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Design of Controller PID and Stability Analysis for Drying of Corn´s Grain

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Abstract

This article presents the results of a work developed in the Universidad de los Llanos, it is the design of PID controller for temperature and stability analysis using various techniques of control theory used for drying grain corn, to improve the quality of the grain of corn, to prevent the growth of mold and putrefaction of moist seed, besides storage insects like weevils, which are more active and multiply faster in the warm and moist grain allowing the growth of mushrooms. The project was divided into three methodological stages, first the characteristics of the system were established, then the PID controller was designed, and third, results were validated by tests simulated in MATLAB®, getting the verification of the parameters required for the physical implementation of the system to correct seed damage.

Keywords. Controller, stability, grain of corn, relative humidity, drying process, simulation

INTRODUCTION

Drying of corn grain is such a large and important issue in the food production chain that it becomes necessary to control the moisture content in the grain. Drying is done to inhibit the germination of the seeds, reduce the moisture content in the grains to a level that prevents the growth of the fungi and avoid the deterioration reactions, understanding the drying as the universal method of conditioning the grain by means of eliminating water to a level that allows its equilibrium with the environment, in such a way as to preserve its appearance, in addition to its nutritional characteristics, including its nutritional quality and the viability of the seed [1].

For this reason, it is necessary to design and analyze the stability of a PID controller that allows obtaining a quality grain for its conservation for much longer periods, eliminating the impurities that the grain has at the time of harvesting this so that its conservation be for periods of more than 30 days.

Currently, the process of drying corn grains is done in a rudimentary way, where the grain is placed in the soil and then wait an approximate drying time of 3 to 4 days depending on the amount of corn ready for this process, being exposed to harmful factors, such as the collection of fungi, bacteria and insects which proliferate in environmental conditions such as those present in the region (Department of Meta - Colombia), in which the relative humidity is approximately 65% to 70%, which affects it since to be stored it must have a humidity lower than 14% in grain, the relative humidity of the environment where it is going to be stored must not be greater than 50%, the temperature not higher than 18ºC and it must be arranged in sacks that are of a certain weight on wooden stretchers.

Modeling and computer simulation of grain drying are currently used in research. Many models have been proposed to describe mass and heat transfer processes in the basic types of convection grain dryers: fixed bed, cross flow, concurrent flow and countercurrent flow..

According to S. Rafiee and others [2], drying conditions affect the quality of dried soybeans. Therefore, an accurate description of the drying rate is required. In this study, the finite element formulation and the diffusion moisture transfer equation solution were presented to improve the simulation of seed drying of asymmetric bodies. The Fick diffusion model was solved. For the experimental stage, soybean seeds were dried, in a thin layer, at air temperatures of 30, 40, 50, 60 and 70 ° C, in triplicate, at a fixed speed of drying air equal to 1 m / s.

For C. W.Cao and others [3], the Agricultural University of China has placed the greatest emphasis on research in grain drying in Mathematical Modeling and Computerized Simulation of grain drying. Since In 1988, the simulation of grain dryers of cocurrent flow, crosscurrent and mixed was investigated. The software developed has been used in the analysis of the performance of the dryers, the design and optimization of new grain dryers and the management of existing ones.

W. Jittanitt others [4] studied the drying effect of wheat, rice and corn seeds in two stages, using germinability as a measure of quality. The first stage was studied for air temperature range of 40-80ºC, while for the second stage, the temperature was 18-30ºC and the relative humidity of 60-70%. In this work, thin-film models were developed: the modified Page model, the modified two-compartment model.

This document presents the design and analysis of the stability of a PID controller that allows the drying of the corn grain complying with the quality and health standards. This having as a reference base the different types of corn that can be found.

Due to the importance of corn in the Llanos Orientales economy (Colombia), it's important to have a drying process that reduces costs, increases the time of grain conservation and increases the production of standard grains with quality and healthiness.

The article is divided into 3 main sections, where the first section is called "Methodology", containing information collection, Corn Drying, Controllers and Controller Design. The second section called "Results and discussions" refers to frequency simulation, poles and zeros analysis, and finally "conclusions", where the findings are exposed after the development of the article.

METHODOLOGY

Last years, the concept of automation, defined as the application of the automatic to the control of industrial processes, has been evolving rapidly because it can improve the operations of a production process, in addition to the quality of the goods produced, guaranteeing companies achieve their objectives with optimal performance.

The automations in the industry until the 70s were executed exclusively on the basis of relays, using what is known as wired logic, but from these years the Programmable Automations (PLCs) burst on, moving to programmed logic.

The first versions and models of PLCs were expensive, difficult to program, with relatively little memory and almost no peripheral elements. Already in the 80's these improved, both in price and in benefits, but even the programming was difficult to perform, which meant that only a small group of specialists was trained to put it into service and maintenance [5].

An automated system is made up of elements or instruments, which are used to measure physical variables, exercise control actions and transmit signals. In all processes it is absolutely necessary to control and maintain certain quantities constant [6].

The dictionary of the Real Spanish Academy defines Automatic as the discipline that deals with methods and procedures whose purpose is the substitution of the human operator by an artificial operator in the execution of a previously programmed physical or mental task [7].

One of the important aspects of the present work consists of the automation based on a PID controller implemented in a PLC, for this, it was chosen to use an evolutionary type methodology, divided into three phases, which are: Analysis, Design and Testing. The methodology also allows you to return to an earlier phase if any inconsistency or error is detected, or if you want to improve some aspect of the system.

The interface systems between user and plant based on panels of control full of light indicators, measuring instruments and push buttons, are being replaced by digital systems that implement the panel on the screen of a computer or touch screen. The direct control is carried out by the digital autonomous controllers and / or programmable automata and they are connected to a computer that performs the functions of dialogue with the operator [8].

Now, the article shows relevant elements for the development of this work, initially the collection of information, including the characteristics of storage, then the corn drying process is analyzed to introduce the characteristics and advantages that controllers represent in the industry, especially the PID controller and thus finish with the design of the controller, based on the Ziegler Nichols method.

Collection of information

First, information gathering was carried out, which covered all the topics related to the theoretical foundation necessary for the development of the project, in this way we have a starting point to move on to the next phase.

Once the necessary aspects to determine the characteristics of the PID controller are known, it is proceeded with its design.

When storing maize sacks, they should be placed on pallets or wooden pallets, in order to obtain better handling and avoid the contact of the packages with the ground.

The dimensions of the sacks where the corn is stored are 80cm high, 40cm wide and 30cm long, and the dimensions of the room are 5m x 5.5m, where the space is distributed as can be seen in the Figure 1.

These data are important for the calculation of storage capacity.

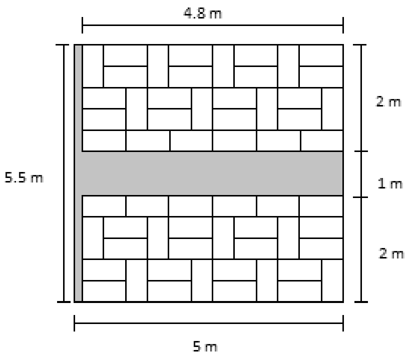

Figure 1. Storage room

Each storage room is divided into two sections, leaving a corridor one meter wide as seen in Figure 1, space arranged to circulate. In this case, the dimensions of the storage sections are:

S= area of the section

a= long of the section (4.8 m)

b= width of the section (2 m)

Equation (1) is to calculate area of the section.

$$S = a \times b \quad (1)$$

Obtaining

$$S = 9.6 \text{ m}^2$$

To know area of each bag of corn, it will use equation (2), which you can determine the amount of corn that is subject to the control process, where:

s= bag´s corn area

c= bag´s corn long (0.8 m)

d= bag´s corn area width (0.4 m)

$$s = c \times d \quad (2)$$

Obtaining:

$$s=0.32 \text{ m}^2$$

The amount of bags of corn in one section, called n, equation (3) is used:

n= numbers of bags of corn (en una sección del cuarto)}

$$n=S/s \quad (3)$$

Obtaining:

$$n=30$$

There are 30 bags in one section of the room, in addition to other section wich has the same dimensions, this way there are 60 bags in the room. If the sacks are stored in the room at a height of 3 m and each bag has a thickness of 30 cm, 10 sacks are stored, one on top of the other, so:

B= total bags in the room

X= 10 bags, one of top of other

Y= 60 (number sacks in the two sections of the room)

To calculate the total amount of bags, use equation (4).

$$B=X \times Y \quad (4)$$

Obtaining

$$B=600$$

600 bags of corn can be stored, these bags contain 50 kg each, for a total of 30 tons that are stored in this room.

Up to this moment there is clarity in the physical conditions of the storage space, important data for the design of the PID controller. Additionally, there are data related to the number of bags of corn that will be benefiting from the controller that will be designed.

Drying corn

Artificial drying produces the main transformation of the grain in what we call the post-harvest and in turn is the procedure that requires more attention to not affect the quality of it. Its fundamental objective is to ensure that, during storage, the grain retains its characteristics for as long as possible.

To do this, the grain drying process must respond to four requirements:

- Decrease the water content in the grains.
- Avoid the germination of the seeds.
- Conserve the maximum quality of the grain.
- Achieve a degree of humidity that does not allow the growth of bacteria and fungi, and, that considerably retards the development of mites and insects.

It can be done with natural air or hot air, however, the temperature that the grain acquires during the drying process is essential to determine if it maintains its initial quality. All the methods used to dry grains use the property of air to absorb moisture from bodies that contain water.

A primary condition for grain drying is the relationship between the moisture content of the product and the relative humidity of the air. The humidity of the air must be lower than the final humidity required. Another important condition is the temperature of the air since as we know the hot air dries more quickly the grain than the cold air. [9]

Controllers

In a process control of variables such as temperature, pressure, flow or liquid level, it is necessary to keep regulated their desired values so that the stability and safety of this process can be guaranteed. The above is done by means of devices (controllers) designed to develop an action on the deviations observed in the values of said conditions and requires coupling with a measurement and transmission mechanism (Sensor / Transmitter) of the process variable, who it will be the source of information for the corrective action along with another enforcement mechanism of the regulatory action decided by the controller.

An automatic controller compares the actual value of the output of a plant with the reference input (desired value), determines the deviation and produces a control signal that will reduce the deviation to zero or to a small value. The way in which the automatic controller produces the control signal is called the control action [10].

The first way to modify the response characteristics of the systems is the gain adjustment (which is defined as proportional control). However, although generally the increase in gain improves the operation in steady state, there is a poor response in transitory regime and vice versa. For this reason, it is necessary to add elements to the simple variation of gain, which gives rise to the different types of controllers [11].

Design specifications are often used to describe what the system should do and how to do it. These specifications are unique to each individual application and often include specifications such as relative stability, steady state accuracy, transient response and frequency response characteristics [12].

Almost all industrial controllers use electricity or the pressure of a fluid such as air as an energy source. Controllers can also be classified, according to the type of energy they use in their operation, such as tires, hydraulics or electronics.

To control industrial processes, distributed control systems, computers for control, or a combination of both are connected through appropriate interfaces. Although the systems are designed to obtain the best results, either in the stability of the process or to optimize it, the final element of control is still necessary to control the flow of a fluid.

In the final control elements it is important that the final control element works in a stable manner and has a good behavior [13].

Controller Design

Once the controller is identified, it is important to mention that there are several design methods, among them the Ziegler Nichols tuning rules, which is based on the response of the open loop system to a step signal [14].

As an important aspect of this temperature controller, the design of a PID controller is highlighted, which will be done using the Ziegler Nichols Tuning rules, the PID controller design, according to the constants that stand out in the equation (5).

$$PID = \mathrm{Kp} + \frac{Ki}{S} + \mathrm{KdS} \qquad (5)$$

These constants are indicated in table 1 and are obtained from the design process, carried out using the first method indicated by the rules.

Table 1. PID Controller Tuning

Tipo	Kp	Ti	Td
P	T/L	INF	0
PI	0.9(T/L)	L/0.3	0
PID	1.2(T/L)	2L	0.5L

Source: Ogata, Katsuhiko. Modern Control Engineering. 5ta edition. Prentice Hall. México

Control system for the drying process of the corn grain will be determined by the block diagram shown in figure 2, where the elements that intervene there, among them the sensor, put in the feedback to establish the system error and thus manage to control said variable.

It is important to say that for PID controller designed, the temperature of the grain will be in a silo drying process at medium temperature, which means that the setpoint will be located in the range of 43 ° C to 60 ° C.

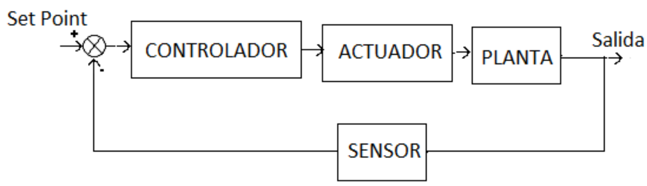

Figure 2. Block Diagram to PID Controller

Use of sensors in technology, both in the industrial and domestic field, has become usual the measurement of mechanical, thermal, electrical and chemical magnitudes in sectors such as automated industries, robotics, experimental engineering, energy saving, environmental control, automobiles, appliances, computers, are tasks that would be unthinkable without the application of sensors [15].

Plant's modeling for drying with controller tuning is described below by means of Ziegler-Nichols method, in which the plant can be described from equation (6), due to the fact that it has a transport delay system:

$$G(s) = \frac{K}{Ts+1} e^{-Ls} \qquad (6)$$

Coefficients K, T and L are obtained from system response in open loop to a step input (heating system at maximum power), as shown in figure 5, starting from the stabilized system in y(t) = y0 for u(t) = u(0) a step input u(0) to u(1) is applied and the response of the output is recorded until it stabilizes at the new operating point.

The parameters can be obtained from the response shown in figure 3.

Figure 3. Exit Response to step entrance

According to the parameters of tuning, from figure 5 it gets:

K=0.604

L=0.125

T=1.125

Based on Ziegler-Nichols method, scaling the response of the plant, proceeds to calculate the values of the constants of the controller, achieving the following results:

Kp=10.8

Ti=0.25

Td=0.0625

With the above data, the simulation of the response of the system to a single-step input is performed.

Once the program is executed, the response is observed as shown in figure 4

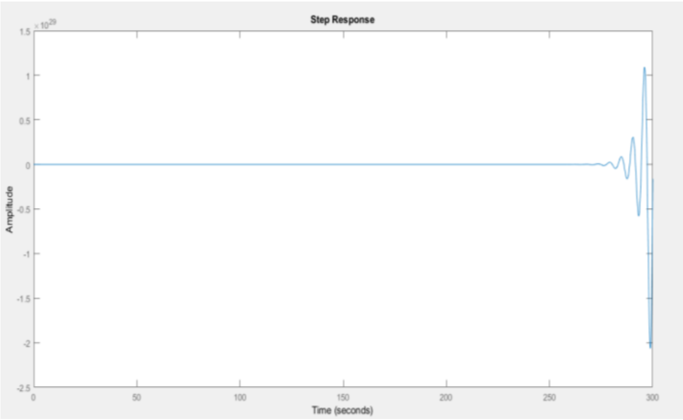

Figure. 4. Initial Response to PID Controller

From figure 4 it is observed that the tuning of the found controller is necessary, specifically an adjustment of the integral action is required, for this reason those values are modified, the constants Kp and Td are conserved in the calculated initial value. The proposed solution shows an increase in the value of the Ti, necessary to decrease the stable state of the output signal.

Again the simulation of the designed system is carried out, now with the following values:

Kp=10.8

Ti=1.4

Td=0.0625

With this new value, the response of the system to a unit step input is simulated, obtaining as a result figure 5.

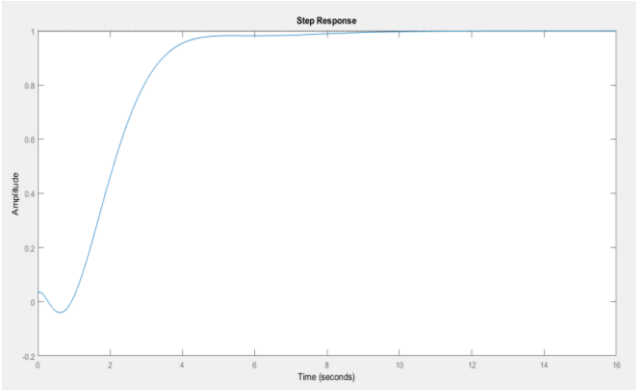

Figure 5. Modified response to PID Controller PID

Time response of a control system consists of two parts: the transient response and the steady state response. The transitory response refers to the one that goes from the initial state to the final state. Stationary response means the way the output of the system behaves as t tends to infinity [16].

Once the final values for the controller have been established, the final block diagram is concluded, as shown in figure 6.

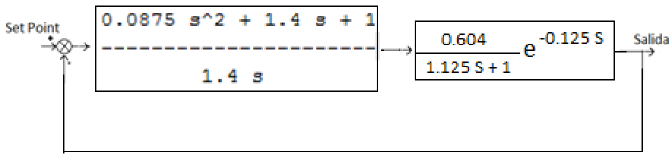

Figure 6. Final block diagram

RESULTS AND DISCUSSIONS

PID controller can be analyzed in many ways, one of them is the response in the time domain, or also called transitory response. From the previous figure it is observed that the response of the system is quite good, characterized mainly by not presenting a maximum overshoot, in addition to the rise time is only 8 seconds.

On the other hand, establishment time is 10 seconds, achieving stabilization at the desired value in a short time, observing that the dead time of the system does not affect the final performance of the controller

On the other hand, the designed system is analyzed using the Nyquist stability criteria, which is a frequency analysis procedure. For this, the diagram of poles and zeros of the open-loop system is needed, as shown in figure 7.

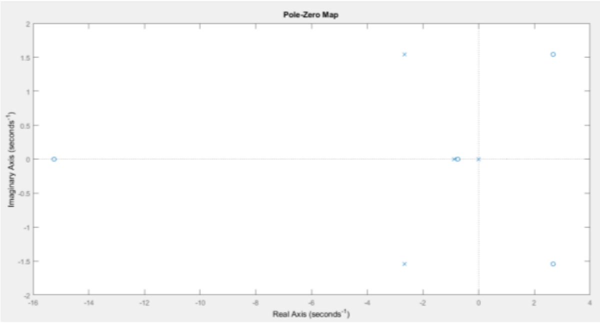

Figure 7. Diagrama de polos y ceros en lazo abierto

From this it is concluded that it does not contain poles in the right half plane, therefore P=0.

Then, the Nyquist trace of the system is obtained in open loop, as shown in figure 8

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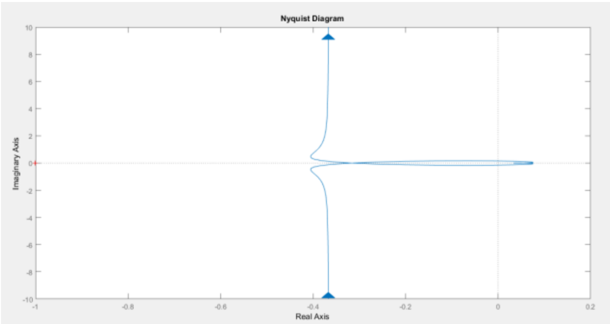

Figure 8. Nyquist Diagram

Nyquist trace shows that the point -1 + j0 is not enclosed, therefore N = 0, following the equation (7)

$$Z = N + P \quad (7)$$

Obtaining

$$Z=0$$

By Nyquist stability criteria, system is stable, because of there are no poles in the right semiplane and there are no enclosures, therefore, the system will not have poles in the right half-plane when it is in closed loop.

The following analysis consists of the location of poles in closed loop, which, to achieve stability, must be located in the left half-plane. The designed system throws the closed-loop transfer function of equation (19).

$$\frac{C(s)}{R(s)} = \frac{0.05285\, s^4 + 0.5637\, s^3 - 3.405\, s^2 + 4.796s + 5.727}{1.628\, s^4 + 10.36\, s^3 \mp 19\, s^2 + 18.07s + 5.727} \quad (19)$$

After applying the pzmap command in MATLAB®, figure 9 is obtained, corresponding to the location of the diagram of poles and zeros of the system in closed loop.

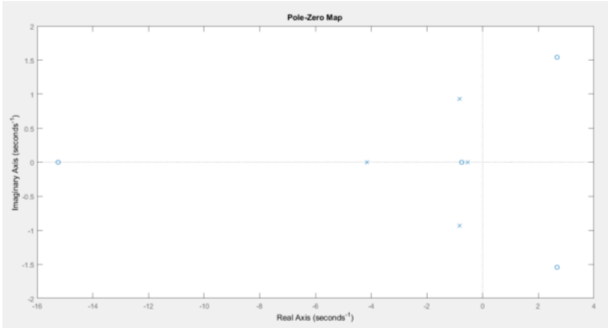

Figure 9. Diagrama de polos y ceros en lazo cerrado

As seen in figure 9, the poles are located in the left half plane, as follows:

$$S_1 = -0.543$$

$$S_2 = -4.15$$

$$S_3 = -0.837 + 0.928i$$

$$S_4 = -0.837 - 0.928i$$

CONCLUSIONS

Ziegler Nichols tuning method gets the constants to PID controller to be properly established for the drying of the corn grain, with which it is desired to reduce the risks of grain damage.

Data found through the technique of stability analysis of the controller in time response, has established that this system can be stable in a short time, additionally, there is no error in the steady state, which allows presuming performance for the subsequent implementation.

According to the information collected in the design of the controller through the frequency response, it can be said that the drying process of the corn grain will yield satisfactory results in the final implementation, thus allowing the commercialization of a good quality product.

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