VOL. 15, NO. 10, MAY 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences


www.arpnjournals.com

# EXPERIMENTAL PRESSURE PLANT CONTROLLED BY PROGRAMMABLE LOGIC CONTROLLER

Faiber Robayo Betancourt, Donna Castillo González and Yeison Quiacha Muñoz
Department of Electronic Engineering, Faculty of Engineering, Surcolombiana University, Neiva, Huila, Colombia
E-Mail: faiber.robayo@usco.edu.co

## ABSTRACT

This work presents the implementation of an experimental compressed air pressure plant controlled by PLC (Programmable Logic Controller). The main contribution of this work is to provide a new tool for training in the control area and industrial instrumentation. Industrial devices such as the Micro830 PLC, a proportional valve and a pressure sensor were used for the construction of the plant. The plant model was identified by Matlab and the controller was implemented using the automatic configuration option of the PLC's IPID block. The IPID controller function showed good performance because it meets the proposed design requirements such as settling time and overshoot.

**Keywords:** PLC, pressure plant, sensors, valve.

## 1. INTRODUCTION

At the beginning of the industrial era, the operation of the processes was carried out with the manual control of the variables using only simple tools, pressure gauges or manual valves that were sufficient due to the simplicity of the processes. However, the gradual complexity of these processes has allowed the progressive development of measuring and control instruments. For the industry, it is necessary to know and understand the operation of the instruments and the role they play in the process control. (Creus, 2010).

In the industry, the first controls were manually operated by the workers, but today there are programmable logic controllers that facilitate the control and management of variables to meet the requirements, they also have controlled environments where monitoring is carried out from a control room (UDLAP, 2016). With the arrival of the PLC to the industry, the control of the variables was simpler. The PLC is a device that allows sequential control of the entire process through the programming ladder (Villalobos and Figuera, 2014).

This document provides an overview of the process carried out for the construction of the experimental pressure plant, with emphasis on the instruments used. The Allen Bradley PLC Micro800 series was used to control the pressure. The plant model was identified by Matlab and the controller was implemented using the automatic configuration option of the PLC's IPID block. Finally, the response of the designed system is performed.

## 2. MATERIALS AND METHODS

To build this experimental pressure plant was necessary to divide the project into stages related to one another which are presented below.

### 2.1 Automatic Control Systems

Industrial systems are formed by a series of elements that work together to achieve an objective, therefore, any modification made to one will influence the other; In other words, a system that maintains a relationship between the output signal, the reference input and the use of its difference as a control signal is called a closed-loop control system (Ñeco *et al.*, 2004). The closed-loop control structure for this project is illustrated in Figure-1.

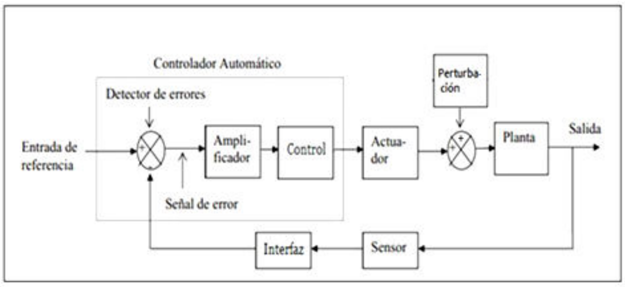



**Figure-1.** Proposed closed loop control system.

In the proposed control system, the controller is fed with the error signal, which corresponds to the difference between the input signal and the process output to reduce the error and bring the system output to the desired value. The basic elements that make up this project are described below.

### 2.2 Set Point

It is the desired value at which a signal is established under certain parameters, it can be adjusted manually or remotely, depending on the type of program assigned to this plant. The signal is conditioned with a range of 0 to 8.65 VDC since an analysis of the instruments shows that said variation corresponds from 0 to 125 PSI as the output signal

### 2.3 PLC Micro830 Series

For the development of this work an Allen Bradley brand PLC, with reference 2080-L30-10QWB is selected (Rockwell, 2018). Figure-2 shows the physical appearance of the PLC.

ARPN Journal of Engineering and Applied Sciences



**Figure-2.** PLC Allen Bradley Micro830.

The Micro Controller830 has incorporated inputs, outputs and accepts up to two plug-in modules, it is also compatible with any external 24 VDC to 1.6 Amp power supply. The CCW (Connected Components Workbench) programming software with free license is used for this range of protocols that also have password protection. In Table-1, the main parts of the PLC are described.

**Table-1.** Description of the connectors of the PLC.

| Number | Description | Number | Description |
|---|---|---|---|
| 1 | Status indicators | 8 | Covered right side |
| 2 | Optional power supply slot | 9 | DIN-rail mounting lock |
| 3 | Plug-in module safety. | 10 | Mode switch |
| 4 | Plug-in module screw hole. | 11 | USB Type B Connector Port |
| 5 | 40-pin high-speed plug-in connector | 12 | Non-isolated combined RS232/RS485 serial port |
| 6 | I/O Terminal Block | 13 | Optional power supply |
| 7 | Mounting screw hole/mounting foot | 14 | Not used |

**2.4 Proportional Valve**

Figure-3 shows the instrument used as an actuator for this plant which is the proportional valve MAC PPC5B-AAA-AGAB - BBB-JD that maintains a constant output pressure, regardless of the magnitude of the pressure at the input; in addition, its output varies with a range of control of 0 to 8.65 VDC previously calibrated (MacValves, 2018).

**Figure-3.** Proportional Macvalve.

**2.5 Implemented System Load**

This element is aimed at controlling the variable and corresponds to the storage tank capable of accumulating up to 7 liters of air as shown in Figure-4. It has a safety valve that will be activated if the filling of the tank exceeds a pressure of 150 psi.


**Figure-4.** System load.

**2.6 Pressure Sensor**

The electronic sensor used in the plant is Jumo Midas 401001 / 000-459-405-502-20-601-61 / 000 with voltage output of 0-10 VDC which bases its operating principle on deformation of the diaphragms in relation to the differential pressure exerted on them generating a change in the signal emitted by the capacitive plates, their physical appearance is shown in Figure-5 (Jumo, 2018).

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences


www.arpnjournals.com

**Figure-5.** Jumo Midas pressure sensor.

## 2.7 Controller Tuning

The tuning is the process that consists of defining the optimal values of the proportional, integral and derivative actions of the control modes to achieve the desired behavior of the control system. (Avalos *et al*., 2002). To adjust the controller, a pilot test to identify the dynamics of the plant model must be performed, then the most appropriate tuning method is chosen.

The Micro830 PLC used for this project has a tool called the IPID Controller function block, which performs the controller adjustment process automatically as shown in Figure-6. The steps to achieve this automatic adjustment are described below.

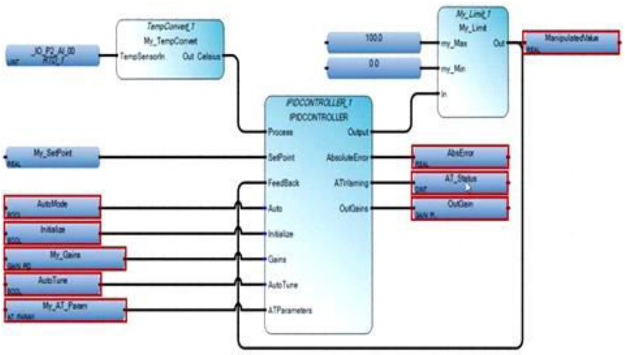
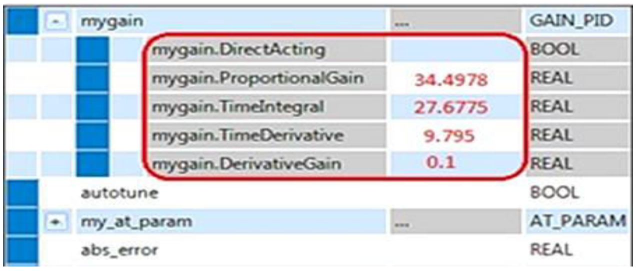



**Figure-6.** IPID Controller function block.

To perform the automatic tuning in this type of PLC should be to carry out the following procedure:

a) Put in place the PLC and restart the setpoint of the IPID Controller block.
b) Check the Auto box in false mode and set the output gain parameters to zero.
c) Adjust the AutoTune block with initial values of load, step, and estimated time to complete the operation; after that activate the check ATReset.
d) Set the Initialize and AutoTune boxes in the real mode so that the program begins to show changes in the load values to stabilize the process variables, then adjust the deviation parameter according to the fluctuation in the process variable.
e) Change the mode of the initialization box to false so that the controller begins the auto-tuning process. When ATWarning reaches a value of 2, it indicates the completion of the process.
f) Once the process is completed, the result is observed in the OutGains box, then it is transferred to the Gains IPID Controller verification function block obtaining a result as shown in Figure-7.

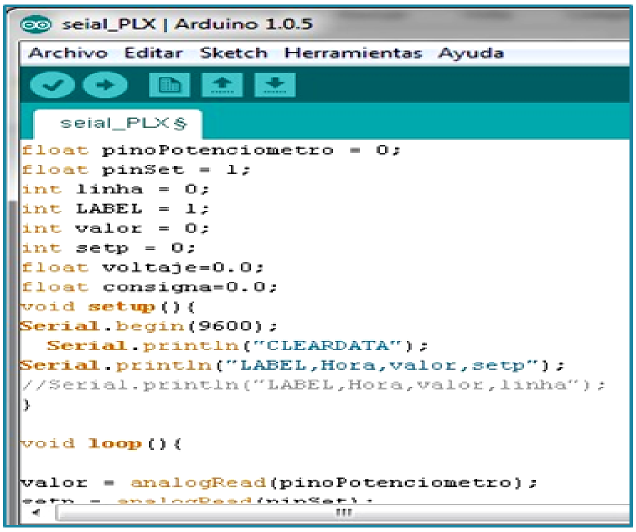


| | | |
|---|---|---|
| mygain | ... | GAIN_PID |
| mygain.DirectActing | | BOOL |
| mygain.ProportionalGain | 34.4978 | REAL |
| mygain.TimeIntegral | 27.6775 | REAL |
| mygain.TimeDerivative | 9.795 | REAL |
| mygain.DerivativeGain | 0.1 | REAL |
| autotune | | BOOL |
| my_at_param | ... | AT_PARAM |
| abs_error | | REAL |

**Figure-7.** Tuned gain settings.

## 2.8 Data Acquisition

In order to obtain the mathematical model of the plant and thus be able to perform the design of the controller, the acquisition of data from analog signals is performed. The Arduino Leonardo card is chosen for this acquisition and code that works for data acquisition is developed as shown in Figure-8.




```
float pinoPotenciometro = 0;
float pinSet = 1;
int linha = 0;
int LABEL = 1;
int valor = 0;
int setp = 0;
float voltaje=0.0;
float consigna=0.0;
void setup(){
Serial.begin(9600);
  Serial.println("CLEARDATA");
Serial.println("LABEL,Hora,valor,setp");
//Serial.println("LABEL,Hora,valor,linha");
}

void loop(){

valor = analogRead(pinoPotenciometro);
```

**Figure-8.** Programming in Arduino Leonardo.

Pressure plant data is taken using a free license application called PLX-DAQ that allows the Arduino Leonardo to interact with Microsoft Excel as shown in Figure-9 (Parallax, 2015). This data is used to determine the mathematical model using the Matlab program.

ARPN Journal of Engineering and Applied Sciences



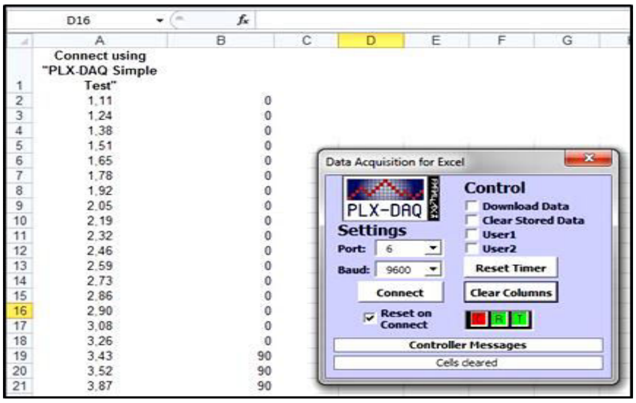



**Figure-9.** Data acquisition with PLX-DAQ.

### 2.9 Programming the PLC Micro830

The software used to program this PLC is the Connected Components Workbench version 7.0, which offers programming and configuration of these devices and integration with the HMI editor for PanelView Component products and simplifies the programming of the Allen Bradley Micro800 family controllers. This software is based on the Microsoft Visual Studio and Rockwell Automation technology-free license with direct and free downloads from its website. It is also compatible with the three standard IEC 61131 programming languages, such as the ladder logic diagram, the function block diagram and the structured text.

The IPID Controller function block, included in the CCW libraries, uses the following components to work as a control block:

A: drive (+/-1)
PG: Proportional Gain
DG: Derivative Gain
DT: Derivative Time
IT: Integral Time

Figure-10 shows the block diagram of the IPID controller. This block is used to develop actions that control physical properties, such as temperature, pressure, level or flow of liquid, through process loops.

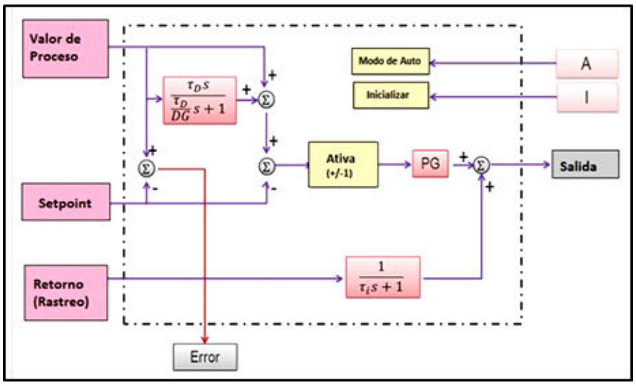



**Figure-10.** Function Block of IPID Controller.

### 2.10 Graphical Interface

This pressure plant can be controlled and monitored remotely through a computer. The software Factory Talk View (FT View) establishes a graphical interface that allows remote communication between the PC and the control unit as shown in Figure-11.


**Figure-11.** Home screen of the FT View.

### 2.11 Communication Devices

To achieve communication between the PLC and the computer the following software is installed: RSLinx Enterprise version 5.6., FTViewPatch Patch Roll-up and Patch Raid592812. Once the complements are installed, the interface design is carried out using the graphic libraries, the trend registration tables, the control buttons and other elements necessary to remotely control and monitoring the performance of the pressure plant.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Pressure Plant

Figure-12 shows the pressure plant completely finished and ready to start operating, which consists of the air compressor, the storage tank and the control module. The functions performed by the other elements installed in the panel and their internal connections are described below.

**Figure-12.** Pressure plant built.

VOL. 15, NO. 10, MAY 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

### 3.2 Proportional Valve Test

Due to the importance of this valve in the control process, the response of the valve with respect to the values of the control signals is analyzed through a PLC test. The results are presented in Table-2 with their corresponding graph in Figure-13.

**Table-2.** Proportional valve test result.

| Ideal pressure output (psi) | Real pressure output (psi) | Signal control (v) | Registration in the PLC |
|---|---|---|---|
| 4,5 | 4,3 | 0,3 | 1943,3 |
| 15 | 15,5 | 1,07 | 7343,86 |
| 30 | 31,21 | 2,15 | 14104,74 |
| 45,00 | 45,52 | 3,14 | 20571,85 |
| 60 | 61,1 | 4,21 | 27612,92 |
| 75 | 74,8 | 5,16 | 04,36 |
| 90 | 90,71 | 6,26 | 40994,57 |
| 105 | 105,9 | 7,3 | 47859,39 |
| 120 | 122,8 | 8,47 | 55497 |
| 125 | 125 | 8,62 | 56491,25 |

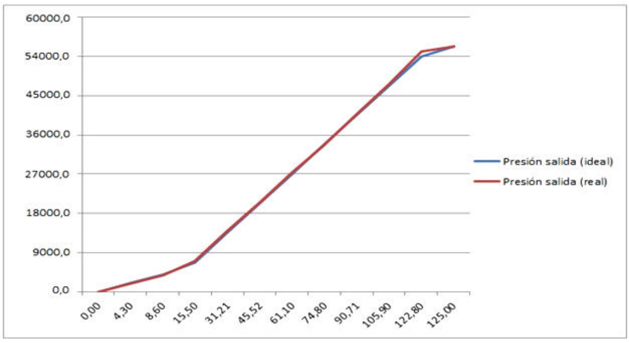



**Figure-13.** The response of the proportional valve.

As a pneumatic valve has some delay dynamics, a relationship between flow and pressure is found to establish its linearity, which is represented by a first-order transfer function, as shown below.

$$G_v(s) = \frac{Q(s)}{U(s)} = \frac{K_v}{\tau_v s + 1}$$

Since the time constant of the valve is very small and therefore the dynamic delay is negligible, the transfer function can approximate to $G_v(s) = K_v$. Therefore, the valve constant is found as follows

$$K_v = \frac{(8.47 - 3.14)}{(122.8 - 45 - 52)} = 0.069 \,{}^{volt}\!/_{psi}$$

### 3.3 Pressure Sensor Test

The transfer function of this linear transducer is given by the mathematical relationship between the physical and electrical response which has the expression $S = a + bs$, where $S$ is the electrical signal, $a$ and $b$ are constants and $s$ is the specific physical signal of the transducer. To calculate this function a test with the sensor is performed and the results are shown in Table-3.

**Table-3.** Measured values of the pressure sensor.

| Pressure (psi) | Voltage (psi) | Psi/volt. |
|---|---|---|
| 5,74 | 0,3958304 | 14,50116009 |
| 30,67 | 2,1150032 | 14,50116009 |
| 40,2 | 2,772192 | 14,50116009 |
| 50,46 | 3,4797216 | 14,50116009 |
| 60 | 4,1376 | 14,50116009 |
| 70,26 | 4,8451296 | 14,50116009 |
| 80,65 | 5,561624 | 14,50116009 |
| 89,93 | 6,2015728 | 14,50116009 |
| 99,95 | 6,892552 | 14,50116009 |
| 110,22 | 7,6007712 | 14,50116009 |
| 120,23 | 8,2910608 | 14,50116009 |
| 125 | 8,62 | 14,50116009 |

From this table, data is extracted to find the arithmetic mean with its respective deviation and thus obtain an approximation to a real value.

$$\bar{x} = 14.50116009, \quad \Delta\bar{x} = 0, \quad \bar{x} + \Delta\bar{x} = 14.501$$

Therefore, the value of the transfer function is given by

$$T(s) = \frac{1}{14.5011}$$

### 3.4 Pressure Plant Identification

The experimental data of the plant is obtained through the data acquisition software, then the data is exported to Matlab and the system identification tool called Ident is used to obtain the model represented by the transfer function shown below.

$$G(s)=\frac{0.0023436*(s+0.5236)}{(s+0.01025)*(s+0.09841)}$$

The system step response without control is shown in Figure-14.

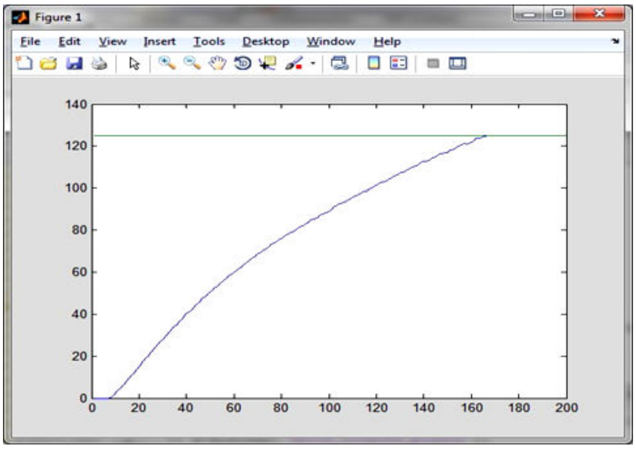



**Figure-14.** Step response of the system.

### 3.5 Designed PID Controller

As shown in Figure-14, the settling time of the system implemented in closed-loop without compensator is approximately 180 seconds, so to test the performance of the PLC's IPID block, it is proposed to reduce the settling time to 25 seconds with an overshoot less than 15% (Ogata, 2010). For the design of the PID controller the classical representation is proposed as shown below.

$$G_{pid}(s)=K_p+\frac{K_i}{s}+K_d s$$

So the objective is to find the parameters $K_p$, $K_i$ and $K_d$ that allow to meeting the desired reference point. The auto setting option is performed through the IPID block and the parameters required to meet the design specifications are found as shown below.

$$K_i=4.360647,\; K_p=112.766734,\; K_d=250.3424$$

Then, the PID controller is found as follow

$$G_{pid}(s)=112.7667+\frac{4.3606}{s}+25.3424s$$

To show the response of the designed system, Matlab is used. Figure-15 shows the system performance in closed-loop without compensator in the blue line. In the same figure, the response of the controlled system is shown in the green line. The design parameters are met by the designed controller as can be observed.

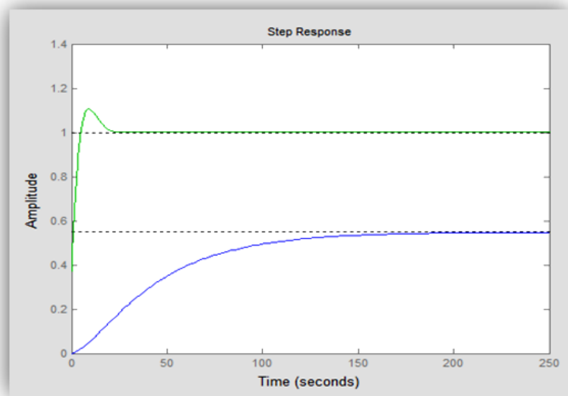



**Figure-15.** System response without compensator vs Compensated system.

## 4. CONCLUSIONS

A new experimental pressure plant was implemented; different operational tests were performed on all the instruments involved in the control process with optimal results.

The implementation of this system helps to improve the training of new professionals, who will expand their knowledge in the most practical way since with this plant it is possible to perform different control modes, similar to real industrial processes.

The graphical interface was developed to monitor and control the air pressure of the plant, but particularly with this controller, it must meet the suggested software requirements for the program to fulfill its successful work. The PLC control program was carried out in Connected Components Workbench, version 7.0 in English for the Micro830 PLC. The IPID Controller function showed good performance because it meets all the proposed design requirements such as settling time and overshoot.

The choice of PLC allows programming using open source software, easy to download, use, distribute and modify for free. It has lower costs for its implementation.

## REFERENCES

Avalos G., Montúfar M., Ortiz F., Villalobos G. 2002. Teoría de control, ajuste de controladores industriales. Instituto Politécnico Nacional. México.

Creus A. 2010. Instrumentación Industrial. Barcelona, España. Ed. Marcombo.

Jumo. 2018. Midas Transductor de presión. [On-line]. Available in:

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences




http://www.jumo.es/productos/presi%C3%B3n/soluciones-oem/transductores/401001/jumo-midas---transductor-de-presi%C3%B3n-401001.html.

MacValves. 2018. Proportional Pressure Controller, Manual de especificaciones. [On-line]. Available in: https://www.macvalves.com/product-category/proportional-pressure-control/.

Ñeco R., Reinoso O., García N., Aracil R. 2004. Sistemas de control. Alicante, España. Ed. Club Universitario.

Ogata K. 2010. Ingeniería de Control Moderna. Madrid, España. Ed. Pearson Educación S.A.

Parallax Inc. 2015. Parallax Data Acquisition tool. [On-line]. Available in:
< http://www.parallax.com/downloads/plx-daq>.

Rockwell Automation. 2018. Micro830 Programmable Logic Controller Systems [On-line]. Available in: https://ab.rockwellautomation.com/Programmable-Controllers/Micro830.

UDLAP. 2016. Controlador Lógico Programable. Universidad de las Américas Puebla. Available in: http://catarina.udlap.mx/u_dl_a/tales/documentos/lmt/maza_c_ac/capitulo4.pdf.

Villalobos V. y Figuera J. 2014. Programación de PLC's: Lenguaje escalera (LADDER). Seminario Instrumentación y Control Industrial. Universidad de Oriente. Venezuela.