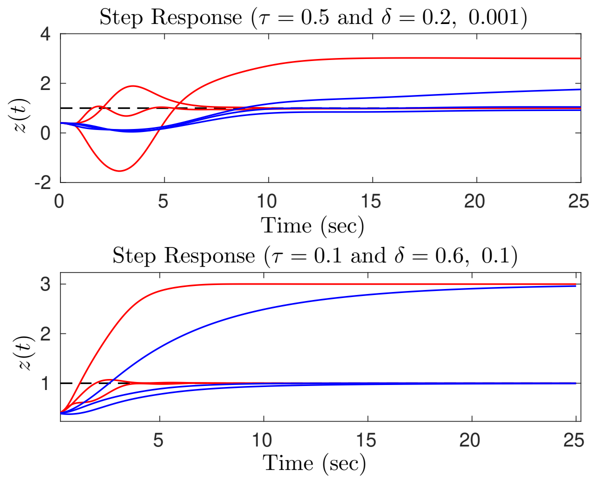

Figura 9. Closed-loop step response for designed controllers with parameter δ. In the first figure: red line ($\delta = 0.2$) and blue line ($\delta = 0.001$), second figure: the red line ($\delta = 0.6$) and blue line ($\delta = 0.1$). Example 3.

Araújo, J.M. and Santos, T.L.M. (2018). Control of a class of second-order linear vibrating systems with time-delay: Smith predictor approach. *Mechanical Systems and Signal Processing*, 108, 173–187.

Belotti, R. and Richiedei, D. (2020). Pole assignment in vibrating systems with time delay: An approach embedding an a-priori stability condition based on linear matrix inequality. *Mechanical Systems and Signal Processing*, 137, 106396.

Fenili, E.P., Souza, F.O., and Mozelli, L.A. (2014). Sintonia de pid via lmis: imposiçao de tempo de acomodaçao em sistemas com retardo no tempo incerto. In *Anais do XX Congresso Brasileiro de Automática*, 1127–1134.

Hiramoto, K. and Grigoriadis, K.M. (2016). Active/semi-active hybrid control for motion and vibration control of mechanical and structural systems. *Journal of Vibration and Control*, 22(11), 2704–2718.

Natori, K., Oboe, R., and Ohnishi, K. (2008). Stability analysis and practical design procedure of time delayed control systems with communication disturbance observer. *IEEE Transactions on Industrial Informatics*, 4(3), 185–197.

Ram, Y., Mottershead, J., and Tehrani, M. (2011). Partial pole placement with time delay in structures using the receptance and the system matrices. *Linear Algebra and Its Applications*, 434(7), 1689–1696.

Santos, T.L., Araújo, J.M., and Franklin, T.S. (2018). Receptance-based stability criterion for second-order linear systems with time-varying delay. *Mechanical Systems and Signal Processing*, 110, 428–441.

Seguy, S., Insperger, T., Arnaud, L., Dessein, G., and Peigné, G. (2010). On the stability of high-speed milling with spindle speed variation. *The International Journal of Advanced Manufacturing Technology*, 48(9), 883–895.

Xia, X., Liu, P., Zhang, N., Ning, D., Zheng, M., and Du, H. (2019). Takagi-sugeno fuzzy control for the semi-active seat suspension with an electromagnetic damper. In *2019 3rd Conference on Vehicle Control and Intelligence (CVCI)*, 1–6. IEEE.

Yu, Y., Guo, J., Li, L., Song, G., Li, P., and Ou, J. (2015). Experimental study of wireless structural vibration control considering different time delays. *Smart Materials and Structures*, 24(4), 045005.

Zhang, J.F., Ouyang, H., Zhang, K.W., and Liu, H.M. (2020). Stability test and dominant eigenvalues computation for second-order linear systems with multiple time-delays using receptance method. *Mechanical Systems and Signal Processing*, 137, 106180.

Zhang, S.Q., Zhang, X.Y., Ji, H.L., Ying, S.S., and Schmidt, R. (2021). A refined disturbance rejection control for vibration suppression of smart structures under unknown disturbances. *Journal of Low Frequency Noise, Vibration and Active Control*, 40(1), 427–441.

Appendix A. AUXILIARY RESULTS

Lemma 1. (Fenili et al., 2014): Consider the system $\dot{x}(t) = Ax(t) + A_d x(t - d(t))$. Let $\tau > 0$ and $0 \leq \mu \leq \tau$ be given , such that $d(t) \in [\tau - \mu, \tau + \mu]$, and $\delta > 0$, the exponential convergence rate. So the system with $d(t) \in [\tau - \mu, \tau + \mu]$ is exponentially stable, with exponential convergence rate δ, if there are matrices of appropriate dimensions: $F, G, P = P^T, S = S^T, Q, R_1 = R_1^T, R_2, R_3 = R_3^T, Z = Z^T$, such that the LMIs below are satisfied

$$\begin{bmatrix} P & \star \\ Q^T & \varepsilon_1 S \end{bmatrix} > 0, \tag{A.1}$$

where $\varepsilon_1 = e^{-2\delta\tau}/\tau$,

$$R = \begin{bmatrix} R_1 & \star \\ R_2 & R_3 \end{bmatrix} > 0, \tag{A.2}$$

and

$$\left[\begin{array}{c|c} \Xi & \star \\ \hline \Gamma^T & \varepsilon_2^{-1}\mu Z \end{array}\right] < 0, \tag{A.3}$$

where $\varepsilon_2 = e^{-2\delta(\tau+\mu)}$, $\Gamma^T = \mu[A_d^T F^T \quad \alpha A_d^T G^T \quad 0 \quad 0]$ and Ξ is give:

$$\Xi = \begin{bmatrix} \mathcal{F} & \star & \star & \star \\ P + \tau R_2 - \epsilon_2(F^T - GA) & \tau R_3 + 2\mu Z - \epsilon_2(G + G^T) & \star & \star \\ \epsilon_1 R_3^T - Q^T + \epsilon_2 A_d^T F^T & \epsilon_2 A_d^T G^T & -\epsilon_1(R_3 + \tau S) & \star \\ 2\delta Q^T - \epsilon_1 R_2^T & Q^T & \epsilon_1 R_2^T & -\epsilon_1 R_1 \end{bmatrix} \tag{A.4}$$

where $\mathcal{F} = 2\delta P + Q + Q^T + \tau R_1 - \epsilon_1 R_3 + S + \varepsilon_2(AF^T + FA^T)$.

ISSN: 2525-8311

DOI: 10.20906/CBA2022/3601