ELIMINATING CYCLING:
A TUTORIAL ON VARIABILITY REDUCTION

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ABSTRACT

Cycling remains one of the key sources of variability in the papermaking process, from pulping and stock preparation through to the dry end. Reducing or eliminating this cyclical behavior can result in rather dramatic reductions of variability. Typically, as much as 50% of machine-direction variability comes from cycling of one kind or another.

Cyclical behavior comes from a wide variety of sources: mechanicals, processes, and controls. In this paper, we will review the sources of variability, discuss methods for identification of the root cause and discuss methods to fix the problem at its root. Modern tools and techniques for the evaluation of loop variation will also be demonstrated.

INTRODUCTION

In most cases, the techniques to evaluate loop performance can be applied while the process is in normal operation. Practical tips for performing tests while minimizing process upsets are discussed. These techniques allow the engineer or technician to pinpoint the root cause in a matter of hours. Half of these problems can be fixed within a few days. A complete paper machine can be analyzed in just 2 weeks. In the end, the student will have an understanding of the tools and techniques required to reduce paper machine variation.

PROCESS OPTIMIZATION

DEFINITION

Process optimization consists of:

Defining performance objectives: this has to be done with the participation of all the departments concerned:

- operation
- management
- maintenance
- engineering
- eventually marketing

Analyzing process, control strategies, equipment, operation procedures and maintenance procedures, determining the performance, etc.

Fixing the problems encountered, such as transmitter location, valve installation, process gain (linearity) and equipment failure

Defining a tuning strategy

Tuning loops and advanced control strategies

Measuring performance

Producing a report

Planning the follow-up

PROCESS OPTIMIZATION BENEFITS

Fewer process upsets.

With controls properly tuned, there are fewer process upsets. The control loops can do what they were designed to do - maintain consistent process results.

Smoother process start-ups.

Process start-ups will be smoother and more consistent. Operations can quickly move into full production. With the process under control, there are fewer alarms.

Faster grade changes.

Product or grade changes can be accomplished smoothly and quickly, with a minimum of scrap.

Better operation.

Each of the benefits reduces the amount of required operator attention for routine operation. This frees the operator to work on other tasks.

With controls properly tuned, there are fewer process upsets. Control loops can do what they were designed to do: maintain consistent process results. Process start-ups will be smoother and more consistent and operations can quickly move into full production. With the process under control, there are fewer alarms. Product or grade changes can be accomplished smoothly and quickly with a minimum of scrap. Finally, operation will be better. Each of the benefits reduces the amount of required operator attention for routine operation. This frees the operator to work on other tasks.

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PROCESS OPTIMIZATION METHODS

LOOP TUNING

Loop tuning is different from process optimization. To optimize a process, it is essential to work on the global picture. To do so, one must organize its work and tune each loop according to interacting loops.

AUDIT

Process and control system audits assess the performance capabilities of operating units to determine where improvements can be made and compare this performance against industry standards.

An audit is done by observing many variables at the same time to determine if the performance criterion for each loop is reached. From an audit, it is possible to observe cycling problems, instability problems and operation problems.

LOOP PERFORMANCE MONITORING

A software package looks at the data from the process and computes performance indices at regular intervals. If a threshold is reached, an alarm is triggered. Usually, the process is first optimized then the performance monitor watches the performance over time. The program identifies the areas of the plant where the greatest economic gains are possible. It is designed to help you make the most impact in your plant and it pinpoints areas that will yield the greatest economic return.

OPTIMIZATION PLAN

A good optimization plan should include and define:

- Budget
- Plan
- Training
- Software, tools
- Data acquisition strategy
- Schedule
- Work plan (auditing, tuning, fixing problems, etc.)
- Reporting
- Follow-up (after)
- Justifications
- Return on investment

Process optimization concerns:

- Quality improvement
- Security
- Cost of material
- Grades change
- Reduction in maintenance costs

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PROCESS OPTIMIZATION, MORE THAN LOOP TUNING

PROCESS OPTIMIZATION

Process optimization corresponds to adjust each loop and each system corresponding to its control objective and at the same time as the main goal for this unit be reached.

PERFORMANCE INDICES

Many performance indices can be used to determine if the goal has been reached:

- Variability (the relative value of twice the standard deviation expressed as a percentage of the mean)
- Response time, settling time
- Overshoot
- Phase and gain margins
- Integral of Absolute Error (IAE)
- Valve travel and valve reversal, variance of controller output
- Others : Integral of squared error (ISE), Integral of time x absolute error (ITAE), Harris Index, comparison to minimum variance control, % of time not in normal mode, % of time at saturation, area in autocorrelation, flat power spectral density, numbers of alarms per day, % of power at a specific frequency (or a cluster of frequencies) on a power spectral density graphic, etc.

EQUIPMENT PERFORMANCE, GOOD DESIGN

TABLE 1 – EQUIPMENT PERFORMANCE ACCEPTED

Process gain	> 0.5 and < 2
Hysteresis	< 2%
Stiction	< 0.5%
Noise	< 2%
Positionner overshoot	< 20%
Linearity (G max/G min)	< 2

NUMBERS, REALITY

Different studies, as well as our observations, confirm that typical performance distribution of North American control loops is divided as below (it remained the same in the last 10 years):

TABLE 2 – NORTH AMERICA REALITY

Typical control loop problems and performances	**% of loops**
Control valves in poor quality or in poor condition	30%
Poor controller tuning (unacceptable values)	30%
Poor controller tuning (not selected according to the performance goal)	85%
Poor loop design	15%
Controller in manual mode	30%
Control loop not performing according to control objectives	85%
Loops that perform better in automatic than manual	25%

Even if 25% of loops perform better in automatic mode than in manual mode, they do not necessarily perform to their maximum capacity. In three out of four cases, not only the controller does not improve the performance of the finished product; it worsens it.

WHAT SHOULD BE EXPECTED

Below is the order of magnitude for common performance indices; the average for a unit or individual for a loop:

TABLE 3 – EXPECTED VALUES FOR PERFORMANCE INDICES

Performance measurement	units	usual	ideal	Realistic target
Variability	%	2-3	0	<1
IAE	%•d	4000	0	<1000
Settling time	s	$20\bullet t_d$	<<	$<10\bullet t_d$
Valve travel	%/d	5000	<<	<1000
Valve reversal	N/d	7500	<<	<2000
Robustness	Absolute	2	>	>2
% of time in normal mode	%	85	~100	99

ANALYZING

To analyze the process and the control systems, various techniques can be used:

Simple observations

Control parameter values: for example, by knowing the type of process, the actual values can be compared to usual values; for example, filter time constant, integral time and derivative time should make sense.

TABLE 4 – USUAL TUNING PARAMETER VALUES FOR COMMON LOOPS

	P	I	D	F	settling time
	K_p	T_i	T_d	T_F	
Flow, Pressure (liquid)	<1	seconds	0	seconds	seconds
Level	>1	minutes	0	seconds	minutes
Temperature		minutes	seconds	seconds	minutes
Analysis		minutes	seconds	seconds	minutes

Finding the most common problems

Tuning too aggressive:

PV and CO trends have a sinusoidal waveform in the time domain and we observe a single peak in power spectral density.

Stiction problem:

CO trend has a saw tooth waveform in the time domain and we observe peaks in multiple cycling period (fundamental + harmonics) in power spectral density; moreover, the data is not distributed normally (bell curve) on a distribution graphic.

Backlash or hysteresis problem:

PV and CO trends have an oscillation but the period increases as the PV reaches SP.

Loops interacting:

Cycling at the same period in many trends and we observe similar power spectral density on many signals; cross correlation analysis will be strong.

TOOLS USED FOR PROCESS OPTIMIZATION:

Power spectral density: should be flat

Cumulative power spectral density: should be continuous

Statistical analysis: data distribution should be a bell curve, variability should be small, valve movements should be minimized

Process modeling: to validate the process and to find tuning parameters

Robustness analysis: to validate tuning parameters

Process analysis: hysteresis and backlash, stiction, noise, process model, hidden cycling, etc.

Autocorrelation: emphases the oscillation; the area under the curve is a good indicator of good control;
Cross correlation and multivariate techniques: to measure interaction between signals and loops; also to determine how helpful multivariable control could be
Performance index monitoring: variability, IAE, Harris Index, etc.

The following figures represent a flow loop in a paper mill before (left) and after (right) optimization. The valve was repaired, since stiction was detected; then the loop was retuned.

Before After

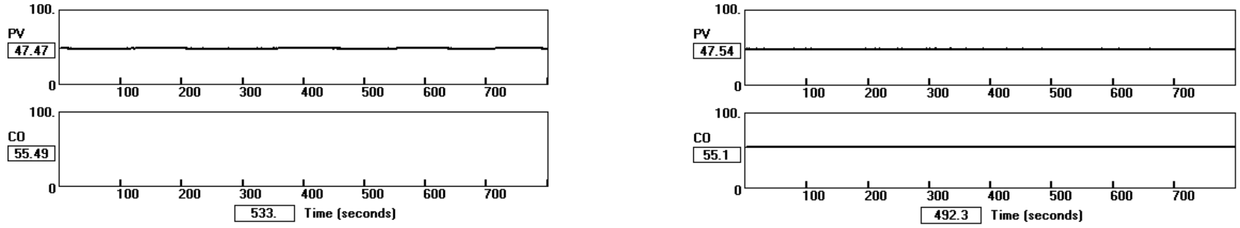
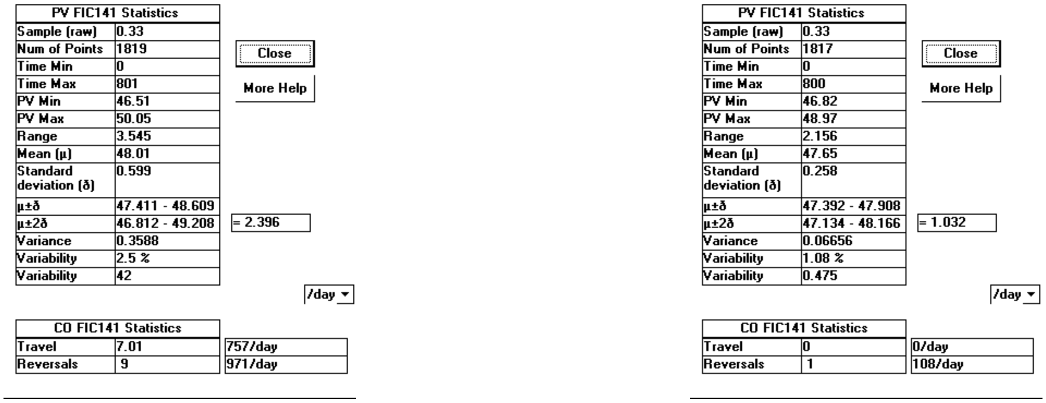


FIG.1 – PV AND CO TRENDS AS OBSERVED ON THE CONTROL SYSTEM SCREEN

Before After



Before

PV FIC141 Statistics	
Sample (raw)	0.33
Num of Points	1819
Time Min	0
Time Max	801
PV Min	46.51
PV Max	50.05
Range	3.545
Mean (µ)	48.01
Standard deviation (ð)	0.599
µ±ð	47.411 - 48.609
µ±2ð	46.812 - 49.208
Variance	0.3588
Variability	2.5 %
Variability	42

= 2.396

CO FIC141 Statistics		
Travel	7.01	757/day
Reversals	9	971/day

After

PV FIC141 Statistics	
Sample (raw)	0.33
Num of Points	1817
Time Min	0
Time Max	800
PV Min	46.82
PV Max	48.97
Range	2.156
Mean (µ)	47.65
Standard deviation (ð)	0.258
µ±ð	47.392 - 47.908
µ±2ð	47.134 - 48.166
Variance	0.06656
Variability	1.08 %
Variability	0.475

= 1.032

CO FIC141 Statistics		
Travel	0	0/day
Reversals	1	108/day

FIG.2 – STATISTICAL ANALYSIS FOR THE FLOW LOOP

Before After

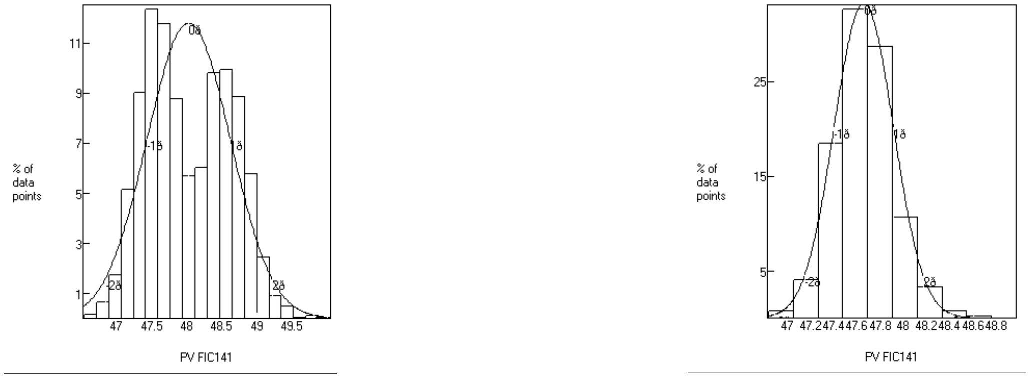


FIG.3 – DATA DISTRIBUTION FOR THE FLOW LOOP

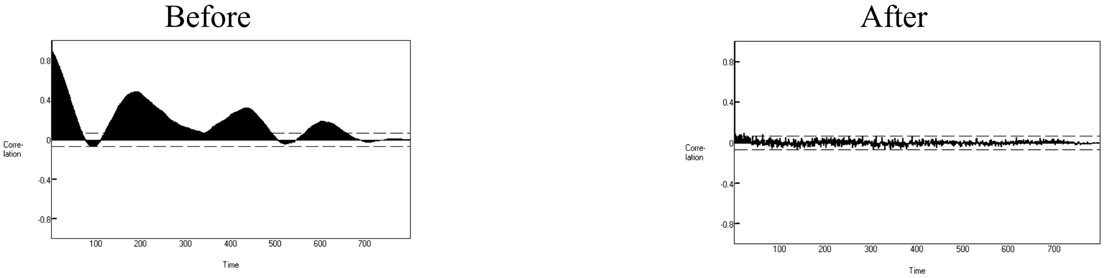


FIG.4 – AUTOCORRELATION FOR THE FLOW LOOP

FIG.5 – ZOOMED DATA FOR THE FLOW LOOP

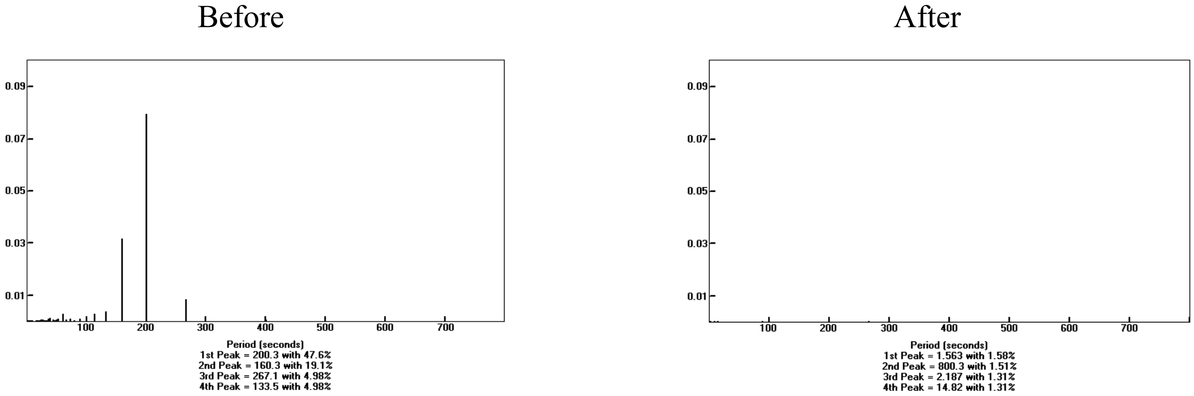


FIG.6 – POWER SPECTRAL DENSITY FOR THE FLOW LOOP

FIXING PROBLEMS

When problems have been identified, they should be fixed:

- Process: mechanical, electrical, process, operation
- Non linear and varying process: a more elaborate control strategy
- Interacting loops: a good tuning strategy is generally enough; if not, multivariable control could help

ELIMINATING CYCLING:
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MAIN GOAL IN A CONTROL LOOP

Remove disturbances
or
Follow set point
or
Reduce variability

The goal of a control system is to maintain the process variable equal to the set point in the presence of load changes, disturbances or set point changes. Tuning a controller means adjusting the parameters (P, I, D) to achieve "Good Control". “Good Control” is a performance criterion that depends on the application.

Tuning objectives will normally vary from loop to loop. Very fast control with slight continuous oscillation may be fine for one loop but dangerous for another loop.

For example, the controller of a robot arm moving a bottle filled with nitroglycerin will be tuned without overshoot and without oscillation. The response will be slow and sluggish.

On the other hand, a flow controller in a loop filling milk bottles will be tuned tightly and aggressively to ensure the maximum speed of the production line with minimum error. In such a system, the process tolerates oscillations but must minimize the error.

Tuning a controller not only makes the process operational, it also makes it meet the performance criterion.

TUNING: A COMPROMISE

Tuning a controller consists of making compromises between speed and stability. The more the loop is stable, the more it reacts slowly and the larger are the errors after a disturbance.

In the industry, control loops are non-linear (the process model is not constant) and it is essential to tune them for the worst case. If possible, if the process model varies too much, the control algorithm should also vary.

The more the loop is tightly and aggressively tuned, the more it will react quickly but the price to pay is instability, cycling and overshooting.

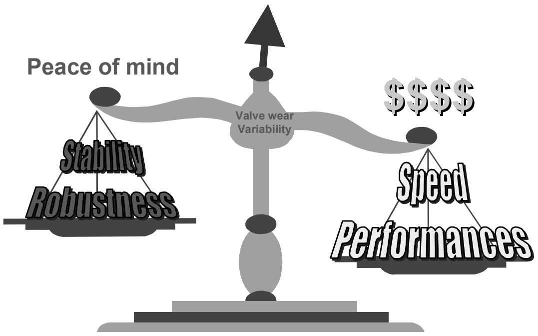

FIG.7 – TUNING, A COMPROMISE BETWEEN STABILITY AND SPEED

BEFORE TUNING A LOOP, YOU MUST ASK:

Is the process slow or fast?
Is the process self-regulating?
Is the process symmetrical?
Is the process linear, is the right valve characteristic used?
Is the process gain near one, is the valve properly sized?
Is the transmitter properly installed and is the transmitter working well?
Does the valve have hysteresis?
Does the valve have stiction?
Is dead time dominant?
Is noise excessive?
Will the tests represent the worst cases?

After tuning, the tuning parameters will be valid until a change is made to the process or to a component in the control loop. Also, if the equipment wears out, the process dynamics could be modified and the loop will have to be retuned.

The role of a control loop is most of the time to maintain the process variable at set point. To achieve this, the controller output modulates a final control element to reject disturbances. For some loops, it is also essential to obtain a good set point response; for example the inner loop of a cascade control system. Finally, in a batch control system, the process variable must follow the profile set point, generally without overshoot.

Hence, when optimizing a process control system, the process control engineer must consider the process control objective for the loop, the unit and the entire plant.

How well each controller accomplishes its task depends on the selection of the controller parameters, according to the process and the control objectives; this is loop tuning.

DATA FOR TUNING AND ANALYSIS

When analyzing data, the first question to ask is: how good is it? To answer to this question, the following should be considered:

Sampling rate, fast enough?
Between points, snap shot or averaging?
Report by exception (report change only if the change is above the threshold)?
Data compression?
Filtering?
Quantization?
Integer or real (floating) number?
Other functions inserted

- Scaling, Filtering, Averaging, Characterizer, Limiters (amplitude, rate), Interlocks

How good are the configuration and the programming?

ELIMINATING CYCLING:
A TUTORIAL ON VARIABILITY REDUCTION

RETURN ON INVESTMENT: BENEFITS VS COSTS

WHAT TO EXPECT

After optimizing all the loops and fixing problems, the average for all loops should be the following:

(Improvement 100•|(After-Before)|/Before

TABLE 5 – EXPECTED RESULTS FROM PROCESS OPTIMIZATION

Performance	Impact from optimization	Improvement
Variability	Reduced by a factor of 2	50%
IAE	Reduced by a factor of 2	50%
Settling time	Reduced by a factor of 2	50%
Valve travel	Reduced by a factor of 5	80%
Valve reversal	Reduced by a factor of 5	80%
% of time not in normal mode	Reduced by a factor of 2	50%
Cycling, oscillations	Removed	-
Robustness	Increased by a factor of 2	100%

The return on investment is generally less than 2 months.

CONCLUSIONS

Process optimization is one of the biggest returns on investment plants can do today, since the objective is to make sure the actual equipment you already own works at its best.

In process optimization, you plan to use the equipment at its best; you do not need new installations with all their procurement costs, engineering, installation and future maintenance cost. In fact, the goal is to achieve the maximum performance possible with the actual equipment.

CREDITS

All the graphics in this paper were obtained using OPC Tuner from ExperTune Software, Hubertus, WI.

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