



## **How to Read “Sine Language”: Reduce Process Cycling to Save Money**

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**George Buckbee, P.E.  
ExperTune, Inc.**

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[www.expertune.com](http://www.expertune.com)

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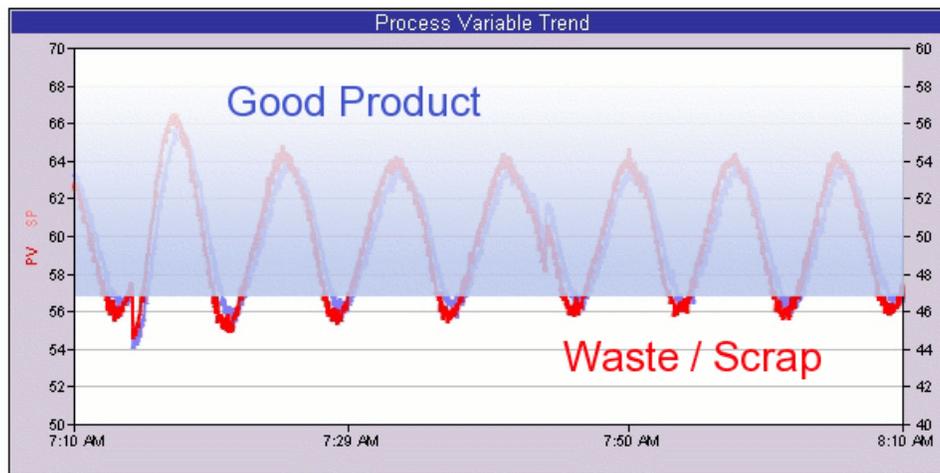
## Summary

Oscillation directly affects plant efficiency. This reduced efficiency typically appears as high energy cost, quality problems, and stability or reliability issues. This white paper demonstrates practical methods to improve process efficiency by detecting, prioritizing, and eliminating cycling.

## Overview

Most process plants are significantly affected by cycling. This white paper provides some practical techniques to find, prioritize, and solve oscillation issues in process plants. First, we will explore the causes and effects of cycling. Then we will learn how to solve cycling problems via detection, prioritization, and root cause elimination.

### *How Does Cycling Effect Efficiency?*



**Figure 1: Cycling Often Creates a Quality Problem.**

Cycling affects process plant efficiency in many ways. For example, cycling often causes the process to stray outside of established quality limits, as shown in Figure 1. The material outside of spec limits must be wasted, scrapped, blended, or recycled. All of these incur process costs, such as additional chemical usage, energy consumption. Further, it often takes operator attention to correct the problem – distracting the operator from other opportunities to improve production.

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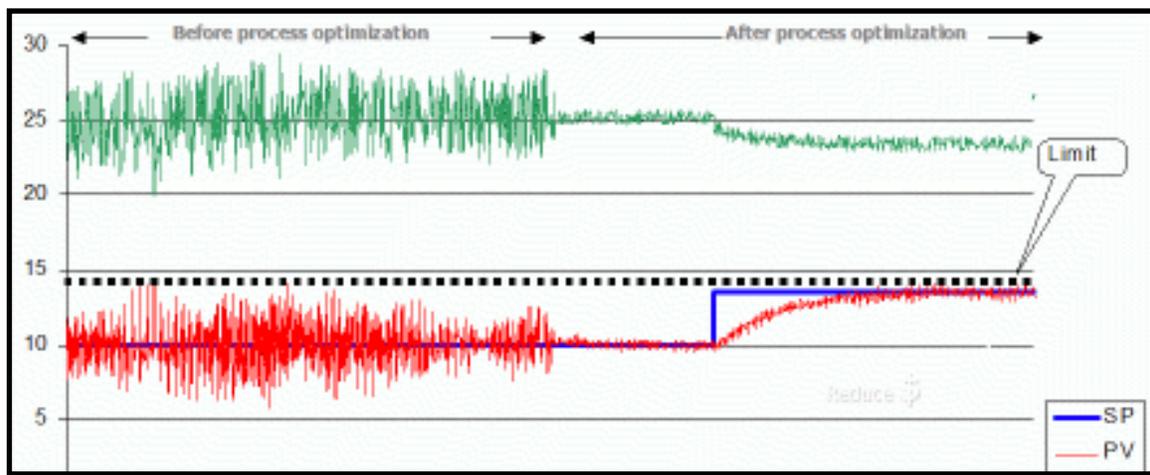
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Another way that cycling causes lost profits is by forcing operation away from the most efficient point. The most efficient point of process operation is typically at or near one of its operating constraints. Dryers should be operated as close as possible to moisture targets, for example.

When a process has high variability, the operator is often forced to adjust the process setpoint to keep the process within an acceptable range of operation. The range may be dictated by safety, quality, or other process requirements. When the process is highly variable, the operator is forced to operate even further away from the upper or lower limits of the acceptable range.

When we reduce variability, we can shift the process closer to its most efficient point of operation, as shown in Figure 2.



**Figure 2. Reduce Variation, then Shift the Process to its Optimum**

There are many other ways that cycling affects process efficiency. Imagine driving your car while cycling your foot up and down on the accelerator. What sort of fuel efficiency do you expect? Even though you may average the correct speed, your fuel efficiency will be terrible...and you will have motion sickness, too!

Now imagine all the energy being wasted in your plant as energy-consuming loops cycle away, day and night. Combustors, boilers, dryers, kilns, distillation columns, and heat exchangers all suffer poor energy efficiency when cycling.

### ***What Causes Cycling?***

There are several common causes to cycling in process plants. The most common causes are:

- Mechanical problems with control valves, such as Stiction and Hysteresis
- Interaction between controllers, especially cascade and ratio controls
- Process batch or sequential operations

- Interactions with mechanical process equipment

In the section “How to Determine Root Cause”, you will learn how to identify the root cause and eliminate the problem at its source.

### ***How Much Cycling is Typical?***

Are you wasting money? Is your plant cycling? Without a doubt! In decades of experience, looking at thousands of plants, we have seen that it is very typical for between 20% and 70% of measured process variables to be cycling. A typical average is roughly 40% of process variables are cycling.

### ***What is this Worth?***

The benefits vary widely, depending on which process variables are affected. When key production or quality variables in a medium-sized plant are cycling, the potential for savings can typically be measured in millions of dollars per year.

### ***How to Solve Cycling Problems***

To capture the savings, you will need a way to:

- Detect Oscillations
- Prioritize Oscillations
- Determine the Root Cause



The remainder of this white paper focuses on practical methods for each of these steps.

## **How to Detect Oscillations**

### ***The Fourier Transform***

The basis of oscillation detection lies in the mathematics of Jean Baptiste Joseph Fourier. In the early 1800’s, Fourier worked out the method, now known as the Fourier Transform, that is the basis of oscillation detection.

According to Fourier’s theory, any periodic signal can be broken down into its component frequencies, as shown in Equations 1, 2, and 3.

$$(1) \quad f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos(n\omega t) + b_n \sin(n\omega t)]$$

$$(2) \quad a_n = \frac{\omega}{\pi} \int_0^{\frac{2\pi}{\omega}} f(t) \cos(n\omega t) dt$$

$$(3) \quad b_n = \frac{\omega}{\pi} \int_0^{\frac{2\pi}{\omega}} f(t) \sin(n\omega t) dt$$

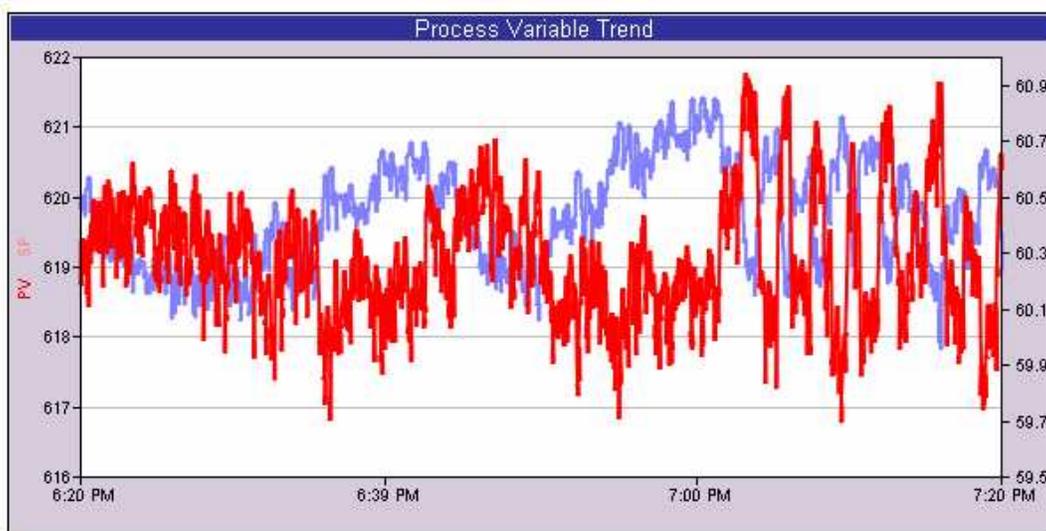
Anyone who was made to perform these calculations in college can attest to the fact that this can be a lengthy, tedious, and cumbersome process.

However, today, streams of process data are readily available directly from the control system, using open methods, such as OPC. The computing power required for Fourier analysis of thousands of process measurements can be handled quite easily by a modern server-class computer.

### **Identify Periods and Strengths**

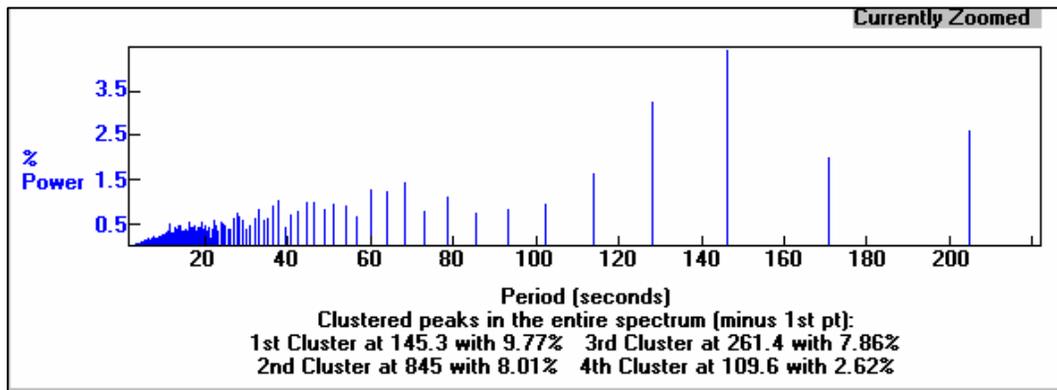
The key results of the Fourier Transform are the period and magnitude of each contributing sine wave. The magnitude tells us how large the impact is. The period (inverse of frequency) becomes an important clue to determining the root cause...more on this later.

Figure 3 shows the raw data from a process flow measurement. It is difficult to determine by inspection whether the loop is cycling, and at what frequency.



**Figure 3. Process Flow Measurement (in red)**

A Fourier Transform, run against this same set of data, is shown in Figure 4. From this view, it is easy to see that there is a cycle at roughly 145 seconds/cycle. According to the analysis, this cycle accounts for nearly 10% of the power in the signal.



**Figure 4. Power Spectrum Shows Cycles in the Data**

## How to Prioritize Oscillations

If 40% of measured process variables are cycling, this could be several hundred items to track down. This section provides some guidance on prioritizing your efforts to eliminate the most costly oscillations first.

### *Important Factors*

There are 3 main factors to determine which oscillations should be addressed first. These are:

- The process (financial) impact of the oscillation
- The Oscillation Period
- The Oscillation Strength

Using these 3 factors together, we can quickly address the most important oscillations. At the end of this section, we discuss an “Oscillation Significance”, which combines measures for a single, powerful way to rank oscillations in your plant.

### *Process Financial Impact*

Some process measurements are more important than others. For example, if key product quality attributes are cycling, this is a major problem for the process. When you start the analysis of oscillation, you should start with the “Money Loops”.

The “money loops” are those that will show the most immediate economic benefit from improvement. These are most typically:

- Key Quality Measurements



- Production Rates
- Energy Consumers (Fuel Flows, Steam Users, Temperature Loops)
- Waste or Recycle Flows

Start your analysis with these loops. Then you will use Oscillation strength and period to move closer to the root cause.



### ***Oscillation Period***

The oscillation period is a critically important measure. This is because oscillations tend to propagate throughout the plant. A simple level cycle in a feedwater tank can make its way through boilers, into the steam header pressure, and eventually every temperature loop in the plant is cycling together.

The oscillation period is like a “fingerprint”. You will find many loops in your plant are oscillating at similar frequencies. The root cause is among them. You will look upstream from your money loops, to find other loops cycling at similar frequencies.

Also, in the section below on Root Cause, you will see that some oscillation periods are like a “red flag” to certain process or equipment problems.

### ***Oscillation Strength***

The strength of the oscillation is also important. When oscillations pass through surge tanks, they usually lose some strength. In fact, this is one of the primary reasons that surge tanks exist: to prevent upstream disturbances from passing downstream.

You will want to focus your efforts on the oscillation periods that contribute to 10% or more of the power shown in the power spectrum.

### ***Oscillation Significance – A Composite Measure***

Still, with a few hundred loops identified, it could take some time to analyze all this data for Oscillation Period, Strength, and Relative Economic Importance. We can streamline the prioritization process by combining this information into a single, common measure.

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Let's call this "Oscillation Significance". Sorting by Oscillation Significance will give you an immediate focus for the entire plant. Figure 5 shows an example of a report, showing every oscillating control loop in the plant, sorted by Oscillation Significance.

Look at the primary oscillation period of the top loop in Figure 5. It is approximately 17 minutes. When we sort by the Oscillation period, as shown in Figure 6, we find that 7 loops are oscillating at approximately the same frequency. The next section of this white paper will explain how to use this information to find the root cause of the cycling.

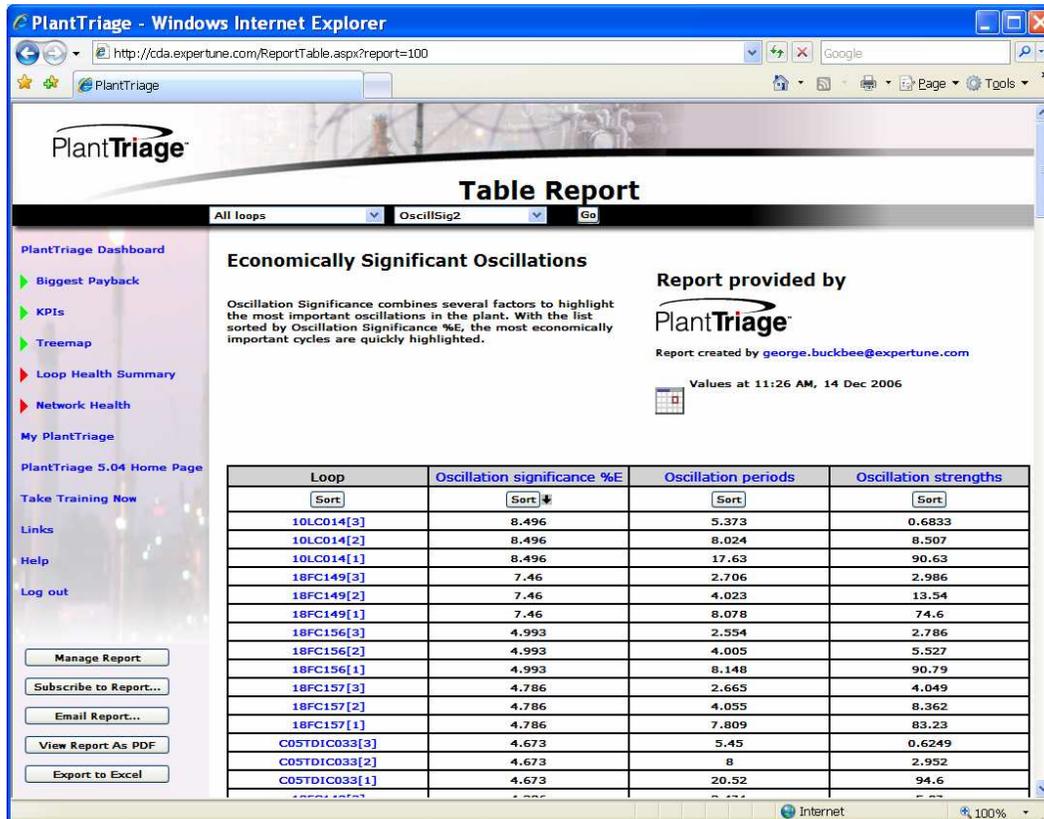


Figure 5. Report of All Control Loops, Sorted by Oscillation Significance

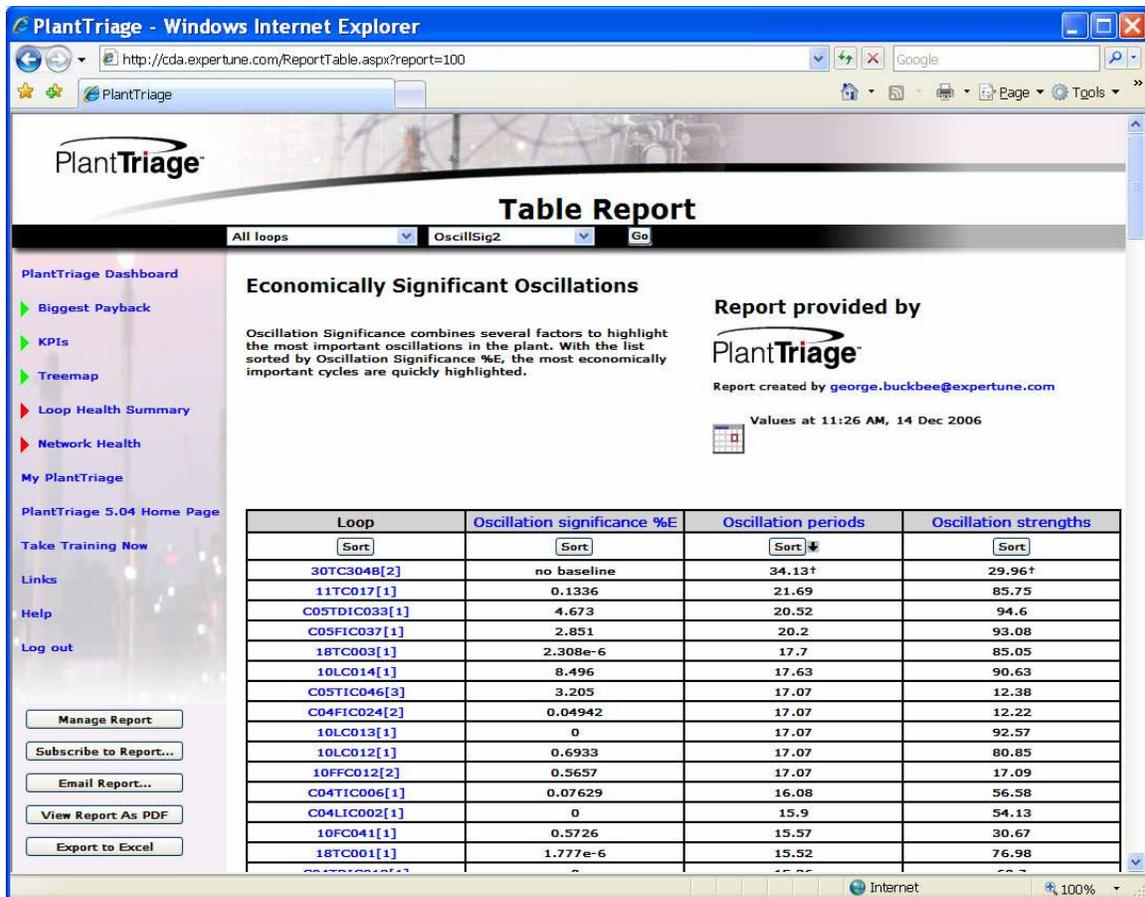


Figure 6. Same Report, Sorted by Oscillation Period, Reveals Common Oscillations

## How to Determine Root Cause

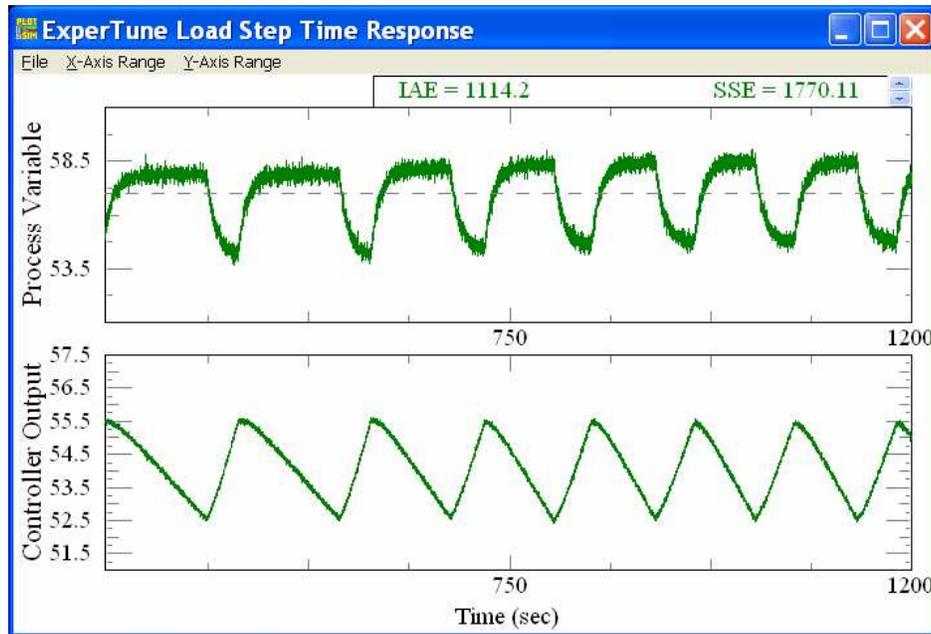
### Learn to Read “Sine Language”

There are 2 very important factors to determine the true root cause of a cycling problem. These are the shape of the wave, and the period. When you know how to recognize the most common wave shapes, and most important periods, you can quickly interpret the data to establish root cause.

### The Shape of the Wave

The shape of the wave can be a dead give-away as to the true cause of the problem. For example, valve stiction is characterized by a “stick-slip” cycle, as shown in Figure 7. Notice the square-wave pattern on the process measurement, and saw-tooth cycle on the controller output. This is usually a sure sign of either mechanical stick-slip. (However, you can duplicate this undesirable effect by adding a deadband to a controller output!!)

Valve stiction problems are caused by physical issues with the valve. Inspect and repair the valve, actuator, air supply, positioner, and feedback linkages to resolve stiction problems.



**Figure 7. A Classic Stiction Cycle.**

Tuning problems most often appear as regular, sinusoidal wave patterns. For example, poorly-tuned cascade control loops or ratio controls can induce a regular sinusoid. Use proper tuning techniques to eliminate these cycles.

### ***The Period***

The period of oscillation is often a valuable clue to the problem. This is particularly true when the oscillation period is a regular time period, such as 1 minute, 20 minutes, or 1 hour. Regular oscillations such as these are often created by some automated sequence, or large rotating equipment in the process.

In one example, a rotating kiln created cycles in temperature control. The root cause: the kiln had segmented “flights” inside, to break up the materials. One of the flights had broken off, and each revolution there was a “gap” in product flow running past the sensor. This caused oscillation in gas flow to the kiln, increasing energy costs. A simple fix – welding a new separator bar in place, saved \$200,000 per year.

### ***Automated Detection***

The process of detecting, prioritizing, and analyzing process cycles has been automated with performance supervision software. The reports presented above, in fact, were created by the PlantTriage Performance Supervision System, using actual process data.

Even the evaluation of curve shape, period, and other criteria can be automated. In this way, software can screen the data, and highlight specific likely causes, as shown in Figure 8.

Loop	Loop diagnosis simple	Loop health %E
Sort	Sort	Sort ↓
10LC014	Oscillating - valve	39.73
10LC027	Oscillating - load	28.58
C05TDIC033	Oscillating - valve	25.43
10LC012	Oscillating - valve	24.15
10FC008	Oscillating - load	23.14
C04PDIC013	Oscillating - valve	22.35
18FC147	Oscillating - valve	22.19
C05TIC046	Oscillating - valve	21.36
11FFC001	Oscillating - valve	20.95
18FC149	Oscillating - load	20.68
C05FIC041	Oscillating - valve	19.98
10FFC014	Oscillating - valve	19.49
10FFC013	Oscillating - load	18.08
10LC013	Failed sensor	17.16
10FFC012	Oscillating - load	17.13
18FC156	Oscillating - load	16.91
11TC017	Oscillating - load	16.88
10TC028	Oscillating - load	16.75

Figure 8 – Automated Diagnosis of Control Loop Issues

### Resolving the Root Cause Issue

One practical method to confirm that you have found source of the problem is to put the suspected control loop in manual. If the cycle goes away, then you have found the culprit.

Oscillation due to valve problems is usually resolved through repairs to the valve, actuator, positioner, or air supply. A close inspection of the valve will usually identify the problem. Another possibility is that over-tightened valve stem packing is creating excessive friction on the valve.

Resolve tuning issues with modern software tools like ExperTune’s PID Loop Optimizer. This software will help you to discover the best tuning for each loop. Using each loop’s Relative response Time, you can eliminate interactions between related loops.



For process batch and sequence-drive upsets, you have a few options. First, see if you can reduce the sudden upsets caused by these sequences. Adding a simple ramp up and down may allow downstream controls enough time to respond. Second, make sure that downstream controls are tuned

aggressively to reject these upsets as they come. Process changes, such as the addition of surge tanks, may be the only way to resolve larger process sequencing or batching issues.

## Conclusions

Process Plants can improve quality and reduce energy costs by eliminating process cycles. We have presented practical methods for detecting, prioritizing, and resolving oscillation problems, with Performance Supervision tools. With 40% of process industry control loops cycling, there is huge potential for financial gain.

## Recommendations

1. Measure oscillation in your plant, using tools such as Fourier Transforms.
2. Prioritize oscillations based on oscillation significance – a combination of the magnitude and economic importance of each oscillation.
3. Sort by oscillation period to find the source of the oscillation.
4. Compare the wave shape to common patterns to establish a specific root cause.
5. Take the appropriate corrective action to eliminate the cycle at its source.
6. Document the Savings. These improvements in efficiency are cumulative. The increased plant stability will often pay out in energy savings, quality, reliability, and sometimes even in production increases.

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### ***About ExperTune***

### ***About the Author***

George Buckbee is Director of Product Development at ExperTune. George has over 20 years of practical experience improving process performance in a wide array of process industries, George holds a B.S. in Chemical Engineering from Washington University, and an M.S. in Chemical Engineering from the University of California.

### ***About PlantTriage®***

PlantTriage is a Plant-Wide Performance Supervision System that optimizes your entire process control system, including instrumentation, controllers, and control valves. Using

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advanced techniques, such as Active Model Capture Technology, PlantTriage can identify, diagnose, and prioritize improvements to your process.

## Glossary

Term	Definition
GDP	Gross Domestic Product
DCS	Distributed Control System. A centralized process control system that typically provides data collection, operator interface, and control functions.
HMI	Human-Machine Interface. Typically, a PC-based interface that allows the operator to control the process.
OLE	Object Linking and Embedding. The Microsoft standard that is at the base of the OPC communications protocol.
OPC	OLE for Process Control. An industry standard communications protocol, allowing
OPCHDA	OPC Historical Data Access. An enhancement to the OPC protocol that allows data to be pulled directly from standard data historians.
PLC	Programmable Logic Controller. A simple controller that provides data collection and control. Often paired with an HMI or SCADA system.
SCADA	Supervisory Control And Data Acquisition.