ONLINE OSCILLATION DETECTION AND ADAPTIVE CONTROL IN CHEMICAL PLANTS

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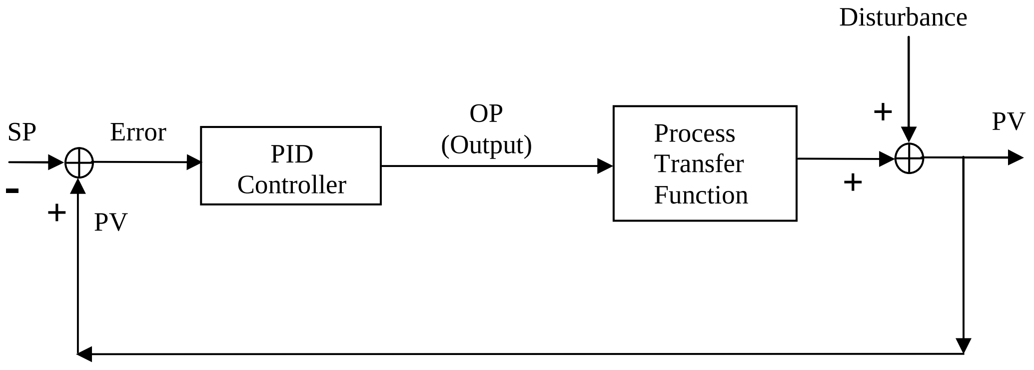
Introduction

Fast and reliable detection of critical signals is important in many chemical processes. Changes in operating conditions, feedstock, product grades, production rates can induce nonlinearities in the process and can initiate feedback controllers to oscillate. Once oscillations creep in just one or a few loops, the entire plant can start to oscillate. This can cause equipment shutdowns, lost production rates, off-grade products or increased utility consumption. Ability to detect oscillations quickly with subsequent immediate corrective action can increase operational reliability and improved production rates in chemical plants and thus impact the plant's profit margin. Quick and timely oscillation detection followed up with alarming or closed-loop adaptive control action can benefit chemical, petrochemical, oil-refining, paper, pharmaceutical and related industries.

Causes of Oscillations and Instability

Figure 1 shows a typical PID feedback controller schematic.

Figure 1. Reactor Temperature Setpoint Change



The first order transfer function is defined by the process gain, process time constant and the process dead time:

$$G(s) = \frac{A\, e^{-\theta s}}{\tau s + 1}$$

A = Process Gain
θ = Dead Time
τ = Time Constant
s = Laplace Operator

As process and operating conditions change, the process gain, dead time and time constant can change. If the changes are significant, the PID control quality will deteriorate. Increase in process gain, increase in dead time or decrease in time constant can result in aggressive control action accompanied by PV oscillations. Decrease in process gain, decrease in dead time or increase in time constant can make the control action to become sluggish, slow or conservative. Various forms of oscillating signals encountered in the chemical, petrochemical and refining industry are shown in various figures below.

Characteristics of Signals in Chemical Processes

Varying amounts of noise and complex unmeasured disturbances superimpose the true process signals in chemical plants. The noise and the disturbances make the detection of oscillations difficult.

Figure 2 shows what a "*clean*" signal looks like. This signal could be, let's say reactor temperature. The temperature was fairly stable and at steady state until location "A" where a temperature setpoint change caused the temperature to reach a higher value that reaches a new steady state at location B. The temperature control appears stable, desirable and acceptable to operators in any control room.

Unfortunately, in a real process, signals are never so "*clean*" and "*nice*". A change in the reactor temperature setpoint, is more likely to look as shown in Figure 3. Figure 3 illustrates the presence of complex disturbances and process noise, electronic disturbances from the temperature sensor and so on, superimposed on the raw (true) temperature signal.

Signs of Incipient Instability (Hunting or Ringing Phenomena)

Let us say that a change in the reactor temperature setpoint caused a significant increase in the process gain, which in turn caused the feedback temperature controller to become too aggressive. Aggressive controller action can cause the signal to "hunt" or "ring". Figure 4 illustrates the hunting or ringing phenomena. Large oscillations of almost identical amplitudes constitute the "*hunting*" or "*ringing*" phenomena. Typically, amplitudes of more than 5% of the average process value are considered to be rather high and are labeled oscillatory, hunting or ringing.

Figure 2. Reactor Temperature Setpoint Change

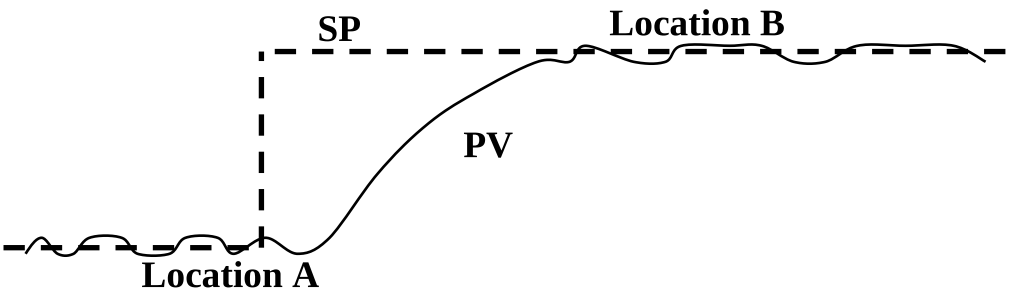
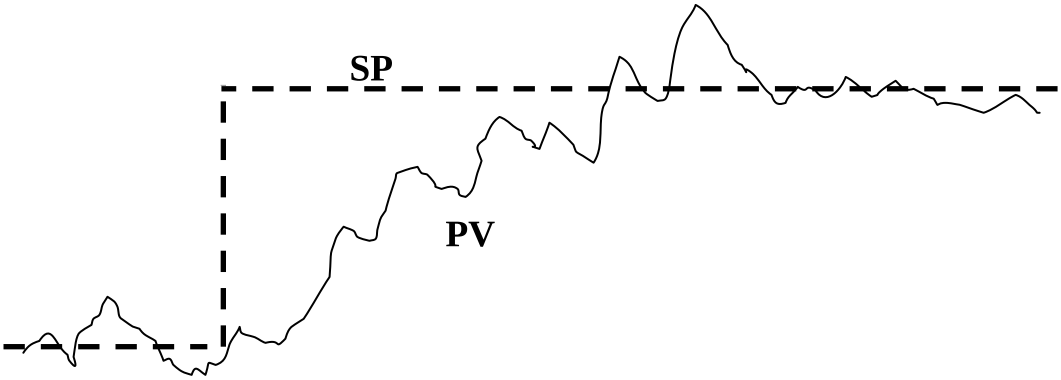


Figure 3. Reactor Temperature Setpoint Change with Noise and Drift



Signs of True Instability (Unstable Phenomena)

If the extent of nonlinearity is high enough to cause even more aggressive control action, the signal may start becoming unstable. Growing amplitudes characterize unstable signals. The height of later amplitudes is bigger than the previous ones. After some time, the signal may start bouncing from the high to the low instrument range. Figure 5 shows a typical unstable signal.

Oscillation Detection Challenge in Chemical Processes

The drift and noise characteristic in most chemical processes make the growing oscillations look more the ones illustrated in Figure 6 rather than Figure 5.

Signs of True Instability (Unstable Phenomena)

In many cases, as a loop becomes unstable, the varying amounts of noise and drift can make the signal look very complex as illustrated in Figure 7. The signal can comprise of fast, medium and low frequency contributions. A fast frequency cycle can look "unstable" based on growing fast frequency amplitudes. There can be any number and any combination of frequencies all combined to generate complex signals that are called "*squibbles*". In some cases, the fastest frequency growing amplitudes may be the true sign of instability. In other cases, the slowest frequency of growing amplitudes may be a sign of instability. This potentially infinite combination of signals, poses challenges for reliable oscillation detection in chemical processes.

Figure 4. The "Hunting", "Ringing" or "Oscillatory" Phenomena

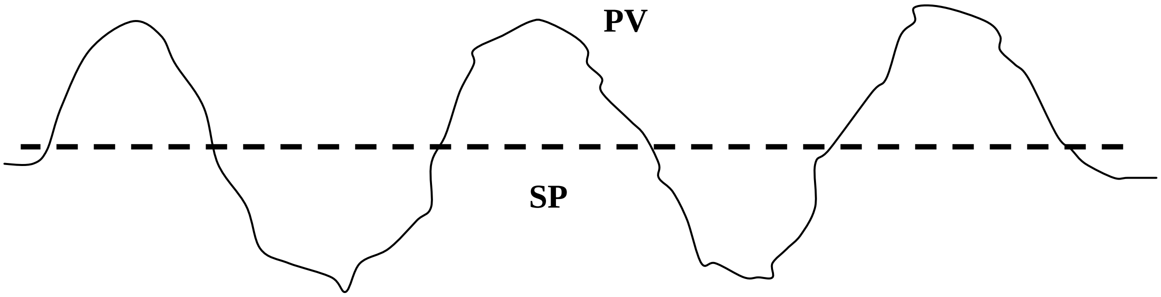
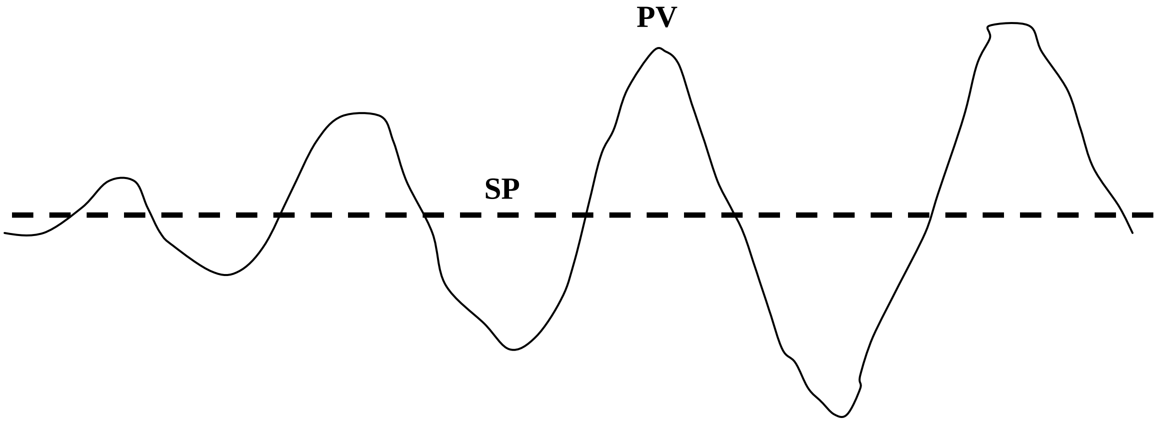


Figure 5. The "Unstable" Phenomena



Distinguishing Between Fast and Slow Frequencies

In certain cascade control schemes, the cascade's setpoint may be oscillating with a slow frequency (caused by its master controller), as shown in the upper trend in Figure 8. The slow frequency cycling in the SP may be the unavoidable nature of the process and could be perfectly acceptable. In this case, the fast frequency cycling in the PV may be the issue to watch for. In the lower trend plot in Figure 8, the PV trend is similar to the upper trend, but in this case, the SP is fixed (flat line). Here, the oscillation detection goal is to watch for the slow frequency oscillations in the PV and treat the fast oscillations as unimportant noise. The oscillation detection algorithm must be able to differentiate between the two cases succinctly and repeat-ably.

Figure 6. The "Unstable" Phenomena

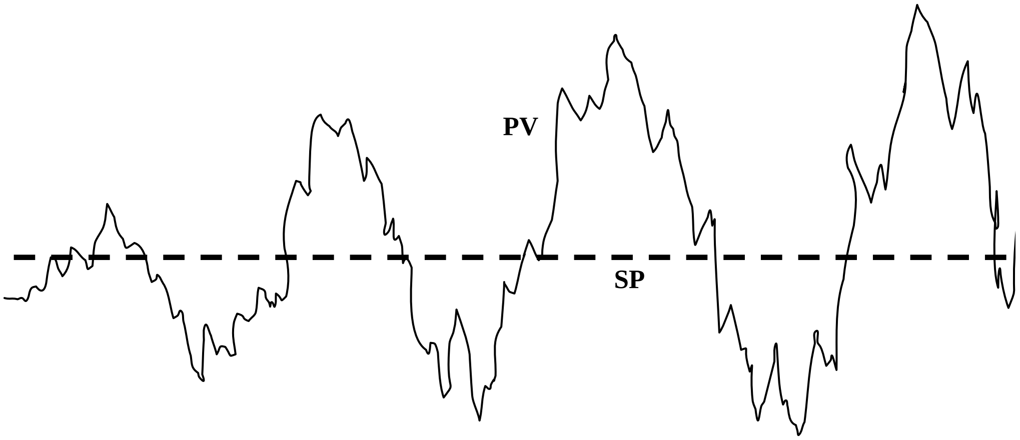
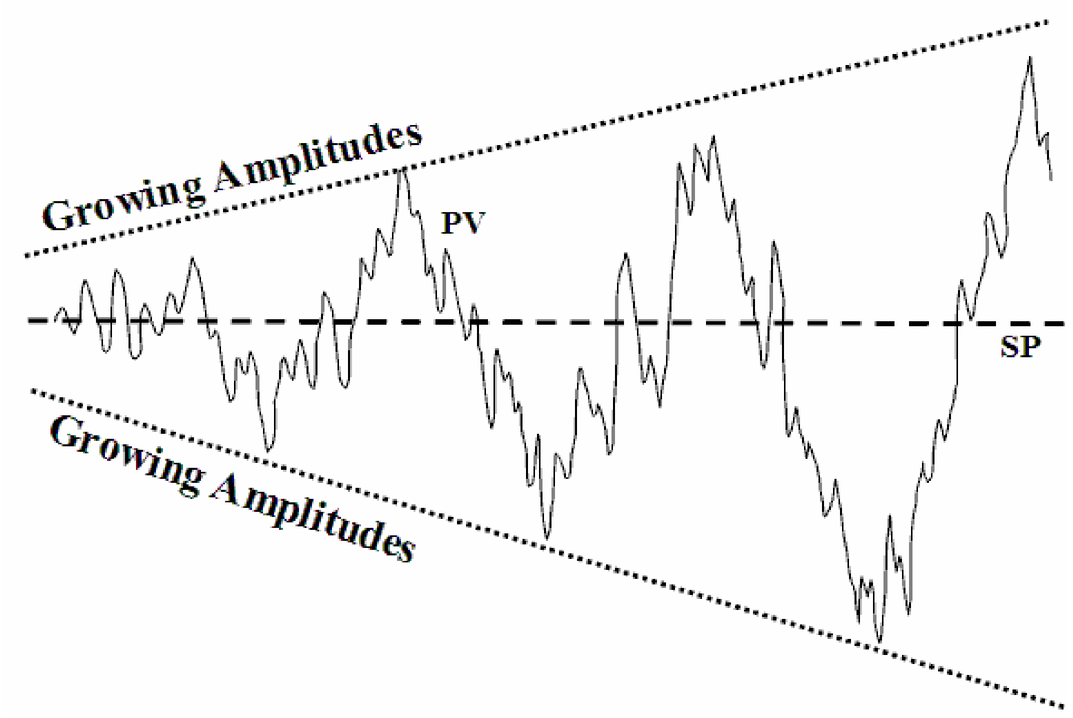


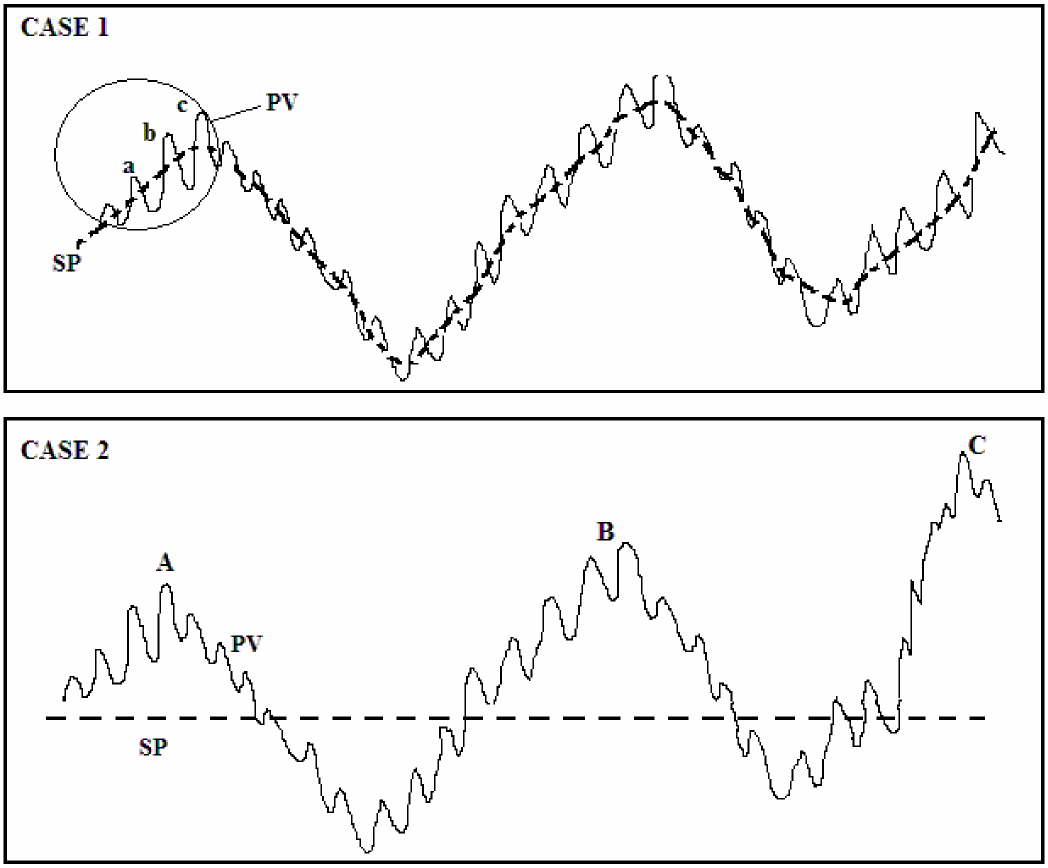
Figure 7. The Growing Cone with Squibbles



The True-Amplitude-Detection (TAD) Algorithm

PiControl Solutions Company has invented a novel, revolutionary algorithm capable of detecting "real" oscillations by identifying the "true" amplitudes. This algorithm is called ***True Amplitude Detection (TAD)***. TAD reliably identifies the oscillations that are real and meaningful. It is capable of distinguishing from oscillations that are not relevant or important to the nature of the process. In Figure 8, the dashed lines are SPs in both cases. In case 1, the growing PV amplitudes as shown by a, b, c may be a matter of concern. In case 2, the a, b, c type squibbles may be noise or fast disturbances of no relevance to the loop, but the slower trend of growing amplitudes A, B, C may be a reason to be alarmed. The TAD algorithm can smartly and reliably differentiate between the two cases.

Figure 8. Cascade and Slave Oscillation Criteria



TADPOLE™ Online Oscillation Detection Software Product

PiControl Solutions Company has packaged the TAD algorithm into a compact, powerful software product called TADPOLE™. "TAD" denotes "True Amplitude Detection". "POLE" denotes the oscillation amplitudes that resemble a pole. TADPOLE™ is designed to run automatically continuously at any desired scan rate on a client PC connected to the DCS or PLC. TADPOLE™ can run automatically at a scan rate as fast as 0.1 seconds or slower like every minute, depending on the process dynamics. It reads data from DCS or PLC and alerts if hunting or instability is detected.

Oscillation Alarming in DCS or PLC

Current DCS and PLC systems provide PV alarming for

- High/Low Trip (often as a warning or alert to the operator)
- High-high/Low-Low Trip (often used as a shut-down for process safety and/or equipment protection)

What is needed is an oscillation status alarm with two states:

- Oscillation Hunting Alarm (larger than normal amplitudes detected)
- Oscillation Unstable Alarm (growing amplitudes detected)

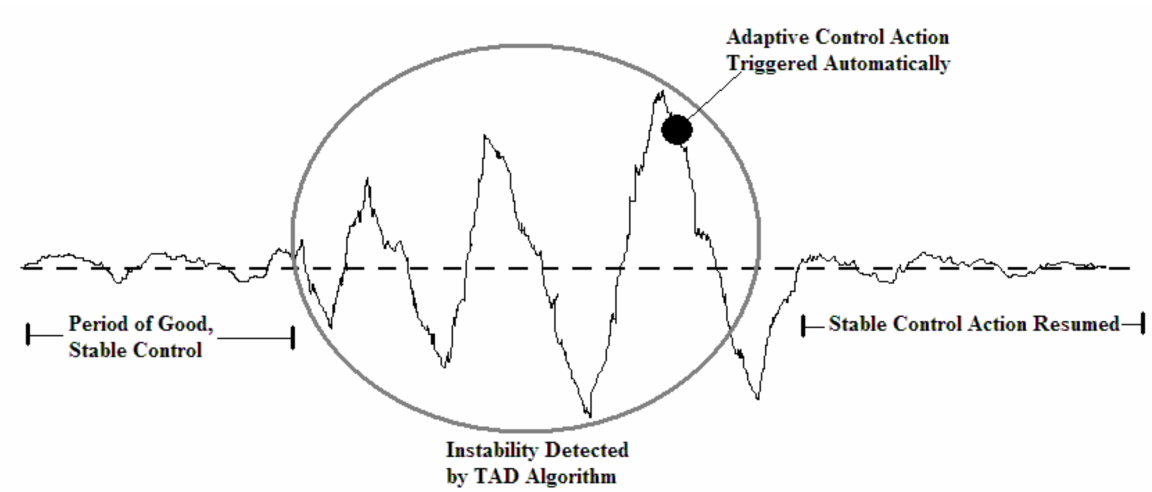
TADPOLE™ provides this new important alarming capability like never before.

Adaptive Control or Gain Scheduling

The TADPOLE^{TM} oscillation alarm can be put to valuable use in the following ways:

- Send a message to the operator to warn him of the oscillations. The operator could take some corrective action, e.g., reducing process/equipment loading.
- Place one or more closed-loop control schemes into manual mode to try and break the oscillations.
- Automatically change/swap PID tuning parameters to more conservative (slower) parameters. An illustration of this action is shown in Figure 9. After detecting oscillations and triggering automatic tuning changes, stable control is reinstated.
- Automatically notify/page control room control engineers or DCS technicians to make them aware of the problem. Plant personnel can quickly focus on the impending oscillation problem.

Figure 9. Cascade and Slave Oscillation Criteria



Summary

Chemical process units such as reactors, superfractionators, furnaces, compressors and many other types of rotating equipment etc; have a handful of critical primary control loops that warrant reliable oscillation detection and timely protection. Online oscillation detection and automatic adaptive control action can arrest the onset of incipient oscillations that could have eventually grown and caused the entire process to oscillate. Many modern processes today are heavily heat and mass-balance integrated using recycle streams and integrated heat exchangers. This integration make the processes even more vulnerable to plant or process-wide oscillations. If oscillations pass unnoticed and grow, it is extremely difficult to identify the source of the oscillations, since all process variables seem to be oscillating. The new, revolutionary TAD algorithm inside the TADPOLE^{TM} software product provides a powerful and reliable way to suppress the oscillations and restore process stability quickly.