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Tuning of a 2DOF Controller for Use with a Highly Oscillating Second-Order-Like Process

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Abstract— This paper investigates using a 2DOF controller to control a highly oscillating second-order-like process having about 85 % maximum overshoot.. The control has three parameters to be adjusted to provide an optimal performance for the closed-loop control system. The MATLAB optimization toolbox is used to tune the controller using five different error-based objective functions. The effect of different levels of the controller parameters on the performance of the control system is investigated. The feasibility of using the 2DOF controller is assigned through comparison with other seven controllers used before with the same process. It is shown that the 2DOF controller can compete with PIP and PPI controllers for better performance

Keywords—2DOF controller; highly oscillating second-order-like process; controller tuning; control system performance.

I. INTRODUCTION

Highly oscillating processes represent a challenge for the control engineers to assign a proper controller suitable for use to provide a closed-loop control system having an acceptable performance either in the time or frequency domain. Researchers handled using 2DOF controllers to control delayed and undelayed processes for set-point tracking and disturbance rejection.

Lecchini, Campi and Savarest (2002) presented the extension of the virtual reference feedback tuning to the design of 2DOF controllers. They showed that this method is an effective way to directly design from data the closed-loop transfer function and the sensitivity function [1]. Mirkin and Zhang (2003) put forward a parameterization of all stabilizing 2DOF controllers for processes with dead time. They discussed some dead time compensation schemes [2]. Miklosovic and Gao (2004) introduced a robust 2DOF control design technique extending the concepts of active disturbance rejection control and PID control in new directions. They used simulation performed on an actual motion control for verification and insight [3]. Smith, Monti and Ponci (2006) presented the polynomial chaos theory as a means to synthesize controller that compensates for the inadequancy of the feedforward control in the presence of parametric changes. They reported the simulation and experimentation of a 2DOF controller. They investigated how the integral action affect the controller design [4].

Vrancic, Strmcnik, Huba and Oliveira (2008) compared a proposed magnitude optimum multiple integration tuning method for integrating processes with some other PI controller tuning methods using 2DOF PI controller structure [5]. Novosad and Macku (2011) developed a 2DOF controller for reactor control. They compared with two control strategies using PID controllers [6]. Bagheri and Nemati (2011) proposed a tuning procedure for PI controllers in 2DOF structure. Their aim was to get good set point tracking , good disturbance rejection and maximum robustness to model uncertainties [7]. Phurahong, Kaitwanidvilai and Ngaopitakkul (2012) proposed a technique for designing a robust controller for an average current mode control. Their technique was based on the concept of 2DOF H∞ loop shaping control adopted to find the robust controller. They used genetic algorithm to solve the structure specified 2DOF H∞ loop shaping control. They verified the effectiveness of the controller through simulation [8].

Alfaro and Vilanova (2013) presented a robust tuning method for 2DOF PID controllers for first-order plus dead time processes. They selected a 2DOF ideal PID with filter controller algorithm.

They allowed to select a maximum sensitivity in the range from 1.4 to 2.0 [9]. Mohiuddin, Kumar and Kumar (2014) proposed a tuning approach for 2DOF PI controller based on FOPDT process model. They considered three essential requirements of the control problem: load disturbance rejection, set point regulation and robustness to model uncertainties [10]. Kumar and Patel (2015) presented the design of 2DOF PID controllers for second-order processes without time delay for smooth control. They concluded that the 2DOF PIP controller has given better results compared with PID controller [11].

II. PROCESS

The process is a second-order –like one having the transfer function, $G_p(s)$:

$$G_p(s) = \omega_n^2 / (s^2 + 2\zeta\omega_n s + \omega_n^2) \quad (1)$$

Where: ω_n = process natural frequency = 10 rad/s
ζ = process damping ration = 0.05

The process is a highly oscillating process because of its low damping ratio where it has a maximum percentage overshoot given by [12]:

$$OS_{max} = 100 \exp[-\pi\zeta / \sqrt{(1 - \zeta^2)}] \quad (2)$$

Eq.2 give the process maximum overshoot as:

OS_{max} = 85.447 %

III. 2DOF CONTROLLER

The 2DOF controller has two parts, one in the forward path of the closed-loop block diagram of the control system of transfer function $G_1(s)$ and the second part is in the backward path having a transfer function $G_2(s)$. The block diagram of the control system incorporating a 2DOF controller is shown in Fig.1 for reference and disturbance inputs [5].

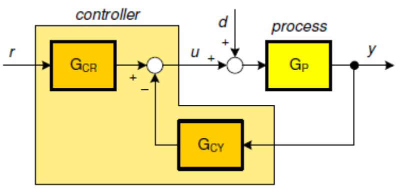

Figure 1. 2DOF controller structure [5].

The following terminology is used instead of those used in Fig.1:

$G_1(s)$ instead of G_{CR}
$G_2(s)$ instead of G_{CY}
$G_p(s)$ instead of G_p
R(s) instead of r
C(s) instead of y

According to Vrancic, Stromcnik, Huba and Oliveira, the control parts have the transfer functions [5]:

$$G_1(s) = bK_{pc} + (K_i/s) \quad (3)$$

And $$G_2(s) = K_{pc} + (K_i/s) \quad (4)$$

Where:

b = forward controller part parameter
K_{pc} = controller proportional gain
K_i = controller integral gain

IV. CLOSED-LOOP TRANSFER FUNCTION

The closed-loop transfer function of the control system for set-point tracking (with d = 0) using the block diagram of Fig.1 and Eqs.1,3 and 4 is given by:

$$M(s) = C(s) / R(s) = (b_0 s + b_1) / (a_0 s^3 + a_1 s^2 + a_2 s + a_3) \qquad (5)$$

Where:

$$b_0 = bK_{pc}\omega_n^2$$
$$b_1 = K_i\omega_n^2$$
$$a_0 = 1$$
$$a_1 = 2\zeta\omega_n$$
$$a_2 = (1 + K_{pc})\omega_n^2$$
$$a_3 = K_i\omega_n^2$$

The denominator of Eq.5 represents the characteristic equation of the control system. Using the Routh-Hurwitz stability criterion of the control system [13], the integral parameter K_i of the control has to satisfy the following condition for a stable control system:

$$K_i < 2\zeta\omega_n (1 + K_{pc}) \qquad (6)$$

Eq.6 is useful in assigning a value for the controller parameter K_i for an assumed value for its proportional gain K_{pc}.

V. CONTROLLER TUNING

The 2DOF controller structure of Fig.1 has three parameters b, K_{pc} and K_i. Those parameters have to be optimally adjusted to yield an optimal time response to the reference input of the control system. The controller parameters are tuned as follows:

1. The MATLAB optimization toolbox is used to minimize an objective function based on the error between the time response of the control system to a unit step input c(t) and the steady-state response c_{ss} [14].
2. The MATLAB control toolbox is used to assign c(t) and c_{ss} [15].
3. Five objective functions are investigated through their relation with the response error e(t) as [16] – [18]:

ITAE: $\int t|e(t)| \, dt$ (7)

ISE: $\int [e(t)]^2 \, dt$ (8)

IAE: $\int |e(t)| \, dt$ (9)

ITSE: $\int t[e(t)]^2 \, dt$ (10)

ISTSE: $\int t^2[e(t)]^2 \, dt$ (11)

4. The optimization command '*fminunc*' is used to minimize the objective functions in Eqs.7 through 11.
5. The tuning parameters of the 2DOF controller using the five objective functions in Eq.7 through 11 are given in Table 1.

Table 1. 2DOF controller tuning and performance parameters.

	ITAE	ISE	IAE	ITSE	ISTSE
b	0.0204	0.0184	0.0190	0.0195	0.0204
K_{pc}	5.0482	4.9505	4.9578	5.0071	5.0643
K_i	1.4972	1.8253	1.7289	1.6580	1.4916
OS_{max} (%)	0	0	0	0	0
T_s (s)	12.0357	9.7129	10.2931	10.8049	12.0946

6. Table 1 reveals the best objective function suitable for the highly oscillating process under control. This is the ISE objective function since beside the zero maximum overshoot of the control system step time response, it provides a minimum settling time of 9.7129 s.

7. Graphically, the unit step time response of the control system using the 2DOF controller and the five objective functions is given in Fig.2.

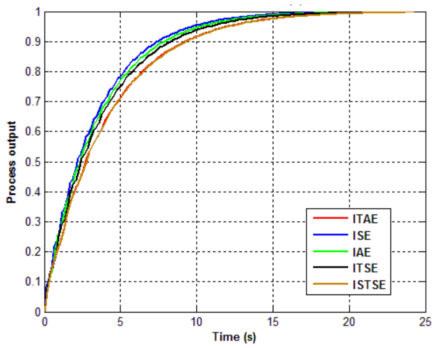

Figure 2. Time response using the five objective functions.

8. Because of the nonlinearity of the optimization process, every guessed level of any of the controller three parameters can produce a local minimum of the objective function with new set of tuned controller parameters different than those in Table 1. The effect of changing the levels of the controller parameter ‘b’ on the time response of the control system is shown in Fig.3.

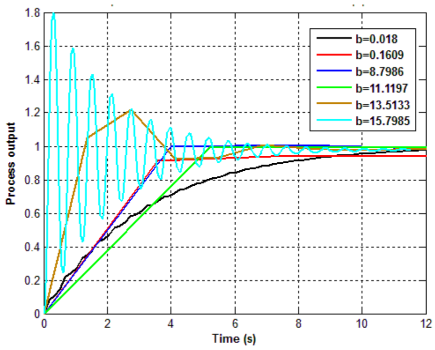

Figure 3. Effect of controller parameter ‘b’.

9. The effect of the proportional gain ‘K_{pc}’ of the controller on the time response of the closed-loop control system is shown in Fig.4.

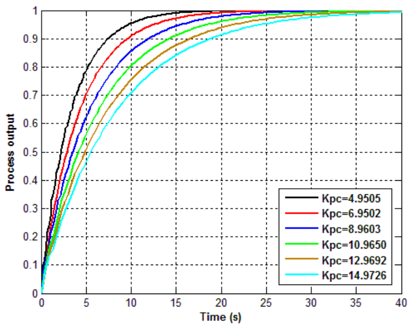

Figure 4. Effect of controller parameter ‘K_{pc}’.

10. The effect of the integral gain ‘K_i’ of the controller on the time response of the closed-loop control system is shown in Fig.5.

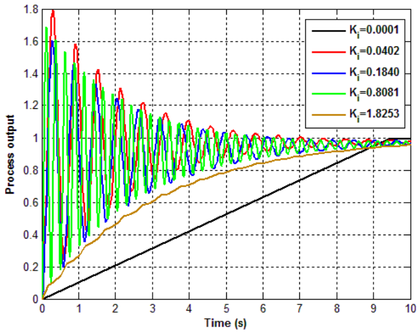

Figure 5. Effect of controller parameter 'K_i'.

VI. COMPARISON WITH OTHER CONTROLLERS

To investigate the effectiveness of the 2DOF controller in controlling the highly oscillating second-order-like process, the unit step response of the closed loop control system is compared when eight controllers are used with the same process. Those are: I-PD controller [19], PD-PI controller [20], PI-PD controller [21], PID + first-order lag controller [22], PID controller [23], PPI controller [24], PIP controller [25] and 2DOF controller (present work). The comparison is presented graphically in Fig.6.

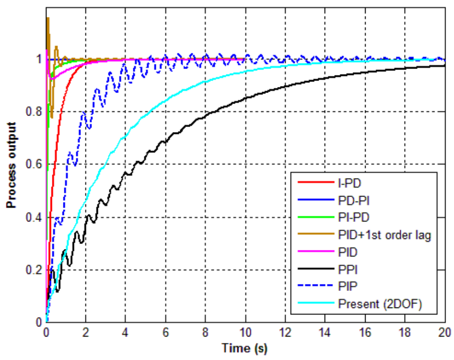

Figure 6. Performance comparison using different controllers.

VII. CONCLUSIONS

- A 2DOF was presented to control a highly oscillating second-order-like process.
- The controller was tuned to adjust its three parameters using both MATLAB optimization and control toolboxes.
- The use of five objective functions was investigated and it has been shown that the ISE objective function was the most suitable one for this application.
- It was possible to reduce the maximum overshoot of the control system to zero.
- The parameter 'b' of the 2DOF controller had a remarkable effect on the dynamics of the control system. Changing 'b' in the range $0.018 \leq b \leq 15.8$ has changed the maximum overshoot of the control system step response from 0 to about 80 % and the settling time from 3.8 to 9.7 s.
- Changing the controller parameter 'K_{pc}' in the range $4.95 \leq K_{pc} \leq 16.97$ had no effect on the maximum overshoot, but has increased the settling time from 9.7 to 27.4 s.
- Changing the controller parameter 'K_i' in the range $0.0001 \leq K_i \leq 1.825$ has changed the maximum overshoot from 0 to 79 % the settling time from 7.9 to 9.7 s.
- Comparing with other controllers used to control the highly oscillating second-order-like process, the 2DOF controller could compare with the PIP and PPI controllers providing better performance.

REFERENCES

[1] A. Lecchini, M. Campi and S. Savarest, "Vertual reference feedback tuning for two degree of freedom controllers", International Journal of Adaptive Control and Signal Processing, vol.16, pp.355-371, 2002.
[2] L. Mirkin and Q. Zhang, "2DOF controller parameterization for systems with a single I/O delay", IEEE Transactions on Automatic Control, vol.48, issue 11, pp.1999-2004, October 2003.
[3] R. Miklosovic and Z. Gao, "A robust two-degree-of-freedom contand its practical application", 39th IAS Annual Meeting, IEEE Industry Applications Society, vol.3, pp.1495-1502, November 2004.
[4] A. Smith, A. Manti and F. Ponci, "Robust controller using polynomial chaos theory", 41st IAS Annual Meeting, Tampa, FL, USA, vol.5, pp.2511-2517, 8-12 October 2006.
[5] D. Vrancic, S. Strmcnik, M. Huba and P. Oliveira, "Comparison of some tuning methods for integrating proceses", 9th International Ph D Workshop on Systems and Control, Izola, Slovenia,, 6 pages, 1-3 October 2008.
[6] D. Novotsad and L. Macku, "Pole placement controller with compensator adapted to semi-batch reactor process", Proceedings of the 18th International Conference on Process Control, Tatranska Lomnica, Slovakia, pp.383-387, June 14-17, 2011.
[7] P. Bagheri and H. Nemati, "Novel tuning strategy for two-degree-of-freedom PI controllers", 18th IFAC World Congress, Milano, Italy, pp.6757-6762, August 28-September 2, 2011.
[8] N. Phurahong, S. Kaitwanidvilai and A. Ngaopitakkul, "Fixed structure robust 2DOF H-infinity loop shaping control for ACMC buck converter using genetic algorithm", Proceedings of the International Multi Conference of Engineers and Computer Scientists, Hong Kong, vol.2, pp.1030-1035, March 14-16, 2012.
[9] V. Alfaro and R. Vilanova, "Model reference based robust tuning of five-parameter 2DOF PID controllers for first-order plus dead time models", European Control Conference, Zurich, Switzerland, pp.3931-3936, 17-18 July, 2013.
[10] M. Mohiuddin, A. Kumar and S. Kumar, "2DOF robust controller design using FOPDT model", IOSR Journal of Electrical and Electronics Engineering, vol.9, issue 3, pp.28-37, 2014.
[11] M. Kumar and V. Patel, "Tuning of two degree of freedom PID controller for second order processes", International Journal of Science, Engineering and Technology Research, vol.4, issue 5, pp.1543-1546, 2015.
[12] K. Ogata, Modern Control Engineering, Pearson Education International, p.232, 2002.
[13] R. Clark, "The Routh-Hurwitz stability criterion revisited", IEEE, pp.119-120, June 1992.
[14] C. Lopez, MATLAB Optimization Techniques, Springer, 2014.
[15] C. Lopez, MATLAB Control Systems Engineering, Springer, 2014.
[16] J. Potra, P. Khuntia and S. Samal, "Analysis and comparison of different performance index factor for conventional PID & GA plus PID controller", International Journal of Emerging Technologies in Computational and Applied Sciences, vol.4, issue 3, pp.242-250, 2013.
[17] K. Hussain, R. Zepherin and M. Kumar, "Comparison of tuning methods of PID controllers for FOPTD system", International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, vol.2, issue 3, pp.1177-1180, 2014.
[18] Y. Karnavas and K. Dedousis, "Overall performance evaluation of evolutionary designed conventional AGC controllers for interconnected electric power syste studiesmin a deregulated market environment", International Journal of Engineering, Science and Technology, vol.2, issue 3, pp.150-166, 2010.
[19] G. A. Hassaan, "Tuning for an I-PD controller used with a highly oscillating second-order process", International Journal of Mechanical Engineering and Technology, vol.5, issue 5, pp.115-121, 2014.
[20] G. A. Hassaan, "Tuning for an PD-PI controller used with a highly oscillating second-order process", International Journal of Scientific and Technology Research, vol.3, issue 7, pp.145-147, 2014.
[21] G. A. Hassaan, "Tuning for an PI-PD controller used with a highly oscillating second-order process", International Journal of Research and Innovation Technology, vol.1, issue 3, pp.42-45, 2014.
[22] G. A. Hassaan, "Tuning for an PID with a first-order-lag controller used with a highly oscillating second-order process", International Journal of Scientific and Technology Research, vol.3, issue 9, pp.314-317, 2014.
[23] G. A. Hassaan, "On simple tuning of PID controllers for underdamped second-order processes", International Journal of Mechanical and Production Engineering Research and Development, vol.4, issue 3, pp.61-68, 2014.
[24] G. A. Hassaan, "PPI controller tuning for use with a highly oscillating second-order-like process", International Journal of Science and Engineering, (under publication).
[25] G. A. Hassaan, "Tuning of a PIP controller for use with a highly oscillating second-order-like process", International Journal of Research in Information Technology, vol.3, issue 7, accepted for publication, 2015.

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