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Design and realization of a welding oscillator

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Abstract: Welding is one of the most popular methods to combine metal pieces in manufacturing processes. Arc welding, among all welding techniques, is the most commonly used in manufacturing due to its cost and flexibility. During the manufacturing process, arc welding is either performed by an operator or by automatic tools such as welding oscillators. Using automatic tools has advantages over manual use, as the process will be faster, cheaper, and have less welding flaws. In this paper, a homemade welding oscillator and the method to manufacture it are presented. The presented welding oscillator can be manufactured for a very low price compared to those on the market. Moreover, it covers industry-level needs and provides even more functionality with small adjustments if needed by the application. With this work, small-scaled manufacturing foundries will benefit from the price and functionality of the welding oscillator.

Key words: Welding oscillator, automation, control, smart welding, stepper motor

1. Introduction

Because metal parts produced in industry are large in volume and have complex geometric shapes, the costs of the molds are high, so they cannot be produced in one piece. Finished pieces to be produced are jointed together by a variety of welding methods [1–5]. Although laser welding, among all others, will result in the best performance, classical welding methods are more common to joint parts in industry due to their simplicity and cost [6,7]. Arc welding, having been widely used in industry for a very long time, ranks at the top of the list of classical welding methods [8–12].

The main advantages of arc welding are its simplicity, cost, flexibility to different environment and work pieces, and continuous enhancement due to technological improvements. With these advantages, this method is still popular in manufacturing, as it can adapt itself to automation technology [13–16].

One of the recent technological improvements in arc welding is the use of welding oscillators instead of an operator. The quality of the welding in welding processes traditionally made by an operator varies accordingly with the operator's experience. That the welding process is done automatically rather than by an operator has some certain advantages, such as uniform and high quality welding, reduced production time and cost of labor, the possibility of realizing different welding shapes that are not practical to be achieved by an operator, minimization of errors due to operators, and minimal risk of work accidents. Consequently, it expands its use every day [3,6,14].

Several companies provide welding oscillator products to the market [17–19]. The main problems of using an off-the-shelf product are high cost and lack of flexibility towards different applications. This work provides

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the design details of a low-cost but highly flexible and modular welding oscillator that will target industry-level performance. The flexibility of the design enables an increase in the functionality of the welding oscillator to address different applications if needed. The rest of this article is organized as follows: Section 2 provides the details of the structure of the designed welding oscillator. Section 3 explains the operation principle of the designed welding oscillator. Sections 4 and 5 give the results and conclusions.

2. The structure of the designed welding oscillator

A welding oscillator on the market generally has a single degree of freedom oscillation, a pendulum-like continuous oscillation on the target. In order to joint 2 targets, one must design a separate system to push the oscillator and position it properly so that it welds the targets. Generally, the communication between these 2 systems is very limited, as the commercial system does not allow it. This situation is not optimal.

The welding oscillator designed in this study eliminates this limitation. The oscillator has 2 or more degrees of freedom oscillations. The first is the pendulum-like swing, similar to commercial ones. The second degree of freedom is the out-of-plane movement. When there is a height step on the line of the welding, the welding oscillator can adapt its z-axis position. The third degree of freedom is the movement of the welding oscillator through the line of the welding. All of these motions are controlled by the same source, so the communication between them can be precisely adjusted. Moreover, additional degrees of freedom movements can be added easily in order to target more complicated welding tasks. For instance, if angular welding processes are requested, the additional degree of freedom will be to rotate the targets while welding. This rotation can also be precisely controlled from the same source.

Additional functionality can be added to the system very easily by just software adjustments. Currently, in the area to be welded, the pendulum swing movement can be performed at a desired speed (if the zone where the welding process will be done is wide, low speed is required; if it is narrow, high speed is needed). The pendulum-like swing can even have 2 different angular speeds towards left and right from the origin point, so that metals with different characteristics or different geometrical shapes can be welded to each other more efficiently. Sometimes, intentional waiting periods are required to improve the quality of the welding. Moreover, the optimum number of welding passes on the line of the welding is different from target to target. For instance, while welding very long and thick targets, several passes of welding will be required; otherwise, the targets will bend due to stresses throughout the welding process. Entering the proper number of passes, as well as other software adjustments, can be easily performed.

The system is compatible with further improvements by additional hardware as well. Using position sensors, which will again be controlled from the same source, for instance, will automatize the several degrees of freedom motion of the welding oscillator. The schematic diagram of the designed welding oscillator within this work is shown in Figure 1.

As seen from Figure 1, the welding oscillator consists of a microcontroller, a stepper motor driver, stepper motors (the number depends on the number of degrees of freedom movements), reducers, and a welding torch. Each stepper motor creates the motion of the corresponding degree of freedom movement. The output torque of each stepper motor is increased by a reducer, which reduces the rotation speed but increases the torque. The welding torch is connected to the corresponding stepper motors to create the final multidegree of freedom welding movement. Each stepper motor is controlled by a single microcontroller, which defines its rotation speed and angle. By modifying the software on the microcontroller, one can easily modify the functionality of the final system.

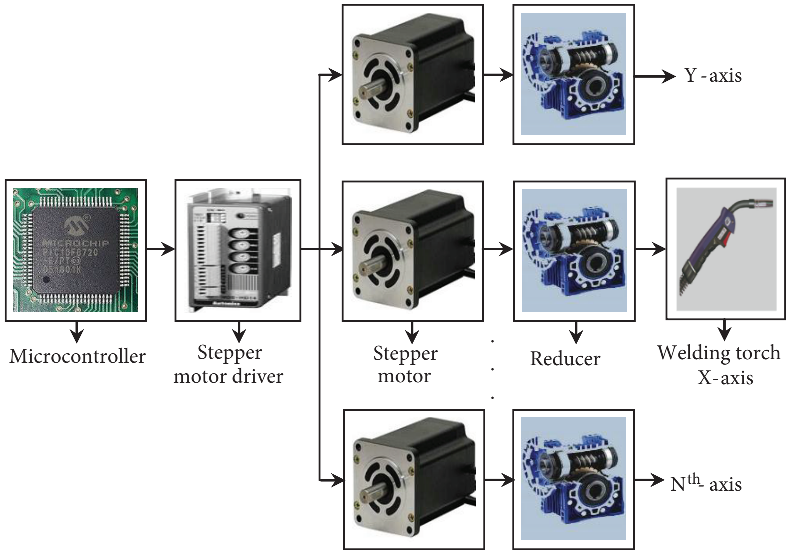


Figure 1. Schematic diagram of the designed welding oscillator.

3. Operational principle of the designed welding oscillator

The most complicated part of the designed welding oscillator is the control of the welding torch swing movement. By adjusting some parameters controlling this swing, a wide range of functionalities can be achieved. The control of the other degree of freedom movements and the overall communication between them will be much simpler compared to the control of the welding torch swing movement. Hence, in this section, only the control of the welding torch swing will be explained.

3.1. Details of the algorithm used in the microcontroller unit

The functionalities that can be achieved from controlling the welding torch swing movement will be to form a differently shaped final welding to address the different welding needs of the application. For instance, in order to joint 2 materials with different properties, the welding time and amount of welding needed will be different for those materials. Thus, the welding torch swing movement will be asymmetric. Similarly, an asymmetric swing movement will be required in order to achieve a differently shaped final welding on the welding line. In this work, 7 parameters (welding width left and right from the center, welding torch swing speed left and right, and waiting time left, center, and right during welding) are defined to create all of these functionalities and more. The 7 parameters that are entered into the welding oscillator are shown in Table 1.

Table 1. Seven parameters that are entered into the welding oscillator.

Controlled physical quantity	Parameters		
Welding width from the center (mm)	Left (LW)		Right (RW)
Torch swing speed (m/min)	Left (LV)		Right (RV)
Waiting time during welding (s)	Left (TL)	Center (TC)	Right (TR)

A sketch of the welding torch is shown in Figure 2. When the parameters from Table 1 are provided to the microcontroller, the microcontroller first calculates the angle of the rotation (QR for the right and QL for the left).

$$QR \cong (360RW)/(2\pi LT) \tag{1}$$

Here, QR is the angle of rotation that the welding oscillator needs to make to the right, RW is the width of the welding range to the right from the center (mm), and LT is the length of the welding torch (mm), which can be adjusted according to the needs. Eq. (1) is derived keeping in mind that LT is a lot larger than RW.

Next, the microcontroller calculates the number of steps that the stepper motor needs to take (SR for the right and SL for the left):

$$SR = (QR/QS)(1/NR), \tag{2}$$

where SR is the number of steps the oscillator will make to the right, QS is the step resolution of the stepper motor (0.7° for this study), and NR is the speed reduction number (the reducer used in this study has a reduction ratio of 1/90).

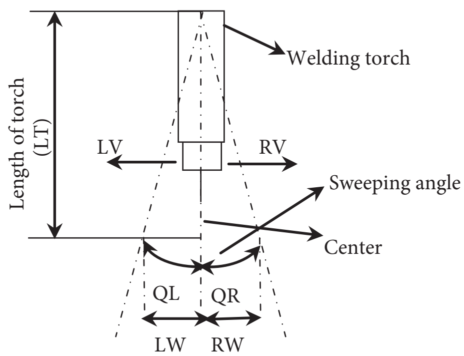


Figure 2. Sketch of the welding torch.

After calculating the number of steps, the microcontroller calculates the frequency of the control pulse according to the input speed data. Figure 3 shows a sketch of the pulse train. The sketch of the applied pulse train having a low frequency will cause the welding torch to swing at low speeds, as shown in Figure 3a, and having a high frequency will make it swing at high speeds, as shown in Figure 3b.

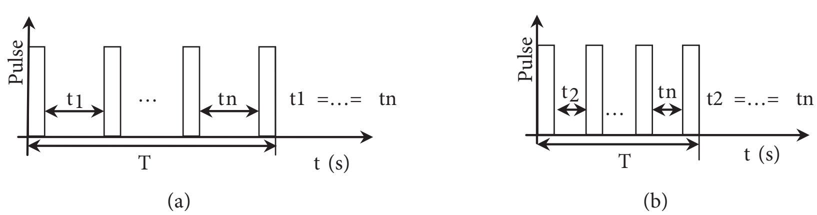


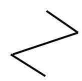
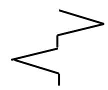
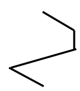
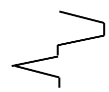
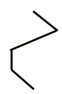
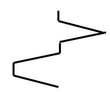
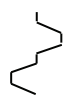
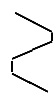
Figure 3. Sketch of the applied pulse train: a) pulse train for low speed and b) pulse train for high speed (t1 > t2).

The time between 2 pulses of the pulse train depends on the input speed (RV for the right and RL for the left), input range (RW for the right and LW for the left), and number of steps (SR for the right and SL for the left) and can be calculated as:

$$t = (60RW)/(1000RV(SR - 1)). \tag{3}$$

Here, t is in seconds, and coefficients 60 and 1000 are required for the correction of the units. The time between pulses for the left can be calculated similarly. It should also be noted that because the width of each pulse in the pulse train is so small compared to the time between the pulses, it is ignored in the above calculation. The time between each of the pulse trains will depend on the waiting times (TC, TL, and TR) defined in Table 1. According to the selection of these waiting times (TC, TL, and TR), different welding patterns can be obtained, which are shown in Table 2.

Table 2. According to the selection of the waiting times (TC, TL, and TR), different welding patterns can be obtained.

Waiting times	Final welding pattern	Waiting times	Final welding pattern
TC = 0 TR = TL = 0		TR = TL = 0 TC > 0	
TC = TL = 0 TR > 0		TC, TR > 0 TL = 0	
TC = TR = 0 TL > 0		TC, TL > 0 TR = 0	
TC, TR, TL > 0		TC = 0 TL, TR > 0	

A flow chart of the program entered into the microprocessor is shown in Figure 4. When the welding process starts, first the starting point is arranged by the operator in the manual mode of the algorithm, and then the data entry section starts. Here, in addition to the parameters mentioned in Table 1, the number of the pass information (PASS), which does not control the swing movement but controls the movement along the welding line, is also provided to the microcontroller. Next, the microcontroller executes the algorithm and the welding process is performed in the desired way.

3.2. The details of the hardware of the welding oscillator

A block diagram of the welding torch and the controlling circuitry is given in Figure 5. Data that can be entered into the microprocessor from the outside and their values are shown in Table 3.

Table 3. Data that can be entered into the microprocessor from the outside and their values.

Item	Specifications
Right width (RW)	25 mm max (resolution 0.1 mm) Depends on torch length, Eq. (1)
Left width (LW)	25 mm max (resolution 0.1 mm) Depends on torch length, Eq. (1)
Sweeping angle	±22.5°
Left speed (LV)	0–3 m/min (resolution 0.1 m/min)
Right speed (RV)	0–3 m/min (resolution 0.1 m/min)
Stop time on the left (TL)	0–5.0 s (resolution 0.1 s)
Stop time on the right (TR)	0–5.0 s (resolution 0.1 s)
Stop time on the center (TC)	0–5.0 s (resolution 0.1 s)

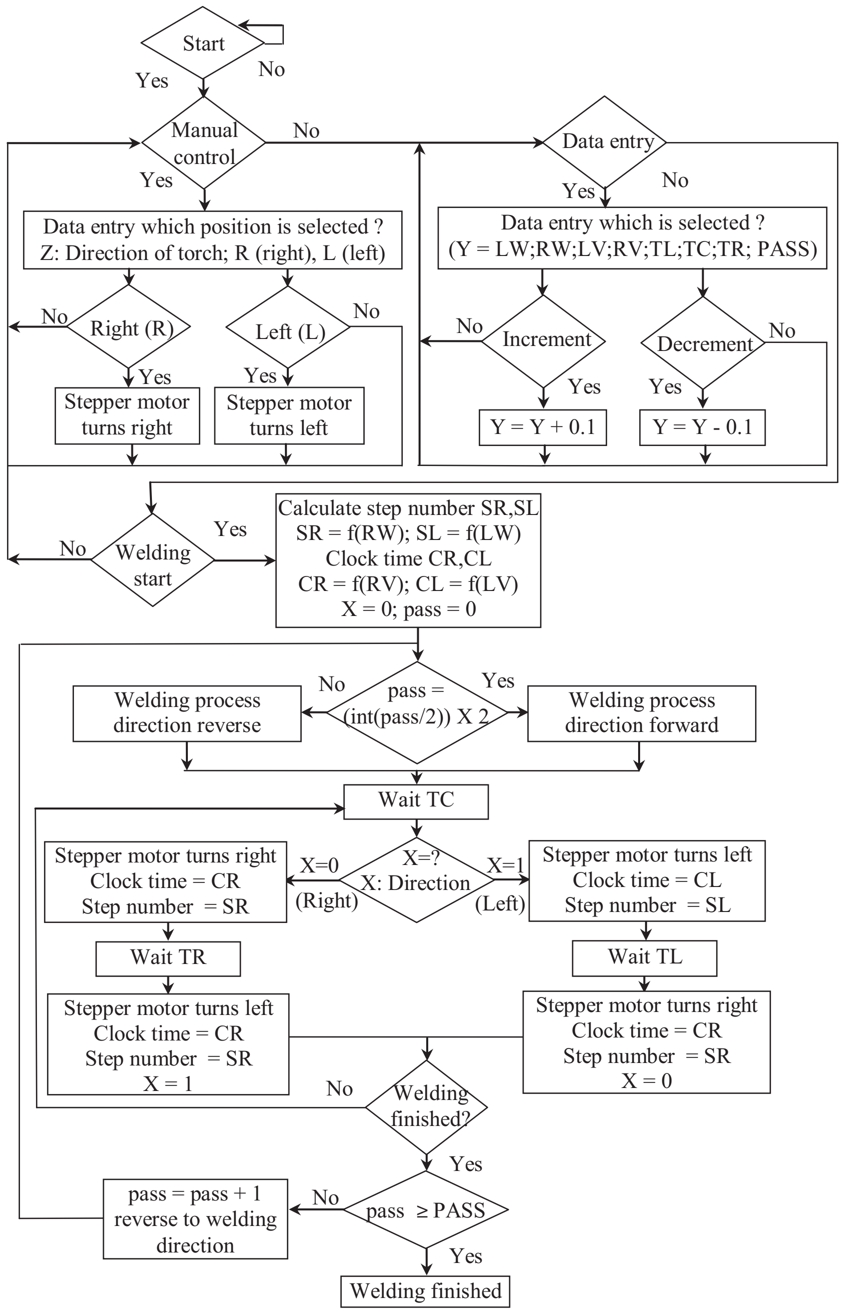


Figure 4. Flow chart of the program entered into the microprocessor.

When the manufacturing phase of the welding oscillator starts, first the reducer and the stepper motor that have the right specifications to move the welding torch are chosen. After that, a stepper motor driver suitable for the stepper motor is chosen. Specifications of the stepper motor and the stepper motor driver are given in Table 4.

Figure 6 shows the general appearance of the welding oscillator and the test frame that holds it.

Figure 7 shows some examples of different welding patterns that could be obtained by changing the welding parameters in the algorithm.

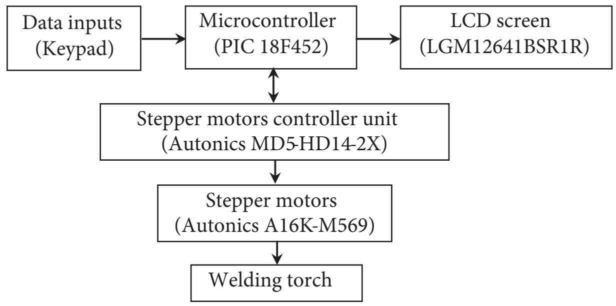


Figure 5. Block diagram of the welding torch and controlling circuitry.

Table 4. Stepper motor and stepper motor driver specifications.

Stepper motor specifications (Autonics A16K-M569)		Stepper motor driver specifications (Autonics MD5-HD14-2X)	
Phase	5	Phase	5
Type	Shaft	Power supply	20–35 V-DC, 5 A
Max. holding torque	1.66 N-m	Run current	0.4–1.4 A/phase
Resolution	0.7° full step	Basic step	0.72°/step
Amps per phase	1.4	Resolution	0.72° to 0.00288°
Winding resistance	1.80 Ω	Input pulse width	0.5 μs min.
Rotor inertia	560 g/cm^2	Rising/falling time	120 ns each max.
Shaft length	22.5 mm	Input frequency	1 Mhz max.
Shaft diameter	8 mm	Axis	Two axes

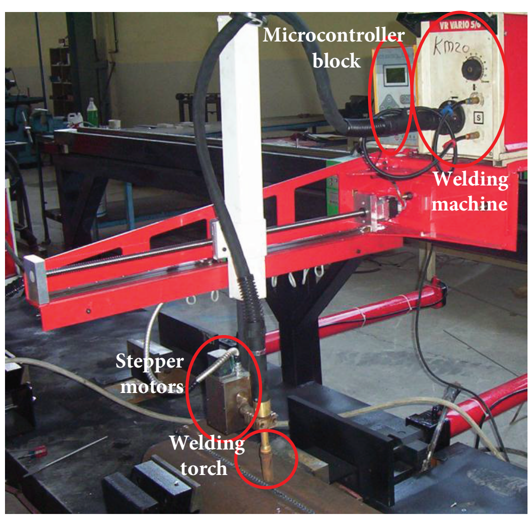


Figure 6. General appearance of the welding oscillator and the test frame that holds it.

4. Results

Table 5 gives an overview of the properties of the designed welding oscillator. This designed and manufactured welding oscillator is compatible with all of the following welding processes: gas metal arc welding (GMAW), plasma arc welding, metal inert gas or metal active gas welding, plasma transfer arc welding, gas tungsten arc welding, and flux-core arc welding. Hence, the developed welding oscillator is adopted to be used in a variety of different welding processes in the current industry.

Figure 7. Different welding patterns that could be obtained by changing the welding parameters in the algorithm.

As additional degrees of motions can be easily added and controlled from the same microcontroller, the developed welding oscillator is also compatible with horizontal and rotational welding processes. The major advantages of the developed welding oscillator over its competitor in the industry are to provide this flexibility and reduced price.

Table 5. Overview of the properties of the designed welding oscillator.

Type	Vibration
Oscillator frequency	17–200 Hz
Oscillator range	0 to ±22.5°
Center position function	No (but the system is flexible to having this option if required)
Oscillator width adjusting	Manuel
Dwell function	3 point stop function left, center, right,
Dwell time	0–2 s
Input power	AC 210–240 V, 50/60 Hz, 250 VA
Size	219 × 136 × 121 mm
Weight	2.8 kg
Control weight	1.2 kg

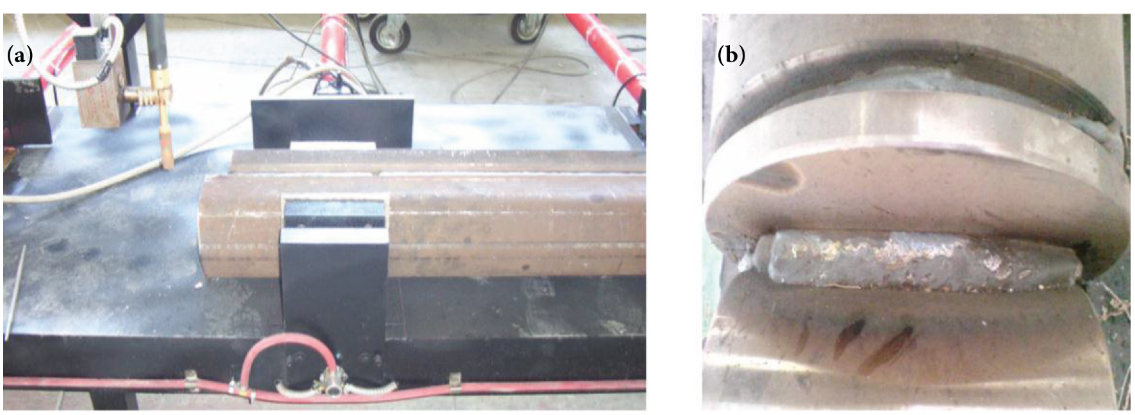
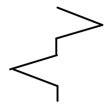
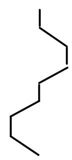
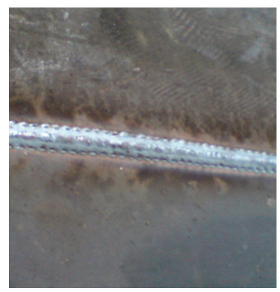
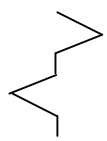
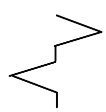
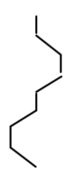


Figure 8. Examples of welded structures using the designed welding oscillator: a) the welded boom for the telescopic crane and b) welding examples of complex applications, jointing 2 cylinders orthogonally.

Table 6. Different parameters used and obtained welding patterns.

Set	Welding parameters	Expected pattern	Realized pattern
1	LW = 35; RW = 35; LV = 20; RV = 35; TL = 0.0 ; TC = 0.2; TR = 0.0 .		
2	LW = 30; RW = 30; LV = 45 ; RV = 45; TL = 0.1 ; TC = 0.2; TR = 0.1 .		
3	LW = 40; RW = 40; LV = 35; RV = 35; TL = 0.0 ; TC = 0.4 ; TR = 0.0 .		
4	LW = 40; RW = 40; LV = 35; RV = 35; TL = 0.0 ; TC = 0 3; TR = 0.0 .		
5	LW = 25; RW = 25; LV = 55; RV = 55; TL = 0.2 ; TC = 0 3; TR = 0.2 .		

This welding oscillator is currently being used to manufacture 10-m-long telescopic booms by butt jointing using GMAW for mobile cranes, each having 5 booms per crane. Figure 8a shows the welded boom for the telescopic crane and Figure 8b shows welding examples of complex applications, jointing 2 cylinders orthogonally.

The thickness of the steel work-piece used to manufacture the booms is 10 mm and the welding gap is approximately 10 mm. Several different welding patterns are tried to optimize the welding process. Table 6 summarizes the different parameters used and the obtained welding patterns. However, the realized patterns and expected patterns are different from each other in the boom welding applications as the metal melts and reshapes in the welding pool created by the corner joints [20]. In all of these trials, the diameter of the welding wire is 1.2 mm, wire feeder speed is 19 mm/s, welding speed is 5.5 mm/s (gas-shielded arc welding), welding current is 430 A, and number of passes is 3.

In the manufacturing of the booms, the fourth parameter set in Table 6 is used. The most interesting parameter sets are the third and the fourth, but in the third case, an undesired tip is created in the middle of the welding line due to a slightly large waiting time in the center (TC = 0.4 s). In the fourth parameter set, TC is reduced to 0.3 s; hence, the tip is eliminated and a very uniform welding pattern is achieved.

In addition to this uniform welding pattern, the second major gain achieved due to the designed oscillator is the speed of the boom manufacturing. Traditionally 1 boom could be manufactured in 1 h, but now, with the designed welding oscillator, 2 booms can be manufactured in the same time.

5. Conclusions

Today, welding processes in the machinery and manufacturing industry are one of the sectors where engineering activities are kept in the forefront. It is inevitable that companies will carry out manufacturing more economically and faster with the developing technology. Competition in the manufacturing of machinery and machine parts has forced companies to manufacture cheaper and better quality products. In this study, a welding oscillator was designed and realized that addresses industry-level high-quality manufacturing with flexible functionality at a cheap cost. The total cost of the designed welding oscillator is around 500 euros, while commercial examples with significantly limited functionalities cost at least 2500 euros. The flexibility of the functionality comes from the fact that a number of parameters controlling the welding, such as different width values, welding speed, and waiting times belonging to each right and left side of the region where welding process will be performed, are controlled from the same source. Thus, materials that have different welding shapes from each other and metals with different welding properties can be welded to each other. Moreover, the system can be further improved by additional hardware or software adjustments, such as online monitoring of the welding using a laser profile sensor, which is again controlled by the same microcontroller. With this study, it is thought that small- or medium-scaled companies will find automated, adjustable, and flexible welding process solutions according to their needs in a cheap and high-quality way.

Acknowledgements

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