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SMALL ALLOY WELDING EQUIPMENT

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Abstract— Welding is the most common process to join two types of metal. Capacitive welding is used in small alloys, jewelry and temperature sensors. A good quality welding is composed by a homogeneous distribution and uniformity of the material at welding point and a mass conservation, keeping the metal crystalline proprieties. Capacitive welding consists in submitting a metal to an electric arc, storing energy in capacitors, when released will melt alloy and creates a union. In an inertial chamber the atmosphere is controlled and Argon is injected by a solenoid valve, responsible to control Argon from a cylinder. Argon is a shielding gas responsible for the non-inclusion of external elements in the weld. This study develops equipment able to make capacitive welding using the principles mass and energy conservation in alloys and gauges pre-established, of different types of metals in an inertial environment, with the objective of create a good quality and efficient weld with low cost equipment with easy manipulation.

Keywords— Capacitive Welding, thermocouple welding, Arduino, Inertial environment welding, Automatic welder

I. INTRODUCTION

The welding is a union process of metals that produces the coalescence of metals by the heating at the right temperature, with or without pressure application, or just pressure application and with or without a filling material or, only the process with the goal the union of two or more pieces, keeping the chemical and physical proprieties [1].

Capacitive welding is one of the most common methods to weld small alloys. One of main characteristics is the simplicity of the system. Welding by capacitive discharge consists the support of an electric arc by a small fissure between the conductive substrate that is keep in the neighborhood of a wire, subject an electrical potential. The high temperature produced melts part of the material near the outflow, what suddenly occupy the empty spaces and solidify, creating the union of the metal alloy involved [2].

A thermocouple is an example of capacitive welding application in small gauges. Thermocouples are composed by 2 wires of homogeneous alloys that need a resistant and almost perfectly homogeneous union, acquiring characteristics as a single metallic alloy, to obtain high levels of precision of temperature measurement. The thermocouple measurement point can be made by a method that will keep the alloy proprieties and a good electrical conduction. The measurement point can be made of two types, twisted or top.

There are some thermocouples that are larger used in industrial process, usually metallic thermocouples, the thermocouples are divided in types, the most common are: type T (cupper-constantan; -180 to 370 ºC); type E (Chromel - constantan; -200 to 900 ºC); type J (Iron - constantan; -40 to 750 ºC); type K (Chromel - Alumel; -180 to 300 ºC) [3].

The mass conservation of the alloys involved is important to assure the quality of the welding in a thermocouple, because there is no addition of a third alloy or element in the system. The inclusion of a third element between the pair of metallic in the welding process must be avoided what attribute a high efficiency and precision the measure equipment [3].

Similar equipment was developed by Zanstra [2] and G. Orr and M. Roth [4]. In a market research, we found these welding equipment [5-7], in this equipment there is just a voltage regulator and there is no way of automation of the amount of energy to be used, depending of the thermocouple or alloy gauge, the welding process is almost completely done by humans, what makes the results susceptible to fails. In this work, we propose a piece of equipment that can be pre-programed to weld small metal alloys, to minimize the energy consumption and provide a high-quality welding.

Capacitive welding equipment create an electric arc thought the energy stored in a capacitor bank. This system intends to avoid unnecessary use of energy during the process, which can lead a low-quality final product. An Arduino microcontroller controls the charge of the capacitor bank according to the type of alloys and metal gages used in the welding, and manage the shielding gas valve and conduction to weld circuit, making an almost completely automation of welding process.

II. METHODOLOGY

A. *Developing Equipment*

The developed equipment of capacitive welding is able to weld metallic wires, commonly find in jewelry and thermocouple. The equipment is composed of: a symmetrical direct voltage source of 31 V associated to a capacitive bank of 37600 µF, a microcontroller Arduino UNO, a relay module with 2 relays (one that will be used as a switch between the capacitive bank and the voltage source, and the other that will be used to control the argon gas valve), a LCD display, 5 buttons menu and a step motor conduction circuit.

The process of the capacitive relies on direct voltage source is monitored by microcontroller Arduino though the measurement of the voltage of the capacitive bank. Arduino's compatible levels of voltage are achieved through a tension division in order to calculate the energy stored in the capacitors. The microcontroller Arduino controls the charge stored in the capacitor bank according to its voltage levels. The Arduino is also responsible for determining the charge level of the bank considering the material used in the alloys. To control the charge circuit of the capacitive bank it was used a relay which is responsible by connecting and disconnecting the charging circuit of the source. It was necessary to use a relay for the bank voltage level is not compatible with the tension level supported by the Arduino.

The capacitor bank is composed of an association of 8 capacitors in parallel, so that the resulting capacitance is summed and the necessary charge is obtained. For this circuit, it was chosen 8 electrolytic capacitors of 4700 µF and 63 V, connected by a 2.5 mm² wire of cupper. Under its max load, the capacitive bank provides an energy od 74.62 J approximately. The energy stored it's enough to weld the pre-established gauges and types of thermocouple and there is an energy over to future new gauges and alloys.

To make the connection between the capacitive bank, the charge circuit and the connection between the Arduino and the solenoid valve was used the two-relay module. The Arduino microcontroller cannot operate the relay of load circuit and the valve directly through its digital gate, so it was necessary an amplify circuit able to activate the relay and promote electric isolation between the microcontroller Arduino and the load circuit. The chosen relay module relay has a coil with working voltage of 5 V and current of 25 mA the relay contacts are able to operate up to 10 A.

The voltage source responsible for feeding the capacitive bank is formed by an output DC symmetrical voltage source with positive amplitude of 31 V, able to obtain 62 V of total amplitude in DC current. The symmetrical characteristic was chosen because the available components at the market by a low-coast, if necessary, the components can be changed and a simple source can be produced.

The voltage source responsible for feeding the capacitive bank is formed by a transformer that lowers the voltage from 127/220 V to 24 V AC. Then a diode rectifies the signal provided by the transformer, the rectification is made by a diode bridge, composed by 4 diodes 1N4007. After the rectification, there will still an oscillatory characteristic at the signal and a filter made by 4700 µF electrolytic capacitor is used to solve this issue.

After the grid voltage is lowered and filtered is necessary adjust it using the dispositive LM317 from positive and LM337 from negative side, since there is a symmetric power source. With the regulator, it was added potentiometers, that are responsible to create a voltage division, generating a controlled output to the source. Before the final output, it is necessary a new filter, that is made by a pair of 10 nF and 100 nF ceramic capacitors, respectively. The final result is a DC symmetrical voltage source with positive amplitude of 31 V, able to obtain 62 V of amplitude in DC current. The symmetrical characteristic was chosen because the available components at the market by a low-coast, if necessary, the components can be changed and a simple source can be produced. Figure 1 illustrates the steps of signal conversion.

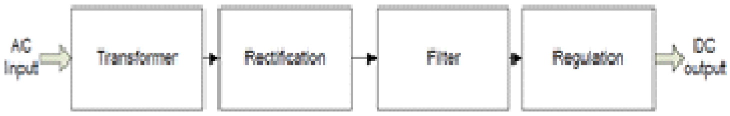

Figure 1. Steps of signal conversion.

A gas valve was chosen to inject a shielding gas in the weld chamber developed. The shielding gas it is necessary to protect the thermocouple of oxygen action, what damage the system by oxidation. The gas valve its activated seconds before the welding, the shielding gas fill all the chamber and create an atmosphere to welding process. The valve it is connected to an Argon cylinder with a pressure regulator.

The approximation system with a step motor consists in a CD/DVD laser motor drive, what were adapted to support a claw. The step motor moves a slippery platform where the claw is affixed, the claw holds the metallic alloy to be welded and the platform conduces the claw until the weld chamber. The claw was connected to a positive terminal of capacitive bank and for the negative terminal it was used a coal brush, usually used in induction motor. The coal was put inside a glass chamber, developed exclusively by this equipment. The weld will be done inside an inertial chamber, the chamber is made of glass and has a cylindrical form, in one side it’s opened and in the other there is a connection with an Argon tube, which is responsible for inject the gas during the welding. Figure 1

B. *Energy consumption estimation*

Conservation mass and energy balances were done to calculate the necessary energy used in each metallic alloy. A good welding makes a perfect union between both the materials, keeping their physical and chemical proprieties. Therefore, it is necessary to provide enough energy to melt the metallic alloys involved. The variables involved in the calculation of heat transfer process were: specific heat, density and melting temperature of the metallic alloys.

The energy estimation it made using the mass and energy conservation.

$$\Sigma Q = 0 \quad (1)$$

$$Q_{total} = 0 \quad (2)$$

$$Q_{total} = Q_{sensible} + Q_{Latent} \quad (3)$$

$$Q_{total} = mc\Delta t + mL \quad (4)$$

As know:

$$m=\rho V \quad (5)$$

So, if we substitute Eq. 5 in Eq.4

$$Q_{total} = \rho Vc(\Delta t+L) \quad (6)$$

Where:

ρ – Density (g cm^{-3})

V – Volume (cm^3)

c – Specific heat (J g^{-1} cm^{-1} K^{-1})

Δt – Temperature gradient (K)

L – Latent heat (J g^{-1})

Using each material proprieties, it possible obtain the amount of energy necessary to melt an specific volume of metallic alloy to weld the wires.

The equipment was developed by 3 gauges of metallic alloys to be welded, 24, 26 and 32 AWG. Reference values of satisfactory radius to weld metallic alloys were established though practical experiments. They were considered to be 2.4 times the diameter for 32 AWG, 1.9 times the diameter for 26 AWG and 24 AWG. With the reference values for the generated weld sphere, it was calculated the weld sphere volume to be generated and that would be used to energy calculation. Table 1 presents the theoretical calculation for the energy needed to melt metallic alloys.

Table 1. Energy needed to melt metallic alloy (J)

Element	Gauge [AWG]		
	32	26	24
Iron	3,535	14,136	24,120
Cupper	2,615	10,464	17,842
Platinum	3,408	13,637	23,253
Constantan	3,037	12,154	20,725
Alumel	4,164	16,662	28,411
Chromel	3,815	15,266	26,020

It was calculated the energy stored by the capacitive bank according to the voltage, to control the stored energy in the capacitor bank and assure that the right values are used in different gauges and alloys by the microcontroller Arduino. The composition of each thermocouple type is: Type E: Chromel and Constantan; Type J: Iron and Constantan; Type K: Alumel and Chromel; Type T: Cupper and Constantan.

The necessary energy to weld the thermocouple is the sum of the energies necessary to weld each metallic alloy.

The conversion equation for energy from Joules to Volts is showed by Eq. 7.

$$V=(2W/C)^{1/2} \quad (7)$$

Table 2 show and the total energy mensuration according the composition converted from Joules to an electricity unit, in this case Volts (V).

Table 2. Necessary energy to weld the thermocouple (V)

Thermocouple	Thermocouple Gauge [AWG]		
	24	26	32
E	49.869	38.191	19.091
J	50.198	38.442	19.217
K	53.813	41.210	20.6
T	49.293	34.686	17.339

C. *Arduino Programming and welding*

In this part values, theoretical calculated will be converted to values that are compatible with the Arduino.

The voltage values that will be monitored by microcontroller Arduino are not compatible with the microcontroller scale. Therefore, it is necessary a circuit to do the voltage conversion from capacitive bank to values between 0 V and 5 V. To obtain this conversion it was developed a circuit known as voltage divider, that use 2 resistors to create a proportional voltage, a resistor of 1M5Ω and another of 100 kΩ, the practical voltage reduction is 16.3, applying voltage values from the capacitive bank to the 0 V to 5 V scale we obtain the values shown in Table 3.

Table 3. Tension values on tension divising

Thermocouple	Thermocouple Gauge		
	24 AWG	26 AWG	32 AWG
E	3.059	2.343	1.171
J	3.080	2.358	1.179
K	3.301	2.528	1.264
T	2.779	2.128	1.064

The microcontroller Arduino make an analogic conversion to values between 0 and 1023, being 0 to 0 V and 1023 to 5 V, in a linear scale. So, it is necessary to create a conversion constant to these units, that will be 4.8828×10^{-3}. Thus, we can program the equipment using a button panel.

The coupling of the welding terminals will be made of an object with conduction characteristics. To make the conduction from the capacitive bank to metallic alloy 6.0 mm^2 wire was been chosen. Fig. 2 and 3 shows the final layout equipment.

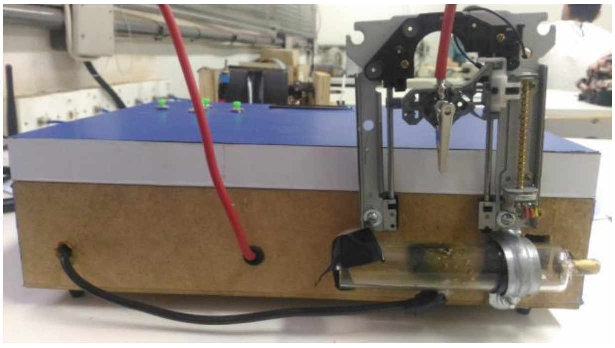

Figure 2. Equipment final layout.

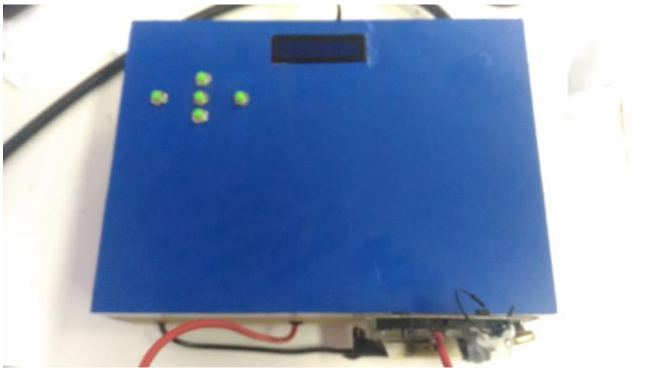

Figure 3. External equipment layout.

III. RESULTS

The experiments were made with thermocouples, type T with gauge 24, 26 and 32 AWG and thermocouples type E and K gauge 32 AWG. The welding was observed at microscope to verify the quality using the established parameters, such as: format, size, color and homogeneity. Fig. 4 and Fig. 5 shows the different weld thermocouples made.

The second analysis were to verify if the amount of energy stored in the capacitive bank were all used in the welding process. To do this analysis was used an oscilloscope connected at the capacitive bank terminal during the welding process. Fig 6,7 and 8 show the waveform of charge and discharge during the welding process of thermocouples E, K and T all of them from gauge 32 AWG.

Figure 4. Thermocouples type T, gauges 32, 26 and 24 AWG respectively.

Figure 5. Thermocouples type E and K, gauge 32 AWG.

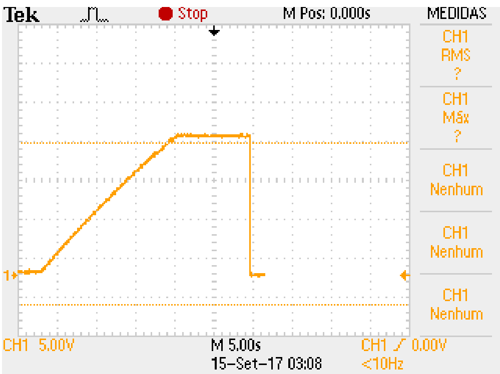

Figure 6. Thermocouple K-32.

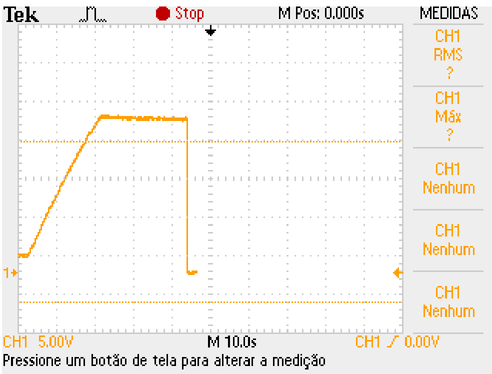

Figure 7. Thermocouple E-32.

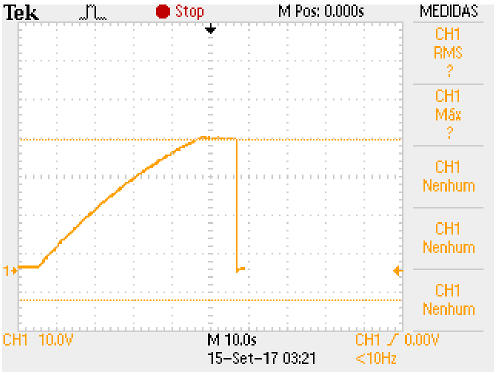

Figure 8. Thermocouple T-26

In a fast analysis of waveform, we can see that the amount of energy obtained in the theoretical calculation were stored in the capacitive bank, and all the amount of energy were all consumed suddenly, what confirm a low conductive resistance and indicates a good result in the energy and mass balance estimations.

An image analysis was made with the software ImageJ. The software is able to measure the image characteristics based on pixel analysis, based on a reference of size. The analyzed aspects were the circularity and round. The results are showed on Table 4.

Table 4. ImageJ analysis results.

Thermocouple - Type	Circularity	Sphericity	Roundness
E - 32	0.829	1	0.939
K - 32	0.856	1	0.907
T - 32	0.906	1	0.965
T - 24	0.851	0.9927	0.841
T - 26	0.912	0.99	0.913

The sphericity indicates how near of spherical form is the analyzed form, the results indicates an almost perfect sphere in all the cases, what confirm our presumptions. The circularity analysis indicate in a 2D vision how near is the form of a circle, the results show a strong proximity, this is not stronger because the irregular union point in the wires. The Roundness indicate how round the sphere is, comparing the result with an ellipsis, the result indicates too a strong connection with the round form. In a general analysis the software was able to confirm the estimations about mass and energy conservation, what indicates a successful methodology.

The fourth parameter analysis were the metallic couple electrical resistance. The resistance determines the opposition of a material to an electrical current, the main objective is to verify the thermocouple union quality.

A good union keep the metal proprieties and a low resistance at union end. With use of a precision multimeter Tektronix TEK DM 5120, the metallic pair had the electrical resistance measured, the precision of the equipment is 15 mΩ. The results are in the Table 5.

Table 5. Thermocouple electrical resistance.

Resistance [Ω]											
Type - Gauge	Samples										
T - 32	1.7405	1.7258	1.8199	1.7942	1.7538	1.7473	1.7431	1.7994	1.6166	1.8553	1.7622
T - 26	1.3865	1.3038	1.3595	1.339	1.3423	1.3577	1.3284	1.3542	1.3778	1.3306	1.3000
T - 24	1.2612	1.3048	1.2784	1.288	1.2815	1.2803	1.2885	1.3078	1.2942	1.2905	1.2930
E - 32	2.1472	1.7738	2.1407	2.0267	1.9094	2.0887	2.1736	2.3145	2.1841	2.1270	2.2066
K - 32	1.9305	1.7755	1.8601	1.9714	1.9964	1.9317	1.7261	1.9901	2.0530	1.9000	1.9010

Making an analysis in the resistance results we will consider a good result the samples inside the interval [Average ± σ], every thermocouple outside this interval will be considered a no quality thermocouple. The Table 6 shows the second part of statistical analysis.

Table 6. Statistical analysis.

Statistical Analysis				
Type - Gauge	Average	Variation	Standard Deviation	[Average ± σ]
T - 32	1.7598	0.0035	0.0588	[1.8186;1.7011]
T - 26	1.3436	0.0007	0.0261	[1.3697;1.3175]
T - 24	1.2880	0.0002	0.0123	[1.3003;1.2757]
E - 32	2.0993	0.0202	0.1423	[2.2416;1.9570]
K - 32	1.9123	0.0085	0.0922	[2.0270;1.7841]

IV. CONCLUSION

It was shown a development and use of a piece of equipment to small alloy metallic welding. This equipment can be easily operated and was developed to use exactly the necessary amount of energy to weld each metallic alloy and gauge of thermocouple. The test objects had a great quality in the analysis.

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