Control Over Kaos

- Process Control & Optimisation Methodologies

NORM LASSLETT
Consultant
Procex Pty Ltd & Covey Consulting

Abstract

You don't need to be Maxwell Smart to control chaos in your process. But, we do need good process design and good process control to ensure that the quality of our product is acceptable to our customers. Process disturbances caused by variability of raw materials, equipment malfunctions and paper breaks must be minimised to keep quality on target. To ensure that we make money when producing our products, we must optimise our process targets.

This paper presents the case for a greater emphasis on improving our process controls to minimise process variability and to maximise our returns. In most mills the tools exist, but the means to implement the improvements are lacking. The costs are low and the gains are significant, so why aren't we doing it?

Outline

Topics covered in this paper are:

- The causes of process disturbances and variability.
- The Opportunities
    - The opportunity to minimise process disturbances and variability.
    - The economic case for improved process control.
    - The economic case for process optimisation.
- Process Control & Optimisation Methodologies
    - Process system design
    - Control system design
    - Process characterisation
    - Control system tuning
    - Performance monitoring
    - Process troubleshooting

Process control engineering is not an art - it is a science. As in every other field of engineering, design must be methodical and not considered in isolation. Good process design and good control system design go hand in hand. Each control loop must be considered as part of the total process system. Effort is required to achieve good design, appropriate tuning, and ongoing monitoring and maintenance over the life of the asset.

INTRODUCTION

High process variability compromises the economic performance of pulp and paper processes through reduced production, increased operating costs and off-quality product. A control loop that is well designed, maintained and tuned can play a key role in minimising process variability.

THE CAUSES OF PROCESS DISTURBANCES AND VARIABILITY.

Variability can originate from the raw materials and services:

- Wood is a variable raw material
- Waste paper is a variable raw material
- White liquor concentration
- Steam pressure and temperature
- Characteristics of drainage aids, retention aids, OBA, starch and other chemicals

Other disturbances can be introduced by equipment malfunctions, paper breaks, etc.

Unfortunately, the control loop often acts to increase process variability due to poor valve dynamics, oscillatory controller tuning, and/or sensor problems.

The instrumentation technician who is given the responsibility of maintaining control loop health and optimising controller tuning sometimes has little or no formal training in these activities. Tuning the controller by 'guesswork' is a frustrating experience, often resulting in little or no improvement in control loop performance.

Appropriate training can provide the 'tools' to identify and correct process control problems using sound engineering principles.

THE OPPORTUNITIES

The opportunity to minimise process disturbances and variability.

This is often a missed opportunity because of a lack of the skills necessary to identify the source of the variability and apply a permanent solution.

The source of the variability must be determined. It may be any one of, or a combination of:

- Raw material or energy variability
- Poor process design
- Poor control system design
- Poor control tuning

Whatever the cause, many of these can be remedied with relatively low expenditure.

The economic case for improved process control.

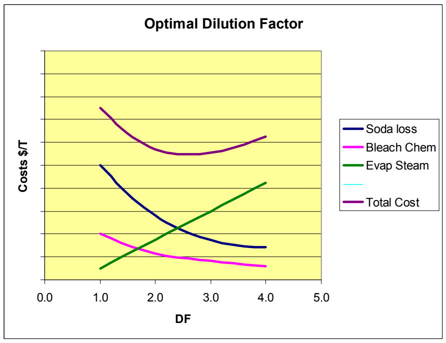
Good process control delivers more robust operation of the process, i.e. fast and stable reaction to changes in the incoming process variable, process load (eg. production rate), and process target. If the control systems can maintain the desired operating point and minimise variability, this will generally pay dividends in:

- Production increases (faster, less breaks and less rejects)
- Lower operating costs (furnish, energy and chemicals)
- Better quality

The economic case for process optimisation.

Once improved process control is achieved, optimization of the process can be considered. Optimization may be as simple as moving targets closer to quality limits. Or it may need the sophistication of neural networks, PCA/PLS (Principal Component Analysis/Partial Least Squares), multiple regression and other statistical techniques, where cost functions can be introduced to determine the most economic operating point.

An example of this is the determination of optimal Washer Dilution Factor, where the costs of soda loss, bleach chemical and evaporator steam are used to find the lowest cost operating point.



PROCESS CONTROL & OPTIMISATION METHODOLOGIES

Process control engineering is not an art - it is a science. As in every other field of engineering, design must be methodical and not considered in isolation. Good process design and good control system design go hand in hand. Effort is required to achieve good design, appropriate tuning, and ongoing monitoring and maintenance over the life of the asset.

To ensure that process control is robust and can be built upon to optimize the process, the following methodologies should be followed.

Process system design

Some processes are inherently stable, and others are not. Good process design will consider the controllability of the process with attention to correct sizing of piping, storages, pumps and valves. Building excessive capacity into pumps and valves results in high gain systems that waste energy, increase wear, and are difficult to control. Variable speed drives on pumps can provide some relief to these situations.

Measurement points must be located where the variable of interest is stable, i.e. where mixing or chemical reactions are essentially complete. Some sensors require straight piping runs upstream and downstream of the measuring element. However, they should be as close as possible to the control actuator to avoid excessive dead-time in the control loop.

Intermediate storage tank capacity should be sufficient to absorb disturbances and agitation sufficient to provide good mixing.

Some general process design principles should include:

- Eliminate sources of variability if possible.
- Move variability from key processes to less important processes.
- Add variability sinks into the process design to reduce variability.
- Linearise the process dynamics in order to maximise control capability.
- Match the process dynamics to the desired control performance.
- Minimise the interaction between related control loops.

Control system design

The objectives of the loop and impediments to achieving those objectives must be considered. For example, a consistency control loop aims to maintain a constant consistency for downstream users, despite a number of potential process disturbances. These disturbances include changes in demand (flow), tank level, dilution water pressure, and fibre characteristics. Control strategies can be designed to minimise the effect of these disturbances.

Minimising dead-time is important to loop performance. A consistency transmitter should be suitably located to measure a well-mixed fibre slurry, but not introduce excessive dead-time into the loop. Process dead-time for a consistency loop should be in the range of 3-7 seconds.

PID control on its own is a simple feedback model. For processes that warrant more elaborate control algorithms, other process tools can be added, such as:

- Adaptive gains
- Cascade and ratio control
- Feedforward components
- Smith Predictors and other forms of model reference and dead-time compensation
- Multivariable controls
- Neural networks
- Fuzzy logic

Consistency control can be improved by using cascade control of dilution water flow and adding feedforward correction due to fibre flow changes.

Process characterization

Each control loop must be considered as part of the total process system. It will be influenced by other phenomena occurring in the process, and the control loop will generate change in various aspects of the process. For example, a basis weight control loop will be influenced by thick stock flow, consistency, total head, retention and machine speed, and it will in turn influence moisture content, calliper, strength, etc.

The process response is often significantly affected by non-linearities in the control loop. There are many sources of non-linearities including sensor non-linearities, inherent process non-linearities (eg. pH), and control valve problems, such as backlash and stiction. The response may also be affected by filtering of the process variable at the transmitter or in the controller.

The performance of the final actuator is critical for a well behaved control loop. The control valve should be tested for stiction and backlash by moving it incrementally and quantifying the non-linearity before attempting to tune a loop.

The parameters of the model may vary under different operating conditions. If an understanding of why these parameters change can be developed, appropriate control algorithms can be designed.

Control system tuning

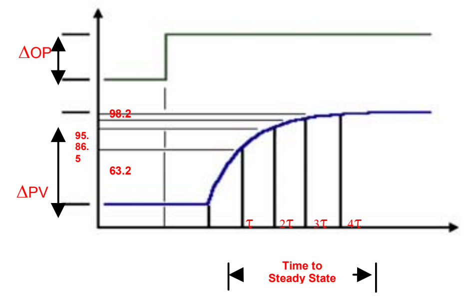
The art of tuning! – it is not an art, it is a science. Don’t tune by the seat of your pants Use information gained from a series of bump tests to mathematically calculate the optimal tuning factors: filtering, proportional gain, integral time and derivative time.

The Zeigler-Nichols tuning methods are well known and have been used for many years. However, most technicians and engineers in the pulp and paper industry refrain from using these methods because of the oscillations that can result and the poor stability margin of the controller. The Lambda tuning method is more appropriate for this industry.

The first step is to establish a simple mathematical model for the loop. The simple model will depend on the type of loop:

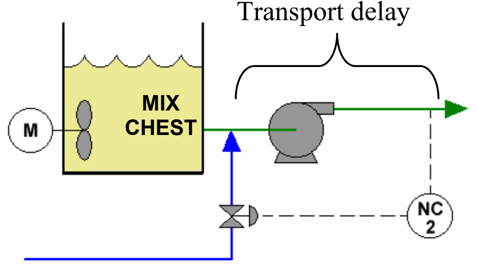
Type of Loop	**Examples**
First order	Many flows
First order plus dead-time	Consistencies, some flows and some pressures
Second order	Temperatures
Integrating processes	Storage levels and some pressures

Process dynamics are measured by conducting open loop step tests. The process response to the step will determine the process gain, process dead-time and process time constant.

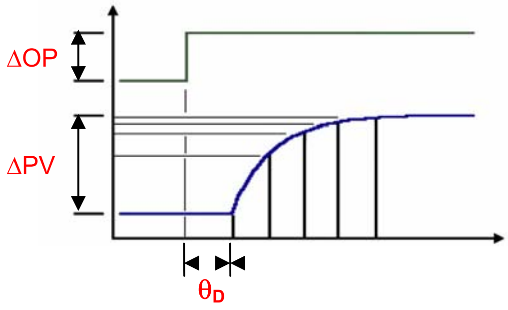


The process *Time Constant* is defined as the time it takes for the process to reach 63.2% of its steady-state change (ΔPV) following a step change into the system. It is often difficult to determine the 63.2% point in the presence of noise. Since the process essentially settles out after 4 time constants, the time constant can be estimated by dividing the time to steady-state by 4.

Deadtime is defined as the time between the controller output change and the initial process response. Deadtime is most often the result of transport delay in the process. Deadtime is *very destabilizing* and should be minimized. Excessive deadtime will compromise control loop performance and increase process variability.



The deadtime in this system can be reduced by locating the sensor closer to the dilution point.



Quite often deadtime is variable and results from changing production rates. This causes particular challenges when tuning loops.

These parameters define the mathematical model that characterizes the loop.

Lambda tuning allows the engineer to choose the closed loop time constant (Lambda constant). This is a key decision for minimising interaction between loops. It is particularly useful in stock blending applications where the closed loop time constant for each component can be matched. This ensures that the stock proportions will be maintained during production rate changes.

Proportional and Integral tuning for a first order loop plus dead-time is accomplished using the following equations:

Process gain is defined as:

$$K_p = \frac{\Delta PV\%}{\Delta OP\%}$$

Controller gain is:

$$K_c = \frac{\tau}{K_p\,(\lambda + \theta_D)}$$

where: τ = process time const. (sec)
K_p = process gain
λ = Lambda constant (sec)
θ_D = dead-time (sec)

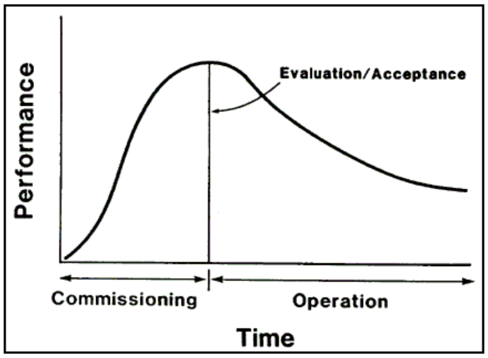
Controller integral is:

$$TI = \frac{\tau}{60}$$

Performance monitoring

The economic benefits from process control and optimisation are paramount. The justification for the initial capital investment and on-going maintenance is to provide on-going economic benefits.

A process and its control system are highly interdependent. If any part of the process or control loops changes in behaviour, the systems performance degrades and must be re-tuned.



Many systems perform poorly because:

- characteristics of the process may change
- control loop components such as control valves may have changed (degraded condition or replaced)
- poor sensor calibration
- poor control tuning (and the control system increases variability rather than reduces it!)
- inadequate operator training
- poor assessment/communication of the business benefits and economic returns
- target values are not properly established.

Classic examples are the high level controls on which most on-machine quality control systems are justified:

- Maximum throughput
- Maximum moisture
- Grade change

The economic benefits of such loops should be monitored to detect any degradation in performance. Automated systems are available to do this.

Process troubleshooting

There are hundreds of potential sources of process variability. The control system may be one of these and be contributing to the variability of the process.

The first step is to accurately identify the problem. Monitor the problem for a period long enough to identify slow cycles.

Is the problem better or worse when the control loop is put into manual mode? If the problem is reduced in manual, the control system must be investigated. The source of the problem could be:

- Actuators
    - Valves, dampers, variable speed pumps and fans are the final element in the control loop, and usually the most troublesome.
    - Valve characteristic
    - Valve health
    - Variable Speed Drives
- Transmitter
    - Filtering
    - Principle
- Controller
    - Filtering
    - Tuning
    - Execution frequency

Use step tests to verify valve performance and appropriate tuning.

Cascade loops are most useful for controlling associated variables where the master loop controls the setpoint of the slave loop. If either loop has a problem, or the closed loop time constants of the two loops are too close together, the loops will interact and amplify variability. Choosing the Lambda time constant for the master loop to be at least 3-5 times that of the slave loop will ensure robustness.

Interacting loops require a tuning strategy that will ensure that the most important variable is controlled well, sometimes at the expense of less important loops. A predefined sequence of closed loop / open loop tests starting with the most important loop will provide the process dynamics and interactions required to design the appropriate tuning strategy.

External disturbances can be attenuated by a PID control loop only if the period of the variability is at least 6.3 times the closed loop time constant (Lambda value) of the loop. Therefore, effort should be made to eliminate or minimise the source of the variation, or include a feedforward component in the control strategy.

Process historians are invaluable for process monitoring and troubleshooting – if you haven't got one, get one! This data is essential for evaluating current performance, and for comparing performance in the past under different operating conditions. A loop may perform well under some conditions and poorly under others. The control strategy may need to be modified to handle a wide variety of conditions. Adaptive tuning, cascade or feedforward control may be appropriate.

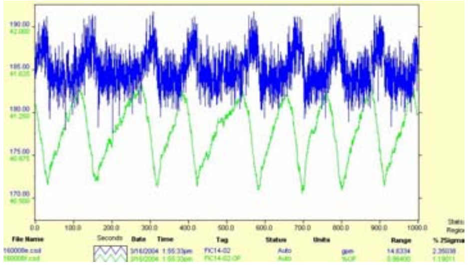
Controller outputs should be logged by the process historian. The action of the output (and hopefully the control valve) indicates:

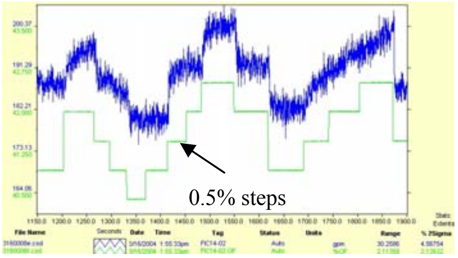
- The amount of work being done by the controller to overcome variability of the incoming materials.
- The amount of output adjustment required to overcome stiction and/or backlash in the valve.

Valve Audits

A good maintenance strategy is to perform an audit of all critical valves before a planned annual shutdown. This will identify major sources of variability caused by control valve non-linearities and ensure that maintenance dollars are invested where they will provide the greatest benefit.

In automatic mode, stiction will produce a square wave in the PV and a sawtooth in the controller output.





Each critical control valve should be tested for stiction and backlash by moving it incrementally and quantifying the non-linearity. The effect of this non-linearity on the process is evaluated and priorities can then be set for maintenance activities.

Any problem with a valve will be magnified by the process gain.

Process gain is defined as $K_p = \frac{\Delta PV\%}{\Delta OP\%}$

So if 5% change to the valve position (ΔOP%) causes a 10% change to the process variable (ΔPV%), the process gain is 2.0.

If after a valve audit, we find that:

- valve A has stiction of 2% with a process gain of 3.0, and
- valve B has stiction of 4% with a process gain of 1.0.

Then, valve A would have maintenance priority, because valve A's problem would be causing 6% variability in the process variable, whereas valve B's greater stiction would be causing lower process variability of 4%.

Ideally, the process gain should be around 1.0. Higher process gains are usually due to over-sizing of pumps and valves. The valve audit would highlight instances of mismatched equipment.

Training

We certainly have the tools to analyse and control our processes. Computing power is more than adequate and the DCS provides the capability for sophisticated control algorithms. However, these tools are not being fully utilised. To be utilised, adequate engineering skill and time is required. The options are to engage consultants to do this, or to provide adequate resources internally.

With a reduced numbers of engineers in many mills, there is little scope for mentoring. Therefore external training must be relied upon to achieve a higher skill level. There are process control troubleshooting course available to bolster the skills of control engineers, technicians and operators. Some are tailored specifically for pulp and paper applications and use process simulators to allow training on relevant processes. Practical experience can be passed on to minimise the problem of control systems personnel "practising" on your process.

CONCLUSION

Process control engineering is not an art, it is a science. As in every other field of engineering, design must be methodical and not considered in isolation. Good process design and good control system design go hand in hand. Each control loop must be considered as part of the total process system. Effort is required to achieve good design, appropriate tuning, and ongoing monitoring and maintenance over the life of the asset.

Audits can highlight problem areas and their solutions. A range of different types of audits can be performed:

Process audits

An independent audit of control system performance often leads to improved control strategies, tuning, and subsequently improved process quality and output.

Control valve audits

Checking valves for stiction, backlash and suitability prior to a planned shutdown allows maintenance to be directed at the most crucial control loops.

Enduring solutions can be achieved from a combination of:

Control strategy improvement
There are many low cost enhancements to control strategies that can yield significant process improvements, eg. consistency control out of high density storages.

Control loop tuning
A structured approach to tuning results in a more stable process, especially where cascade and interacting control loops are involved.

Control systems training
Process Control Troubleshooting courses for engineers, E & I trades and operators can be arranged on-site using the ProNamics paper machine simulator.

Control systems standards
Standards for control system design and tuning can be developed.

By doing so, you'll keep CONTROL over KAOS and look smart to the Chief, not give him another headache or be forced to use the cone of silence (and that one's for all you die-hard Get Smart fans)!

References

Process Control Fundamentals for the Pulp & Paper Industry: TAPPI Press 1995

Nelson D - **Process Control Troubleshooting Course**: ProNamics Control Inc.