



















- ISA Transactions, 66: 344-361. <https://doi.org/10.1016/j.isatra.2016.09.021>
- [9] Ranganayakulu, R., Babu, G.U.B., Rao, A.S. (2018). Analytical design of Enhanced Fractional filter PID controller for improved disturbance rejection of second order plus time delay processes. *Chemical Product and Process Modeling*, 14(1). <https://doi.org/10.1515/cppm-2018-0012>
- [10] Padula, F., Visioli, A. (2013). Set-point weight tuning rules for fractional-order PID controllers. *Asian Journal of Control*, 4: 1-13. <https://doi.org/10.1002/asjc.634>
- [11] Das, S., Saha, S., Das, S., Gupta, A. (2011). On the selection of tuning methodology of FOPID controllers for the control of higher order processes. *ISA Transactions*, 50(3): 376-388. <https://doi.org/10.1016/j.isatra.2011.02.003>
- [12] Tavakoli-Kakhki, M., Haeri, M. (2011). Fractional order model reduction approach based on retention of the dominant dynamics: Application in IMC based tuning of FOPI and FOPID controllers. *ISA Transactions*, 50(3): 432-442. <https://doi.org/10.1016/j.isatra.2011.02.002>
- [13] Liu, L., Pan, F., Xue, D. (2015). Variable-order fuzzy fractional PID controller. *ISA Transactions*, 55: 227-233. <https://doi.org/10.1016/j.isatra.2014.09.012>
- [14] Zeng, G.Q., Chen, J., Dai, Y.X., Li, L.M., Zheng, C.W., Chen, M.R. (2015). Design of fractional order PID controller for automatic regulator voltage system based on multi-objective extremal optimization. *Neurocomputing*, 160: 173-184. <https://doi.org/10.1016/j.neucom.2015.02.051>
- [15] Shamsuzzoha, M., Skliar, M., Lee, M. (2012). Design of IMC filter for PID control strategy of open-loop unstable processes with time delay. *Asia-Pacific Journal of Chemical Engineering*, 7: 93-110. <https://doi.org/10.1002/apj.497>
- [16] Vinopraba, T., Sivakumaran, N., Narayanan, S., Radhakrishnan, T.K. (2012). Design of internal model control based fractional order PID controller. *Journal of Control Theory and Applications*, 10(3): 297-302. <https://doi.org/10.1007/s11768-012-1044-4>
- [17] Bettayeb, M., Mansouri, R. (2014). Fractional IMC-PID-filter controllers design for non integer order systems. *Journal of Process Control*, 24(4): 261-271. <https://doi.org/10.1016/j.jprocont.2014.01.014>
- [18] Li, D., Liu, L., Jin, Q., Hirasawa, K. (2015). Maximum sensitivity based fractional IMC-PID controller design for non-integer order system with time delay. *Journal of Process Control*, 31: 17-29. <https://doi.org/10.1016/j.jprocont.2015.04.001>
- [19] Morari, M., Zafiriou, E. (1989). *Robust Process Control*. Prentice hall: Englewood Cliffs, NJ.
- [20] Alfaro, V.M., Vilanova, R. (2012). Fragility evaluation of PI and PID controllers tuning rules. In *PID control in the third millennium*. Springer: London, 349-380. [https://doi.org/10.1007/978-1-4471-2425-2\\_12](https://doi.org/10.1007/978-1-4471-2425-2_12)
- [21] Malek, H., Luo, Y., Chen, Y. (2013). Identification and tuning fractional order proportional integral controllers for time delayed systems with a fractional pole. *Mechatronics*, 23(7): 746-754. <https://doi.org/10.1016/j.mechatronics.2013.02.005>
- [22] Das, S., Pan, I., Das, S. (2013). Performance comparison of optimal fractional order hybrid fuzzy PID controllers for handling oscillatory fractional order processes with dead time. *ISA Transactions*, 52(4): 550-566. <https://doi.org/10.1016/j.isatra.2013.03.004>
- [23] Pan, I., Das, S. (2013). Model reduction of higher order systems in fractional order template. In *Intelligent Fractional Order Systems and Control*, Springer: Berlin Heidelberg, pp. 241-256. [https://doi.org/10.1007/978-3-642-31549-7\\_9](https://doi.org/10.1007/978-3-642-31549-7_9)

## NOMENCLATURE

G	process model
C	controller
f	IMC filter
T	complementary sensitivity function
L	process multiplicative uncertainty bound
RFI	robustness fragility index
M	maximum sensitivity
D	fractional operator
S	Laplace transform of D
Y	process output
U	process input
K	system gain
L	time delay
T	time constant

## Greek symbols

$\alpha$	fractional order
$\beta$	fractional order
$\omega$	frequency
$\zeta$	damping coefficient
$\lambda$	fractional order of integrator
$\mu$	fractional order of differentiator
$\gamma$	IMC filter time constant
$\eta$	additional degree of freedom

## Subscripts

p	proportional
i	integral
d	derivative
m	model
n	natural
l	low
h	high