Automatic Controller Dynamic Specification

(Summary of Version 1.0, 11/93)

This is a summary of a generic specification which applies to the design and dynamic performance of automatic feedback controllers suitable for use in optimizing pulp and paper mill process variability. The full document is available upon request.

1.0 Competitive Marketplace - Background

The global market for manufactured products continues to focus on product quality and uniformity and more and more attention is being paid to process control equipment and its condition. EnTech™ Control Engineering Inc. has specialized in the analysis and optimization of pulp and paper manufacturing where product uniformity specifications are now approaching 1%. Paper product can be rejected when it deviates outside specified limits, or when the variability characteristics of the products adversely affect the operation of the customer's secondary manufacturing such as a printing press. Mill audits have shown[1] that product variability is caused mainly by the combined behaviour of the many upstream process variables. In many cases it is possible to trace these causes to individual control loops. Of equal importance is the impact of process variability on manufacturing efficiency in which small and subtle improvements in the process variability of key variables can have a large impact. Audits have identified that the cyclic behaviour of automatic control loops is a major cause for destabilizing production in the pulp and paper industry.

To date, only about 20% of all control loops surveyed were found to actually reduce process variability in automatic model while the remaining 80% of loops were found to increase variability. Of these, some 30% were found to oscillate directly due to control valve nonlinearities[2] and another 30% were found to oscillate due to controller tuning. It is recognized that controller tuning is to a great extent a human training issue (a separate issue from that of controller design). Most people are only familiar with the original controller tuning method known as Quarter-Amplitude-Damping (published by Ziegler and Nichols in 19423) or, they just “tune-by-feel.” These methods often produce loops which tend to cycle and de-stabilize product uniformity. By nature, trial and error methods accept the capabilities of existing controllers without question. For this reason, controllers have not advanced significantly in dynamic performance terms over the years despite the major advances in control system implementation technology from pneumatic to electronic to digital with 64-bit microprocessors. In fact, the tendency has been for each new generation of controllers to mimic the functional capabilities of the previous generation notwithstanding the availability of the additional computational power of the new technology. For this reason most digital controllers are “analog like", in that they do only what analog controllers could do in the past. What of deadtime compensation, velocity mode control, feedforward control? On the other hand, as digital controllers have become prevalent, sampling rates have been relaxed and, in some cases, little or no attention has been paid to signal aliasing. The result has been badly implemented digital control which has de-stabilized product uniformity for reasons of slow sampling and signal aliasing.

In the last decade, modern model-based methods such as Lambda Tuning[4] and Internal Model Control (IMC)[5] have been used extensively in pulp and paper mills with considerable success in variability reduction. The use of these methods has “pushed" existing controller designs to the limit. For example it has been very disappointing to discover that the recommended tuning parameters based on these methods could not be entered into some commercially available controllers because they were outside the controller limits - or that a particular feature of the modern control solution could not be implemented because it was not part of the available control algorithm.

Summary of Controller Problems Encountered

The types of problems encountered included:

- slow digital controller sampling rates,
- lack of anti-aliasing filters,
- lack of controller structure flexibility,
- too narrow parameter ranges,
- lack of feedforward control,
- lack of velocity mode control,
- lack of deadtime compensation,
- lack of adequate controller documentation.

Controller Specification - Purpose

Control in the pulp and paper industry is provided via a wide range of equipment including distributed control systems (DCS's), single loop controllers, programmable logic controllers (PLC's), variable speed drives, computer control systems and specialized, application oriented systems (e.g. bleach plant brightness control systems, turbine governors). This specification is aimed at providing a guide for controller design that is suitable to meet the needs of the majority of pulp and paper mill process control problems in which modern model-based control solutions could be used to enhance competitiveness. The specification is intended for any application where "general-purpose" process control is attempted in which an "automatic feedback controller" is connected to a transmitter or sensor on the one hand, and a final control element on the other (it excludes variable speed drive internal dynamics such as speed and armature current). The specification has two intended purposes: as a tool to be used by pulp and paper companies when specifying and assessing the capabilities of control equipment, and as a design guide for control equipment suppliers.

2.0 The Pulp and Paper Control Problem

Virtually all pulp and paper mills use PID controllers for "analog type" or continuous control (this includes digital control with adequately fast sampling rates) with 4 to 20 mA outputs to control valves and other actuators. Derivative action has been turned off in 98% of all cases. Most commercial controllers have controller gain adjustments ranging from about 0.1 to 10. A small number of important control loops deal with motor driven or "velocity mode" type actuators such as electric valves, refiner plates and headbox vertical slices. These loops by nature use discrete or velocity mode algorithms with digital output logic to handle increase/decrease motor action. In addition, some loops have extensive deadtime and require deadtime compensation algorithms. Other loops require feedforward control in order to achieve acceptable dynamic performance.

3.0 Specification

3.1 Bump Tests

The controller will have a "manual" mode in which feedback control will be suspended. Should safety considerations preclude this under normal operation, an equivalent "test mode" will be available for use under the supervision of a qualified person.

It will be possible to initiate small step changes in the (0.1% to 10%) controller output under the control of the user. These step changes will be as near as possible to pure steps.

It will be possible to record both the controller output and the process variable as seen by the controller at the controller update frequency. This could be done either via a file save software utility or via assignable digital to analog converters having at least 12 bit resolution.

3.2 Gain Scheduling as a Function of Error

Whereas gain scheduling is a useful feature which controllers should have available, a means of scheduling the controller gain ("Kc", for ISA standard form and classical form PID) as a function of controller error will be provided. This will allow a pre-selected gain suitable for minimum variance control to be used as long as the absolute error is below a low value. Above this value, a different gain suitable for more aggressive control can be selected. Care should be taken to avoid the possibility of a limit cycle between these values. For a parallel path PID implementation, the same method of gain scheduling must be arranged for all three parameters.

3.3 Control Structure - Controller Filter

To permit IMC type control structures, which may require the cancellation of a process zero (β 13 value) with a controller pole, there will be a first order filter implemented in series with the PID algorithm. The filter can be on either the controller error (before the PID) or after PID. The filter must be properly initialized (bumpless transfer). The transfer function of the filter will be:

$$G_F(s) = \frac{1}{(\tau_F s + 1)}$$

The time constant τ_F is to be user-selectable between 0 seconds and 60 minutes.

3.4 Control Structure

The available control structures will include the following combinations:

- P, I, PI, PD, PID (both real and complex zeros)
- Each of these will have a series filter available (see 3.3 above).
- The derivative filter τ_D will be nominally one tenth and no more than one eighth of T_D

3.5 Alternative PID Structures

If alternative structures such as “D” on PV and “P” on PV are offered, they must only be as options. There must be a full PID alternative driven by controller error.

3.6 PID Parameter Ranges

Parameters (K_C, T_R, T_D, K_1, K_D, τ_F).
These must be adjustable continuously (not in steps) and calibrated to at least 2 significant figures.

- K_C: 0.001 to 20 (% output)/(% span), (ISA standard or classical PID),
- K_C: 0.0 to 20 (% output) (% span) (Parallel PID),
- T_R: 0.1 seconds/repeat to 10 hours/repeat,
- T_D: 0 seconds to 60 minutes,
- K_1: 0 to 500%/%/sec,
- K_D: 0 to 1500 %/% minutes,
- τ_F: 0 seconds to 60 minutes.

3.7 Process Variable Filter

The process variable will have a filter prior to the error summing junction of the form:

$$G_{F_{PV}}(s) = \frac{1}{(\tau_{PV} s + 1)}$$

The time constant τ_{PV} should be user adjustable from 0 to 1.0 minutes.

3.8 Feedforward Control

A dynamic feedforward control option will be provided as per:

$$G_{C_{FF}}(s) = K_{C_{FF}} \left(\frac{\tau_{Lead} s + 1}{\tau_{Lag} s + 1} \right) \cdot e^{-sT_{FF}}$$

The feedforward controller output will be added to the output of the feedback controller with due regard for bumpless transfer, limits and reset wind-up. The user selectable adjustments will be:

$K_{C_{FF}}$: 0 to +/- 100, τ_{Lead}, τ_{Lag}: 0 to 10 minutes,
T_{FF}: 0 to 10 minutes.

3.9 Setpoint Filter

There will be a provision to filter the setpoint through a filter of the form:

$$G_{F_{SP}}(s) = \frac{1}{(\tau_{SP} s + 1)}$$

with a user selectable time constant from 0 to 100 minutes.

3.10 Deadtime Compensation

There will be a deadtime compensation algorithm available of the form:

$$G_C(s) = \frac{(\tau s + 1)}{K_P\left(\lambda s + 1 - e^{-sT_d}\right)}$$

Parameter values will include:
τ: 1 second to 10 minutes, K_P: 0.01 to 50,
λ: 2 seconds to 30 minutes, T_d: 0 to 10 minutes.

3.11 Controller Output Integrity

The controller output should not be altered dynamically by rate limiters or other means.

3.12 Sampling and Controller Execution Rates (Ts)

Analog signal sampling and controller execution should be 10 times faster, and no slower than three times faster, than the process time constants. Process time constants faster than 0.5 seconds need not be considered in the "general" process control problem. Sampling can be slowed down to one sample per second when time constants are equal to three seconds or slower.

Analog signal sampling and controller execution should be at 0.1 seconds/sample. However, it can be slowed down to between 0.3 seconds for time constants of 1.0 second ($T_s = \tau/3$) to as slow as 1.0 second/sample for time constants of 3 seconds and longer.

3.13 Anti-Aliasing

Anti-aliasing filters shall be present at every point of signal sampling, from raw analog input to the point of use of the feedback signal at the controller. At each point of sampling the anti-aliasing filter shall provide a minimum of -12 dB of attenuation at the Nyquist frequency of the next sampler.

3.14 Bit Resolution

The minimum acceptable bit resolution for both inputs and outputs is 12 bits. Report-by-exception reporting should never be used inside a control loop.

3.15 Motor Driven Actuators Velocity Mode Control

A velocity mode PI algorithm should be available of the form:

$$\begin{aligned}\Delta u &= K_C(e_k - e_{k-1}) + K_1 e_k \\ &= K_C(e_k - e_{k-1}) + \left(\frac{K_C T_S}{T_R}\right) e_k\end{aligned}$$

The "time duration" digital output handler should execute at a minimum update time of 0.05 seconds. Preferably, it should execute at such a rate which would allow the final actuator to achieve a quantization equivalent to about 12 bits of resolution, or 1:4000. Parameter ranges will be as defined for PID parameter ranges above. Output limiting and wind-up issues must be considered.

3.16 Controller Documentation

Controller documentation will include the following:
- controller transfer function for each option and signal path,
- parameter units and,
- parameter ranges available.

Nomenclature and Symbols

a	= 0 or 1 exponent on integrator(0=none, 1=present in transfer function),
β	= lead time constant (+ve or -ve),
e_k	= current error (setpoint - PV),
e_{k-1}	= last error,
$G_C(s)$	= controller transfer function,
$G_F(s)$	= filter transfer function,
$G_{FF}(s)$	= feedforward transfer function,
$G_{F_{PV}}(s)$	= process variable filter transfer function,
$G_P(s)$	= process transfer function,
$G_{F_{SP}}(s)$	= setpoint filter,
I	= Integral algorithm,
k	= current time index for discrete time difference equation,
K_C	= controller gain,
$K_{C_{FF}}$	= feedforward gain,
K_D	= controller derivative gain (parallel PID),
K_1	= controller integral gain (parallel PID),
K_P	= process gain,
P	= Proportional algorithm,
PD	= Proportional-Derivative algorithm,
PI	= Proportional-Integral algorithm,
PID	= Proportional-Integral-Derivative algorithm,
PID.F	= Proportional-Integral-Derivative algorithm with series filter,
τ	= process time constant,
τ_1, τ_2	= process time constants,
τ_F	= filter time constant,
T_{FF}	= feedforward deadtime compensation,
τ_{PV}	= process variable filter time constant,
τ_{Lead}, τ_{Lag}	= feedforward lead/lag time constants,
T_d	= deadtime,
T_D	= derivative time (standard and classical PID),
τ_D	= derivative term filter (parasitic pole) normally set to $T_D/10$ or $K_D/10$,
τ_{PV}	= process variable filter time constant,
T_R	= reset or integral time (standard and classical PID),
T_S	= controller sampling time,
τ_{SP}	= setpoint filter time constant,
Δu_k	= current desired change in controller output,
ς	= damping coefficient.

References

1) Bialkowski, W.L., *Keynote Address, Control Systems 92 Conference*, Whistler, British Columbia, Sept. 1992, to be published in Pulp and Paper Canada.
2) EnTech™ - Control Valve Dynamic Specification (Version 2.0,7/93).
3) Zeigler, J.G. and Nichols, N.B., *Optimum settings for automatic controllers*, Transactions ASME, pp. 759-768, 1942.
4) Dahlin, E.B., *Designing and Tuning Digital Controllers*, Instrumentation and Control Systems 41(6), 77, 1968.
5) Morari, M. and Zafiriou, E., *Robust Process Control*, Prentice Hall, 1989.

For more information:

For more information on Variability Management please visit our website www.EmersonProcess.com/solutions/VariabilityManagement , or

Contact us at:

email: AAT@emersonprocess.com
phone: +1 512-832-3575

Emerson Process Management
12301 Research Blvd.
Research Park Plaza, Building III
Austin, Texas 78759 USA