Date: ________________ Name: ___________________________________

LABORATORY EXERCISE 12
TUNING LIQUID LEVEL CONTROL LOOPS

OBJECTIVE: To illustrate the characteristics of level control loops, in particular the non-self-regulating character, and to illustrate several different tuning philosophies.

PREREQUISITES: Completion of the following exercise:

7 Level Control Loop Characteristics

BACKGROUND: Whereas most processes exhibit some degree of self-regulation, level control applications are usually non-self regulating. That is, unless the inflow and outflow are exactly equal, the level will continue to rise or fall until the vessel overflows or becomes empty.

For most self-regulating processes, three parameters (process gain, dead time and time constant) can be used to approximate the process dynamic characteristics. For most liquid level loops, one, or at most two, parameters characterize the process. Instead of process gain, a relevant parameter is the *tank residence time, T_R*. For a vertical tank, the residence time of the vessel is given by

$$T_R = \frac{\text{Quantity of fluid between upper and lower level taps}}{\text{Maximum flow rate through vessel}}$$

$$= \frac{\pi\, d^2\, h}{4\, F_m} \qquad [1]$$

where d = diameter of vessel, feet
h = distance between upper and lower level taps, feet
F_m = maximum controllable throughput through vessel, cu ft/min

Notes: (1) 1 cu ft = 7.48 gallons.
(2) The residence time could also be computed using any compatible units, such as metric units.

If the level controller is cascaded to a flow controller, then F_m is simply the maximum reading of the flow transmitter, and d and h come from tank geometry.

If the level controller output goes directly to a valve, then $\mathbf{T_R}$ for the current operating point can be found by making a process test. In addition, another parameter, K_V, the valve gain, can also be found from the same test.

Exercise 7 described a test procedure for determining T_R and K_V. If you have not completed that exercise, complete it now.

The significance of these parameters is that from them plus the tuning parameters, gain (K_C) and integral time (T_I), the behavior of the level control loop can be predicted. Alternatively, if a certain behavior is desired, such as a particular decay ratio, then the required tuning parameters can be calculated. Specifically, the parameter group

$$\frac{K_C K_V T_I}{T_R}$$ for applications where the level controller output connects directly to a valve, or [2]

$$\frac{K_C T_I}{T_R}$$ for applications where the level controller is cascaded to a flow controller. [3]

determine the behavior of the control loop.

To avoid duplication, we will use equation [2] for both circumstances, with the understanding that for cascade applications, K_V should be set equal to 1.0.

If $\frac{K_C K_V T_I}{T_R} > 4.0$, the level control loop vwill be overdamped.

If $\frac{K_C K_V T_I}{T_R} = 4.0$, the level control loop will be critically damped.

If $\frac{K_C K_V T_I}{T_R} < 4.0$, the level control loop will be underdamped.

Two special cases.

If $\frac{K_C K_V T_I}{T_R} = 0.185$ (or approximately 0.2), the level control loop will respond with a quarter-decay ratio.

If $\frac{K_C K_V T_I}{T_R} = 0.743$ (or approximately 0.75), the level control loop will respond with a 1/20 decay ratio (the second peak overshoot will be 0.05 times the first overshoot).

In most liquid level control applications, the set point is rarely changed. Instead, the purpose of the control loop is to maintain the level at (or acceptably near) set point in the presence of load changes. Hence we will focus on the response to a load change, rather than to a set point change in this exercise.

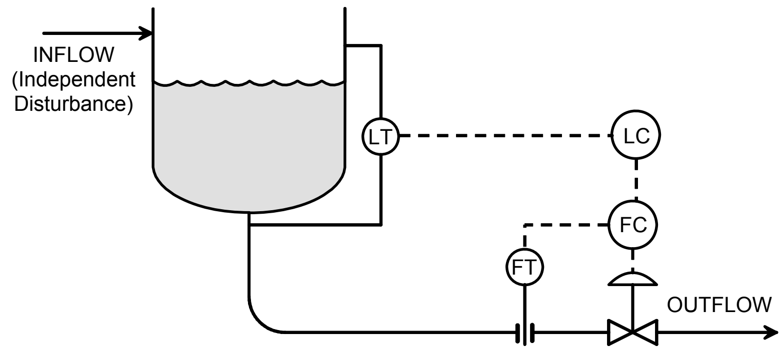
1. STARTING THE PROGRAM

Start **Windows**.

Run **PC-ControLAB**.

2. WHY LIQUID LEVEL CONTROL IS DIFFERENT

Press **Control I Retrieve Strategy, Model and Tuning**. Highlight “Level.stg” and press **Open**. *Be sure you follow those instructions exactly, else redo them.*



LEVEL CONTROL WITH CASCADE

> *The simulation is of a liquid level controller cascaded to a flow controller. All we will work with in this exercise is the level controller. Both controllers are initially tuned.*

Select **View I Variable Plot Selection.** Select **No** for Load-2.

Press **Sel** on the Level controller **(**left hand controller).

Press **Tune.** Note the initial tuning parameters for the level controller.

Gain = ___________

Reset = ___________ minutes/repeat

Record the value for tank residence time and valve gain found from Section 3 of Exercise 7.

T_R ___________ minutes

K_V ___________

Press **Casc** on the Flow controller (right hand controller).

Press **Auto** on the Level controller (left hand controller.)

Press **Sel** on the Level controller (if it is not already selected), then press **StepIncr** twice in rapid succession. This causes a 10% step change in inflow.

Observe the response of the level**.** Does this look like approximately a quarter-decay? ___________

From the tank residence time and controller tuning, what type of response should we expect? (Since in this application, the level controller is cascaded to a flow controller, use $\mathbf{K_V = 1.0}$**,** rather than the value found in Exercise 7.)

____

Suppose you want less oscillation? A conventional approach would be to reduce the gain. With the Level controller still **Sel**ected, change the controller gain from 1.0 to 0.5**.**

Press **StepDecr** twice in rapid succession. (Same size load change, only in the opposite direction.) Did that decrease the oscillation? __________

Reduce the gain by half again. Change the Level controller gain from 0.5 to 0.25, then press **StepIncr** twice in rapid succession. Did that decrease the oscillation?

____

What happened to the response as the gain was decreased?______________________________

This has illustrated the fact that rules of thumb often used for other types of loops are counter-intuitive when applied to liquid level loops.

3. CALCULATION OF TUNING PARAMETERS

Suppose the maximum anticipated step change in inflow (ΔF_{in}) is 10%. Also suppose that the allowable change in level (ΔL) is 5%. Use Table 1 below to calculate tuning parameters for each type of response, critically damped, 0.05 decay ratio and quarter decay ratio. (Use $K_V = 1.0$.)

DECAY RATIO	K_C	T_I
Critically Damped	________________	________________
0.05	________________	________________
0.25	________________	________________

TABLE I
LEVEL CONTROLLER TUNING RELATIONS

DECAY RATIO	**K_C**	**T_I**
Critically Damped	$\frac{0.74\,\Delta F}{K_V\,\Delta L}$	$\frac{4.0\,T_R}{K_C K_V}$
$\frac{1}{20}$	$\frac{0.50\,\Delta F}{K_V\,\Delta L}$	$\frac{0.74\,T_R}{K_C K_V}$
$\frac{1}{4}$	$\frac{0.32\,\Delta F}{K_V\,\Delta L}$	$\frac{0.19\,T_R}{K_C K_V}$

TABLE 2
LEVEL CONTROLLER PERFORMANCE RELATIONS

DECAY RATIO	Level Arrest Time - T_{aL}	Period of Oscillation – P	Outflow Arrest Time - T_{aF}	Max Outflow Change - ΔF_o
Critically Damped	$0.5T_I$	Not Applicable	T_I	$1.13\ \Delta F_{in}$
$\frac{1}{20}$	$1.45T_I$	$8.08T_I$	$2.90T_I$	$1.34\ \Delta F_{in}$
$\frac{1}{4}$	$3.22T_I$	$14.93T_I$	$6.45T_I$	$1.55\ \Delta F_{in}$

NOMENCLATURE

ΔF_{in}	=	Maximum change in inflow, % of full scale
ΔF_o	=	Maximum change in outflow, % of full scale
K_C	=	Controller gain
K_V	=	Valve gain (for cascaded loops, use $K_V = 1.0$
ΔL	=	Maximum allowable level deviation from set point, % of full scale
P	=	Period of oscillation, minutes
T_{aF}	=	Outflow arrest time, minutes. Time of maximum deviation of outflow from inflow
T_{aL}	=	Level arrest time, minutes. Time when level first reaches maximum deviation from set point
T_I	=	Controller reset time (minutes per repeat)
T_R	=	Vessel residence time

4. TESTING THE RESPONSE

For each type of response, enter the parameters you calculated. When the loop is in equilibrium, make a 10% step change in inflow by pressing **StepIncr** or **StepDecr** twice in rapid succession. (DON'T go above 85% load, to avoid saturating the outflow.)

Use Table 2 to spot check a few of the parameters below, to see if the predicted value comes close to what you actually observe:

Decay Ratio	Level Arrest Time	Period of Oscillation	Outflow Arrest Time	Max Outflow Change
Crit. Damped	____________	____________	____________	____________
0.05	____________	____________	____________	____________
0.25	____________	____________	____________	____________

Considering both performance of the level control and the effect on outflow (this may be potential disturbance to a downstream process unit), which form of response do you like best?

Crit. Damped ________ 0.05 Decay Ratio ________ 0.25 Decay Ratio _________

We will now go to a control strategy without the cascaded flow controller.

Select **Control I Select Strategy I Feedback**.

Select **Control I Control Options**. Select **Direct Acting** for Control Action.

Select **Load**.

In the sub-panel labeled “Auto Load Change”, click in the field adjacent to the label “Correlation.”

Press **ESC** on your keyboard.

Key in 0.90 and press **Enter** on your keyboard.

Press **Clear**.

From Table 1, calculate parameters for the 0.05 decay ratio. Use K_V value found in Exercise 7. Use the same ΔF_{in} and ΔL as you used in Section 3.

Gain ____________

Reset ____________ minutes/repeat

Enter these parameters.

Put the controller in **Auto**.

Press **AutoLoad**. The simulation now exhibits a randomly changing load. Observe this for at least two full screen changes. What is the maximum deviation from set point?

____

Press **AutoLoad** again to discontinue random load changes.

Press **Pause.**

5. NON-LINEAR LEVEL CONTROL

Another level controller tuning approach favored by many is non-linear, often called “error squared” control. By a slight modification to the control algorithm, the controller appears to have a low gain when the level is near set point, with an increasing gain as the deviation from set point increases.

Put the controller in **Manual**.

Select **Control I Control Options**. For the option “Error Squared” select **Yes**. Press **Clear.**

The modified error is computed as

$$\hat{e} = \frac{e \times |e|}{100}$$

before being passed to the PID section of the algorithm.

Enter (or retain) the tuning parameters for the 0.05 decay ratio from the previous section.

Press **Run.**

Put the controller in **Auto**.

Press **AutoLoad** to activate random load variations.

After observing the response for about an hour (simulated time) estimate the following:

Maximum deviation from set point: ________

Note that there is much more deviation in level. You should also observe that there is a considerably lower frequency activity in the controller output. If the outflow were the feed rate to a downstream process unit, then the disturbances to that unit would be much less severe than with ordinary PI control. This is accomplished at the expense of greater fluctuation in the level measurement. If the deviation is too great, you can increase the controller gain and shorten the reset time, recognizing that there will be an increase in the outflow activity, consequently an increased disturbance to the downstream process unit.

Enter the following:

Gain:	10.0
Reset:	30 minutes/repeat

After observing the response for an adequate amount of time, estimate the maximum deviation from set point:

____

Press **AutoLoad** to deactivate random load changes.

After observing the response for an adequate amount of time, describe the behavior of the loop.

____

Put the controller in **Manual.**

Press **Pause.**

6. AVERAGING LEVEL CONTROL

Still another approach to the tuning of liquid level control loops is called "averaging" control. No attempt is made to keep the level at set point. Rather, the level is maintained within bounds, and is guaranteed not to exceed those bounds.

Select **Control I Control Options**.

In the “Control Algorithm” sub-panel, select “Proportional Only.”

In the “Error Squared” sub-panel, select “No.”

Suppose we want to maintain the level within ± 10% of set point (that is, between 40 and 60%). That would require a proportional band of 20%, or a gain of 5.

Press Tune and set:

Gain:	5
Manual Reset:	50

Press **Run**.

Put the controller in **Auto**. (AutoLoad should now be OFF.)

Record the following:

Record the following:	Set Point:	__________%
	Process Variable:	__________%
	Error(= PV - SP):	__________%
	Controller Output:	__________%

Calculate the theoretical controller output from the Proportional-Only equation:

Output = Gain x Error + Manual Reset __________%

Does the theoretical value agree with the actual output value? ____________

Press **StepIncr** until the load (inflow) is just below 100%. What is the PV? __________%

Press **StepDecr** until both the load and the controller output are above 0%. PV? __________%

Press **AutoLoad** to activate random load changes. Observe the response for some time.

Does the PV remain at set point? ____________

Maximum value of PV? ___________% Minimum value of PV? __________%

We are guaranteed of keeping our level within the desired bounds of 40 – 60%. The *penalty we pay is that, even with a constant load, the level will not be at set point.*

This control scheme shows up very well for surge tank level control, where we can tolerate more variation in level. Suppose we allow the level to vary ± *25% (or from* 25% to 75%). *This would require a proportional band of 50%, or a controller gain of 2.0.*

Change the gain to 2.0.

With **AutoLoad** on, observe the response for some time. Does the level remain within the bounds of 25% to 75%?

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