Identification and Control based on PID and Smith Predictor Applied to a Prototype Crushing

Ronald Alexander Reyes Asanza, José Leonardo Benavides Maldonado

***Abstract*— This article discusses the identification of the crushing process, which widely used in copper mining discussed; this is done using the ident tool with MATLAB®. Then apply two strategies to control process one based on PID (Proportional out, integral, derivative) and another on the Smith Predictor, mainly by the big current delay in the process. Finally, the best option is chosen, and the results were shown.**

***Index Terms*— Identification Systems, PID control, Smith Predictor Control,**

I. INTRODUCTION

At present, different techniques have been applied to various institutional control prototypes, as is the system board fan [1]. The importance of these prototypes is the low cost they have on real systems, such as a projectile in flight, a space station, a satellite orbiting the earth or maglev[2].

The cost is lower when working with prototypes with a real process, the advantages that allow simulating different environments. Is possible mainly because, through sensors installed at a DAQ (data acquisition device), you can monitor the behaviour of the process and thus obtain data to find a mathematical model of the dynamics.

In the academic world, in the evolution towards nonlinear models, it can be seen that linear and nonlinear models can construct with the mechanical knowledge (patterns of white box) or data input-output available (models black box). In general, the latter method can be used flexibly and without great effort, these linear models are often preferred in industrial practice, where identification techniques black box systems are well known and described in[3].

In impact crushers, an impact force high speed on the rock particles using hammers or blow bars is applied. The rate of energy input is much greater, and this causes the particles to break. Impact crushers can achieve reduction ratios higher than those of rotating jaws, but these limited by the high rates of abrasion and therefore confined to the softer rocks [4].

Jaw crushers have been around for almost 175 years. All jaw crushers distinguished by the presence of two plates, one of which fixed and another that opens and then closes between the two surfaces. There are three types of jaw crushers: Blake, Dodge, and Universal. They classified according to the location of the pivot point of the swing jaw. Eli Whitney Blake today patented the most common type of jaw crusher Blake in 1858 [5].

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For the selection of the kind jaw crusher should be taken into account the following aspects [4], [5], (Minerals) Jaw crushers are big and strong, capable of crushing large amounts of hard and abrasive materials machines. They have typically used as primary crushers within plants aggregate processing. These crushers most commonly defined by its size and open mouth.

A crusher plates of this type is used to apply compressive forces, which induce tensile stresses within the particles, causing them to fracture. Particles are bitten several times until they pass through the crushing chamber. The rupture process occurs between the jaws plates and acts simultaneously with a classification process. The classification process defines whether or not a particle subjected to crushing and depends on the settings of the crusher size and particle [6].

A. *Mathematical Modeling*

It is a mechanism by which you can apply analytical techniques in solving a practical problem; the complete model represented by differential equations in the domain S or difference in field Z.

Two unusual situations to try to find the mathematical model of a system (process, plant, etc.) may occur.

There are no actual process data, and only the physical process took as such. In such a situation it is advisable from the fundamental physical laws, bearing in account whether the system is to analyse thermal, level, mechanical, or electrical.

By using this way to obtain the mathematical model of the plant, they must meet the fundamental equations that govern the process that is trying to shape, thereby permitting build so-called white-box models.

If you have the time to develop the mathematical model data input and output, but do not know what happens in the process. An example would be to have the measurements of the amount of energy (which is being used and generated in an electric) plant, temperature, a day of the year (the time of day influences the response as it needed in the mathematical model relating the input to the output).

Given this, we can say that if it does not consider the physical facts, modelling or identification of black box is built with measured data without using the physical knowledge. Values are simply parameters that can be modified to optimise the model obtained. These are very efficient for modelling dynamic systems (system dynamics is an approach to understanding the behaviour of complex systems over time).

These models based on a black box are linear and flexible structures and require less engineering time for its construction.

Importance of Developing Mathematical Models.

Determines the process behaviour in certain situations, in

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which you can try to optimise the process model by changing certain parameters to ensure that behaves in some specific way.

On the other hand, it also facilitates the development control methods, and then integrate them into the process to be controlled [7].

B. PID Controllers.

It is the most used in industry and called a three-term controller or PID controller.

It is mainly present when the system's behaviour does not comply with the desired specifications [8].

The output of a PID controller, as the control input to the plant, in the time domain is the type shown in equation (1).

$$u(t) = K_p\, e(t) + K_i \int e(t)dt + K_p \frac{de}{dt} \qquad (1)$$

Firstly, the PID controller sees how operates in a closed loop system. The variable (e) represents the tracking error, i.e., the difference between the desired input value (r) and the actual output value (y). This error signal (e) sent to PID controller and the controller calculates both the derivative and the integral of this error signal. The control signal (u) the plant is equal to the magnitude of the error multiplied by the sum of the proportional gain (K_p) plus the gain of the integral of the error (K_i) plus the gain of the derivative of the error (K_d).

This control signal (u) sent to the plant and the new output (y) obtained is then fed back and compared with the reference to find the new error signal (e). The controller takes this new error signal and applies the above procedure again and until the error reduced to zero or to a predetermined value, or simulation time desire [9].

C. Smith Predictor.

When the delay is enormous, the regulator does not work, the Smith predictor, eliminates this problem and is widely used for processes with dominant delays.

As known one of the factors that affect the quality and stability of a control system, whether it based on PID or any other, it is the presence of pure transport delay by the control channel. Many solutions have been tried to offset the negative effect of the delay, standing out among others for its simplicity and effectiveness of the call' 'Predictor Smith."

The Smith predictor in its original form, process modelling means to control by a transfer function of the first order delay, like the equation (2).

$$G(s) = \frac{Ke^{-\theta s}}{T_s + 1} \qquad (2)$$

In Figure 1, representing the gain, delay and time constant of the process and the corresponding parameters of the model, note that for convenience are shown in separate blocks delay and delay model (Aguado, 2010)[10].

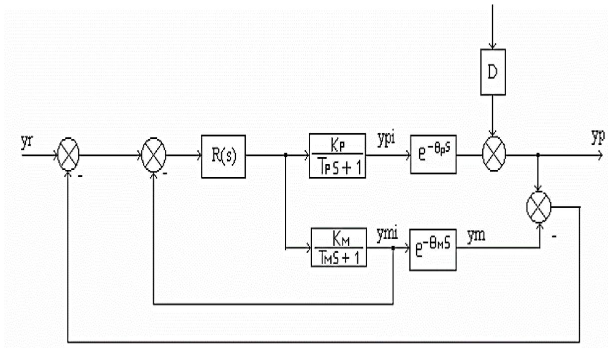

Fig 1. Control loop with Smith Predictor, Source: (Aguado, 2010).

II. MATERIALS AND METHODS

To design of the process type crushing jaw model German made Retsch such as that shown in Figure 2, to which added a drum side observed.

Fig 2. Control loop with Smith Predictor, Source: (Aguado, 2010).

A. Data Quality Required

In the case of not having a Data-Logger, the tool that allows the analysis of all these measurements, that is, the graphical analysis, statistical analysis and signal analysis in the frequency domain, it is the MATLAB® software, and this is the primary tool for CADCS. We proceed to load the data previously distributed to this case, first as variables in the workspace and then the MATLAB® Editor .m. This time all values placed, i.e., 1024 data sampled every 30 seconds, but for ease of simulation assumes like each sample was taken every second, leaving a mono-variable system. The variables are the weight as input and output weight (shown on the x-axis, respectively).

B. Identification System

In Figure 3, a photo of the crusher in which the input signals, output and the two shocks indicated shown. version, after your paper has been accepted, prepare it in two-column format, including figures and tables.

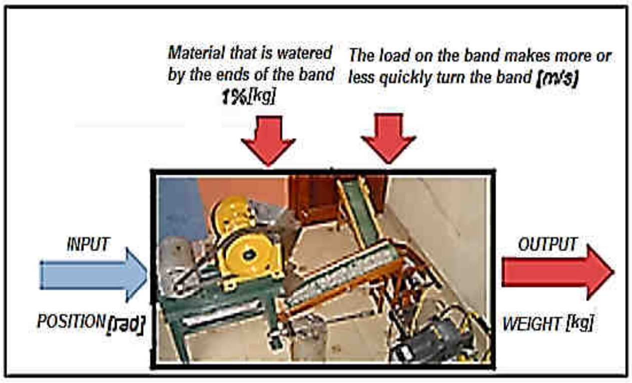

Fig 3. Photo of the crusher in which the input signals, output and disturbance are indicated Source: Author.

In this process the identification of states that will control cascade, where the torque does not play a significant role by being an intermediate and not independent variable, what does exist is a linearly proportional relationship between the torque and position.

Then it is part of a black box model, a single input, one output and two disturbances as shown in Table 1.

Table 1 Variables involved in this process

SHREDDER MODEL	
Variable Input	**Variable Output**
Position (*Po*) [rad]	*Weight* (*We*) [kg]
Disturbances	
Load weight changes the engine rotation speed -(*Rcar*) [m/s•kg]	
Material that is irrigated, is 1% of the total material used (*Mri*) [kg]	

Then in Figure 4 you can see the response to a signal input step, or what known in English as (step-test), the value of experiments is one, and that represented with a blue colour, and same response to this input can seen with a brown colour.

In each of the measurements made for each position or they have been conducted experiments 256, with its respective delay time due to material transport in a band at the outlet of the crusher and whose value is 17.58 seconds.

In each experiment, you can see the increase in output because the strain gauge begins to receive greater weight falling from the conveyor belt. The amplitude of the input signal or set point is 2 kg (change from 0 kg 2 kg).

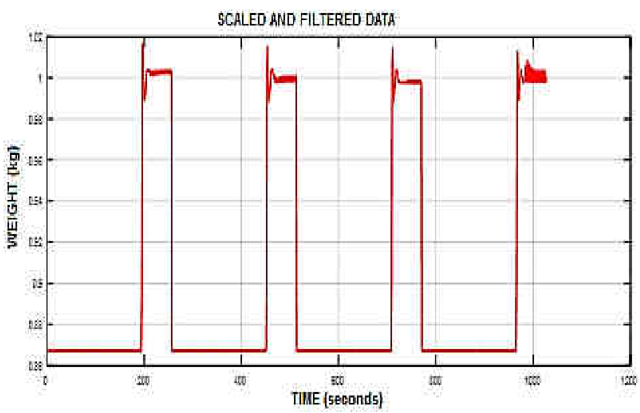

Fig 4. Output data filtered and scaled Source: Author.

Then input and output data shown in Figure 5. Represented in blue with brown entry and exit

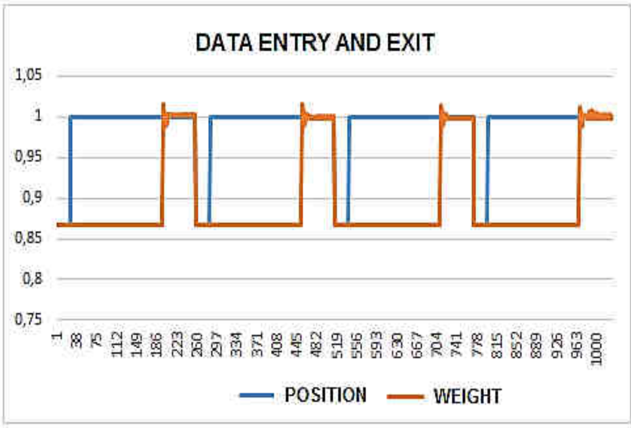

Fig 5. Data input and output Source: Author.

C. Verification of the mathematical model using the tool APPS (MATLAB® applications).

Another variant to find the mathematical model of the crusher is the use of the APPS tool that allows us to find a new design, compare it with the already found, and thus choose the best to behave at the time of your choice. Then it explains how to use this tool.

With the help of the MATLAB® toolboxes, we proceed to load the data found experimentally to use optimisation tools. So when sending data Optimizer identification systems identified the error between the signals is minimised, which is known as fit and data.

Then, with this tool the results shown in Figure 6, the left part of the blue and the form of the plant to use to apply different control strategies obtained.

To the left of the criteria taken into account for model selection:

• The PEM (Prediction Error Minimization) Minimization prediction error method

• The FPE (Fit Prediction Error) method the error between the data identified and fit

Give us the desired mathematical model using the PEM (prediction and error minimization) for its acronym in English. The FIT (provide the data estimate) gave 95.63%, and FPE (fit prediction-error) for its acronym in English yielded a value of 0.00047335. With the information obtained above and knowing that the output will be stable for entry 2kg. You can confirm that the output after a time constant of 5,538 is 63.2% x 2kg, or what is the same 1,264 kg. Then the mathematical model of the crusher will be the equation (3)

$$TF = \frac{PESO\,(s)}{POSICIÓN\,(rad)} = \frac{1{,}2725}{5{,}538s+1} e^{-17.58s} \qquad (3)$$

D. Control PID.

These controllers are widely used in the industry for its easy implementation, and come as a programming block in the PLC are physically teams that adjust the Kp, Ki, Kd gains (proportional gain, integral and derivative respectively) of the processes for those who have been required. Next, it is shown in Figure 7 the use of this type of controller to propose a cascaded control to the grinding process.

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This control consists of a PAP motor (stepping motor) and a model of the crusher where the input is the motor position PAP, both regulators are PID and control periods are not the same, the engine is 10 times less, than the control period of the main variable is the weight. The result of this simulation it can be seen in Figure 8.

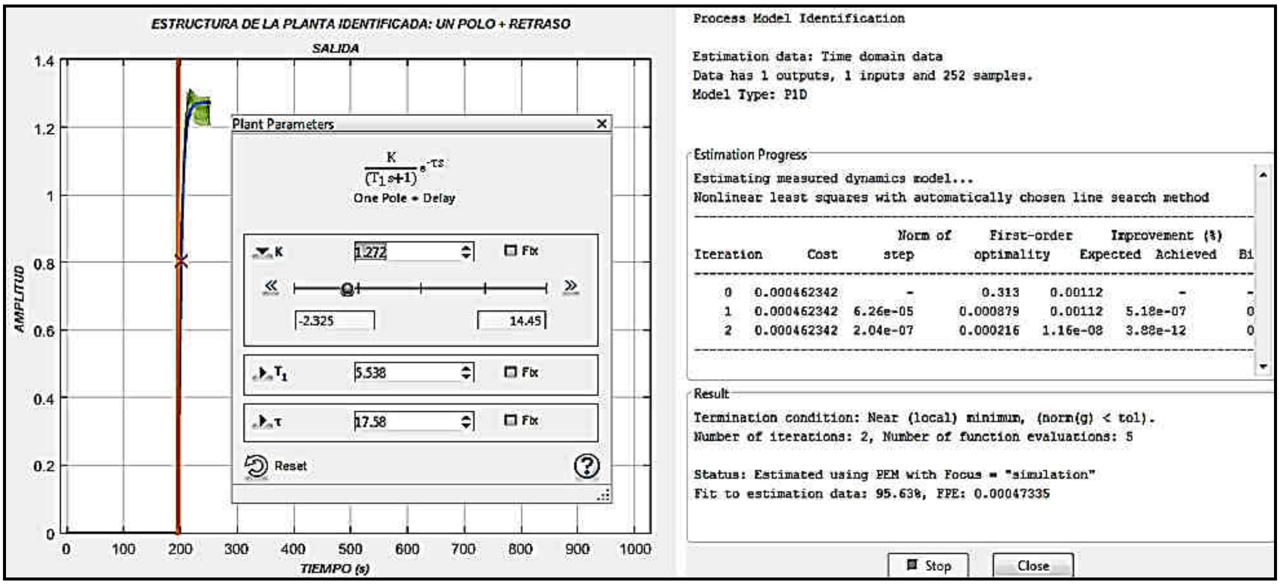

Figure 6. Results obtained with MATLAB® APPS, Source tool: Author..

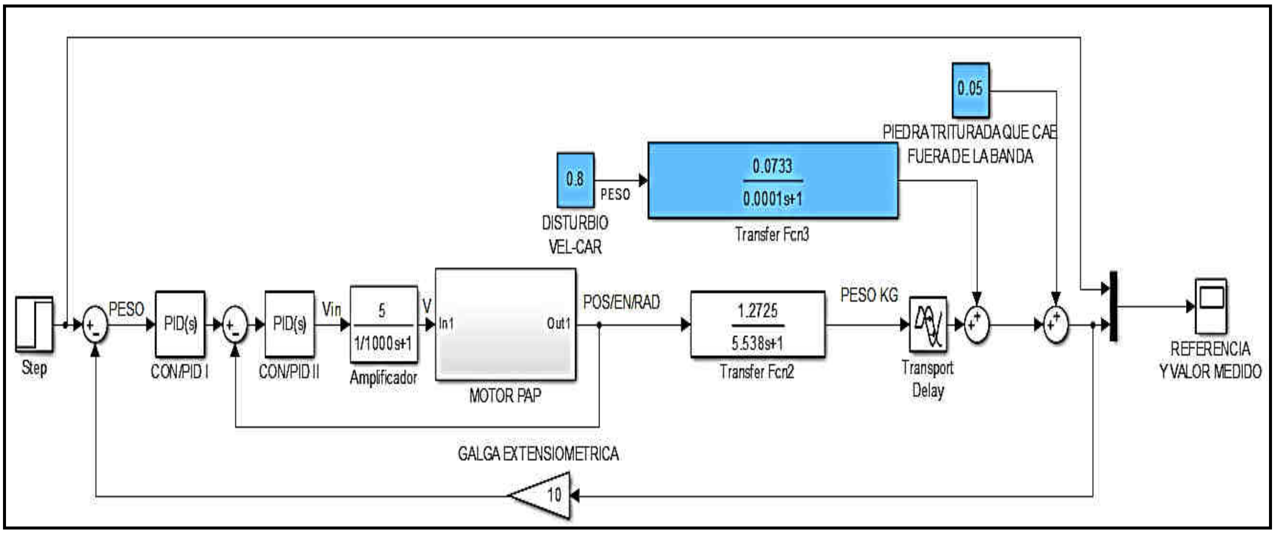

Figure 7. Cascade control scheme, raised to the crusher, Source: Author..

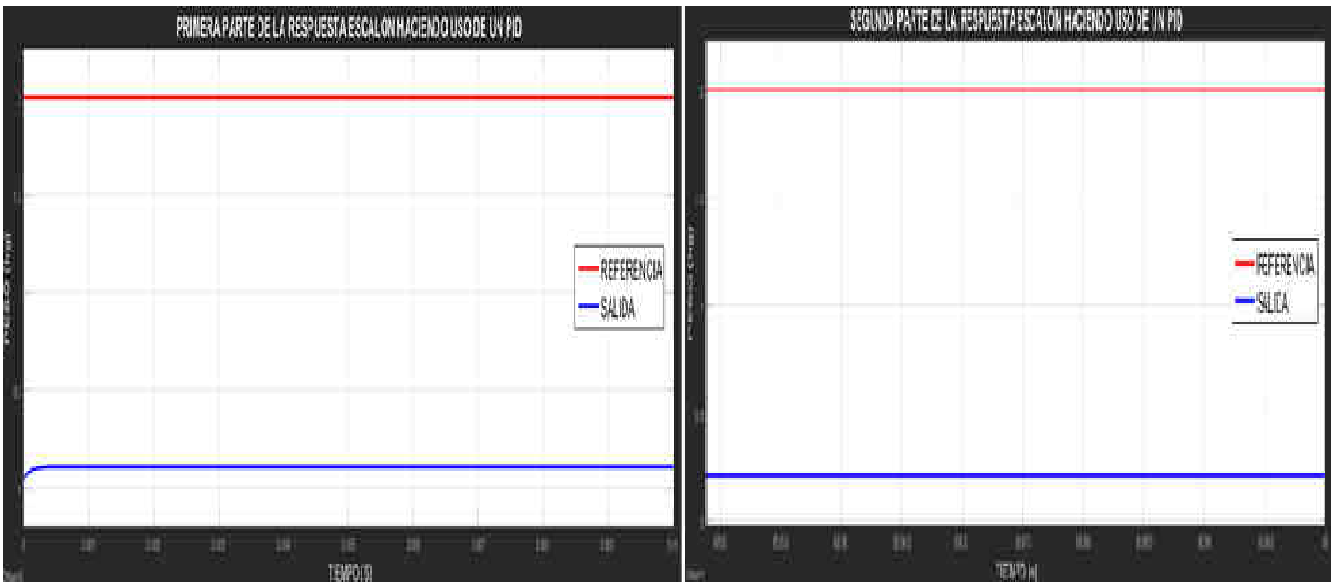

Figure 8. Response system with a PID signal, Source: Author.

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E. Controller with Smith Predictor

This type of controller used for systems with the large presence of delay, so that the control scheme of Figure 9, which would make a variant of that shown in Figure 7 proposed. Later, it became a control signal type reference sequence of values, increasing the sampling time can be better appreciated based on Smith predictor control. In Figure 10 you can see the first part of this monitoring, which lasted 10 seconds, this increased sampling time and the response time of the transfer function as the system delay decreased.

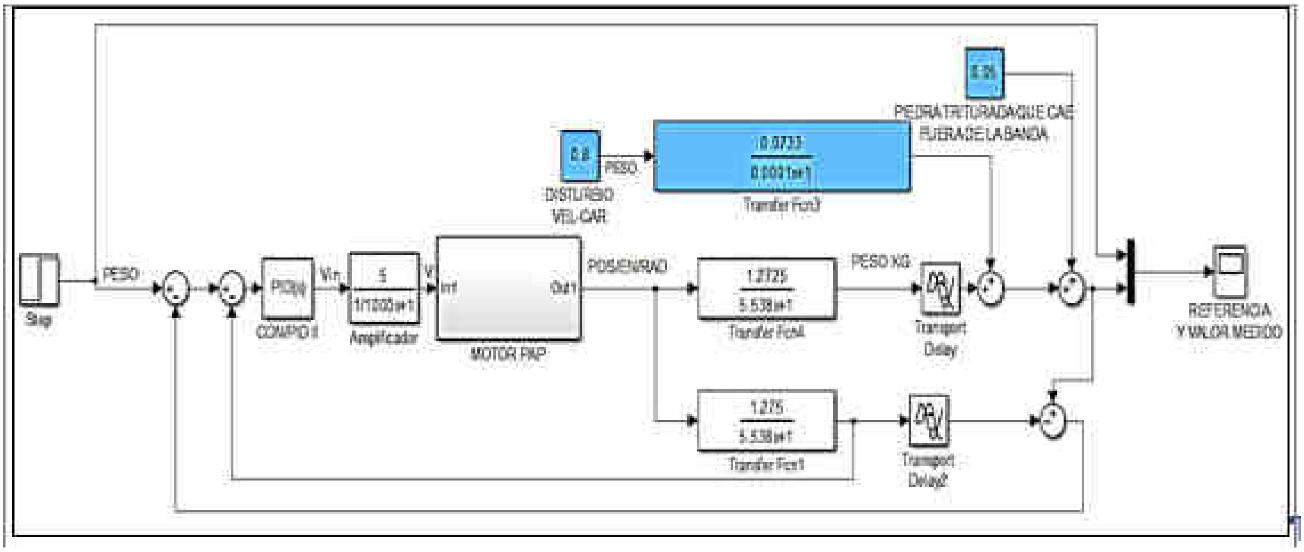

Figure 9. Response system with a PID signal, Source: Author

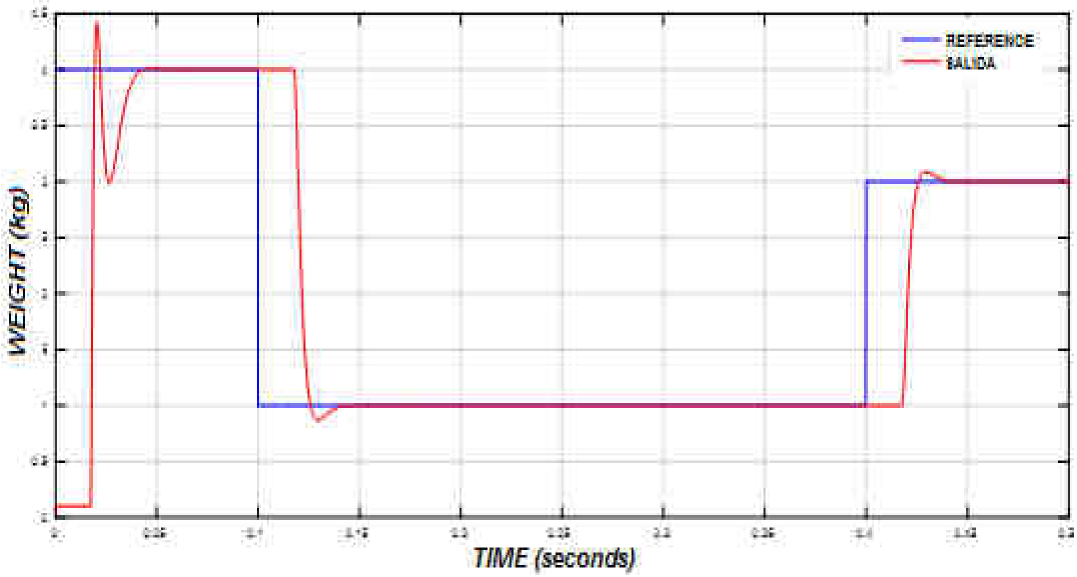

Figure 10. Response system using a Smith Predictor, Source: Author

III. Results

Then Table 2 shown to indicate the parameters that have been obtained when the process four different control techniques applied to a step input and 10 seconds simulation, as this the best result he is the Predictor Smith, pointing with red parameters of each strategy are not acceptable and are the reason for these procedures to dropped.

Table 2 Result of applying different drivers for the control loop.

	CONTROLLER1(PID)	CONTROLLER2 (PREDICTOR DE SMITH)
OVER	-5%	2 %
SHOOT		
SETTING TIME	17.58 s	37 s
RISE TIME	15 s	25 s
STABLE ERROR	0.2 kg	0,04 kg

IV. Conclusions

The mathematical model was first order and found with the APPS tool. Being used a classic cascade control in the system, because it gives a better solution than the control with a single controller, it is also more immune to disturbance and will have a faster and more accurate response.

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Then Table 2 shown to indicate the parameters that have been obtained when the process four different control techniques applied to a step input and 10 seconds simulation, as this the best result he is the Predictor Smith, pointing with red parameters of each strategy are not acceptable and are the reason for these procedures to dropped. By using a signal with different set points increased sampling time is produced and improves stabilization system time.

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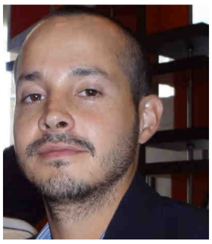

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