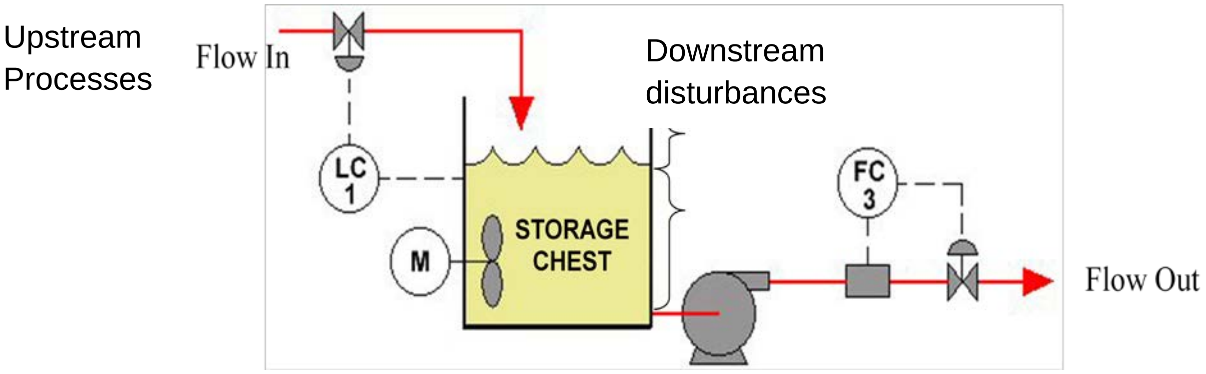
ProNamics Control Inc.

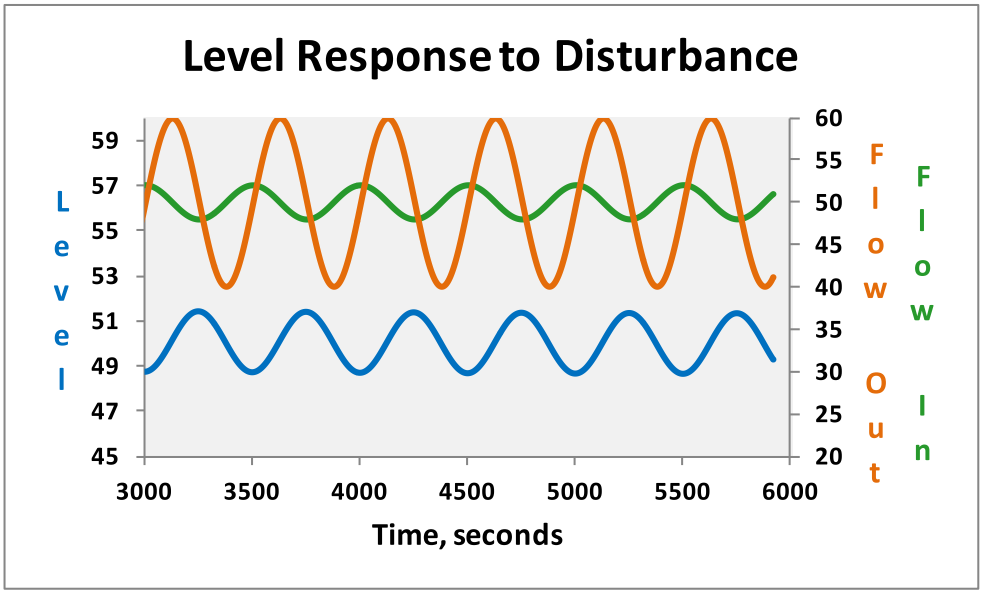
Tip Sheet - Tuning Storage Tank Level Loops

This tip sheet reviews the steps necessary to achieve ‘optimum’ level controller tuning.

The process control objectives for storage tank level loops are substantially different from the majority of control loops. Minimizing level variation is rarely an important objective. Rather, ‘good’ level tuning utilizes the tank capacity to decouple upstream and downstream processes. It will also maintain the level within an acceptable ‘range’ in order to prevent process problems such as insufficient pump head, poor mixing or in the worst case a production stoppage.

Developing tuning constants is somewhat counterintuitive and the ‘By Gosh and By Golly’ method rarely works well. The Lambda tuning procedure is a structured method that allows the user to ‘dial in’ a speed of response that achieves the overall process objectives.





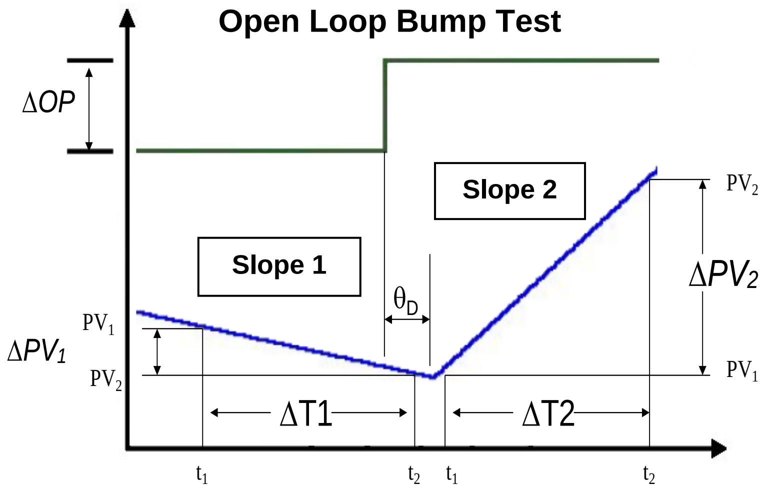
An example of ‘good’ storage tank level tuning – the strong flow disturbance (Flow Out) is not passed on aggressively to the upstream processes and the Level varies within a reasonable range

Step 1 Measure or estimate the process dynamics

It's critically important that you understand how the process responds to a change in the controller output (the process dynamics) before you attempt to tune the loop. Level loops, such as the one shown below, have an integrating process response. The key feature of the integrating response is that the rate of change in the process value is constant. An integrating response can be described fully by the process gain (rate of change/%OP) and by the deadtime.

Measure the dynamics by conducting Open Loop Bump tests

The best way to measure the process dynamics is by conducting open loop bump tests. In addition to measuring the dynamics, open loop bump tests reveal loop health and loop design problems. The bump testing should be done at the normal operating condition and a minimum of 5 to 10 step tests should be conducted to produce an accurate average.


Open Loop Bump Test

$$K_P = \frac{Slope_2 - Slope_1}{\Delta OP}$$

θ_D = **Time of Initial Response – Start of Bump Time**

Estimate the process gain if open loop bump tests are not possible

If open loop bump tests can't be conducted or the results are inconclusive you might be able to come up with a reasonably good estimate of the process gain. First we can estimate the process gain in *engineering units* if we know the ***tank dimensions***.

For **Cylindrical Tanks** the

Rate of change to a unit flow step =$\frac{k}{D^2}$, where D is the tank diameter.

For **Rectangular Tanks** the

Rate of change to a unit flow step = $\frac{k}{W*L}$ (W is tank width, L is tank length)

The k value for various engineering units is shown in the table below. As an example let's calculate the process gain for a cylindrical tank with a diameter of 16 ft.

$$Process\ Gain\ (Eng\ Units) = \frac{0.1702}{16^2} = 0.00665\frac{FT}{MIN}/GPM$$

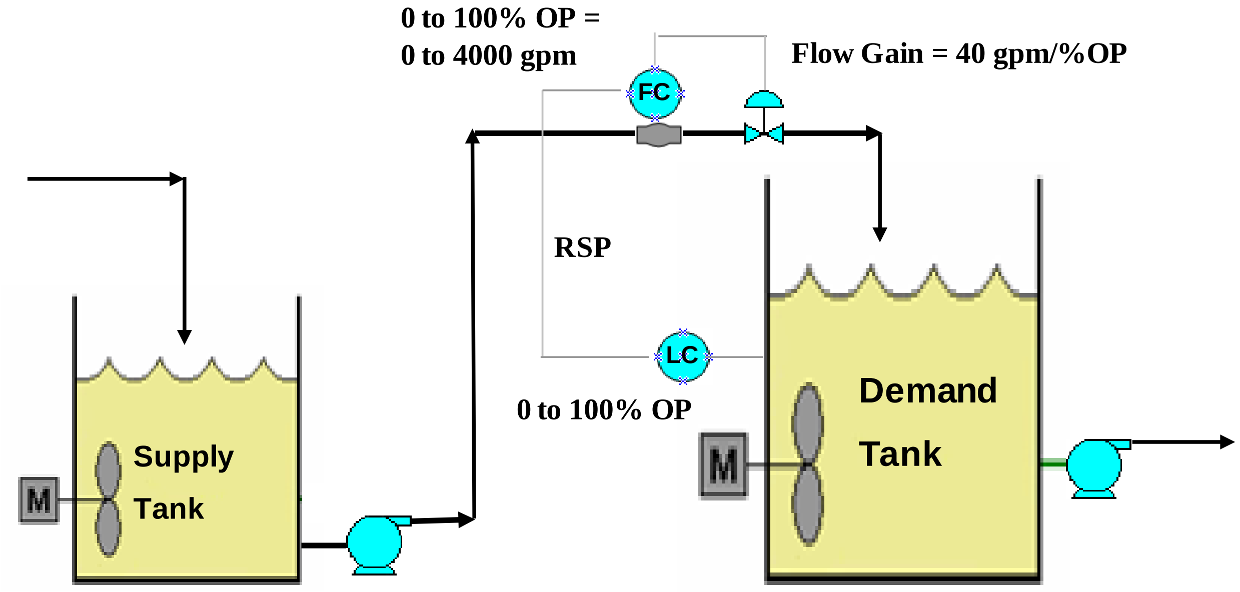
Table 1 – k factors for Cylindrical and Rectangular Tanks

Level Units	Area Units	Flow Units	Level Gain Units	Cyl k	Rect k
Feet (FT)	FT^2	USGPM	Feet/min/gpm	0.1702	0.134
Metres (M)	M^2	M^3/HR	Metre/min/M^3/HR	0.02122	0.0167
Metres (M)	M^2	Litres/sec (LPS)	Metre/min/LPS	0.0764	0.0601

For the purposes of developing tuning constants we need to estimate the process gain in units of $\frac{\%Span}{min}/\%OP\%$. We can convert the Engineering Unit process gain to these units if we know the **flow gain** (how much does the flow change in response to a 1% level controller output step) and the **level PV range**. Let's use the example above and assume that the flow gain is 30 GPM/%OP and the level EU range is 0 to 20 ft.

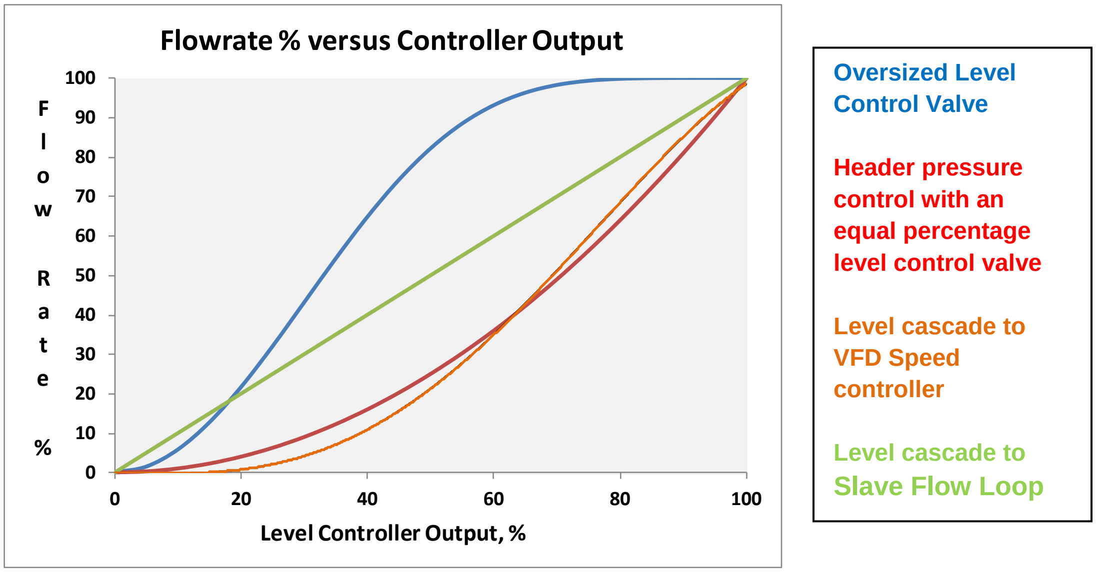
$$Process\ Gain\left(\frac{Rate}{\%OP}\right) = \frac{0.000665\frac{FT}{MIN}}{GPM} * \frac{30GPM}{\%OP} * \frac{100\%Span}{20FT} = 0.1\frac{\%Span}{MIN}/\%OP$$

Some level controllers ***cascade*** to a slave flow loop. In this case estimating the flow gain is straightforward. A 1% OP step will produce a setpoint change in the slave loop equal to the flow range divided by 100. For example if the slave flow loop has a range of 0 to 4000 gpm then a 1%OP step will change the flow setpoint by 40 gpm. A key benefit of the slave loop is that the flow gain is constant - a 1% OP change will produce a 40 gpm flow change every time. This results in a 'linear' level loop process gain and consistent level control performance.



Level Controller cascades to slave flow loop

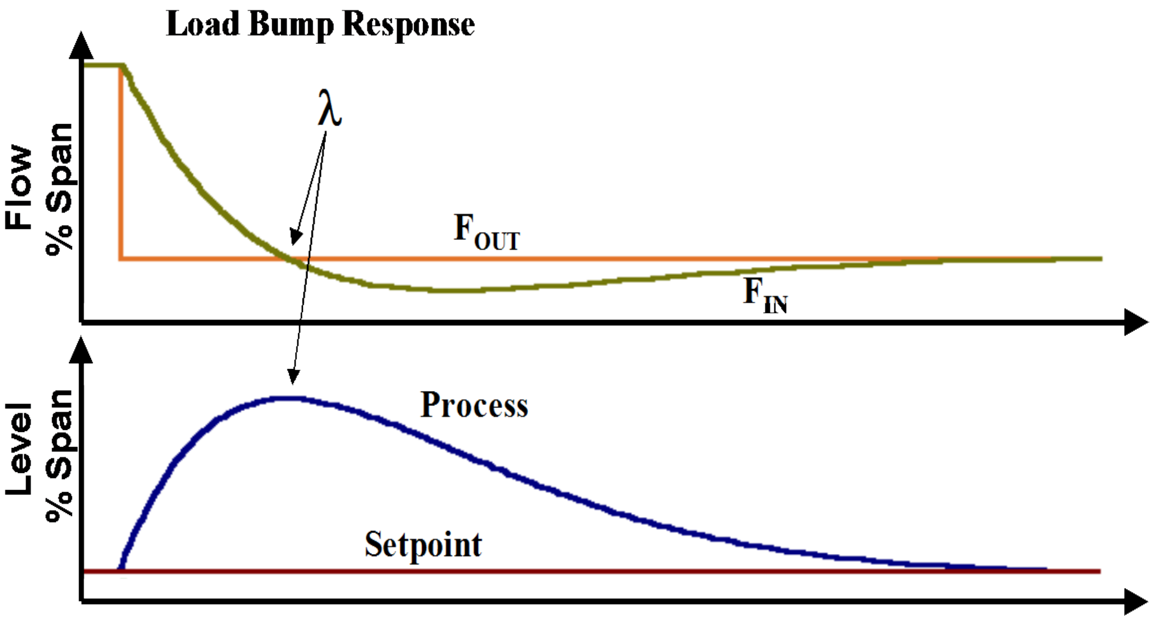
If the level controller output **adjusts the valve position directly** then the flow gain will be more difficult to estimate and it will be **non linear.** The magnitude of the non-linearity will have a lot to do with the process design and valve selection. Some typical situations are shown below**.** **T**he flow gain is the slope of the flow versus controller OP curve – and is only constant in the case of the level to flow cascade.



If you can’t conduct open loop bump tests you might be able to use *the process historian* to plot the flowrate (or a proxy) against the level controller output. This can provide valuable insight about the degree of non-linearity. The historian can also be useful in identifying the process deadtime, valve flaws and other factors affecting control loop performance.

Step 2 Select a Lambda value that satisfies the process objectives

When you Lambda tune an integrating process like storage tank levels, an important concept to understand is that the Lambda value (which you get to define) is the time required by the controller to *rebalance* the flow in with the flow out after a load disturbance. This concept allows us to ***select a reasonable Lambda value*** that will take advantage of the tank capacity while maintaining the level within an acceptable range - even following a worst case disturbance.



Shows the level response to load disturbance with Lambda tuning. The disturbance is arrested after one lambda time period

Lets' use our 16 ft diameter cylindrical tank example again and assume that the disturbance to the flow out of the chest is 1000 gpm. Since the rate of change in response to a **1 gpm** flow disturbance is 0.000665 FT/MIN, the rate of change to a **1000 gpm** flow disturbance is 0.665 FT/MIN or 3.3 %Level/min for our 20 ft high tank.

If the level controller were in Manual mode the level rate of change following the disturbance would be constant at 3.3 %Level/min. In Auto mode though the ***average*** rate of change between the time of the disturbance and the first Lambda time period will be ***½ times the initial rate of change***. After one Lambda time period the rate of level change ***is zero*** because the level controller has rebalanced the flow in with the flow out. So in Auto mode the average rate of change over the first lambda time period is 1.65 %Level/min. How big will the level excursion be if our Lambda value is 10 minutes?

$$LevelExcurison = \frac{1}{2} * \frac{3.3\%Level}{min} * 10\ minutes = 16.5\ \%Level$$

It's important to understand that when you select the Lambda value you are also defining how big the level excursion will be in response to a specific flow disturbance.

Lets' choose a Lambda value that will ensure that the level stays within 10% of setpoint following the most severe disturbance of 1000 gpm. We can back-calculate the required Lambda value.

$$\begin{aligned} Lambda &= \frac{2 * MaximumAllowableLevelExcursion}{Initial\ Rate\ of\ Level\ Change} \\ &= 2 * \frac{10\%\ Level}{3.3\%Level/min} = 6.1\ minutes \end{aligned}$$

Step 3 Calculate Lambda tuning constants and conduct setpoint step

Once the Lambda value has been selected, the tuning constants can be calculated using the formulas below. The main gotcha is not using consistent units in the numerator and denominator. Remember that the process gain has built-in time units.

Gain Kc	Integral Time T_I
$\dfrac{T_I}{K_P(\lambda + \theta_D)^2}$	$2\lambda + \theta_D$

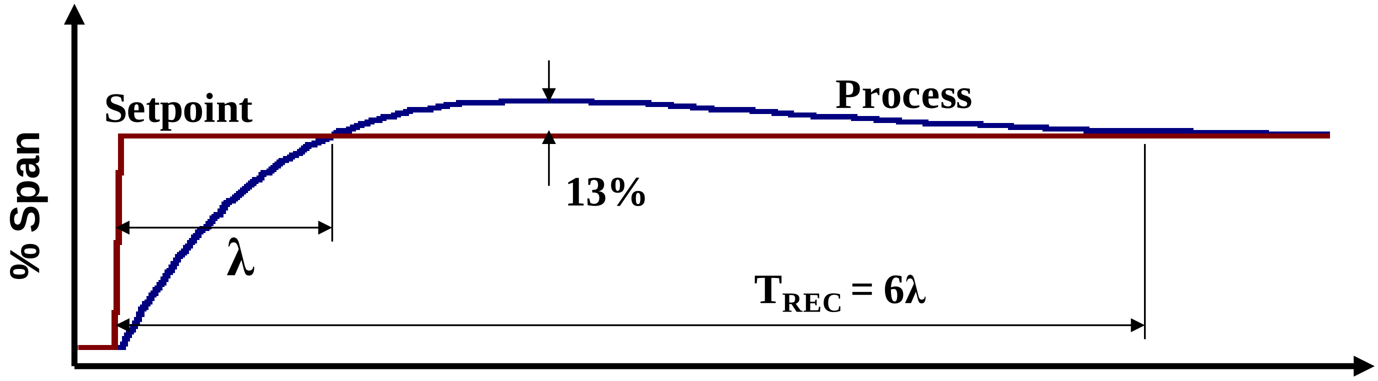
Let's continue with our example. The process gain is 0.1 %Span/MIN/%OP and lets assume the deadtime is 30 seconds. The desired Lambda value is 6.1 minutes.

$$T_I = 2 * 6.1 + 0.5 = 12.7\,\mathrm{min} \qquad K_C = \frac{12.7\,\mathrm{min}}{\frac{0.1\%Span/\mathrm{min}}{\%OP} * (6.1 + 0.5\,\mathrm{min})^2} = 2.91 \frac{\%OP}{\%Span}$$

Note that the heavy lifting is done with Proportional Action. As the Lambda value is adjusted (see table below) the Gain and Integral tuning constants are maintained in proportion. This table shows that faster level tuning will reduce level variation - but will also increase variation in the upstream processes.

Lambda, minutes	Gain, %OP/%Span	Integral Time, minutes	Maximum Level Excursion to 1000 gpm disturbance
2	7.2	4.5	3.3
4	4.2	8.5	6.6
6	2.95	12.5	9.9
8	2.2	16.5	13.2
10	1.85	20.5	16.5
12	1.56	24.5	19.8

The final step is to conduct a setpoint step to test the tuning. The new setpoint should be reached in 1 lambda time period.



Expected setpoint response when Lambda tuning an integrating process

Step 4 – Add a PV Filter

You should install a PV Filter. High frequency level variation – perhaps caused by sensor noise or agitator sloshing – will be amplified in the output signal due to the relatively high controller gain. Installing a λ/10 PV filter will not affect control performance significantly – but will severely dampen controller response to high frequency variations. In our example we could safely add 0.61 minutes of PV filtering.

Summary

Let's sum up the steps for tuning storage tank level loops.

Step 1 Measure the process dynamics using open loop bump tests. Estimate the process dynamics if open loop tests can't be conducted

Step 2 Select a Lambda value that will utilize the tank capacity while maintaining the level within an acceptable range even after a worst case disturbance.

Step 3 Use Lambda tuning formulas to develop tuning constants. Test the tuning by conducting setpoint response testing

Step 4 Add a PV Filter equal to λ/10 to dampen control response to high frequency level variations

The excel workbook ***pci_level_tuning*** is a useful tool for estimating level loop process dynamics, defining an appropriate Lambda value and calculating level loop tuning concepts. The workbook is located in the download section of the www.pronamicscontrol.com website.