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PARAMETERIZATION OF GMAW WELDING WITH SWITCHBACK TECHNIQUE USING MECHANIZED MOVEMENT SYSTEM

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Abstract. The Switchback torch movement technique, applied in the Gas Metal Arc Welding (GMAW) process, consists of a controlled back-and-forth motion in the direction of the weld bead. This periodic oscillation aims to improve the granular structure of the molten metal. Although the approach is relatively recent and usually employs adapted welding robots, it was not possible to use a robotized mechanism to apply the technique in the laboratory where the research was conducted. To circumvent this limitation, linear torch movement equipment already available in the laboratory was used, developing an adaptation with two overlaid motion mechanisms. This alternative solution allowed the application of the Switchback technique, even in the absence of specific robots, contributing to the improvement of the granular structural quality of the weld metal and expanding knowledge about the technique in question. Since it is an adaptation, the definition of parameters for performing the GMAW process with Switchback needs to be structured to result in precise movements, with advance and return distances, speeds, and other previously established variables. Aiming to facilitate the acquisition of parameters for the process using the mechanized system, an input variable insertion system was developed for the operating ranges of the mechanism, thus generating responses that can be more easily visualized and controlled for research application purposes with higher reliability and repeatability of the pieces. Based on the known formulation, it is possible to create a table that presents precise advance and return lengths as a result, as well as their speeds and other variables inherent to the technique. The graphs generated after the appropriate formulations also allow understanding how these variables interrelate, thus enabling better parameter control, depending on the research line or necessary objective. At the conclusion of the work, weld beads were made using the selected parameters to verify the applicability of the results and conditions such as repeatability and stability of both the arc and the table with the double-tartílope system. The importance of this work lies in its contribution to advancing welding research, enabling greater efficiency and precision in GMAW processes with Switchback. Moreover, the development of a mechanized system and improved parameters can positively impact the industry, enhancing weld quality and increasing the reliability of welded components.

Keywords: switchback, GMAW, welding parameters, drive mechanism, forward, backward

1. INTRODUCTION

1.1 SWITCHBACK MOVEMENT TECHNIQUE IN WELDING

The continuous evolution of technology and science has driven significant advances in various engineering fields. One of these areas is welding, which has witnessed a growing need for more efficient and precise techniques. This article aims to explore the Gas Metal Arc Welding (GMAW) technique with the switchback method.

The study is based on previous works that have explored the GMAW welding technique, but it seeks to go beyond by analyzing the implementation of the switchback method using a dual-tartílope system. This system is of particular importance due to its relatively low cost compared to using a robotic arm, making the switchback technique more accessible for a variety of welding applications.

The switchback technique involves a straight movement of the welding torch; however, with a periodic oscillation of forward and backward motions, respectively, in the welding direction. This forward and backward motion needs to be analyzed to determine how many times the torch will pass through a specific section of the joint to be welded. Therefore, the switchback technique occurs when there is the formation of homogeneous modules along the weld bead.

It will be observed that, in a 50% proportion of forward and backward motions, where the forward motion is twice as long as the backward motion, a three-layered weld bead will form. In this scenario, during a forward motion, a layer of weld is deposited on the joint, followed by the backward motion, which deposits the second layer, and finally, another forward motion adds the third layer to that section. In summary, this results in a three-layered module, as depicted in Figure 1.
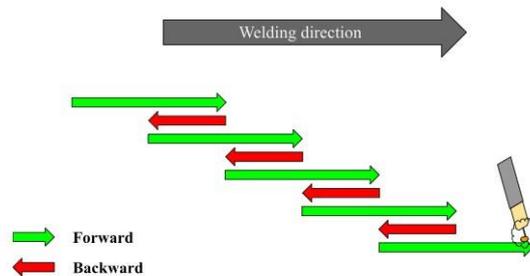

Figure 1. Weld bead layer deposition using the switchback technique.

As described in the figure, there is the formation of three-layered modules that do not overlap each other and are evenly distributed due to the correct parametrization of the mechanism. However, there is not only one type of parametrization for switchback welding; there will be other possibilities that can be anticipated through the parameters studied here.

With the welding direction defined, the angle of the welding torch can be determined. If there is an inclination below 90° with the welding direction, we call it "pull," and conversely, when the angle is greater than 90°, we call it "push".

In this research, the push-pull mode, described in Figure 2, was chosen, which allows for the formation of equiaxial grain size in the weld (Almeida et al., 2012).
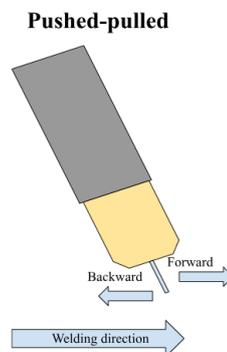

Figure 2. Pushed-pulled mode in switchback welding.

1.2 OBJECTIVES

The objectives of this work are the parametrization of the dual-tartílope system, which is characterized by the periodic movement of the welding torch, as well as understanding the variables that compose this parametrization, investigating the influence of various advance-reverse proportions, and exploring the system's limitations. In addition to these, the specific objectives of this study also include:

- Finding the maximum and minimum application parameters;
- Defining the application limits, aiming at the safety of the system operator and the integrity of the used equipment.

2. PARAMETERS OF THE SWITCHBAK TECHNIQUE WITH DOUBLE-TARTÍLOPE

The parameters of the switchback technique using the dual-tartílope mechanized system can be obtained through the system's input variables. Understanding the variables to be directly input into the tartílope movement control is necessary. This mechanism's manipulation allows for the insertion of only three variables, which are.

- Amplitude (Amp);
- Frequency (f);8
- Welding speed (Ws).

These three input variables are directly configured in the controls of the tartílopes, with the welding speed being inserted in Tartílope V1 and the amplitude and frequency in Tartílope V2. With these variables, we can obtain the system's output variables, or dependent variables. These are:

- Forward motion (F);
- Backward motion (B);
- Proportion (Prop);
- Forward motion speed (Fs);
- Backward motion speed (Bs).

Teixeira (2019) establishes a sequence of equations that allows the determination of the dependent variables. For example, to find the weaving speed (Wp), we use the weaving distance (Wd), which is equal to twice the amplitude and the period (T) of the torch movement relative to Tartílope V2. Thus:

$$Wp = \frac{W_d}{T} \ (mm/s), \tag{1}$$

Furthermore, we have the forward motion speed (Fs) and backward motion speed (Bs), which are given by the following equations:

$$Fs = Wp + Vs \ (mm/s), \tag{2}$$

and

$$Bs = Wp - Vs \ (mm/s), \tag{3}$$

In addition to the above, we can determine the elapsed time (t), forward motion distance (F), and backward motion distance (B) using the following expressions:

$$t = \frac{T}{2} \ (s), \tag{4}$$

$$F = Fs * t \ (mm), \tag{5}$$

$$Fs = Bs * t \ (mm), \tag{6}$$

3. METHODOLOGY

3.1 EQUIPAMENTS

The study in question was conducted using a dual-Tartílope system, which involves positioning two overlapped and aligned Tartílopes in the same welding direction. Tartílope V1, serving as the base of the system, is responsible for the translational movement in the welding direction. Tartílope V2, overlapped onto Tartílope V1, performs the switchback movement, providing the forward and backward motions. This system was originally designed for performing weaves in weld beads, but when repositioned 90 degrees from its original point, it allows for the implementation of the switchback technique.

The equipment that assisted the Tartílopes in achieving the GMAW switchback welding was:

- Transistorized electronic welding power source model Inversal IMC 300;
- Wire feeder model IMC - STA 20;
- Welding bench.

The tartílopes are controlled by individual external controls that are connected to the carts via cabling. These controls are responsible for allowing the insertion of input variables in such a way that the desired parameters for welding using the switchback technique can be achieved. In Figure 3, you can visualize these controls.

As for the welding power source, an Inversal 300 source from IMC was used. It allows the input of wire feeding parameters, gas settings, voltage values, and current values. In Figure 6, there is an image showing the physical characteristics of the welding power source.
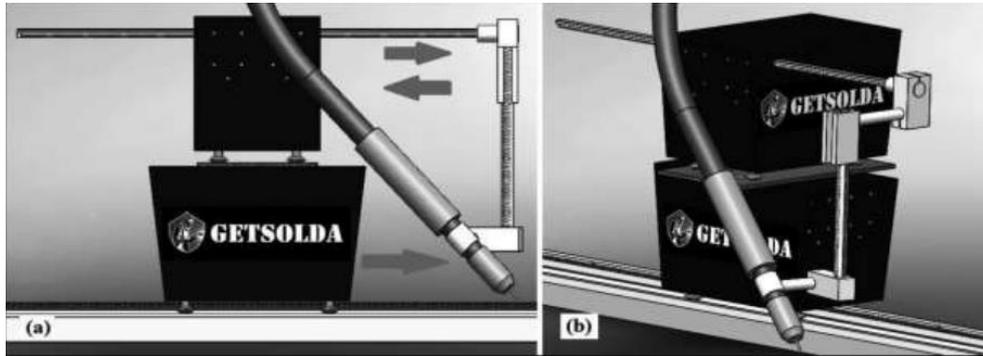

Figure 3. Illustrated representation of the overlapping dual-tartílope system and the welding bench (Teixeira, 2019).

3.2   METHODS

The theoretical formulation plays a fundamental role in this study as it provides an understanding of the variables involved in the GMAW switchback welding process and their interaction. The system used in this study incorporates three independent variables: amplitude, frequency, and welding speed. These variables are directly inputted into the Tartílope controls, allowing the operator to determine the welding conditions.

However, the variables of interest for this study, such as forward motion, backward motion, welding proportion, forward motion speed, and backward motion speed, cannot be arbitrarily selected by the operator since they depend on the three independent variables. Therefore, it is necessary to develop a theoretical formulation that allows the calculation of these dependent variables based on the independent variables.

The weaving speed is obtained by dividing the weaving distance by the period, as indicated by Equation 1. This equation in terms of the independent variables becomes:

$$Wp = \frac{2Amp}{1/f} \ (mm/s), \tag{7}$$

or better,

$$Wp = 2Amp * f \ (mm/s), \tag{8}$$

The forward and backward motion speeds are calculated by adding and subtracting, respectively, the weaving speed from the welding speed. As we know the expression for Wp in terms of the independent variables, we have:

$$Fs = 2Amp * f + Ws, \tag{9}$$

$$Bs = 2Amp * f - Ws \ (mm/s), \tag{10}$$

Research on the switchback aims to determine the precise forward and backward ratios within specific proportions to understand the functioning of the process. These variables are so significant that they serve as a basis for validating welding comparisons at different proportions, as it is now possible to determine the same forward distances with distinct reversals.

To achieve maximum forward and backward speeds, the weaving speed (Wp) must be as high as possible. Therefore, Fs and Bs will be at their maximum when the amplitude (Amp) and frequency (f) are also at their maximum. The same logic is applied to find the minimum values. Now, we can define the forward distance (F) and backward distance (B). For the forward motion, we have:

$$F = Amp + \frac{Ws}{2f} \ (mm), \tag{11}$$

And for the backward distance:

$$\mathbf{B} = \mathbf{Amp} - \frac{Ws}{2f} \; (mm),$$ (12)

Analyzing Equation 11, it can be observed that the forward distance will be maximum when the amplitude and welding speed are at their maximum, and the frequency is at its minimum. This analogy is of utmost importance as it allows the operator to search for maximum amplitude values within certain application ranges, providing clarity on which input variables should be modified and how to make these changes.

Regarding the backward motion, as indicated in Equation 12, the analogy differs. The reversal length will be maximum when the amplitude and frequency are at their maximum, and the welding speed is at its minimum. This understanding enables the operator to seek maximum reversal lengths, allowing a comprehensive analysis of the welding process and providing valuable insights to improve weld quality. By adopting this theoretical formulation and understanding the relationships between the variables involved in the GMAW switchback welding process, it is possible to make precise and strategic adjustments to achieve the desired conditions of forward motion, backward motion, and welding proportion.

4. RESULTS AND DISCUSSIONS

4.1 PHYSICAL LIMITATIONS

It was observed that in Tartílope V2, there are some physical limitations that need to be investigated and understood. The system restricts the insertion of variable values depending on the situation. Depending on the chosen amplitude, there will be a maximum and minimum possible frequency. Analogously, the higher the amplitude value, the lower the frequency value will be.

From what was observed, the system limits the frequency intervals since it does not take into consideration the distance covered and can cause issues in the mechanism depending on the amplitude values inserted. Analogously, the higher the amplitude value, the lower the frequency value will be.

After the calculations and before the theoretical tests, the maximum values for the welding speed (Ws) were verified, as well as the maximum and minimum values for frequency and amplitude. The tests began with the highest amplitude value, and the maximum and minimum frequency values were obtained, with a 5 mm interval between amplitudes.

For all amplitudes, the minimum frequency was 0.1 Hz. The maximum frequency values can be observed in Table 1.

Table 1. Maximum frequency values for various amplitudes.

Weaving amplitude (*mm*)	Maximum frequency (*Hz*)
45	1
40	1,2
35	1,3
30	1,6
25	1,9
20	2,4
15	3,2
10	4,8
5	9,6
0.5	10

In tests conducted by TEIXEIRA (2018), where real amplitude measurements were taken, it was noticed that the system displays values on the control equipment's screen that do not correspond to the actual measurements. Therefore, it is necessary to perform a conversion of these values. Through Table 2, we can visualize the value shown on the system's display and the actual measured value.

Table 2. Conversion of amplitude values.

Theoretical amplitude (*mm*)	Real amplitude (*mm*)
45	38,34
40	34,08
35	29,82
30	25,56
25	21,30
20	17,04
15	12,78
10	8,52
5	4,26
0,5	0,426

With this information, we can calculate the value of the real amplitude using Equation 13.

$$Amp_{real} = 0,852 * Amp_{theoretical},$$ (13)

4.2 APPLICATION

In welding using the switchback technique, there are applicable proportions between forward and backward motions that allow for the formation of continuous weld beads. The minimum applicable proportion is 50%, to ensure the formation of a continuous bead during the welding torch's reversal (Kaneko et al., 2009). In the forward motion of the welding torch, the reversal occurs subsequently, so the switchback motion proportion corresponds to the percentage of reversal in relation to the forward motion.

It is crucial to know the application parameters of the switchback technique, as well as the most favorable proportions for its use. For example, if there is inadequate parametrization, discontinuities in the weld bead and undesired geometric characteristics may arise.
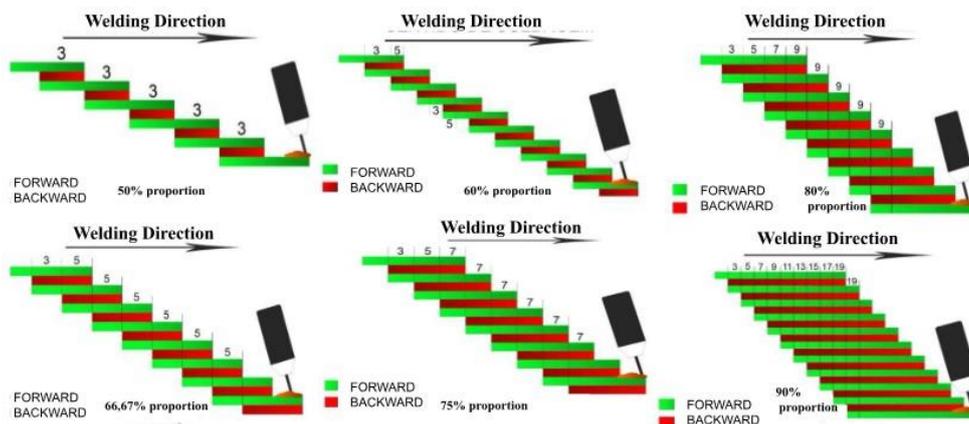

Figure 4. Applicable proportions in the Switchback technique (Farias, 2019. Edited).

It is noticed that in all proportions, there are sections at the beginning and end that are not similar to the others in terms of the deposited layers. There is no way to eliminate these sections with this mechanized equipment; therefore, these parts are considered as waste. Weld beads that do not have equal modules, with the same number of layers, will have higher surface stresses. For example, in the 60% proportion, there is a variation in the number of layers per module.

Based on Figure 4, it can be observed that the proportions with the highest number of homogeneous modules are 50%, 66.67%, 70%, and 80%. In the 50% proportion, there is the formation of modules one section after and one section before the beginning and end of the weld bead, respectively, each with three layers.

For the proportion of 50%
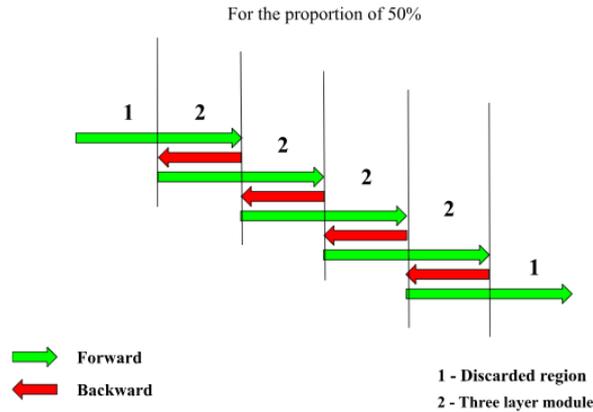

1 - Discarded region
2 - Three layer module

Figure 5. Modules of three layers formed in the 50% proportion.

Tests were conducted with the objective of observing the geometric characteristics in welds with different proportions. This allows for a visual analysis of the geometric aspects of the weld bead for various advance and reversal ratios. Table 3 presents the initial parameters of the welds, and Table 4 displays the parameters of the switchback technique used, along with the respective units of measurement already mentioned. Following that, in Figure 6, images of the geometric appearance of welds with different switchback proportions are presented.

Table 3. constant test parameters.

Welding mode	Pushed-pulled
Welding position	Flat
Polarity	CC+
Gas flow	14 L/min
Stick out	15mm
Torch angle	15°
Feeding speed	6 m/min
Voltage	30V

Table 4. switchback parameters.

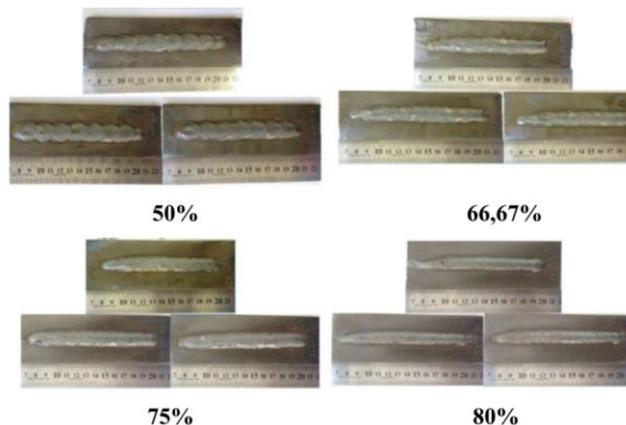| Ws	Prop	f	Amp	Fs	Bs	F	B
3,33	0,5	0,2	24,99	13,33	6,66	33,33	16,66
3,33	0,67	0,3	27,78	20,00	13,33	33,33	22,22
3,33	0,75	0,4	29,16	26,66	19,99	33,33	24,99
3,33	0,8	04	37,49	33,33	26,66	41,66	33,33
3,33	0,9	0,9	35,18	66,66	59,99	37,03	33,33

Figure 6. Geometric aspects of weld beads using switchback with the mechanized system.

4.3 GLOBAL MAXIMUMS AND MINIMUMS

This study aims to understand the general limitations of the created system, specifically regarding the ranges of maximum amplitude that can be achieved and how it compares to practical application. As explained in the theoretical foundation, to obtain the maximum forward and backward distances, the frequency needs to be at its minimum, and the input amplitude must be at its maximum. However, it is essential to highlight that in extreme cases, where the frequencies are very low and the speeds are very high, the system does not behave as expected, resulting in negative reversal proportions and speeds.

Two of the input parameters were held at constant levels, while the amplitude values were adjusted to obtain both the forward and backward lengths, as well as their respective proportions. The frequency values were set at 0.1 Hz, and the welding speed was maintained at 26.67 cm/min, yielding the values represented in the graph displayed in Figure 7.
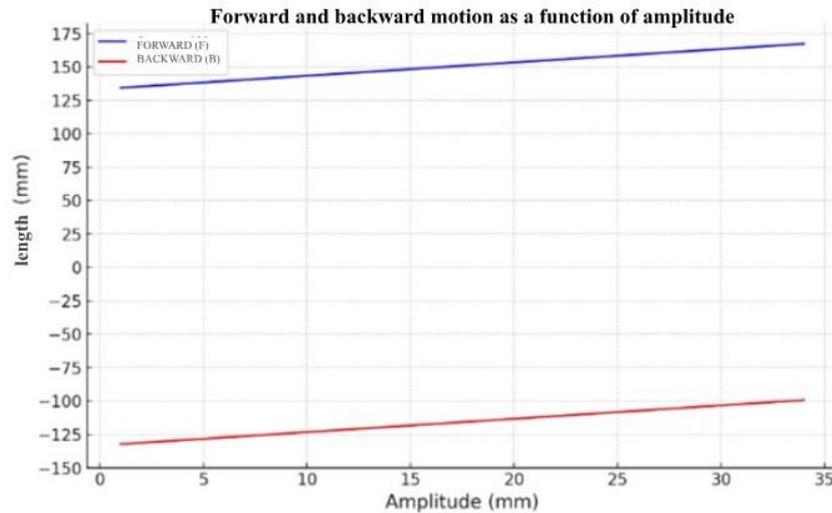

Figure 7. Forward and backward motion values as a function of amplitude with constant frequency and welding speed values.

This indicates that with minimum frequency values, the weaving speed cannot exceed the welding speed, resulting in a system that still advances, albeit at a slower pace. To overcome this limitation, the study introduces a condition for the occurrence of the switchback technique, in which the weaving speed (Wp) must surpass the welding speed (Ws). Therefore, to increase the value of Vt, we changed the frequency value from 0.1 Hz to 0.4 Hz.

Table 5. Forward and backward motion values as a function of amplitude satisfying the condition Wp > Ws.

Amp (mm)	F (mm)	B (mm)	%	(Wp/Ws)
30	63,34	-3,34	-5,27	0,9
31	64,34	-2,34	-3,63	0,93
32	65,34	-1,34	-2,05	0,96
33	66,34	-0,34	-0,51	0,99
34	67,34	0,66	0,98	1,02
35	68,34	1,66	2,43	1,05
36	69,34	2,66	3,84	1,08
37	70,34	3,66	5,21	1,11
38	71,34	4,66	6,54	1,14

By applying this condition, the study reveals that the switchback process occurs, allowing a maximum forward distance for the system of 71.34mm. However, for this distance, the switchback proportion is very low, only 6.54%. Therefore, the challenge is to find the maximum amplitudes for the optimal proportions previously shown. To make the search for these amplitudes more efficient, a table was created in which the amplitude is a dependent variable, allowing

the discovery of values for exact proportions. This approach enables the user to obtain amplitudes that will always respect the ordered proportion, without having to make assumptions for the amplitude.

Adopting the amplitude as a dependent variable and performing algebraic manipulation on Equation 14.

$$Bs * Prop = Fs, \tag{14}$$

Based on the previous equations, the amplitude can be determined as a function of frequency and welding speed for the 50% proportion.

$$Amp = \frac{1,5 * Ws}{f}, \tag{15}$$

Table 6. Discovery of maximum forward and backward motion for the 50% proportion.

Ws (cm/min)	Prop	F (Hz)	Amp	Fs (mm/s)	Bs (mm/s)	F (mm)	B (mm)
26,67	0,5	0,10	400,05	106,68	53,34	533,4	266,7
26,67	0,5	0,20	200,03	106,68	53,34	266,7	133,35
26,67	0,5	0,30	133,35	106,68	53,34	177,8	88,9
26,67	0,5	0,40	100,01	106,68	53,34	133,35	66,68
26,67	0,5	0,50	80,01	106,68	53,34	106,68	53,34
26,67	0,5	0,60	66,68	106,68	53,34	88,9	44,45
26,67	0,5	0,70	57,15	106,68	53,34	76,2	38,1
26,67	0,5	0,80	50,01	106,68	53,34	66,68	33,34
26,67	0,5	0,90	44,45	106,68	53,34	59,27	29,63
26,67	0,5	1	40,01	106,68	53,34	53,34	26,67
26,67	0,5	1,10	36,37	106,68	53,34	48,49	24,25
26,67	0,5	1,20	33,34	106,68	53,34	44,45	22,23
26,67	0,5	1,30	30,77	106,68	53,34	41,03	20,52

As the maximum amplitude of our system is 38.34 mm, we sought to find values close to this using Equation 15. Thus, the closest value found falls between amplitudes of 40.01 mm and 33.34 mm. In order to obtain a more refined result, two decimal places were added to the frequency.

Table 7. Refinement of decimal places to increase precision.

Ws (cm/min)	Prop	f (Hz)	Amp (mm)	Fs (mm/s)	Bs (mm/s)	F (mm)	B (mm)
26,67	0,5	1	40,01	106,68	53,34	53,34	26,67
26,67	0,5	1,01	39,61	106,68	53,34	52,81	26,41
26,67	0,5	1,02	39,22	106,68	53,34	52,29	26,15
26,67	0,5	1,03	38,84	106,68	53,34	51,79	25,89
26,67	0,5	1,04	38,47	106,68	53,34	51,29	25,64
26,67	0,5	1,05	38,1	106,68	53,34	50,8	25,4
26,67	0,5	1,06	37,74	106,68	53,34	50,32	25,16
26,67	0,5	1,07	37,39	106,68	53,34	49,85	24,93
26,67	0,5	1,08	37,04	106,68	53,34	49,39	24,69
26,67	0,5	1,09	36,7	106,68	53,34	48,94	24,47
26,67	0,5	1,10	36,37	106,68	53,34	48,49	24,25

Using 50% as an example, although there are larger forward distances, only the frequency of 1.05 Hz remains within the physical limit of the system, which is an amplitude of 38.34 mm.

Through this methodology, it was possible to determine the maximum amplitudes in the main proportions demonstrated throughout the study. The analysis of these tables and graphs provides valuable insights into the system's behavior and allows the user to adjust the parameters to achieve the desired results.

Table 8. Maximum amplitudes for the main proportions.

Ws (cm/mm)	Prop	f (Hz)	Amp (mm)	Fs (mm/s)	Bs (mm/s)	F (mm)	B (mm)
26,67	0,5	1,05	38,1	106,68	53,34	50,8	25,4
26,67	0,67	1,76	38,34	161,64	108,3	45,92	30,77
26,67	0,75	2,44	38,26	213,36	160,02	43,72	32,79
26,67	0,8	3,13	38,34	266,7	213,36	42,6	34,08
15	0,9	3,72	38,31	300	270	40,32	36,29

However, it is important to note that each individual system will have its own characteristics and limitations, and these tables and graphs are specific to the particular system under study. With each modification, a new calibration and setup must be applied. However, once the system is installed and calibrated, it can be used indefinitely, requiring only periodic maintenance.

5. CONCLUSIONS

Through the creation of graphs and tables, the understanding and expertise in obtaining and handling switchback parameters for the mechanized system were enhanced. Despite being an adaptation, the double-tartílope system demonstrated precision and stability in executing switchback movements. Repetition in the process was observed, meaning that with the same electrical and switchback parameters, cords with similar geometric characteristics were obtained. Amplitudes, advance, and reversal distances vary inversely with frequencies. Additionally, due to the ease of installation and maintenance, the double-tartílope system can be easily assembled and disassembled, as well as adapted to different locations. It was noted that the higher the switchback proportion, the greater the number of inserted layers, resulting in thinner layers.

6. REFERENCES

Farias, T.V.C., 2019. Parametrização de Um Sistema Mecanizado Com Switchback Para Soldagem GMAW. Final graduation project or Undergraduate thesis, Graduate Program in Mechanical Engineering, Federal University of Pará, Belém, Brazil.

Almeida, H.A.L., Mota, C.A.M., Scotti, A, 2012. Efeitos do Comprimento de Reversão e do Ângulo de Ataque sobre a Estrutura de Solidificação do Cordão em Soldagem MIGMAG com Switch Back. Soldagem e Inspeção, vol. 17, p. 123, 2012.

Kaneko, Y., Yamane, S., Oshima, K., 2009. Numerical Simulation of MIG Weld Pool in Switchback Welding. Welding in the world, vol. 53, nº 11/12, 2009. P. 333-341. 2009.

Neto, F.B., 2018. Otimização de Parâmetros Operacionais Para Aplicação de Revestimento Duro Por Soldagem com Processo FCAW Através do Projeto Robusto Taguchi. Final graduation project or Undergraduate thesis, Graduate Program in Mechanical Engineering, Federal University of Pará, Belém, Brazil.

Teixeira, F.R., 2019. Operational behavior of the switchback GMAW process using a mechanized rig for arc movement. Journal of Materials Processing Tech. [S.l.] 269 (2019), p. 135-149.

Bonacorso, N. et al, 2017. Técnica da Oscilação Longitudinal da Tocha para o Incremento da Produção na Soldagem em Ângulo entre Chapas de Espessuras Dissimilares. Soldagem & Inspeção, vol. 22, nº 2, 2017. p. 2017-216.

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