APPLICATION OF DESIGN OF PID CONTROLLER FOR CONTINUOUS SYSTEMS

J. Paulusová, M. Dúbravská

Institute of Control and Industrial Informatics,

Slovak University of Technology, Faculty of Electrical Engineering and Information Technology

Abstract

The aim of this paper is to describe the principles of control loop synthesis for linear continuous systems control using classical conventional methods. Different methods of PID controller design are used for different types of continuous systems. These methods are compared in terms of quality of control. Design of PID controller is implemented in MATLAB/Simulink (Graphical User Interface - GUI), where user can design, compare and verify different controllers using proposed methods.

1 Introduction

PID control is the most common form of feedback control. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. In process control today, more than 95% of the control loops are of PID type, most loops are actually PI control. PID controllers can these days be found in all areas where control is used [2].

Nowadays a lot of different methods for PID controller design for continuous systems exist.

These methods are compared in terms of quality of control. There are four major characteristics of the closed-loop step response: rise time, overshoot, settling time and steady-state error.

An application for controller design making use of chosen methods is created in MATLAB/Simulink (GUI), where users can design, compare and verify different PID controllers for given model plant using proposed methods. The time responses of variables (output variable, reference variable, error and manipulated variable) are depicted. The practical using of this GUI like appropriate tool is for study matters concerning synthesis of control.

2 PID Controller Structure

The controller is used in a closed loop unity feedback system according to Fig. 1.

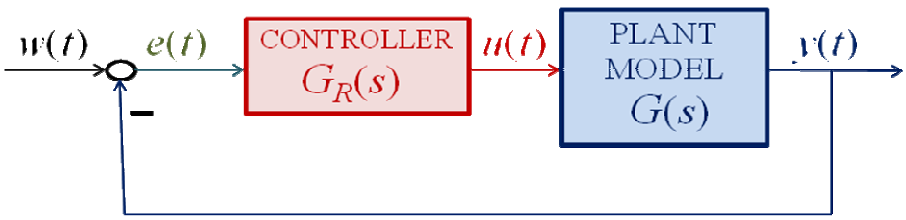

Figure 1: Block scheme of closed loop control system

The variable *e* denotes the tracking error, which is sent to the PID controller, *w* is reference variable and *y* is controlled (output) variable. The control signal *u* from the controller to the system is equal to the proportional gain *P* times the magnitude of the error plus the integral gain *I* times the integral of the error plus the derivative gain *D* times the derivative error [4]. A mathematical description of the PID controller is

$$u(t) = Pe(t) + I\int e(t)dt + D\frac{de(t)}{dt} \tag{1}$$

where $u(t)$ is the input signal to the plant model, the error signal $e(t)$ is defined as $e(t)=w(t)-y(t)$, and $w(t)$ is the reference input signal.

PID controlled system [5] is shown in Fig. 2.

Transfer function of the most basic form of PID controller is

$$G_R(s) = \frac{U(s)}{E(s)} = P + \frac{I}{s} + Ds \tag{2}$$

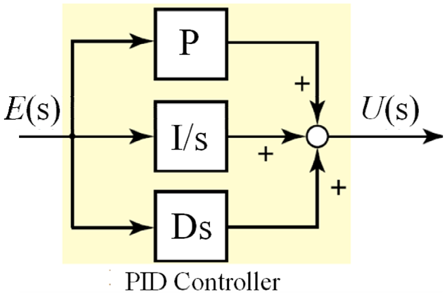

Figure 2: PID Controlled System

The PID parameters affect the system dynamic [3]. Four major characteristics of the closed-loop step response are evaluated:

- rise time – the time it takes for the control system output *y* to rise beyond 90% of the desired level for the first time,
- overshoot – how much the peak level is higher than the steady state, normalized against the steady state,
- settling time – the time it takes for the system to converge to its steady state,
- steady-state error – the difference between the steady-state output and the desired output.

3 Case Study

PID controller is tested in electric furnace temperature control, manipulating changes of power requirement. The actual temperature is sensed, whereby the control algorithm modulates the furnace power requirement. Block scheme of electric furnace control is on Fig. 3.

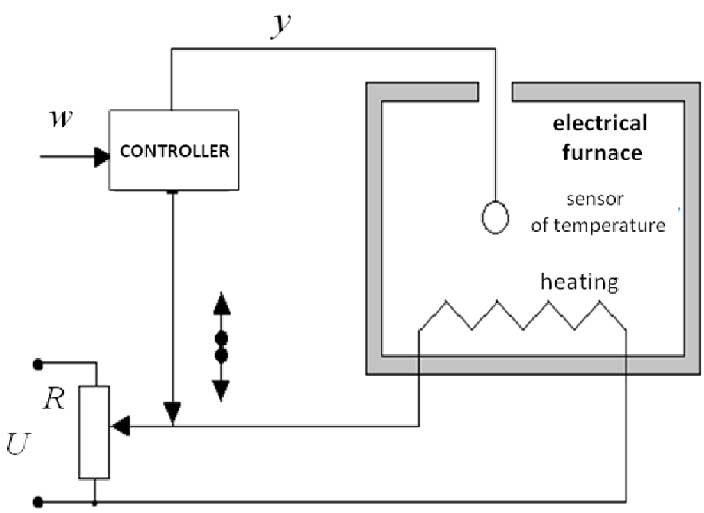

Figure 3: Block scheme of electric furnace control

Model of electrical furnace is described by the following transfer function:

$$G(s) = \frac{b_0}{a_2 s^2 + a_1 s + a_0} e^{-Ds} = \frac{0.15}{s^2 + 1.1s + 0.2} e^{-1.5s} \tag{3}$$

For this transfer function (electrical furnace model) PID controllers are designed making use of various methods, which are compared in terms of quality of the control.

The transfer function of a time delay is

$$H(s) = e^{-Ds} = e^{-1.5s} \tag{4}$$

For the design of the controller parameters using some of the methods (Naslin, Graham-Lathrop, Butterworth) it is necessary to substitute Eq. 4 with an approximation in form of a rational transfer function. The most common approximation is the first order Padé approximation:

$$e^{-Ds} \approx \frac{1-\frac{D}{2}s}{1+\frac{D}{2}s} = \frac{1-0.75s}{1+0.75s} \tag{5}$$

With the approximation of the time delay the transfer function is

$$G(s) = \frac{0.15}{s^2+1.1s+0.2}\,\frac{1-0.75s}{1+0.75s} = \frac{-0.1125s+0.15}{0.75s^3+1.825s^2+1.25s+0.2} \tag{6}$$

4 Design of PID controller

Tuning a control loop is the adjustment of its control parameters (proportional band/gain, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response. Stability (bounded oscillation) is a basic requirement, but beyond that, different systems have different behavior, different applications have different requirements, and requirements may conflict one with another.

PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, and more sophisticated techniques are the subject of patents; this section describes some traditional manual methods for loop tuning.

Designing and tuning a PID controller appears to be conceptually intuitive, but can be hard in practice, if multiple (and often conflicting) objectives such as short transient and high stability are to be achieved. Usually, initial designs need to be adjusted repeatedly through computer simulations until the closed loop system performs or compromises as desired.

First group are standard methods [7]. These methods are based on knowledge of the mathematical model (Optimum magnitude method, Naslin's method and methods based on the characteristic equation of the closed loop system; the controller gains are chosen such that the characteristic equation matches one of a set of standard forms: Graham-Lathrop's methods, Butterworth's method).

Second group included graphical-analytical methods (Ziegler-Nichols1 method, method of Direct synthesis and three other methods based on knowledge rise time and time delay from step characteristic of system: Ziegler-Nichols2, Cohen-Coon, Minimum ITAE, Direct Synthesis [6]).

Detailed algorithms of design of controller parameters for all of the above methods are introduced in [1].

The PID controller parameters (Eq. 2) for individual methods are shown in Tab.1.

Table 1: OPTIMAL COEFFICIENTS OF PID CONTROLLER

METHOD	***P***	***I***	***D***
Naslin	3.7455	1.0254	3.5343
Optimum Magnitude	2.7755	0.4917	2.7698
Graham-Lathrop	5.7065	1.6281	5.6466
Butterworth	4.4527	1.3171	3.7567
Ziegler-Nichols1	4.0235	1.0411	3.7321
Ziegler-Nichols2	6.011	1.545	5.847
Cohen-Coon	3.9931	0.4144	2.6267
Direct Synthesis	2.515	0.4572	2.2864

The comparison of step responses of closed loop systems variable (y) under PID control is shown in Fig. 4.

The comparison of time step responses of closed loop systems variable (u) under PID control is shown in Fig. 5.

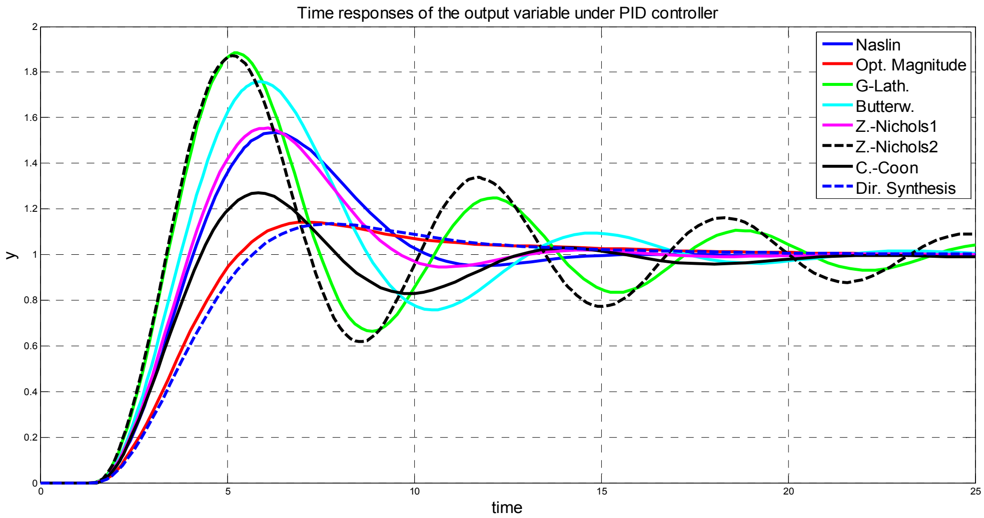

Figure 4: Step responses of closed loop systems variable (y) under PID controller

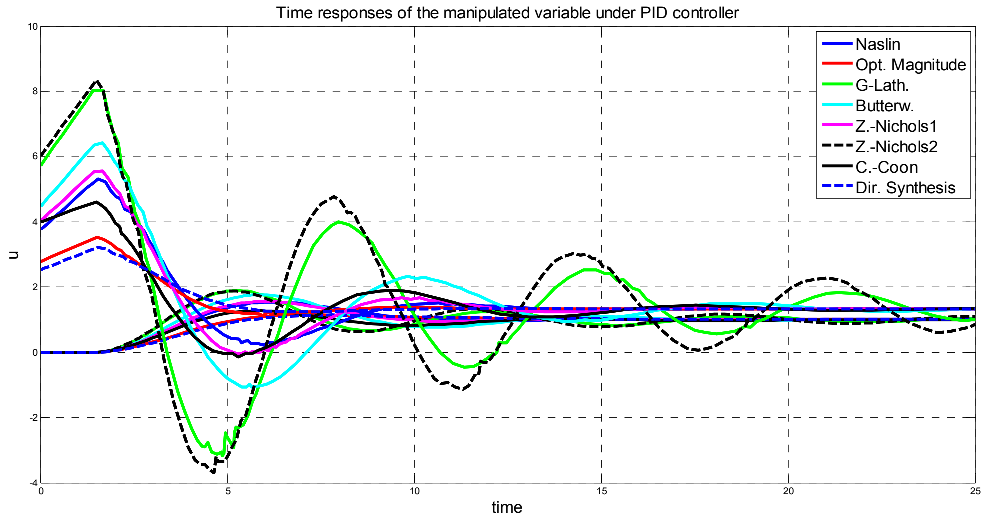

Figure 5: Step responses of closed loop systems variable (u) under PID control

Table 2: EVALUATION OF THE QUALITY OF CONTROL

METHOD	t_{reg} [s]	t_n [s]	η_{max} [%]
Naslin	13.7707	1.7499	53.5064
Optimum Magnitude	15.9130	2.5717	13.9852
Graham-Lathrop	24.3667	1.3226	80.7012
Butterworth	20.7419	1.5183	74.9228
Ziegler-Nichols1	12.3640	1.6684	55.4308
Ziegler-Nichols2	24.0470	1.3348	71.7901
Cohen-Coon	19.1892	1.8942	28.4835
Direct Synthesis	14.9596	2.8198	13.2742

Three major characteristics of closed loop step responses [8] are evaluated in Tab. 2: settling time t_{reg}, rise time t_n and overshoot η_{max}.

The Tab. 2 shows that the most appropriate methods for the synthesis of PID control loops for the process are the following methods: Optimum Magnitude and Direct Synthesis. These methods ensure low value of settling and the rise times and also have reached the lowest values of the maximum overshoot.

5 Application of Design of Controller Parameters

Design of controller is implemented in MATLAB/Simulink (GUI) for the commonly used controller type PID, see Fig. 6. It is believed that the developed tool may be very useful for design and tuning of industrial controllers.

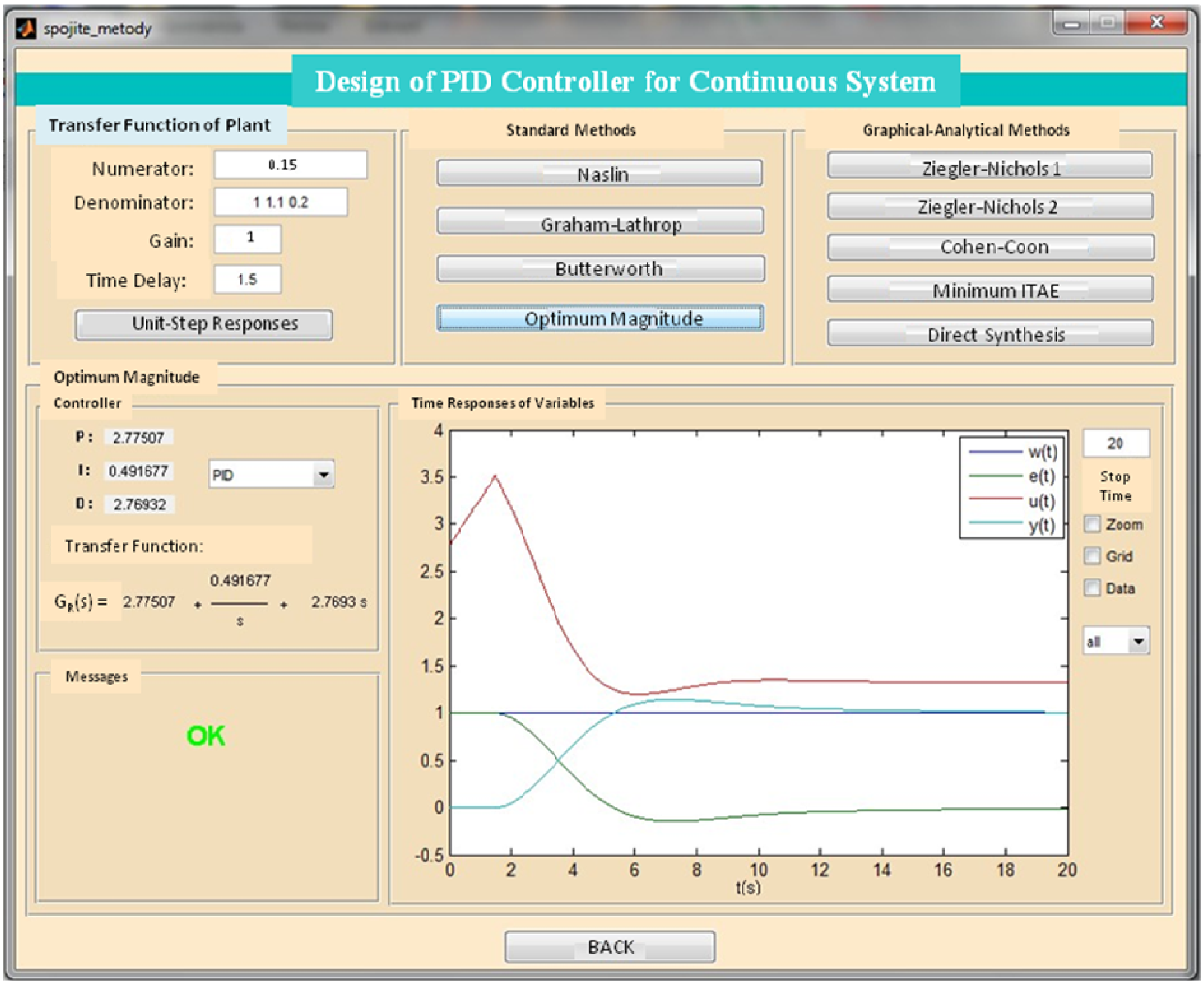

Figure 6: The Graphical Tuning Window

GUI can accept any model plant transfer function. User can choose one of the methods for PID controller design and compare it with other methods offered in GUI menu on the basis of the possibility of step response of closed control loop. The quality and stability of control with PID controllers can be evaluated.

6 Conclusion

GUI was created for educational purposes in subjects which the basics of automatic control are introduced. Students can see the influence of each control parameters on the quality and stability of control.

ACKNOWLEDGMENT

This paper has been supported by the Slovak Scientific Grant Agency, Grant No. 1/2256/12 and Grant No. 1/1241/12.

References

[1] P. Birkus. *Control of linear continuous systems*. Master Thesis, FEI STU, Slovak Republic, May 2012.
[2] http://www.cds.caltech.edu/~murray/courses/cds101/fa02/caltech/astrom-ch6.pdf
[3] http://wwwdsa.uqac.ca/~rbeguena/Systemes_Asservis/PID.pdf
[4] http://www.siam.org/books/dc14/DC14Sample.pdf
[5] http://ece.ut.ac.ir/classpages/S84/Mechatronics/PID%20Controller/pid.pdf
[6] M. Vítečková, A. Víteček, L. Smutný. *Controller Tuning for Controlled Plants with Time Delay*. Preprints IFAC Workshop on Digital Control. Past, present and future of PID Control, ESAII Universitat Politecnica de Catalunya, 2000, pp. 283-289.
[7] Š. Kozák: *Lineárne číslicové systémy* 1, 1.vydanie, Editačné stredisko STU v Bratislave, 1991, 241s, ISBN 80-227-0435-0.
[8] http://www.posterus.sk/?p=12703

Jana Paulusová and Mária Dúbravská

Institute of Control and Industrial Informatics,
Faculty of Electrical Engineering and Information Technology,
Slovak University of Technology,
Ilkovičova 3,
812 19 Bratislava, Slovak Republic
e-mail: jana.paulusova@stuba.sk, maria.dubravska@stuba.sk