NATIONAL TAIWAN UNIVERSITY
DEPARTMENT OF CHEMICAL ENGINEERING
CHEMICAL ENGINEERING LABORATORY

EXPERIMENT 8

PROCESS CONTROL STUDY: LEVEL CONTROL

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Date : November 12, 2020

Temperature : 21.9°C

Atmosphere : 767.7 mm Hg

Relative Humidity : 82.0%

Chemical Engineering Laboratory
Department of Chemical Engineering
National Taiwan University

November 26, 2020

Professor Hsiu-Po Kuo
Department of Chemical Engineering
National Taiwan University
Taipei 10617, Taiwan

Dear Sir,

On November 12, 2020, our research and design department received your request to study the process control, and we take level control for example.

In this experiment, we tried to identify the dynamic results of controllers by two models, auto-tuning variation (ATV) and open-loop step response (OLSR). Later on, we used two kinds of tuning methods to decide our parameters, Ziegler-Nichols Quarter Decay-Ratio Tuning and internal model control (IMC). And we entered the parameters for P, PI, PID controllers from those methods, and then get the trend of liquid level. At the end, we tried to control level manually and observe the result of liquid level.

The analysis of the controllers shows that, P control may result in an offset when it reaches steady state, while PI and PID control spends more time reaching steady-state. And the result of PI and PID control using ATV identifying method shows overshooting phenomena due to I control and short integrating time. However, we didn't see overshooting condition in the result PI and PID control using OLSR method because of the longer integrating time.

We sincerely hope the following report and analysis meet with your approval.

Yours truly,

Project Manager

ABSTRACT

In the experiment, we learned how to identify process dynamic, decided parameters of controllers from tuning methods, and understood mechanisms, applications, benefits of different controllers.

1. Process Dynamic Identification

We learned two methods to identify process dynamic, which are auto-tuning variation, and open-loop step response. We controlled the valve at u_s ±15% to get the parameters of ATV method; and automatically control the valve opening at 2% to get the parameters of OLSR method.

2. Tuning Parameters of Controllers

In the experiment, we used two tuning method to decide the parameters of P, PI, and PID controllers. The methods are Ziegler-Nichols Quarter Decay-Ratio Tuning and internal model control (IMC). We used the parameters we got from ATV and OLSR identification methods, and filled them into some equations to get the steady-state gain, integration time, and derivative time of PID controllers.

3. PID Controllers

From the results of different controllers, we can compare the functions of P, PI, PID controllers. And we found out that P controller make error time a proportional constant that makes liquid level reach steady-state soon, but with a steady-state offset. I controller integrates error in an integrating time, which makes error reach zero, but it takes time. And D controller derives error in derivative time to predict error in the future, which let system become stable, but it enlarges minor bias at the same time.

To sum up, after understanding features of three different controllers, we should combine them in different order to make good use of automatic control system.

TABLE OF CONTENTS

OBJECTIVES

1. Model Identification of Process Dynamics

Take liquid level for example, learning how to identify the process dynamic through auto-tuning variation (ATV), open-loop step response (OLSR) method.

2. Tuning Methods and Controllers

Understanding process and mechanism of P, I, and D controllers and knowing the advantages, disadvantages, and applications of P, PI, PID controllers. And put in the parameters calculated by model identification through two tuning methods, Ziegler-Nichols Quarter Decay-Ratio Tuning and internal model control (IMC), observe the response of controllers.

THEORY

There are many process control strategies available, but the most widely used in industry at present to use PID controllers for feedback control. The advantage of PID controllers is that they are relatively stable and easy to implement. Before determining the parameters of a controller, we need to have some understanding about the properties of the process concerned. Therefore, the design of a PID controller is divided into two steps generally: model identification of process dynamics and parameter tuning.

1. Model Identification of Process Dynamics

In this experiment, we use two methods for model identification. The results of the two methods will generate two sets of data for parameter tuning.

(1) Auto-Tuning Variation, ATV

ATV is a frequently used method for model identification in recent years. With a simple ON-OFF controller, the ultimate gain and ultimate period of a process can be determined and thereby the required tuning parameters can be determined. A block diagram of a process under auto-tuning is shown in Figure 1.

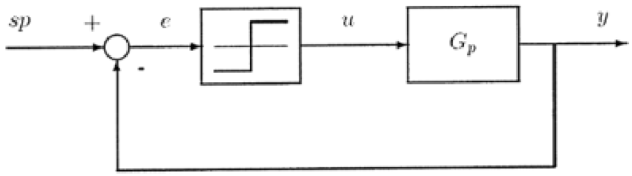

Figure 1. ATV process control block diagram.

(Source: "Experiment 8. Process Control Study: Level Control", Handout of UNIT OPERATIONS LAB II, p.34 (2020))

On-OFF control means that when the error is positive, the output of the controller is minimum; on the contrary, when the error is negative, the output is maximum, as indicated in Figure 2. After a while, the process will reach a state of continuous oscillation. At this time, the values indicated in Figure. 2 are measured to estimate the ultimate gain and the ultimate period of the process which are represented as K_u and T_u, respectively. To calculate K_u, we use Equation (1).

$$K_u = \frac{4h}{\pi k} \approx \frac{5h}{4k} \tag{1}$$

where

h:	range of controlling valve	(%)
K_u:	ultimate gain	(-)
k:	amplitude of level of tank	(%)
π:	mathematical constant	(-)

(2) Open-Loop Step Response

This is the most traditional method of model identification. An approximate model of the process is developed by making a step change in the process and analyzing the response. The most frequently used model is the First Order Plus Dead Time, FOPDT model. We will utilize its transfer function. The classical response is in Figure. 3. To estimate the parameters, use the following equations:

$$G_p(s) = \frac{K}{\tau s + 1} \tag{2}$$

$$K_p = \frac{\Delta y_z}{\Delta u} \tag{3}$$

$$\tau = \frac{3}{2}(t_{0.632} - t_{0.283}) \tag{4}$$

$$d = t_{0.632} - \tau \tag{5}$$

where

d:	dead time	(s)
G_p:	transfer function	(-)
K_p:	process gain	(%)
s:	Laplace transfer variable	(-)
$t_{0.283}$:	time as y reaches to 0.238y	(s)
$t_{0.632}$:	time as y reaches to 0.632y	(s)
τ:	time constant	(s)
Δu:	changing range of control valve	(%)
Δy_z:	changing range of level of tank	(%)

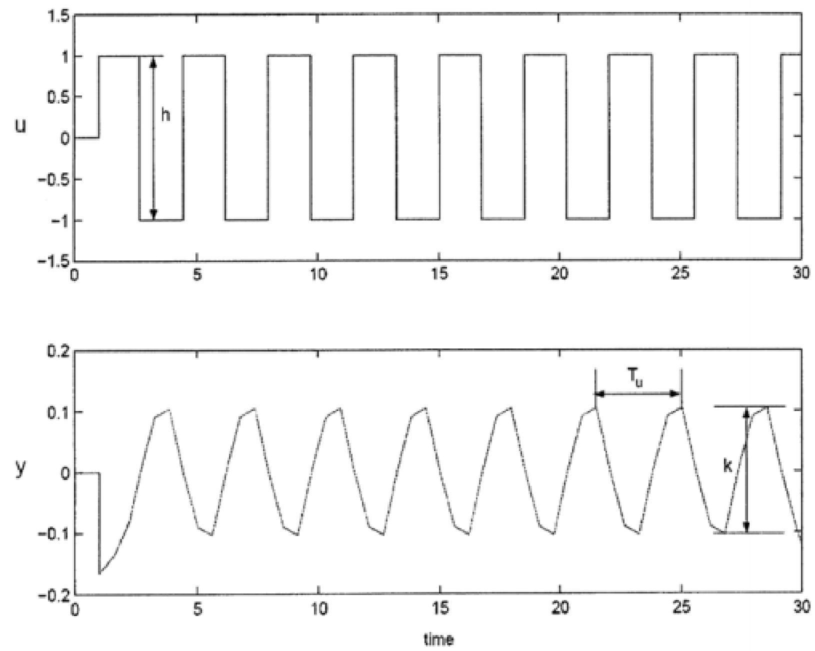

Figure 2. ATV test.

(Source: "Experiment 8. Process Control Study: Level Control", Handout of UNIT OPERATIONS LAB II, p.35 (2020))

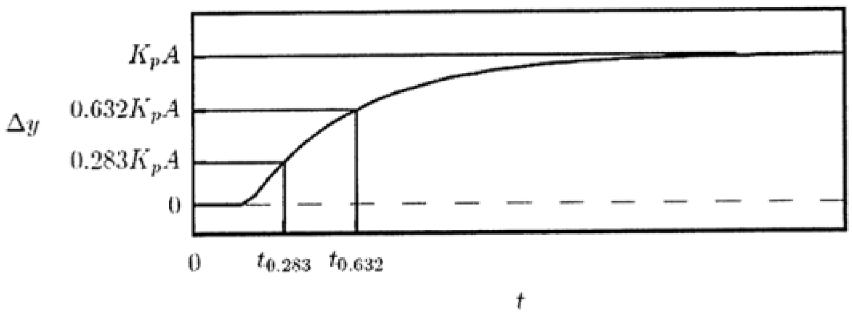

Figure 3. Response curve of FOPDT test (Δu=A).

(Source: "Experiment 8. Process Control Study: Level Control", Handout of UNIT OPERATIONS LAB II, p.36 (2020))

2. Parameter Tuning of Linear PID Controller

Through model identification, we have obtained a dynamic model of the process. Parameter tuning is a process that takes into account the control objective and the dynamic characteristics of the process to achieve the control objectives. For a linear PID controller, there are three main adjustable parameters: controller gain, K_c, of proportional control; integration time, τ_i, of integral control; differential time, τ_d, of differential control.

Two commonly used methods for parameter tuning are introduced in the following paragraphs. these two methods will also be compared based on the performance of the controller in this experiment.

(1) Ziegler-Nichols quarter decay-ratio tuning

The goal of Z-N tuning is to make each successive peak in the oscillation of the control variable be 1/4 the height of the previous peak. The formulae for tuning for ATV and for FOPDT are given in Table 1. and Table 2., respectively.

Table 1. Parameter tuning formulae according to ultimate data

Control Mode	K_c	τ_i	τ_d
P	$0.5K_u$	-	-
PI	$0.45K_u$	$T_u/1.2$	-
PID	$0.59K_u$	$T_u/2$	$T_u/8$

Table 2. Parameter tuning formulae according to FOPDT

Control Mode	K_c	τ_i	τ_d
P	$\tau / K_p d$	-	-
PI	$0.9\tau / K_p d$	3.3d	-
PID	$1.2\tau / K_p d$	2.0d	0.5d

where

K_c: steady state gain of proportional control (-)

τ_d: differential time constant of differential control (s)

τ_i: integration time constant of integral control (s)

(2) Internal model control (IMC) tuning

The basic idea of IMC tuning is to use an assumed model including the controller to predict the output and to cancel the perturbation. The formula for parameter tuning for linear PI controllers is given in Table 3. Data from FOPDT are utilized for calculation.

Table 3. Parameter tuning formulae for IMC

Control Mode	K_c	τ_i	τ_d
PI	$0.5\tau / K_p d$	Min{τ, 6d}	-

EXPERIMENTAL PROCEDURES

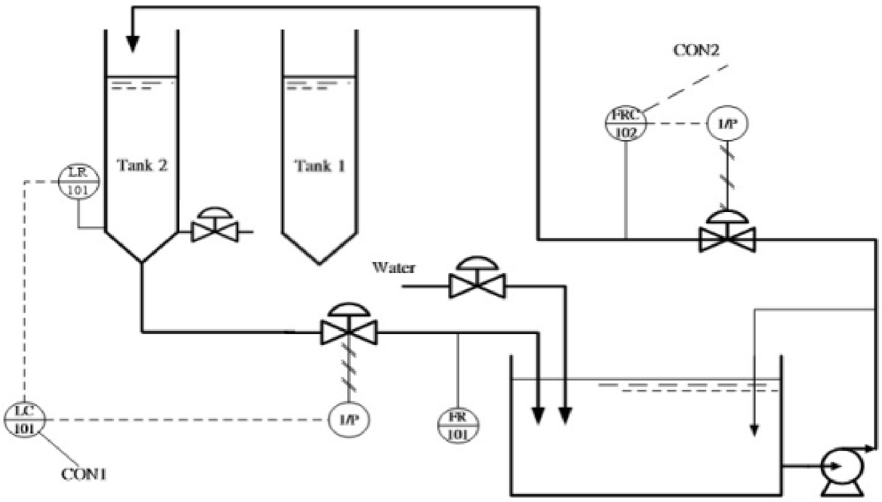

Figure 4. Equipment for liquid level control experiment.

(Source: "Experiment 8. Process Control Study: Level Control", Handout of UNIT OPERATIONS LAB II, p.37 (2020))

Turn on the water pump, air compressor, CON1, CON2, REC, and the DC switch.

↓

Adjust the set point of CON1 to 70% and switch to automatic control, and remain the set point of CON2 at 50%.

↓

Press "START" when the liquid level becomes stable around the set point.

↓ FOPDT test ↓ ATV test

ATV test

Maintain the liquid level at 70% and record the valve opening, u.

↓

Press "A/M" button to switch the valve opening manually to u_s - 15%. And switch the valve opening manually to u_s + 15% immediately. Repeat those operations for minutes.

↓

Calculate ultimate data from the result and fill in Table 1.

FOPDT test

Maintain the liquid level at 70%, and use manual control mode to change the valve opening by 2%.

↓

Record the change of liquid level until steady state. Calculate FOPDT data and fill in Table 2. and Table 3.

Switch to manual control when the liquid level is maintained at 70%. And enter a new set point and parameters (from Table 1., Table 2., and Table 3.) for CON1.

↓

Switch the mode to automatic control, and record the change of liquid level and observe the performance. (Test P, PI, PID control by using parameters in Table 1., Table 2., and Table 3.

Try to maintain a sable liquid level manually after setting three different liquid level, and record the steady-state valve opening.

↓

When all steps are finished, press “STOP” to save data and load data by “UnivViewer” on desktop of computer.

RESULTS

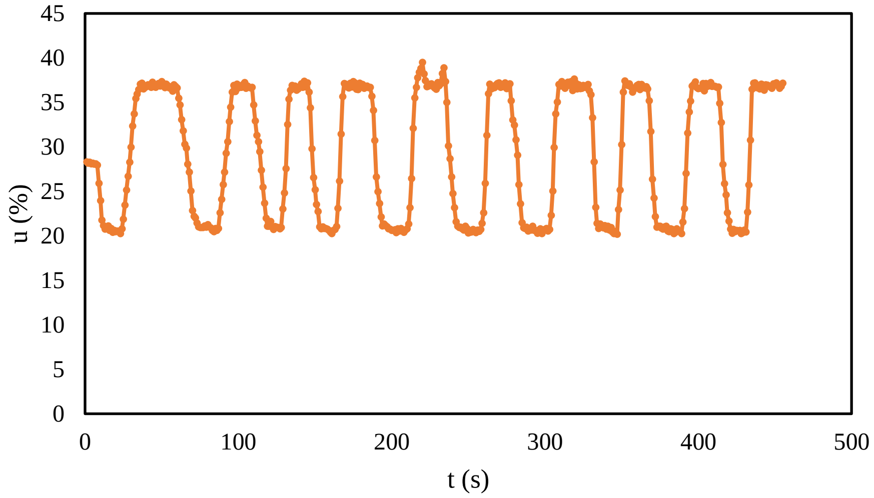

Figure 5. Valve opening while setting parameter of ATV test.

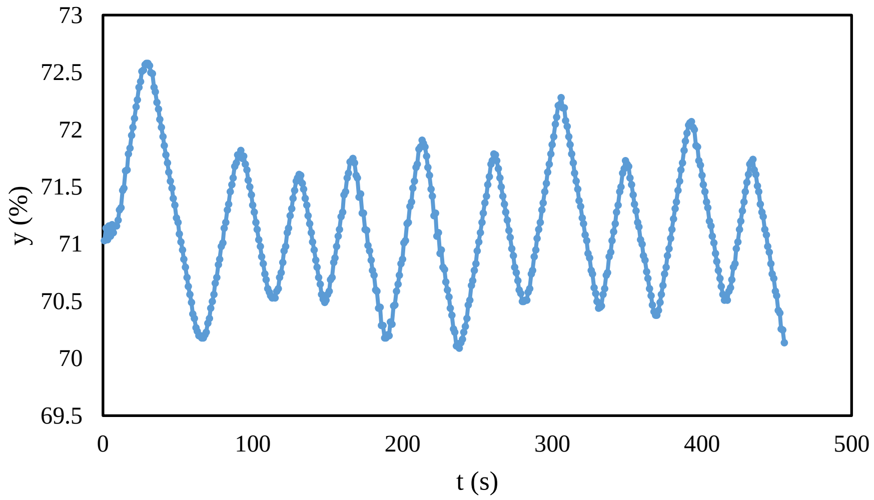

Figure 6. Liquid level of tank of ATV test.

Table 4. Setting parameters of ATV process

h (%)	30	average of k (%)	1.51
T_u (%)	46.0	K_u (%)	25.3

Table 5. Controller parameters of ATV process

controller	K_c (%)	τ_i (s)	τ_d (s)
P	12.67	-	-
PI	11.40	38.33	-
PID	14.95	23.00	5.75

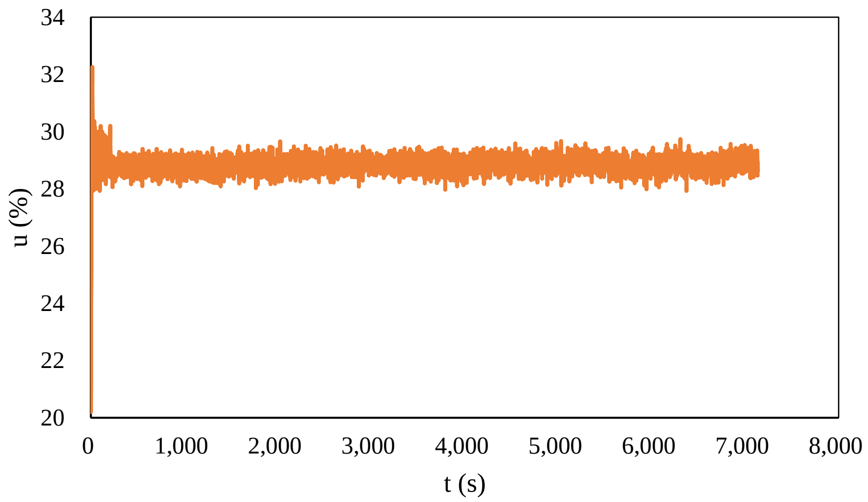

Figure 7. Valve opening of setting parameters of OLSR test.

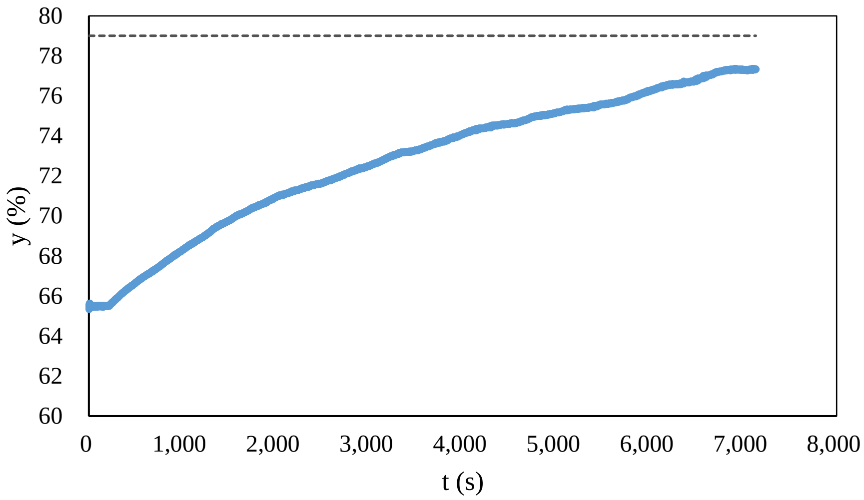

Figure 8. Liquid level of tank of setting parameters of OLSR test.

Table 6. Setting parameters of OLSR process

Δu (%)	2	Δy_z (%)	11.87
$t_{0.283}$ (s)	3196	$t_{0.632}$ (s)	1151
τ (s)	3067.5	d (s)	128.5

Table 7. Controller parameters of OLSR process

controller	K_c (%)	τ_i (s)	τ_d (s)
P	4.02	-	-
PI	3.62	424.05	-
PID	4.83	257.00	64.25

Table 8. Controller parameters of IMC process

controller	K_c (%)	τ_i (s)	τ_d (s)
PI	2.01	771	-

Table 9. Results of manual control

Water level of tank (%)	Valve opening (%)
75.2	30.0
67.0	28.6
61.3	29.9

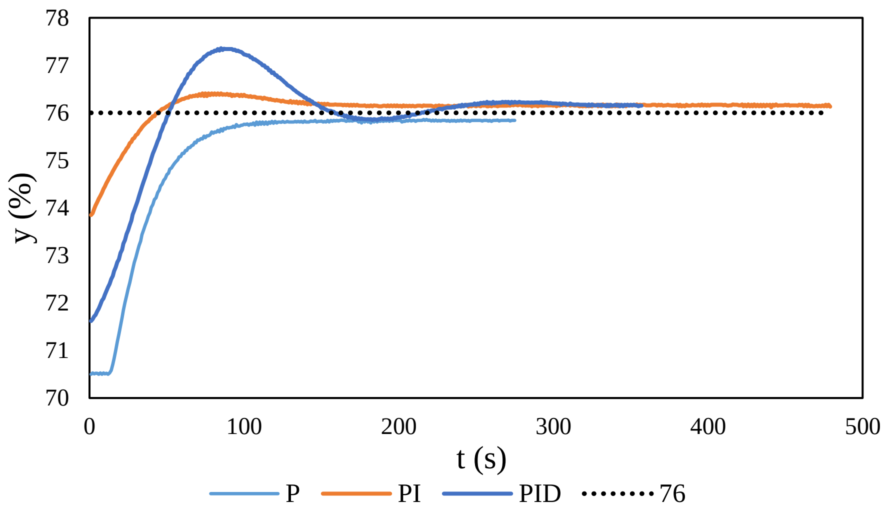

Figure 9. Results of automatic control of ATV test.

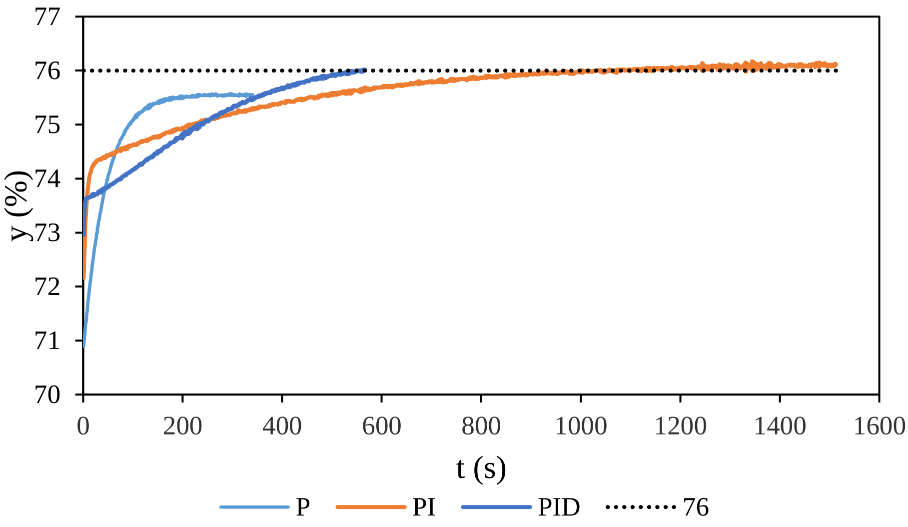

Figure 10. Results of automatic control of OLSR test.

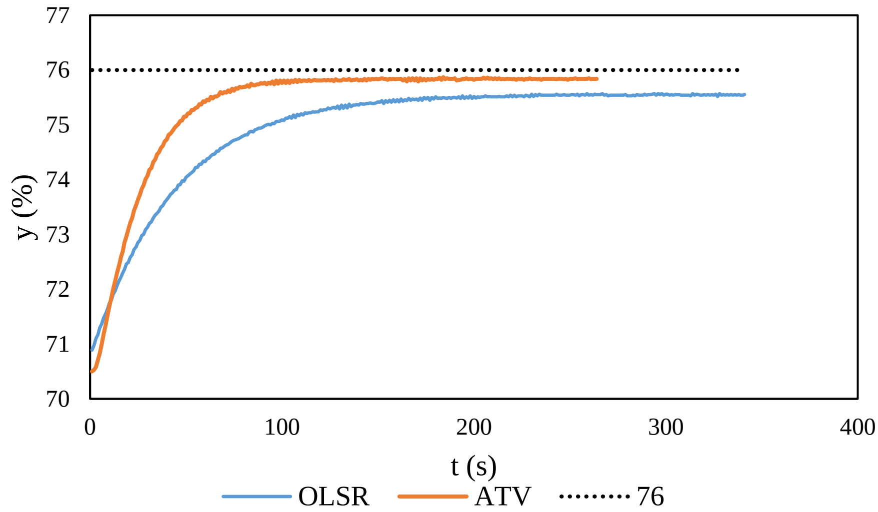

Figure 11. Results of automatic control of P control in different tests.

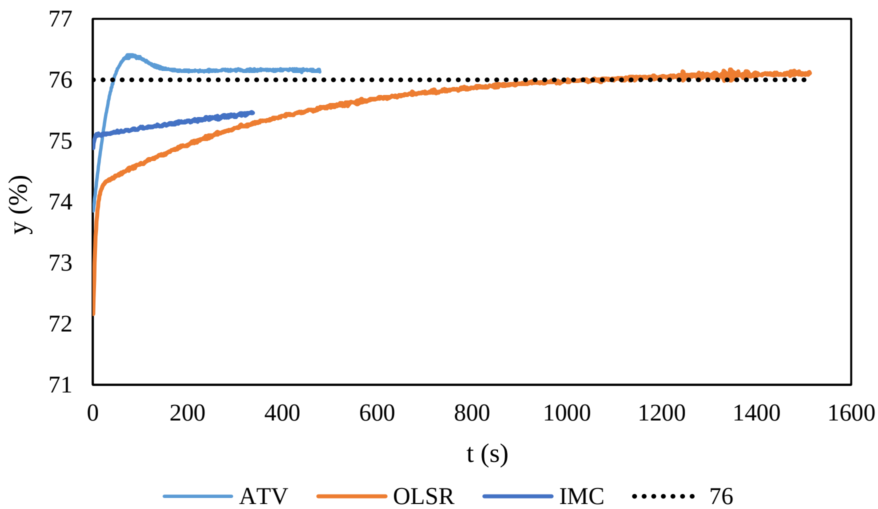

Figure 12. Results of automatic control of PI control in different tests.

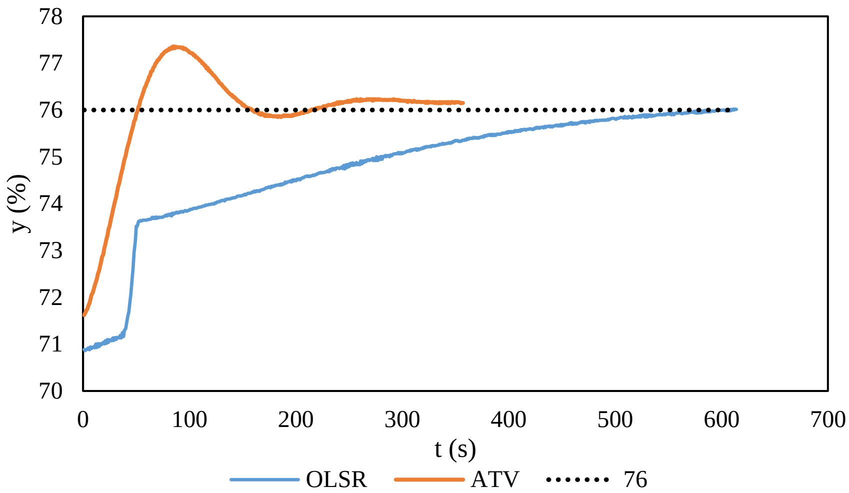

Figure 13. Results of automatic control of PID control of different tests.

Table 10. Parameter of tuning methods and valve opening and liquid level at steady state

	K_c (-)	τ_i (s)	τ_d (s)	valve opening (%)	liquid level (%)
ATV					
P	12.67	-	-	29.04	75.84
PI	11.40	38.33	-	29.06	76.15
PID	14.95	23.00	5.75	29.22	76.16
OLSR					
P	4.02	-	-	29.13	75.55
PI	3.62	424.1	-	28.83	76.1
PID	4.83	257.0	64.25	28.74	76
IMC					
PI	2.01	771.0	-	29.19	75.46

DISCUSSIONS

1. Parameter Setting

At the beginning of the experiment, we used two models to identify the results of automatic control, which are auto-tuning variation and open-loop step response.

Auto-tuning variation is set by manually controling the liquid level at 70% with valve opening u_s + 15% or - 15%, which is showed in Figure 5., which means parameter “h” is 30%. And we got the a jagged profile result as Figure 6., I calculated the average amplitude of Figure 6. to get parameter “k”. Later on, we translate the information in the profile into parameters K_u and T_u, in order to get Table 5.

The second model is open-loop step response. The controller maintained the liquid level at 78%, and use manual control mode to change the valve opening by 2%. And we got the result as Figure 8. By comparing Figure 8. and Figure 3., we can calculate K_p, τ, and d. Later on, we can fill in Table 6. and Table 7.

2. Indicating Error Between Sensor and Controller

We figured out that there existed an indicating error about 0.8 ~ 1.2% between sensor and the controller. When we set the set point to 78%, the sensor showed the result at about 79%, so that we changed the set point in our result figures to be y_{sp} + 1% so as to get a clearer analyzation. (The set point we set in controller is 75%, and I marked 76% in Figure 9., Figure

10., Figure 11., Figure 12., and Figure 13.)

The reason of indicating error would be a wrong transfer of signal between the signal the sensor got and signal the sensor send out. Assuming the transfer function is a polynomial function, y = ax + b, the error may result from a shift of “b” or a proportional error by “a”. So, the reason of indicating error could be a shifting error by 1%, or a proportional error by $\frac{76}{75}$%. And the error correcting method I used is the former one, which may result in error, too.

3. Comparison of Different Controllers

Figure 9. and Figure 10. show results of three controllers identified by two models, ATV and OLSR tests. And the set point of liquid level is 75%, which is showed about 76% on the sensor.

First, speaking of ATV method, Figure 9. shows out that the liquid level of P control approaches the set point first with a 0.2% offset. The trend of PI and PID show an overshoot before reaching steady state, which is result from the integrating mechanism of I control. The final steady state of PI and PID is a little bit higher than 76%, which may due to our rough level approximation at 75 + 1%.

Second, speaking of OLSR method, Figure 10. shows the same result of P control as ATV method that P control reaches steady state first with a 0.6% offset. And the results of PI and PID seem not stable yet, and they don’t overshoot, which is due to the large integrating and derivative time.

4. Comparison of Different Controllers

We used three kinds of controllers in the experiment, which were P, PI, PID controllers. First of all, to compare the results of P control with different tuning models, we can see Figure 11. and the following table.

Table 11. Parameters and results of P control

	K_c (-)	valve opening (%)	liquid level (%)
ATV	12.67	29.04	75.84
OLSR	4.02	29.13	75.55

The process of P control is a proportional enlarge of error, showed as equation 6. However, a proportional signal may not adjust error to be zero. Therefore, there may be an offset when the liquid level reaches steady state, which is called steady-state offset. In Figure 11., we can see that the liquid level of ATV test reaches steady state faster than the result of OLSR test, which is due to the larger steady state gain. A larger gain may let the enlarging process become faster, which means a larger slope and a faster liquid-level growing. And we got the steady-state offset of ATV and OLSR models of P control are 0.2% and 0.6% respectively.

$$p(t) = p_{s.s.} + K_c e(t) \tag{6}$$

where

$e(t)$: error of liquid level at set point and at a time (%)

$p_{s.s.}$: result of liquid level at steady state (%)

$p(t)$: result of liquid level at a time (%)

Second, the process of I control indicates an integrating correction of system signal. After an integrating time, I controller integrates an area and reads if the error area is larger or smaller than 0, and then, make the corresponding responds to keep liquid level at the set point, show as the following figure and equation.

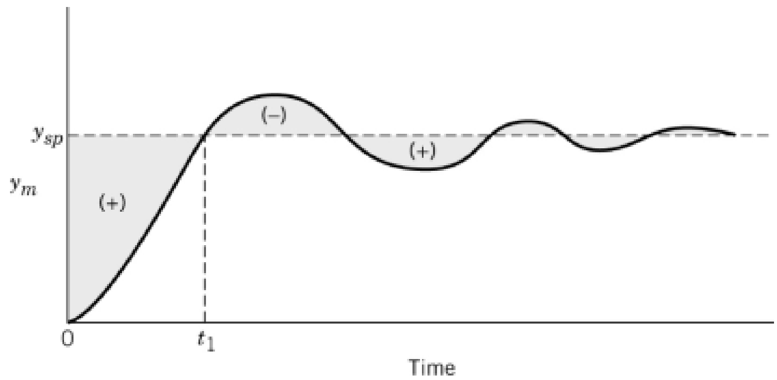

Figure 14. Process mechanism of I control.

(Source: "Experiment 8. Process Control Study: Level Control", 化工實驗(二), p.34(2020))

$$p(t) = p_{s.s.} + \frac{K_c}{\tau_i}\int_o^t e(t^*)dt^* \quad (7)$$

Table 12. Parameters and results of PI control at steady state

	K_c (-)	τ_i (s)	valve opening (%)	liquid level (%)
ATV	11.40	38.33	29.06	76.15
OLSR	3.62	424.1	28.83	76.1
PI	2.01	771.0	29.19	75.46

After understanding the process of I control, we can know that we may need more time in I control to reach steady state. In Figure 12., result of ATV identifying method reaches steady state first at about 3 minutes, while the others spend more than 10 minutes to reach steady state due to the much larger integrating time. Plus, the mechanism of I control may result in an overshooting due to the integration process, we can observe the overshooting in the result of ATV test. However, we couldn't observe the same phenomenon in the results of the other two tuning methods by two reasons: the larger steady-state gain (about 2 to 3 times larger) and the smaller integrating time (about 10 times smaller). A larger gain makes a bigger amplitude of modifying liquid level, and a smaller integrating time results in a faster signal output and a faster correction. A slower signal output results in slow correction; therefore, the slope becomes flat, reaches the set point slower and decrease the overshooting; or maybe we stopped at a time before the overshooting phenomenon happened. The IMC tuning method has the smallest gain and the biggest integrating time, so the modifying time should be the longest. We can see the same result in Figure 15., the figure shows that if integrating constant is large, integrating process becomes so slow, it may not have overshooting phenomenon.

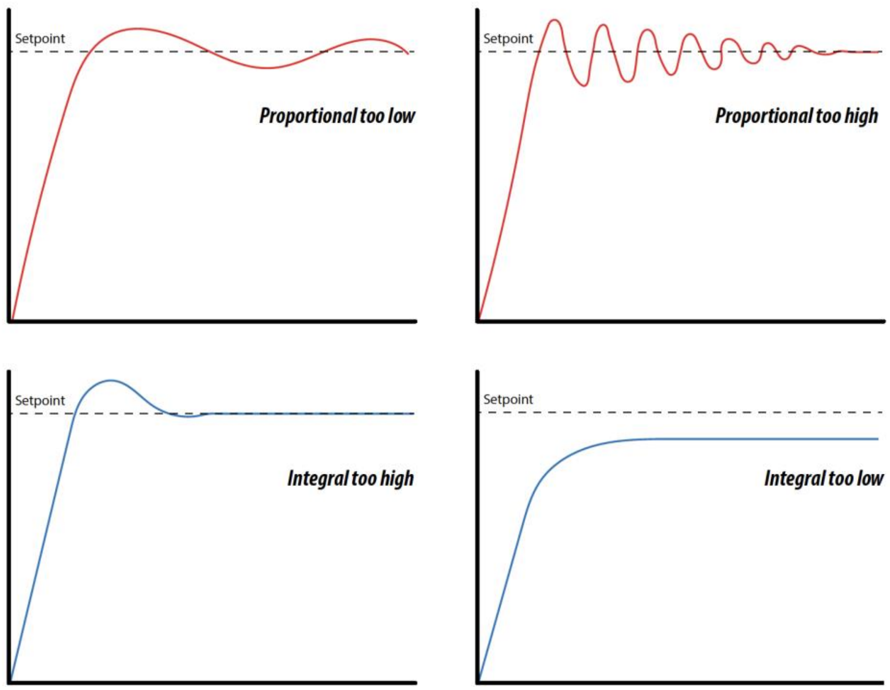

Figure 15. Result and trend in different conditions.

(Source: "Practical PID Process Dynamics with Proportional Pressure Controllers", https://clippard.com/cms/wiki/practical-pid-process-dynamics-proportional-pressure-controllers)

The third controller we added is D control, D control is a derivative controller. It derives the error at a short time to predict future error, and then does the corresponding response. Disadvantages of D control that it is easy to respond too fast, and enlarge minor bias, which is showed in Figure17.

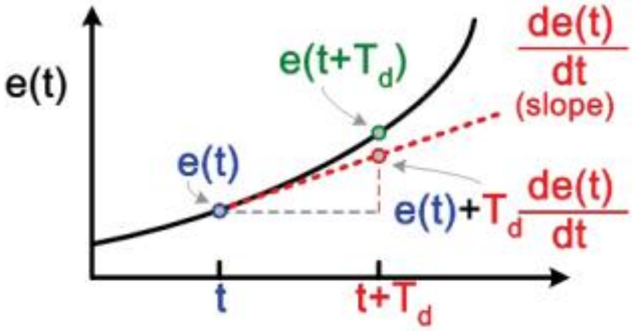

Figure 16. Mechanism of D control.

(Source: Handout of process control, PID_r2, 陳誠亮教授講義, p.15 (2020))

$$p(t) = p_{s.s.} + K_c[e(t) + \frac{1}{\tau_i}\int_0^t e(t^*)dt^* + \tau_d \frac{de(t)}{dt}] \tag{8}$$

Table 13. Parameters and results at steady state of PID controller

	K_c (-)	τ_i (%)	τ_d (%)	valve opening (%)	liquid level (%)
ATV	14.95	23	5.75	29.22	76.16
OLSR	4.83	257	64.25	28.74	76

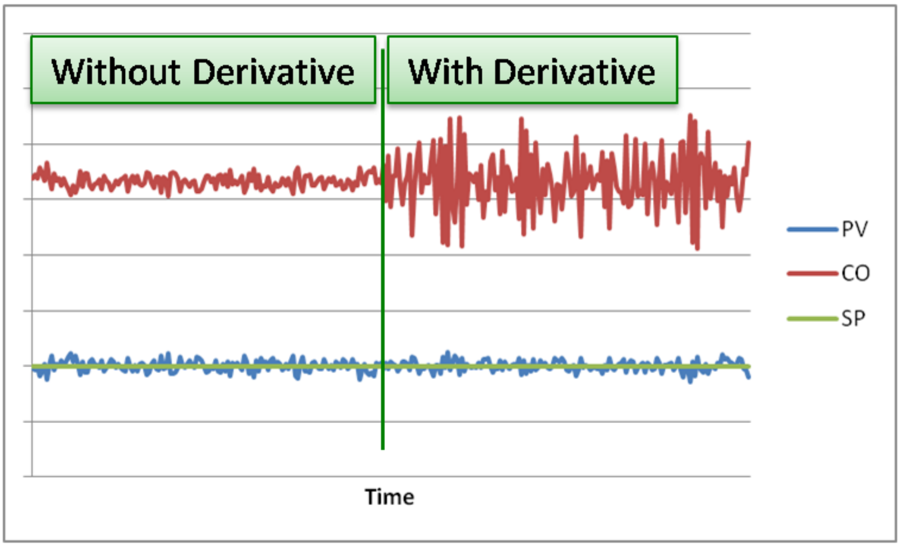

Figure 17. Bias enlargement of I control.

(Source: "PID Controller Algorithms", https://www.cnblogs.com/shangdawei/p/4826702.html)

Combining three controllers, we call the combination "PID controller". The process works as equation 8., and the results are showed in Figure 13. and Table 13. We can see that the overshooting of ATV method is more obvious than others, which is due to the smaller integrating time and derivative time. The smaller integrating time results in the more sensitive reaction of controller, while the smaller derivative time make the poorer prediction ability, so that makes the larger overshooting. On the other hand, we can see the same result from PI control: the result of OLSR method doesn't overshoot due to the larger integrating time.

5. Manual Control

After comparing different tuning models and different automatic controllers, we tried to control liquid level manually. We set the set point at y = 76.2%, 68.0%, and 62.3%. And it's obvious to observe that it's not easy to control the liquid level at a steady state by human.

The common result of three figures below is that we turned on or off the valve fully so that the slope of the liquid level raises up or goes down fast at first. Later on, we can observe the “overshooting” phenomenon in Figure 19. and Figure 21. It’s because of the lag between human reading output of the sensor and the controller reading response human adjust. At the end, we did fine adjustment to keep the liquid level at set point. (failed when y = 76.2%)

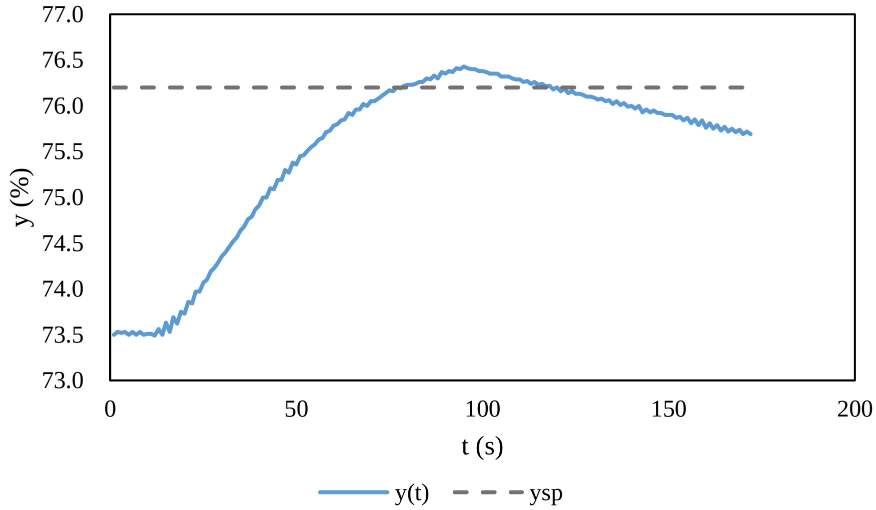

Figure 18. Liquid level when set point is 76.2% using manual control.

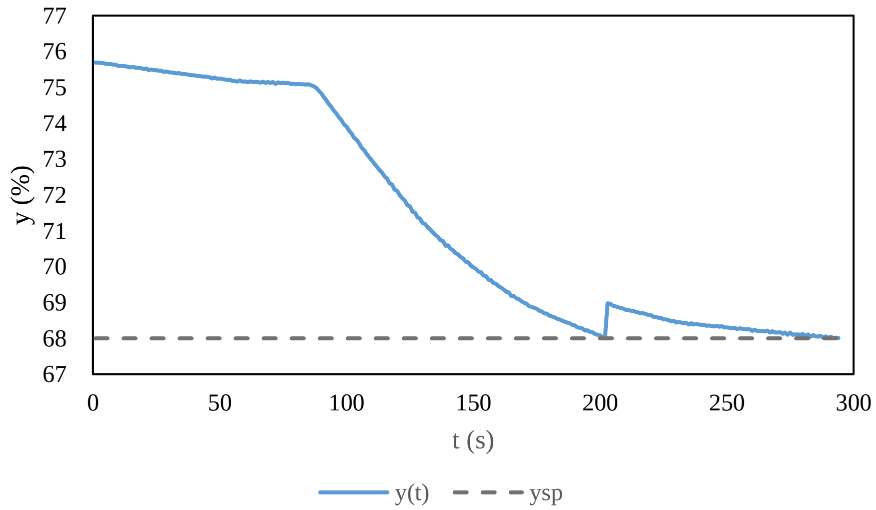

Figure 19. Liquid level when set point is 68.0% using manual control.

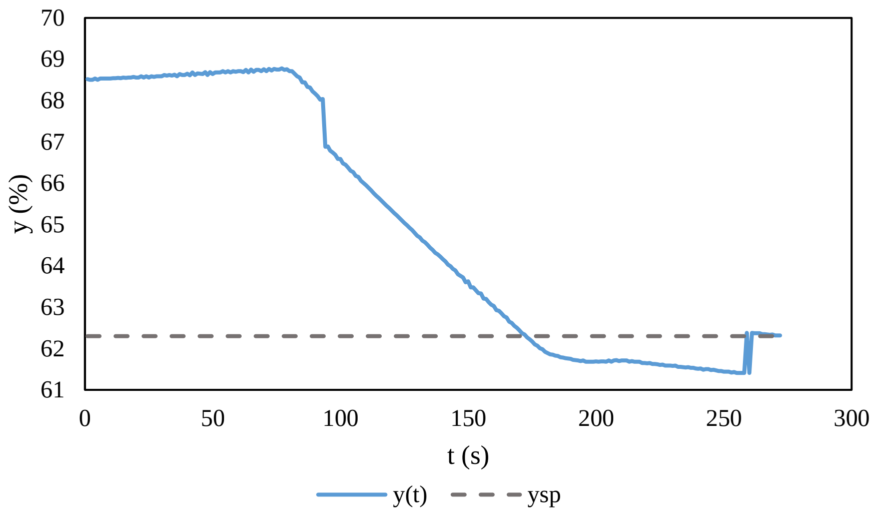

Figure 20. Liquid level when set point is 62% using manual control.

6. Correction of Parameters

As I mentioned in topic 2, I set parameter “h” as 30% due to the definition of model; however, the valve opening didn’t reach $\pm 15\%$ in our experiment. Instead, it was only about 16%. So, I calculated the average of each amplitude of valve opening and ultimate period, and I did corrections of our parameters as the following table. And we can get new parameters of PID controllers as Table 15.

Table 14. Corrections and original calculations of ATV parameters

h (%)	30	average of k (%)	1.51
T_u (%)	46.0	K_u (%)	25.3
average of h (%)	16.11	k (%)	1.51
average of T_u (%)	45.13	K_u’ (%)	13.60

Table 15. Corrections parameters PID controllers of ATV test

controller	K_c (%)	τ_i (s)	τ_d (s)
P	6.80	-	-
PI	6.12	37.60	-
PID	8.03	22.56	5.64

And speaking of indicating error, I corrected the parameters of ATV test by a proportional error by $\frac{76}{75}$% in the following tables. And we can see that the main difference is parameter of proportional control, K_c, which influences the speed that the level reaches steady state. So, I educated guess that the exact result may be faster than our original result.

Table 16. Corrections for indicating error and original calculations of ATV parameters

h (%)	30	average of k (%)	1.51
T_u (%)	46.0	K_u (%)	25.3
average of h (%)	16.11	k' (%)	1.53
average of T_u (%)	45.13	K_u'' (%)	13.42

Table 17. Corrections parameters for indicating error PID controllers of ATV test

controller	K_c (%)	τ_i (s)	τ_d (s)
P	6.71	-	-
PI	6.04	37.60	-
PID	7.92	22.56	5.64

QUESTIONS

1. Illustrate the Advantages and Disadvantages of Automatic Control and Manual Control, and Make Examples about the Applicable Situations.

The process of automatic control is, after the controller receives the data from sensor, it modifies the control system (ex. control valve) through P, PI, or PID control, repeat those steps until error reaches zero. Therefore, advantages of automatic control are reducing of manpower, and the precision of final steady-state result. However, the disadvantages of automatic control are the disability of responding to emergency, and it takes time for I control to integral. Take an isothermal tank for example, we may choose a PI controller, which is connected to a heater, to maintain temperature as a constant. The PI controller can do the modification by integration process and let error become zero; however, we don’t need a D controller, which may enlarge minor bias and make huge temperature changes as temperature increases in a short time.

On the other hand, the process of manual control is, totally open or close the valve until the level reaches the set point, and finely adjust the valve until it stable. Take level control for example, we totally opened the valve until it got over set point, and then we slowly closed the valve till it reaches steady-state. The advantage of manual control is that to response to emergency, people can turn on or off valve to control the situation. For example, in an exothermal reactor, when the temperature in the reactor suddenly increase, we should turn off the feed of reaction immediately by manual control to avoid the accident. The disadvantage of manual control is that a process may need lots of manpower to control, which means lots of cost.

2. In Conventional Process, Automatic Control is The Mainstream. Please Make an Example to Explain the Improvement of a Production Line Before or After Using Automatic Control. And Show Out How to Control and Precautions while Automatic Controlling.

There are some processes that involve reactions which have to be reacted under specified temperature. Take isothermal tank for example, we can operate the environment annually or automatically.

To keep the temperature at constant, we have to be caution to the temperature change in any time. And if the temperature displayed on the thermometer drops down, we should turn on heater after we read thermometer, in order to raise the temperature of the tank.

On the other hand, if we control the isothermal tank automatically, we add an automatically PI controller into the system. There may be a sensor in the system reading the temperature signal, and it may send the signal to controller. What the controller do is to calculate the error between the signal and the set point, and then send a signal to heater to do some modification. After steps of modifications, the temperature of tank may reach a new steady state (which is, ideally, equal to set point).

Though automatic control seems convenience to operate in the system and production line, there are some disadvantages or precautions to notice. First, D control is not suitable for this process. Because the minor change of temperature may be enlarged in D control; however, a huge temperature change in a factory process may cause severe trouble. Second, we have to be aware the maximum and minimum power of heater. If the controller gives the signal that is out of the control range of heater, the heater cannot offer the modification that controller offered.

3. If Changing the Experiment to Feedforward Control, What May the Flowchart (Figure 21.) Change? And If the Flowchart is Not Suitable Using, Explain Why.

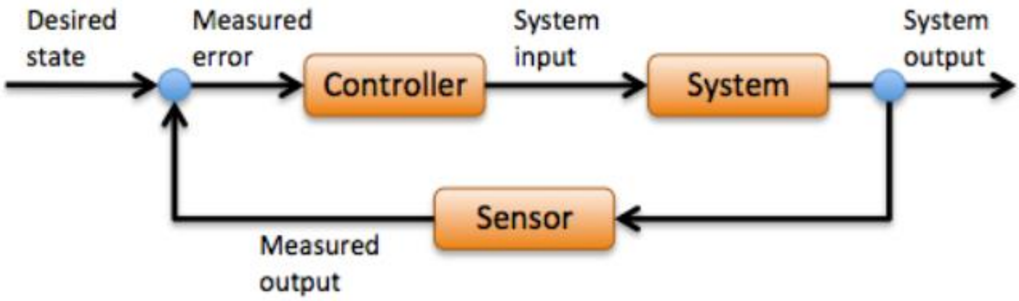

Figure 21. Flow chart of feedback control.

(Source: "實驗八 程序控制實驗—液位控制", 化工實驗(二), p.34(2020))

Changing the experiment from feedback control to feedforward control, the process may get the signal from the input flow of the system. And after sensor gets the signal, it sends error to controller in order to make corresponding adjustment for input of the system. The process flowchart shows in the below figure.

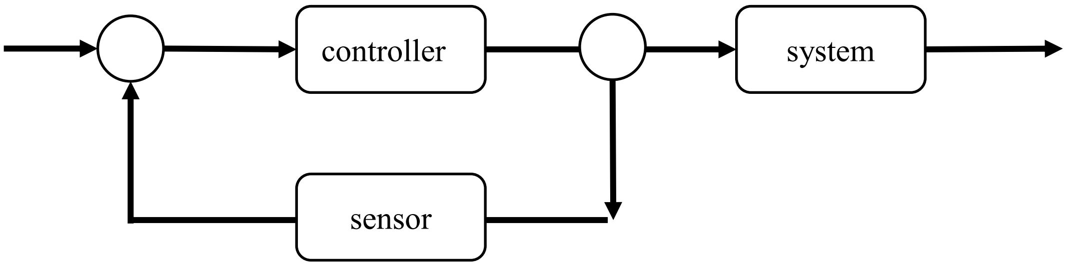

Figure 22. Flowchart of feedforward control.

The main difference between two kinds of controller is the signal that sensor gets. For feedforward control, controller gets signal from input, and anticipates the error that output may have. So, the advantage of feedforward control is that the controller can do the modification before the output comes out. However, we couldn’t know whether the result is influenced by the controller’s modification or not.

For example, if the temperature of a reaction’s feed increases, a feedforward controller will get the signal to reduce heater’s power supplication. Thus, the reaction temperature may not increase. On the other hand, a feedback controller will get the temperature increasing signal from output, and then do the modification to inlet temperature, which may be too late to control. However, the feedforward controller may not be a good choice for controller unless we know the corresponding temperature change between inlet and outlet.

CONCLUSIONS

1. PID Controllers

P control, which stands for proportional controller, may proportionally enlarge the error, in order to let the liquid level reach the set point. However, P control cannot let error become zero, there exists a steady-state offset while stead state is reached. I control, represents integral control, integrates the error in a period of time, in order to keep the level around the set point. But, I control takes a lot of time for integration. D control, stands for derivative control, derive the error in a short period of time to predict future error. However, D control may give the response too fast so that enlarge the unimportant bias. In factories, we should understand the characteristics of three controllers and make good use of the different combinations of them to control systems.

2. Model Identifications

In the experiment, we used two kinds of model to identify the results of control, which are auto-tuning variation and open-loop step response. In ATV test, we set the valve-opening by manual control, so that makes some manual error. On the other hand, the OLSR result we analyzed didn't reach steady state yet, which results in a bigger error so that time constant of integrating and derivation are so large.

To sum up, I think ATV test is a better identification method in the experiment we did.

SUGGESTIONS

1. The Indicating Error Between Sensor and Controller

There is a floating error about 0.8 ~ 1.2% between sensor and controller, which makes set point drifting and the incorrect result.

2. Complicated Operation of the Sensor

In order to get the data, we need to operate complicated steps after every single result, stop the recording and pick up SD card from the sensor, and insert SD card into computer. We suggest that change a sensor to have a better way to record data through sensor to computer.

3. Parameter Setting of Open-Loop Step Response

We picked up the data that was run by teacher assistant, and unfortunately, it didn’t reach steady state yet. I should make sure if the level reached steady state or not before downloading the data.

NOTATIONS

d:	dead time	(s)
$e(t)$:	error of liquid level at set point and at a time	(%)
G_p:	transfer function	(-)
h:	range of controlling valve	(%)
K_c:	steady-state gain of proportional control	(-)
K_p:	process gain	(%)
K_u:	ultimate gain	(-)
k:	amplitude of level of tank	(%)
$p_{s.s.}$:	result of liquid level at steady state	(%)
$p(t)$:	result of liquid level at a time	(%)
s:	Laplace transfer variable	(-)
$t_{0.283}$:	time as y reaches to 0.238y	(s)
$t_{0.632}$:	time as y reaches to 0.632y	(s)
π:	circular constant	(-)
τ:	time constant	(s)
τ_d:	differential time constant of differential control	(s)
τ_i:	integration time constant of integral control	(s)
Δu:	changing range of control valve	(%)
Δy_z:	changing range of level of tank	(%)

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APPENDICES

The followings are original experimental data: