Developed of a Cartesian CNC System for Plasma Metal Sheet Cutting

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***Abstract*— A Cartesian system was one of the first mechanism used to carried out a kinematical model, which characterise its advantages and restrictions in order to enhance different motions for industrial applications. This paper describes one of the most used applications in the industry called Computerized Numerical Control (CNC) used as a machine automated tool. The project development is divided into two large structures, the mechanical system and the electronic system. The 3 DOF automated CNC machine is driven with transmission by tooth-belt and spindle attached with to one manual plasma cutting equipment; with the constraint of generation of high index of electromagnetic interference due to its configuration of arc start by high frequency. It limitations was solved and highly decrease thanks to the implementation of complementary electronic designs such as filters, opto-couplers and a physical grounded. The execution of G-codes is compliances with established technical standards ensuring a uniform fluid-arc and safe behaviour.**

Keywords—CNC, Plasma Cutter, Industrial Finish, Electromagnetic Interference.

I. INTRODUCTION

The implementation of new technologies in the development of the industry in developing countries (being the case of Latin America) and how it impacts efficiently in production: filling gaps in the production chain, generating greater volume and quality in the final result for the development and implementation of computerized numerical control systems; In addition to raising different types of automation, automatic process control, processing of electronic data, automation called as fixed, computerized numerical control or automation called as flexible. [1]. Computerized numerical control was taken as an automation approach due to the purpose of the development of this project.

It should be emphasized that computerized numerical control has an endless number of applications in industrial, semi-industrial, academic and related platforms and processes, in which the need to improve a product and its production, assembly, mechanized or distribution for it opted for industrial automation, that's where the term "industrial robotics" comes off. Over time, industrial robotics has been used for processes of machining and transformation of raw materials generating a higher level of productivity, due to the "flexibility of the process" [2]. This term has been assigned for industrial processes or automated production, which have been integrating technology and modern systems, replacing human labour with robotics, generating greater productivity, precision, availability and quality in the transformation of processes, in addition to acquiring a large workspace and low production cost, industrial robots are increasingly used for machining tasks, such as die-cast, cutting, debarring, grinding and polishing processes and for 3D modelling [3].

Giving an approach to the machining of metallic material, specifically plates or sheets, by cutting automated by different technologies such as laser, plasma, gas by oxy-fuel, water jet and some others, which are basically chemical and / or physical processes elaborated.

The generated routes are in a format called G-Code or Gerber, whose purpose is to position the cutting or action tool [4]. As for CAM systems "computer-aided manufacturing", are those that allow transforming the design process either in 3D for a plastic printer, or for a CNC system of five degrees of freedom, or 2D for a Cartesian system of cutting or roughing, as a disadvantage has limitations in terms of the trajectories generated as it depends on the type of material to be processed, the workspace and the complexity of the design [5].

Since the implementation of computerized numerical control machine tools in 1952, they have undergone significant changes and improvements, including their applications, communication protocols and control up to the standards that govern and structure a CNC system, among the standards found in the standard (ISO 6983) which was the pioneer to structure from the manufacturing, generation of code, trajectories and transformation CAD "Computer Aided Design" -CAM "Computer Assisted Manufacturing" to -CAPP "Computer-Assisted Process Planning", but like all technology that advances to big steps this normative was staying short generating a "bottle neck" and limiting the interoperability in the manufacture CNC, to counterattack and to be able to continue advancing it began to generate the norm (ISO 14649) also known as STEP-NC of constant updating, which raises and gives the possibility to provide in detail the information about the design of components, the planning of the processes and the different machining strategies for the manufacture of parts of the current and next generations of intelligent CNC [6].

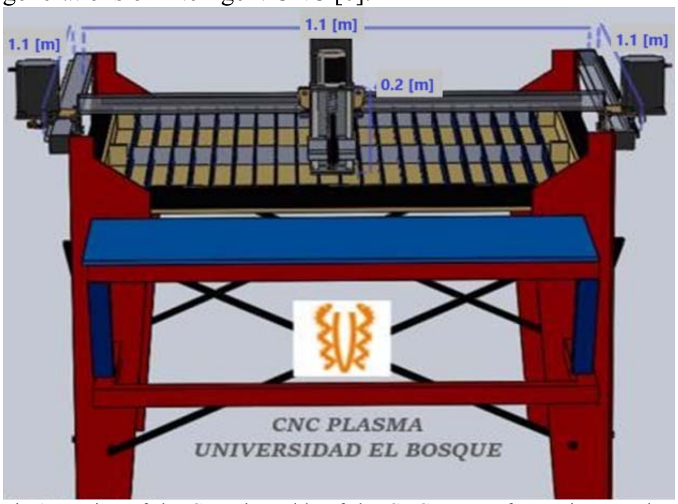

Fig.1: Design of the Cartesian table of the CNC system for cutting metal sheet by plasma.

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For the process of manufacturing a Cartesian system for an industrial environment, we must take into account the mechanisms or methodologies that have been developed throughout the process, improving and studying in order to improve all the processes of research, design , implementation and sustainability among which are the approaches (KM and Lean), they present study tools and process techniques to interpret and improve production in industrial developments and in this case, by implementing automated processes through computerized numerical control. See figure 1.
Some techniques of abstraction that are implemented are the analysis of the following variables for any process, initializing a term called "flow of knowledge" [7], which allows to understand the business logic seen from a bloke or group, "Bicheno and Holweg identified 7 types of services waste in 2009 "[8] starting with the delay in the process, the duplication of unnecessary actions, movements that are not indispensable, lack of communication, error in service transactions among others, which allow me determine errors and losses of any kind, from the production line to the final service in the process, in order to determine actions and response to counteract and thus improve the same [9].

II. ELECTROMAGNETIC DISTURBANCES IN MACHINE TOOL OF COMPUTERIZED NUMERICAL CONTROL

In Plasma Arc Cutting "plasma arc cutting 'PAC'" is an unconventional machining process capable of transforming a variety of electrically conductive materials was developed approximately thirty-five years ago, uses a high-energy torrent of ionized gas disassociated plasma as a source of heat, however, presents drawbacks when integrated with a computerized numerical control system. [10], [11]
To reach the energy state of the plasma material, it is necessary to heat a gas at a high temperature, which is electrically conductive, now to integrate the cut an electric arc is generated between an electrode and the base metal, 'highly ionized gas', the arc is strangled in the terminal or nozzle, giving rise to the effect of "blowing" required to displace the molten metal [12].
There are three types of technologies in terms of the beginning of the arc and how it develops in the interior of the plasma cutting unit, starting with the start of "recoil, Blowback", is a start of mechanical type, uses the pressure supplied in order to force a small piston inside the head of the torch to go backwards, to create the arc, in the inner cavity of the consumable, ionizing the air to generate a small plasma flame, maintaining the pilot arc which generates a level of interference With respect to the other electronic units, another cheap option and more used in manual cutting is the high frequency start "HF". Generates high frequency high voltage to ionize the air, also requires a special circuit to generate the pilot arc although the most economical equipment with this technology does not have it, what generates that you have to touch the consumable with the work material to start. Finally, the most expensive but convenient option for an integrated system with CNC, the start by an inductor circuit, uses a high voltage, but a lower current and frequency to ionize the air, which generates a fast start and with a minimal interference [13].

III. MECHANICAL CONFIGURATIONS OF CARTESIAN SYSTEM

There are different types of configurations for the mechanical transmission of a three-degree-of-freedom system called "PPP". This depends on the type of load and work performed by the robot, since moving the axes from one end to the other accelerates.
On the other hand is circular and linear output is allowed by the screw or end rack, presents little slack but generates drawbacks with friction, finally a linear entry and exit circular, It is generated by an articulated bar or a rack, it has a medium clearance but generates problems with control and friction [14]. In this case, belt drive was used because it did not require large torque and medium speed.

IV. DESIGN AND OPERATIONS CHARACTERISTICS

We can observe the integration of all the electronic systems that make up the mental plasma cutting system which allow the correct functioning of the same and helping to execute each of the proposed actions in the project, the system in general has a controller, a power supply, a plasma system activation relay, push buttons, power drivers and HF filters showing in figure 2.

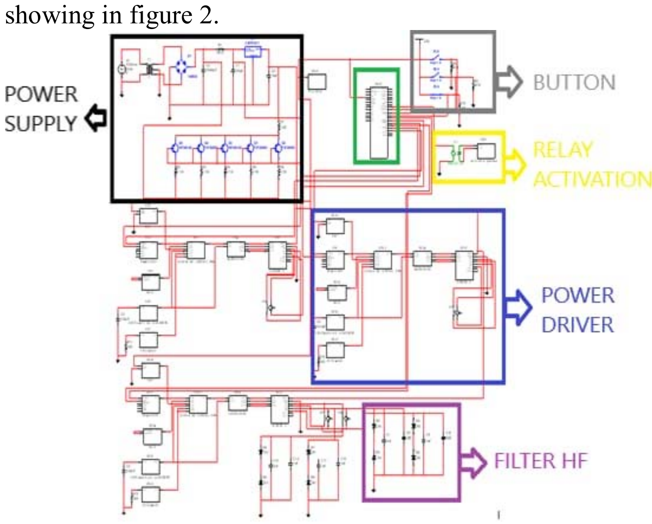

Fig. 2: Schematic of the electronic system for the plasma cutting system.

The system has a source of 12 volts at 50 amps that allow the feeding of the entire system. Continuing with the schematic of the plasma cutting system we will observe the power part in this case the M880A driver was used, which generates a maximum current of 4 amps. For this we will illustrate that this compound is internally the circuit in order to better understand its operation. The circuit has a DAC which converts an analogue signal into digital, also composed of a translator that allows interpreting and processing the PWM signal (Step, DIR); when its respective interpretation is carried out it is passed to the GATEDRIVER stage which it works as a demultiplexer allowing that with an input of data X, different PWM control signals are generated.
When all these signals are present, they are passed through a bridge H which is conformed by transistors and diodes for their respective stage of power, these signals are sent to the stepper motors for the correct positioning and operation of the same.

Then we will see that the schematic is composed of an Arduino Uno which is an acquisition card composed of a microcontroller in this case an ATmega328p and a development environment that facilitates the development of different projects since it is open source.
When arduino Uno, has a value of 0 volts analogue which is interpreted in digital form as B0000000000 (0) and the value of 5V analogue in digital form as B1111111111 (1023), this means that the analogue value is between 0 and 1023, that is, sumo 1 in binary every 4.883 mV. It should also be noted that it has a resolution of 10 bits, that is, values between 0 and 1023.
The Arduino has 2 serial communication ports for data transmission in this case the USART which is a serial port of the microcontrollers in this case pin 0 is RX and pin 1 is TX, besides this has a port serial is known as UART which allows to handle the interruptions of the devices (Computer) connected to it and transform the data into a type of parallel format, transmitting to the system bus in serial format so that they can be received and sent from the microcontroller to the computer system, in this case it handled a speed of 115200 baud per second.
The system also has limit switches that allow sending an instruction to the controller when they are pressed, these switches are used when the cutting machine will pass the established limits. Also implemented a relay system which allows the activation of the plasma torch electronically in this case the relay is conformed by a transistor which allows the activation by means of a photo-resistor allowing to protect the electronic part of it, when it is activated with a signal of 5 volts generated by the Arduino in this case the signal leaves pin11 allows to open and close the circuit of the torch when this is necessary.

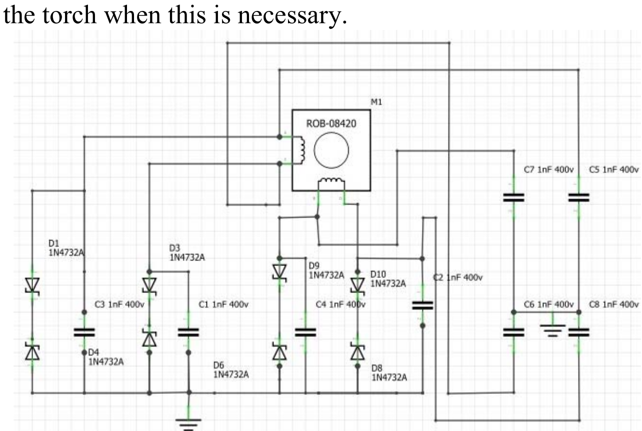

Fig. 3: Schematic of the HF filter for electromagnetic noise suppression.

Figure 3 showing an electronic design was made that includes Zener diodes and capacitors in a noise suppression and cleaning configuration in each phase of the motor, generating a cleaner and safer interaction between the control system, the power system and the actuators.

The physical design and prototype can be evidenced in figure 4, which the dimensions of the different axes are evident: for the X axis 1.20 [m], for the Y axis 1.20 [m] and for the Z axis 0.2 [m]. It should be noted that the workspace on axes 'X' and 'Y' are 1m, but for structural reasons the measures in the different axes stand out a bit, this in order to guarantee the work space proposed in the requirements of a total of 1x1 [m] on the axes 'X' and 'Y'.


Fig. 4: Physical structure of the CNC prototype for cutting metal sheet by plasma.

V. Electromagnetic Configuration to improve the integration of a system (PAC) with a CNC System

As mentioned previously when performing the integration of a system (PAC) "plasma arc cutting" with a (CNC) "computerized numerical control" system generates interruptions and problems due to electromagnetic interference, which produces parasitic signals in the control (PWM) due to the on and off, large amount of current and voltages in the plasma equipment give rise to EMI, also known as radio frequency interference (RFI) these signals can stop the manufacturing process to generate path errors [15] . To mitigate this noise, several technologies can be used, including the use of filters, and techniques such as chaotic frequency modulation present the same principle as the simple modulation technique, the dispersion in the case of the control signal for the system. Cartesian frequency (PWM) is chaotic or the energy will be distributed with a lower amplitude, so the EMI is reduced [16]. EMI filters in addition to preventing noise from entering the system, allows to eradicate the noise made by the system to prevent it from dispersing throughout the circuit, these filters have various configurations such as' step capacitors', 'L circuits',' PI circuits 'and circuits' T' [17]. In addition to this, other techniques can be implemented in terms of wiring and grounding the entire system as this generates stability by filtering high power or line signals with an amplitude of 120 [V] and low power and control signals. electronic amplitude from 5 to 12 [V], should be implemented a physical ground system generating a return path for the conductive current at a low potential difference, according to the 'national electrical code' is to introduce a conductive rod generally of copper to a specific depth and terrain, and from there draw the ground connection of the whole system [18]. Once the electromagnetic interference has been eradicated, it is possible to control the adequate levels of security for the user, which is why several techniques have been implemented to lower the levels of contamination due to the plasma cutting process, regardless of whether a method of manual or automated thermal cutting with a machine (CNC) will face the following environmental problems which characterize the plasma cutting process, 'toxic emissions of gases harmful to the health of the operator', 'emission of ultraviolet rays that can generate burns ', among others, this is why it is necessary to reduce the level of pollution to the maximum in order to generate a good environment of occupational and health safety, for this the implementation of a water bed system on the lower surface of the workspace of the machine (CNC), which will contain a wide level of contamination in addition to generating a cleaner and safer cut [19].

VI. DIFFERENT TYPES OF EQUIPMENT FOR THE CUTTING OF METALLIC MATERIAL

In the current market we can find different types of cutting technology, whether for sheet metal, profiles or pipes. Among those who use the forms of cutting by abrasion, either the puncture and the water jet, and those that implement thermal methods such as laser, oxy-fuel or plasma, as for the most implemented we have the water jet cutting, ideal for machining materials that can be affected by heat. Cutting by oxy-fuel, the initial investment is low, this technology is perfect for carbon steel of considerable thickness, but it is not ideal for stainless steel or aluminium, besides presenting advantages in its portability as it does not include a special electrical connection. On the other hand, we have plasma cutting presents benefits in the cost-benefit ratio compared to laser cutting in thin and thick thicknesses, it is suitable from 5 [mm] and above 30 [mm] which better it is supported, you can make cuts in ferrous and non-ferrous materials, painted, mesh or oxidized. Finally, the CO2 laser cutting which allows a more precise cutting ratio, especially with a thin thickness and making small holes, it is suitable for thicknesses between 5 mm and 30 mm [20].

VII. ROBOT KINEMATICS FOR CNC PRISMATIC COMFIGURATION

Modeling the Cartesian system through the Denavit-Hartenberg Methodology:

For the elaboration of this model, the origin of the coordinate systems of each of the links of the Cartesian system is defined. The axis i is denoted as the connection axis of the elements i-1 to i; to define the framework of element i. Which will allow the correct development of the Denavit-Hartenberg methodology allowing to establish the location of each of the reference systems of the links of the robotic system.

The methodology for direct kinematics based on the Denavit-Hartenberg system is developed in 9 steps, which allow the systematic procedure to be interpreted for the kinematic structure, in this case the Cartesian robot, for which the process is described below:

1. Setup the axes directions Z_0, Z_1, …Z_{n-1}.
2. Determine the origin O_0 of the coordinate system of the Z_0 axis.
3. Define the origin Oi at the junction of Z_i with the common normal between the Z_{i-1} and Z_i axes.
4. Choose the Xi axis along the normal common to the Z_{i-1} and Z_i axes with joint direction i + 1.
5. Determine the Y_i axis, allowing the rule of the right hand to be fulfilled with X_i.
6. Choose the coordinate system of the work tool where X_n is normal to Z_{n-1}.
7. For i=1, 2, …n elaborate a table with the criteria of a_i, d_i, α_i, Θ_i.
8. Having these parameters, homogeneous transformation matrices are elaborated and calculated, which will allow to analyze and interpret the robot's kinematics correctly.
9. When the parameters are obtained, the model of the direct kinematics can be represented for the position and orientation of the tool based on the previously established coordinate system [21]

Figure 5 establishes the coordinate systems for the Cartesian robot PPP from the Denavit-Hartenberg algorithm.

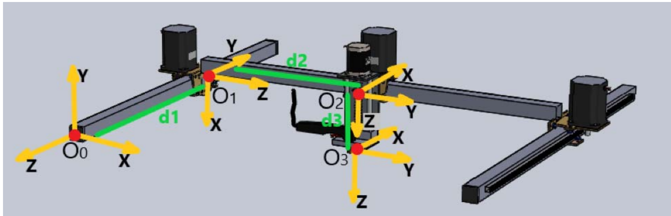

Fig. 5: CAD model of the Cartesian robot (PPP), Denavit-Hartenberg methodology configuration

When determining the elements, the position and orientation of each one of the reference frames previously established, we proceed to assign each of the following parameters:

- αi: This is the angle between the Z_{i-1} and Z_i axes around the X_i axis, which can be positive when the rotation is done clockwise, for each of the links based on the reference that was established in this case the Z axis.
- Θi: In this case, it is the angle between the X_{i-1} and X_i axes around Z_{i-1}, which can be positive when the rotation is done in a clockwise direction, based on the previously established reference for the development of the Denavit-Hartenberg methodology.
- di: This is the coordinate or starting point of Oi along Z_{i-1} for each of the links.
- a: It is the distance between O_i and O_{i1} along X_{n-1} for each one of the links which allow to complete the Denavit-Hartenberg parameters to correctly complete their development. [21]

In accordance with the previous parameters and taking into account figure 5 are the Denavit-Hartenberg parameters that represent the robot's kinematics:

Table 1: Results of Denavit-Hartenberg parameters.

Link	α_i	θ_i	d_i	a_i
1	90	90	d1	0
2	90	-90	d2	0
3	0	0	d3	0

$$\begin{bmatrix} cos\theta_i & cos\alpha_i\ sin\theta_i & sin\ sin\theta_i & a_i\ cos\theta_i \\ sin\theta_i & cos\alpha_i\ cos\theta_i & -sin\alpha_i\ sin\theta_i & a_i\ sin\theta_i \\ 0 & sin\theta_i & cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$A_1^0 = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$A_2^1 = \begin{bmatrix} 0 & 0 & -1 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$A_3^2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$T = A_1^0\, A_2^1\, A_3^2 \quad (5)$$

$$T = \begin{bmatrix} 0 & 1 & 0 & d2 \\ 0 & 0 & 1 & -d3 \\ 1 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

VIII. ROBOT KINEMATICS CNC PRISMATIC CONFIGURATION

An interpretation of the mechanical structure of the Cartesian robot is made. Which allows to analyse better the dynamic behaviour to relate the mechanical movement and the causes or forces that intervene in it. There are different methodologies that help to make the mathematical model of the dynamics of the Cartesian system, in this case the Lagrange - Euler method will be used since by means of this dynamic model it allows me to obtain terms of energies and works.

This model analyses the mechanical system from the energy point of view, with the aim of determining different coordinates that allow the formulation of Lagrange-Euler to be developed for the dynamic development of the prismatic configuration, then we will find the math expression [21], [22]:

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}} - \frac{\partial L}{\partial q} = \tau \quad (7)$$

$$\mathrm{L}(\mathrm{q}, \dot{q}) = \mathrm{K}(\mathrm{q}, \dot{q}) - \mathrm{U}(\mathrm{q}) \quad (8)$$

Where:

L= It represents the Lagrange which is the difference between the potential energy and the kinetic energy

U= Potential energy of the Cartesian robot

K= kinetic energy of the Cartesian robot

Based on the configuration in figure 5, the kinetic and potential energy equations were calculated in each of the established reference points, when these values are already available, the calculation of the Euler-Lagrange motion equation is applied to obtain the matrix that represents the dynamics of the robot:

$$K_1 = \frac{1}{2}(m_1 + m_2)\dot{q_1}^2 \quad (9)$$

$$U_1 = 0 \quad (10)$$

$$K_2 = \frac{1}{2}m_2\dot{q}_3{}^2 \quad (11)$$

$$U_2 = m_2 g q_2 \quad (12)$$

$$\begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & (m_1 + m_2)\ddot{q_1} \\ 0 & m_2 g & 0 \\ m_2\ddot{q_3} & 0 & 0 \end{bmatrix} \quad (13)$$

IX. DESCUTIONS AND CONCLUSIONS

Throughout the development of the CNC prototype for cutting metal sheet by plasma, several problems were generated in the integration of subsystems, specifically in the subsystem of control, the mechanical subsystem and subsystem of cutting, although in the tests carried out individually to each subsystem the expected results were found, for example, when testing the control subsystem, it was evidenced by the measurements made with an oscilloscope, the signals of passage and direction, thus finding the relation of pulse width and the final movement in the actuator. bipolar. On the other hand, when running tests on the Cartesian mechanism of three degrees of freedom, the expected results were found in the path, smoothness and maximum travel variables, fulfilling the main objectives of guaranteeing a work space of 1 X 1 [m] as well as providing thanks to the selected transmission system, by belt, a speed of between 1000 and 2500 [mm/ (min]) for the axes [X, Y] and for the axle [Z] between 500 and 1000 [mm/ (min]) suitable for cutting metal material by plasma. Finally, when testing the plasma cutting equipment once implemented the adjustment to obtain the pilot arc and with a manual operation, behaved well reaching to cut sheets up to 8 [mm] thick, with a configuration of 40 [A] and 40 pounds of air pressure.

Although all these isolated tests behaved as expected, the problem was evidenced by the integration to generate the global system that would be in charge of automating the entire plasma cutting process, which includes trajectory visualization, software movement control In the interface, verification of errors and emergency stops, in addition to the activation of plasma cutting equipment and actuators using G & M codes, the problem lies in the electromagnetic interference generated by the cutting equipment due to the start of the pilot arc by high frequency. When using low-end equipment is predisposed to these circumstances as they are not designed for integration by CNC, but on the contrary their specific purpose is for manual cutting. The use of this equipment was assigned due to its low cost compared to others in the market with different and better type of technology at the beginning of the arc, such as recoil.

In order to attack the problem and give it a solution, a series of consultations were made, evidenced and documented in the state of the art, which allowed us to generate a stage of adjustments and improvements, in each stage of the development forming a set with everything necessary for the objective For example, for all the single-phase electrical installation to 120 [V] it was necessary to investigate in installation manuals, technical standards of electrical installations, authorized installation codes, calibers needed to carry out the wiring, manufacturers, articles, magazines, publications, types of protections and grounding allowing to collect a great knowledge and a repository to be based on the actions that were executed throughout the project, helping to reduce electromagnetic interference and improve the global system. On the other hand following the research methodology could identify another problem with the characteristics of plasma cutting equipment a Chinese team called 'CUT 50', it was generated modifications in order to provide a good performance in the integration of all subsystems , was to draw a conductor of the mass to the end point of the torch to close the circuit at all times and thus create a constant pilot arc without having to be touching the material to be cut, also integrate a coupled opto relay to isolate potentials different and noises. A Faraday cage was also a key point of the implementation because, as has been said on repeated occasions, we fight against electromagnetic noise and through this component we isolate the control system of parasitic signals that can break into the cutting tasks.

Taking into account that a manual plasma cutting equipment with high frequency pilot arc start generates a high level of electromagnetic interference in the environment, it is not recommended to perform an integration with a computerized numerical control system since it generates problems with the central processing unit, electronic circuits, power modules, actuators and sensors degrading and making it impossible to control the Cartesian platform. However, by means of adjustments and complementary electronic designs, electromagnetic interference can be greatly reduced so that both the cutting system and the control system work in a coherent and continuous manner. The adjustments made through filters to the electronic system, generation of the pilot arc to the cutting equipment (without touching the material), the installation and correct connection of a physical earth in this project generated a uniform, solid, fluid and safe behaviour in the Court interaction. Another important factor that allowed the interaction of efficient form in the cut by plasma is that the adequate speed of displacement was generated so that a cut of quality was executed, this thanks to the success of the design based on systems of transmission by toothed belt in the axes of greater travel. Finally, the creation and optimization of G & M code for the plasma cutting process guarantee a good machining and allows taking better advantage of the configuration of air supply and current in the cutting equipment.

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