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Design Of A Melting Furnace Temperature Control With Active Disturbance Rejection

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ABSTRACT:

This paper presents the design of a control strategy based on the active rejection of disturbances, applied to the temperature regulation of a crucible furnace for the aluminum smelting process. For this purpose, the generalized proportional integral control was used, which was designed based on the simplified model of the furnace identified by means of the Matlab PIDtuner app.

When applying the designed control to the model, follow-up data were taken from the reference signal and analyzed using the percentage of quadratic error measured. This showed that the generalized integral proportional control applied to the system model obtained a mean square error percentage of 0.433%, and with a 50% variation of the model parameters the mean square error percentage was 2.88%.

Keywords: Aluminum smelter, active disturbance rejection, control, modeling, tracking error

INTRODUCTION

The aluminum smelting process is important for numerous industrial applications, this importance is reflected in the increase of quality requirements in the aluminum industries demanding a stable control of the process from its beginning and during its processing (Riedel et al., 2021). Currently, the Universidad Francisco de Paula Santander Ocaña (UFPSO), has an aluminum smelting laboratory, in which Mechanical Engineering students perform academic practices using a crucible furnace that uses motor fuel oil as fuel (Shvidkiy et al., 2018). This process is completely manual, and its success depends on the operator's expertise, which does not guarantee that the process meets the quality standards of aluminum smelting. The quality of the casting can be affected by lack of fluidity during solidification (Madki et al., 2022), which in turn is also affected by H2 and O2 gases, which are gases inherent to this melting process that affect the chemical composition, mechanical characteristics, physical and technological properties of the casting (Chandra Kandpal et al., 2021).

Performing this process manually generates losses of time and resources, since there is no control of the temperature reached for aluminum smelting or the amount of fuel burned to maintain the temperature in the furnace for complete melting of the material Zagoskina et al., 2019). The fact that this process is maintained in this way generates higher energy consumption (Shcherba et al., 2020).

For these reasons, the automation of this process is proposed, specifically the design of a control strategy that meets the working characteristics of the system, which are the tracking of a signal resulting from the combination of a ramp type signal and a step type signal with an overshoot of less than 25% and a tracking error of less than 15%, for this a control strategy based on active disturbance rejection (ADRC) is proposed. The GPI control strategy provides a tool for the design of controllers capable of rejecting different types of structured disturbances that add to the system response, being more robust against unknown constants (Zurita-Bustamante et al., 2011). This type of controller uses the simplified model of the system and rejects unmodeled dynamics (endogenous and exogenous system disturbances). It is designed in the framework of "active disturbance rejection(Coral-enriquez et al., 2015), and includes a polynomial time model of the state-dependent disturbances and those that are exogenous in nature without any special structure (Cortés-romero, 2015).

The paper is organized as follows: It starts with the introduction in section 1; section 2 presents the materials and methods, where the process description is shown. Section 3 presents the design of the GPI control. Section 4 presents the simulation results of the proposed control, and Section 5 presents some conclusions.

MATERIALS AND METHODS

The system for aluminum smelting consists of a cylindrical crucible furnace connected to an intake where the mixture of diesel and air enters, this mixture is given in the duct where the fuel enters by gravity, controlled by a throttle valve with a constant flow, on the other hand the air is injected into the system by a centrifugal fan driven by a three-phase motor of 1HP power at 1730rpm controlled by a variable speed drive, with which the furnace temperature is controlled as shown in Figure 1.

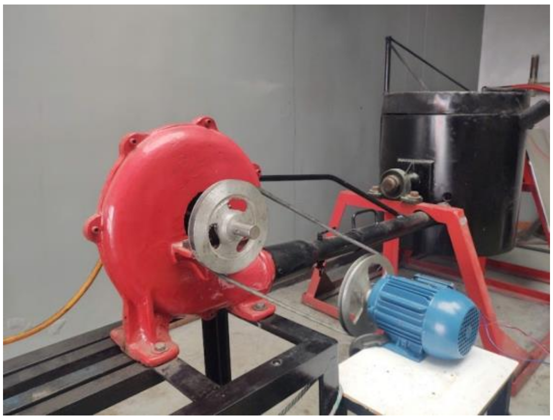

Figure 1. Crucible furnace with forced-air fuel injection.

For the temperature data acquisition and motor speed control a virtual instrument was made in labiew as shown in figure 2, the data acquisition was done through a NI CompactDAQ - cDAQ-9178 Chassis, for this a type k thermocouple was connected to the chassis through a NI 9213 C Series Temperature Input Module.

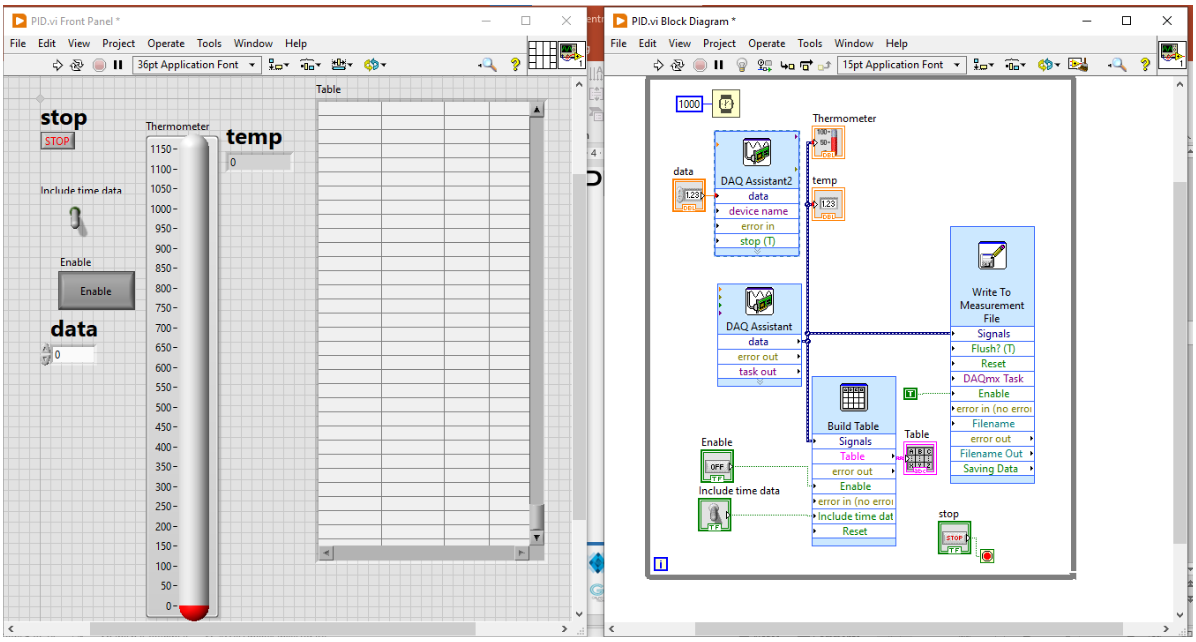

Figure 2. Virtual instrument for data acquisition.

For the identification of the approximate mathematical model of the system, a step type signal was sent to the system in open loop and the system response temperature data was taken as shown in Figure 3.

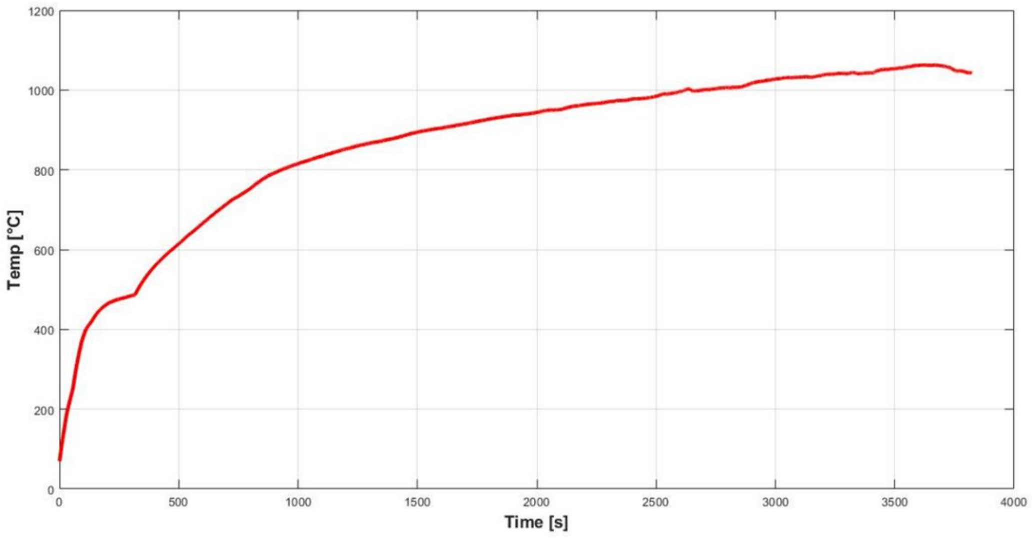

Figure 3. Temperature data taken.

Resulting in the approximate model shown in Figure 4, where the green line represents the response to the real model and the blue line represents the approximate model obtained by the Matlab PIDtuner app.

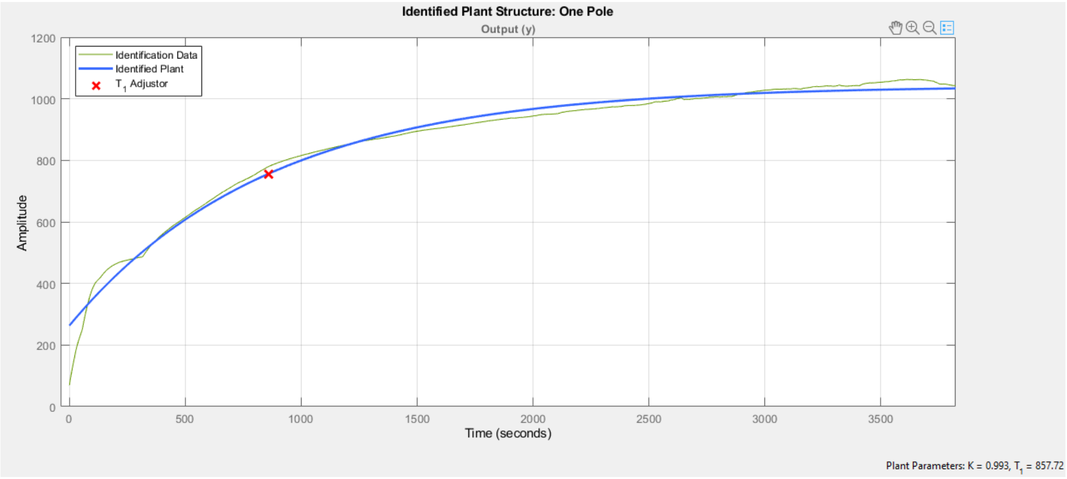

Figure 4. Matlab PIDtuner app.

This model is represented by the transfer function of Equation 1, which represents the simplified model of the system, which does not take into account the endogenous and exogenous characteristics that affect the dynamics of the system behavior, however, it is useful for the analysis.

$$G(s) = \frac{0.993}{857.72s+1} \qquad (1)$$

Figure 5 shows the step response graph of the system e where τ represents the time constant of the sstem equivalent to 63.2% of the final value of the signal.

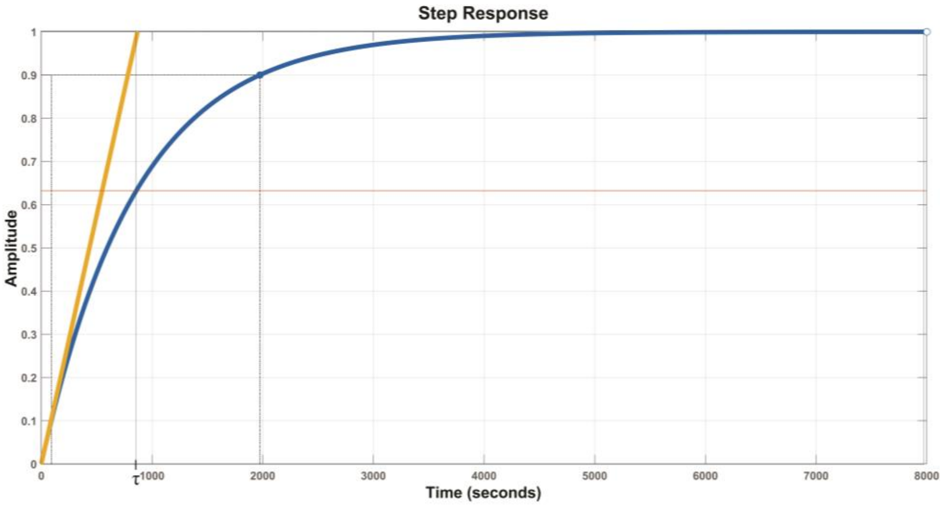

Figure 5. Step response.

DESIGN OF THE GPI CONTROL STRATEGY

As specified in equation 1 representing the simplified mathematical model of the system, this can be expressed as $G(s) = {}^{\theta_{(s)}}/_{\alpha_{(s)}}$ where $\theta_{(s)}$ represents the system outlet temperature and $\alpha_{(s)}$ the system inlet. Then it can be said that equation 1 can be expressed as:

$$\frac{\theta_{(s)}}{\alpha_{(s)}} = \frac{0.993}{857.72s + 1} \approx \frac{1}{\tau s + 1} \qquad (2)$$

Where τ represents the time constant of the system (858 seconds), in this same sense equation 2 can be expressed as a function of time as:

$$\frac{d\theta}{dt} = \frac{1}{\tau}\alpha - \frac{1}{\tau}\theta \quad (3)$$

Equation 3 representing the dynamic temperature behavior of the system, has the structure of a perturbed linear system represented by equation 4 according to (Regino et al., 2018)

$$y^{(n)}(t) = \kappa u(t) + \xi(t) \qquad (4)$$

The structure of the GPI control is shown in Equation 5, where κ is ${}^{1}/_{\tau}$ and the output Y of the system is the temperature θ in the furnace crucible; m is the order of the polynomial with which the perturbation is approximated; n is the order of the system; $K_{n+m}, \ldots, K_1, K_0$ correspond the gains of the polynomial of the numerator; and $Y^*$is the reference signal which for this case is equivalent to the combination of a ramp-type signal and a step-type signal as shown in Figure 6.

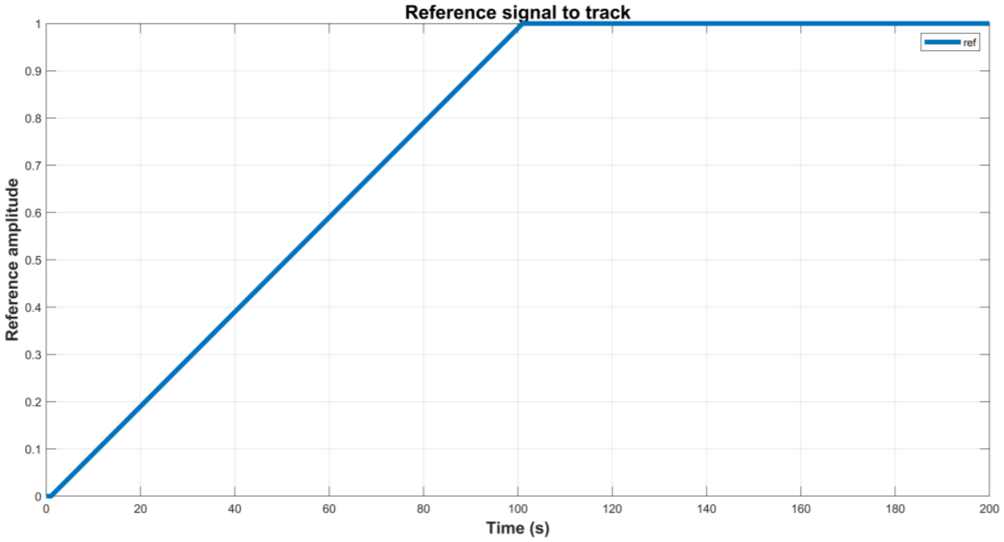

Figure 6. Reference signal to track.

$$U = \frac{1}{K}\left[y^{*(n)} + \left(\frac{K_{n+m}s^{n+m}+\cdots+K_1 s+K_0}{s^{m+1}(s^{n-1}+K_{2n+m-1}s^{n-2}+\cdots K_{n+m+1})}\right)(y^* - y)\right] \quad (5)$$

Considering that the system is of first order and it is desired to approximate the perturbation with a polynomial of order 2, equation 5 remains:

$$U = \tau\left[y^{*(1)} + \left(\frac{K_3 s^3 + K_2 s^2 + K_1 s + K_0}{s^3}\right)(y^* - y)\right] \quad (6)$$

In The coefficients K_3, K_2, K_1 and K_0 are chosen such that the roots of the polynomial are on the left side of the complex plane, the tracking error will be bounded and the coordinate can be made as small as desired.

RESULTS AND DISCUSSIONS

Taking into account that the objective of the control is the monitoring of a specific signal since the aluminum smelting process indicates it, the mean square error between the reference signal and the output signal is taken as a monitoring measure. In this case, a traditional PID control strategy is established to make the comparison between this and the proposed control strategy.

The analysis of the results will be presented as follows, first, compare the results of the GPI control strategy and PID control strategy, the idea is to observe the behavior of these strategies to a variation of system parameters, other data to analyze is the behavior of the system to the variation of the poles of the polynomial characteristic of the GPI controller.

The graph in Figure 7 shows the tracking of the reference signal when applying a PID control strategy. When buying the two signals the mean square error resulting from the application of this control strategy is 11.62%.

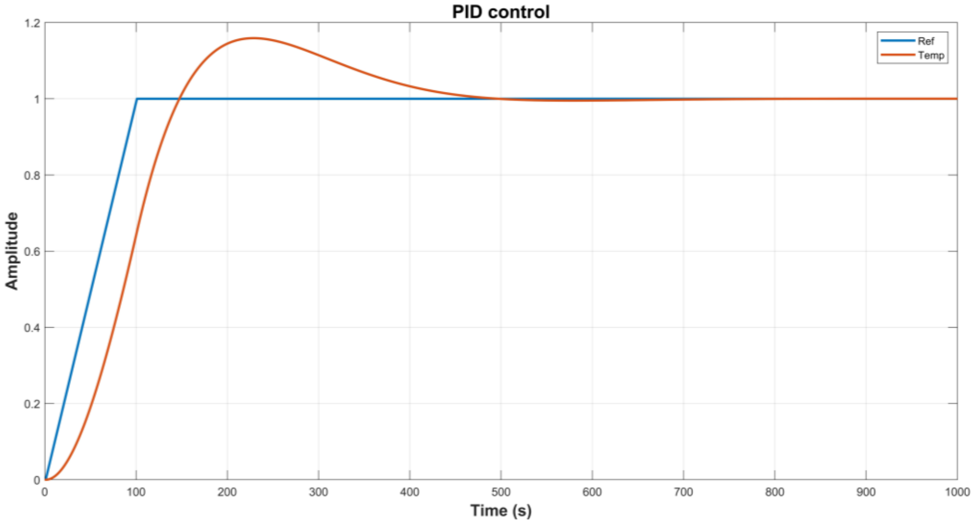

Figure 7. Tracking of the reference signal.

A variation of parameters at the time constant of 10% to 50% was performed, resulting in an increase in the tracking error from 11.62% to 15.73% as shown in the graph in Figure 8.

For the GPI control strategy, the roots of the characteristic polynomial of the controller were selected in such a way that the constants of

The graph in Figure 9 shows the tracking of the reference signal when applying a GPI control strategy. When buying the two signals the mean square error resulting from the application of this control strategy is 0.433%.

A variation of parameters at the time constant of 10% to 50% was performed resulting in an increase in the tracking error from 0.43% to 2.88% as shown in the graph in Figure 10.

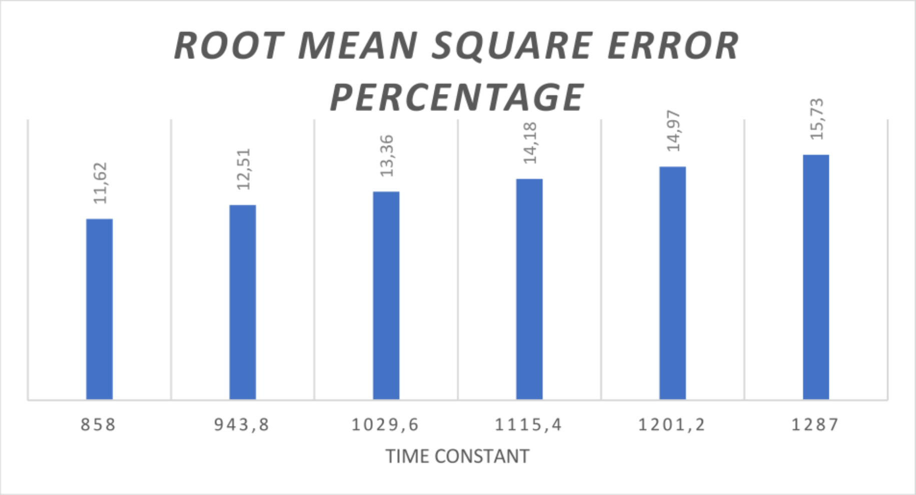

Figure 8. Root mean square error percentage.

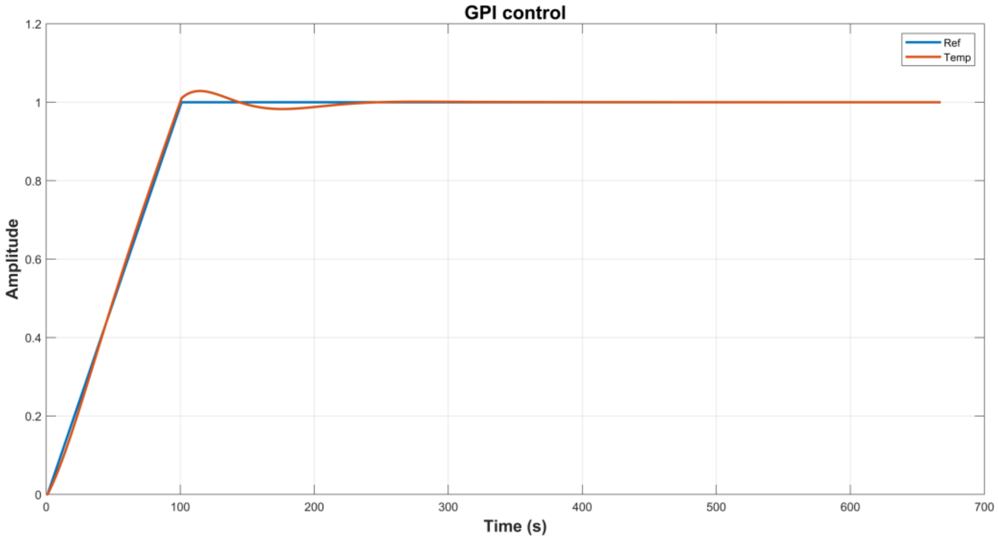

Figure 9. Tracking of the reference signal.

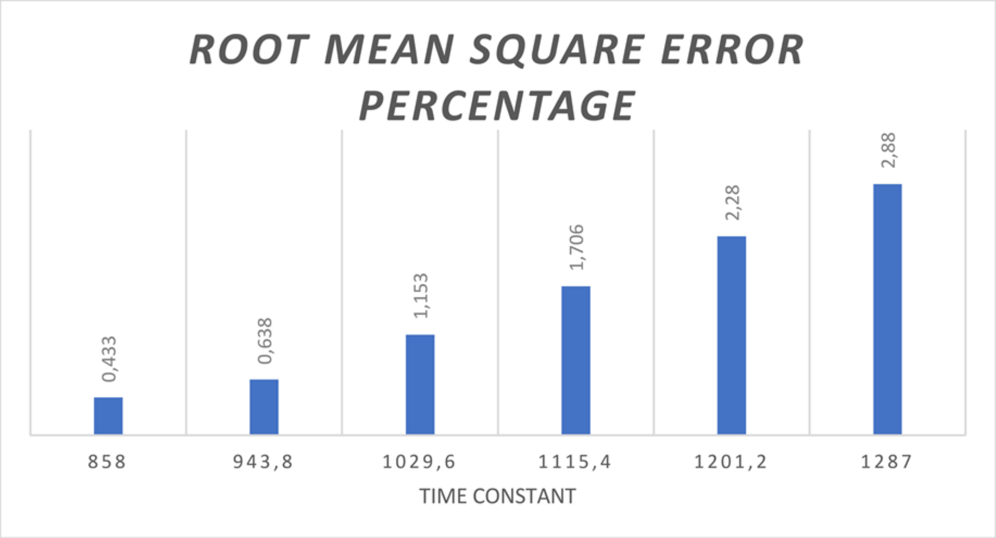

Figure 10. Root mean square error percentage.

CONCLUSIONS

The control strategies based on the active rejection of disturbances such as GPI control, have substantial advantages over a traditional control strategy such as PID control, this is evidenced in the tracking error, where the GPI control obtained a percentage of mean square error less than unity.

The two control strategies meet the objectives, in terms of parameter variation the GPI control has a superior performance, since with a variation of 50% in the model, the mean square error percentage was less than 3%. This is a good indicator of robustness to the uncertainty that the system model could present.

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