Mats Friman*

Tuning of Control Loops with Valve Problems

Abstract: Control valve non-linearities may cause control loop oscillations. Usually, it is not possible to instantly replace a valve in operation just because it causes oscillations in the process, but with proper controller tuning we can minimize valve wear and reduce oscillation amplitudes, and sometimes even eliminate the oscillations. We discuss two major valve non-linearities, backlash and stick-slip, and how to tune the PID controller for such valves.

Keywords: backlash, stick-slip, oscillations, PID tuning

*Corresponding Author: Valmet Automation, E-mail: firstname.lastname@valmet.com

1 Introduction

Control valves play a crucial role in the process industry, regulating the flow of fluids, such as gases, liquids, and slurries. These valves are essential for maintaining the desired process conditions, such as pressure, temperature, and flow rate, ensuring the efficient and safe operation of industrial processes.

An industrial control valve package consists of a valve body, a pneumatic actuator, and a valve positioner. All these components consist of mechanical part that are subject to wear and dirt (Kirmanen et al. 1997).

Control valves can encounter several problems that may affect their performance and reliability. Example problems include increased friction in valve body and actuator, pneumatic leakage in actuator and positioner, wear in mechanical parts, and design problems, most commonly improper sizing of valve or actuator.

Valve problems frequently cause oscillations in the PID control loop. Instant replacement of a faulty valve because of loop oscillations is usually not an option. Instead, we can minimize the damage by re-tuning the PID controller. In this study we discuss how to decrease the oscillation amplitudes (in both process value (PV) and control output (CO)) to minimize impact of oscillations on the process. Moreover, increasing the period of oscillations reduces valve wear.

To our knowledge, PID tuning recommendations for faulty valves have not been previously reported. Still, we believe that special tuning recommendations for faulty valves are useful and that there is a great possibility to stabilize oscillating processes and improve quality and economic performance in the entire process industry.

2 Modeling Common Valve Non-Linearities

To model non-ideal valve behavior, we consider two non-linearities: 1) backlash and 2) stick-slip. These non-linearities are illustrated in Figure 1 below.

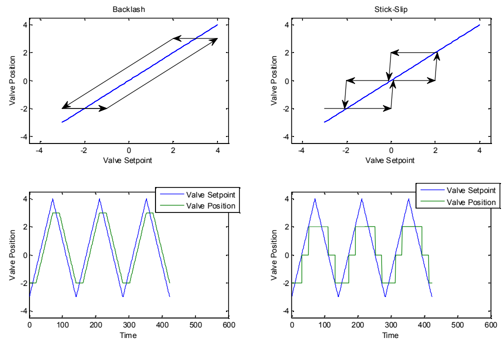

Figure 1. Illustration of backlash (left) and stick-slip motion(right).

Stick-slip is useful to model sticky valves with high friction. In that case, valve positioner must increase actuator pressure extensively to move the valve. Stick-slip movement makes it impossible to position the valve properly. Valve stick-slip is also useful to model a control valve with an undersized actuator. On the other hand, valve problems where friction is not an issue are best modeled with simple backlash. A very common example is a worn-out link between valve shaft and valve body of a rotary valve. Such a case is best modeled using backlash.

Usually, the process dynamics of typical process industry controls are well modeled using simple linear transfer functions. However, control valves with pneumatic actuators don’t show such an ideal behavior. For example, valve positioners typically have a dead-band specification (defined as how much valve setpoint can change before we can expect valve movement) of 0.2 % (Valmet Flow Control, 2024). Hence, PID tuning recommendations based on ideal linear transfer functions, are not necessarily optimal when we have a control valve in the loop.

3 Impact of Valve Non-Linearities on Control Loop Performance

Next, we discuss how a linear transfer function (describing flow, level, pressure, and temperature controls) controlled by a PID controller behaves when we have stick-slip or backlash in the control valve.

A fundamental question is: does backlash or stick-slip in the valve cause control loop oscillations?

For the stick-slip case the answer is quite straight-forward: yes, the loop will oscillate with and amplitude and period that depends on amount of stick-slip, the PID controller tuning parameters, and process dynamics.

For the backlash case, the situation depends on the PID controller tuning parameters and process dynamics: we may see oscillations in the loop, or we may get a stable loop.

As an example, consider a simulated level control loop with some 1 % backlash in the control valve. We model the level using a first-order-plus-deadtime model (with gain $K = 40$, time constant: $T = 600$, dead time $L = 6$) and employ a PI controller (with gain $K_p = 1.0$ & integration time $T_i = 60$, tuned by SIMC rules, Grimholt and Skogestad, 2012). Simulations suggest that this system oscillates with a period of 260 and PV oscillation amplitude 0.54, as illustrated in Figure 2 (green lines).

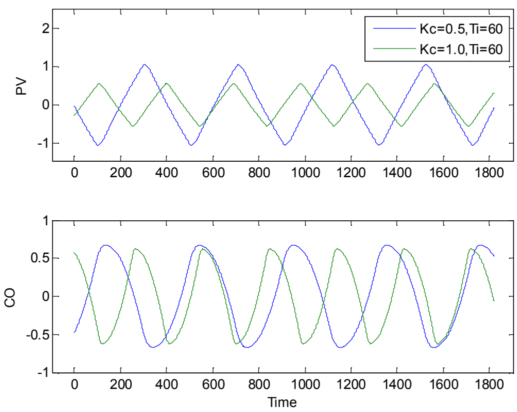

Figure 2. Example control loop oscillating because of backlash in valve. Original tuning in green and detuned (gain 50% of original) loop in blue.

At this point a natural question is: how should we tune the PI controller to reduce impact of oscillation generally on the process (to reduce PV amplitude), and to reduce valve wear (by increasing period of oscillation and decreasing amplitude of CO)? A surprising result, even to experienced control engineers, is that detuning controller gain by 50 % ($K_p = 1.0 \rightarrow 0.5$) is a bad option, as it *increases* the amplitude of PV oscillations, in this case by 93% (blue trends in Figure 2). A tighter tuning ($K_p = 1.0 \rightarrow 1.5$) decreases the PV amplitude, but with a cost of increased valve wear due to faster oscillations (not shown).

Table 1 summarizes impact of some PI tuning changes to the level example, where we have simulated a 50 % increase/decrease of PI controller gain, and a 100 % increase of PI controller integration time.

Table 1. Impact of PI tuning on example backlash loop. Green color indicates improved and red worse performance compared to original tuning.

Tuning	Period of Oscillation	PV Amplitude	CO Amplitude
Original	260	0.54	0.66
$0.5\times K_p$	364	1.04	0.72
$1.5\times K_p$	210	0.37	0.64
$2\times T_i$	465	0.49	0.58
$1.5\times K_p$ $2\times T_i$	383	0.34	0.57

In this presentation we will on a general level discuss how to tune a PID controller to reduce valve wear and to avoid oscillations when we have stick-slip or backlash in the loop. Moreover, we also discuss simple modifications to the control loop. For example, adding a deadband in the PI controller (i.e. to allow a certain controller error) may sometimes stabilize an oscillating loop.

4 References

Grimholt, C. and Skogestad, S.. Optimal PI-Control and Verification of the SIMC Tuning Rule. IFAC Conference on Advances in PID Control, PID'12, Brescia Italy. 2012.

Kirmanen J., Niemelä I., Pyötsiä J., Simula M., Hauhia M., Riihilahti J. The Flow Control Manual,.4th ed. Metso Automation. 1997.

Valmet Flow Control. Neles™ NDX™ intelligent valve controller, standard model. Technical Bulletin. 2024.