World Journal of Engineering Research and Technology
WJERT
www.wjert.org
SJIF Impact Factor: 5.924

TUNING OF CONTROLLERS FOR REFERENCE INPUT TRACKING OF A FOURTH ORDER BLENDING PROCESS

Dr. Prof. Galal Ali Hassaan*

Emeritus Professor, Department of Mechanical Design and Production, Faculty of Engineering, Cairo University, Egypt.

Article Received on 03/02/2022 **Article Revised on 24/02/2022** **Article Accepted on 16/03/2022**

***Corresponding Author**
Dr. Prof. Galal Ali Hassaan
Emeritus Professor, Department of Mechanical Design and Production, Faculty of Engineering, Cairo University, Egypt.

ABSTRACT

The paper presents four controllers to control a fourth order blending process. Two controller (PID and PIDD) from the first generation of PID controllers and two controllers (PD-PI and PI-PD) from the second generation. Each controller is tuned and used to generate a time response for step input tracking with focus on the maximum percentage overshoot, settling time and steady state error as time based characteristics for the control system. The best controllers to control the process are outlined after comparison of the control systems generated using the four controllers.

KEYWORDS: Fourth order blending process, conventional PID controller, PIDD controller, PD-PI controller, PI-PD controller, controller tuning for step reference input tracking.

INTRODUCTION

The blending process is one of the important processes encountered in many applications such as the cement industry[1], powder blending[2], slurry blending[3], paint blending[4], drug blending[5] and plastics industry.[6] For accurate and efficient blending automatic control is required which will be studied in this research work.

Kizilastan, Ertugrul, Kural and Ozsoy, 2005 classified a coupled tank system using the transient response analysis, the pseudorandom binary sequence and the least square method. They designed a PID and fuzzy logic controller for two-coupled tanks.[1] Mahony et. al., 2017 investigated a predictive control technique to control a powder blending process to improve the performance of a closed loop control system for powder blending process. They investigated the use of a number of predictive control principles including Kalman filters producing faster dynamic response and greater accuracy.[2] Oulhig et.al., 2019 presented a dynamic analysis for the tank and the centrifugal pump and derived the global model of the mixing and pumping units. They examined through simulation the system dynamic response to small and large variation in slurry flow rate and density.[3]

Yin, Bai and Guo, 2011 proposed an automatic settling control method to achieve an optimal operation control objective of the blending process in the sintering alumina production. They adopted case-based reasoning to attain appropriate set point of the control loops according to process data and state.[7] Li, Yu and Yuan, 2012 established a nonlinear time-varying model for the cement raw material blending process. They used different objective functions for the optimal ingredient ratios under various production requirements. They presented a framework to solve the nonlinear constrained optimization problem.[8] Mehta and Swarnalatha, 2018 modeled 4th and 7th order blending processes as first order plus dead time using two points method of approximation. They used a conventional PID to control both blending processes. They used different tuning techniques and concluded that the Internal Model Control was the best.[9] Gyurkes et. al., 2020, presented the design of a continuous powder blending process design of acetylsalicylic acid and microcrystalline cellulose based on time distribution models leading to the reduction of the material and instrumental costs of process design and implementation.[10] Zheng et.al., verified the global distribution of aerosol mixing state represented by modal models. They quantified potential model bias in simulating mixing state in different regions.[11]

The Controlled Process

The controlled process is a fourth order blending process having a transfer function, $G_p(s)$ given by[9]:

$$G_p(s) = [1/(10s+1)][1/(0.1s+1)][1/(s+1)][1/(0.05s+1)] \quad (1)$$

The dynamic model of the blending process as given by Equation 1 is written in terms of the poles of the process transfer function. This is not a standard form for dynamic models which has to be in a polynomial form for both numerator and denomenator of the process transfer function. In a standard form Equation 1 becomes:

$$G_p(s) = 1 / (0.05s^4+1.555s^3+11.65s^2 +11.15s+1) \quad (2)$$

The unit step response of the process is generated using Equation 2 and the ' ' command of MATLAB.[12] This response is shown in Figure 1.

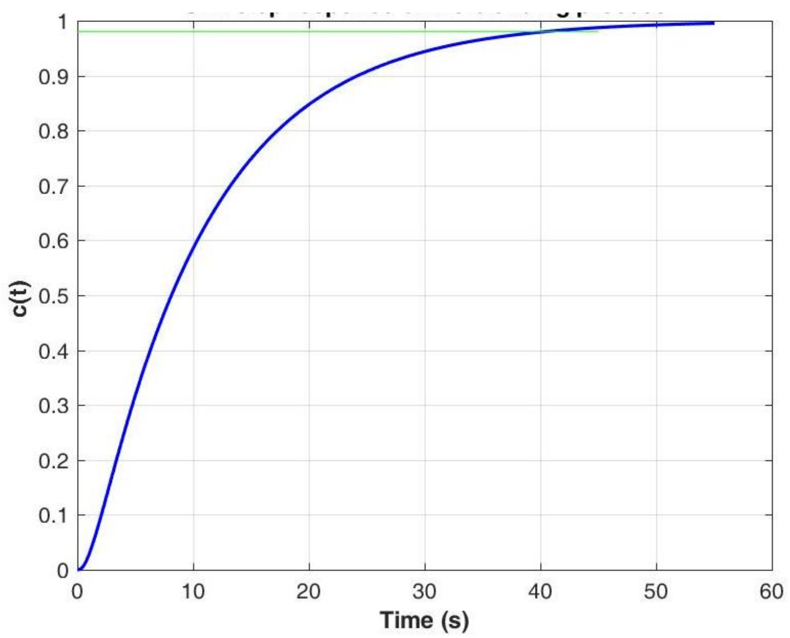

Figure 1: Reference input tracking step time response of the blending process.

Based on Figure 1, the process under study has the time based characteristics:

- Maximum percentage overshoot: zero
- Settling time: 40s

Controlling the Blending Process using a Conventional PID Controller

A conventional PID controller has a transfer function, $G_c(s)$ given by:

$$G_c(s) = K_{pc} + (K_i/s) + K_d s \qquad (3)$$

Where: K_{pc} = controller proportional gain

K_i = controller integral gain

K_d = controller derivative gain

The block diagram of a control system incorporating a PID controller and the blending process is shown in Figure 2 for reference input tracking.

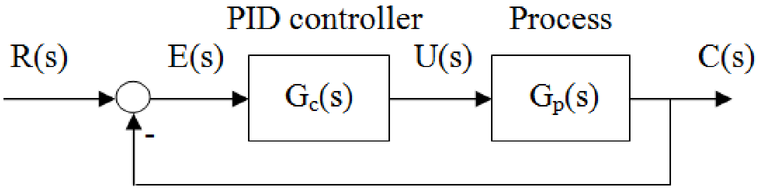

Figure 2: Control system for reference input tracking.

Using the block diagram in Figure 2, the controller transfer function in Equation 3 and the process transfer function in Equation 2, the transfer function of the closed loop control system for reference input tracking, M(s) is:

$$M(s) = C(s)/R(s) = G_c(s)G_p(s) / [1 + G_c(s)G_p(s)] \quad (4)$$

The MATLAB optimization command '*fmincon*'[13] is used to tune the PID controller using the integral of time multiplied by absolute error (ITAE) as an objective function subjected to functional constraints on the maximum percentage overshoot and the settling time to enhance the time-based characteristics of the closed loop control system. The tuning results are:

$$K_{pc} = 30.1296,\ K_i = 4.4873,\ K_d = 35.5956 \quad (5)$$

The unit step time response of the control system using the transfer function in equation 4, process parameters in Equation 2 and tuned PID controller parameters in Equation 5 is shown in Figure 3.

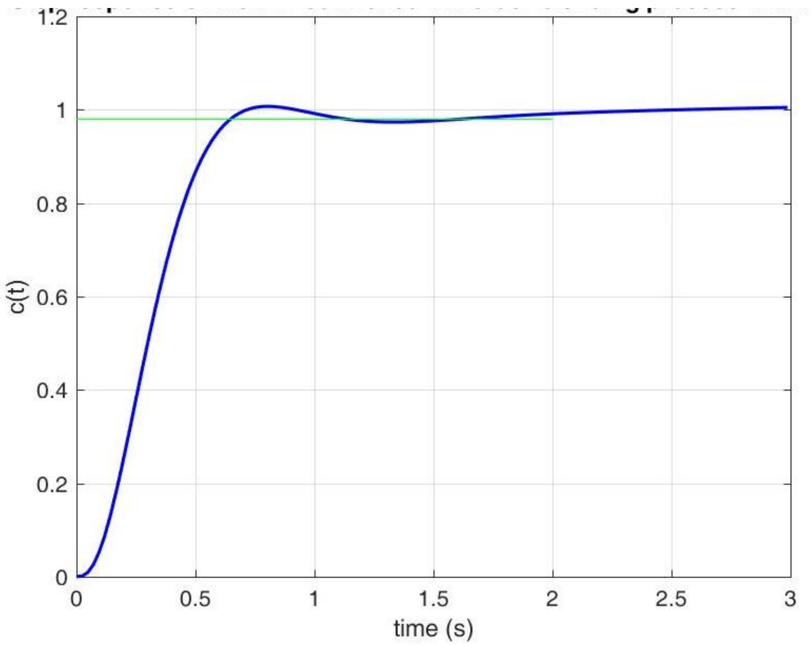

Figure 3: Step time response of the PID controlled blending process.

Some of the characteristics of the step time response during reference input tracking using the PID controller are as follows:

- Maximum percentage overshoot: 0.7327%
- Settling time (using a ±0.02 band around the steady state response): 1.61s
- Steady state error: 0

Controlling the Blending Process using a PIDD Controller

The PIDD controller is considered as one of the old generation of PID controllers. It was used in 1996 to control a third order process.[14] It consists of four actions: proportional action (P), integral action (I), derivative action (D) and double derivative action (DD).[15]-[17] A simplified structure of the PIDD is shown in Figure 4.[18] The derivative action is not shown in Figure 4 which is connected in parallel with the other three actions.

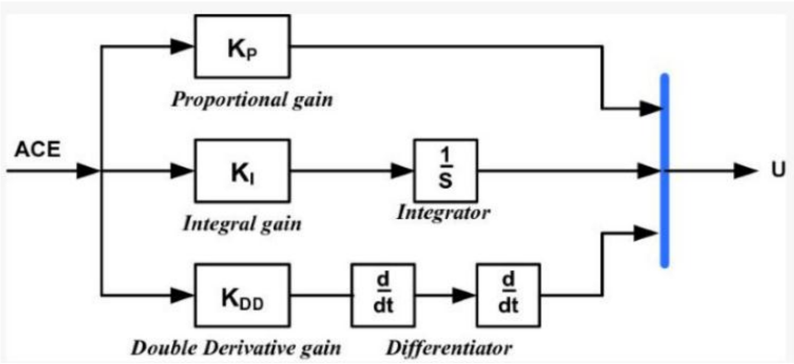

Figure 4: Structure of a PIDD controller.[18]

The transfer function of the PIDD controller, $G_c(s)$ is given by[15] -[17]:

$$G_c(s) = K_{pc} + (K_i/s) + K_d s + K_{dd} s^2 \qquad (6)$$

Where: K_{dd} = controller double-derivative gain

The closed loop transfer function of the control system incorporating the PIDD and the blending process is derived using the block diagram in Figure 2, the controller transfer function in Equation 6 and the process transfer function in Equation 2.

The PIDD controller is tuned using the optimization toolbox of MATLAB through the command '*fmincon*' as a constrained optimization problem.[13] The objective function used is the Integral of Square Error (ISE) with constraints on maximum percentage overshoot, settling time and steady state error. The tuning results are as follows:

$$K_{pc} = 90.0479,\ K_i = 0.6255,\ K_d = 100.2207,\ K_{dd} = 10.4276 \qquad (7)$$

The unit step time response of the control system using the transfer function in equation 4, process parameters in Equation 2 and tuned PIDD controller parameters in Equation 7 is shown in Figure 5.

Some of the characteristics of the step time response during reference input tracking using the PIDD controller are as follows:

- Maximum percentage overshoot: 0.5353 %
- Settling time (using a ±0.02 band around the steady state response): 0.2684 s
- Steady state error: 0.0106

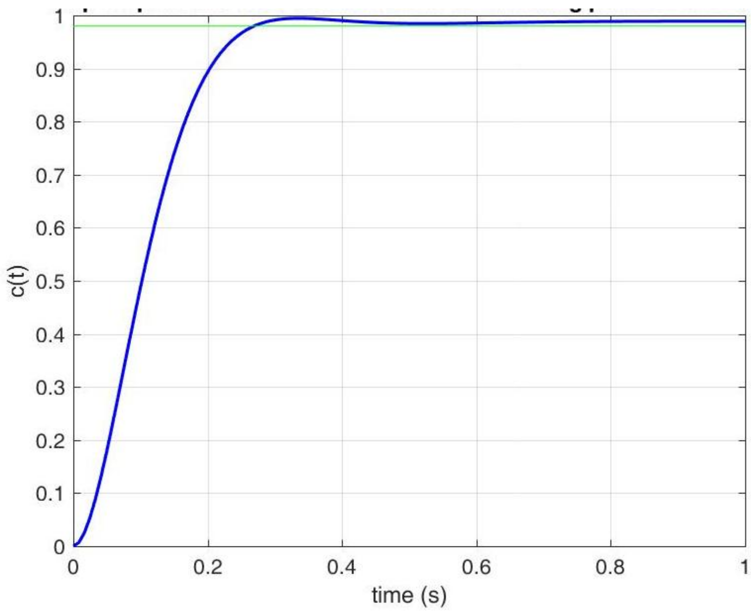

Figure 5: Step time response of the PIDD controlled blending process.

Controlling the Blending Process using a PD-PI Controller

The author investigated and tuned the PD-PI controller to control some difficult dynamics processes such as integrating plus time delay process[19], first order delayed processes[20] and highly oscillating second order process.[21] The structure of the PD-PI controller is shown in Figure 7.[22] The PD-PI controller has three parameters: derivative gain K_d , proportional gain K_{pc} and an integral gain K_i which have to be tuned to adjust the performance of the closed loop control system.

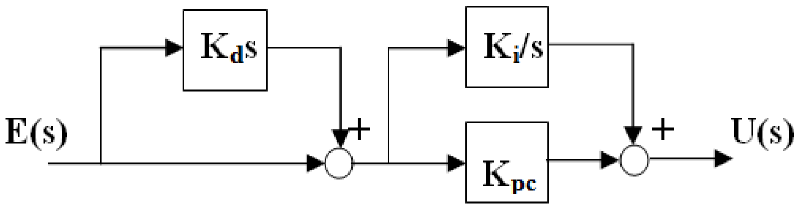

Figure 6: Structure of the PD-PI controller.[22]

Using the block diagrams in Figures 2 and 6, the transfer function C(s)/R(s) is derived and used to tune the PD-PI controller when used to control the blending process having the transfer function given in Equation 2. The tuned controller parameters using an ITAE objective function and the MATLAB command '*fmincon*'[13] with functional constraint on the maximum percentage overshoot and settling time are:

$$K_d = 5.0788,\ K_{pc} = 5.9649,\ K_i = 4.5999 \qquad (7)$$

A unit step reference input results in a step response of the control system using the PD-PI controller with the tuned parameters in Equation 7 is shown in Figure 7.

The effectiveness of using the PD-PI controller for reference input tracking associated with the blending process under study is measured through using the following functional parameters:

- Maximum percentage overshoot: 0
- Settling time (using a ±0.02 band around the steady state response): 0.815 s
- Steady state error: - 0.014

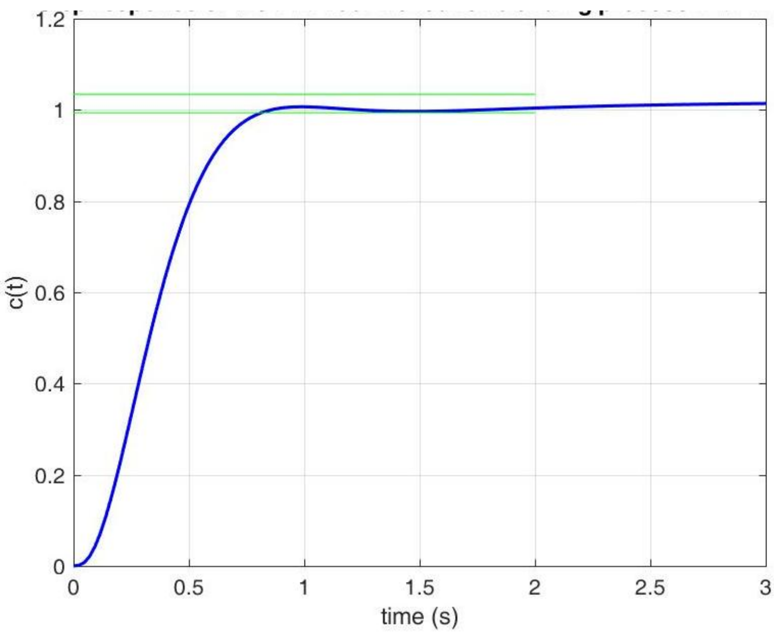

Figure 7: Step time response of the PD-PI controlled blending process.

Controlling the Blending Process using a PI-PD Controller

The author| applied and tuned a PI-PD controller to control a highly oscillating second order process for reference input tracking[23] and investigated the use of a PI-PD control for the disturbance rejection associated with the same process.[24] The author applied and tuned a PI-PD controller for the disturbance rejection associated with a delayed double acting process.[25] The structure of the PI-PD controller and its location in the closed loop control system to control a specific process is shown in Figure 8.[26] The controller has two parts: A feedforward PI sub-controller with K_{pc1} and K_i parameters and a feedback PD sub-controller with K_{pc2} and K_d parameters in a closed loop with the process. The PI-PD controller has four parameters to be tuned to adjust the performance characteristics of the closed loop control system. They are:

- Proportional gain of feedforward PI sub-controller, K_{pc1}.
- Integral gain of feedforward PI sub-controller, K_i.
- Proportional gain of feedback PD sub-controller , K_{pc2}.
- Derivative gain of feedback PD sub-controller , K_d.

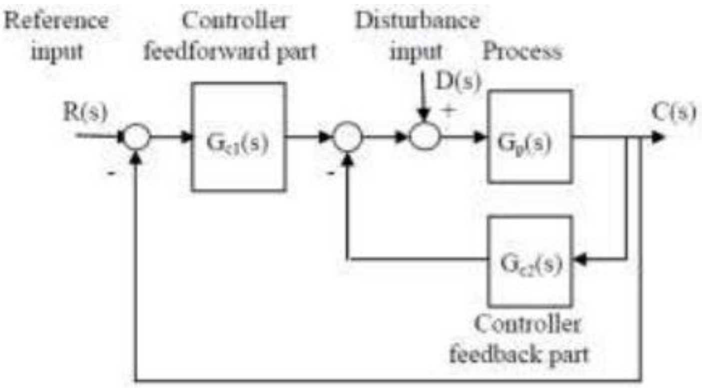

Figure 8: Structure of the PI-PD controller.[26]

The transfer function C(s)/R(s) with D(s) = 0 was derived using the mathematical models of the PI and PD sub-controllers and Equation 2 for the blending process. The parameters of the PI-PD controller are tuned using an ITAE objective function and the MATLAB command '*fmin*con' for a constrained optimization problem.[13] The tuned PI-PD controller parameters are:

$$K_{pc1} = 54.1269,\ K_i = 40.9778,\ K_{pc2} = 28.9430,\ K_d = 38.8863 \qquad (8)$$

A unit step reference input results in a step response of the control system using the PI-PD controller with the tuned parameters in Equation 8 shown in Figure 9.

The effectiveness of using the PI-PD controller for reference input tracking associated with the blending process is measured through using the following functional parameters:

- Maximum percentage overshoot: 0.885 %
- Settling time (using a ±0.02 band around the steady state response): 1.820s
- Steady state error: 0

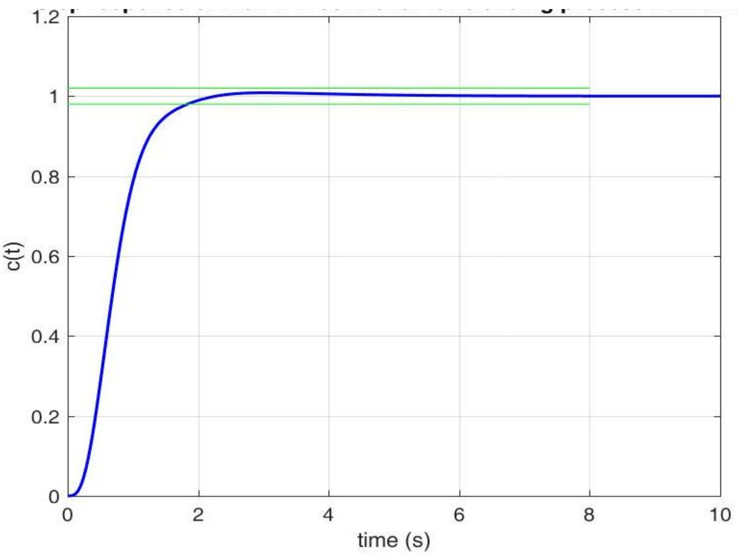

Figure 9: Step time response of the PI-PD controlled blending process.

Comparison of Controllers for Coupled Liquid Tank Control

The analysis presented in the previous sections was focused on the control of a fourth order blending process using four controllers: PID and PIDD controllers from the first generation of PID controllers and PD-PI and PI-PD controllers from the second generation presented by the author.[27]

The unit step response of the control system representing the reference input tracking of the control system is shown in Figure 10 for PID, PIDD, PD-PI and PI-PD controllers.

The characteristics of the reference input tracking associated with the coupled dual tanks process using the four controllers are collected in Table 1.

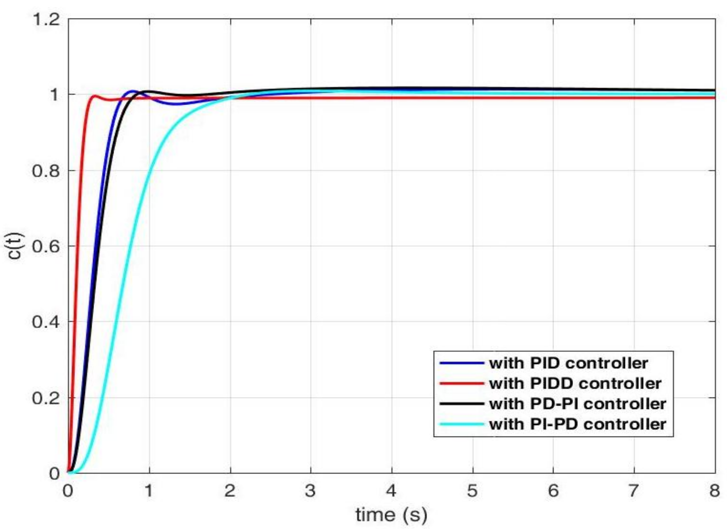

Figure 10: Step time response of the blending process controlled using four controllers.

Table 1: Reference input tracking characteristics associated with the blending process.

Controller	PID	PIDD	PD-PI	PI-PD
Number of Parameters	3	4	3	4
Error Criterion	ITAE	ISE	ITAE	ITAE
OS_{max} (%)	07327	0.5353	0	0.885
T_s (s)	1.61	0.2684	0.815	1.820
e_{ss}	0	0.0106	-0.014	0

CONCLUSION

- The paper presented the use of a PID and PIDD controllers from the first generation of PID controllers and two controllers from the second generation of PID controllers (PD-PI and PI-PD controllers) to control a fourth order blending process for reference input tracking.
- The blending process considered in this study had a fourth order transfer function providing a settling time for its step input of 40 seconds and zero maximum percentage overshoot.
- A PID controller from the first generation of PID controllers was tuned using the MATLAB toolbox and an ITAE error criterion with functional constraints enhancing the time based specifications of the step time response of the control system. It could provide a step response for reference input tracking with maximum percentage overshoot of 0.7327 % and an 1.61 s settling time.
- A PIDD controller from the first generation of PID controllers was tuned using the MATLAB toolbox and an ISE error criterion with functional constraints enhancing the time based specifications of the step time response of the control system. It could provide a step response for reference input tracking with maximum percentage overshoot of 0.5353 % and an 0.2684 s settling time. It practiced a steady state error of 0.0106.
- A PD-PI controller from the second generation of PID controllers was tuned using the MATLAB toolbox and an ITAE error criterion with functional constraints enhancing the time based specifications of the step time response of the control system. It could provide a step response for reference input tracking without any overshoot and an 0.815 s settling time. It practiced a steady state error of - 0.014.
- A PI-PD controller from the second generation of PID controllers was tuned using the MATLAB toolbox and an ITAE error criterion with functional constraints enhancing the time based specifications of the step time response of the control system. It could provide

a step response for reference input tracking with maximum percentage overshoot of 0.885 % and an 1.82 s settling time.

- The performance of the four controllers applied in this research work to control the fourth order blending process was compared graphically for step input tracking.
- The maximum percentage overshoot, settling time and steady state error of the step input time response were compared numerically for the four controllers proposed to control the fourth order blending process.
- The comparison could help the control engineer to select the proper controller for the blending process according to the time-based characteristic of interest. For example if the control engineer is planning for a minimum maximum percentage overshoot, then the PD-PI controller from the second generation of PID controllers is the ***best controller***.
- On the other hand, if the control engineer is planning for a minimum settling time, then the PIDD controller from the first generation of PID controllers is the ***best controller***.

REFERENCES

1. Kizilaslan, K., Ertugrul, S., Kural, A. and Ozsoy, C., "A comparison study on modeling of a raw material blending process in cement industry using conventional and intelligent techniques", Proceedings of the 2003 IEEE Conference on Control Applications, 2003.
2. Mahony, N. O. et. al., "Improving controller performance in a powder blending process using predictive control", 28th Irish Signals and Systems Conference, 20-21 June, Killarney, Ireland, 2017; 6.
3. Oulhiq et. al., "Dynamic modeling and simulation of a slurry mixing and pumping process: An industrial case study", Proceedings of the 9th International Conference on Simulation and Modeling Methodologies, Technologies and Applications, Prague, July 2019; 29-31: 27-35.
4. Qi, D., Chen, Z., Yang, L., Cao, Z. and Wu, M., "Improvement of dispersion and color effect of organic pigment in polymeric films via microencapsulation by the miniemulsion technique", Advances in Materials Science and Engineering, 2013, Article ID: 790321, 6 pages.
5. Nyamweya, N., "Applications of polymer blends in drug delivery", Futur Journal of Pharmaceutical Sciences, 2021; 7(18): 15.
6. Santos, J. and Guthrie, J., "Polymer blends: The PC-PBT case", Journal of Materials Chemistry, 2005; 15: 1-10.

7. Yin, L., Bai, R. and Guo, W., "Automatic setting of the raw slurry blending process based on the case-based reasoning", Advanced materials Research, 2011; 299: 667-670.
8. Li, X, Yu, H. and Yuan, M., "Modeling and optimization of cement raw materials blending process", Mathematical Problems in Engineering, Hindawi Publishing Corporation, 2012; 2012, ID: 392197, 1-30.
9. Mehta, A. and Swarnalatha, R., "Performance evaluation of conventional PID control tuning techniques for a first order plus dead time blending process", Journal of Engineering Science and Technology, 2018; 13(11): 3593-3609.
10. Byurkes, M. et. al., "Process design of continuous powder blending using residence time distribution and feeding models ", Pharmaceutics, 2020; 12(11): 1119.
11. Zheng, Z. et. al., "Quantifying the structural uncertainty of aerosol mixing state representation in a modal model", Atmospheric Chemistry and Physics, 2021; 21: 17727-17741.
12. Houpis, C. and Shelden, S., "Linear control system analysis and design with MATLAB", CRC Press, 6th Edition, 2013.
13. Venkataraman, B., "Applied optimization with MATLAB programming", J. Wiley and Sons, Second Edition, 2009.
14. Jung, S. and Dorf, R., "Analytic PIDA controller design technique for a third order system", Proceedings of the 35th IEEE Conference on Decision and Control, Kobe, Japan, 13 December 1996; 6.
15. Izvoreanuq. B. and Cojuhari, I., "The tuning of the PID and PIDD algorithms to the model objects with inertia and identical elements and time delay", Buletinul Institutui Poletenic Din Iasi, 2013; LIX(4): 14.
16. Eswaramua, K. and Kalyan, G., "An automatic voltage regulator system control using P-I-DD controller", International Journal of Advanced Engineering and Research Technology, 2017; 4(6): 499-506.
17. Hassaan, G. A., "Tuning of controllers to control a non-interacting dual tank process", International Journal of Engineering and Techniques, 2022; 8(1): 144-152.
18. Navuri, P. and Boddepalli, M., "Implementation of firefly algorithm employed PIDD controller for an interconnected power system", in Sekhar, G. et. al. (editors), "intelligent computing in control and communication", Lecture Notes in Electrical Engineering, 2021; 702, Springer, Singapore.

19. Hassaan, G. A., "Tuning of a PD-PI controller used with an integrating plus time delay process", International Journal of Scientific and Technology Research, 2014; 3(9): 309-313.
20. Hassaan, G. A., "Tuning of an PD-PI controller used with first order delayed processes", International Journal of Engineering Research & Technology, 2014; 3(4): 2751-2755.
21. Hassaan, G. A., "Tuning of a PD-PI controller used with a highly oscillating second order process", International Journal of Scientific and Technology Research, 2014; 3(7): 145-147.
22. Jain, T. and Nigram, M., "Optimization of PD-PI controller using swarm intelligence", Journal of Theoretical and Applied Information Technology, 2008; 6: 55-59.
23. Hassaan, G. A., "Tuning of a PI-PD controller used with a highly oscillating second order process", International Journal of Research and Innovative Technology, 2014; 1(3): 42-45.
24. Hassaan, G. A., "Disturbance rejection with highly oscillating second order-like process, Part III: PI-PD controller" Journal of Research in Science, Technology, Engineering and Management, 2015; 1(1): 53-58.
25. Hassaan, G. A., "Controller tuning for disturbance rejection associated with delayed double integrating process, Part III: PI-PD controller" International Journal of Recent Engineering Science, 2015; 2(3): 1-5.
26. Kaya, I. and Atherton, D., "Simple analytical rules for PI-PD controller to tune integrating processes", International Control Conference, Glasgow, Scotland, 2006; 5.
27. Hassaan, G. A., "Second generation of PID controllers for reference input tracking", International Journal of Progressive Research in Engineering Management and Science, 2021; 1(3): 25-30.

BIOGRAPHY

Galal Ali Hassaan

- Emeritus Professor of System Dynamics and Automatic Control.
- Has got his B.Sc. and M.Sc. from Cairo University in 1970 and 1974 respectively.
- Has got his Ph.D. in 1979 from Bradford University, UK under the supervision of Late Prof. John Parnaby.
- Now with the Faculty of Engineering, Cairo University, EGYPT.
- Research on Automatic Control, Mechanical Vibrations, Mechanism Synthesis and History of Mechanical Engineering.
- Published about 295 research papers in international journals and conferences.
- Author of books on Experimental Systems Control, Experimental Vibrations and Evolution of Mechanical Engineering.
- Member of the Editorial Board of a number of International Journals including the WJERT journal.
- Reviewer in some international journals.