Innovations In Plant-Wide Monitoring, Diagnostics & Optimization

Robert C. Rice, PhD
Control Station, Inc.
642 Hilliard Street
Manchester, CT 06042
bob.rice@controlstation.com

Abstract

Here's the problem: The typical paper mill operates 100s of PID control loops and maintains an even larger quantity of production assets. The typical plant historian stockpiles data, and extracting information that's actionable and relevant to performance can be a challenge. Meanwhile, pressure just increased on everyone to improve production efficiency.

Control loop performance monitoring (CLPM) solutions leverage the information stored in a production facility's data historian. They actively evaluate PID control loops on a plant-wide basis and identify issues that undermine production performance and that can eventually lead to shut-down. Some CLPM solutions also isolate root-causes and recommend situation-appropriate corrective actions.

From operations and engineering to maintenance and management, control loop analytics target the unique information needs of those groups that are tasked with maximizing up-time and achieving production goals. This paper covers recent innovations in CLPM technology specifically in the context of the pulp and paper industry to demonstrate the value of loop analytics. Further, it leverages insights gained from analysis of over 200 PID control loops using data from a paper mill.

Project Overview

PlantESP is a CLPM solution utilized in an initial regulatory control audit of a non-integrated paper mill located in central Wisconsin. The mill is considered among the largest and most modern in North America. The audit's primary objectives were: 1) identify opportunities to improve regulatory control performance, and 2) provide mill staff with confirmation of issues and the associated root-causes.

The audit was performed remotely with data supplied by the mill. Less than three (3) weeks of process data associated with 245 out of 635 PID control loops was supplied for analysis. Only PID loops considered "high" or "medium" priority were included in the audit. The PIDs were culled from a total of seven (7) different process units, including two paper machines, three stock preparation and one boiler areas. As a subset of the mill's regulatory control environment it was understood that various standard and advanced CLPM capabilities such as interaction analysis would be limited.

Figure 1 – The project was performed remotely and audited the performance of 245 PID control loops associated with seven (7) process units.

The extent and quality of process data supplied by the mill varied from loop to loop. The average sample rate was approximately ten (10) seconds. Additionally, the data was limited to a given loop's Tag Name, Set Point, Controller Output, Process Variable, and Time Stamp. Other relevant loop data was not included such as details associated with Controller Type, Controller Spans, Existing Tuning Parameters, etc. Prior to the start of the audit the mill's I&E staff acknowledged the potential impact that the omitted tags would have on fully characterizing mechanical issues such as Stiction and evaluating PID controller tunings.

The audit proved successful and met the mill's primary objectives. In particular the CLPM audit accurately identified numerous opportunities for PID controller optimization, effectively characterizing control loop behavior using the provided data. Those opportunities touched on key process areas and included loops designated as high priority. The CLPM audit also provided clear evidence of performance issues, confirming the assumptions of the mill's E&I staff and facilitating the isolation of the associated root-causes. The presence of Stiction was thoroughly documented by the CLPM technology, including detailed assessments of the probability and corresponding amount of Stiction within each loop. Collectively these insights confirmed the value of CLPM in terms of both managing the mill's day-to-day operations and meeting its stated performance goals.

Industry Trends

Process optimization has become an increasingly lofty goal for manufacturers in general and the pulp and paper industry in particular. While some manufacturing segments have seen demand slip the majority of market segments has experienced a major decrease in staffing levels. From the start of 2008 thru September of 2012 the US Bureau of Labor Statistics documented a loss of 1.77 million jobs from the United States' manufacturing sector. That number represents nearly 13% of the domestic manufacturing workforce. While the jobs have evaporated the work associated with production has remained.

Pulp and paper is a key sector of the broader manufacturing industry. With a 21% decline over the past decade in various coated paper products, the sector has suffered disproportionately (Belz, 2013). According to Georgia Tech's Center for Paper Business and Industry Studies nearly 120 mills located in the United States were shuttered between 2000 and 2012 in response to lower market demand. With those mill closures came the loss of approximately 223,000 jobs.

With fewer resources on hand manufacturers across the process industries have been forced to prioritize engineering and maintenance tasks. They have also looked to technology as a means of maintaining safe, efficient operations. More data and better analytics are empowering manufacturers to proactively identify and correct issues that would otherwise impede production. Among the technologies both gaining market acceptance and contributing to improved plant-wide operations are CLPM solutions.

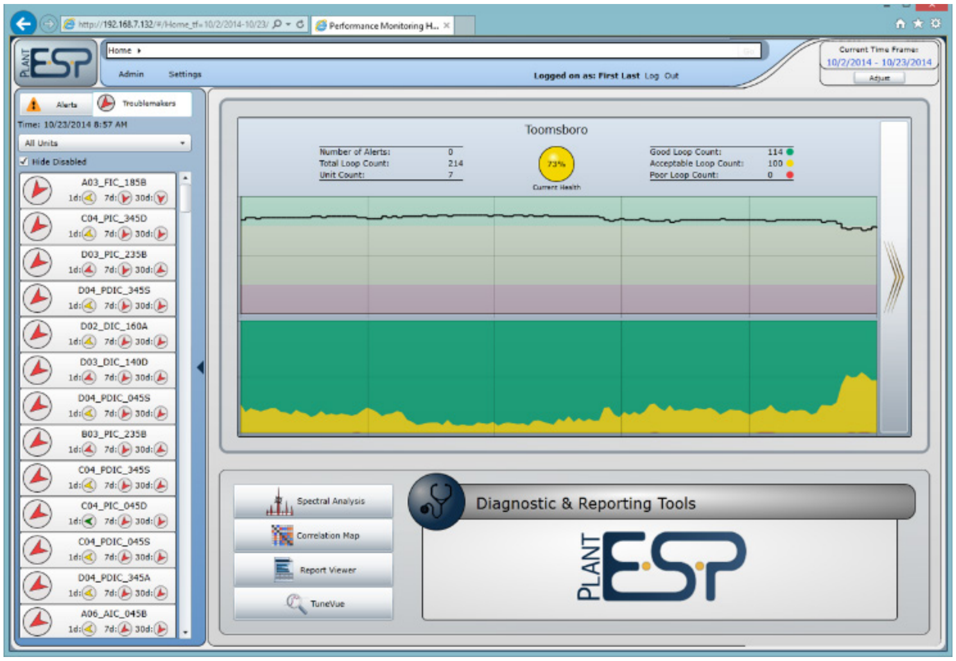

Figure 2 – The pulp and paper industry was an early adopter of technologies such as CLPM. These solutions provide monitor PID control loops on a plant-wide basis and provide mill staff with enhanced awareness of issues that negatively affect mill efficiency and throughput.

The pulp and paper industry has a long history of both advancing the state-of-the-art in manufacturing and enacting new best-practices. Mills in the US and abroad were among the earliest adopters of distributed control systems (DCSs), utilizing the supervisory technology both to stabilize control of complex processes and to achieve more consistent production output. So too the industry was an early adopter of CLPM solutions. Numerous mills implemented CLPM tools when they first entered the market at the start of the new Millennium. Even at the time basic CLPM capabilities provided valuable insight into regulatory-level controller performance and offered a more analytic approach to process optimization.

At their core CLPM solutions monitor performance on a plant-wide basis. They keep a constant watch on a mill's regulatory control layer – the extensive network of PID controllers that manage individual control loops. Since the digital PID controller's introduction in the late 1950s it has become the most common and widespread form of control applied at production facilities around the globe and across the process industries (VanDoren, 2003). PID controllers reliably respond in real-time to the ever changing dynamics of production processes. They adjust to fluctuations in flow, pressure, temperature, among other process types. By manipulating valves, dampers, etc. PIDs help to maintain safe, efficient, and profitable control of highly dynamic, interacting systems.

The pulp and paper industry continues to evolve largely in response to a dramatic decrease in demand and to an increase in global competition. According to the Pulp and Paper Products Council demand has slipped in each of the last three (3) years (Council, 2015). While the decrease doesn't impact all sub-segments or geographies uniformly, a total loss of more than 10% in demand for paper products is credited mostly to increased use of digital media. Even though demand has increased in select markets such as China so too has overseas competition. Transportation costs and other factors require other regional manufacturers to improve efficiency in order to compete for share. CLPM solutions are among the technologies that pulp and paper producers are employing to optimize production processes and to establish a sustainable competitive advantage.

Control Loop Performance Monitoring

In his study of control loop performance, David Ender of Techmation determined that most PID control loops within the average production facility operated inefficiently. His analysis revealed that nearly 85% of loops operated inefficiently while in closed-loop and 65% of them were designated as either poorly tuned or de-tuned so as to conceal other PID-related problems (Ender, 2001). While most other automation vendors advocate an agenda of advanced control solution to solve the performance needs of manufacturers, Enders' analysis underscored the need for more basic improvements to regulatory control.

Figure 3 – While process manufacturers have utilized technologies such as the Distributed Control System (DCS) to monitor and control production, control loop performance has been broadly overlooked. David Ender's study clarified the impact of poor regulatory control on production efficiency and throughput. The date of Ender's study generally coincides with the launch of the first CLPM solution.

CLPM solutions are a direct outgrowth of traditional process modeling and PID controller tuning technologies that remain a staple of regulatory control. Rather than examining control loops one at a time, CLPM solutions simultaneously evaluate each of the many loops located across one or more production facility. Using various key performance indices (KPIs) they work to identify a range of performance challenges associated with mechanical issues and architectural constraints as well as loops that require tuning. Core capabilities of CLPM solutions include the following:

Principal Analytics

The typical pulp and paper mill has a wealth of untapped information. Included in the process data is insight into the performance of business-critical production loops along with essential details concerning the health of costly mechanical assets. Core KPIs should include the following:

- General Loop/Unit/Plant Health
- Mechanical Health
- Mode Changes
- Noise and Oscillation
- Controller Tuning

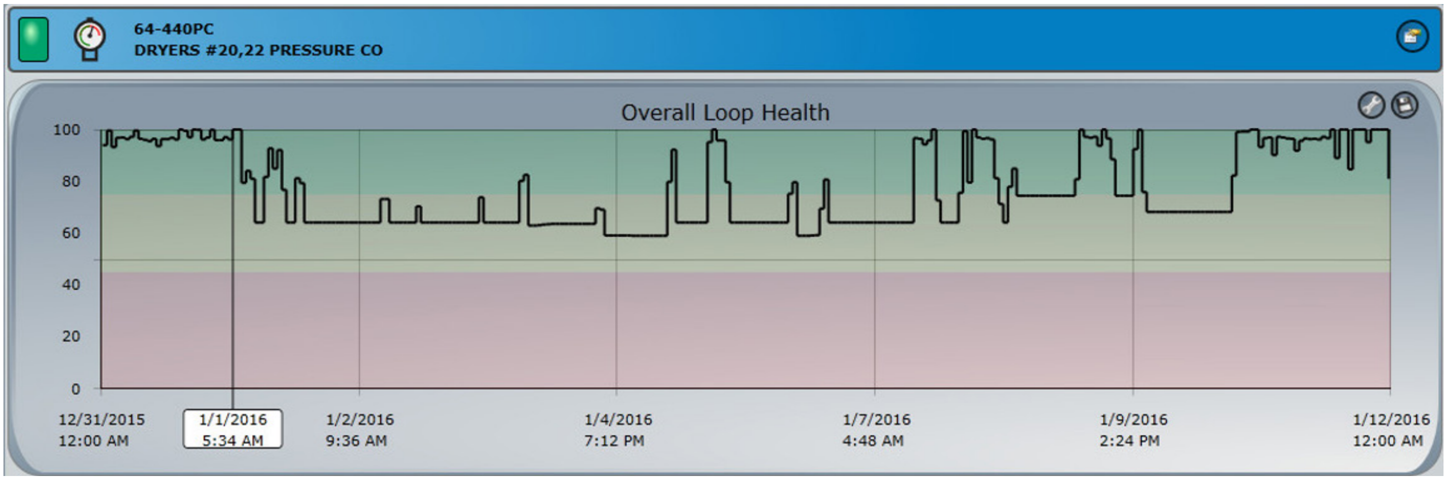

Figure 4 - CLPM solutions include an array of key performance indices (KPIs) that evaluate the health of PID control loops. Above is a trend of Overall Loop Health that showcases the type of performance changes that occur daily at a typical paper mill.

Advanced Forensics

With an abundance of PID control loops it can be difficult to distinguish symptoms from root-causes. Advanced forensic tools reveal the true source of performance-related issues. They facilitate the isolation of actual problem areas. The following are essential tools found within most CLPM solution:

- Correlation Analysis
- Power Spectrum Analysis
- Process Modeling Analysis
- Tuning Analysis

Alerts & Reports

Metric-driven alerts provide timely awareness of deviations that can potentially undermine performance. Similarly reports offer a range of perspectives, reflecting important plant-wide trends as well as more narrow and loop-specific insights. Most CLPM solutions offer alerting and reporting options take the following into consideration:

- Performance-Based
- Functional Groups & Shifts
- Area(s) of Responsibility
- Dynamic, Sortable Details

Recommendations

A fundamental purpose of technology is to transform large amounts of diverse data into succinct and actionable information. Basic capabilities related to Recommendations generally include the following:

- Mechanical, Tuning, Process
- Advanced Heuristics
- Step-by-Step Instructions

Prioritization

The typical mill has limited resources with which to maintain safe and efficient operations. To that end most CLPM solution include the following methods for weighting and prioritizing:

- Economic Importance
- Degree of Change
- Low Hanging Fruit

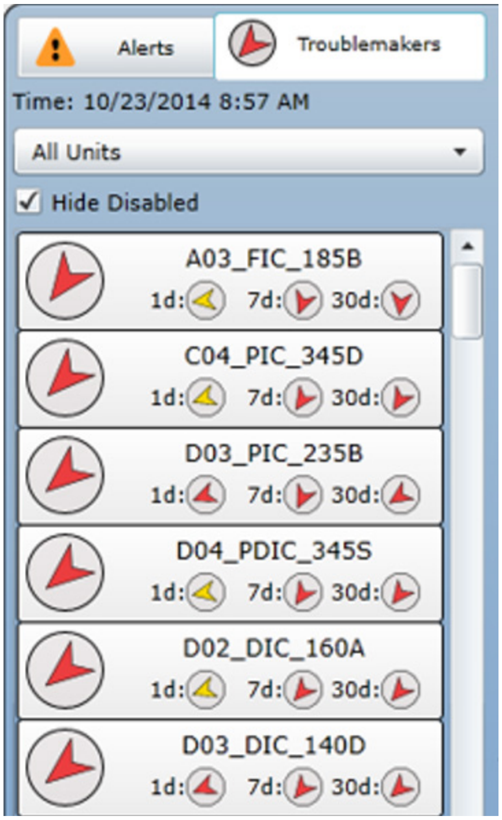

Figure 5 – Rather than focusing exclusively on Hi-Hi and Lo-Lo alert thresholds, some CLPM solutions detail the amount of change exhibited in common time periods (i.e. 1-, 7-, and 30-days). This provides a means of prioritizing performance improvement efforts.

Security & Administration

Digital security is a critical consideration and it both usually and rightfully takes precedence over administrative ease. Even so, a mill's infrastructure can be dynamic and, whether due to changes in loop architecture or staff responsibilities. Most CLPM solutions are designed to adapt to changing requirements and include the following common administrative attributes:

- User-Specific Credentials
- Local vs. Remote Access
- Ease of Administration
- Adjustable/Scalable
- Fully Documented

A subset of CLPM solutions go beyond basic KPIs and diagnostics, offering recommendations for corrective action specifically related to PID controller tuning. These solutions compare each newly generated process model relative to the corresponding loop's historical performance. The resulting analysis clarifies the effectiveness of existing controller tuning coefficients, offering graphical evidence that the controller is either performing satisfactorily or requires tuning. For manufacturers in general and pulp and paper producers in particular this capability facilitates plant-wide process optimization.

Until recently CLPM solutions were limited in their ability to model complex process dynamics and to recommend adjustments to PID controller tuning parameters. Like the majority of commercial tuning software, CLPM solutions failed to accurately model noisy, oscillatory process data. What's more, the data capture and modeling functions within CLPM solutions were typically incompatible with certain processes.

These constraints put the value of CLPM solutions in question. In 2013 select CLPM solutions gained important ground through the application of a proprietary non-steady state (NSS) modeling innovation (Nash, 2008). The innovation enabled accurate modeling of highly dynamic process data that is typical of industrial process manufacturing.

First introduced in 2008 the innovation was applied narrowly to traditional PID controller tuning software. The novel approach to modeling eliminated the need for a steady-state condition. Further, it supported both integrating and non-integrating processes. Noisy, transitional, and otherwise oscillatory data no longer prevented the accurate calculation of models needed for tuning and optimization.

More recently the innovation was adapted for use with select CLPM solutions. The enhanced capability accurately models the troublesome dynamics that are commonplace in industrial applications. Like their controller tuning predecessor, CLPM solutions equipped with the NSS modeling innovation are capable of automatically capturing and modeling data from integrating and non-integrating processes alike. In order to provide the necessary and comparative analysis the feature requires details associated with the PID controller's configuration, including Controller Type, Spans and Tuning Parameters.

Figure 6 - CLPM solutions are now equipped to automatically identify Set Point changes and to calculate process models. Select solutions can accurately model a process even under typical oscillatory conditions.

Economic Benefits

The economic benefits of improved regulatory control are widely published. Studies have quantified the impact on plant profitability in clear financial terms, ranging from increases to throughput and quality to decreases in energy consumption and the use of production inputs. There is also an increasingly clear connection between control loop performance and asset reliability. By using a control loop's process data to assess the performance of a facility's abundant mechanical devices such as valves and dampers, CLPM solutions offer valuable insight into their health that can be used to avoid costly unplanned downtime.

While specific benefits will vary from industry to industry and facility to facility, economic gains have been generalized in a way that translates easily for most process manufacturers. The following opportunities for gain were published in 2001 by the UK's Energy Efficiency Best Practices Programme:

- Reduce energy consumption 5% - 15%
- Increase production throughput 2% - 5%
- Reduce quality defects 25% - 50%
- Increase production yield 5% - 10%

Entitled "Invest in Control – Payback in Profits" the publication's findings were based on a variety of process diagnostic and optimization projects performed worldwide (Various, 2001). The report also cites related findings from studies performed by DuPont, University of NSW, and Orica (formerly ICI).

Figure 7 – Research performed by the United Kingdom's Energy Efficiency Best Practices Programme documented a wide array of economic gains associated with improved PID control loop performance.

Remote Audit Findings

Analysis performed by the CLPM solution met the objectives that were set for the audit. In particular, the CLPM solution identified numerous opportunities which could contribute to improving the mill's regulatory control loop performance once they were addressed. Similarly, the CLPM solution both verified assessments made by mill staff and provided a resource with which to isolate the associated root-causes. A select group of KPIs and advanced forensic tools proved particularly valuable, including Stiction, Oscillation, and Power Spectrum tools.

Stiction Metric

The Stiction metric identifies a form of nonlinear behavior that commonly affects valves and other final control elements (FCEs). A combination of the words 'sticky' and 'friction', Stiction prevents a FCE from responding on a direct and apportioned basis to changes in Controller Output (CO). Rather, the FCE requires the application of excess force by the associated actuator in order to enact the desired change, resulting in persistent overshooting of Set Point and oscillation within the process. Failure is precipitated by the constant back and forth of the FCE – a behavior which is revealed in either saw-toothed or square-wave data trends.

Stiction Report

Current Report Range:	11-Jan-2016	to	18-Jan-2016
Previous Report Range:	04-Jan-2016	to	11-Jan-2016

Valve Stiction Likelihood

Loop Name	Units	Previous Stiction Likelihood	Current Stiction Likelihood	Percent Change	Previous Average Stiction Amount	Current Average Stiction Amount
65-436PIC	PM35, All Loops	55.99 %	60.39 %	7.28 %	2.07 %	1.86 %
65-422PIC	PM35, All Loops	58.37 %	55.97 %	-4.30 %	0.78 %	0.79 %
05-005PC	Boiler, All Loops	45.08 %	47.76 %	5.63 %	0.74 %	0.82 %

Figure 8 - Reporting capabilities within most CLPM solutions enhance awareness of a range of issues associated with PID control loop performance, including Stiction – a leading mechanical issue. The report shown above provides insight into both the probability and the amount of Stiction associated with a given PID control loop.

Many CLPM solutions assess Stiction and other conditions that affect mechanical performance. The CLPM solution used in the regulatory audit employs a proprietary technique that analyzes oscillatory behavior in both the Process Variable and Controller Output. The technique quantifies the probability and amount of Stiction associated with a given loop's FCE. During the audit numerous loops were identified as having a level of Stiction that was potentially detrimental to the production. The following loops were highlighted:

- Tag: 65-436PIC

CLPM calculated a 68% probability of 2.0% Stiction.

- Tag: 65-422PIC

CLPM calculated a 87% probability of 1.0% Stiction.

- Tag: 05-005PC

CLPM calculated a 51% probability of 2.0% Stiction.

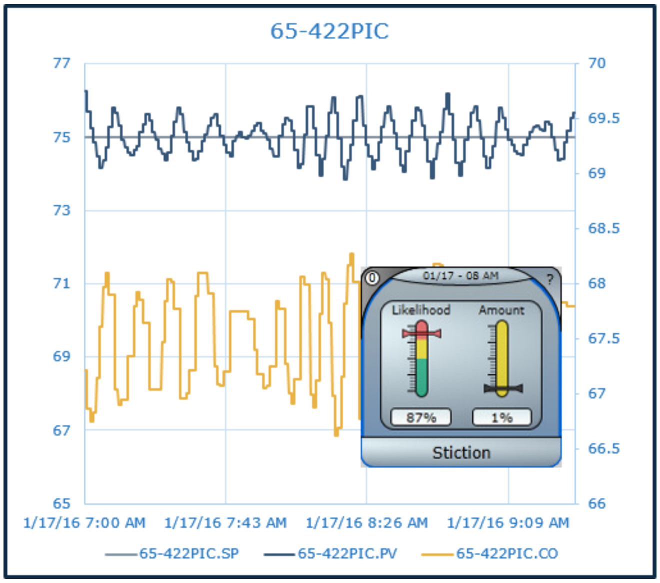

Figure 9 - Stiction is a common mechanical issue that is characterized by either square-toothed or saw-toothed behavior similar to that shown in the above trend. CLPM solutions can be used to identify the existence of Stiction and to quantify the amount present in the Final Control Element.

Oscillation Metric

Variability in a process hampers control and unnecessarily accelerates the mean time to failure (MTTF) of the associated process instrumentation. Loops that oscillate force the FCE in particular to exert greater effort than necessary – a behavior that can often be attributable to an oversized FCE, poor controller tuning, or process interactions. As a metric, Oscillation identifies loops with significant oscillations as well as loops that exhibit other issues resulting from variable behavior upstream in the process. Increased Oscillation points to these changing dynamics and provides advance warning of potential negative consequences.

The Oscillation metric within this particular CLPM solution is based on spectral data analysis. Variation within each loop's Process Variable is evaluated to identify a single, dominant frequency. Although the behavior is often difficult to identify, the variability can usually be confirmed through visual inspection after the fact. The following loops were identified as demonstrating a significant change in oscillatory behavior:

- Tag: 65-516PIC
- Tag: 64-417PC
- Tag: 64-432PC

Power Spectrum

Power Spectrum is a method of evaluating interactions among and between PID control loops. It is calculated by applying a discrete Fourier transform to a production facility's process data. As a mathematical expression, a discrete Fourier transform presents the data in the form of two-dimensional sign waves where the x-axis represents time. The y-axis shows both the frequencies at which changes in process performance occur and the magnitude of those same changes.

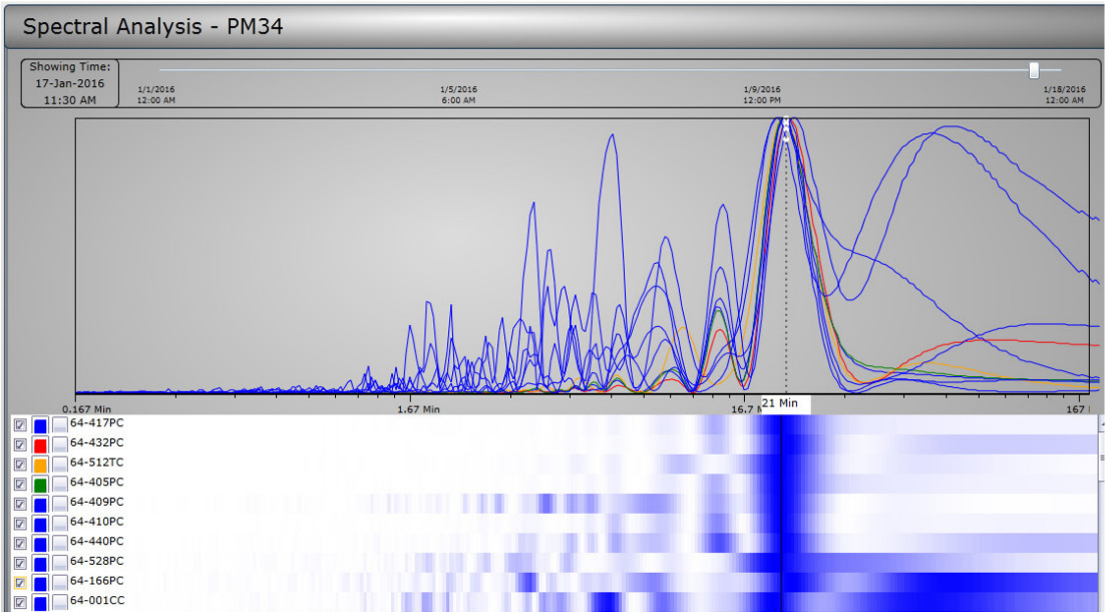

Figure 10 – CLPM solutions are commonly equipped with advanced forensic tools such as Power Spectrum. Power Spectrum calculates the frequency peaks associated with each PID control loop and allows users to identify loops that share the same peak. Shown above are several color-coded loops that share a peak at 21 minutes.

A Power Spectrum plot graphically reveals loop interaction by showcasing common or shared frequency peaks. Each peak is attributed to deviations from the control loop's historical mean (e.g. Set Point). Although the interrelationship may be unobvious, loops that share a peak at a common frequency – or time – are understood to possess a degree of interactivity. Additionally, the curve of the spectrum itself offers clues related to a given process upset by showcasing a unique shape associated with the disturbance's duration and intensity. Whereas the Oscillation metric facilitates the identification of loop variability, Power Spectrum enables practitioners to isolate the root-cause.

Starting with the CLPM solution's Oscillation findings it was then possible to identify other loops that shared the same frequency peaks. The dominant Process Variable oscillation associated with both 64-417PC and 64-432PC had been found to have a frequency of 21 minutes. That frequency was shared by multiple control loops within the PM43 unit.

Cross Correlation

Cross Correlation is another method of establishing the relationship between and among control loops. With accurate measurement of process signals, loops can be compared against each other using a time-shift to identify those loops that are correlated. The resulting detail indicates whether one loop leads or lags another, and it enables production staff to quickly zoom in on the source of control loop performance issues.

More specifically Cross Correlation analyzes the relationship between two data series, calculating a value ranging between one (1.0) and negative one (-1.0). When applied to PID control loops a value of one (1) indicates that two loops share identical dynamics and move in a mirror-like fashion whereas a value of negative one (-1) indicates that the dynamics are shared but the loops move in opposite directions.

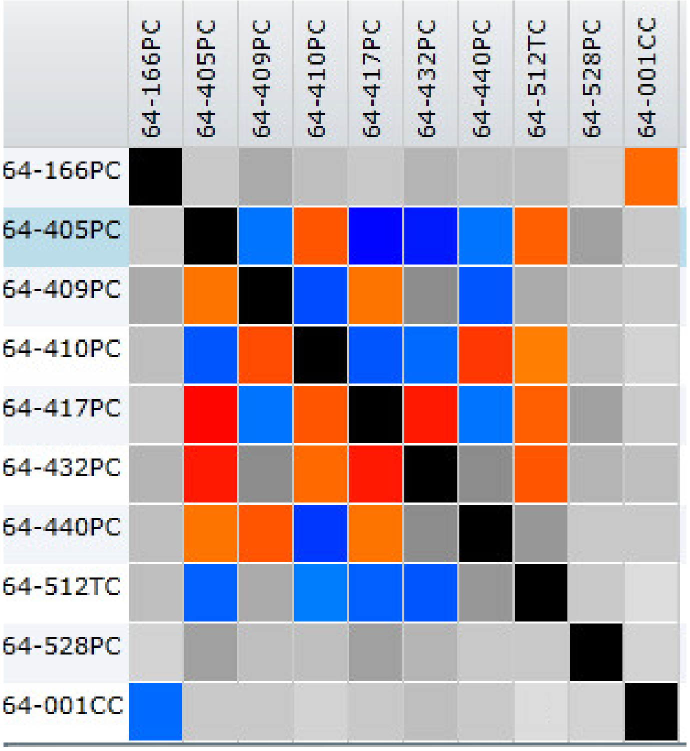

Figure 11 – Cross Correlation is a common tool used in determining the lead-lag relationship between and among control loops. The matrix above applies color-coding to indicate how each of the ten (10) loops within the PM 43 unit either leads (blue) or lags (red) the others. With knowledge of the process it is possible to determine the root-cause of performance issues.

Most loop pairings fall somewhere between these extremes with many equaling zero (0) and signaling no relationship between the two loops.

As noted above Power Spectrum was used to identify numerous control loops within the PM 43 unit that shared a common frequency peak at 21 minutes, Cross Correlation was used to determine the actual root-cause. Knowledge of the mill's process architecture led staff to conclude that 64-512TC was the root-cause of the oscillations. The 64-512TC loop was the farthest upstream in the process.

While these and other of the audit's findings have been documented all details of the associated financial impact are currently not available for disclosure. The findings remain under review by the mill's management.

Conclusion

CLPM solutions equip manufacturers in general and pulp and paper mills in particular with value-added capabilities for both achieving and maintaining optimal performance. As demonstrated through a remote audit CLPM solutions such as the one available from Control Station accurately identify underperforming PID control loops and help to characterize a given PID loop's behavior. CLPM solutions also add value by confirming assumptions of E&I staff while facilitating the isolation and remediation of bad actors.

Technologies such as CLPM empower production staff to simultaneously assess both all loops and individual loops. A growing concern in the pulp and paper industry that is shared by all manufacturers is the steady decline in staffing levels. That concern has been compounded with the consistent rise in production expectations. With fewer staff to maintain complex production processes and higher expectations for output, process manufacturers are increasingly looking to technology. By monitoring regulatory control on a plant-wide basis and facilitating the correction of performance issues, solutions such as CLPM are enabling manufacturers to meet those challenges.

Data supplied for the audit proved useful in identifying a range of performance issues. As the leading concern shared by production staff, Stiction was identified in a number of PID loops and its magnitude was accurately quantified. The data was suitable for identifying other behavior that is routinely associated with mechanical problems and that eventually leads to equipment failure. Additional tags and faster data was not available during the audit with which to capitalize on the mill's everyday Set Point changes.

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For more information, please contact us at:

Control Station, Inc.

642 Hilliard Street, Suite 2301,
Manchester, CT 06042
+1 (860) 872-2920

