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TUNING OF A PI-PD CONTROLLER USED WITH A THIRD ORDER PROCESS

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ABSTRACT

Highly oscillation in industrial processes is completely undesirable, and controller tuning has to solve this problem. PI-PD is a controller type of the PID family which is suggested to overcome this problem with improved performance regarding the spike characteristics associated with certain types of controllers. This work has proven that using the PI-PD controller is capable of solving the problems of the highly oscillated third order process. A highly oscillated third order process of 57% maximum overshoot and 75 seconds settling time is controlled using a PI-PD controller (through simulation). The controller is tuned by minimizing the sum square error (ISE) of the control system using a software package. The MATLAB optimization toolbox is used assuming that the tuning problem is with functional constraints. The overshoot, undershoot and settling time are used to investigate the performance of the closed loop control system. The performance of the control system using an PI-PD controller using the present tuning technique is compared with that using the ITAE standard forms tuning technique.

KEYWORDS: Controller tuning; third order process; PI-PD Controller; improving control system performance.

I. INTRODUCTION

Highly oscillating time response is present in various industrial processes. The PID controller is used, conventionally, for better performance of the control system. The PI-PD controller is considered, one of the new generation of PID controllers, after researches and some applications are required to explore its effectiveness compared with conventional PID controllers. This controller is used in wide range in industry. Kuo and Li (1999) presented genetic algorithm –based fuzzy PI-PD controller for an automotive active suspension system to cope with different road conditions.[1] Kaya (1999) introduced a model-based controller design enabling a tighter control for integrating processes. He used ISTE standard forms.[2] Kaya (2003) introduced a model-based PI-PD controller design. He used ISE standard forms for controller tuning comparing with several methods used in controlling integrating processes.[3] Roy, Iqbal and Atherton (2004) proposed the PI-PD tuning used with open-loop unstable sampled-data control systems incorporating first and second order plants taken from industry.[4] Ryu and Ryu (2005) dissected a feedback control model for the transmission control protocol (TCP)/active queue management (AQM) dynamics. They submitted an PI-PD controller to overcome the reactive control behavior of existing AQM proposals.[5] Kaya, Derek and Atherton (2006) introduced a simple approach to tune a PI-PD controller for the control of integrating and unstable processes[6] Mohan and Ghosh (2008) offered mathematical models for fuzzy PI/PD controllers employing two skewed fuzzy sets derived by symmetrical fuzzy sets.[7] Tan (2009) introduced a graphical method for the computation of all stabilizing PI-PD controllers by plotting the stability boundary locus in the parameter plane.[8] Charan, Reddy and Babu (2010) introduced a scheme for tuning of fuzzy PI-PD controller based on fuzzy logic. They made a comparison for the performance of conventional fuzzy logic controller and the PI-PD controller.[9] Prasad and Mugada (2011) obtained a control system model to simulate pipeline element by analyzing kinetic feature and physical properties of fluid in the pipeline. They designed a PI-PD-Smith predictor and used the ITAE criterion to tune the position controller.[10] Palmeira, Magalhaes, Conteate and Ferreira (2012) explained the potential of a fuzzy PI + PD control system compared to classical PID applied to a mobile robot.[11] Sundaram and Padhy (2013) introduced a PI-PD controller for active queue management able to control present congestion reactively. They used the ISTE objective function to tune the controller.[12] Ali (2014) presented a design of robust PI-PD position controller for an unstable magnetic levitation ball system. He used the particle swarm optimization method to tune the PI-PD controller.[13] Hassaan (2014) tuned a PI-PD controller used with a high oscillating second order system, which reduces the maximum percentage overshoot, the maximum percentage undershoot to zero, and also reduces the settling time of the response.[14]

II. PROPOSED ALGORITHM

2.1 The Process

The process is a third order process having the following forward transfer function in a unity feedback system as shown in Fig.1:

$G_p(s) = [K_{ip}\omega^2_n/(s^3+2\zeta\omega_n s^2+\omega^2_n s+K_{ip}\omega^2_n)]$ (1)

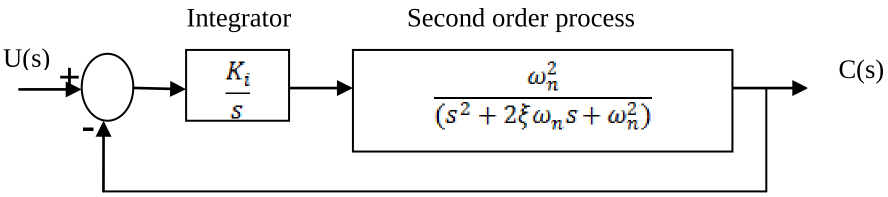

Figure 1: Block diagram of third order process simulator.

where

K_{ip} integral gain (K_i) of the process (in this prescribed third order process K_i = 0.5)

ω_n natural frequency (ω_n = 0.447 rad/s)

ζ damping ratio (ζ=1.34)

The third order process under consideration has the time response to step input voltage of 1.66 V shown in Fig.2 as simulated by MATLAB.

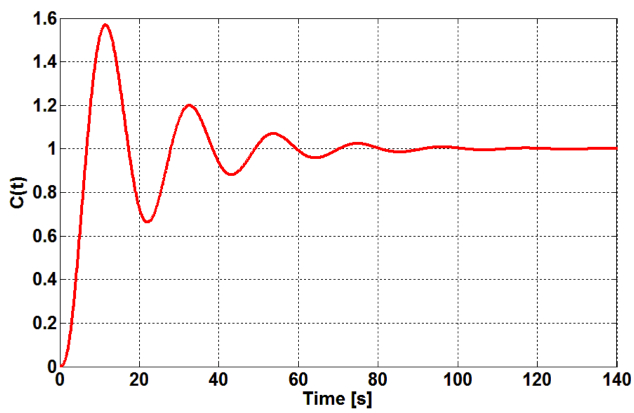

Figure 2: Step response of the studied third order process.

It has the time based specifications

- Maximum percentage overshoot: 57 %
- Maximum percentage undershoot: 18 %
- Settling time: 75s

2.2 The Controller

A [proportional + integral] (PI) - [proportional + derivative] (PD) controller type is used in this research.

The parts of the controller used in this study are connected in series. The input to the PD part is the output of the controlled system, and the PI controller part is connected in series. The output of the PD part is subtracted from the second summing point as shown in Fig.3.[6,15] The output signal of the second summing point is the control signal acting on the controlled third order process.

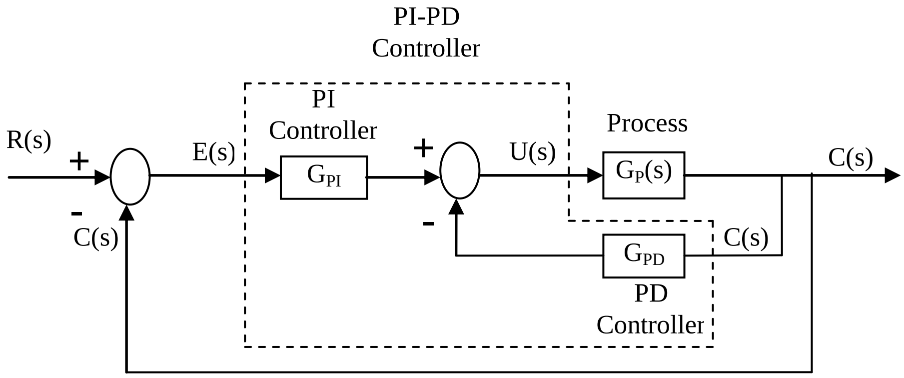

Figure 3: PI-PD controller-based control sytem.

2.3 Control System Transfer Function

The process output, C(s) is related to its input U(s) through the process transfer function, Gp(s). That is:

$C(s) = G_p(s)\ U(s)$

The mathematical model of the control system in the s-domain is:

$U(s) = G_{PI}E(s)-G_{PD}C(s) = (K_{pc1}+K_i/s)[R(s)-C(s)]-(K_{pc2}+K_d s)C(s)$

$U(s) = [(K_{pc1}+K_i/s)R(s)]-[(K_{pc1+}\ K_i/s+ K_{pc2+}\ K_d s)C(s)]$ (2)

$C(s) = G_p(s)U(s)$

$U(s) = [1/G_p(s)][C(s)]$ (3)

Using Eqs.2 and 3:

$[1/G_p(s)][C(s)]=[(K_{pc1}+K_i/s)R(s)]-[(K_{pc1+}\ K_i/s+ K_{pc2+}\ K_d s)C(s)]$

$\{[1/G_p(s)]+(K_{pc1+}\ K_i/s+ K_{pc2+}\ K_d s)\}C(s) = (K_{pc1}+K_i/s)R(s)$

$M(s) = C(s) / R(s) = (K_{pc1}+K_i/s) / \{[1/G_p(s)]+(K_{pc1+}\ K_i/s+ K_{pc2+}\ K_d s)\}$ (4)

Combining Eqs.1 and 4 the closed loop transfer function of the control system M(s) becomes:

$M(s) = [\, b_0 s^4 + b_1 s^3 + b_2 s^2 + b_3 s + b_4 \,] / [a_0 s^4 + a_1 s^3 + a_2 s^2 + a_3 s + a_4]$ (5)

Where

$b_0 = 0$, $b_1 = 0$, $b_2 = 0$, $b_3 = (K_{ip}K_{pc1}\, \omega_n^2)$, $b_4 = (K_{ip}K_i\, \omega_n^2)$.

$a_0 = 1$, $a_1 = (2\zeta\omega_n)$, $a_2 = (\omega_n^2 + K_dK_{ip}\omega_n^2)$, $a3 = (K_{pc1}K_{ip}\, \omega_n^2 + K_{ip}K_{pc2}\, \omega_n^2 + K_{ip}\omega_n^2)$,

$a_4 = (K_iK_{ip}\omega_n^2)$.

K_i ... Integral gain of the PI controller

$K_{i\,p}$ ... Integral gain of the prescribed third order process ($K_{i\,p} = 0.5$)

K_d ... Derivative gain of the PD controller

K_{pc1} ... proportional gain of the PD controller

K_{pc2} ... proportional gain of the PI controller

The controller has 4 parameters to be identified to control the third order process and produce the desired performance, K_i, K_d, K_{pc1}, and K_{pc2}.

2.4 Control System Step Response

A system with a voltage reference input was selected for the simulation in Matlab-Simulink platform. The step input value was assumed to be 1.66 V.

III. CONTROLLER TUNNING

The sum of square of error (ISE) is used an objective function, F of the optimization process. Thus:

$F = \int [c(t) - c_{ss}]^2\, dt$ (6)

where c_{ss} = steady state response of the system

MATLAB is used to minimize the optimization objective function. The performance of the control system is judged using three time-based specifications:

a) Maximum percentage overshoot, OS_{max}

b) Maximum percentage undershoot, US_{max}

Settling time, T_s

3.1 Tuning Results

The MATLAB block "Check Step Response Characteristics" is used to minimize the optimization objective function given by Eq.6 with functional constraints.[16,17,18,20]

The tuned parameters of the PI-PD controller using the technique proposed in this work is:

$K_{pc1} = 0.0713$

$K_{pc2} = 5.83$

$K_i = 0.93$

$K_d = 15.35$

To investigate the performance of the control system using the tuned PI-PD controller, its step time response is compared with an un-tuned PI-PD controller having the parameters:

$K_{pc1} = 34.5577$

$K_{pc2} = 0.0022$

$K_i = 1.1054$

$K_d = 51.9558$

The step response of the control system incorporating the tuned and un-tuned PI-PD controller and a third order process is shown in Fig.4.

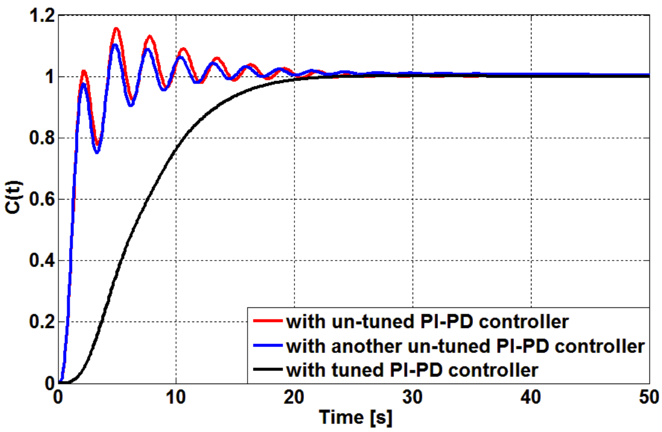

Figure 4: Step response of the studied third order process with tuned and un-tuned PI-PD controller.

IV.COMPARISON WITH STANDARD FORMS TUNING

The control system in terms of its transfer function is a fourth order one. The optimal characteristic equation of such a system with a first-order numerator is given using an ITAE criterion by[20]:

$$s^4 + (2.41\ \omega_0)\ s^3 + (4.93\ \omega_0^2)\ s^2 + (5.14\omega_0^2)\ s + \omega_0^4 \qquad (7)$$

Comparing Eq.7 with the corresponding one in Eq.5 we get 3 equations in K_i, K_{pc1}, K_{pc2}, and K_d

i.e. 4 unknowns and 3 equations. To be able to get the controller parameters using this tuning technique, one of the parameters has to be assumed. It was reasonable from the equations to assign K_{pc1} (it was taken as 0.0713 as obtained in the present tuning technique using the ISE criterion).[21] The tuned controller parameters using the ITAE standard forms are calculated as:

$K_{pc1} = 0.0713$ (assumed value)

$K_{pc2} = 6.2447$

$K_i = 0.611$

$K_d = 22.526$

The time response of the control system using this standard forms tuning technique is shown in Fig.5:

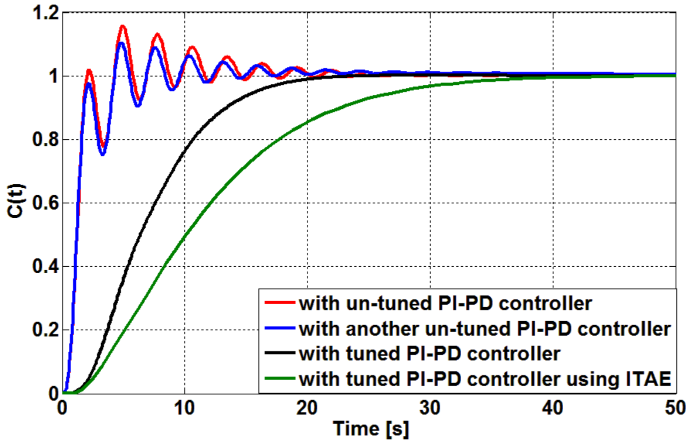

Figure 5: Step response of the PI-PD controlled third order process.

The time-based specifications of the control system incorporating the PI-PD controller and the third order process are compared in Table 1.

Table 1: Time-based specifications of the PI-PD controlled third order process.

	OS_{max} (%)	US_{max} (%)	T_s (s)
Un-tuned PI-PD controller	15.5	22	17
Other un-tuned PI-PD controller	9	10.5	16
Tuned PI-PD controller using ITAE	0	0	29
The tuned PI-PD controller with present tuning technique	0.5	2	50

V.CONCLUSION

- It was possible to suppress completely the higher oscillations in processes through using the PI-PD controller.

- It was conceivable to overcome the set-point kick problem associated with the standard PID.
- It was possible to reduce the maximum percentage overshoot and maximum percentage undershoot using the PI-PD controller.
- It was possible to reduce the settling time to only 14 s using the tuned PI-PD controller prescribed in this research compared with 24.8 s using the ITAE standard form.
- Tuning the controller using the MATLAB block "Check Step Response Characteristics" produced a time response of the closed loop system having 0.105 % maximum percentage overshoot compared with 15.7 % when using an un-tuned controller.
- The performance of the closed loop control system can be improved further if other types of objective functions are tried. This is the purpose of future work going on.

REFERENCES

1. Y. Kuo and T. Li, “GA-based fuzzy PI/PD controller for automotive active suspension system”, IEEE Transactions on Industrial Electronics, December 1999; 46(6): 1051-1056.
2. B. I. Kaya, “A PI-PD controller design for integrating processes”, Proceedings of the Control Conference, 1999; 1: 258-262. 2004,
3. I. Kaya, “A PI-PD controller design for control of unstable and integrating processes”, ISA Transactions, 2003; 42(1): 111-121.
4. A. Roy, K. Iqbal and D. Atherton, “Optimum tuning of PI-PD controllers for unstable sampled-data control systems”, 5th Asian Control Conference, Melbourne, Australia, July 2004; 1: 478-485, 20-23 .
5. S. Ryu and B. Ryu, “PI-PD controller for adaptive and robust active queue management for internet congestion control”, Simulation, 2005; 81(6): 437-459.
6. I. Kaya, P. Derek and P. Atherton, “Simple analytical rules for PI-PD controllers to tune integrating and unstable processes”.
7. B. Mohan and A. Ghosh, “Fuzzy PI-PD controllers with skewed input and output fuzzy sets”, ISA Transactions, 47: 008, pp.300-310.
8. N. Tan, "Computation of stabilizing PI-PD controller", Int. J. Automation and Systems, 2009; 7(2): 175-184.
9. K. Charan, B. Reddy and P. Babu, “Self tuning of a robust fuzzy PI-PD controller”, Int. J. of Computer Applications, 2010; 13(1): 5-8.P.

10. K. Prasad and R. Mugada, “Design of series logging correction PI-PD-Smith predictor for position control application with time delay”, Int. J. of Advanced Engineering Science and Technology, 2011; 11(1): 196-201.
11. A. Palmereira, R. Magalhaes, C. Contente and A. Ferreira, "Comparison between classical PID and fuzzy PI + PD controller applied to a mobile robot", 15th Latinamerican Control Conference, Lima, Peru, 23-26 October 2012.
12. C. Hsu and J. Wu, Multi-resolution Watermarking for Digital Images", IEEE Transactions on Circuits and Systems- II, August 1998; 45(8): 1097-1101.
13. R. Sundaran and P. Padhy, "GA-based PI-PD controller for TCP routers", International Journal of Machine Learning and Computing, August 2013; 3(4): 361-364.
14. H. Ali, "Robust PI-PD controller design for magnetic levitation system", Engineering and Technology Journal, 2014; 32(3): 667-680.
15. G.A. Hassaan, et al " Tuning of a PI-PD Controller used with a Highly Oscillating Second-Order Process", International Journal of Research and Innovative Technology, August 2014; 1(3).
16. J. Rodriguez and A. Coelho, “IMC tuning of a PI-PD controller. for FOPDT, SOPDT and IFOPDT plants”, 2nd Mercosur Congress on Chemical Engineering, 2005.
17. J. D'Azzo, C. Houpes and S. Sheldon, "Linear control system analysis and design with MATLAB", Marcel Dekker Inc., 2003.
18. P. Venkataraman, "Applied optimization with MATLAB programming", J. Wiley, 2009.
19. G.A. Hassaan, " Tuning of an I-PD controller used with a highly oscillating second -order process", International Journal of Mechanical Engineering and Technology (IJMET), ISSN 0976 – 6340, ISSN 0976 – 6359, May 2014; 5(5): 115-121.
20. G.A. Hassaan, " Tuning Of A PD-PI Controller Used With A Highly Oscillating Second – Order Process", Internationl Journal Of Scientific & Technology Research, ISSN 2277-8616, 3(7): July 2014.
21. D. Graham and R. Lathrop, “The synthesis of optimal response: criteria and standard forms”, Transactions of AIEE, Nov.1953; 72.