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Improvement in the packaging process of chocolate bars by automating the process with LabVIEW in Peru

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Abstract– This research describes the design and simulation of a pilot plant applied to the packaging of chocolate bars, where various instrumentation equipment is used for the measurement of physical variables such as temperature, flow and level, which interact each other in the 3 threads that help in the automation of the equipment that is developed according to the current need of SMEs in Peru.

Keywords-- LabVIEW; Chocolate; Automation; Pilot plant.

I. Introduction

Peru being one of the largest cocoa producers in the world (see table 1), the importance of taking advantage of this opportunity and developing processes that allow the use of this raw material arises [1]. In addition, it is estimated that in Peru there are 60% of the world's cocoa varieties, originating from the Caribbean, Central America and Ecuador [2].

TABLE I
Exports of cocoa beans in thousands of tons

Exporters	2016/17	2017/18	2018/19	2019/20
Ivory Coast	1562	1530	1567	1786
Ghana	611	525	649	516
Ecuador	285	288	314	303
Cameroon	236	178	273	336
Belgium	97	114	168	203
Netherlands	222	110	193	147
Malaysia	90	104	109	71
Peru	78	66	64	52

In 2020, US$ 273.4 million in cocoa products and derivatives were exported, having registered a decrease of 7.1% compared to 2019, due to the effects of COVID-19, which has limited sales, especially cocoa butter, cocoa beans and chocolate [3], as of August, a slight recovery in prices was observed to the extent that the world economy tends to improve and the countries to relax their confinement measures, hence, the price showed an increase to a value of US$ 2,358 and US$ 2,407 per ton in the months of November and December 2020, respectively.

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During the period January-March 2021, international prices have experienced a recovery (see Fig. 1) to reach US$ 2,462 per ton in March [4]. It is estimated that the value received by producers per ton of cocoa sold is equivalent to 6.6% of what the final consumer pays for cocoa-based products. Grain traders and shippers receive 6.3%, primary processors and milling receive 7.6%, manufacturing (basically chocolate) receive 35.2%, and retail trade receives 44.2% [5].

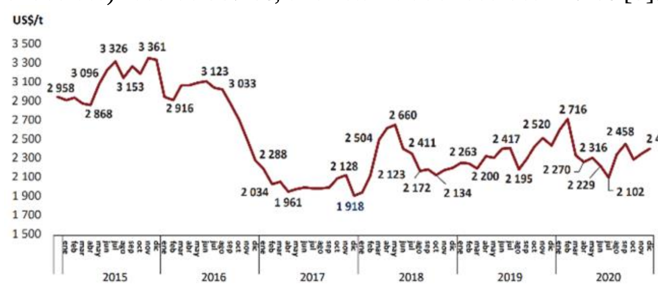

Fig. 1 Monthly international price of cocoa beans [3]

With the evolution of economic thought, Peruvian cocoa producers work on the pre-processing of their raw materials to obtain better profits by exporting cocoa in different derivatives such as butter, liquor, paste and chocolate [6]. The exports of cocoa beans and chocolate have a big difference since Peru exports rawer materials than products with added value, such as chocolates or other food preparations that contain cocoa [7].

TABLE II
Exports of cocoa beans and chocolate

Customs descriptions	Product	Total records	Total Kg	US$/kg
1801001900	Raw cocoa, whole o broken	1022	52,425,6662	2.462
1806900000	Chocolate and food preparations with cocoa	4	623	8.363

Despite the fact that Peru is one of the main exporters of fine and aroma cocoa, the production of chocolates in Peru is low, which is why these products are usually imported, creating a negative trade balance (exports minus imports) [7]. One of the biggest problems in Peru is that its national industry does not have the installed capacity to cover all the management. In addition, the inexperience of the operators can cause the chocolate to burn, to become very hot and lose its flavor, to cool and harden, making it difficult to make it liquid again or it can also cause the product to spill on the sieve due to because there is no alert of the exact level [8]. At the end of 2019, the chocolate industry only used half of its capacity using poor quality grains due to the lack of processes [6].

Small and medium-sized industries (SMEs) are at a disadvantage compared to large companies, due to globalization and the updating of technologies, which leads SMEs to seek increased productivity. New technologies and specifically automation increase efficiency and productivity in industrial processes [9]. Although it is true that there is also fully automated technology on the market, this is not convenient for the project, since it requires a strong economic investment that would lead to an increase in the company's debt levels and fixed costs. Although semi-automated technology also requires a large investment, it is consistent with the required production levels [10].

For this reason, this research project seeks to implement and simulate in LabVIEW a pilot plant that is in charge of the chocolate packaging stage using current technology that can reduce the high costs of commonly used equipment and standardize the configuration for monitoring through applications that allow it, using interfaces that achieve the same results.

II. DESIGN

For the development of the design, it will be divided into two stages: physical and software, where the instruments that we will use for the development of the pilot plant will be explained in detail. In addition, Fig. 2 shows the block diagram of the system.

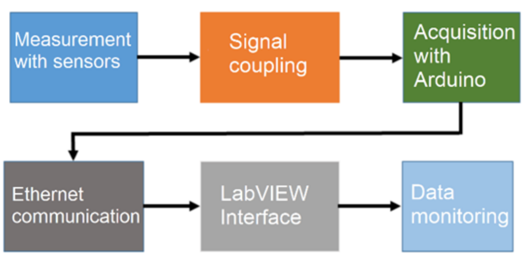

Fig. 2 Block diagram of the system processes [11]

A. *Hadware design*

Regarding the process that is carried out, it can be observed in the diagram (see Fig. 3) that sensors and actuators have been considered that have the necessary characteristics for the operation of the pilot plant, the function of each element will be explained later.

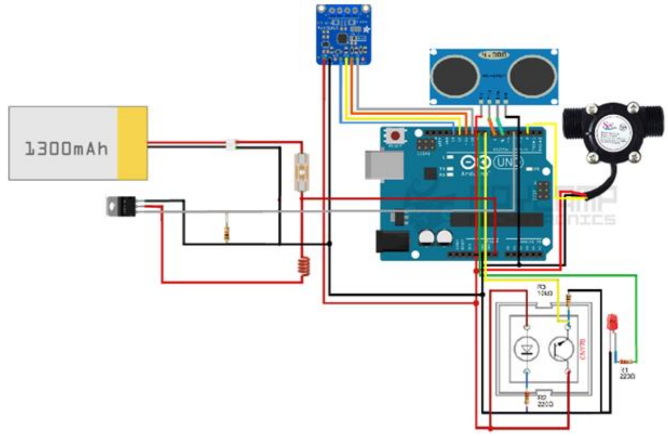

Fig. 3 General scheme of the system

1) Tempering stage: In this stage, the temperature of the chocolate is reduced so that the crystallization is stable, by means of a heating and cooling system, but taking care that it does not exceed 32º C [12]. In addition, it consists of a main structure, which is the tank, which has two layers, the internal one, which is where the chocolate is stored and the external one, through which the liquid circulates to cool the content (see Fig. 4).

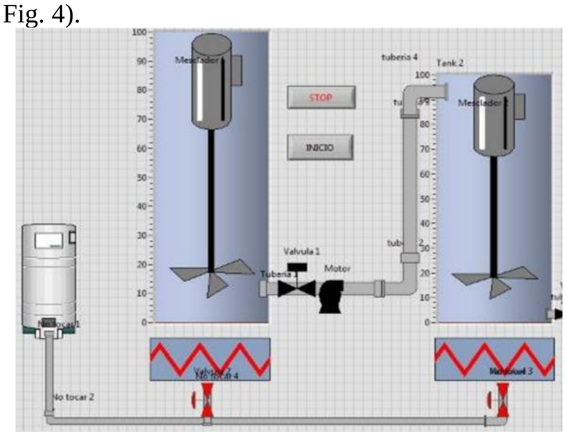

Fig. 4 Modeling of the temperature process

• Chocolate tank: We dimension the tank that will be used to mix the ingredients. For this, the capacity requirement of 78.3 kg is taken into account. In order to carry out a correct dimensioning of this element, it is necessary to know the density of the chocolate in liquid, for chocolate that contains 70% cocoa, the density that appears in equation (1) is assumed.

$$\rho = 1246 \left[\frac{kg}{m^3} \right] \tag{1}$$

Substituting the known capacity and density values in equation (2), the volume that appears in equation (3) is obtained as a result.

$$V = \frac{m}{\rho} \tag{2}$$

$$V_{\tan} = \frac{78.3[kg]}{1246\left[\frac{kg}{m^3}\right]} = 0.062841m^3 = 62841cm^3 \quad (3)$$

Obtaining the value of equation (3) proceeds to calculate the dimensions of the tank for which the volume formula of a cylinder that appears in equation (4) is used. Where H is the height of the cylinder and r is the radius of the base.

$$V_{cilin} = \pi r^2 h \quad (4)$$

To obtain the estimated dimensions of the tank, a diameter of 40 cm is assumed at the base of the tank (see Fig. 5). Then we replace its value in equation (4), this diameter is selected for a uniform distribution in the tank [13] finally a comparison is made with equation (3) to find h.

$$62841cm^3 = \pi\left(20cm\right)^2 h \quad (5)$$

$$h = 50cm$$

Fig. 5 Tank with chocolate inlet and outlet

• Mixer for chocolate: This process consists of generating a mixture that allows giving texture, flavor and aroma to chocolate, mixing cocoa butter in different percentages.

By convention, a mixer with a ½ HP motor will be used for the case of a pilot plant. Also, when considering the size of the tank with an internal diameter of 40 cm, the ideal mixer measurement marked fin to fin would be approximately 30 - 35 cm; thus giving space so that it can intensify and redirect the temperature to all the chocolate evenly.

• Chocolate extractor pump: This pump will work with a ½” inlet and outlet pipe for generic use in the pilot plant, in addition to having a fixed pressure gauge for visual passage check.

• Solenoid valve: A common ½” 12 VDC solenoid valve will be used (see Fig. 6), which will fulfill the function of opening the passage of the chocolate at the inlet of the tank until it reaches the height predetermined by the control and is automatically closed again. It is the device that executes the regulation action. In this case, the control sends an electrical signal that "turns on" the solenoid valve to allow the passage of the chocolate [14]. The sensor by perceiving a flow by its blades, transforms them into a train of pulses which is interpreted in terms of frequency by the arduine controller and then by means of equation (7) which is the conversion equation "pulse-flow". It is possible to obtain the flow that passes through the sensor. Where 7.5 is a conversion factor k which is provided by the manufacturer for this fluxometer.

$$f\left(Hz\right) = 7.5 \times Q\left(L/\min\right) \quad (6)$$

Fig. 6 1/2 "YF-S201 Water Flow Sensor

• Ultrasonic sensor: In the control of the level, an HC-SR04 ultrasonic sensor is used with a 5VDC feed (see Fig. 7). Which records the initial distance to the desired, and then start with the filling tank filling at the previously fixed level by sending the opening signal and closing the solenoid valve.

Fig. 7 Ultrasonic sensor

• Pt100 temperature sensor: The MAX31865 transmitter module that appears in Fig. 8 A, allows you to easily and reliably and reliable the temperature measurements of the RTD PT100 sensors (see Fig. 8 b), which is a known and used model for testing, allows us to use it in conjunction with the Arduino interface. It adapts perfectly to the process of temperature range control, and its accuracy is suitable for the process. Your body is constructed of stainless steel, suitable for direct contact with chocolate without altering the safety required in the food sector [15].

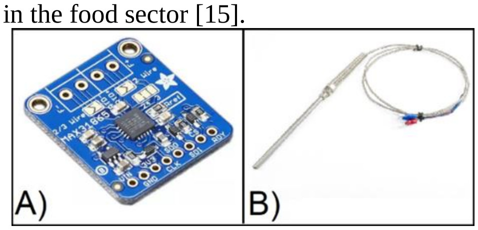

Fig. 8 a) Transmitter Max31865, B) RTD sensor PT100

• Heating system: This is the option to be used to generate the necessary heat by heating resistances (see Fig. 9), to increase the temperature of the chocolate, which also corresponds to an average power of 500 watts. The heating system is activated (drive / hot water valve drive). In hot water heating system at a temperature of 50 ° C so that this way cocoa butter does not lose its crystallization and the finished product has a soft and bright texture [16].

Fig. 9 Heating resistances

• Refrigeration: The operator is responsible for supervising that the units that come out of the molding machine correctly enter the tunnel to comply with the cooling cycle (see Fig. 10) and at the output passes through a manual demolde process and then head to the machine of packaging [1].

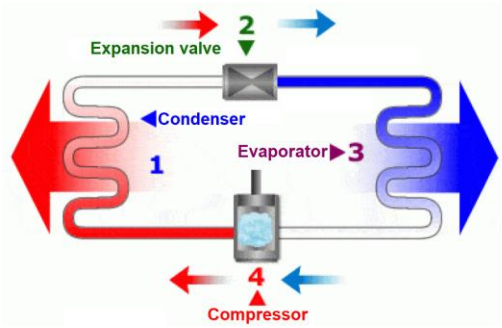

Fig. 10 Refrigeration cycle

2) Molding stage: The molding stage, consists of producing pieces with precise sizes. It will be delimited by a motion sensor, which, when detecting the chocolate mold, will activate the solenoid valve to give the chocolate step and fill the mold, these molds must be previously sanitized, and should not be broken, after Liberation molds are placed in the conveyor belt [17].

• Motion sensor: For the recognition of the mold, it is considered the use of the CNY70 sensor which is a short-range infrared sensor (see Fig. 11). Because our system does not need great distances so that the mold is detected, it was concluded that this type of sensor was the most indicated, for being low cost, easy assembly and is relatively stable when making detection [18].

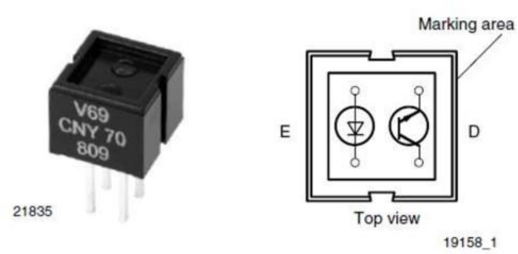

Fig. 11 CNY70 Infrared Sensor

• Chilling machine and demolded: Cooling is carried out on the machine of Fig. 12 and is a combination of heat dissipation by conduction, convection and radiation. Molds with chocolate paste, are introduced into a low temperature cooling tunnel to harden chocolate [1]. In addition, for the demolding, the machine has an internal process which is responsible for removing the mold easily, thus avoiding the chocolate crumble or break.

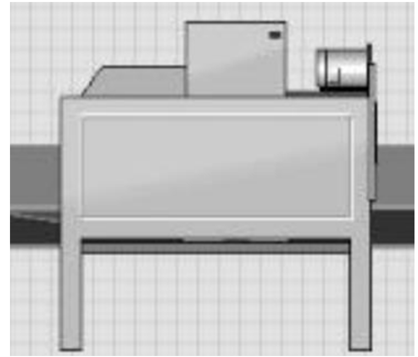

Fig. 12 Cooling and release machine

3) Packaging stage:

• Electric actuator: For the development of sealing and cutting, a mechanical equipment is necessary, and so that it can be carried out at a high speed, activated actuators will be used electrically (see Fig. 13). These actuators consist of internal motors which generate the necessary power to elongate the sealant and shear.

Fig. 13 Linear / electric actuator

• Conveyor belt: The implementation of the conveyor belt in this project aims to facilitate the process of filling chocolate in the molds, it will be developed at a higher speed since the bar is already solidified, taking into account also that it will possess plastic topes for it The bar obtains the necessary position to enter the bagging or packaging as it can be seen in Fig. 14 [19].

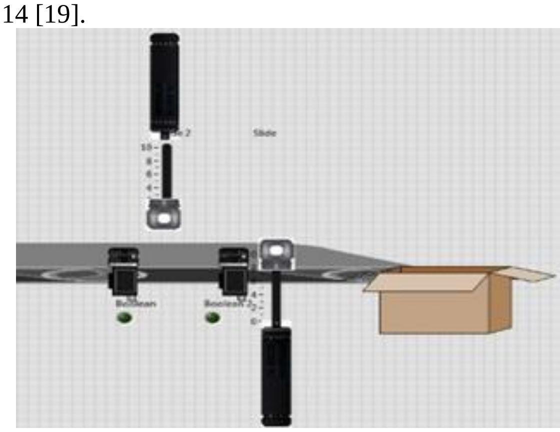

Fig. 14 Packaging stage

III. Methods and Materials

A. Arduino

Arduino is an open source electronic platform based on hardware and software, which through your pins can read entries, both analog, and digital from sensors, process that information and perform actions such as turning on or off lights, motors and send information to Internet [20].

B. LabVIEW

LabVIEW offers a graphic programming approach that allows the user to visualize each aspect of its application, including hardware configuration, measurement and debugging data, this display allows an easy hardware integration from any provider, represent a complex logic in the form of diagram, Develop data analysis algorithms and design a custom user interface [21] for these reasons we will use it to automate the pilot plant.

Before proceeding to use LabVIEW, the Toolkit Linx tool is installed, to be able to link Arduino with LabVIEW, through a firmware (sketch) that must be loaded to the board. To use the software properly, we perform the following steps.

1) Start by installing the necessary programs on a computer:

- We recommend using LabVIEW's latest version to execute the software interface.
- The LINX for LabVIEW is also required to establish communication with the Arduino for translational stage control.

2) Before executing the GUI, Arduino load with the LINX firmware:

- To do this, start LabVIEW, click on Tools >> MakerHub >> Linx >> Firmware Wizard and follow the instructions.
- At this point, the LabVIEW software interface and all the necessary controllers must be loaded and ready to be used [22].

Once the software installation is finished, we proceed to use LabVIEW, for data acquisition, measurement analysis and data presentation.

First, we can see a picture that surrounds all the elements or blocks that we will use in Fig. 15, this picture means everything that this inside will be executed in loop until a condition is met which is to run the stop Emergency (STOP) as shown in the following Fig. which in programming language is similar to the While function.

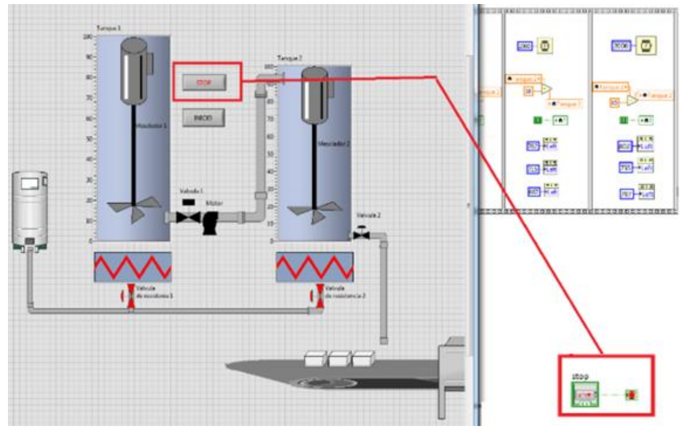

Fig. 15 Emergency stop signal

The first step so that the process is executed after the verifications to all instruments, such as having a correct power, there is no danger or object that can generate a problem at the time of the process is proceeded to start the pre-programmed sequence by means of a start button which is displayed on the operator panel and its respective diagram in the programming (see Fig. 16).

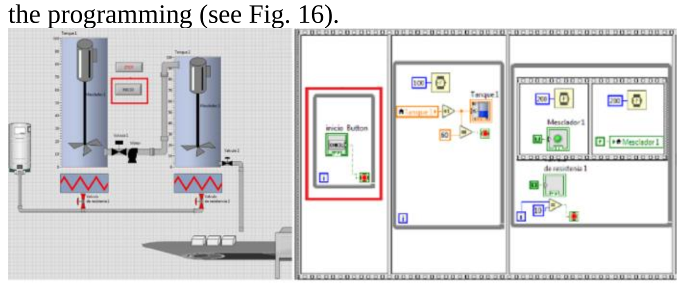

Fig. 16 Process start button

This part of the programming is dedicated to the filling of the tank as can be seen in Fig. 17. In addition, the activation of the mixer is produced, the activation of the resistance that will increase the temperature of the mixture and a control will be maintained by a PT100.

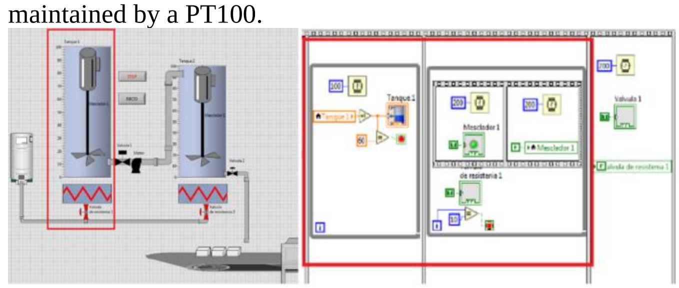

Fig. 17 Program for filling the tank

This part is responsible for the control of the motor and valve (see Fig. 18) that will be activated after a certain time in which the chocolate will be ready to enter the other tank where the cooling phase occurs.

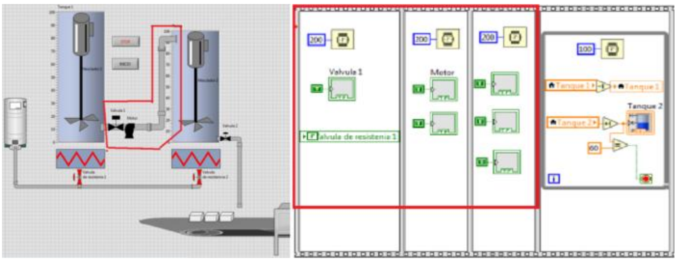

Fig. 18 Program for engine control

In this part of the program it is where the filling of the second tank is further the activation of the agitator belonging to the tank and its temperature control to achieve the temperate of chocolate as can be seen in Fig. 19.

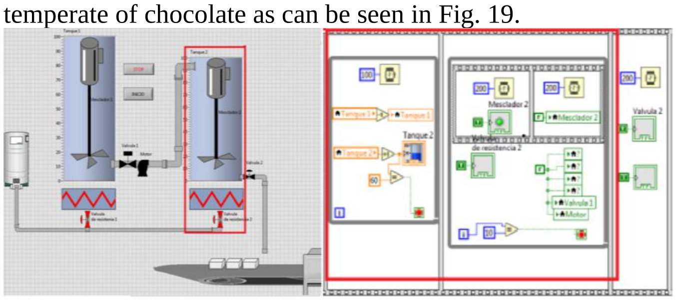

Fig. 19 Temperate chocolate program

In the next stage the molding phase of the chocolate that is already tempered is shown (see Fig. 20), in this phase the mixture is separated into small molds by means of a control at a valve that acts as a dosing system up to that reaches it cooler which will reduce the temperature of the molds at 15 ° C.

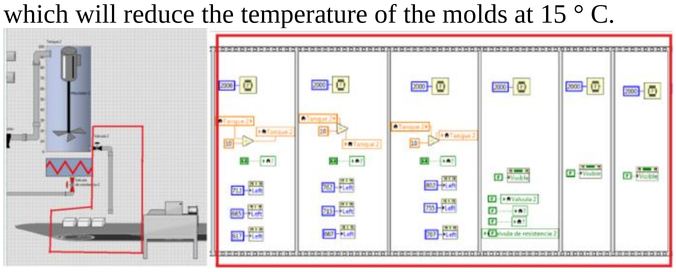

Fig. 20 Program for the molding of chocolate

In this final phase, the programming that was performed for chocolate packaging is shown in Fig. 21.

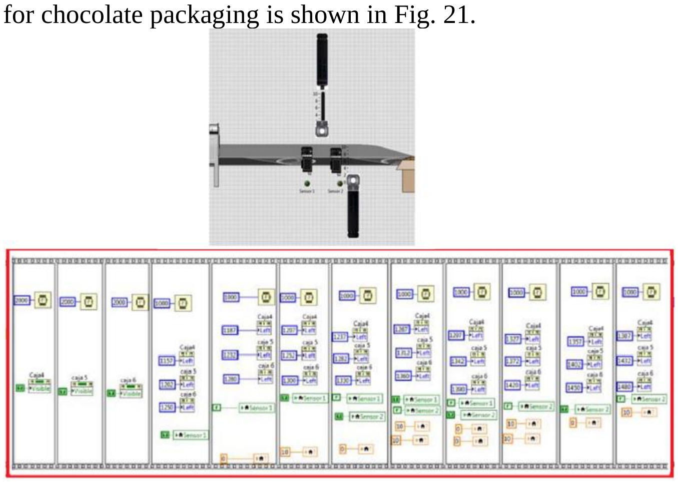

Fig. 21 Program for the packaging stage

IV. Results

LabVIEW test was performed, loading the test diagram with the HC-SR04 ultrasonic sensor that we can see in Fig. 22.

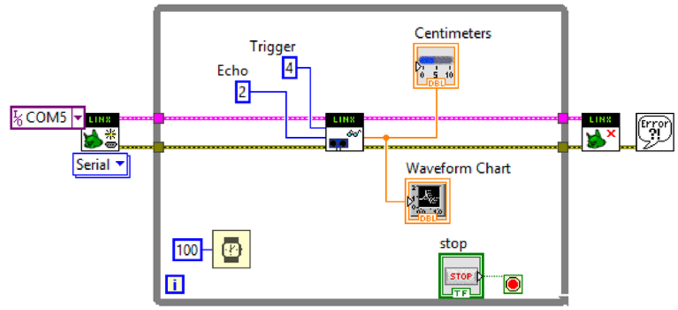

Fig. 22 Internal Program of the Ultrasonic Sensor- LabVIEW

Of the collected data, Fig. 23 is obtained, where only the values of 5, 10, 15 and 20 cm were placed, from which it can be visualized that it increases linearly and that there is no much variation when it is marked in a specific distance.

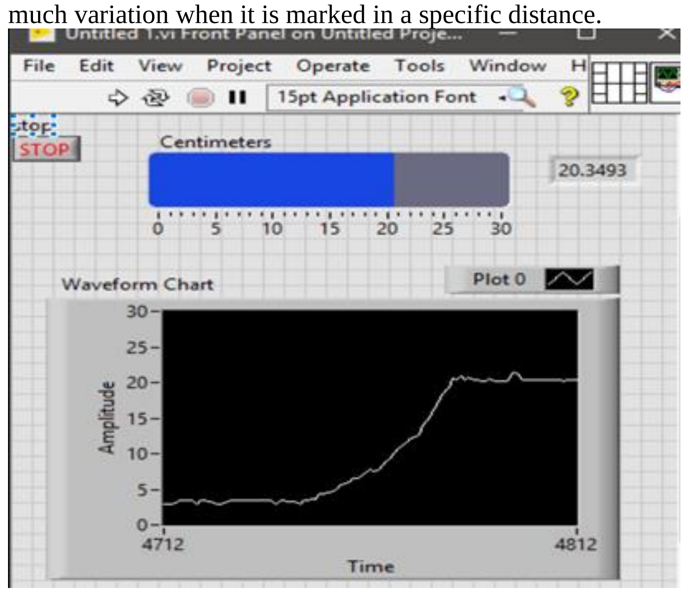

Fig. 23 Reading 2 to 20 cm

Testing was performed on LabVIEW, loading the diagram for testing with the PT100 sensor that we can see in Fig. 24.

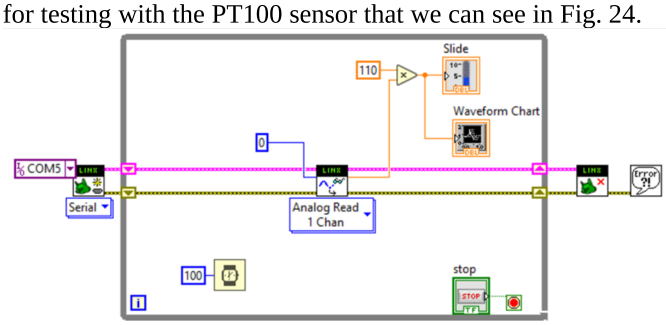

Fig. 24 Internal Sensor Program PT100 - LabVIEW

It can be observed in Fig. 25, extracted from LabVIEW software, that the PT100 sensor detects the ambient temperature and transforms it to digital data, as shown in the visual window, as the temperature increases, the graph up, and in Otherwise, low.

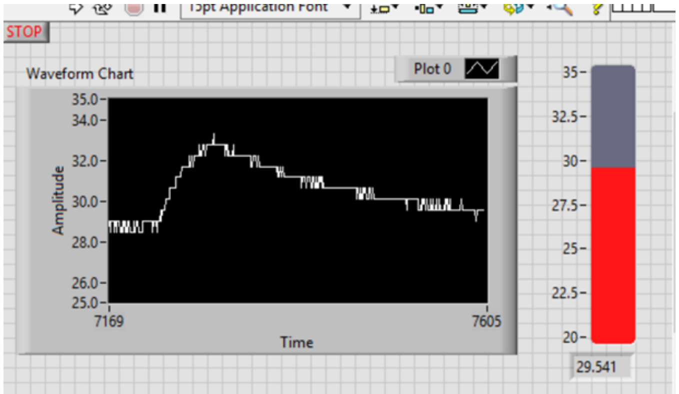

Fig. 25 Graphic result of temperature variation with PT100 – LabVIEW

The solenoid valve test was performed with visual programming in the main software - LabVIEW as can be seen in Fig. 26.

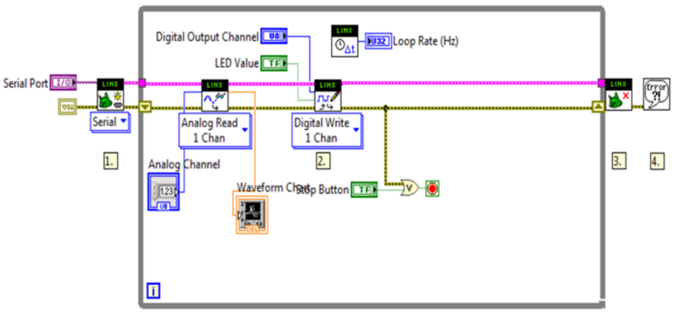

Fig. 26 Internal Program of the Sensor YF-S201B – LabVIEW

As we can see in Fig. 27, the LabVIEW is also obtained by the pulse signal, this signal is applied equation (7) and the flow that passes through the instrument is obtained.

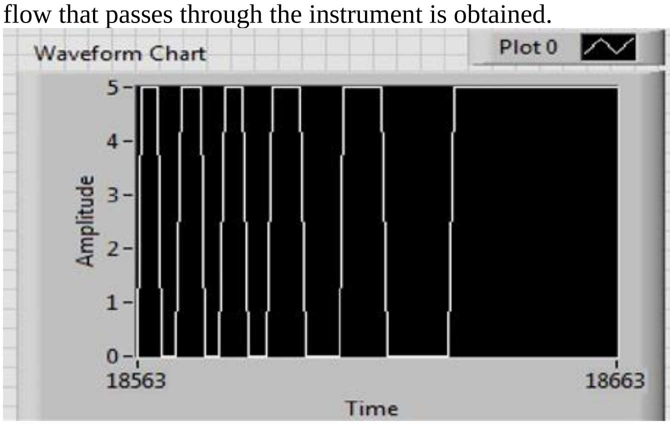

Fig. 27 Pulse graphic result from YF-S201B - LabVIEW

IV. Conclusions

For the flow measurement it is concluded that an electromagnetic principle is feasible because it does not have contact with the fluid therefore the required maintenance is less frequent which is more economical considering the time of operation.

The developed pilot plant constitutes an economically and useful automation form in relation to the manual processes carried out by the workers. In addition, the machine is easy to operate, apply maintenance, coupling and uncoupling its parts.

The pilot plant designed fulfills the demand for production in less time and with fewer human resources (1 worker, compared to 3 workers who requires the process without automation). What will allow to increase the productivity of SMEs.

V. Recommendations

In case you want to build the pilot plant, it is recommended to use an AISI 304 steel plate with the thickness of not less than 1 mm, to ensure an ideal welding process, which is not invasive for the material.

It is recommended that the team be operated by a competent person who has knowledge about the operation and maintenance of the pilot plant.

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