Level Controller Tuning Using Novel PID Tuning Optimization Methodology

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Abstract

This paper illustrates a novel, modern and practical method for tuning level PID controllers (LCs). The example is based on a distillation column sump. The new PID tuning algorithm works entirely in the time domain (no Laplace or Z-discrete domain). It neither requires data preprocessing nor data preconditioning. The process model parameters are first identified followed by simulation and optimization of the PID tuning parameters. The process identification and tuning techniques are performed using Pitops and Simcet software from PiControl Solutions LLC.

1. Introduction

Many level controllers (LCs) in chemical plants do not work well because their PID tuning parameters are not optimally tuned. Poor LC tuning can cause cycling or sluggish control response. Cycling of LC output can cause many downstream flows to oscillate. This in turn can cripple the performance of higher level Advanced Process Control (APC) systems resulting in reduced profit margins and fail to deliver the expected payback.

Many authors use different commonly known tuning techniques for controller parameters optimization. These include: Ziegler–Nichols tuning formulas like: Paor et al. 1989, Hang et al. 1991, Astrom et al. 2004, Hagglund et al. 2008, Lambda method like: Ingimundarson et al. 2005, Lennartson et al. 2009, Cohen Coon tuning method like: Chen 1989, Astrom et al. 1993, Kilian 2000 and Shen 2002 or Internal Model Control (IMC) tuning method like Seborg et atl. 2004. Many other tuning methods and their comparisons are available in various open literatures but are not the subject of this paper.

This paper shows a new, quick, simple and powerful new PID tuning method which is simpler and more practical than currently known methodologies. Past efforts in this area include contributions from: Mehra et al. 1972, Gabriele et al. 1977 and Perdew et al. 1996. With this new method described in this paper, it is possible to tune LC parameters effectively and improve the overall plant control quality quickly and easily.

2. Chemical Process Dynamics

Most chemical process dynamics can be well represented by the transfer functions shown in Figure 1.

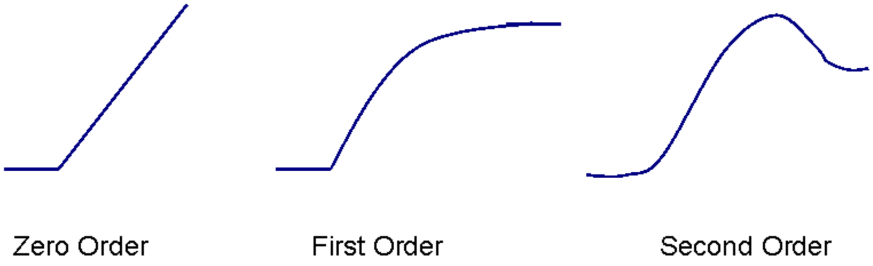


Figure 1 - Common Chemical Process Transfer Functions

The first and second transfer functions are typical for flow, pressure and temperature controllers. The zero order transfer function characterizes level controllers (LCs). Detailed explanation on transfer functions is available in Seborg et al. 2004.

Figure 2 illustrates zero order processes. If flow is going into a tank and exact flow is leaving the tank, then the level in the tank will be held constant. Now, if the flow out from the tank is reduced by ΔF, then the level starts to rise at a steady rate (called Ramp Rate) and will continue to rise until the tank overflows. Let's say, after time Δt, the change in level is ΔL. The Ramp Rate is calculated as:

$$\textbf{Ramp Rate} = \Delta L / \Delta t / \Delta F$$

Note that the engineering units of Ramp Rate in this example will be %/minutes/m^3/h. This is the zero order transfer function behavior, where there is no final new steady state like a first, and second or higher order transfer functions. The zero order transfer function is also called an integrating type transfer function. At a first glance, the zero-order transfer function appears the simplest since it has only two parameters: Process Dead Time and Ramp Rate. There are no Time Constants involved as in the case of first and second order transfer functions. However, the zero-order transfer function interestingly, poses some unique challenges when it comes to determining optimal tuning parameters for the LC PID.

Figure 3, shows a distillation column bottoms sump LC trends. The LC is a cascade control PID. LC is the master loop and its slave is the bottoms product flow controller (FC) connected directly to the valve.

The top window shows the LC setpoint (SP), the horizontal line at a fixed SP of 60. The cyclical trend in the top window is the actual process value (PV). Notice that the level is cycling about ±5% from the LC's SP. The bottom trend shows the LC's output, OP. The OP directly manipulates the SP of the FC. If the LC's PV increases, the LC's OP increases the FC's SP to take more liquid out of the sump and vice versa.

Level is the controlled variable (CV) because it is controlled by the flow. The bottoms flow is the manipulated variable (MV) because of it the level is kept on the desired value. The level (CV) range is 0 – 100% and the FC (MV) range is 0 – 200 t/hr.

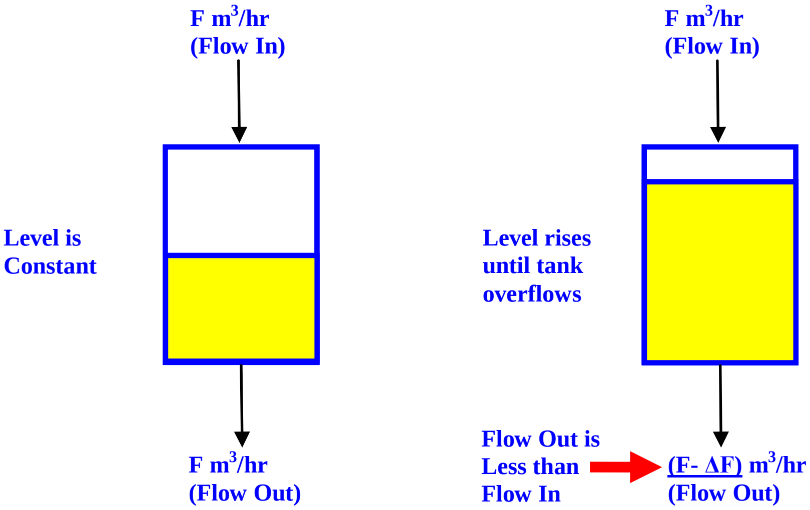


Figure 2 - Level in Tank- Level to Flow Dynamics

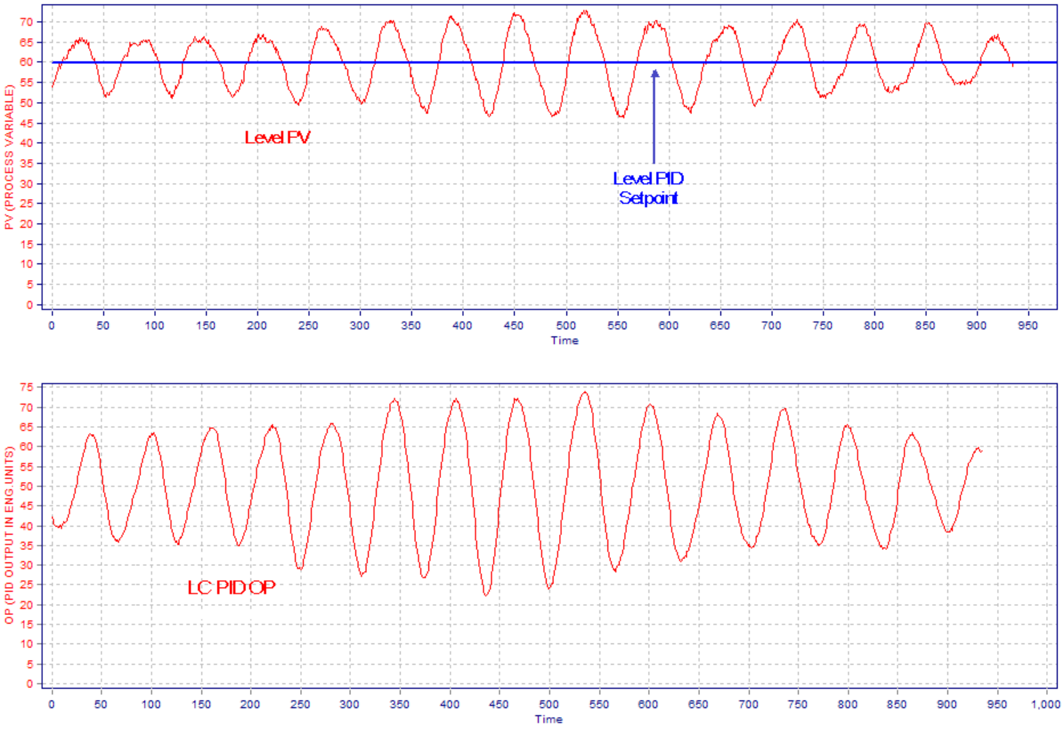


Figure 3 - Distillation Column Sump Level Control

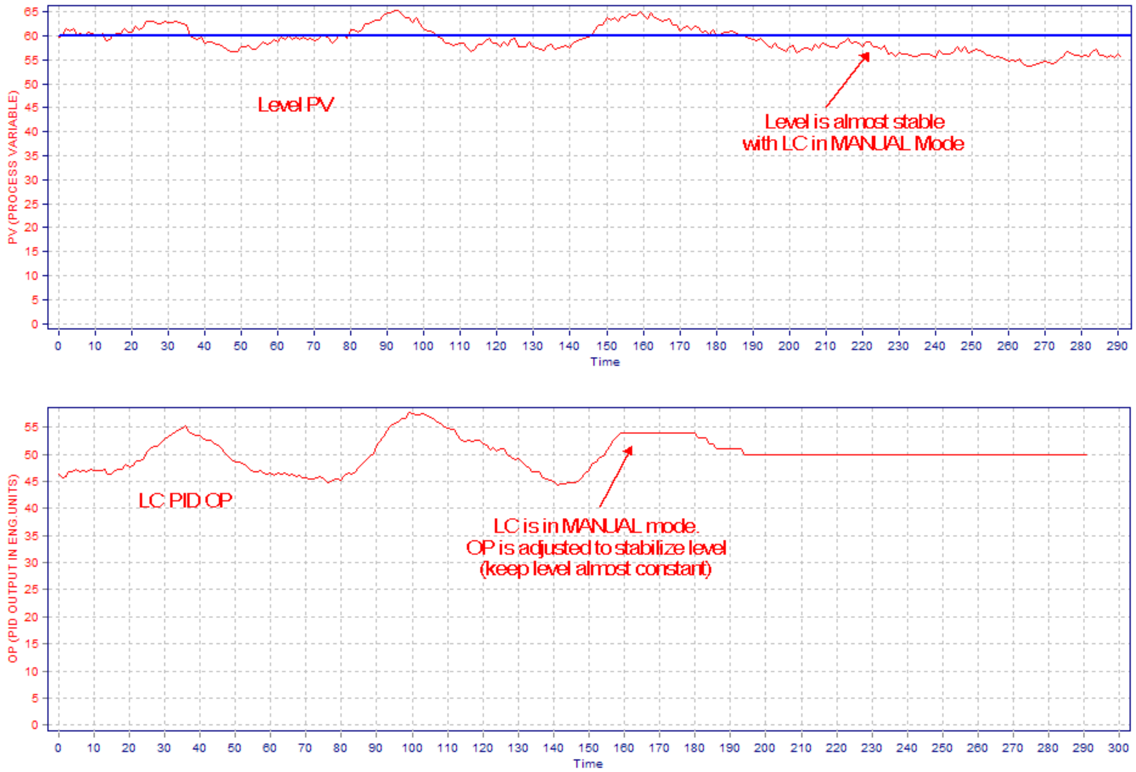
The LC's PID equation is:

$$OP_{(t)} = OP_{(t-1)} + P\,[\Delta E + E_{(t)}\,\Delta t/ I + D\,\Delta(\Delta PV)/\Delta t\,]$$

Where:
$OP_{(t)}$ = PID controller Output in the time *t;*
P = Proportional Gain;
I = Integral Constant;
D = Derivative Constant;
$E_{(t)}$ = Controller Error ($PV_{(t)} - SP_{(t)}$) in the time *t*;
ΔE = Controller Error ($E_{(t)} - E_{(t-1)}$);
ΔPV = Process Value ($PV_{(t)} - PV_{(t-1)}$);
Δt = Scan Time of PID.

The initial LC's tuning parameters that are causing the oscillations in Figure 3 are:
P = 0.5,
I = 3 min,
D = 0 min.

To scientifically calculate optimum PID parameters for the LC, first put the LC in Manual mode and set the LC's OP at approximately the average value to try and keep the level reasonably stable, like in Figure 4.



Level PV

Level is almost stable
with LC in MANUAL Mode

LC PID OP

LC is in MANUAL mode.
OP is adjusted to stabilize level
(keep level almost constant)

Figure 4 - LC in Manual Mode

Now bump the flow for at least 10 minutes to see a noticeable change in the level like in Figure 5 which shows a bump in the FC's SP by 5 ton/h.

The level is allowed to drop all the way to about 30%. This is a rather large change and is shown here only for clarity of the illustration, but the level could have been allowed to drop to only 45% in a shorter time period without much loss of information.

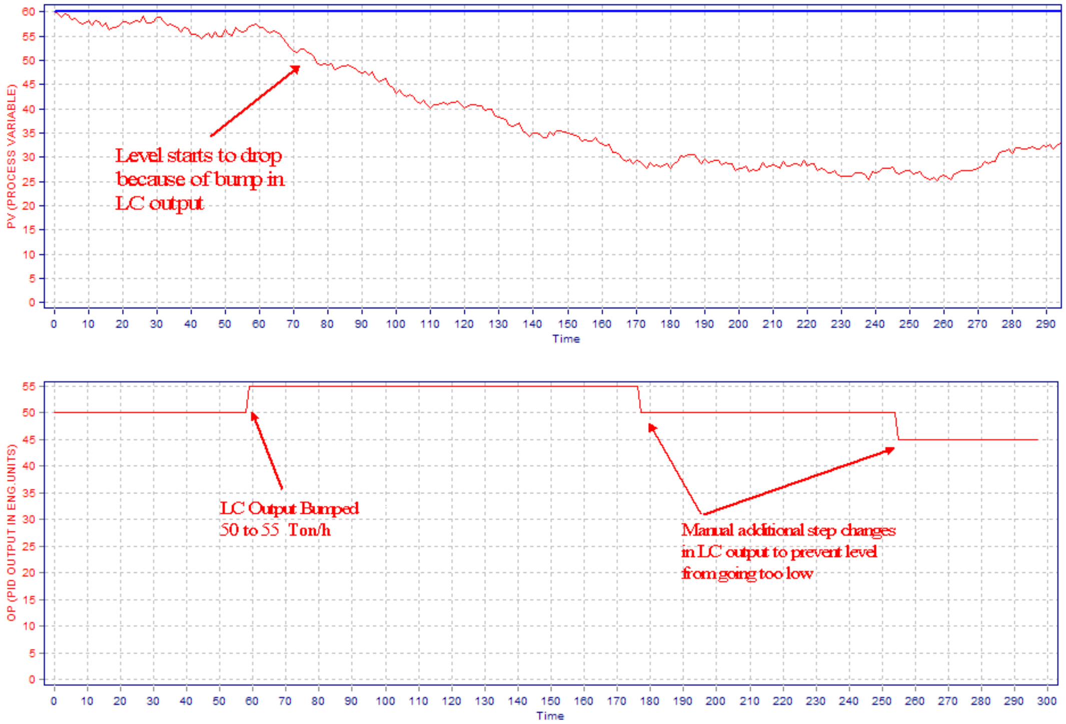


Figure 5 - Level Ramp Rate vs Flow Dynamics

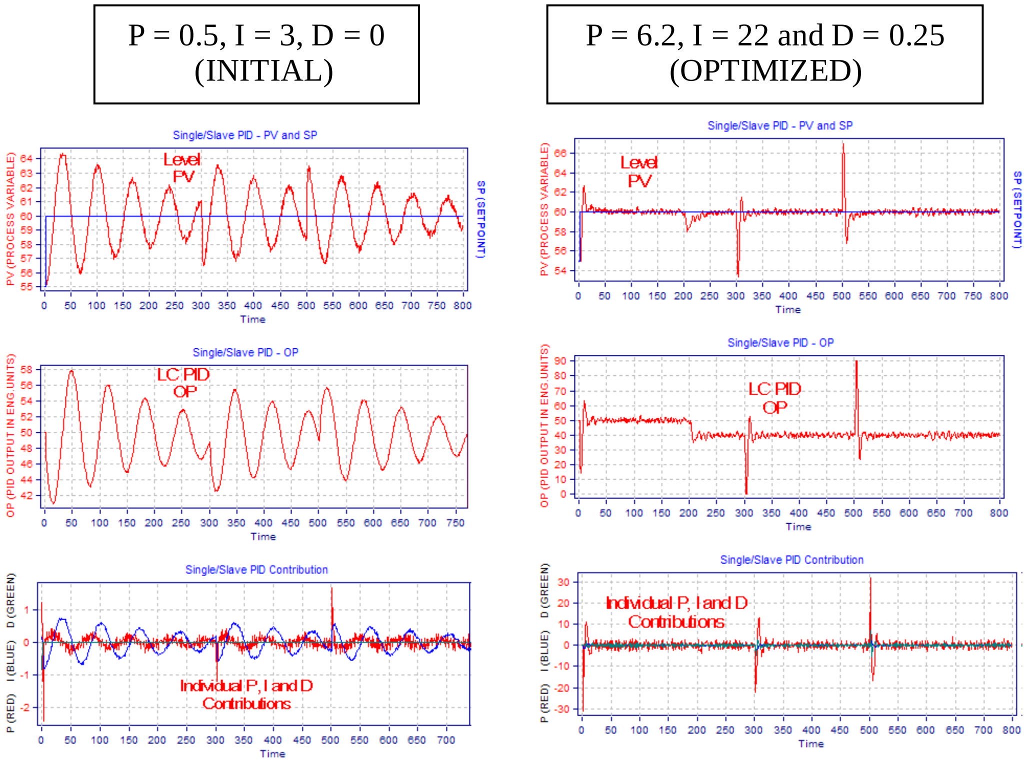
The Ramp Rate is calculated as *(57 – 33) / (160 – 60) / 5 = 0.05 % / (ton/h) / min*. The process dead time can be seen by visual inspection of the data and this is approximately 2 minutes in this case. Now we can build a LC simulation in the Pitops software with the following additional configuration information:

MV range = 0 – 200 ton/h (PV range of the slave FC)
CV range = 0 – 100% (PV range of the LC)

New tuning PID parameters are optimized by Pitops software from PiControl Solutions LLC. A simulation illustration is shown in Figure 6. The new optimized tuning PID parameters correspond to the mathematical optimization solution that minimizes the error for the following custom controller challenges:

1. Setpoint change
2. Typical noise in the LC PV
3. Injection of a Ramp disturbance simulating a production rate change.
4. Injection of a Pulse disturbance simulating minor upsets.

New tuning PID parameters are:
P = 6.2,
I = 22 min,
D = 0.25 min.


P = 0.5, I = 3, D = 0
(INITIAL)

P = 6.2, I = 22 and D = 0.25
(OPTIMIZED)

Figure 6 - Comparison of Initial and Optimized PID Parameters

The optimized tuning PID parameters might be a little aggressive for the real process. The optimized tuning sets upper limits on the level of aggression and tuning tightness, beyond which incipient oscillations will start and might grow, making the controller possibly unstable. To strike a balance between tight control and smoothness of downstream flow, the final tuning PID parameters are somewhat detuned to be:

P = 2,
I = 40 min,
D = 0 min,
Gap gain = 0.5,
Gap high/low = 2%.

If the level is within 2% of the SP, the gap action detunes the controller action by 50% and to further smooth out the downstream flow changes. This control action is shown in Figure 7. Now, as typical disturbance come, the control action is just about right. The level is controlled nicely without excessive oscillations or jerking around of the downstream flow. Note that the ripples seen are because of external oscillatory disturbances causing the level to cycle a little, and this could be because of upstream valve problems on interacting controllers or process issues which are often unavoidable.

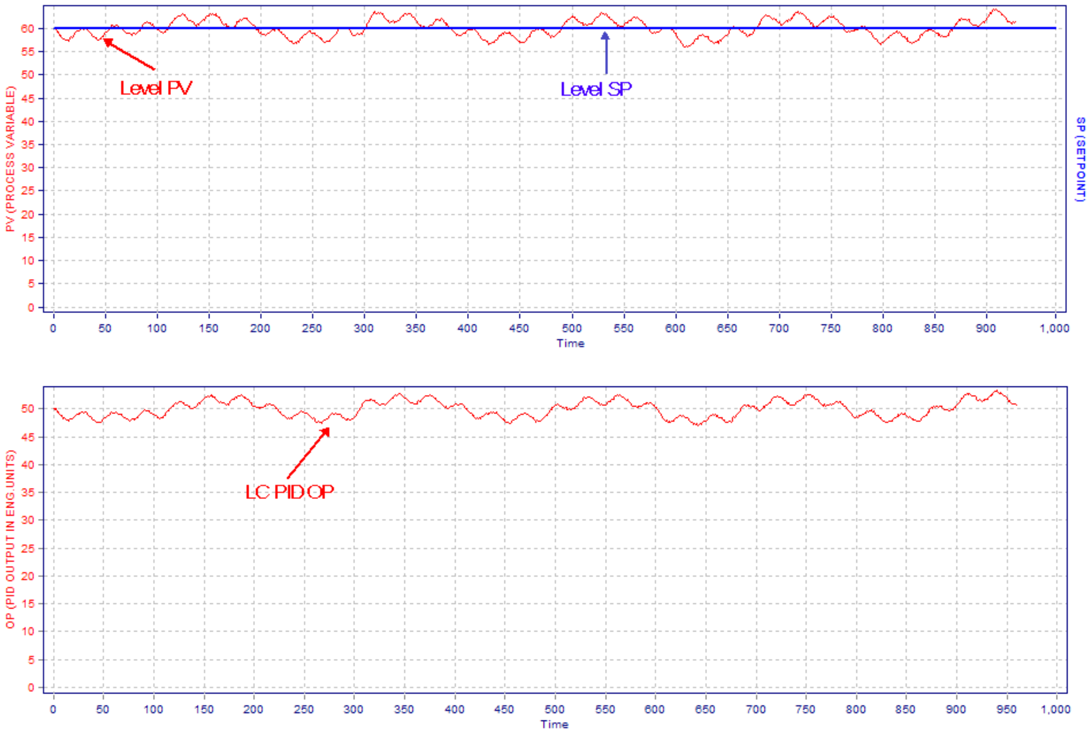


Figure 7 - Final Tuned PID parameters for Smooth and Stable Control

3. Conclusion

All illustrations above were generated using Pitops and Simcet process control software from PiControl Solutions Company. The use of this software and the RGR techniques allow fast and precise tuning of critical controllers and can reduce oscillations and improve control performance in any industrial process. The software benefits tuning of all PID controllers encountered in the industry: FC, PC, TC, LC, AC, compressor surge control, motor control turbine control, power control, robotics and all related control problems.

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