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Rolling Strip Thickness Control using PD-PI, PI-PD and 2DOF-2 Controllers Compared with Single Model Adaptive Smith Predictor

Galal Ali Hassaan
Department of Mechanical Design and Production, Faculty of Engineering, Cairo University, Egypt
Email: galalhassaan@ymail.com

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Abstract:

The paper presents PD-PI, PI-PD and 2DOF-2 controllers to control a rolling mill strip thickness. The gain parameters of the three controllers are tuned to provide optimal performance for the control system providing better characteristics in terms of maximum percentage overshoot, maximum undershoot and settling time. The ITAE performance index is selected for the three proposed controllers and their step time response for reference input tacking is compared with a single model adaptive Smith predictor controller used to control the same process in a previous research work. The best controller is assigned for reference input tracking based on the best performance provided.

Keywords — **Rolling strip thickness control, PD-PI controller, PI-PD controller, 2DOF-2, controller tuning, Single model adaptive Smith predictor.**

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I. INTRODUCTION

Production of metallic sheets is of vital strategic importance because of its application in too many civilian and military industries. The authors proposed the control of milling strip thickness using compensators from the second generation introduced by him in 2014 and hear he continues his research work by proposing some controllers from the second generation of PID presented by the author since 2014. We start by having an overview of some of the research efforts aiming at the thickness control of strips produced by the rolling process.

Wang (1999) in his Ph. D. thesis proposed an intelligent control for rolling mills using neural networks and fuzzy systems to improve thicknes control performance. He applied the back propagation neural networks to model the nonlinear relationship between roll gap, rolling force and exit thickness. He derived an adaptive fuzzy controller tom produce control signals to the exit thickness error and the required gap adjustment control signal [1]. Frayman, Wang and Wan (2002) designed a direct model-reference adaptive control scheme using cascade-correlation neural network for a cold rolling mill thickness control. They concluded that their proposed control scheme improves the thickness accuracy in the presence of disturbances and noise when compared with conventional PID controllers [2]. Zarate (2005) presented a method to determine the appropriate adjustment for thickness control using roll gap and front and back tensions. He used a predictive model based on the sensitivity equation of the process. He considered a first-order transfer function model with an integrator for the process under control [3].

Karim and Tarek (2007) presented the implementation of a predictive functional controller for the Sendzimir 20 high cols rolling mill. They presented third-order transfer function model with pure time delay. Their simulation showed that the predictive functional control provided better control performance compared with conventional PID controller [4]. Xu, Bu, Cai and Xu (2009) designed a fuzzy PID controller and derived the mathematical model of the rolling mill. They considered the influence of parameters perturbation and external disturbances. They claimed that the anti-interference capability and robustness of the fuzzy PID controller are much better than the conventional PID controller. They derived a 0/5 transfer function model for the cold rolling process and compared the step response of the control system using fuzzy PID and PID controllers [5]. Gong and Qi (2013) proposed an ARM9-based gauge control system using fuzzy PI controller. They showed that their presented system had better performance than the traditional one. They presented dynamic models for the used servovalve, hydraulic cylinder, servo amplifier and the step time response of the closed loop control system with a fuzzy PID controller [6].

Li, Wang and Li (2014) developed a control system for the automatic gauge control in a rolling process based on multiple Smith predictor models. They presented the block diagram of the strip thickness control using the multiple adaptive Smith predictor. They used a first-order transfer function model with delay time for the strip thickness process and presented the step time response of the control system with single adaptive Smith, multiple adaptive Smith and combined single adaptive and multiple fixed Smith [7]. Fan, Shi and Wang (2015) designed a fuzzy-PID controller to control the position of the hydraulic system of a rolling mill. They compared their proposed controller with a conventional PID controller tuned by Ziegler-Nichols method. Their step time response didn't practice any overshoot [8].

Sarena and Sharma (2017) used a PI-controller in the outer loop for the strip output thickness and PD-controller in the inner loop for the work roll actuator position, They proposed a roll eccentricity compensation using fuzzy-neural network with online tuning. They used a first-order transfer function model with an integrator for the controlled process and presented the time response of the exit thickness with and without compensation [9]. Li, Yang and Shardt (2018) proposed a simultaneous robust decoupled feedback control approach for multivariable industrial process with parameters uncertainties. They the effectiveness of their proposed approach through a case study on thickness control of a hot strip mill process [10]. Ji and Zhao (2019) proposed an integral separation PID (IPID) control algorithm tuned by a modified particle swarm optimization to avoid the low yield of the rolled strip due to transverse deviation and overcomes the disadvantages of the conventional PID controller. They concluded that their IPID controller can perform well in the central position control of the rolling line [11].

Breesam, Mohamad and Rashid (2020) proposed SIMULINK models implemented for the entire structure of a cold rolling mill. They used a first-order model with integrator for the hydraulic servo system and presented step time responses for motors speed and output strip thickness [12]. Yu, Zeng, Xue and Zhao (2023) established the model of a rolling mill plate thickness control system using Ziegler-Nichols method, particle swarm optimization algorithm and linear weight particle swarm optimization algorithm to tune the gain parameters of the PID controller. They presented the block diagram of the roll position control system with transfer functions of the servo-amplifier, servovalve, hydraulic cylinder and displacement transducer. They presented the step time response of the roll gap using the three tuning techniques providing 15.1, 4.92 and 0.84 % maximum overshoot respectively [13]. Hassaan (2024) investigated the use of I-P, I-PD and PI-first order compensators from the second generation of control compensators to control the strip thickness in a rolling mill. He used the MATLAB optimization toolbox to tune the three compensators and compared their performance in the time domain with an adaptive PI controller used in a previous work to control the same process. He used a delayed first-order transfer function model for the strip thickness and presented the time step response of the rolling process for both reference input and disturbance rejection. He assigned the best compensator/controller for reference input tracking for two selection criteria (maximum overshoot and settling time) [14].

II. THE CONTROLLED STRIP THICKNESS AS A PROCESS

Li and Wang investigated an automatic gauge control of a rolling mill [7]. They used a delayed first-order transfer function for the strip thickness, $G_p(s)$ given by [7]:

$$G_p(s) = 0.210 \exp(-0.35s)/ (0.053s+1) \quad (1)$$

To simplify the dynamics analysis, the exponential term in Eq.1 may be replaced by a second-degree Pade approximation given by [15]:

$$\exp(-T_d s) \approx (T_d^2 s^2 - 6T_d s+12) / (T_d^2 s^2+6T_d s+12) \quad (2)$$

Combining Eqs.1 and 2 with T_d = 0.35 gives the strip thickness transfer function as:

$$G_p(s) = (0.02572s^2-0.441s+2.52) / (0.006492s^3+0.2338s^2+2.736s+12) \quad (3)$$

. Using the exponential Pade approximation resembles a third-order process having a unit step time response shown in Fig.1 as generated by the step command of MATLAB [16].

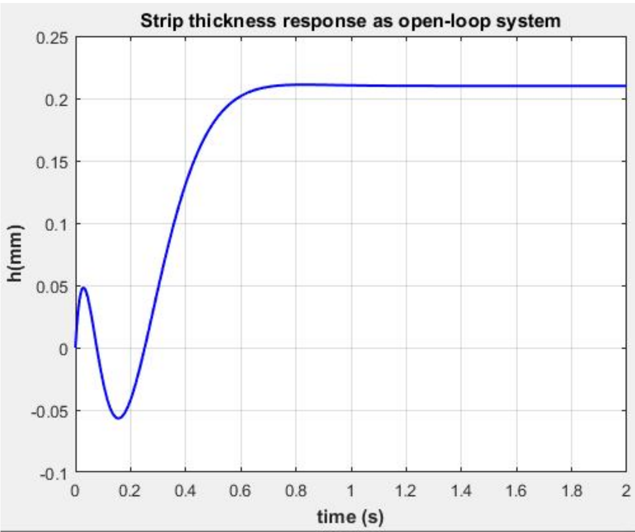

Fig.1 open-loop step response of the rolled strip thickness.

- Strip thickness dynamic process has the dynamic characteristics:
  - Maximum overshoot: 0.46 %
  - Maximum undershoot: -0.0568 mm
  - Settling time: 0.725 s
  - Steady-state error: -0.79 mm
- This process dynamically has bad dynamics because of its bad steady-state characteristics.
- Any proposed controller has to overcome the bad characteristics of the process and provide good performance characteristics.
- This will be the main objective of the proposed controllers.

III. CONTROLLING THE STRIP THICKNESS USING A PD-PI CONTROLLER

The PD-PI controller was introduced by the author in 2014 as one of the good controllers of the second generation of the PID controllers. The author tested the performance of the PD-PI controller through its use in controlling first-order delayed processes [17], highly oscillating second-order process [18], integrating plus time-delay process [19], delayed double integrating process [20], third-order process [21], boost-glide rocket engine [22], rocket pitch angle [23], LNG tank pressure [24], boiler temperature [25] boiler-drum water level [26], greenhouse internal humidity [27], coupled dual liquid tanks [28], BLDC motor [29], furnace temperature [30] and electro-hydraulic drive [31].

The block diagram of the control system incorporated the PD-PI controller of PD-control and PI-control modes in series after the error detector feeding its output directly to the controlled furnace.

The PD-PI controller has a transfer function, $G_{PDPI}(s)$ given by [27]:

$$G_{PDPI}(s) = [K_d K_{pc2} s^2+(K_d K_i+K_{pc1} K_{pc2})s+K_{pc1} K_i]/s \quad (4)$$

Where:

K_{pc1} = proportional gain of the PD-control mode.

K_d = derivative gain of the PD-control mode

K_{pc2} = proportional gain of the PI-control mode.

K_i = derivative gain of the PI-control mode

The PD-PI controller has four gain parameters to be tuned to optimal performance for the control system.

- The transfer function of the control system comprising the PD-PI controller and the strip thickness process is derived using the block diagram of the control system and Eqs.3 and 4.

- The performance index to me minimized by the optimization technique was selected as the ITAE [32].
- The MATLAB optimization toolbox [33] is selected to perform the minimization of the ITAE and provide the optimal gain parameters of the PD-PI controller.
- The tuned parameters of the PD-PI controller are as follows:

K_{pc1} = 30.625966 , K_d = 0.308862
K_{pc2} = 0.0428189 , K_i = 0.281891 (5)

- Using the closed-loop transfer function of the closed-loop control system and the PD-PI controller gains in Eq.5 with reference input and zero disturbance input and the transfer function of the closed-loop control system with disturbance input and zero reference input, the unit step response is shown in Fig.2.

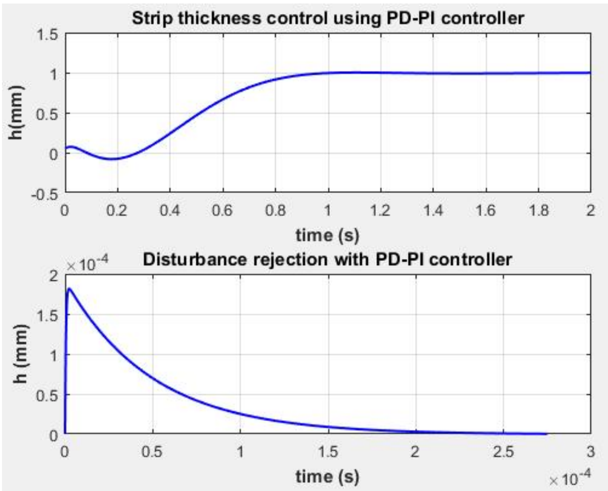

Fig.4 Strip thickness reference and disturbance rejection step time response using a PD-PI controller.

COMMENTS:

- Control system characteristics for reference input tracking:
  - ➢ Maximum percentage overshoot: 0.102 %
  - ➢ Settling time: 0.93 s
  - ➢ Maximum undershoot: -0.0807 mm
- Control system characteristics for disturbance rejection:
  - ➢ Maximum time response: 1.813×10^{-4} mm
  - ➢ Time of maximum time response: 0.25×10^{-5} s
  - ➢ Minimum time response: 0
  - ➢ Settling time to zero: 2×10^{-4} s

IV. CONTROLLING THE STRIP THICKNESS USING A PI-PD CONTROLLER

The PI-PD controller was introduced by the author in 2014 as one of the good controllers of the second generation of the PID controllers. The author tested the performance of the PI-PD controller through its use in controlling a highly oscillating second-order process [34], second-order processes [35], delayed double integrating process [36], third-order process [37], boost-glide rocket engine [22], LNG tank pressure [24], boiler-drum water level [26], greenhouse internal humidity [27], coupled dual liquid tanks [28], BLDC motor [29], and electro-hydraulic drive [31].

The block diagram of the control system incorporated the PI-PD controller is shown in Fig.5 [38],[39]. It is composed of a forward element which is a PI control mode and a feedback element in an internal loop about the process which is a PD control mode.

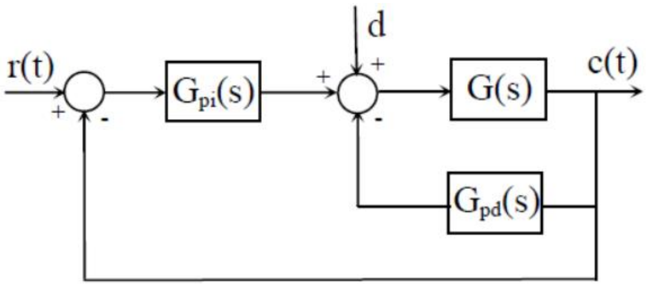

Fig.5 Structure of the PI-PD controller [38], [39].

The PI-PD controller elements have the transfer functions:

$$G_{PI}(s) = K_{pc1} + (K_i/s)$$
$$G_{PD}(s) = K_{pc2} + K_d s \quad (6)$$

Where:

K_{pc1} = proportional gain of the PI-control mode.

K_i = integral gain of the PI-control mode

K_{pc2} = proportional gain of the PD-control mode.

K_d = derivative gain of the PD-control mode

The PI-PD controller has four gain parameters to be tuned to provide the optimal performance of the control system. The tuning technique is the same as that used in the PD-PI controller in the previous section.

- The tuned parameters of the PI-PD controller are as follows:

K_{pc1} = 2.390354 , K_i = 10.967866

K_{pc2} = 0.533169 , K_d = 0.267569 (7)

- Using the closed-loop transfer function of the closed-loop control system and the PI-PD controller (using the block diagram in Fig.5 with zero disturbance signal) and the controller gains in Eq.7 with reference input and the transfer function of the closed-loop control system with disturbance input and zero reference input, the unit step response of the control system incorporating the PI-PD controller is shown in Fig.6.

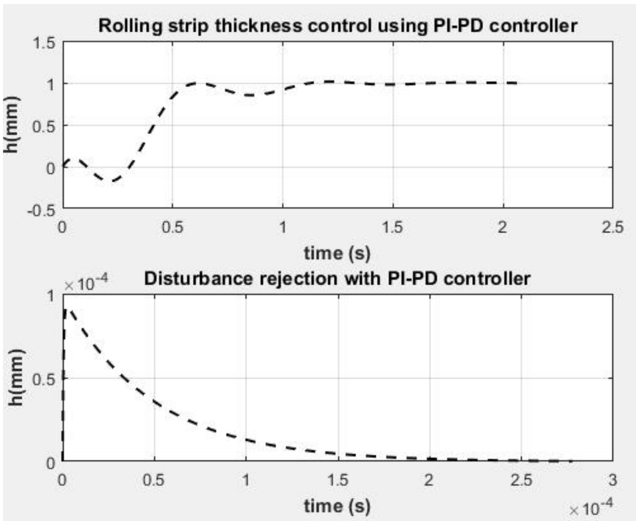

Fig.6 Strip thickness reference and disturbance rejection step time response using a PI-PD controller.

COMMENTS:

- Control system characteristics for reference input tracking:
  - ➢ Maximum percentage overshoot: 1.31 %
  - ➢ Settling time: 1.53 s
  - ➢ Maximum undershoot: -0.175 mm
- Control system characteristics for disturbance rejection:
  - ➢ Maximum time response: 0.926×10^{-4} mm
  - ➢ Time of maximum time response: 0.25×10^{-5} s
  - ➢ Minimum time response: 0
  - ➢ Settling time to zero: 2.5×10^{-4} s

V. CONTROLLING THE STRIP THICKNESS USING A 2DOF CONTROLLER

The 2DOF controller is one of the second generation controllers introduced by the author starting from 2014 to replace the first generation PID controllers. The author used different structures of 2DOF control to control a variety of industrial processes with bad dynamics such as: liquefied natural gas pressure control [24], coupled dual liquid tanks [28], boost-glide rocket engine [22], BLDC motor control [29], highly oscillating second-order process [40], delayed double integrating processes [41], boiler drum water level [26], furnace temperature [30], boiler temperature [25] and an electro-hydraulic drive [26].

The block diagram of a control system incorporating a 2DOF controller and the rolled strip thickness is shown in Fig.7 [42].

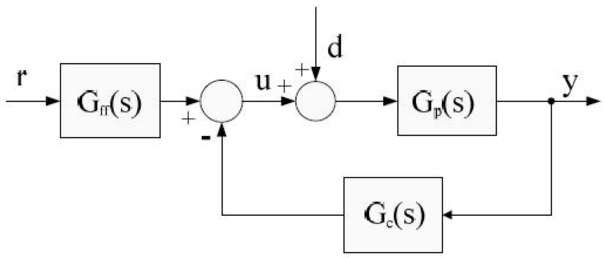

Fig.7 Strip thickness control system using 2DOF-2 controller [42].

The 2DOF-2 controller structure having the structure shown in Fig.7 is composed of two elements of transfer functions $G_{ff}(s)$ (of a PI-control mode) and $G_c(s)$ (of a PID-control mode) given by:

$$G_{ff}(s) = K_{pc1} + (K_i/s) \quad (8)$$

and

$$G_c(s) = K_{pc2} + (K_i/s) + K_d s \quad (9)$$

Where: K_{pc1} = proportional gain of the PI-control mode.

K_i = integral gain of the PI and PID-control modes.

K_{pc2} = proportional gain of the PID-control mode.

K_d = derivative gain of the PID-control mode.

The 2DOF-2 controller has four gain parameters to be tuned to provide the required performance of the closed-loop system of the strip thickness control.

- The closed-loop transfer function of the control system incorporating the 2DOF-2 controller is derived from the block diagram in Fig.7 and using the process transfer function in Eq.3 and the controller transfer functions in Eqs.8 and 9.
- The controller parameters are tuned using the same procedure presented for the PD-PI and PI-PD controllers. The tuning results are as follows:

$K_{pc1} = 0.418628$, $K_i = 5.861318$

$K_{pc2} = 0.041971$, $K_d = 0.032575$ (10)

- The closed-loop transfer function of the control system for a disturbance input is derived from the block diagram of the control system (Fig.7) with zero reference input.
- The closed-loop transfer functions are used to plot the unit step input step time response of the control system using the '*step*' command of MATLAB as shown in Fig.8.

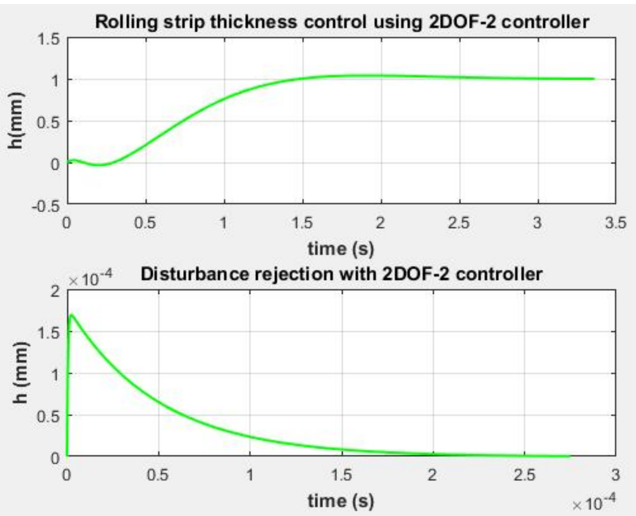

Fig.8 Step response of the strip thickness using a 2DOF-2 controller.

COMMENTS:

- Control system characteristics for reference input tracking:
  - Maximum percentage overshoot: 3.95 %
  - Settling time: 2.45 s
  - Maximum undershoot: -0.035 mm
- Control system characteristics for disturbance rejection:
- Maximum time response: 1.69×10^{-4} mm
- Time of maximum time response: 0.2×10^{-5} s
- Minimum time response: 0
- Settling time to zero: 2.5×10^{-4} s

VI. COMPARISON ANALYSIS

- To evaluate the effectiveness of using the proposed controllers, the step time response for reference input is compared with that using a single model adaptive Smith predictor controller [7] and shown in Fig.9.

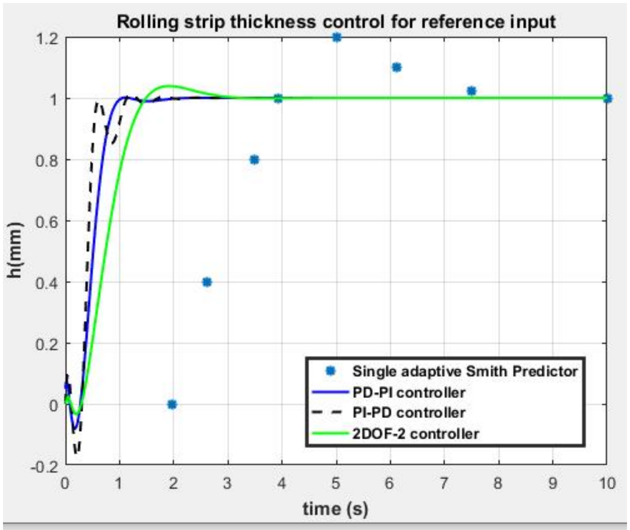

Fig.9 Comparison of reference input tracking step time response.

- For disturbance input, the step time response of the control system representing the disturbance rejection using the proposed three compensators from the second generation of PID controllers is compared and presented in Fig.10.
- A quantitative comparison for the time-based characteristics of the control systems used to control the rolled strip thickness is given in Table 1 for a reference step input.

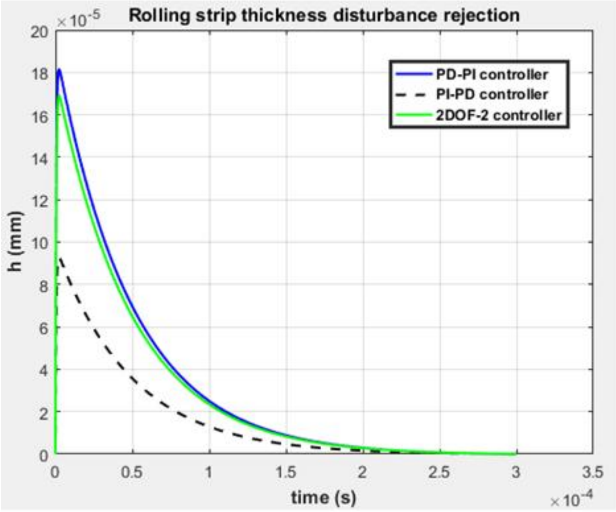

Fig.9 Comparison of disturbance input tracking step time response.

TABLE 1
TIME-BASED CHARACTERISTICS OF THE STRIP THICKNESS CONTROL SYSTEM FOR REFERENCE INPUT TRACKING

Controller	Maximum overshoot (%)	Maximum undershoot (mm)	Settling time (s)
PD-PI	0.102	-0.0807	0.93
PI-PD	1.310	-0.1750	1.53
2DOF-2	3.950	-0.035	2.45
Single model adaptive Smith predictor	19.600	-	7.70

- A quantitative comparison for the time-based characteristics of the control systems handled in the present work to control the strip thickness is given in Table 2 for a disturbance step input indicating the disturbance rejection capability of the proposed controller.

TABLE 2
TIME-BASED CHARACTERISTICS OF THE DISTURBANCE STEP TIME RESPONSE OF THE STRIP THICKNESS

Controller	10^4 Maximum time response (mm)	10^5 Time of maximum time response (s)	10^4 Settling time to zero (s)
PD-PI	1.813	0.25	2.0
PI-PD	0.926	0.25	2.5
2DOF-2	1.69	0.20	2.5

VII. CONCLUSIONS

- This research work investigated the use of PD-PI, PI-PD and 2DOF-2 controllers from the second generation of PID controllers to control a rolling mill strip thickness.
- The process under control (strip thickness) is an example of processes with bad dynamics since it has a large steady-state error.
- The paper proposed three controllers from the second generation controllers presented by the author starting from 2014.
- The performance of the proposed controllers was compared with that of a single model adaptive Smith predictor controller from a previous research work.
- The PD-PI controller succeeded to reduce the maximum overshoot to only 0.102 %, provide minimum settling time of less than one second and provide a moderate maximum undershoot.
- The PI-PD controller could generate a step time response with about 1.3 % maximum overshoot and 1.53 s settling time (compared with 19.6 % and 7.7 s for the single model predictive Smith predictor respectively).
- The 2DOF-2 controller could generate a step time response with 3.95 % maximum overshoot and 2.45 s settling time (compared with 19.6 % and 7.7 s for the single model predictive Smith predictor respectively).
- Depending on this analysis, the PD-PI controller is considered as the best selection for the control of the rolling mill strip thickness. Different models for the controlled process may change this final selection.
- Regarding the disturbance rejection, the three proposed controllers provided very low maximum time response, time of maximum time response and settling time to zero with using a proper second-order high-pass filter with the disturbance input. This means that the three proposed controllers provide excellent disturbance rejection.

REFERENCES

[1] S. Wang, "Real-time neuro-fuzzy control for rolling mills", Ph. D. Thesis, University of Wollongong, Department of mechanical Engineering, 1999.

[2] Y. Frayman, L. Wang and C. Wan, "Cold rolling mill thickness control using the cascade-correlation neural network", *Control and Cybernetics*, vol.31, issue 2, 4 pages, 2002.

[3] L. E. Zarate, "A method to determine the thickness control parameter in cold rolling process through predictive model via neural networks", *Journal of the Brazilian Society of Mechanical Science and Engineering*, vol.27, issue 4, pp.357-363, 2005.

[4] M. Karim and K. Tarek, "Predictive functional control of a Sendzimir cold rolling mill", *4th International Conference on Computer Integrated Manufacturing*, 3-5 November, 5 pages, 2007.

[5] X. Xu, Z. Bu, Y. Cai and X. Xu, "Fuzzy logic based thickness control system and its simulation", *1st International Conference on Information Science and Engineering*, pp.3792-3795, 2009.

[6] T. Gong and L. Qi, "Intelligent gauge control system using ARM and fuzzy PI controller", *Studies in Informatics and Control*, vol.22, issue 1, pp.43-50, 2013.

[7] J. Li, K. Wang and Y. Li, "Automatic gauge control in rolling process based on multiple Smith predictor models", *Abstracts and Applied Analysis,* vol.2014, 10 pages, 2014.

[8] L. Fan, X. Shi and R. Wang, "Fuzzy tuning PID control of strip rolling mill hydraulic APC system", *International Symposium on Computers and Informatics*, Atlantis Press, p.818-847, 2015.

[9] S. Saxena and P. Sharma, "Strip thickness control of cold rolling mill", *International Journal of Innovative Research in Science, Engineering and Technology*, vol.6, issue 2, pp.3038-3045, 2017.

[10] P. Li, X. Yang and Y. Shardt, "Simultaneous robust decoupled output feedback control for multivariable industrial systems", *IEEE Access,* vol.6, pp.6777-6782 2018.

[11] L. Jia and X. Zhao, "An improved particle swarm optimization (PSO) optimized integral separation PID and its application on central position control system", *IEEE Sensors Journal* vol.19, issue 16, 2019.

[12] W. Breesam, K. Mohamed and M. Rashid "Simulation model of cold rolling mill", *Iraqi Journal for Electrical and Electronics Engineering*, vol.16, issue 1, pp.72-77, 2000.

[13] Y. Yu, R. Zeng, Y. Xue and Y. Zhao, "Optimization strategy of rolling mill hydraulic control gap control system based on improved particle swarm PID algorithm", *Biomimetics*, vol.8, issue 143, 18 pages, 2023.

[14] G. A. Hassaan, "Rolling strip thickness control using I-P, I-PD and PI-first order compensators compared with an adaptive PI controller", *World Journal of Engineering Research and Technology*, vol.10, issue 4, pp.50-64, 2024.

[15] V. Hanta and A. Prochazka, "Rational approximation of time delay", *Institution of Chemical Technology,* Prague, Department of Computing and Control Engineering, vol.5, 7 pages, 2009.

[16] Mathworks, "Step response of dynamic system", https://www.mathworks.com/help/ident/ref/dynamicsystem.step.html , 2023.

[17] G. A. Hassaan, "Tuning of PD-PI controller used with first-order delayed process", *International Journal of Engineering Research and Technology*, vol.3, issue 4, pp.51-55, 2014.

[18] G. A. Hassaan, "Tuning of PD-PI controller used with a highly oscillating second-order process", *International Journal of Science and Technology Research*, vol.3, issue 7, pp.145-147, 2014.

[19] G. A. Hassaan, "Tuning of PD-PI controller used with an integrating plus time delay process", *International Journal of Scientific & Technical Research*, vol. 3, issue 9, pp. 309-313, 2014.

[20] G. A. Hassaan, "Controller tuning for disturbance rejection associated with delayed double integrator process, Part I: PD-PI controller", *International Journal of Computer Techniques*, vol.2, issue 3, pp.110-115, 2015.

[21] G. A. Hassaan, "Tuning of PD-PI controller used with a third-order process", *International Journal of Application or Innovation in Engineering Management*, vol.9, issue 8, pp.6-12, 2020.

[22] G. A. Hassaan, "Control of a boost-glide rocket engine using PD-PI, PI-PD and 2DOF controllers", *International Journal of Research Publication and Reviews*, vol.4, issue 11, pp.913-923, 2023.

[23] G. A. Hassaan, "Control of rocket pitch angle using PD-PI controller, feedback first-order compensator and I-PD compensator", *International Journal of Computer Techniques*, vol.11, issue 1, 8 pages, 2024.

[24] G. A. Hassaan, "Liquefied natural gas tank pressure control using PID, PD-PI, PI-PD and 2DOF controllers", *World Journal of Engineering Science and Technology*, vol.10, issue 2, pp.18-33, 2024.

[25] G. A. Hassaan, "Control of boiler temperature using PID, PD-PI and 2DOF controllers", *International Journal of Research Publication and Reviews*, vol.5, issue 1, pp.5054-5064, 2024.

[26] G. A. Hassaan, "Control of Boiler-drum water level using PID, PD-PI, PI-PD and 2DOF controllers", *International Journal of Engineering and Techniques*, vol.10, issue 1, 10 pages, 2024.

[27] G. A. Hassaan, "Tuning of PD-PI and PI-PD controllers to control the internal humidity of a greenhouse", *International Journal of Engineering and Techniques*, vol.9, issue 4, 9 pages, 2023.

[28] G. A. Hassaan, "Tuning of controllers for reference input tracking of coupled-dual liquid tanks", *World Journal of*

Engineering Science and Technology, vol.8, issue 2, pp.86-101, 2022.
[29] G. A. Hassaan, "Tuning of controllers for reference input tracking of a BLDC motor", *International Journal of Progressive Research in Engineering, Management and Science*, vol.2, issue 4, pp.5-14, 2022.
[30] G. A. Hassaan, "Furnace control using I-PD, PD-PI and 2DOF controllers compared with fuzzy-neural controller", *International Journal of Computer Techniques*, vol.11, issue 2, 10 pages, 2024.
[31] G. A. Hassaan, "Control of an electro-hydraulic drive using PD-PI, PI-PD and 2DOF-2 controllers compared with a PID controller", *International Journal of Engineering and Techniques*, vol.10, issue 2, 10 pages, 2024.
[32] F. G. Martins, "Tuning PID controllers using the ITAE criterion", *International Journal of Engineering Education*, vol.21, issue 5, pp.867-873, 2005.
[33] C. P. Lopez, MATLAB optimization techniques, Apress, 2014.
[34] G. A. Hassaan, "Tuning of a PI-PD controller used with a highly oscillating second-order process", International Journal of Research and Innovative Technology, vol.1, issue 3, pp.42-45, 2014.
[35] G. A. Hassaan, "Robustness of I-PD, PD-PI and PI-PD controllers used with second-order processes", International Journal of Scientific Technology Research, vol.3, issue 10, pp.27-31, 2014.
[36] G. A. Hassaan, "Controller tuning for disturbance rejection associated with delayed double integrating process, Part III: PI-PD controller", International Journal of recent Engineering Science, vol.13, 6 pages, 2015.
[37] A. Singer, G. A. Hassaan and M. Elgamil, "Tuning of a PI-PD controller used with a third-order process", World Journal of Engineering Research and Technology, vol.6, issue 4, pp.367-375, 2020.
[38] I. Kay, P. Derek and D. Atherton, "Simple analytical rules for PI-PD controllers to tune integrating and unstable processes", International Control Conference, Glasgow, Scotland, 5 pages, 2006.
[39] G. A. Hassaan, "Disturbance rejection with highly oscillating second-order-like process, Part III: PI-PD controller", Journal of Research in Science, Technology, Engineering and Management, vol.1, issue 1, pp.53-58, 2015.
[40] G. A. Hassaan, "Tuning of a 2DOF controller for use with a highly oscillating second-order-like process", *International Journal of Modern Trends in Engineering and Research*, vol.2, issue 8, pp.292-298, 2015.
[41] G. A. Hassaan, "Controller tuning for disturbance rejection associated with delayed double integrating process, Part V: 2DOF controller", *International Journal of Engineering and Techniques*, vol.1, issue 4, pp.26-31, 2015.
[42] H. Nemati and P. Bagheri, "A new approach to tune two-degree-of-freedom (2DOF)", IEEE International Symposium on Computer-aided Control System Design, Yokohama, Japan, pp.1819-1824, September 8-10, 2010.

DEDICATION

DELTA IRON & STEEL COMPANY

- I dedicate this research work to the **Delta Iron & Steel Egyptian Company. Why ?**
- It is one of the leading steel and iron companies in Egypt.
- It was founded in 1947 (77 years old company).
- It uses the latest multi-stage cold drawing technology.
- It had an information center with high speed computers.
- It produced steel pipes since 1962.
- Its production capacity was 250,000 ton in 2019.
- You are looking great dear Delta Iron & Steel Company.
- Keep carrying your Egyptian name and be in the bossom of Egypt forever.
- Good luck if your are still alive.

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.
- 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 more than 320 research papers in international journals and conferences.
- Author of books on Experimental Systems Control, Experimental Vibrations and Evolution of Mechanical Engineering.
- Honourable Chief Editor of the International Journal of Computer Techniques.
- Reviewer in some international journals.
- Scholars interested in the authors publications can visit:

http://scholar.cu.edu.eg/galal