STICTION: THE HIDDEN MENACE

How to Recognize This Most Difficult Cause of Loop Cycling By **Michel Ruel**

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A control loop consists of the process, measurement, controller, and a final control element (a valve, damper, etc., and its associated equipment such as a positioner). Optimal process control depends on all of these components working properly. Hence, before tuning a loop, one must verify that each component is operating properly and that the design is appropriate.

Choosing the optimal PID tuning should be done after assuring that all of the other components are working correctly. The optimal tuning parameters ensure your equipment is used at maximum efficiency.

Valve considerations

A valve is often the weak link of the loop. The only piece of equipment that moves is the valve and its accessories. Because of this movement, problems occur, and those problems reduce control loop performance. When selecting a valve, one must consider:

- Capacity (C_v) or size.
- The appropriate characteristics curve (linear, parabolic, equal-percentage, or other).
- Materials for trim, packing, body, etc.
- Accessories.
- The positioner.
- The actuator.

If the (C_v) is not computed properly, the valve process gain (G_p) will be too high and the valve problems will be amplified. The process gain should be maintained under 2 or 3. For example, if the process gain is 5, each time the valve moves by 1%, the process variable moves by 5%.

If the characteristics of the valve are not properly selected, the process gain will vary. The process gain should vary less than a factor of 2 or 3.

The actuator needs to be strong; first to deal with the process forces applied on the valve, second to break the friction from the mechanical pieces in contact and from the packings. We recommend an actuator developing three times the force required to overcome the dynamic and frictional forces.

The valve, actuator, and positioner must fit with close tolerances and resist wear. Loose mechanical parts lead to backlash: the valve movement will be different from the signal.

Valve problems

The resolution of a valve is the smallest increment of input signal in one direction for which movement of the valve is observed. Resolution can be limited by a sensor such as a wirewound resistor, where each loop of wire produces an output jumping each time a new loop is reached. Digitizing a signal can give the same result. For example, the resolution for an eight-bit system is 1/256=0.4%.

Figure 1 illustrates the terms dead band, resolution, backlash and hysteresis. If resolution is perfect, backlash = deadband = hysteresis.

THE STICTION GANG

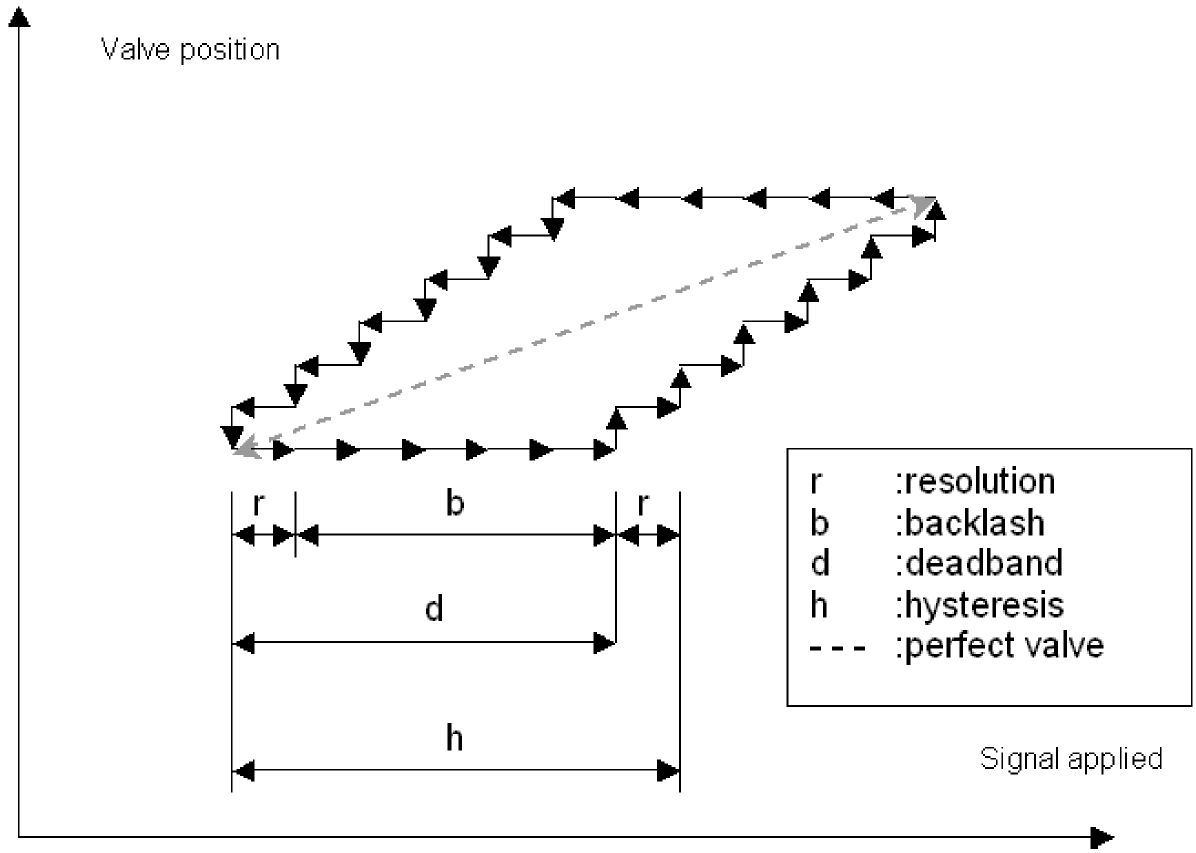


Figure 1

Stiction hides in a crowd that includes deadband, resolution, backlash, and hysteresis. If resolution is perfect, backlash = deadband = hysteresis

Figure 2 illustrates how a valve with backlash responds, and Figure 3 shows how the valve responds to bumps.

BACKLASH EFFECT

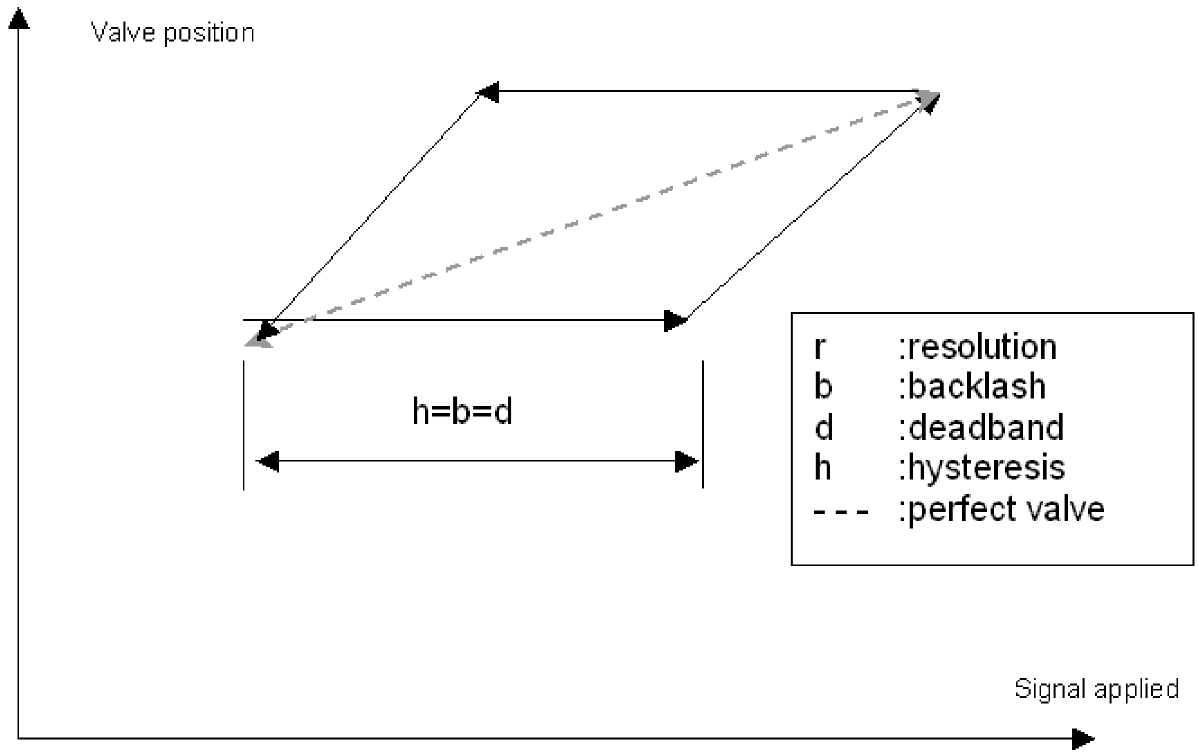


Figure 2

Resolution, backlash, and deadband all show the response of the valve.

BUMP IT

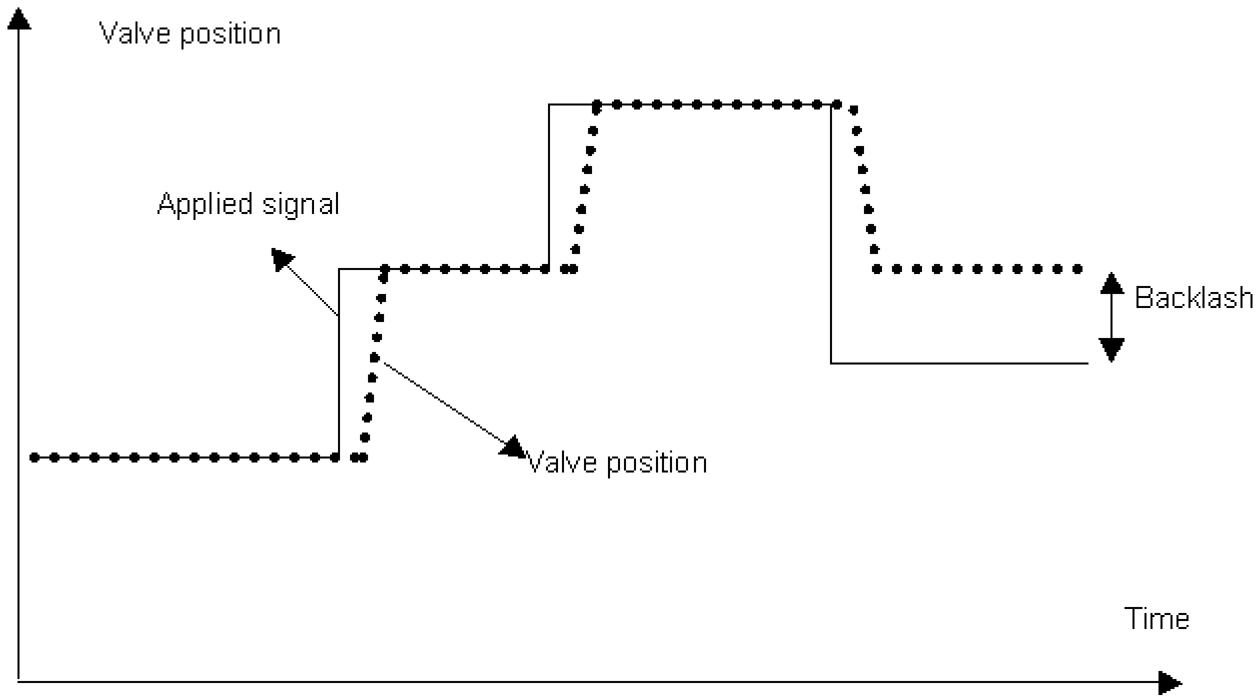


Figure 3
Valve response to a bump in the signal shows the effect of backlash and how to measure it. It deals backlash is zero, but in most valves it is near 1%

Figure 3 also illustrates how to determine the backlash in a valve. If the backlash is zero, the valve position and hence the process variable will go back to the previous position. Ideally, backlash in a valve is zero, but in most valves, it is near 1%. On most processes, a backlash of 2 or 3% is acceptable if the controller is not tuned too aggressively. Such backlash adds deadtime to the loop and reduces performance.

Stiction

Stiction is the resistance to the start of motion, usually measured as the difference between the driving values required to overcome static friction upscale and down scale.

The word stiction is a combination of the words stick and friction, created to emphasize the difference between static and dynamic friction. For example, it is sometimes hard to move a piece of furniture. You apply increasing pressure and it suddenly gives, moving rapidly. Similarly, stiction causes the piston of an air cylinder to suddenly lurch forward at the start of a stroke or to move jerkily during its travel.

Stiction exists when the static (starting) friction exceeds the dynamic (moving) friction inside the valve. Stiction describes the valve's stem (or shaft) sticking when small changes are attempted. Friction of a moving object is less than when it is stationary. Stiction can keep the stem from moving for small control input changes, and then the stem moves when there is enough force to free it. The result of stiction is that the force required to get the stem to move is more than is required to go to the desired stem position. In presence of stiction, the movement is jumpy.

STICTION'S SIGNATURE

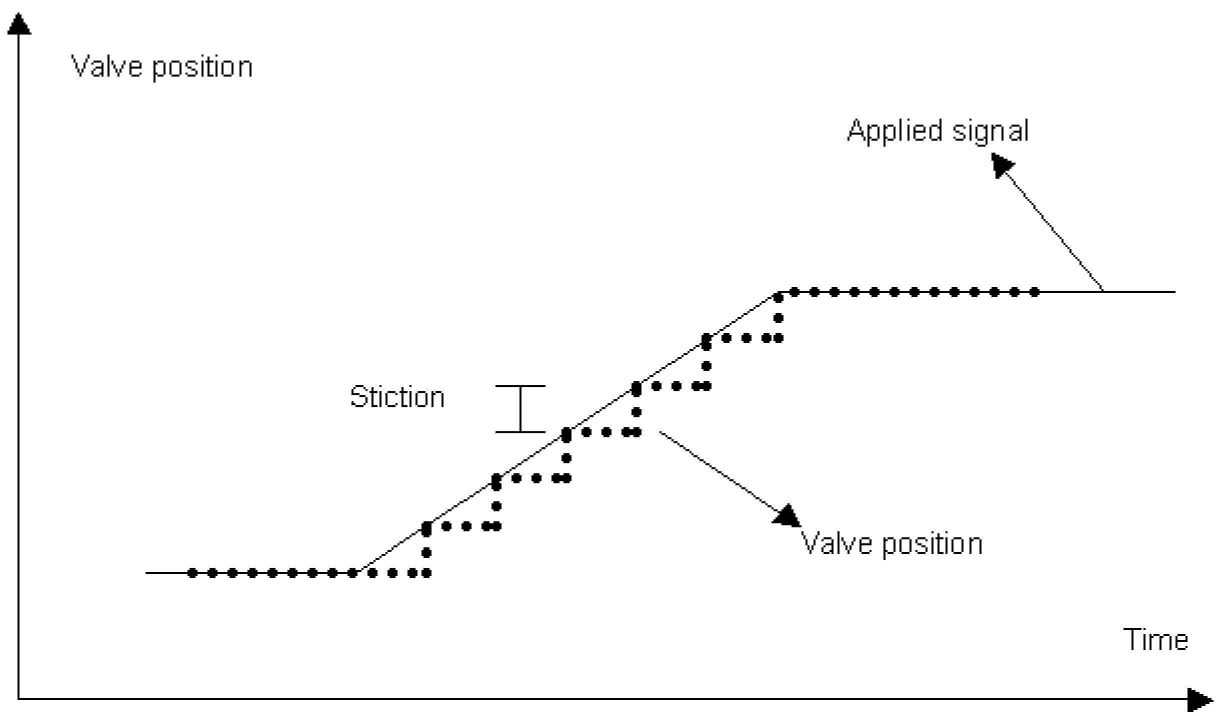


Figure 4

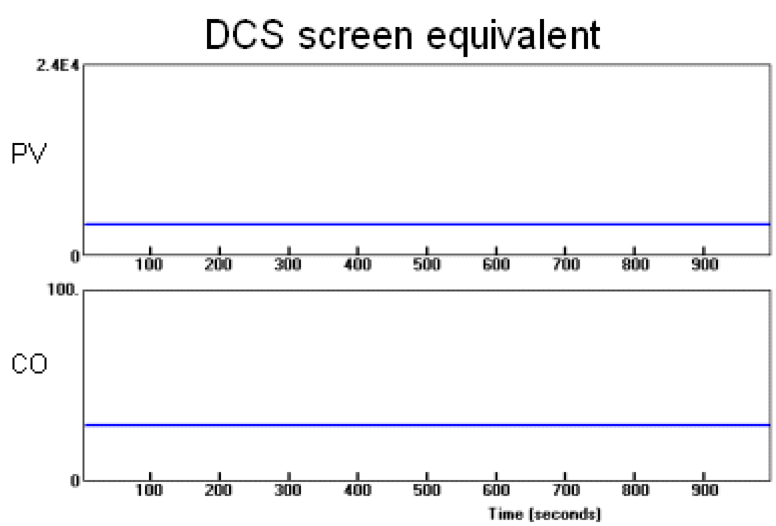
Valve response to a bump in the signal shows the effect of backlash and how to measure it. It deals backlash is zero, but in most valves it is near 1%

In a control loop, stiction is a big problem, since the controller will push to move the valve until the process variable reaches the setpoint. If stiction is present, the valve will move too much and the process variable will overshoot. Then, the controller output will reverse direction and it will happen again. The limit cycle caused when the control valve sticks and 3ps during a change in input signal is called stick/slip cycle.

In Real Life

In a refinery, hidden cycling was detected in most loops of a unit. After analysis using power spectral density and cross correlation, a flow loop with cycling is found. This was undetectable looking at the DCS screen. The amplitude of the cycling was too small and the signal was filtered. The graphics in the upper half of Figure 5 shows what was seen on the DCS and the graphics in the lower half display the same information, but unfiltered. Figure 6 displays the same data, but zoomed.

HIDDEN CYCLING



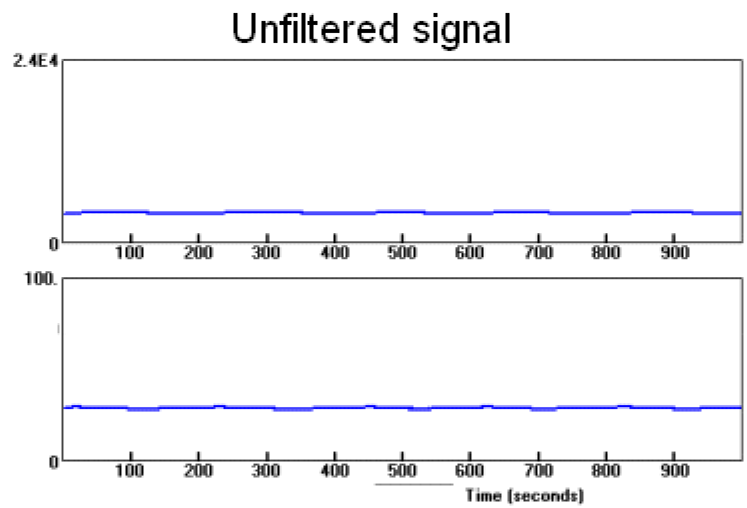
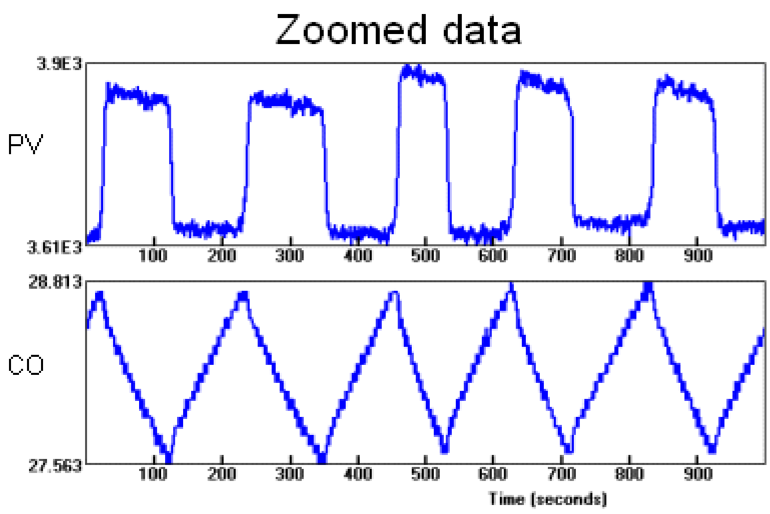


Figure 5

Though undetectable on the DCS screen (top), power spectral density analysis and cross correlation showed a flow loop with cycling (bottom)

HIDDEN CYCLING



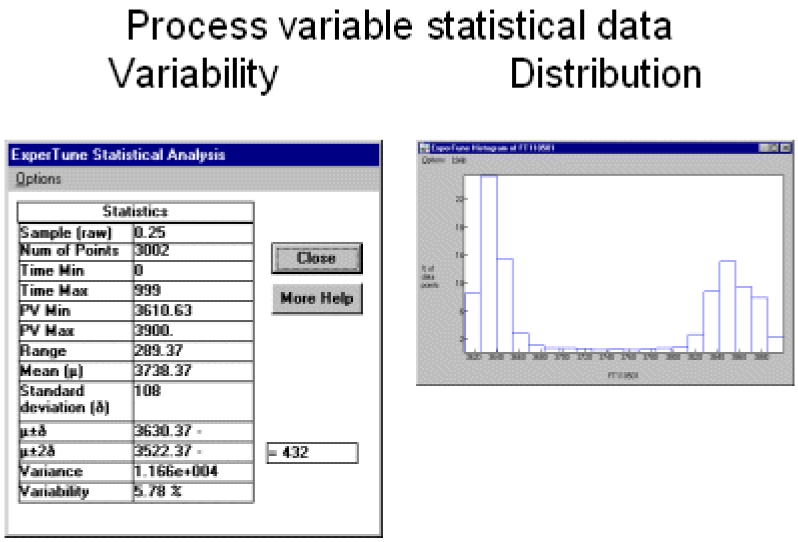


Figure 6

Zooming in on the variation in Figure 5 showed the nature of the cycling (top) that was causing variation in a refinery product (bottom)

In automatic mode, a loop with a sticky component will behave like the one in Figure 6. The process variable will look like a square wave. Sometimes, if the process has a large time constant or has an integrating process, it will not be easy to detect. The controller output will move like a triangular wave or a sawtooth. When the process variable is too low, the controller output is pushed and when the valve moves, the movement is too large. The process variable then goes too high and the controller moves the other way.

STICK/SLIP

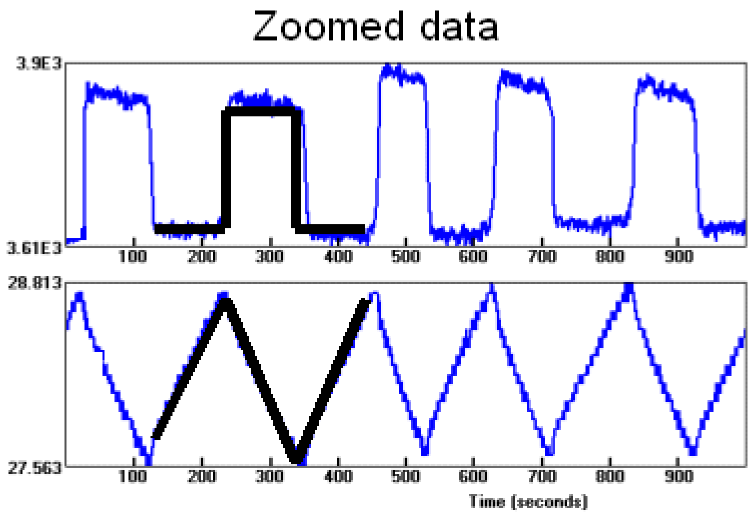


Figure 7

Analysis of the variation in Figure 6 showed the process gain was close to 1. Observing the Stick/Slip cycling shows the stiction is close to 1%, since that is the valve movement.

The process gain in Figure 7 is close to 1, determined by using bump tests and looking at the trends for the last days. This can be verified using the stick/slip cycle on the graphic:

Observing the stick/slip cycling, we now know the stiction is close to 1%, since this is the valve movement.

Before tuning a loop, it is good practice to perform manual tests that analyze the process for gain, linearity, backlash, stiction, hidden cycling, etc. Steps to detect and measure stiction are: 1) Remove the backlash by doing a large bump of 2-3%. 2) Move the controller output slowly, doing a slow ramp and observing the controller output. This is not easy to accomplish on a DCS, so this procedure is replaced by small bumps of 0.1 or 0.2 %. Depending on the DCS system, the resolution is 0.4% (eight bits), 0.1% (10 bits) or less. The time between each bump must be long enough, depending on the process dynamics. 3) The stiction is the amount of controller output change to detect a change in the process variable.

MEASURING STICTION

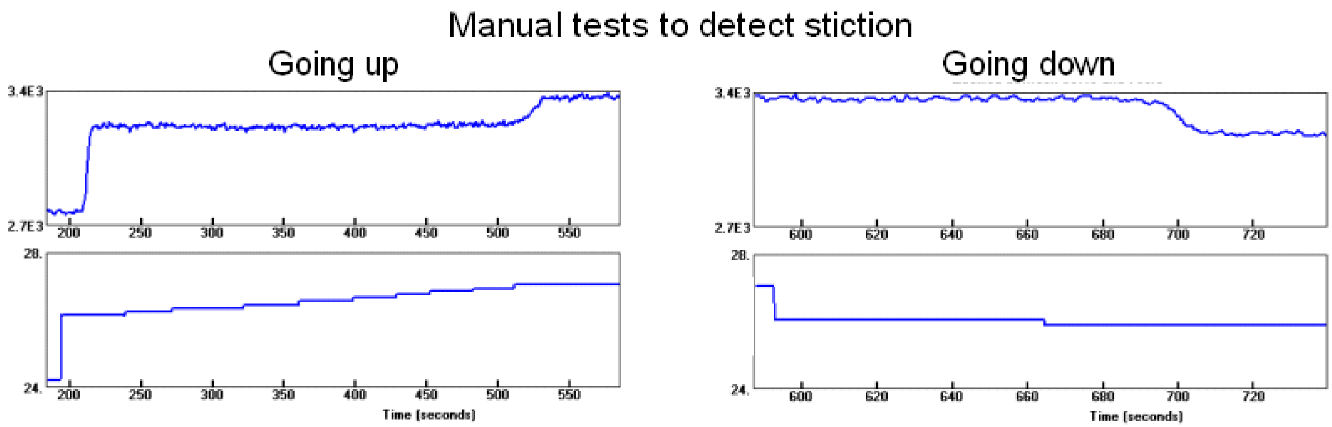


Figure 8

In this case, after a 2% bump to remove backlash, the controller output is increased by small increments of 0.1%. The stiction is the total of the increments before the valve moves.

These steps are shown in Figure 8. The graphic on the left shows the controller output is first bumped by 2 %. This bump ensures the backlash, if present, is removed and we observe a change in the flow after this 2% change. Then the output is increased by small increments of 0.1 %. After 10 of those bumps, the process variable finally moves, meaning the valve moved.

The tests were repeated going down. The first bump after removing the backlash is 1% and the valve does not move. Adding 0.1% is enough to move the valve, confirming a stiction of 1%.

The problem in this case was the positioner. After the positioner was repaired, the cycling disappeared. The loop was retuned and the production level went back to normal (Figure 9).

PROBLEM SOLVED

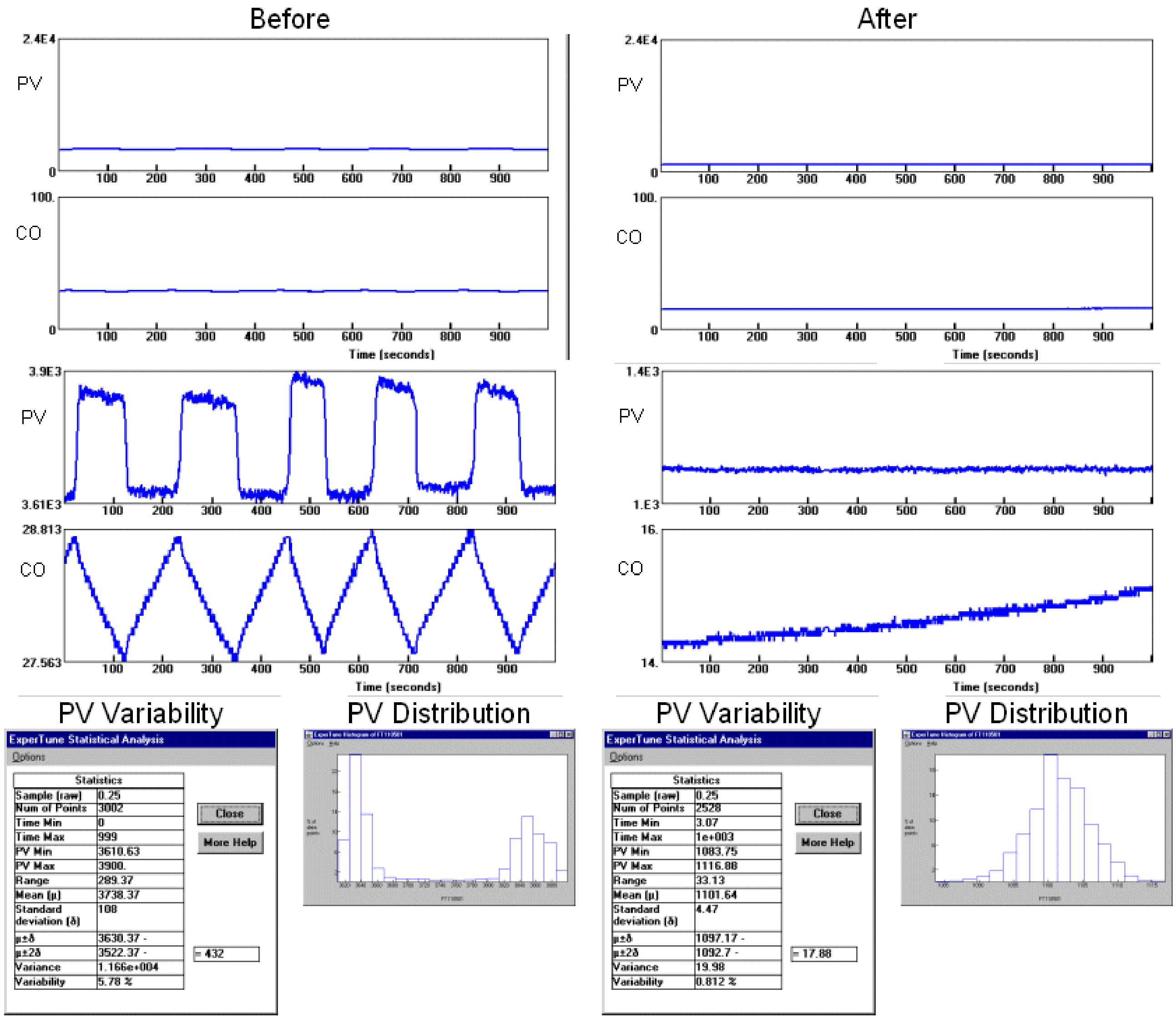


Figure 9

Eliminating Stiction eliminated the cycling and corrected the product variability. Compare these results to Figures 6 and 7.

How much stiction is acceptable? To answer this question, one must know the process. Stiction is insidious, generating cycling of constant amplitude. The cycling period depends on the controller tuning. This cycling also generates a lot of harmonics into the process, since the process variable is a square wave.

In many processes, 0.5% of stiction is too much. Stiction guarantees cycling and variability. Stiction is much more harmful than the other valve problems. For example, hysteresis is undesirable, but usually not really a problem. Another example is the valve characteristic, which can be compensated by a non-linear function inserted in the controller output or in the positioner.

Based on our experience and on the equipment people use, we usually recommend the maximums shown in Table 1.

		Ideal	Tolerable limit
Process gain	G_p	1	<3
Non-linearity	G_{pmax}/G_{pmin}	1	<3
Backlash	b [%]	0	<3
Stiction	s [%]	0	<<<

Table 1

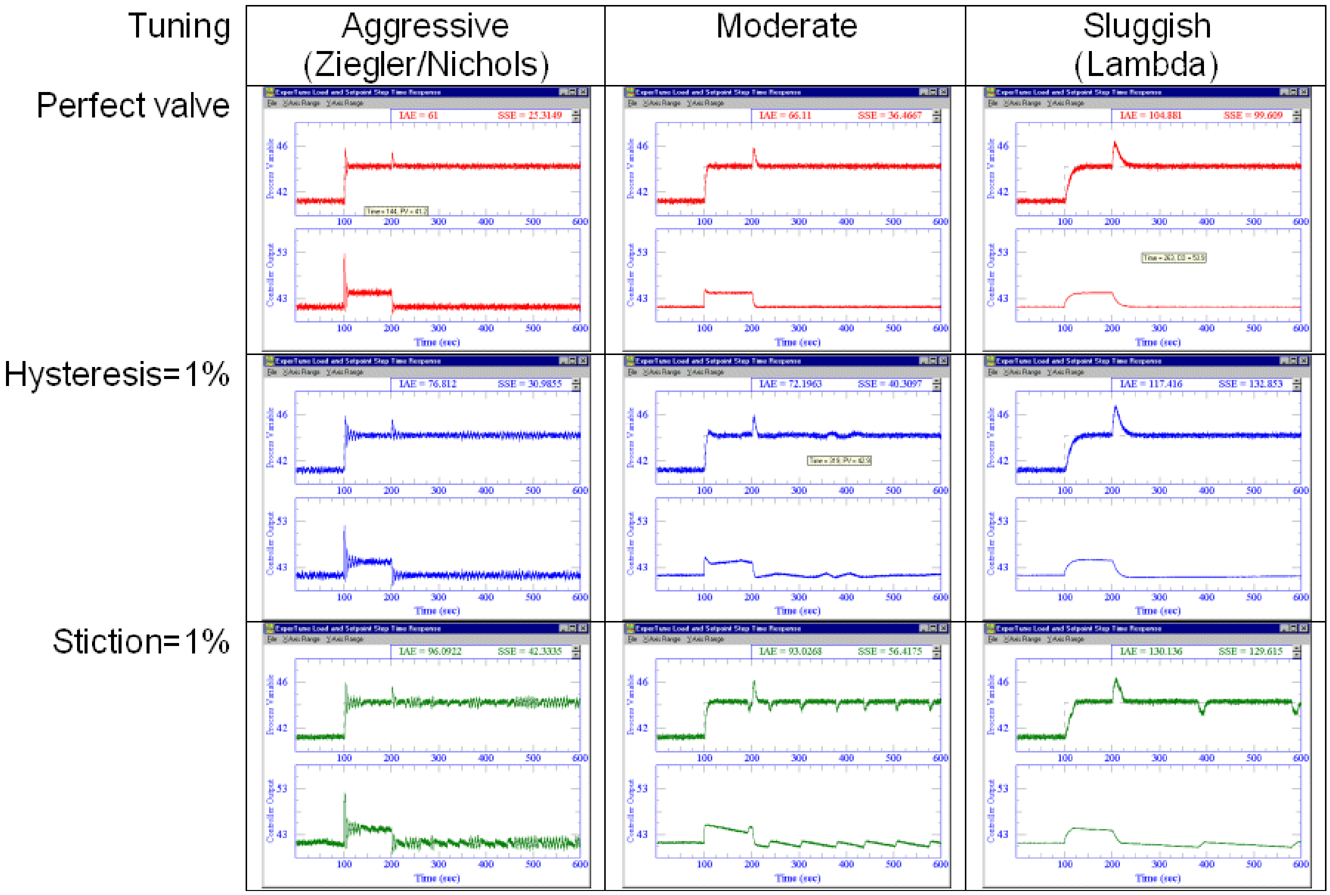
Simulation To observe the impacts of stiction and hysteresis (backlash), we simulated a process with G_p=1, dead time = 1 sec., and a time constant of 3 sec. A white noise with a standard deviation of 0.1% was added to the process variable.

Three situations were simulated:

1. A perfect valve.
2. A valve with 1% hysteresis.
3. A valve with 1% stiction.

Three PI controllers (ISA algorithm) were used for each case:

1. Aggressive tuning based on Ziegler/Nichols: Kp= 2.7, Ti=3 sec.
2. Moderate tuning: Kp= 0.84, Ti=2.4 sec.
3. Sluggish, based on Lambda tuning: Kp= 0.28, Ti=3 sec.



Tuning
Aggressive (Ziegler/Nichols)
Moderate
Sluggish (Lambda)
Perfect valve
Hysteresis=1%
Stiction=1%
IAE = 61
SSE = 25.3149
IAE = 66.11
SSE = 36.4667
IAE = 104.881
SSE = 99.609
IAE = 76.812
SSE = 30.9855
IAE = 72.1963
SSE = 40.3097
IAE = 117.416
SSE = 132.853
IAE = 96.0922
SSE = 42.3335
IAE = 93.0268
SSE = 56.4175
IAE = 130.136
SSE = 129.615
Time (sec)

Tuning	Aggressive (Ziegler/Nichols)					Moderate					Sluggish (Lambda)				
	Variability (300 to 600s)	Settling time for SP change	Time to remove a disturbance	PV upset after load change	IAE	Variability (300 to 600s)	Settling time for SP change	Time to remove a disturbance	PV upset after load change	IAE	Variability (300 to 600s)	Settling time for SP change	Time to remove a disturbance	PV upset after load change	IAE
	%	s	s	%	%s	%	s	s	%	%s	%	s	s	%	%s
Perfect valve	0.49	16	11	1.3	61	0.45	8	14	1.6	66	0.45	33	40	2.1	105
Hysteresis=1%	0.55	16	11	1.1	77	0.48	18	15	1.6	72	0.45	33	41	2.5	117
Stiction=1%	1.10	21	18	1.1	96	0.80	18	13	1.4	93	1.16	24	28	2.1	130

Table 2

At 100 seconds we applied a setpoint change of 3% and we introduced a load change of 3% at 200 seconds. We can draw several conclusions from the results in Table II:

- With a perfect valve, more aggressive tuning reduces load change effect.
- Aggressive tuning emphasizes valve problems.
- Variability at steady state depends mainly on the noise level; variability in real life depends also on the amount of disturbances.
- Sluggish tuning reduces valve problems but is slow to remove a disturbance and slow to follow the setpoint.
- If hysteresis is present, the valve will move more but the performances (variability, IAE, SSE) will be slightly affected.
- If stiction is present, the variability will increase and cycling will appear.
- Moderate tuning represents a good compromise for IAE, speed of response, and variability.
- Backlash or hysteresis is a problem but stiction is a lot worse; backlash has fewer impacts if sluggish tuning is used.

To reduce stiction:

- Select properly the valve and the actuator.
- Maintain your valves regularly.
- Buy a strong actuator and a good positioner.
- Check your valves often while the process is running, especially before a shutdown.

About the author:
Michel Ruel is a registered professional engineer, university lecturer, author of several publications and books on instrumentation and control. A pioneer in implementing fuzzy logic, Ruel has 23 years of plant experience at companies including Monsanto Chemicals, Domtar Paper, Dow Corning and Shell Oil.

Source: http://pc-education.mcmaster.ca/Instrumentation/go_inst.htm