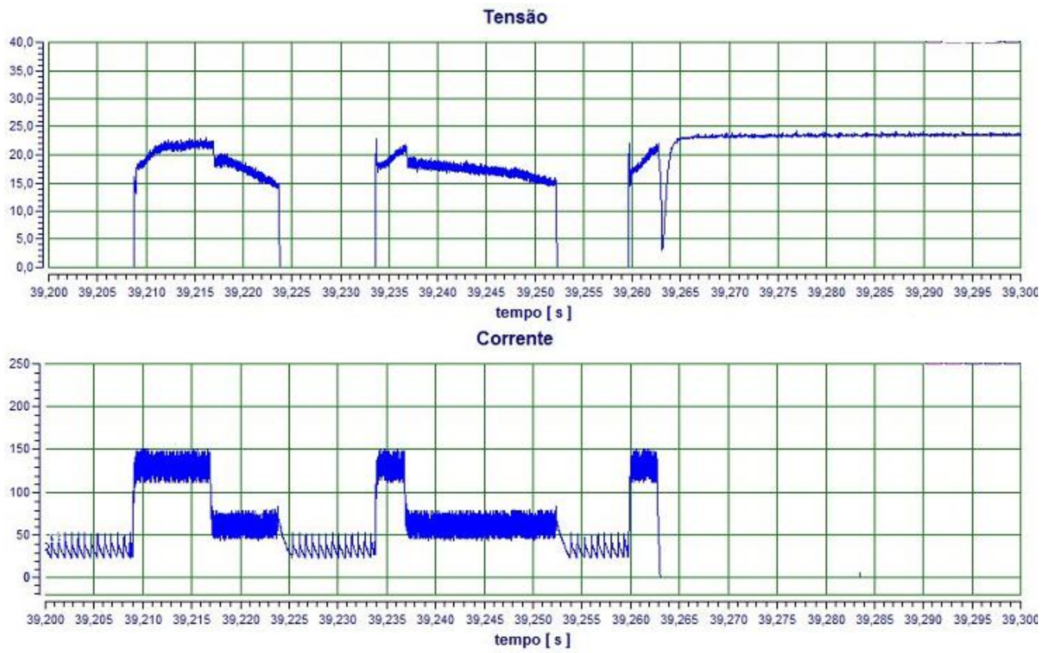


Figure 8 - Voltage and current oscillograms with highlight for the finishing stage

As a way of evaluating the dynamic feed unit prototype constructed and its applicability in a MIG / MAG process, a series of deposits was performed. In each test the operator is allowed to vary the main welding parameters directly at the flexible welding power source, as desired. Each change promotes a direct influence on the stability of the process, as well as on the result of the deposit. Good parameter setting ensures the final quality of the weld. In Figures 9 and 10 two aluminum alloy beads are shown, which were deposited with different filler material. The objective here has not been set to obtain a deposit having good wettability or penetration characteristics. The intention was to verify the deposit stability in order to prove the validity of the control strategy used.

In order to adapt the process to other types of adding material, deposits were made using steel alloys. For this, the original waveform was modified by adding a current pulse with predetermined time at the beginning of the short-circuit phase. The waveform in this situation can be seen in the oscillogram of Figure 11, which corresponds to the result of the deposit with a steel alloy using the ER70S-6 wire electrode as filler metal wire, shown in Figure 12.

Figure 9 - Bead # 1, ER4043 aluminum wire, 1.2 mm in diameter

Figure 10 - Bead # 2, ER5183 aluminum wire, 1.2 mm in diameter

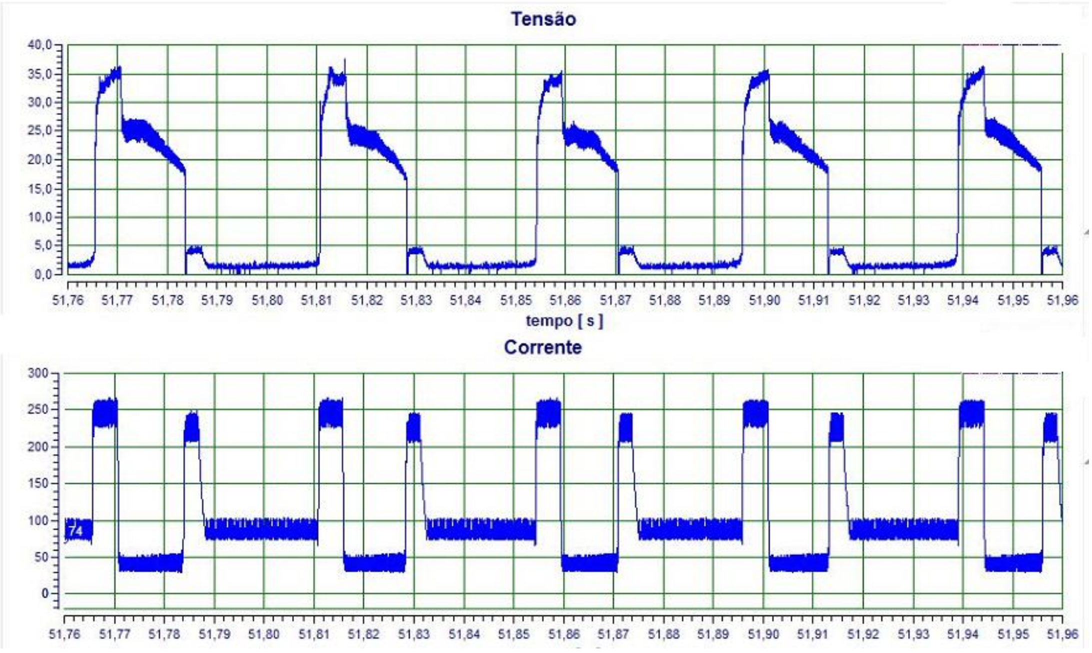


Figure 11 - Voltage and current oscillograms with highlight for the additional pulse in the short-circuit stage, in a weld bead made with ER70S-6 steel wire Ø = 1,2 mm

Figure 12 - Bead # 3, steel wire ER70S-6, 1.2 mm diameter

Table 3 quantitative data were collected regarding the deposits shown in Figures 9 , 10 and 12. The input parameters are those that the user sets at the beginning of the process directly at the welding source. It is worth mentioning that in the table only some of the options of the parameters available in the source are exposed. The current and voltage values were obtained with the SAP and the frequency calculated on the basis of the oscillograms.

Table 3. Parameters involved welding tests

			Input						**Output**		
			Current (A)				time (ms)		Average		
nº	Wire-electrode	Base Material	Ip	Ib	Ipc	Icc	tap	tpb	Arc Current (A)	Arc Voltage (V)	Frequency (Hz)
1	ER4043	Alumínio	150	70	0	50	8	0	90	11,5	41,7
2	ER5183	Alumínio	130	60	0	30	8	0	71	11,4	39,7
3	ER70S-6	Aço	250	40	220	80	5	3	106	11,3	24,6

Finally, to evaluate the behavior of the metal transfer obtained with the prototype, the use of high speed filming was used. In Figure 13, images of the contact region of the wire with the molten pool were assembled in a chronological sequence of the transfer over a period.

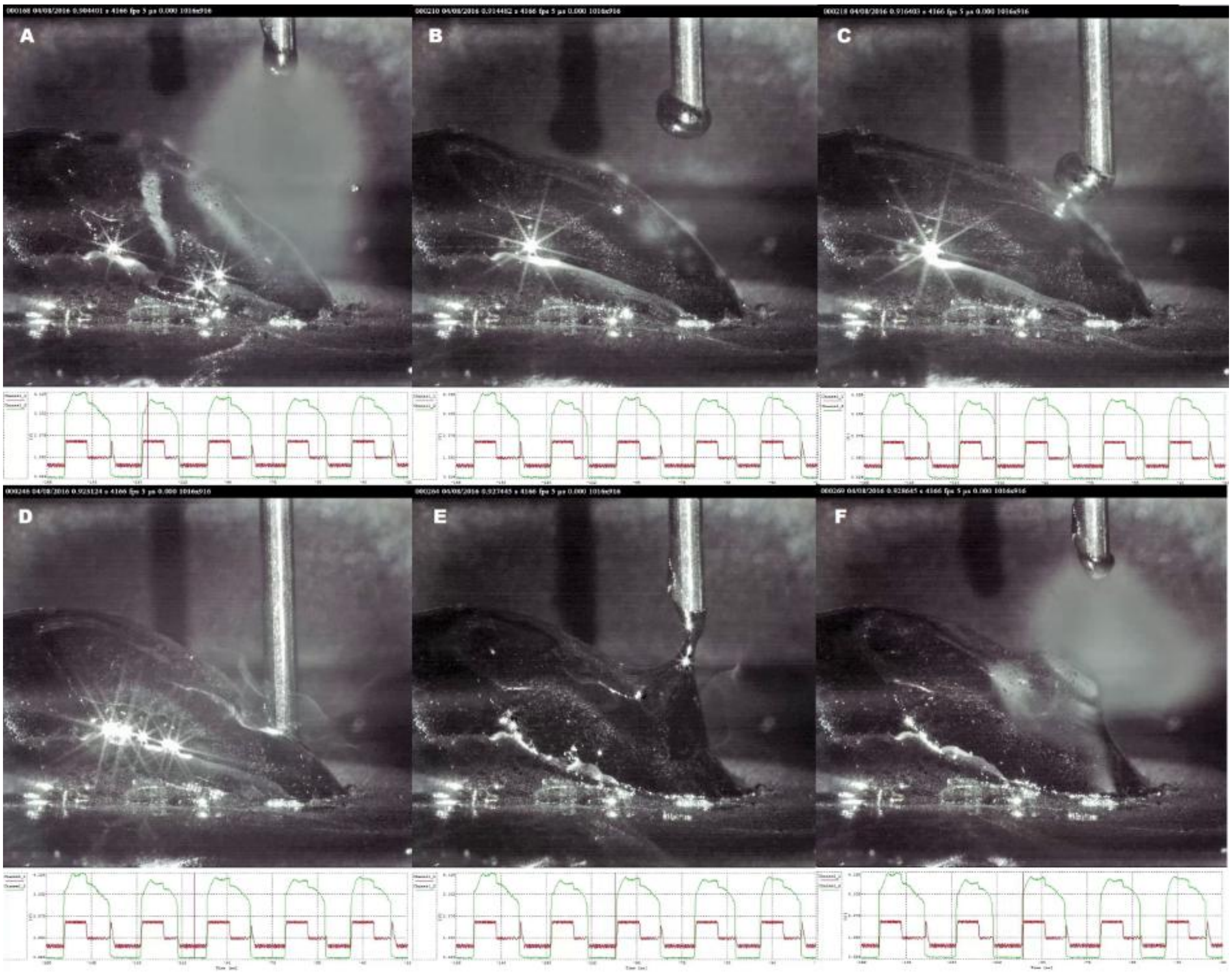


Figure 13. Sequence of the metal transfer using the prototype on aluminum MIG welding, ER5183 wire electrode

5. Conclusions

The main objectives sought with the construction of the prototype were achieved. The tests for evaluating the motors led to the selection of the 100 W AC servomotor and this drive integrated into the feed system was able to respond to the commands of the welding power source in a satisfactory manner. In some deposits it was possible to obtain transfer frequencies up to 68 Hz, with good repeatability. However, it has been observed that the drive system used still has limitations, with respect to the acceleration and deceleration times of the motor. Besides not allowing for higher short-circuiting frequencies, also a difficulty associated with the ability to control the arc length arises.

Through the analysis of the data obtained in the welding tests it is possible to conclude on the feasibility and pertinence of the continuity in the developments with the technique of dynamic wire feed. The results presented were promising and some additional comments could be raised:

- Welding using the aluminum alloy ER4043 (Figure 7) proved to be laborious due to the fact that this wire type is quite malleable. This has caused failures in several occasions caused by the wire bending in the traction system;

- The results obtained with aluminum alloy ER5183 were achieved more easily compared to the other two wires;
- Although it was possible to obtain a steel deposit with good bead regularity, presence of spatter and a greater difficulty to increase the frequency of metal transfer in a stable way were observed. Maximum frequency obtained was greatly reduced compared to the tests with aluminum, approximately 25 Hz for steel and 40 Hz for aluminum alloys.

Finally, it can be stated that the current limiting factor in the process is the drive dynamics. In tests carried out with high-speed filming, it was found that the reversal of the motor's direction took, on average, just over 3.5 ms. The time factor is fundamental to this system and it was expected that the change of direction of rotation of the motor would be effected in smaller intervals of time. Future work will be carried out using different servo motors, in order to achieve higher transfer frequencies. Also, the possibility of having a totally flexible system allows for deeper and broader investigations both in the scientific and technological fields, thus permitting solutions assessments of several different specific welding conditions that may emerge.

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