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BACKSTEPPING AND PIV CONTROL APPLIED TO MAGNETIC LEVITATION

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Abstract. *In this work, we have compared two methodologies to design control in a nonlinear magnetic levitation plant. The design controllers are backstepping and PIV. The performance analysis was studied considering the steady state error, settling time and maximum overshoot. The plant considering in this paper has one input that is electric current, and three outputs that are electric current, position and velocity of steel ball. The backstepping control has shown a bigger steady-state error than PIV control, but the oscillation of the ball position is smaller for the backstepping than PIV.*

Keywords: *control, backstepping, nonlinear, PIV.*

1. INTRODUCTION

The magnetic levitation plant (MagLev) is an electromagnetic action on a solid one-inch steel ball in order to control and actuate its suspension. It mainly consists of an electromagnet, located at the upper part of the apparatus, capable of lifting from its pedestal and sustaining in free space a steel ball. Two system variables are directly measured on the maglev rig and available for feedback. They are namely: the coil current and the ball distance from electromagnet face according to the MagLev User Manual.

Figure 1. The MAGLEV apparatus

The backstepping control methodology consists in a recursive selection of some appropriate state variable functions as pseudocontrol inputs for lower dimension subsystems of the overall system. Each backstepping stage results in a new pseudocontrol design, expressed in terms of the pseudocontrol inputs from the preceding design stages. At the end of this recursion, a feedback design for the true control input in obtained. The final control function achieves the original design objective by means of a final Lyapunov function, formed by summing up the Lyapunov functions associated with each individual design stage. Thus, the backstepping control approach is capable of keeping the robustness properties with respect to the uncertainties (Khalil, 2002).

In this work the backstepping control method is applied in the magnetic levitation plant with the objective to make the ball follow a reference trajectory achieving a smaller error in comparison to the manufacturer’s standard control, which is the PIV control.

2. EXPERIMENTAL PROCEDURE

2.1 Mathematical model

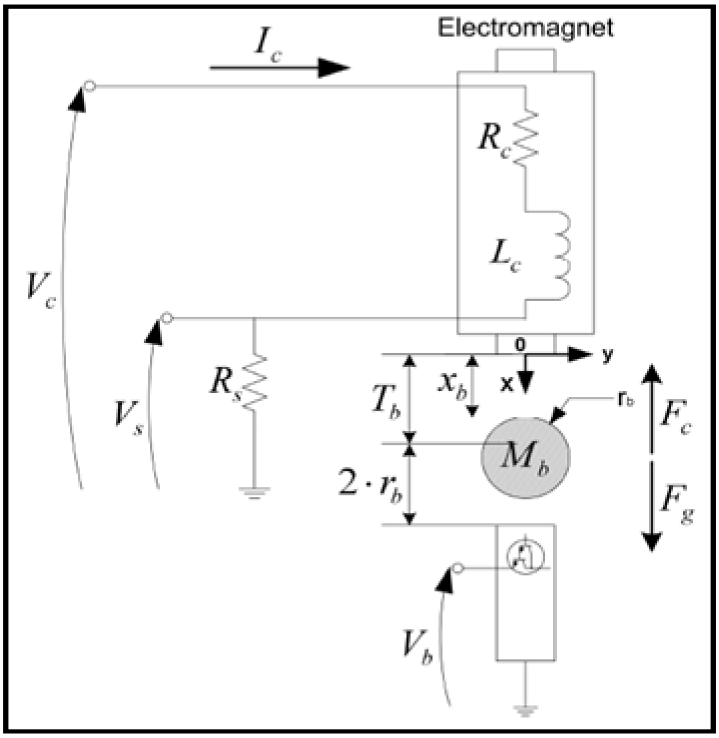

Figure 2. Schematic of the MAGLEV Plant

In figure 2 the schematic of the MAGLEV Plant is represented. In this figure we can see the ball on the middle and the electromagnet on the top. Furthermore, we have a representation of all variables that involved in this problem like the ball mass (M_b), gravity force (F_g), electromagnet force (F_c), distance from electromagnet (x_b) an the current (I_c)

The force due to gravity applied on the ball is expressed by:

$$F_g = M_b g \tag{1}$$

The attractive force, generated by the electromagnet and acting on the steel ball is assumed to be expressed as:

$$F_c = \frac{1}{2}\frac{K_m I_c^2}{x_b^2} \tag{2}$$

Applying the Newton's second law of motion to the ball, the following nonlinear equation of motion is obtained:

$$F_g + F_c = M_b g + \frac{1}{2}\frac{K_m I_c^2}{x_b^2} \tag{3}$$

$$F_g + F_c = M_b \ddot{x_b}$$

Then we can write $\ddot{x_b}$ like:

$$\frac{d^2 x_b}{dt^2} = g - \frac{1}{2}\frac{K_m I_c^2}{M_b x_b^2} \tag{4}$$

At equilibrium, all time derivatives terms are equal to zero and equations become:

$$0 = g - \frac{1}{2}\frac{K_m I_c^2}{M_b x_b^2} \tag{5}$$

From equation (5) we can write I_c ans I_{c0} like:

$$I_c = \sqrt{2}\sqrt{\frac{M_b g}{K_m}} X_b \tag{6}$$

$$I_{c0} = \sqrt{2}\sqrt{\frac{M_b g}{K_m}} X_{b0} \tag{7}$$

2.2 Backstepping Project

First of all we wrote the system (4) in variable of states (x_1 and x_2) and define the control variable u.

$$x_1 = x_b$$

$$x_2 = \dot{x_b} \tag{8}$$

$$u = I_c^2 - I_0^2$$

$$\begin{cases} \dot{x_1} = x_2 \\ \dot{x_2} = g - \frac{x_0^2}{x_1^2} - \frac{k_m}{2m_b x_b^2} u \end{cases} \tag{9}$$

After that we define new variables of states z_1 e z_2 and a virtual controller α_1

$$z_1 = x_1 - x_0$$

$$z_2 = x_2 - \alpha_1 - \dot{x_0} \tag{10}$$

Then we define a candidate to Lyapunov function positive defined and design the virtual controller to get a derived negative defined.

$$V_1 = \frac{1}{2} z_1^2$$

$$\dot{V_1} = z_1 \dot{z_1}$$

$$\dot{V_1} = z_1(\dot{x_1} - \dot{x_0}) \tag{11}$$

$$\dot{V_1} = z_1(x_2 - \dot{x_0})$$

$$\dot{V_1} = z_1(z_2 + \alpha_1)$$

$$\alpha_1 = -k_1 z_1$$

$$\dot{V_1} = -k_1 z_1^2 + z_1 z_2 \tag{12}$$

In the second step we define a new candidate to Lyapunov function positive defined and design the controller u to get a derived negative defined:

$$V_2 = V_1 + \frac{1}{2} z_2^2$$

$$\dot{V_2} = \dot{V_1} + z_2 \dot{z_2}$$

$$\dot{V_2} = -k_1 z_1^2 + z_1 z_2 + z_2(\dot{x_2} + \dot{\alpha_1} + \ddot{x_0}) \tag{13}$$

$$\dot{V_2} = -k_1 z_1^2 + z_2(z_1 + g - \frac{x_0^2}{x_1^2} - \frac{k_m}{2m_b x_b^2} u + k_1 \dot{z_1} + \ddot{x_0})$$

$$u = \frac{2m_b x_b^2}{k_m}\left[z_1 + g - \frac{x_0^2}{x_1^2} + k_1 \dot{z_1} + \ddot{x_0} - k_2 z_2\right]$$

$$\dot{V_2} = -k_1 z_1^2 - k_2 z_2^2 \tag{14}$$

3. RESULTS AND DISCUSSION

3.1 PIV design

According to the MagLev User Manual from Quanser, the PIV is a control strategy to regulate and track in mid-air the ball position. This type of control is designed to compensate small variations from the linearized operating point, it means that the controller compensates for dynamic disturbances.

The PIV implementation used for the purpose of this paper is designed by the MAGLEV's manufacturer. The program below is the default code for the manufacturer´s plant. All the plant parameters were originally set by the manufacturer.

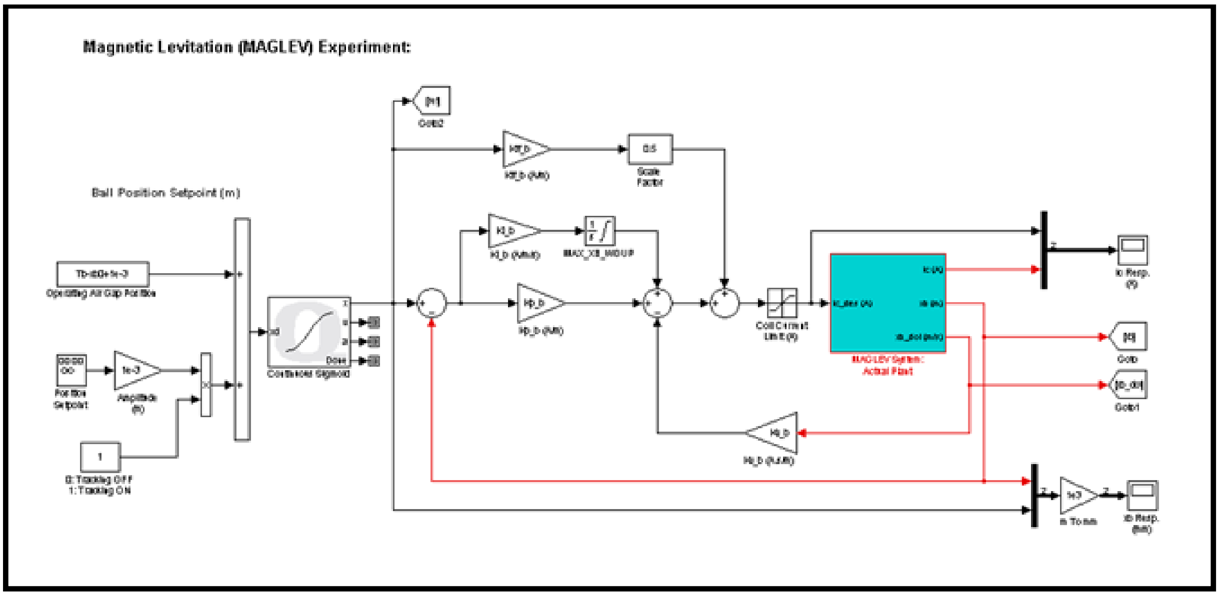

Figure 3. Simulink schematic for magnetic levitation using PIV control design

Simulations then are performed for PIV method design and figure 4 and 5 depict the results.

Figure 4 show the time evolution of the ball position and the signal reference input. Pink line represents the input referential signal , yellow line represents the ball position From the figure 4 is possible to see that the ball position error is around 3% of the input value

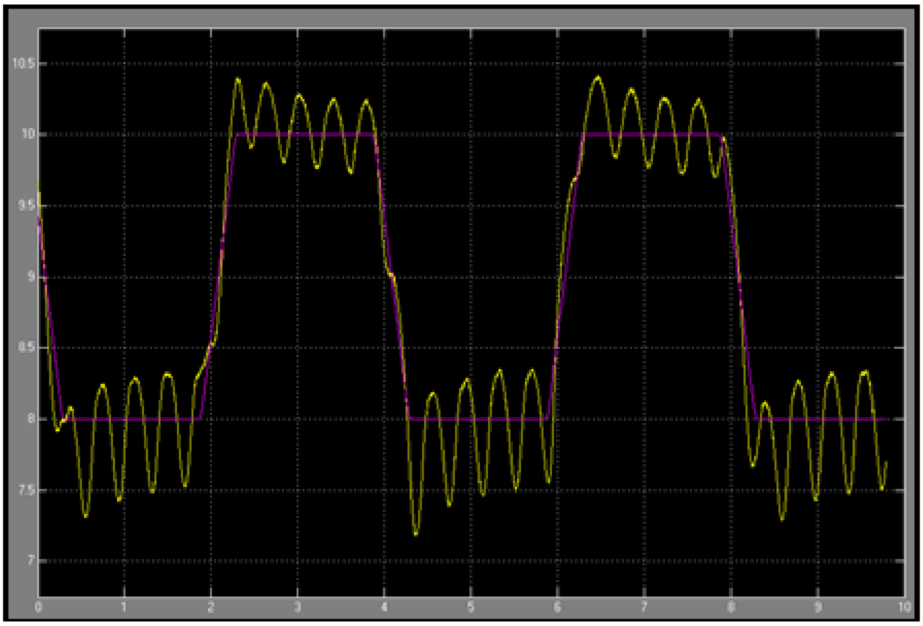

Figure 4. Ball's position compared to input signal

Figure 5 represents the comparison of the current calculed by the controller and the output current from the maglev plant. In yellow signal is represented the output current and in pink the input current. Fig 5 shows that the current curves are aligned.

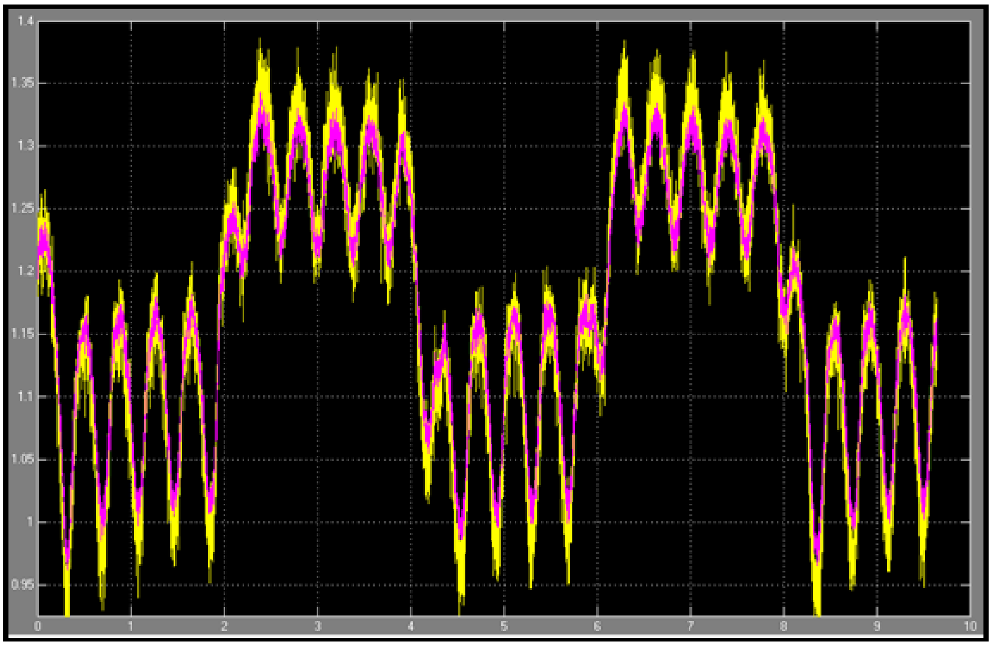

Figure 5. Comparison of the input current and the signal generated by the MAGLEV

4.2 Backstepping Project

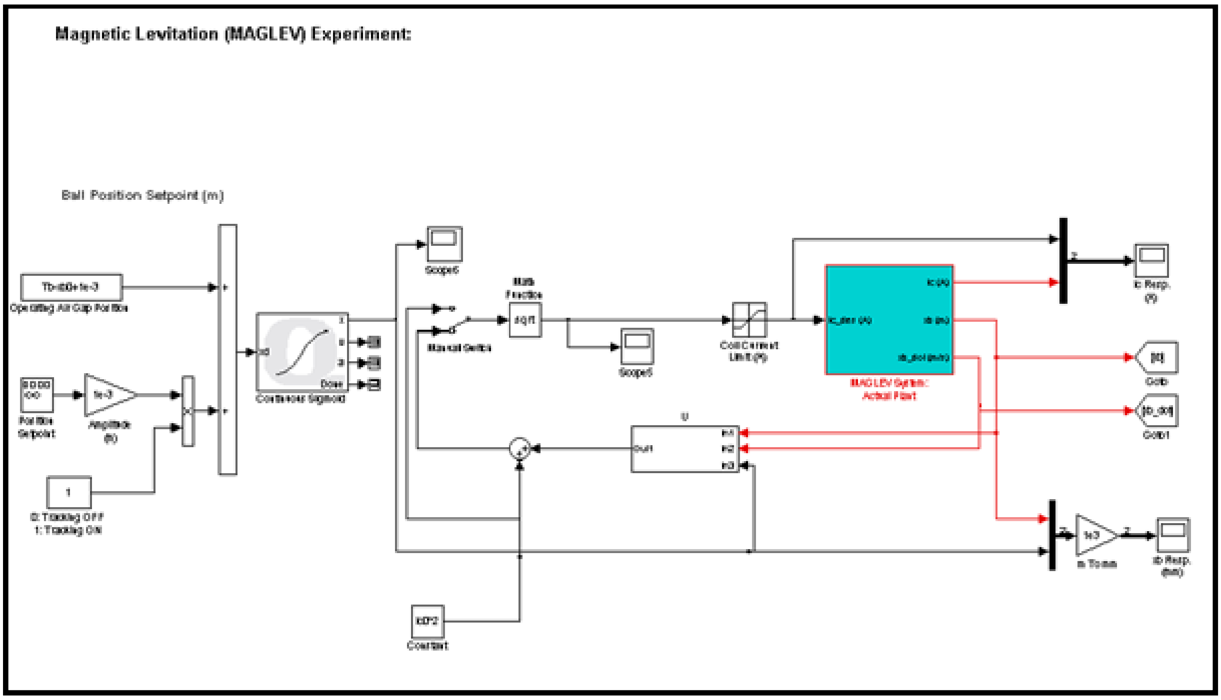

Figure 6. Simulink schematic for magnetic levitation using backstepping control

In the past figure the blue square represents the magnetic levitator, it has one input (electric current), and three outputs (electric current, ball position, velocity). In the left side it is possible to observe how the square wave signal is generated. Then a closed loop is made using the design control "u".

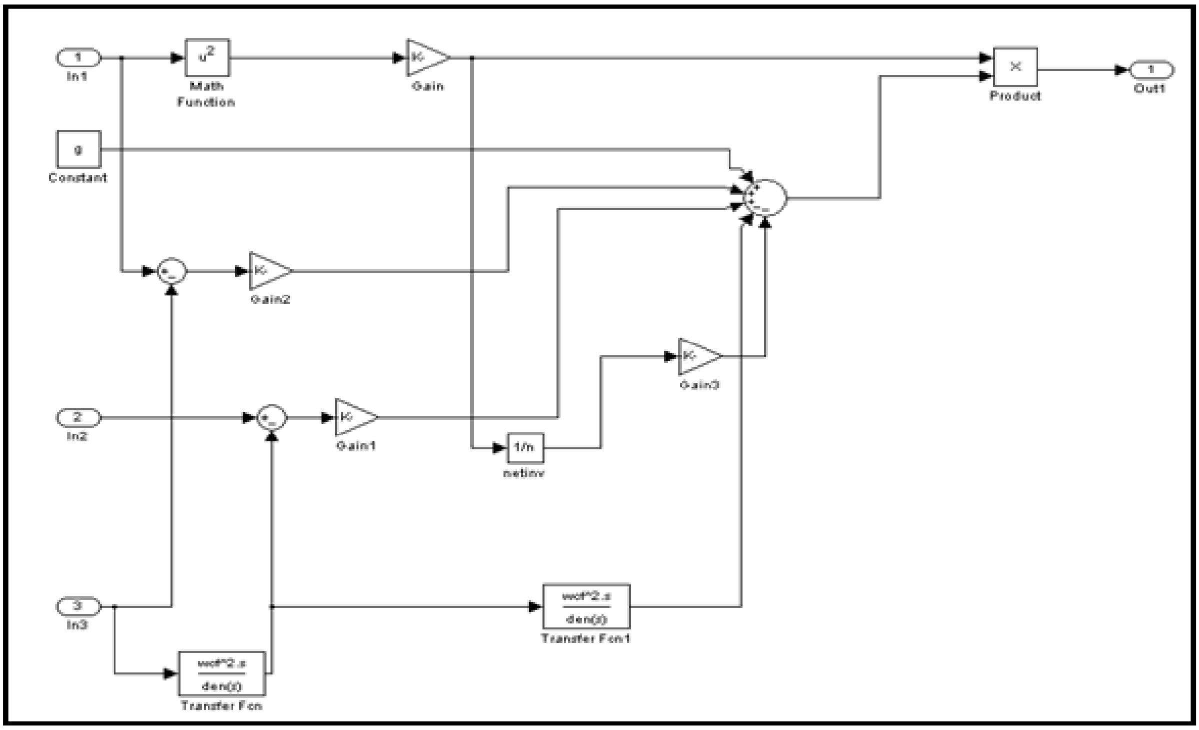

Figure 7. Simulink schematic of the design control of the Backstapping block

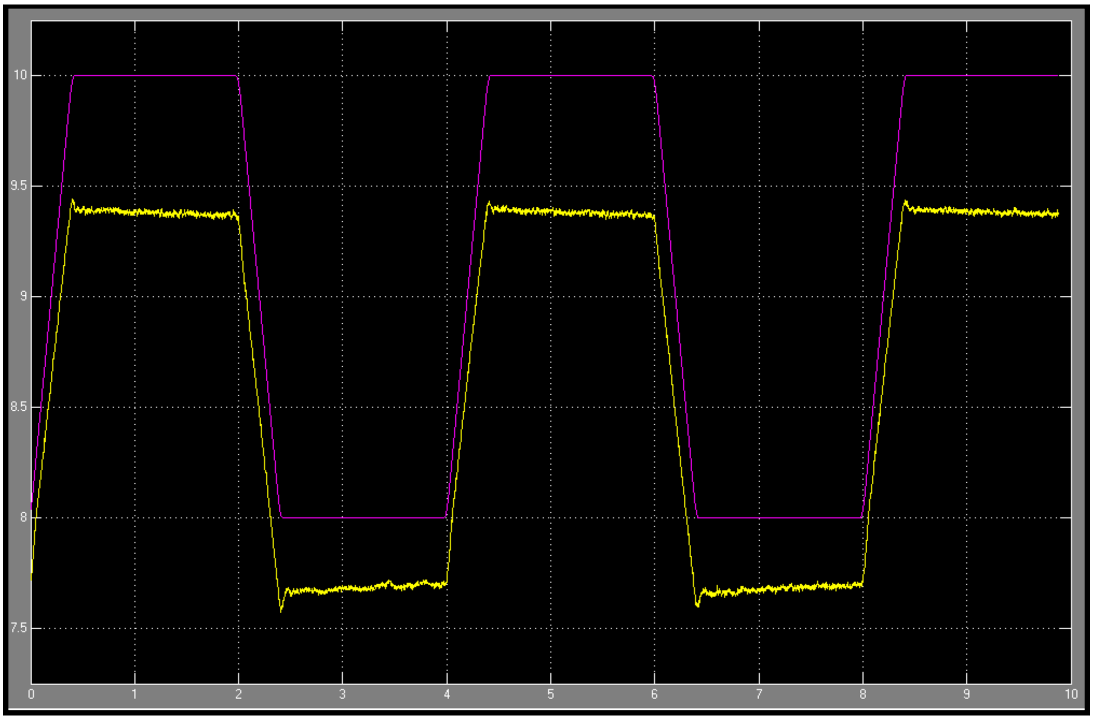

Figure 8. Ball's position compared to input signal using Backstepping control

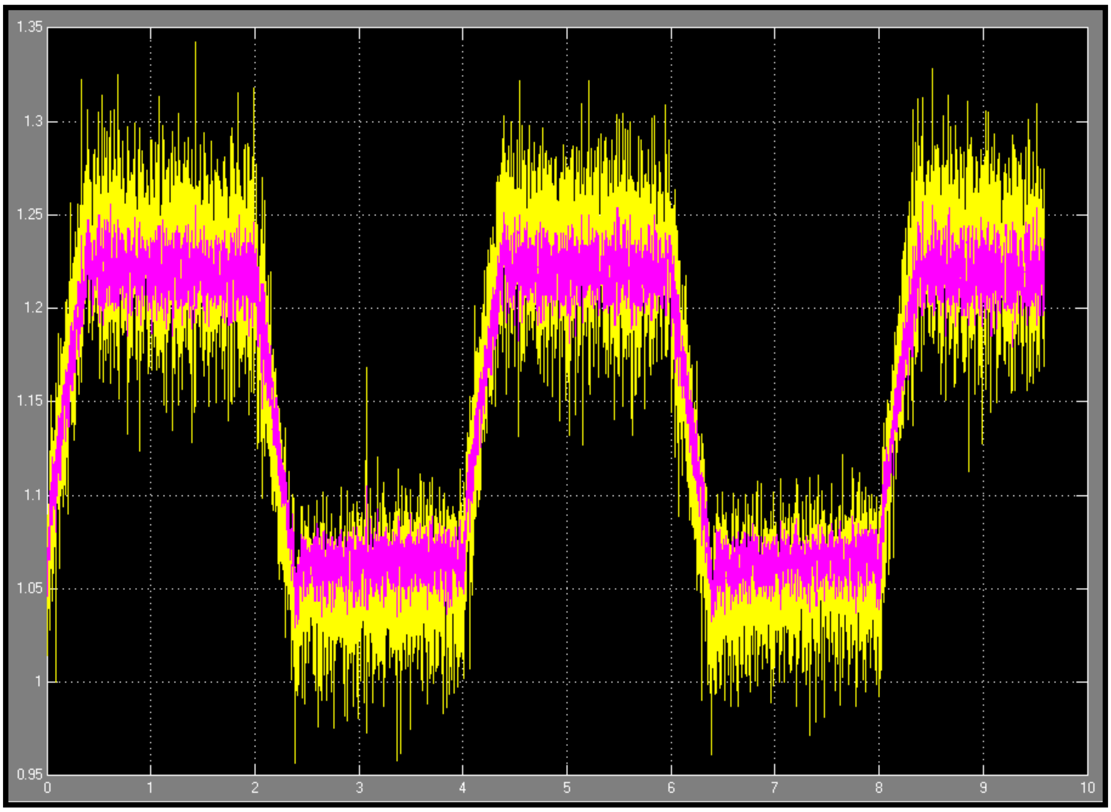

Figure 9. Comparison of the input current and the signal generated by the MAGLEV

These figures show that the Backstepping control has a bigger robustness and stability than the PIV one, but the error is higher than the previous method. The error is around 7% of the input value, but it's possible to reach a minimal oscillation in the stationary state.

4. CONCLUSIONS

During the tests it was possible to verify that the system's behaviour with the PIV control was better than the backstepping control.

The system working with the 2-state Backstepping control showed a major error on the ball's position in comparison to the input signal and the expected response.

The system working with the PIV control has an oscillation error that makes the system's response, the ball's position, circle around the value of the input signal, and this oscillation's error is not as huge as the backstepping control's error in the output.

It is possible that this error on the backstepping case could be minimized using not a 2-stage Backstepping control, but a 3-state Backstepping control or an adaptive-Backstepping control that might be designed and developed in a further research, making this type of control a better solution to this problem instead of using the PIV control.

5. REFERENCES

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Quanser, 2012. *MagLev User Manual.* Markham, Ontario.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.