International Journal of Systems Signal Control and Engineering Application

MEDWELL PUBLICATIONS SINCE 2000

Fractional PI Stabilization of Delay Systems: A Thermal Application

Aymen Rhouma, Sami Hafsi and Kaouther Laabidi

Faculte´ des Sciences de Tunis, Universite de Tunis El Manar, LR-11-ES20 Analyse, Conception et Commande des Syste`mes, 1002 Tunis, Tunisia

Key words: Fractional-order calcul, fractional order PI controller, first order delay system, thermal system

Corresponding Author:
Aymen Rhouma
Faculte´ des Sciences de Tunis, Universite de Tunis El Manar, LR-11-ES20 Analyse, Conception et Commande des Syste`mes, 1002 Tunis, Tunisia

Page No.: 140-146
Volume: 10, Issue 6, 2017
ISSN: 1997-5422
International Journal of Systems Signal Control and Engineering Application

Abstract: We propose in this paper an application of fractional-order PI^{λ} controller as an alternative to solve some of the control problems that can arise. It aims to apply the analytical tuning procedure to control the heat flow systems. The system modeled by first order system involving time delay, this kind of systems whose closed-loop characteristic equation are fractional order quasi-polynomials. Using the proposed method, the entire stability region of PI^{λ} controllers is obtained and visualized in the plane (K_p, K_i, λ). Simulation and experimental results on thermal system are given to show the effectiveness of this type of controllers and this tuning rule.

INTRODUCTION

Several engineering systems and industry processes are modeled using fractional calculus which can be defined as a natural extension of the classical mathematics (Tenreiro, 1997; Monje *et al*., 2010). Usually, the famous tools to model dynamic systems at a macroscopic level are integrals and deriatives, hence, the earliest theoretical contributions related to the fractional derivatives and integrals were made by Euler, Liouville and Abel (Monje *et al*., 2010). Also, it should be stated that the fractional order representation is more adequate to describe real world systems than those of integer order models (Tan *et al*., 2009). Since, that time, many studies exhibit that differ-integral operators may be applied advantageously in diverse areas. Especially, in control theory and applications, it is extensively applied and researchers find many opportunities to develop new directions for research in fractional-order control.

Recently, with the development of fractional calculus theory, the implementation of fractional order controllers is become feasible. According to researchers by Xue and Chen (2002) are classified in four categories, Oustaloup's CRONE controller and its three generations, fractional PID controllers or Podlubny's $PI^{\lambda}D^{\mu}$ (Podlubny, 1999), FO lead-lag compensator (Monje *et al*., 2010) and FO phase this kind of controller. Some practical application studies are presented by Petras and Vinagre (2002), Bhambhani and Chen (2008). The water level control was studied by using PI^{λ} controller in Bhambhani and Chen (2008) where some numerical simulations and experimental results were given. In Petras and Vinagre (2002) the temperature control of heat solid modeled using fractional order calculus was made, respectively by using conventional PID and $PI^{\lambda}D^{\mu}$ controllers. Traditional PID controller, proportional control and On/Off control are usually used for temperature control. In this study, as a new control scheme for temperature regulation, so, we proposed using fractional-order PI^{λ} controller for a more accurate temperature profile. Also, the fractional order controller could be advantageous for temperature control, since, there are frequently variations in parameters in heat flow systems and most of desired specifications which are not readily achieved simultaneously by traditional PID controller.

MATERIALS AND METHODS

Mathematical background: There are several definitions for fractional order integral and differential calculus, however the most frequently used are the Grunwald-Letnikov (GL), the Riemann-Liouville (RL) and the Caputo definitions (Monje *et al*., 2010; Caponetto *et al*., 2010a, b; Podlubny *et al*., 1997). The GL definition is given by:

$$_{a}D_{t}^{r}f(t) = \lim_{h\to 0} h^{-r}\sum_{j=0}^{\left(\frac{t-a}{h}\right)}(-1)^{j}\binom{r}{j}f(t-jh) \quad (1)$$

where, a and t are the limits of the operation, $r\in R$ and [.] means the integer part.

The Riemann-Liouville RL fractional integral of function f(t) is defined as:

$$_{a}D_{t}^{r}f(t) = \frac{1}{\Gamma(r-n)}\frac{d_{n}}{dt^{n}}\int_{a}^{t}\frac{f(\tau)}{(t-\tau)^{r-n+1}}d\tau \quad (2)$$

Where, (n-1<r<n). The Caputo fractional integral is defined as:

$$_{a}D_{t}^{r}f(t) = \frac{1}{\Gamma(r-n)}\int_{a}^{t}\frac{f^{(n)}(\tau)}{(t-\tau)^{r-n+1}}d\tau \quad (3)$$

The continuous integro-differential operator is defined as:

$$_{a}D_{t}^{r} = \begin{cases}\frac{d^{r}}{dt^{r}} & : r>0\\ 1 & : r=0\\ \int_{a}^{t}d\tau & : r<0\end{cases} \quad (4)$$

Fractional integrals and derivatives also appear in the theory of control of dynamical systems when its is described by a fractional differential equation.

Fractional order integrals:

$$I^{n}f(t) \triangleq = \frac{1}{\Gamma(\alpha)}\int_{c}^{t}(t-\tau)^{n-1}f(\tau)d\tau,\ t>c, n\in R^{+} \quad (5)$$

where, t>c, $n\in Z^{+}$

$$I_{c}^{n}f(t) \triangleq = \frac{1}{\Gamma(\alpha)}\int_{c}^{t}(t-\tau)^{n-1}f(\tau)d\tau,\ t>c, n\in Z^{+} \quad (6)$$

$$I^{n}f(t) \triangleq = \frac{1}{\Gamma(\alpha)}\int_{c}^{t}(t-\tau)^{n-1}f(\tau)d\tau,\ t>c, n\in R^{+} \quad (7)$$

$$I_{c}^{n}f(t) = \phi_{\alpha}(t)*f(t) \quad (8)$$

where the factorial function is define as:

$$\Gamma(\alpha) = \int_{0}^{\infty}e^{-u}u^{\alpha-1}du \quad (9)$$

and

$$\phi_{\alpha}(t) = \frac{t^{\alpha-1}}{\Gamma(\alpha)},\ \alpha\in R^{+} \quad (10)$$

using the Laplace trasform, we have:

$$L\{\phi_{\alpha}(t)*f(t)\} = \phi_{\alpha}(s)\times f(s) \quad (11)$$

$$L\left\{\frac{t^{\alpha-1}}{\Gamma(\alpha)}\right\} = \frac{1}{s^{\alpha}} \quad (12)$$

Fractional-order derivatives: The fractional-order derivative is not a fractional order integral by a direct substitution α by -α. It provide an excellent instrument for the description of memory and hereditary properties of various processes (Caponetto *et al*., 2010a). The fractional derivative of order of function f(t) can be defined as:

$$\frac{d^{\alpha}}{dt^{\alpha}}f(t)\begin{cases}f^{n}(t) & \text{if } \alpha = n\in N\\ \frac{t^{n-\alpha-1}}{\Gamma(n-\alpha)}*f^{n}(t) & \text{if } n-1<\alpha<n\end{cases} \quad (13)$$

Fractional quasi-polynomial: As a preliminary step, we define the fractional quasi-polynomial as follows:

$$\delta(s) = q_{0}(s) + \sum_{i=1}^{n}q_{i}(s)e^{-L_{i}s}$$

is a fractional quasi-polynomial of degree m. where:

$$q_{i}(s) + \sum_{j=0}^{m}a_{ij}s^{\alpha_{j}}$$

$\alpha_0<\alpha_1<, ..., <\alpha_n$ are generally fractional power, aij are real numbers and $L_1<L_2<, ..., L_n$ represent time delays. There are two classes of fractional quasi-polynomials:

- Retarded-type fractional quasi-polynomials if deg $q_0(s)$>deg $q_i(s)$ for all i = 1, 2, ..., n
- Neutral-type fractional quasi-polynomials if deg $q_0(s)$ = deg $q_i(s)$ for at least one i = 1, 2, ..., n

Controller design concept: The aim of this section is to present the system which will be controlled by a fractional order PI controller and to present the design of the fractional controller. The first order time delay systems can be described by:

$$G(s) = \frac{K}{1+Ts} e^{-Ls} \tag{14}$$

Our tuning strategy, is based on Hermite-Biehler theorem and the Pontryagin condition to determine the K_p and K_i parameters. The fractional PI^λ controller transfer function C(s) is given by the following equation:

$$C(s) = K_p + \frac{K_i}{s^\lambda} \tag{15}$$

In Fig. 1, r(t) is the reference input or the setpoint signal, e(t) is the error, u(t) is the control and y(t) is the output signal. Consequently, the control input of the PI^λ controller is:

$$u(t) = K_p\left(r(t)-y(t)\right) + K_i D_t^{-\alpha}\left(r(t)-y(t)\right) \tag{16}$$

where, $D_t^{-\alpha}$ is the fractional differential/integral operators. The control design method proposed in this study is based on a Hermite-Biehler and Pontryagin theorem which consist on interlacement property of the real roots of the polynomial characteristic.

The closed-loop characteristic polynomial of a first order time delay system is given by:

$$\delta(s) = \left(KK_i + KK_p s^\lambda\right)e^{-Ls} + (1+Ts)s^\lambda \tag{17}$$

$$\delta(s) = e^{Ls}\delta(s) = \left(KK_i + KK_p s^\lambda\right) + (1+Ts)s^\lambda e^{Ls} \tag{18}$$

Replacing the term Ls in the previous expression by z we obtain:

$$\delta^*(z) = KK_i + KK_p\left(\frac{z}{L}\right)^\lambda + \left(1+T\left(\frac{z}{L}\right)\right)\left(\frac{z}{L}\right)^\lambda e^z \tag{19}$$

We consider: z = jω.

$$\delta^*(j\omega) = KK_i + KK_p\left(\frac{j\omega}{L}\right)^\lambda + \left(1+T\left(\frac{j\omega}{L}\right)\right)\left(\frac{z}{L}\right)^\lambda \left(\cos(\omega) + j\sin(\omega)\right) \tag{20}$$

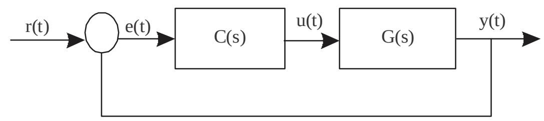

Fig. 1: Closed-loop control of a time-delay system

$$\delta^*(j\omega) = \left(KK_i + KK_p\left(\frac{j\omega}{L}\right)^\lambda\right) + \left(\frac{j\omega}{L}\right)^\lambda\left(\cos(\omega) - \frac{T}{L}\omega \sin(\omega) + j\left(\frac{T}{L}\omega\cos(\omega) + \sin(\omega)\right)\right) \tag{21}$$

The expression (Eq. 21) can be rewritten:

$$\delta^*(j\omega) = \delta_r^*(\omega) + j\delta_i^*(\omega) \tag{22}$$

$$\delta_r^*(\omega) = KK_i + \left(KK_p + \cos(\omega) - \frac{T}{L}\omega\sin(\omega)\right)\frac{|\omega|^\lambda}{(L)^\lambda} - \left(\frac{T}{L}\omega\cos(\omega) + \sin(\omega)\right)\left|\mathrm{Im}\left\{(j)^\lambda\right\}\right|\frac{|\omega|^\lambda}{(L)^\lambda}\mathrm{sign}(\omega) \tag{23}$$

$$\delta_i^*(\omega) = \left(KK_p + \cos(\omega) - \frac{T}{L}\omega\sin(\omega)\right)\left|\mathrm{Im}\left\{(j)^\lambda\right\}\right|\frac{|\omega|^\lambda}{(L)^\lambda}\mathrm{sign}(\omega) + \left(\frac{T}{L}\omega\cos(\omega) + \sin(\omega)\right)\left|\mathrm{real}\left\{(j)^\lambda\right\}\right|\left(\frac{|\omega|}{(L)}\right)^\lambda \tag{24}$$

Clearly, the controller parameter K_p only affects the imaginary part of $\delta^i(\omega)$ whereas both parameters K_p and K_i appear in the real part $\delta^r(\omega)$. In order to solve our stabilization problem, we need first to determine the range of K_p for which a solution to the PI^λ stabilization problem of a closed-loop stable plant is given. According to Pontryagin Theorem, $\delta^i(\omega)$ has only real roots for every:

$$K_p \in [K_{u-}, K_{u+}]$$

where, K_u and K_u+ are respectively the lower and the upper bound of K_p range. The successive step is to establish the ranges of the values of K_p and K_i that fulfil the interlacing condition between the roots of $\delta^*_i(\omega)$ and $\delta^*_r(\omega)$.

However, we present our theorem Hafsi *et al*. (2013) useful to compute the stability region of first order first order system with time delay. Based on the first property of Hermite-Biehler (Silva *et al*., 2002; Guillermo *et al*., 2001; Hafsi *et al*., 2015) which consist that all the roots of the polynomial characteristic of the closed loop equation are real.

Theorem 1: Hafsi *et al*. (2013), we consider a first order plant given by the following transfer function:

$$G(s) = \frac{K}{1+Ts}e^{-Ls}$$

where the parameters T, L and K are positive. We can determine the set of all stabilizing (K_p, K_i) values for the given plant using the fractional order PI controller (PI^λ):

$$C(s) = K_p + \frac{K_i}{s^\lambda}$$

The stabilizing set of parameters K_p values for a closed-loop stable plant is given by:

$$\bullet \max\left(-\frac{1}{K}, K_{u-}\right) < K_p < K_{u+}$$

Where:

$$K_{u-} = \frac{1}{K}\left(\left(\frac{T}{L}\alpha_1\cos(\alpha_1)+\sin(\alpha_1)\right)\frac{\mathrm{real}\{(j)^\lambda\}}{\mathrm{Im}\{(j)^\lambda\}} - \left(\cos(\alpha_1)-\frac{T}{L}\alpha_1\sin(\alpha_1)\right)\right)$$

$$K_{u+} = -\frac{1}{K}\left(\left(\frac{T}{L}\alpha_1\cos(\alpha_1)+\sin(\alpha_1)\right)\frac{\mathrm{real}\{(j)^\lambda\}}{\mathrm{Im}\{(j)^\lambda\}} + \left(\cos(\alpha_1)-\frac{T}{L}\alpha_1\sin(\alpha_1)\right)\right)$$

$\alpha_1 \in [-\pi; 0]$ and $\alpha_2 \in [0; \pi]$ are respectively the solutions of the two previous equations:

$$\tan(\alpha_1) = -\frac{\frac{T}{L}\alpha_1\left|\mathrm{Im}\{(j)^\lambda\}\right| + \left(1+\frac{T}{L}\right)\left|\mathrm{real}\{(j)^\lambda\}\right|}{\left(1+\frac{T}{L}\right)\left|\mathrm{Im}\{(j)^\lambda\}\right| - \frac{T}{L}\alpha_2\left|\mathrm{real}\{(j)^\lambda\}\right|}$$

$$\tan(\alpha_2) = -\frac{\frac{T}{L}\alpha_2\left|\mathrm{Im}\left\{(j)^{\frac{a}{b}}\right\}\right| + \left(1+\frac{T}{L}\right)\left|\mathrm{real}\left\{(j)^{\frac{a}{b}}\right\}\right|}{\left(1+\frac{T}{L}\right)\left|\mathrm{Im}\left\{(j)^{\frac{a}{b}}\right\}\right| - \frac{T}{L}\alpha_2\left|\mathrm{real}\left\{(j)^{\frac{a}{b}}\right\}\right|}$$

Once the K_p range established, we determine K_i as follows:

$$\bullet \max\{-m_jK_p - b_j\} < K_i < \min_{j=1,3,5,\ldots}\{-m_jK_p - b_j\}$$

Where:

$$m_j = m(\omega_j) = -\left|\mathrm{real}\{(j)^\lambda\}\right|\frac{|\omega|^\lambda}{(L)^\lambda}$$

$$b_j = b(\omega_j) = -\left(\cos(\omega_j) - \frac{T}{L}\omega_j\sin(\omega_j)\right)\left|\mathrm{real}\{(j)^\lambda\}\right|\frac{|\omega|^\lambda}{(L)^\lambda} + \left(\frac{T}{L}\omega_j\cos(\omega_j)+\sin(\omega_j)\right)\left|\mathrm{Im}\{(j)^\lambda\}\right|\frac{|\omega|^\lambda}{(L)^\lambda}\mathrm{sign}(\omega_j)$$

ω_j, j = 1, 2, 3, ... are the roots, arranged in ascending order of magnitude of $\delta^*_i(\omega)$.

Application to a thermal system: Practical experience play an important role in demonstrating the accuracy of the new controller PI^λ for different for values of λ.

Modelling and identification: Temperature control arises in diverse engineering fields, but note that it is very difficult to find a precise model of transfer function of the output temperature change from the power input, thus, we use an approximated integer-order transfer function for heat flow while a fractional PI controller is used to regulate the temperature profile.

Figure 2 shows the set of test equipment: computer, AD/DA converter (NI-USB-6009 data acquisition module) and thermal system. The thermal system includes aluminium rod, of 41 cm length and 2 cm section, heating resistor, PWM converter and a sensor to measure the temperature. The system block diagram is presented in Fig. 3.

The input signal of the thermal system is a thermal flux generated by a heating resistor which is controlled by a computer with AD/DA converter. The controller and the heating resistor are separated by a dimmer phase angle (PWM converter). The output signal of this system is the aluminium rod temperature measured by an LM35DZ sensor. Then, this signal is amplified to obtain an output voltage varying from 0-5 V.

In order to determine the thermal system model, we have applied to the heating resistor a pseudo random binary sequence given by Fig. 4. This last depicts also the corresponding temperature at distance d = 6 cm of the aluminum rod extremity. We note that the sample time is

Fig. 2: Real schema of the thermal system

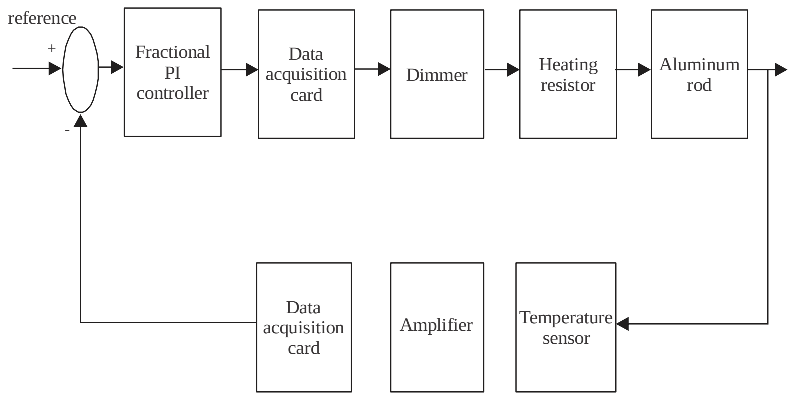

Fig. 3: Synoptic schema of the closed loop of thermal system

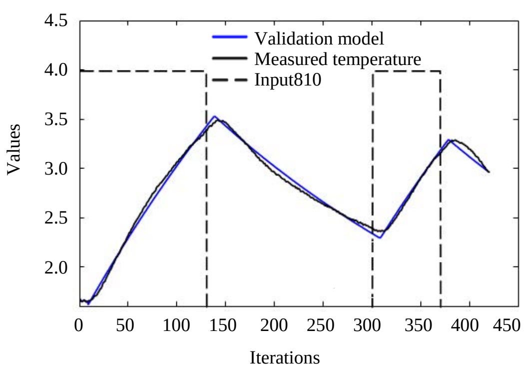

Fig. 4: Identification data

equal to 10 sec. Through a simple system identification process, the thermal system can be approximately modeled by the following transfer function:

$$G(s) = \frac{K}{Ts+1}e^{-Ls}$$

where: the delay time L = 12.2, response time T = 164.22 and the static gain K is equal to 0.8667. If the system model is determined, it is easy to design a controller to control the system.

Simulation results: Extensive simulation results are included to illustrate the simple yet practical nature of these type of controller. This study presents some simulation results to validate the design method.

In view of Theorem 1, an algorithm to determine the stabilizing set of the fractional PI controller parameter for the plant $G(s) = \frac{0.8667}{164.22s+1}e^{-12.2}$ is presented as follows:

Algorithm:

Step 1. Choose fractional integral of order λ

Step 2.Compute the K_p range using first part of the theorem 1

Step 3. Calculate the K_i range for each K_p computed in step 2

Step 4. Return to step 1

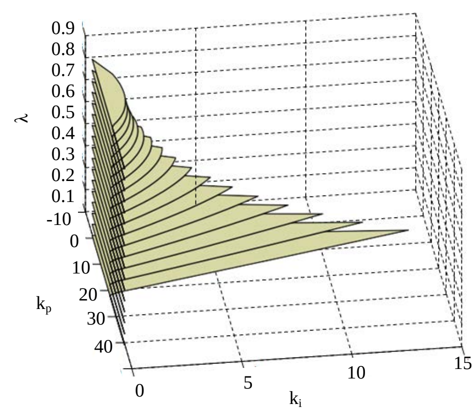

Fig. 5: Stability region of the thermal system for $0<\lambda<1$

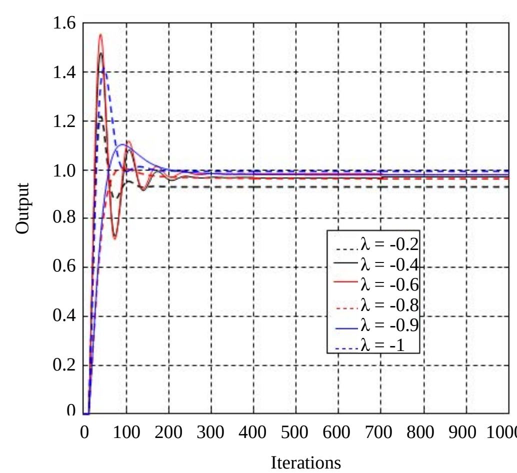

Fig. 6: Step responses of PI^{λ} controller where $0<\lambda<1$

By sweeping over the fractional order λ range and using the algorithm presented earlier, we obtained the admissible set of (K_p, K_i) for each λ value. By varying the value of the non-integer order λ in the range of [0.1: 0.1: 1.9], the stability regions of each PI^{λ} controllers are plotted in the (K_p, K_i, λ) plane. Figure 5 and 6 shows the global stability regions obtained using $\lambda \in [0.1: 0.1: 1]$ and $\lambda \in [1.1: 0.1: 1.9]$ values for the fractional order PI^{λ} controllers.

Shown in 6 the step responses of the closed-loop systems for different values of λ. In fact, for λ [0.1: 0.1: 0.9] and for a fixed point of (K_p, K_i) in the stability region (5) correspondingly to each λ values. So, we constate that the effects of the integral action is to eliminate the steady-state error. In fact, for a small values of λ such as λ = 0.1, λ = 0.2 the output does not converge to the reference value and when this fractional order integral increase the steady-state error decrease. It is observed that the response of PI^{λ} controlled system show a fairly better response in comparison with the case of the $PI^{0.3}$ controller. Also, it is interesting to note that the fractional order integrator λ which is an extra degree of freedom contribute to the performance improvement of the closed-loop system by making the step responses reveal that the steady-sate error decreases as the order λ increases. In Fig. 7 and 8 the step responses of the model:

$$G(s) = \frac{0.8667}{164.22s+1} e^{-12.2}$$

corresponding to the thermal system controlled by the fractional controller PI^{λ} where λ = 1.1, 1.2, 1.3, 1.4, 1.5. are represented. We observe from this figure that the output of the model converge to reference input which confirm the effectively of this kinds of regulators.

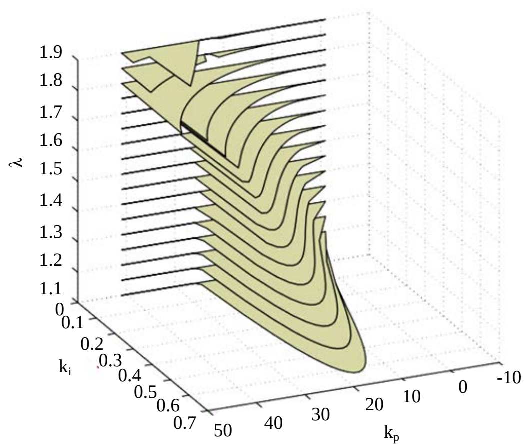

Fig. 7: Stability region of the thermal system for 1.1<λ<1.9

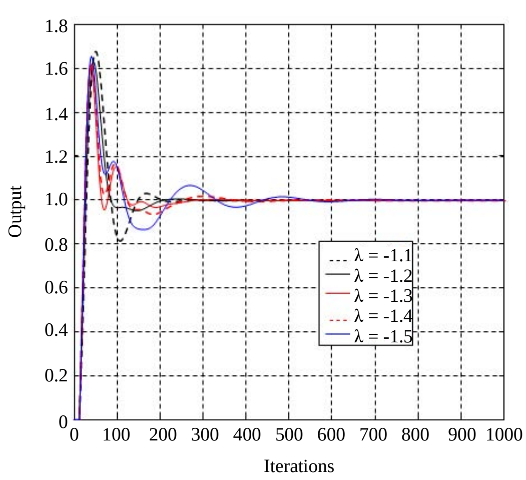

Fig. 8: Step responses of PI^{λ} where 1.1<λ<1.9

RESULTS AND DISCUSSION

Experimental results: In order to illustrate the effectiveness the approche given by the theorem (1), we consider the thermal system given by Fig. 2-4.

In fact, the thermal system is defined as a first order system with time delay. The evolutions of the reference signal, the measured temperature (output signal),control signal obtained with a fractional order controllers $PI^{-0.9}$ and $PI^{-1.2}$ are represented respectively in Fig. 9, 10.

From Fig. 9, we observe a small steady-sate error which cost on the weak value of the integrator order (λ = 0.9) which confirm the simulation results given in Fig. 6. Whereas for the $PI^{-1.2}$ controller, we remark that measured temperature meets the desired requirements and provide a small variation which gives a null steady-sate error.

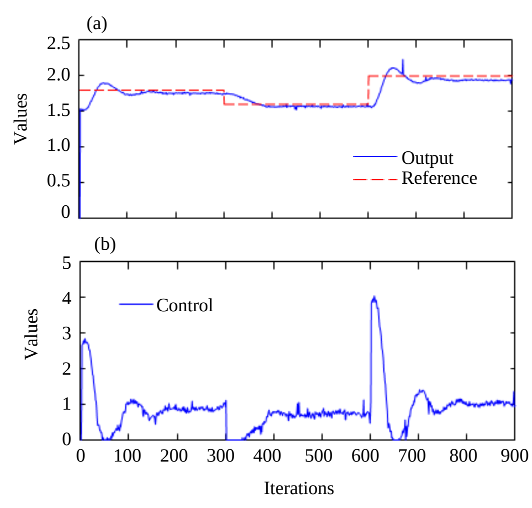

Fig. 9(a, b): Closed-loop results obtained with $PI^{-0.9}$ controller where K_p = 10 and K_i = 0.7

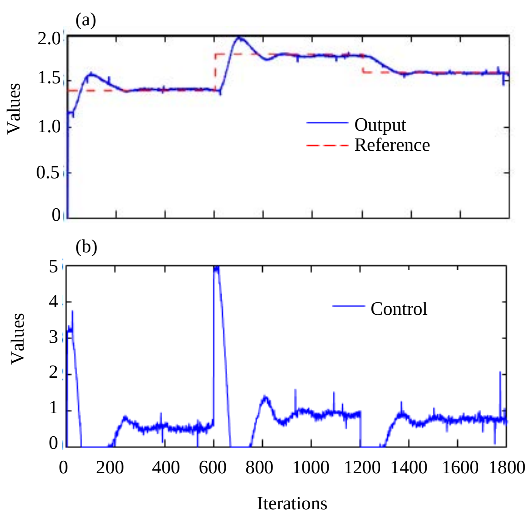

Fig. 10(a, b): Closed-loop results obtained with $PI^{-1.2}$ controller where $K_p = 15$ and $K_i = 0.5$

CONCLUSION

In conclusion, simulation and experimental results show that the closed-loop system can achieve favorable dynamic performance.

In this study, fractional order proportional integral controller is designed for temperature profile control of a metallic rod. The FO-PI controller tuned by our analytical method based on Hermite-Biehler theorem gives a strong performance. Also, from experimental and simulation results, it is observed that the designed fractional order controller works efficiently.

RECOMMENDATION

In our future research efforts, we would like to consider a fractional model uncertainty problem which will be controlled by a robust fractional order PI^{λ} and $PI^{\lambda}D^{\mu}$ controllers.

REFERENCES

Bhambhani, V. and Y.Q. Chen, 2008. Experimental study of fractional order proportional integral (FOPI) controller for water level control. Proceedings of the 47th IEEE Conference on Decision and Control, December 9-11, 2008, Cancun, Mexico, pp: 1791-1796.

Caponetto, R., G. Dongola, L. Fortuna and A. Gallo, 2010. New results on the synthesis of FO-PID controllers. Commun. Nonlinear Sci. Numer. Simul., 15: 997-1007.

Caponetto, R., G. Dongola, L. Fortuna and I. Petras, 2010. Fractional Order Systems: Modeling and Control Applications. World Scientific, Singapore, ISBN-13:978-981-4304-19-1, Pages: 177.

Guillermo, J.S., D. Aniruddha and S.P. Bhattacharyya, 2001. PI stabilization of first-order systems with time delay. Automatica, 37: 2020-2031.

Hafsi, S., K. Laabidi and R. Farkh, 2013. Synthesis of a fractional PI controller for a first-order time delay system. Trans. Inst. Measur. Control, 35: 997-1007.

Hafsi, S., K. Laabidi and R. Farkh, 2015. A new tuning method for stabilization time delay systems using PIλDμ controllers. Asian J. Control, 17: 821-831.

Machado, J.A., 1997. Analysis and design of fractional-order digital control systems. SAMS, 27: 107-122.

Monje, C.A., Y. Chen, B.M. Vinagre, D. Xue and V. Feliu-Batlle, 2010. Fractional-Order Systems and Controls: Fundamentals and Applications. Springer Science & Business Media, Berlin, Germany, Pages: 415.

Petras, I. and B. Vinagre, 2002. Practical application of digital fractional-order controller to temperature control. Acta Montanistica Slovaca, 7: 131-137.

Podlubny, I., 1999. Fractional-order systems and PIλDμ controllers. IEEE Trans. Automat. Control, 44: 208-214.

Podlubny, I., L. Dorcak and I. Kostial, 1997. On fractional derivatives, fractional-order dynamic systems and PIλDμ controllers. Proceedings of the 36th IEEE Conference on Decision and Control Vol. 5, December 12, 1997, IEEE, San Diego, California, pp: 4985-4990.

Silva G. J., A. Datta and S. P. Bhattacharyya, 2002. New results on the synthesis of PID controllers. IEEE Trans. Automat. Control, 11: 241-252.

Tan, N., O.F. Ozguven and M.M. Ozyetkin, 2009. Robust stability analysis of fractional order interval polynomials. ISA Trans., 48: 166-172.

Xue, D. and Y. Chen, 2002. A comparative introduction of four fractional order controllers. Proceedings of the 4th World Congress on Intelligent Control and Automation Vol. 4 (Cat. No. 02EX527), June 10-14, 2002, IEEE, Shanghai, China, pp: 3228-3235.