Implementation of Autotuning in Interacting Tanks to Emulate a Bioreactor

http://dx.doi.org/10.3991/ijoe.v8i3.2160

C.R. Nippert, SorelleVeigne, Steven Voelker,Charles Owens
Widener University, Chester, PA

***Abstract*—The set of two interacting tanks in the Chemical Engineering Lab is a prototype process that can be used to test novel and interesting control schemes. For this project a process that can be represented as a form of an either first order plus dead time (FOPDT) or a second order plus dead time (SOPDT) is tuned using a self-tuning algorithm, with Deadtime added to the control scheme to allow the simulation of a bioreactor. The algorithm uses an intelligent form of a PID controller that determines the tuning settings; thereby eliminating the need for the manually setting of the classical PID controller settings. Because there are a myriad of tuning algorithms, we followed the suggestion of Luyben (1) to provide 3 user selectable tuning settings that the user could choose from "on the fly". These PI settings are calculated using three distinct methods; Ziegler Nichols (ZN), TyreusLuyben (TL) and IMC methods. The auto-tuning algorithm and deadtime loop were designed, and the PLC and relay feedback tests were conducted to validate that the set up worked properly. An auto-tuning relay feedback algorithm implemented and system parameters values calculated. The algorithm was successfully able to maintain control during upsets.**

***Index Terms*—digital control, automatic control, level control**

I. INTRODUCTION

The Chemical Engineering laboratory has a two tank interacting system that can be tuned and controlled, so that the levels of water in these tanks are kept at a set point. This system is linked to an OPTO 22 Programmable Logic Controller (PLC), where the process is monitored and preserved in a history file on the computer. The interacting tanks system is a prototype process that the Chemical Engineering department can use to test novel and interesting control schemes. For this project, a process that emulates a bioreactor was controlled. Since obtaining and configuring an actual bioreactor is expensive, tedious and beyond our capability, we will simulate this bioreactor using the auto tuned two tank interacting system as reference. The system can either be represented as a first order plus dead time (FOPDT) or Second Order Plus Dead time (SOPDT) process. The system used for our controlled scheme is shown in Figure 1.

A simplified version of the system used was developed with the essential component shown along with their transfer functions. For many process such as bioreactors or fermenters, deadtime is intrinsic to the process. This deadtime delays the signal sent to the valve and creates a quene of data/signals, which are collected after a certain time frame set in this deadtime block. Each tank in our system is driven by a first order transfer function; by controlling the level in tank 1 make the system first order and controlling tank 2 makes it second order. Inorder to sucessfully simulate a biorector the overall transfer function of our two tank system should be similar to that of a bioreactor. Figure 2 shows the block diagram of the developed system.

Figure 1. Two tank Interacting System

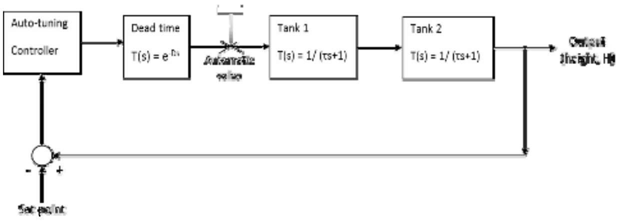


Figure 2. Block diagram of the system

The tuning process for a PID controller is tedious and frequently expensive, and has to be repeated when the process set point is changed because of the system's nonlinearity. Auto-tuning software helps automate the process of tuning controllers.

A relay feedback test is a method that is useful for tuning controllers. Relay-feedback tests involve inserting a

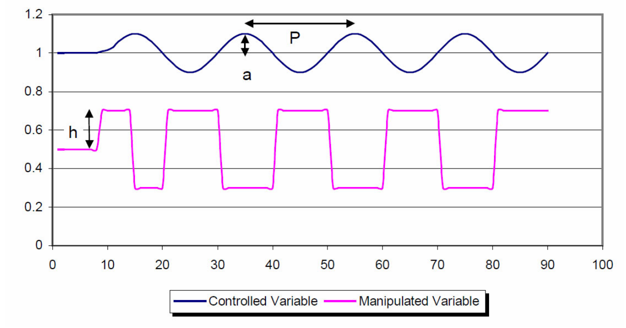


Figure 3. Relay feedback response

change in the feedback system loop and noting the system response. Once the signal change in the manipulated variable is sent to the system, the feedback loop responds around the set point, with the controller output switching each time the system height is away from set point. The system response of such test is shown in figure 3.

In conventional auto-tuning, the system response is then used to calculate the system gain and ultimate periods which are then used to calculate the controller's settings. The general transfer function that represents many bioprocesses requires the inclusion of deadtime in the model. This inclusion increases the complexity of the model of the system by replacing a simple first order lag with a process described by a first order plus dead time process (FOPDT). Deadtime is an important part of our project making conventional relay test useless for our purposes. Thus for this auto tuning project we would utilize Luyben's method which is a complex method of feedback test that accounts for deadtime.

Knowing that different processes yield differently shaped curves (have different curvature factor) during a relay feedback test, Luyben found that when this processes are subjected to a feedback test, the shape of the resulting curvature factor depends on the deadtime involved in the system. Systems with infinitely large deadtimes respond is a series of rectangular pulses, and the system response involving very low (close to zero) deadtime is a series of up and down ramps. Also, systems with moderate deadtime yield an output signal with some relative curvature. Luyben developed system of equations that can be used to calculate the system's deadtimes by analyzing the output signal curvature. This same principle would be applied in this project in order to obtain our tuning constants that are needed to calculate our controller algorithm.

All the system parameters can then be obtained from such test, and the controller algorithms calculated using these parameters. There are different ways to calculate these settings. For our purposes we would be using Ziegler Nichols (ZN), TyreusLuyben (TL) and Morari's (IMC), method as they have been proven to yield the best tuning results. The tuning equations are shown in equation 1-7 below.

- Morari (IMC) tuning equations

$$\lambda = max\ (1.7D,\ 0.2\tau) \ldots\ldots\ldots\ (1)$$
$$KcKp = (2\tau + D)/2\lambda \ldots\ldots\ldots\ (2)$$
$$\tau_I = \tau + D/2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

- Ziegler-Nichols(ZN)

$$Kc = Ku/2.2 \ldots\ldots\ldots\ (4)$$
$$\tau_I = Pu/1.2 \ldots\ldots (5)$$

- Tyreus-Luyben (TL) tuning equations

$$Kc = Ku/3.2\ \ldots\ldots (6)$$
$$\tau_I = 2.2Pu\ \ldots\ldots (7)$$

First Order PlusDeadtime behavior can be used to model many processes, both Biological and non-biological. For example, the dynamic response of a fermenter was measured by Hristov and Perez [2] and the graph is shown in figure 4.

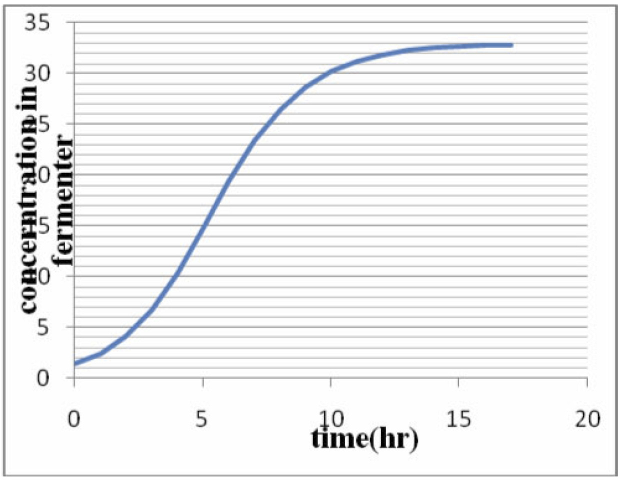


Figure 4. System response of Fermentation Process involved in bioreactor [2]

Using Riggs approach [3], the controller settings were calculated and the data fits a FOPDT mode with value as shown in table 1. As was predicted in Luyben's paper, the curvature factor depends on dead time. Given that the data obtained for a fermentation process was found to have been carried out at a 2.6 hr dead time, the system response fit Luyben's prediction, thus the same pattern was observed as is for FOPDT, but the curvature factor was different.

TABLE I.
CALCULATED SETTINGS FOR BIOREACTOR

k_p	0.000385
τ_p	4.142857 hr
Θ_p	2.642857 hr

II. EQUIPMENT AND USER INTERFACE

A significant portion of our design was the creation of an easy to use user interface for use with the algorithm. The requirement was that the device be intuitive and easy to use.

The Graphical User Interface (GUI) for the two-tank system used is shown in Figure 5. This setup is connected to the PLC that sends signals into the system so that the controller can make adjustments based on the error detected, and then reports the controlled variables (height) to the user. This is where the process is monitored and changes inputted. Here the user selects whatever conditions the process will run at such as dead time, and tuning method. Also the signal to the system can be changed to a sin wave function here, so that the process response the same.

An auto-tuning loop for the process was developed to direct the signal to the process. Figure 6 shows the designed loop for the control system. This loop is the code that the PLC follows as the control process proceeds. For the system to startup or stop, the signal has to pass through the start auto-tuning or stop auto-tuning loops respectively. Once the signal passes through either one of those loops it is directed to the upper half or lower half loops which makes the control valve to either open or close (response follows as explained in the relay feedback section), so that the fluid (in our case water) flows through or stops following through the pipe so that the height of the water in the tanks are keep at the set point. Once the close or open valve instruction is passed, the signal goes to the run auto-tuning loop were the error is calculated and fed back into the system for adjustments to be sent to the PID loop and this is where the controller settings are calculated using IMC, TL and ZL methods, so that the controller adjusts those PID settings.

III. PROCEDURE

The algorithm was changed so that it automatically calculates all tuning constants used from data being gathered and reevaluates the controller settings.

The steps taken to implement this new tuning method in this simulated bioreactor process are simple.

The test of the controllers are based on 3 fairly simple concepts of a control loop

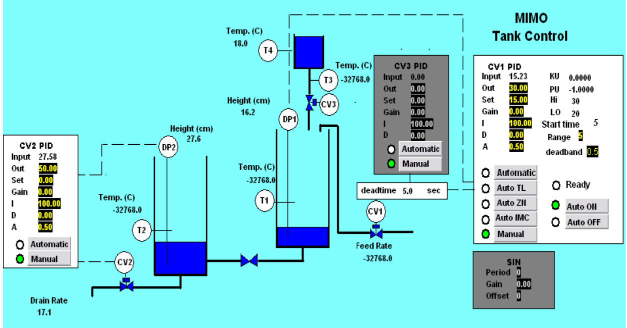
1. When a controller is turned on. The control variable will move to the set point
2. If the set point of the controller is changed while the controller is changed, the controller will adjust the manipulated variable to bring the controlled variable to the new set point
3. If an upset occurs in some other variable (a “wild variable” The controller will maintain the controlled value at the set point.

A second order system was tested as a natural consequence of our interacting tanks, in order to verify if stability was still maintained and if it stayed at optimum condition. We use this to verify that the auto-tuning would successfully work in any case controlled by a SOPDT process.

Our tests verified that the autotuning controller worked with all three control algorithms, as described in the following sections.

IV. DATA/RESULT

The system was run at different dead times in order to test the tuning capability of the system. Once the system response was obtained, the control parameter and settings for the PID controller were calculated from equations derived from Luyben's paper [1]. These parameters were then fed into the system and let to run at a set point of 25cm. The system responded pretty well when the settings were fed into system. The height of the water in tank 1 gradually increased and stabilizes at the set point, therefore tuning the system works.



CV2 PID
Input 27.58
Out 50.00
Set 0.00
Gain 0.00
I 100.00
D 0.00
A 0.50
○ Automatic
● Manual

CV3 PID
Input 0.00
Out 0.00
Set 0.00
Gain 0.00
I 100.00
D 0.00
○ Automatic
● Manual

deadtime 5.0 sec

CV1 PID
Input 15.23
Out 30.00
Set 15.00
Gain 0.00
I 100.00
D 0.00
A 0.50
KU 0.0000
PU -1.0000
Hi 30
LO 20
Start time 5
Range 5
deadband 0.5
○ Automatic
○ Auto TL
○ Auto ZN
○ Auto IMC
● Manual
○ Ready
● Auto ON
○ Auto OFF

SIN
Period 0
Gain 0.00
Offset 0

Figure 5. Two tank interacting system in Chemical Engineering Lab

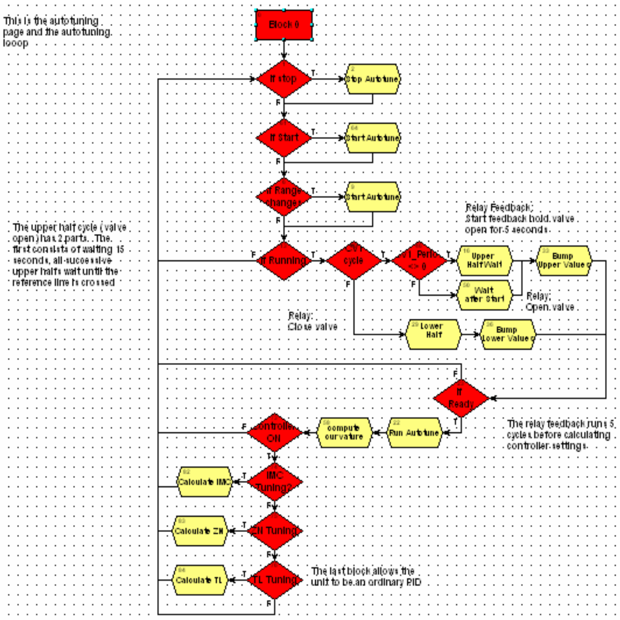


Figure 6. Auto tuning loop of system

The deadtime was a user selected variable (see GUI) that ranged from 0 to 60 seconds. For deadtimes greater than about 15 seconds control proved difficult and will not be discussed further. The major testing of the algorithm was completed using a significant deadtime of 5 seconds.

Final auto-tuning was conducted with the apparatus set on automatic with used dead time of 5 seconds. The test was set up so that it is a first order plus deadtime system (that is by monitoring the level in tank 1). Using Tyreus-Luyben setting, and set point of 15cm, the system was turned on and left to run until the algorithm was able to determine PI settings. It was observed that the level of tank 1 stabilized at that set point. Then after about 963 seconds the set point was changed to 25, and it was noted that level adjusted accordingly, followed the change, and stabilized at the new set point. After about 1390 seconds the system was upset by opening Control Valve 2 (CV2) to 100. The system responded and adjusted correctly while maintaining the 25cm set point. At about 1572 seconds, CV2 was closed to 50, but the level was still maintained which proved TyreusLuyben’s worked for the system.

At 1740 seconds, the system setting was switched to ZN and CV2 maintained at 50. No change in the level was observed, the controller seamlessly handled the switch of tuning method; thus the level of tank 1 stayed at the 25cm

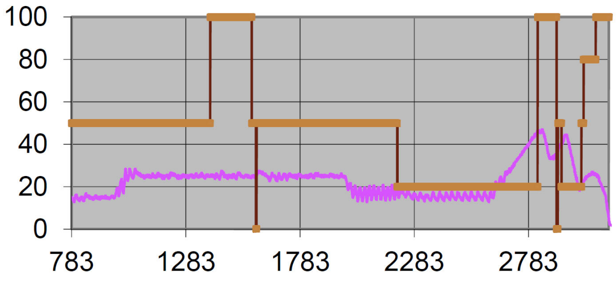


Figure 7. System response for FOPDT during auto-tuning

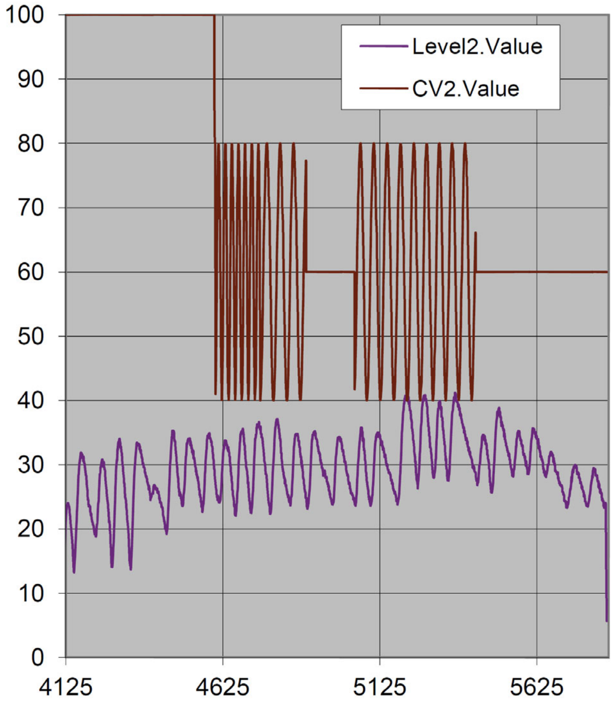


Figure 8. System response for SOPDT during auto-tuning

set point. For the last run using ZN, the system was set to 15 at 2214seconds and CV2 changed to 20. The system responded accordingly and kept the set point at 15.

Finally, testing was switched to IMC after 2588 seconds, and set to 25. The system wouldn't respond accordingly and the gain (K) went to 0. First order tests were stopped, and second order auto-tuning was started. Figure 7 shows the system response for FOPDT at these different settings and upsets made.

Testing was switched to second order by controlling the level in tank 2. A sine wave generator built in the PLC which drive CV2 was used instead of manually adjusting CV2 as it was with the case with the FOPDT trial; this was used as a test to shows the stability of the system.

Testing was started with TL at 4126s and set point of 25, the level in tank 2 oscillated within the set point. Then at 4604s, CV2 was connected to a to sine wave signal. The period of the sine signal used was 60 seconds because it seemed close to the natural period of the closed loop response. Level in tank 2 oscillated around 30, which is where the tank level was set at.

Setting was switched to ZN at 4890s and the sine signal was turned off while the set point was kept at 30, and the level in tank 2 still oscillated at 30, thus set point was maintained. The set point was kept the same and the sine signal switched back on at 5039s. This time the level in tank 2 went up a little and oscillated around 35; still quite away from the 30 set point. Finally testing was switch to IMC at 5340s and set to 25. The system responded ok but K was moving toward 0. Figure 8 shows the system response for this SOPDT at the sinusoidal settings.

V. CONCLUSION

The system response for a bioreactor process fits a FOPDT system as it has a distinct curvature factor, and follows the pattern predicted by Luyben.The controller seamlessly handled the switch from one control method to another.

Results from both 1st order and second order show that TL is better than ZN because it gives fewer oscillations.

Also, the results show that the system works when a sinusoidal input is used for the outlet valve (CV2).

REFERENCES

[1] William L. Luyben, Getting More Information from Relay-Feedback Tests, Ind. Eng. Chem. Res. 2001, 40, 4391-4402 http://dx.doi.org/10.1021/ie010142h

[2] J. Hristov, V.H.Perez , Critical analysis of data concerning Saccharomyces cerevisiae free-cell proliferations and fermentations assisted by magnetic and electromagnetic fields, International Review of Chemical Engineering, Vol. 3, pp. 3-20, January 2011

[3] J.B. Riggs, Chemical Process Control, 2nd edition, Ferret Publishing, Lubbock, Texas, 2001

AUTHORS

C. R. Nippert is an Associate Professor at Widener University, Chester PA. USA (e-mail: crnippert@mail.widener.edu.

SorelleVeigne, Steven Voelker, and Charles Owens are undergraduate students at Widener University anticipating graduation in May 2012.

Received 20 June 2012. Published as resubmitted by the authors 21 July 2012.