International Journal of Current Trends in Engineering & Technology
Received 3 Dec., 2018, Revised Received, 20 Dec., 2018, Accepted 23 Dec., 2018, Available online 25 Dec., 2018
www.ijctet.org, ISSN: 2395-3152
Volume: 04, Issue: 06 (November- December, 2018)

A Comparative Study of Performance Analysis of IMC-Based PID Controllers Tuning System

Siddharth Shukla[1] and Nagendra Singh[2]
[1]Department of Electrical Engineering, SSSUTMS, Sehore, MP
[2]Department of Electrical Engineering, Trinity College of Engineering & Technology, Karimnagar
sidd1250@gmail.com, nsingh007@rediffmail.com

Abstract: - PID controllers have been used to track industrial operations for over 70 years. An understandable algorithm and the fundamental significance of its three tuning parameters make a PID control simpler for control professionals to understand. Kp, Ki, and Kd, respectively, in proportion. The settings of a PID controller must be specifically adjusted to the process dynamics to obtain good, consistent loop time responsiveness and robust performance. Many tuning guidelines have been developed for PID controllers in recent years. One of the control methodologies utilized in industries is the internal model controller-based methodology for controller design. An in-depth discussion of the various PID controller tuning techniques is provided in this paper.

Keywords: PID controller, Oscillation, Steady-state operations, tuning methods

1. Introduction

Process control is only one of the industrial uses for PID controllers. The rationale is that engineers can easily comprehend a PID controller's straightforward form [1]. This is made feasible by the algorithm's straightforward structure, which is theoretically simple to comprehend and allows manual customization. It also performs adequately in the great majority of applications [2]. Due to its straightforward structure and resistance to modelling mistakes, it is frequently utilized in process industries. The PID algorithm is the foundation for more complex control algorithms like model predictive control [3]. PID controllers regulate most industrial processes, although only a tiny section of the control loop functions well.

Additionally, 20% of the loops employ factory tuning, and 30% of the controllers are handled manually [4]. The manual tuning approach used in traditional PID control is time-consuming [1] and depends on the operator's understanding of the process. This indicates that PID controllers are often employed but not properly adjusted. Tuning issues can result in mechanical damage brought on by excessive control activity, subpar control performance, and even defective goods [5]. The development of an automated tuning system for PID controllers used in industrial process control is being pursued by researchers. We require some tuning mechanism to determine the critical gain and frequency of a closed loop process [6]. The three control parameters, proportional gain (KP), Derivative time (KD), and Integral time (KI), are calculated using the PID controller tuning procedure to ensure that the controller satisfies the required performance criteria. The fundamental purpose of auto-tuners is some experimental process through which plant information is gathered to compute the controller settings because the actual dynamics of the plant are typically unknown. As a result, tuning strategies may be categorized using this experimental method [7]. Before electronic controllers were introduced, systems were significantly quicker than mechanical control. Due to the tiny size of the electrical components, the size of the electronics controller is reduced; nevertheless, this has the drawback of making it particularly temperature sensitive [8]. To solve this issue, a flexible digital PID controller was added to a control system in 1980. Programming has replaced complicated control logic in modern electronic controllers [9]. Researchers are continuously seeking the finest PID controller tuning methods. PID controller design has undergone several improvements, including adaptive PID control [10], automated tuning PID control [12], and intelligent PID control [13]. Integrating processes are not naturally automated, and if thrown out of equilibrium, the output will change over time. In most real-world circumstances, it is highly tough and complex to control these sorts of processes in a desirable manner [14]. The internal model control (IMC) methodology has grown significantly in relevance among model-based PID tuning techniques since it only needs one tuning parameter, i.e., the closed loop time constant [15].

2. PID CONTROLLER MODELS

International Journal of Current Trends in Engineering & Technology
Received 3 Dec., 2018, Revised Received, 20 Dec., 2018, Accepted 23 Dec., 2018, Available online 25 Dec., 2018
www.ijctet.org, ISSN: 2395-3152
Volume: 04, Issue: 06 (November- December, 2018)

The PID controller's basic structure, shown in Fig. 1, has proportional gain K_p, integral time constant T_i and derivative time constant T_d.

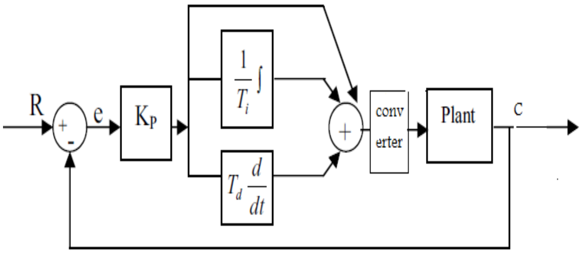

Fig.1 PID control in the closed loop.

Basic eq. for PID controller is given as follows,

$$U^{PID} = K_P e + K_I \int e dt + K_D \frac{de(t)}{dt} \quad (1)$$

Where e is the tracking error.

Conventional PID control is the sum of three different control actions. The proportional gain K_P, integral gain K_I, and derivative gain K_D represent the strengths of different control actions. Proportional action can reduce the steady-state error, but too much of it can cause the stability to deteriorate. Necessary action will eliminate the steady state. Derivative action will improve closed-loop stability.

2.1 Tuning of PID Controller

Three separate control actions are added together to form conventional PID control. The strengths of various control operations are represented by the proportional gain KP, integral gain KI, and derivative gain KD, respectively. While proportional action can lower steady-state error, too much of it might compromise stability. The steady-state will disappear with integral activity. Closed-loop stability will increase with derivative activity. Tuning" is the technical process of modifying the controller's settings to provide the desired characteristics in the control system. If the controller tuning constants are set at the wrong values, the control system functions badly and may even become unstable. In order to obtain optimal control performance, the controller parameters must be tuned using the right tuning constants [16]. PID control provides a simple way to minimize the effect of disturbances on a system. The system consists of a closed feedback loop between two elements. The controller has two inputs: a set point, a measure, and an output. The difference between the set point and measure inputs is the error signal, "e=set point – measure value.

2.3 PID Controller Tuning Methods

2.3.1 Ziegler Nichols Closed Loop Method (First Method)

Let us consider the S-shaped response shown in Fig. 2, which is characterized by two constants, the dead time L and the time constant T. The transfer function of such a plant may be approximated by a first-order system with a transport delay [17].

$$\frac{C(s)}{U(s)} = \frac{Ke^{-Ls}}{Ts+1} \quad (2)$$

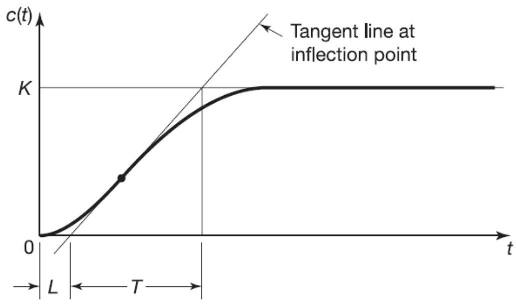

Fig. 2 S-shaped response of the plant

The transfer function of the PID controller for such a system,

$$G_c(s) = K_P\left(1 + \frac{1}{T_i s} + T_d s\right)$$

$$G_c(s) = \frac{1.2T}{L} * (1 + \frac{1}{2Ls} + 0.5Ls$$

$$G_c(s) = 0.6T\frac{(s+\frac{1}{L})(s+\frac{1}{L})}{s} \quad (3)$$

2.3.2 Ziegler- Nichols Tuning Rule Based on Step Response

Table 1 Represents the type of controller.

Type of Controller	K_p	T_i	T_d
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	$2L$	$0.5L$

2.3.3 Ziegler Nichols Closed Loop Method (Second Method)

The method is straightforward. First, set the controller to P mode only. Next, set the controller's gain (k_c) to a small value. Make a small set point (or load) change and observe the response of the controlled variable. If k_c is low, the response should be sluggish. Increase k_c by a factor of two and make another small change in the set point or the load. Keep increasing k_c (by a factor of two) until the

International Journal of Current Trends in Engineering & Technology
Received 3 Dec., 2018, Revised Received, 20 Dec., 2018, Accepted 23 Dec., 2018, Available online 25 Dec., 2018
www.ijctet.org, ISSN: 2395-3152
Volume: 04, Issue: 06 (November- December, 2018)

response oscillates. Finally, adjust k_c until a response is obtained that produces continuous oscillations. This is known as the ultimate gain (k_u). Note the period of the oscillations [18]. It is unwise to force the system into a situation with continuous oscillations, representing the limit at which the feedback system is stable. Generally, stopping at the point where some oscillation has been obtained is a good idea. It is then possible to approximate the period (Pu), and if the gain at this point is taken as the ultimate gain (k_u), then this will provide a more conservative tuning regime. The control law settings are then obtained from the following table,

Table 2: Tunning parameters for P, PI and PID controller

	K_p	T_i	T_D
P	$K_u/2$		
PI	$K_u/2.2$	$P_u/1.2$	
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

The transfer function of the system is given as

$$G_c(s) = K_P\left(1 + \frac{1}{T_i s} + T_d s\right)$$
$$G_c(s) = 0.6$$
$$G_r(s) = K_P(1 + \frac{1}{ST_i} + T_d S) \quad (4)$$

2.3.4 Cohen – Coon Method for PID Tuning

This method depends on identifying a suitable process model (previous lectures have covered plant identification). Cohen-Coon recommended the following settings to give responses with ¼ decay ratios, a minimum offset, and other favourable properties,

Table 3: Parameters used in Cohen coon method for tuning of PID controller

	k_c	T_i	T_D
P	$\frac{1}{k_p}\frac{\tau}{\theta}(1+\frac{\theta}{3\tau})$		
PI	$\frac{1}{k_p}\frac{\tau}{\theta}(\frac{9}{10}+\frac{\theta}{12\tau})$	$\theta\frac{30+3(\theta/\tau)}{9+20(\theta/\tau)}$	
PID	$\frac{1}{k_p}\frac{\tau}{\theta}(\frac{4}{3}+\frac{\theta}{4\tau})$	$\theta\frac{32+6(\theta/\tau)}{13+8(\theta/\tau)}$	$\theta\frac{4}{11+2(\theta/\tau)}$

The table k_p is the process gain, τ the process time constant and ϑ the process time delay.

2.3.5 Internal Model Control (IMC)

Model-based control methods are used in this procedure. Good set-point tracking benefits this method, but the disturbance reaction is slow, especially when the process has a short delay time or constant time ratio [19]. Figure 3 depicts the model used for IMC tuning.

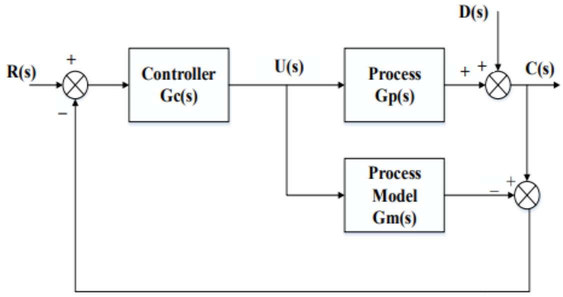

Fig.3 IMC tuning model for PID controller [12]

2.3.6 Chien-Hrones-Reswick Tuning

This approach highlights the significance of set point response and disturbance rejection. The quickest reaction with 0% overshoot or the quickest response with 20% overshoot is used as a design criterion in this modified open loop Z-N approach. The Ziegler-Nichols tuning technique and the CHR tuning formula are based on a 20% overshoot design criterion [20].

2.3.7 Wang-Juang-Chan Tuning

The best ITAE Criterion is the foundation for this tuning formula. Finding PID parameters is a fairly quick and easy process. If the plant's parameters, K (plant gain), L (time delay), and T (time constant), is known [21].

2.3.8 Robust PID Controller

An effective controller manages plant unpredictability. The robust controller will offer uncertainty and accomplish robustness and stability even with a little change in gain K, time constant T, and delay time L [22].

3. CONCLUSION

It is discovered that, in general, IMC controllers are capable of giving smooth replies with good set-point tracking behaviour based on the closed-loop responses for diverse process models. Their performance during load recovery, however, falls short of expectations. The IMC design may have both tight tuning and an auto-tuning option to enhance load rejection.

References

[1]. D. J. Wang, "Synthesis of PID controllers for high-order plants with time-delay," J. Process Control, vol. 19, no. 10, pp. 1763–1768, 2009.
[2]. H. Zhang, Y. Shi, and A. Saadat Mehr, "Robust static output feedback control and remote PID design for networked motor systems," in IEEE

International Journal of Current Trends in Engineering & Technology
Received 3 Dec., 2018, Revised Received, 20 Dec., 2018, Accepted 23 Dec., 2018, Available online 25 Dec., 2018
www.ijctet.org, ISSN: 2395-3152
Volume: 04, Issue: 06 (November- December, 2018)

Transactions on Industrial Electronics, 2011, vol. 58, no. 12, pp. 5396–5405.

[3]. J. Ahn, S. Cho, and D. H. Chung, "Analysis of energy and control efficiencies of fuzzy logic and artificial neural network technologies in the heating energy supply system responding to the changes of user demands," Appl. Energy, vol. 190, pp. 222–231, 2017.

[4]. W. Tan, J. Liu, T. Chen, and H. J. Marquez, "Comparison of some well-known PID tuning formulas," Comput. Chem. Eng., vol. 30, no. 9, pp. 1416–1423, 2006

[5]. P. Chalupa, M. B. A. Ř. Inova, J. Novak, and M. Benes, "Control System for Chemical Thermal Processes and Its Usage for Measurement of Collagen Shrinkage Temperature," vol. 10, pp. 445–452, 2015. [17] S. S. Mikhailovich, S. A. Baydali, and F. Manenti, "Development of a tunable method for PID controllers to achieve the desired phase margin," J. Process Control, vol. 25, pp. 28– 34, 2015.

[6]. M. Shamsuzzoha and M. Lee, "IMC-PID Controller Design for Improved Disturbance Rejection of Time-Delayed Processes," Ind. Eng. Chem. Res., vol. 46, no. 7, pp. 2077– 2091, 2007

[7]. D. Rivera, M. Morari, and S. Skogestad, "Internal model control: PID controller design," Chem. Process Des, pp. 252–265, 1986.

[8]. S. Saxena, and Y. V. Hote, "Load frequency control in power systems via internal model control scheme and model-order reduction," IEEE Trans. Power Syst., Vol. 28, no. 3, pp. 2749–57, 2013.

[9]. I. G. Horn, J. R. Arulandu, J. G. Christopher, J. G. VanAntwerp, and R. D. Braatz, "Improved filter design in internal model control," Ind. Eng. Chem. Res, Vol. 35, pp. 3437–41, 2011

[10]. J. Lee, W. Cho, and T. F. Edgar, "Simple analytic PID controller tuning rules revisited," Ind: Eng. Chem. Res, Vol. 53, pp. 5038–47, 2014.

[11]. Q. Wang, C. Lu, and W. Pan, "IMC PID controller tuning for stable and unstable processes with time delay," Chem. Eng. Res. Des., Vol. 105, pp. 120–9, 2016. 24. S. Saxena, and Y. V. Hote, "Internal model control based PID tuning using a first-order filter," Int. J. Control Automat. Syst., Vol. 15, no. 1, pp. 149–59, 2017.

[12]. M. Shamsuzzoha, "IMC based robust PID controller tuning for disturbance rejection," J. Cent. South Univ., Vol. 23, pp. 581–97, 2016.

[13]. R. Vilanova, O. Arrieta, and P. Ponsa, "Robust PI/PID controllers for load disturbance based on the direct synthesis," ISA Trans., Vol. 81, pp. 177–96, 2018.

[14]. C. Grimholt, and S. Skogestad, "Optimal PI and PID control of first-order plus delay processes and evaluation of the original and improved SIMC rules," J. Process Control, Vol. 70, pp. 36–46, 2018.

[15]. D. Krishna, K. Suryanarayana, G. Aparna, and R. P. Shree, "Tuning of PID controllers for continuous stirred tank reactors," Indian Chem. Eng., Vol. 54, no. 3, pp. 157–79, 2012

[16]. M. Shamsuzzoha, S. Lee, and M. Lee, "Analytical design of PID controller cascaded with a lead-lag filter for time-delay processes," Korean J. Chem—Eng., Vol. 26, no. 3, pp. 622–30, 2009.

[17]. Q. B. Jin, and Q. Liu, "IMC-PID design based on model matching approach and closed-loop shaping," ISA Trans., Vol. 53, no. 2, pp. 462–73, 2014.

[18]. S. Saxena, and Y. V. Hote, "Simple approach to design PID controller via internal model control," Arab. J. Sci. Eng, Vol. 41, no. 9, pp. 3473–89, 2016.

[19]. H. Najafizadegan, F. Merrikh-Bayat, and A. Jalilvand, "IMC-PID controller design based on loop shaping via LMI approach," Chem. Eng. Res. Des., Vol. 124, pp. 170–80, 2017.

[20]. C. H. Clerget, J. P. Grimaldi, M. Chebre, and N. Petit, "An example of robust internal model control under variable and uncertain delay," J. Process Control, Vol. 60, pp. 14–23, 2017

[21]. C. V. N. Rao, and R. Padma Sree, "IMC based controller design for integrating systems with time delay," Indian Chem. Eng., Vol. 52, no. 3, pp. 194–218, 2010.

[22]. T. L. Chia, and I. Lefkowitz, "Internal model-based control for integrating processes," ISA Trans., Vol. 49, pp. 519–27, 2010.