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Practical Guidelines for Identifying and Tuning PID Control Loops with Long Deadtime and/or Time Constants

Siemens Process Automation
User Community Conference
Advanced Control Case Studies – Session B1
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David B. Leach

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Practical Guidelines for Identifying and Tuning PID Control Loops with Long Deadtime and/or Time Constants

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- **Outline**
  - Nature of the Problem & Solutions
  - Practical Guidelines for Tuning Long Deadtime/Time Constant Loops
  - Example Case Study: Cooling Tower Water Quality Control
  - References
  - Appendix

Nature of the Problem & Solutions - Definitions

- **Definitions**
  - **Deadtime (or Delay)**
    - Time interval between the initiation of an input change or disturbance to a process, and the start of the resulting process variable response
    - Delay is primarily due to physical, mechanical, or electrical characteristics of the process system
      - An innate property of a process system whose value can be minimized, *but cannot be totally eliminated*
    - Deadtime, especially if it is relatively long, is the most common cause of many closed control loop performance problems
    - Deadtime is *usually* easy to measure or estimate, depending on the process and input disturbance types

Nature of the Problem & Solutions – Definitions (Cont'd)

- **Definitions (Cont'd)**
  - **Lag**
    - Dynamic characteristic of a system where the measured output lags or falls behind the system input (graphic example follows)
    - First order lag is the most common type for process systems (represented by a linear 1^{st} order diff. eqn.)
    - Many processes can be modeled as a combination of a 1st order lag plus deadtime (FOLPDT)
    - A 1st order process has a single lag; a 2^{nd} order process has 2 lags; a 3^{rd} order process has 3 lags; etc.
      - 2^{nd} order and above systems are referred to as "Higher Order Systems" and are more difficult to tune
      - Multiple process lags usually (but not always) can be represented as a series of 1^{st} order lags

Nature of the Problem & Solutions – Definitions (Cont'd)

Definitions (Cont'd)

—Time Constant(s)

- Time interval between the initiation of a process input change or disturbance and when the resulting process output variable approaches a predefined or final steady state value
  - The time constant(s) is (are) calculated starting *after* the process deadtime expires
- For a series lag process system, the overall time constant is comprised of the sum of the individual time constants--one for each process lag
- Time constants can be difficult to measure or estimate for many processes--especially for "Higher Order Systems" that contain multiple lags
- Process time constant(s) and the process gain can vary over time depending on various factors such as the process production rate

Nature of the Problem & Solutions – Example of "Textbook Ideal" 1st Order Lag Process Response

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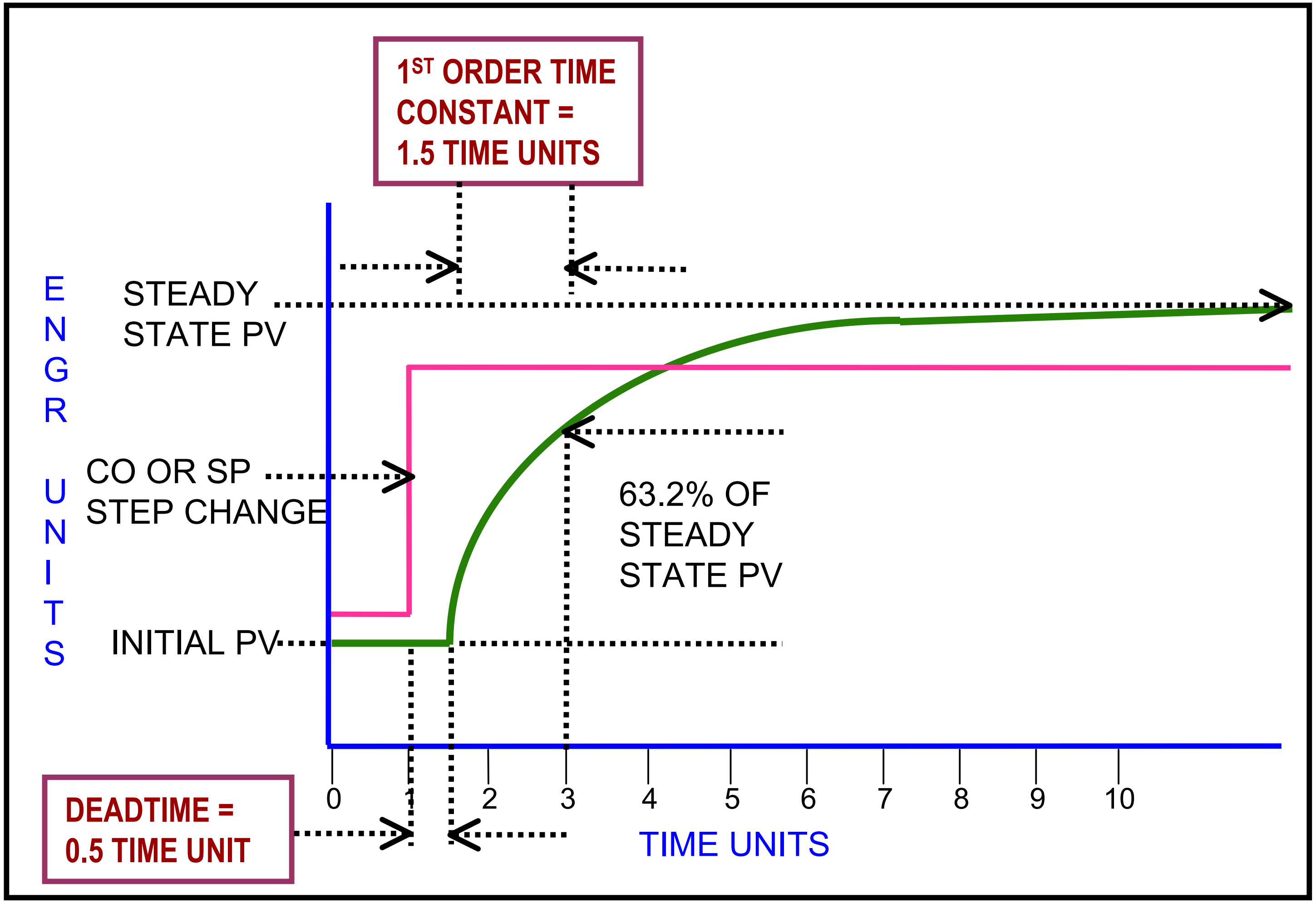

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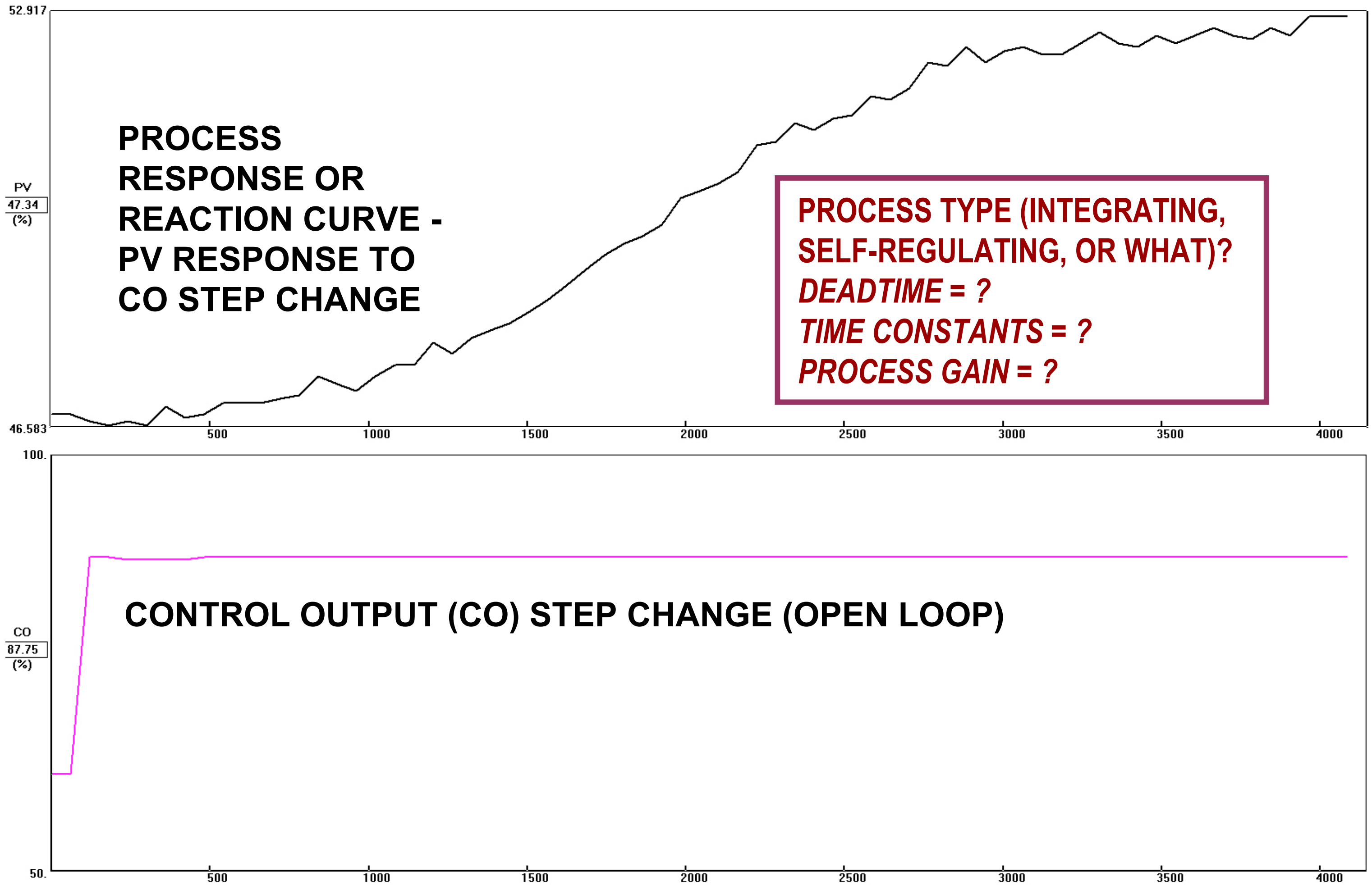
Nature of the Problem & Solutions – Example of Actual "Higher Order" Process Response with Long Deadtime and Multiple Time Constants



⇑ENGR UNITS (% of range)

⇒TIME UNITS (secs)

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Nature of the Problem & Solutions – Comparison of "Load Slow*" Tuning for a Second Order Plus Deadtime Simulated Process

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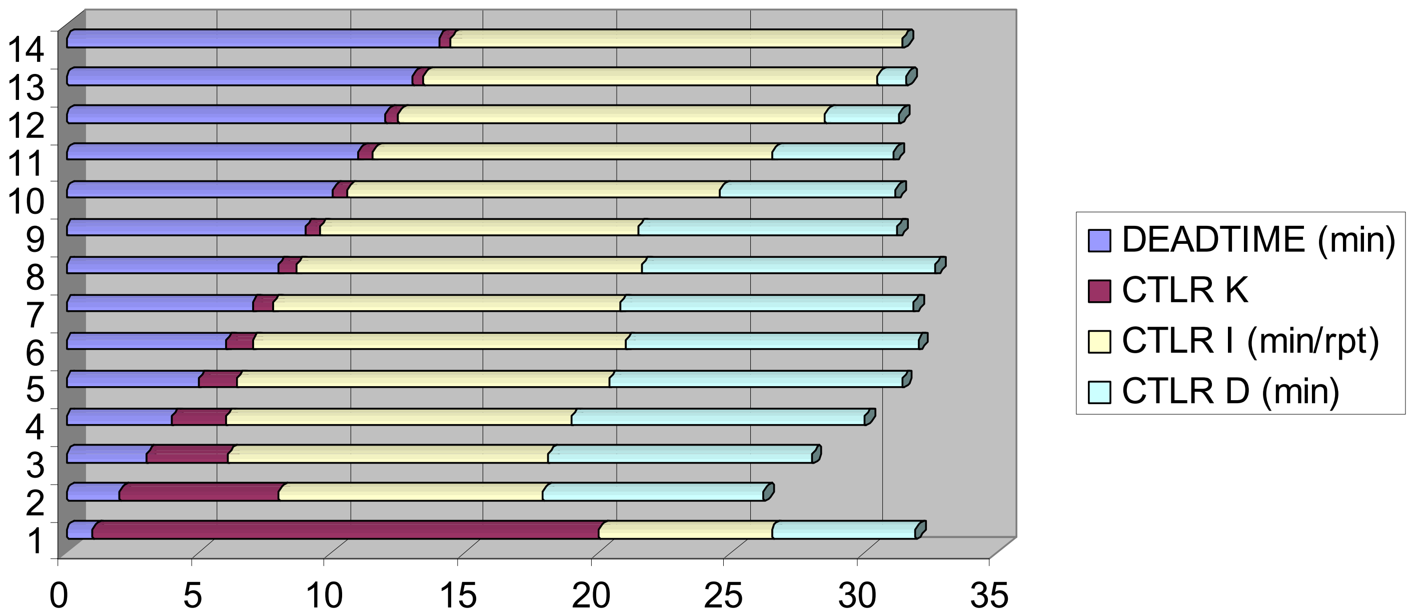
DEADTIME VS. EXPERTUNE RECO'D PID CONSTANTS FOR 2ND ORDER SIMULATED PROCESS (Deadtime=Var., Proc. Gain=1, Lag1=20m, Lag2=10m, Load Slow Tuning)



*A slow PID output response to load changes, as opposed to a Medium or Fast response, using the Siemens APACS+ series interacting PID eqn.

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Nature of the Problem & Solutions – Comparison of “Load Slow*” Tuning for a Second Order Plus Deadtime Simulated Process (Cont’d)

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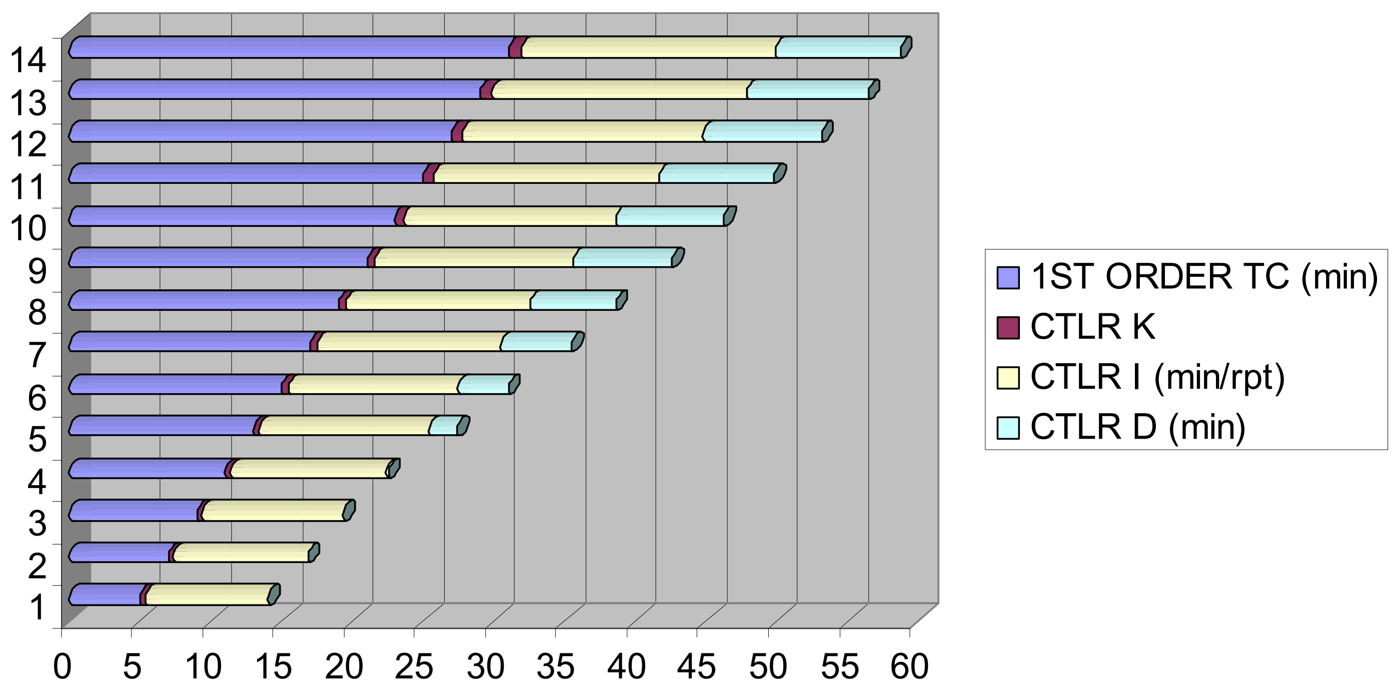
1ST ORDER TIME CONSTANT VS. EXPERTUNE RECO'D PID TUNING CONSTANTS FOR 2ND ORDER SIMULATED PROCESS (Deadtime=10m, Proc. Gain=1, Lag1=Var., Lag2=10m, Load Slow Tuning)



*A slow PID output response to load changes, as opposed to a Medium or Fast response, using the Siemens APACS+ series interacting PID eqn.

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Nature of the Problem & Solutions – Comparison of Performance of a Smith Predictor Deadtime Compensator vs. a Conventional PID Controller

The figures and Notes text in this slide were excerpted from Ref. A.4 by Gregory K. McMillan, pp. 271-273, © 1994 Instrument Society of America (ISA.)

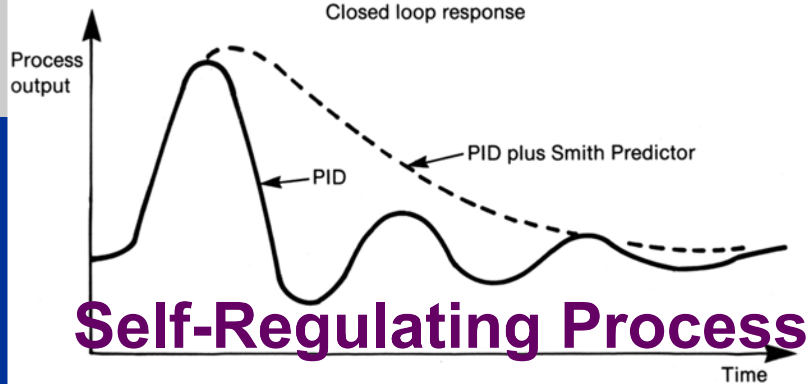

FIGURE 11.14
Comparison of Smith Predictor response with conventional PID controller (self-regulating process)

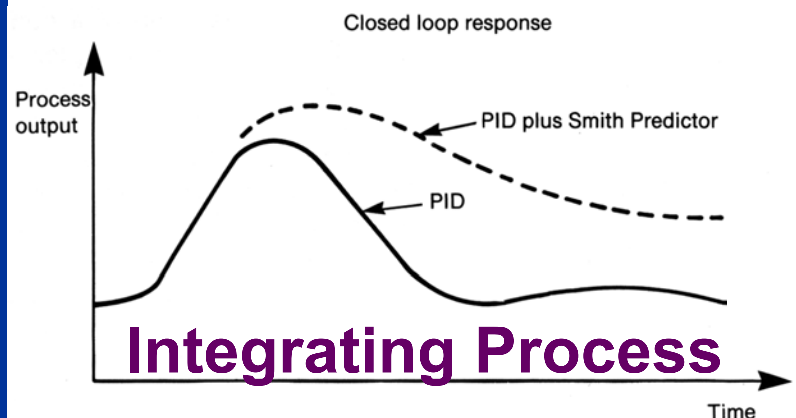

FIGURE 11.15
Comparison of Smith Predictor response with conventional PID controller (integrating process)

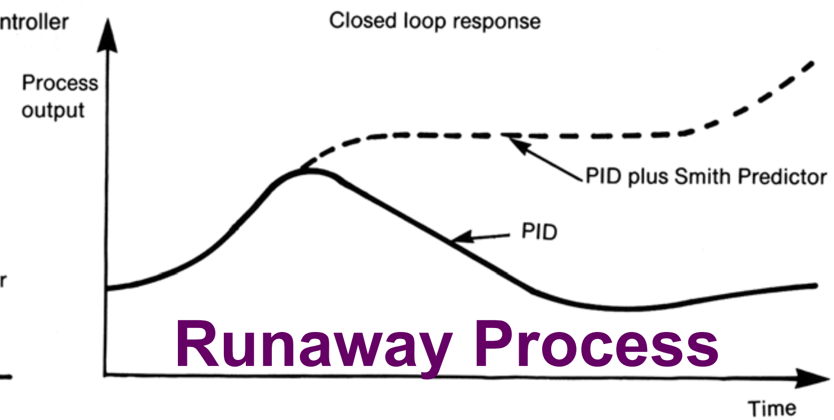

FIGURE 11.16
Comparison of Smith Predictor response with conventional PID controller (runaway process)

Solutions: Comparison of PID Loop Tuning Approaches

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- **Use "Lookup Table" Default or Typical Settings* Then Tweak for Best Tuning**
  - **Advantages**
    - Gets control loop up and working quickly (important for startups)
    - Minimizes *1^{st} pass* time investment in tuning
    - Does not require a process response test
    - Does not require an investment in tuning tools
    - Works OK for many simple processes (typically without interactions or complex process dynamics)
  - **Disadvantages**
    - Rarely gives optimal tuning results, depending on performance criteria
    - Extensive tweaking may be required to get satisfactory results *(2^{nd} pass, 3^{rd} pass, etc.)*
    - Can give totally inappropriate results for more complex processes (one size does not fit all!)

***Refer to Appendices 1 & 2 for examples of Tables of Default and Typical Settings for various types of processes.**

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Solutions: Comparison of PID Loop Tuning Approaches (Cont'd)

- **Use Closed Loop Tuning Methods with Rule Set**

—Advantages

- Loops stay in control (AUTO mode)--especially important for safety-related control loops
- Includes the full effects of process controller and final control element dynamics in tuning
- Faster response to input disturbances than Open Loop--tuning is completed faster

—Disadvantages

- Requires an operable set of beginning tuning constants
- Requires identification (or prior knowledge) of the process type (self-regulating, integrating, inverse response, runaway, etc.)
- Most common method requires a sustained oscillation of the controlled variable within a controllable limit (to get ultimate gain & period)—not practical for slow processes
- Requires a tuning test and the interpretation and application of an appropriate tuning rule set*

***Refer to References A.1, A.4, C.6, C.7, and C.8 for examples of rule sets. Note that Reference C.6 cites a total of 453 rule sets for PI/PID controllers!**

Solutions: Comparison of PID Loop Tuning Approaches (Cont'd)

- **Use Open Loop Tuning Methods with Rule Sets**

—Advantages

- Some methods do not require the PV to be at a steady-state or lined out value (but with no load or other disturbances occurring of course)
- Unlike the closed loop method, does not require a sustained controlled variable oscillation
- Depending on the method used, can be effective for integrating or ramp-type processes

—Disadvantages

- Requires the loop to be in MANUAL mode, out of AUTO control
- Does not include the full effects of process controller and final control element dynamics
- Requires identification (or prior knowledge) of the process type (self-regulating, integrating, inverse response, runaway, etc.)
- Requires a tuning test and the interpretation and application of an appropriate tuning rule set*

***Refer to References A.1, A.4, C.6, C.7, and C.8 for examples of rule sets.**

Solutions: Comparison of PID Loop Tuning Approaches (Cont'd)

- **Use Open or Closed Loop Process Response Testing and an Online Tuning Software Tool**

—Advantages

- Depending on the tool employed, does not require the prior identification of process type
- Does not require the interpretation and application of an appropriate tuning rule set!
- Fastest method to achieve optimal tuning
- Depending on tool cap. can aid in effectively tuning controllers for more complex processes (integrating, inverse response, higher order process dynamics, etc.)

—Disadvantages

- Requires an initial investment in a suitable online tuning software tool and the control system interface, and continuing investment to maintain and upgrade them
- Requires an initial investment in training and obtaining "hands-on" field tuning experience for the individual(s) responsible for tuning
- Usually requires multiple tuning tests (unless you're either really good, or really lucky!) which can be time-consuming

Practical Guidelines for Tuning Long Deadtime/Time Constant Loops

- **BEFORE conducting any tuning exercises work with the operations personnel to:**
  - Establish the control loop performance criteria
  - Determine the allowable operating and safety limits for the control loop and other affected variables
  - Obtain any necessary operations and safety permits
- **Regardless of the tuning method used:**
  - ALWAYS conduct at least one process response test
    - Using an appropriate input disturbance such as a step or pulse (doublet pulse preferred )
    - If possible conduct a process response test at the lower, middle, and upper part of the normal operating range of the controlled variable and average the results (to assess nonlinearity)
  - Familiarize yourself with the process (there is no substitute for thorough process knowledge!) and the control algorithm & control system features and options

Practical Guidelines for Tuning Long Deadtime/Time Constant Loops (Cont’d)

- **Use the results of the process response test to estimate the process gain (or pseudo-integrator gain for an integrating process), average deadtime and overall time constant***
- **Calculate one simple index of *Process Controllability:***
  - The (Overall Process Time Constant--sum of all time constants) / [(Overall Process Time Constant + Process Deadtime)]
  - If this ratio is < 0.5, then use the most conservative estimate of process gain (highest) and controller gain (lowest recommended by tuning method used) to avoid a conditionally or marginally stable loop
- **If possible use an online software tuning tool (like ExperTune) to conduct the process response test, analyze the results, and arrive at an optimal set of tuning constants**

***Refer to References A.3, A.4 for estimation methods.**

Practical Guidelines for Tuning Long Deadtime/Time Constant Loops (Cont'd)

- **If ExperTune is used:**
  - **And the process dynamics are Higher Order**
  - **Or the process type is not FOLPDT self-regulating (integrating, inverse response, runaway, etc.)**
  - **Or performance is still unsatisfactory after a properly conducted initial tuning exercise (regardless of process type)**
  - **And there is an immediate payback for investing additional testing and analysis time**
  - **Then use ExperTune to:**
    - Conduct a series of process response tests
    - Save the results in the ExperTune Loop Summary Table*
    - Import the results to the ExperTune Loop Simulator** and perform "What-If" and other more advanced analyses to arrive at the optimal set of tuning constants

***A unique feature of ExperTune where the results of multiple tuning tests can be recorded, averaged, compared, and selectively used for analysis. The desired set of tuning constants can then be loaded to the controller.**
****Optional add-on feature for the ExperTune Advanced version.**

Practical Guidelines for Tuning Long Deadtime/Time Constant Loops (Cont'd)

- **If the loop is deadtime-dominated (previously defined Process Controllability index << 1):**
  - **And the process type is self-regulating**
  - **And tight control is economically important**
  - **And more advanced control approaches such as Feedforward-Feedback Control, Model Predictive Control, etc. are not cost-justified**
  - **Then use ExperTune to:**
    - Conduct a series of process response tests
    - Save the results in the ExperTune Loop Summary Table*
    - Consider using Lambda or Simplified Lambda Tuning Methods*
    - Import the results to the ExperTune Loop Simulator** and perform "What-If" and other more advanced analyses to arrive at the optimal set of tuning constants

***Refer to Ref. A.1 by G. McMillan for a description of the Simplified Lambda Tuning Method, and to Ref. C.14 for the article "Should You be Using Lambda Tuning?" by John Gerry.**

****Optional add-on feature for the ExperTune Advanced version.**

Example Case Study: Cooling Tower Water Quality Control

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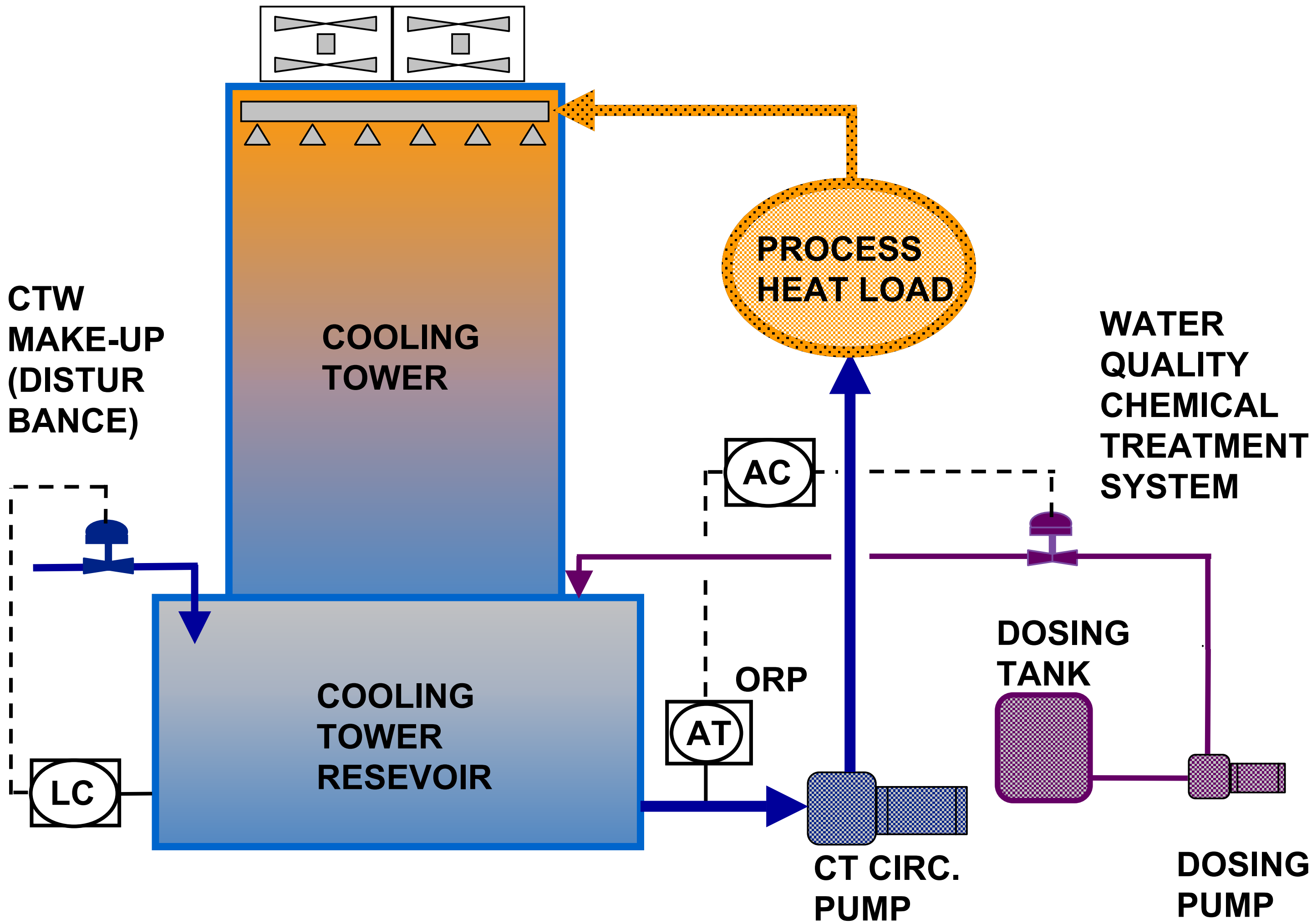

Example Case Study: Cooling Tower Water Quality Control – Open Loop Process Response Test Results

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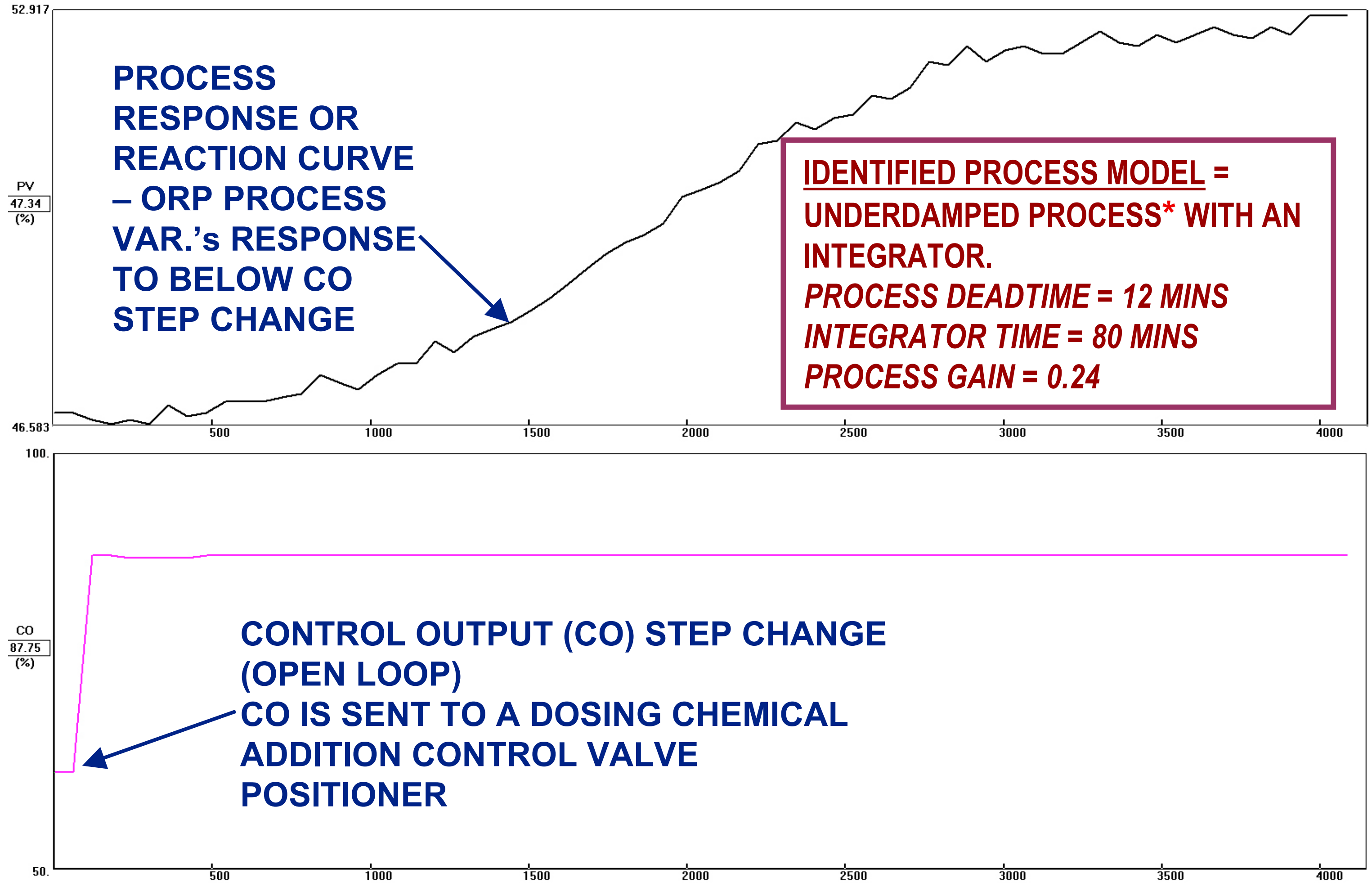

⇑ENGR UNITS (% of range)

⇒TIME UNITS (secs)

*The polynomial portion of the Laplace equation used to model and simulate this underdamped process in ExperTune is: 1 / (C0 + C1 * s + C2 * s**2 + C3 * s**3)

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Example Case Study: Cooling Tower Water Quality Control – ExperTune ASCII/DDE Tuner & Analysis Displays

ExperTune ASCII PID Tuner

File Options Help

OPEN TAG | SAVE TAG | IMPORT ASCII | LOOP SETUP

PID Tuning

Analysis

	Current	New
P	6	1.6
I	120	21
D	0	15
F	0	0.73

Probable Performance Increase: 52%

Controller Tuning

PID Grid | Done tuning

Load tuning - Fastest

Safety Factor : 2.5

☑ Use derivative if possible

☑ Use 1st order PV Filter

Loop Summary | Add to Table

Loop Notes

Created From D:\Program Files\Xtune\dde\CT_ORF

Existing TC's: P=6, I=120 mins/rpt, D=0 mins.
New TC's: P=1.6, I=21 mins/rpt, D=15 mins

Change Notes

ExperTune Loop Summary Table

Archive	Zoom start	Zoom end	P	I	D	F	Fit	Gain	DT min	Lag1 min	Lag2 min	Intg	Stability	RRT sec
003			58	30	5.7	0.28	fair	0.00073	9.2			yes	4	9400
006			1.6	21	15	0.73	ex'lent	0.24	12	imag	imag		100	7900
	Average		30	26	10	0.51		0.12	11					8700
Most	conservative		1.6	21	15	0.73	ex'lent	0.24	12	imag	imag		100	7900

Add | Remove | Copy to New | View Archive | Report | OK | Cancel | Help

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Example Case Study: Cooling Tower Water Quality Control – ExperTune ASCII/DDE Tuner & Analysis Displays (Cont'd)

ExperTune PID Tuning Grid

	Load Tuning	Setpoint	Lambda
		Response time (sec)	Lambda time (sec)
	Safety Factor : 2.5	6600	4500

		Load Fastest	Load Fast	Load Slow	Setpoint	Lambda
P	(Gain)	2.1	0.74	0.41	N/A	N/A
I	(minutes/repeat)	48	11	9.5	N/A	N/A
Filter	(minutes)	4.3	3.4	5.4	N/A	N/A
RRT	(seconds)	6800	11000	14000	N/A	N/A
P	(Gain)	1.6	0.78	0.38	N/A	N/A
I	(minutes/repeat)	21	12	8.9	N/A	N/A
D	(minutes)	15	12	0.19	N/A	N/A
Filter	(minutes)	0.73	0.59	0.0094	N/A	N/A
RRT	(seconds)	8200	10000	15000	N/A	N/A

Quality of frequency data fit: excellent

Sample interval checks OK

☑ Use 1st order PV Filter

Close

Help

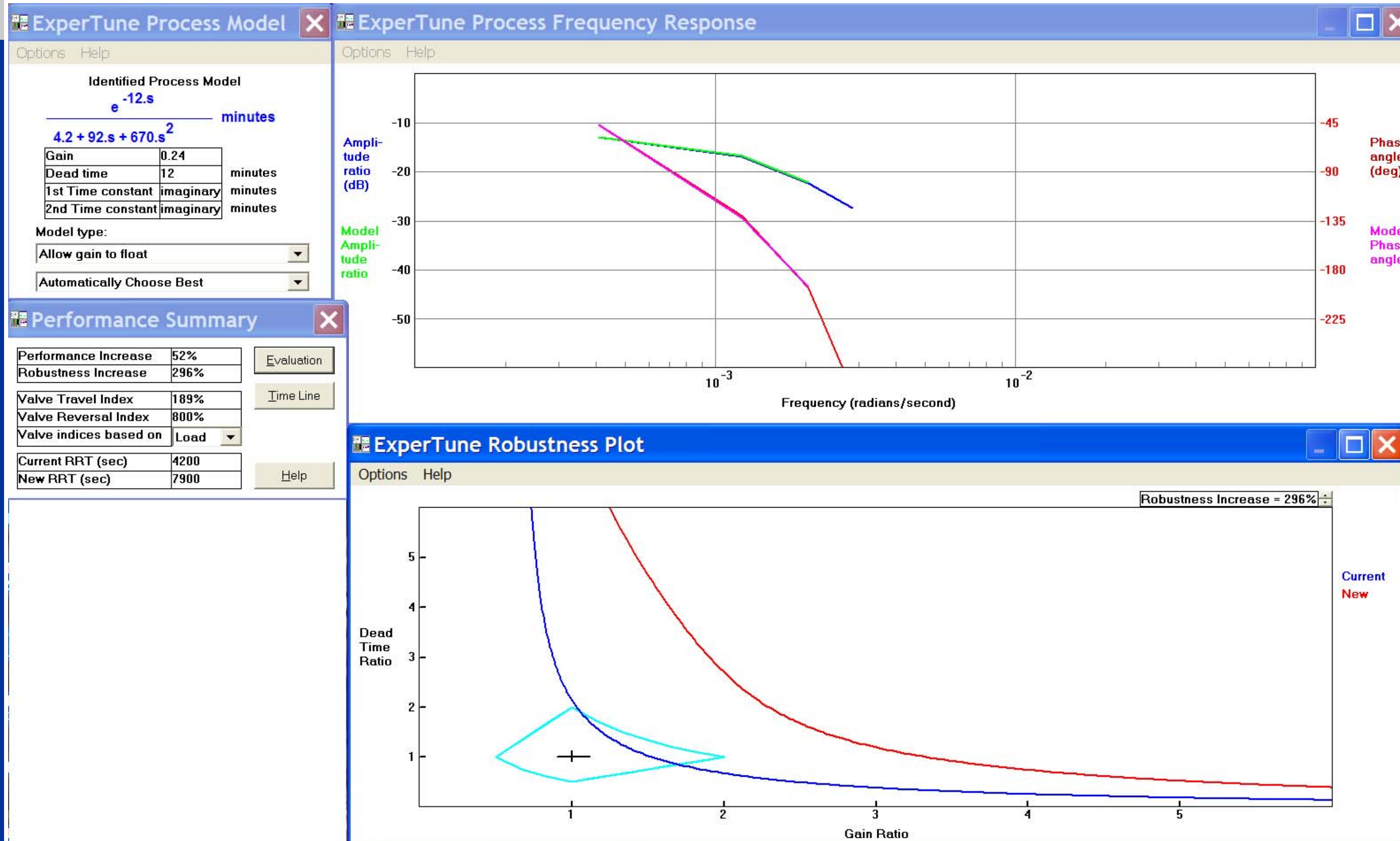
Copy

Lambda

- (•) Lag rule
- ( ) Intg rule

Lag rule only

Example Case Study: Cooling Tower Water Quality Control – ExperTune ASCII/DDE Tuner & Analysis Displays (Cont'd)



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Example Case Study: Cooling Tower Water Quality Control – ExperTune ASCII/DDE Tuner & Analysis Displays (Cont'd)

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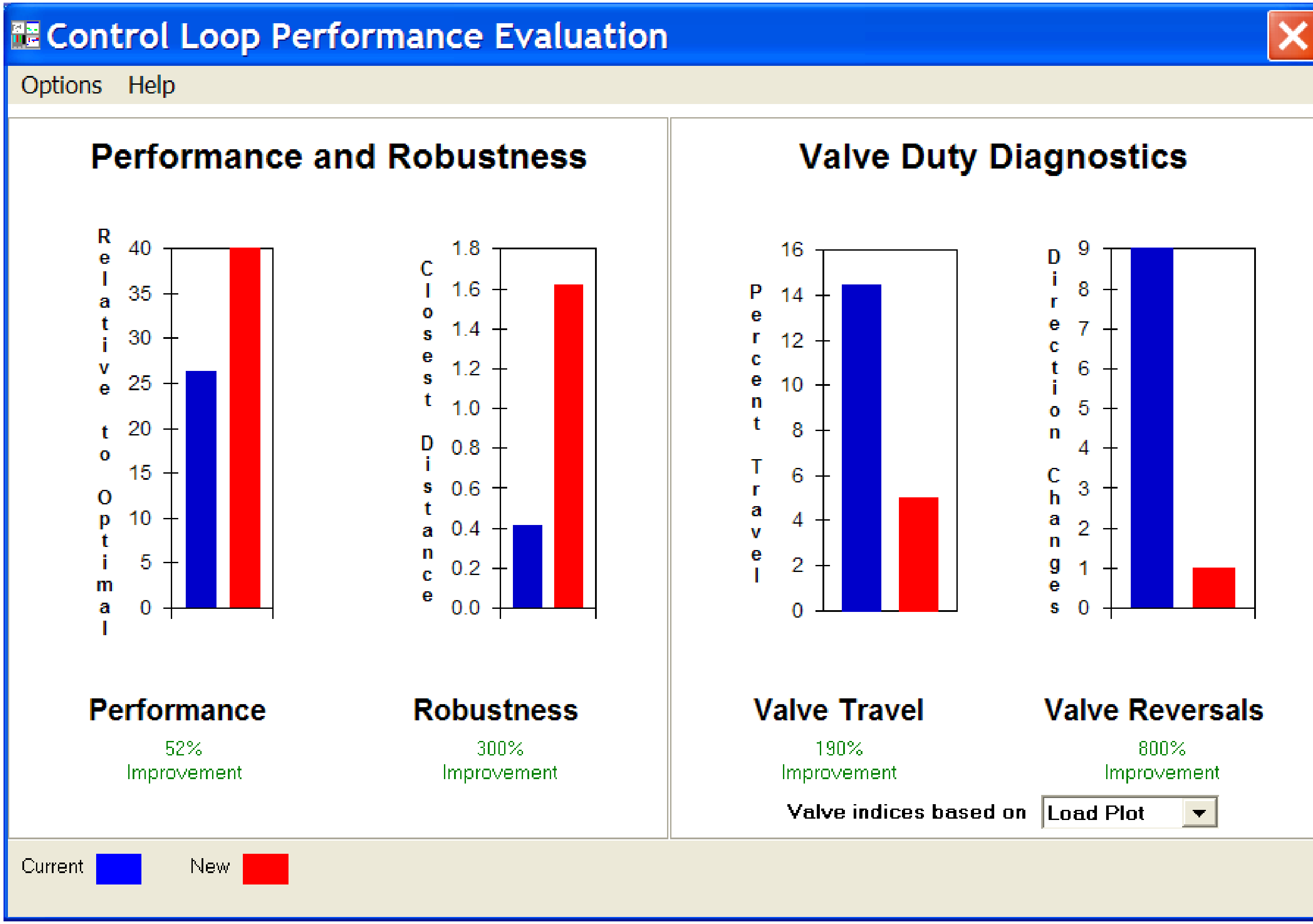

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Example Case Study: Cooling Tower Water Quality Control – ExperTune ASCII/DDE Tuner & Analysis Displays (Cont'd)

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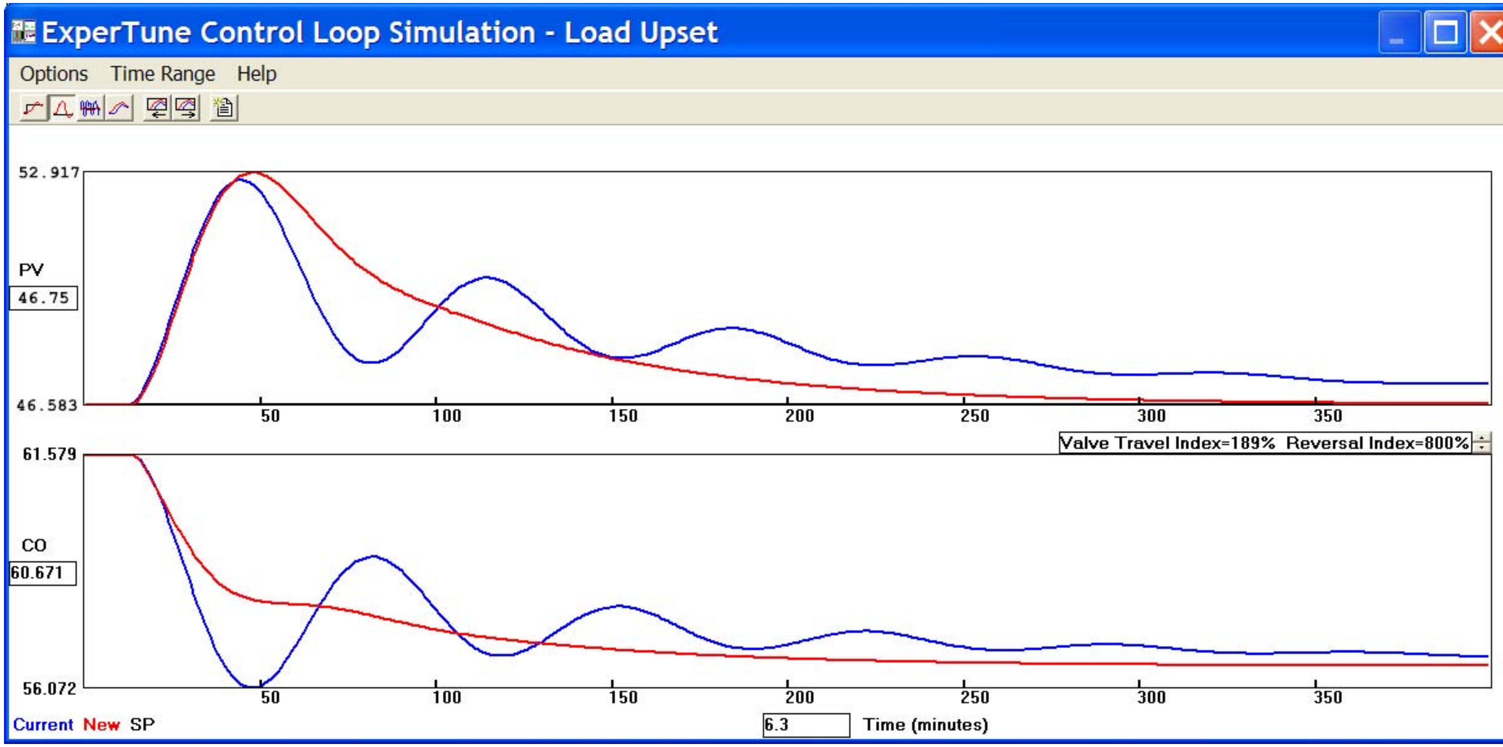

<u>ACTUAL PLANT PERFORMANCE RESULTS:</u> REDUCED AVERAGE ORP PV VARIANCE FROM SETPOINT FROM +/- 45% BEFORE EXPERTUNE TUNING TO LESS THAN +/-5% AFTERWARDS WITH NEW TUNING CONSTANTS

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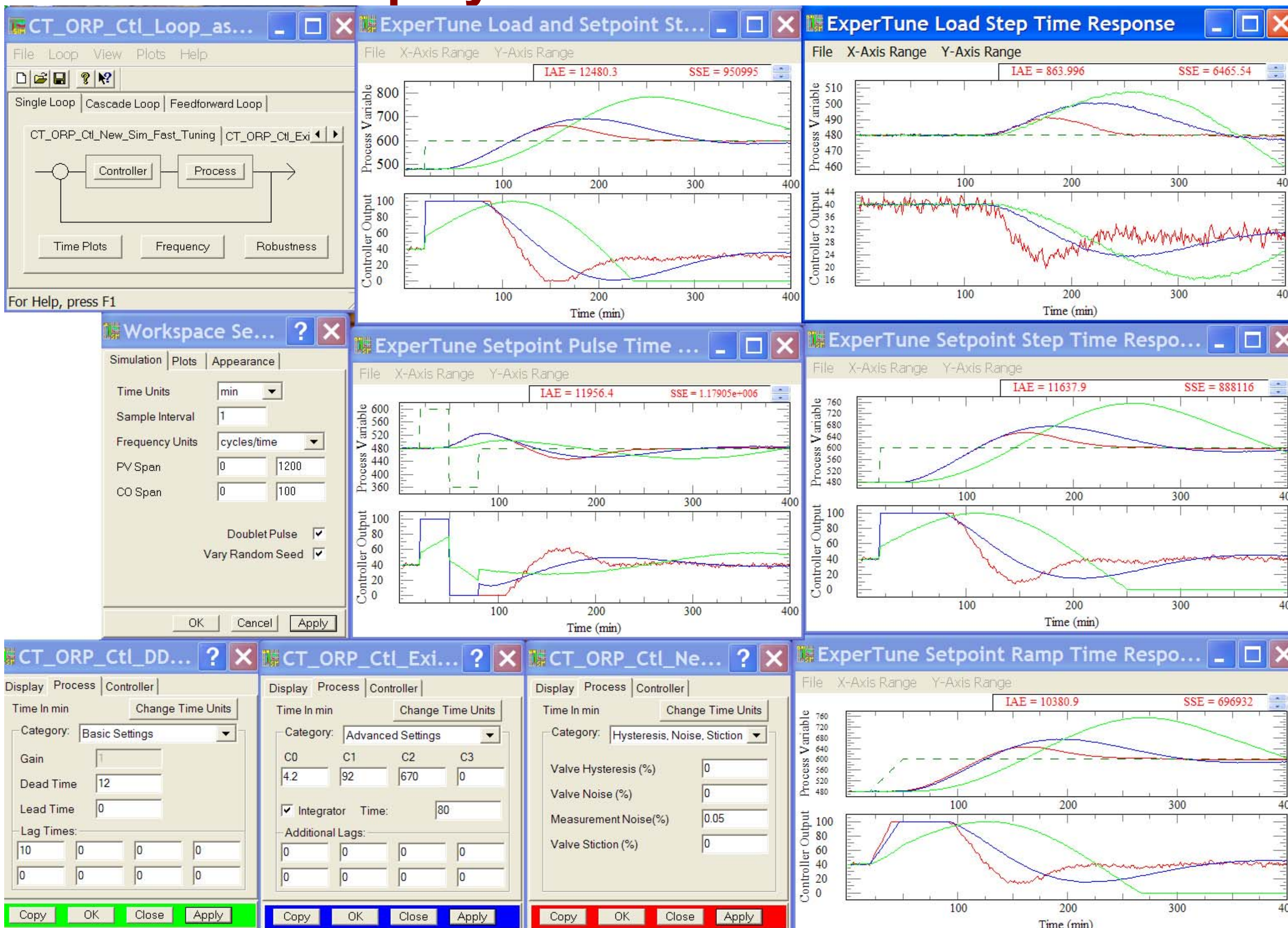
Example Case Study: Cooling Tower Water Quality Control – ExperTune Optional PID Loop Simulator Displays



References

A. Useful Reference Texts – Controller Tuning

— (1) Good Tuning: A Pocket Guide*, Vol. EMC 27.01, Gregory K. McMillan, ISA Press, 2000, ISBN 1-55617-726-7, 112 pp.

— (2) Controller Tuning and Control Loop Performance - A Primer, 2nd Ed., David W. St. Clair, Straight-Line Control Co., Inc., 3 Bridle Brook La., Newark, DE 19711-2003 (ph. 302-731-4699,) 1993, ISBN 0-9669703-0-6, 94 pp.

— (3) Tuning of Industrial Control Systems, 2nd Ed.*, Vol. EMC 51.01, Armando B. Corripio, ISA Press, 2001, ISBN 1-55617-713-5, 254 pp.

— (4) Tuning and Control Loop Performance – A Practitioner's Guide, 3rd Ed., Gregory K. McMillan, ISA Press, 1994, ISBN 1-55617-492-6, 432 pp. (out-of-print--a reprint from microfiche can be ordered from AstroLogos Books**:https://secure.bibliology.com/enquiry/Enquiry_Options.html?bfbid=7338714)

— (5) PID Controllers: Theory, Design, and Tuning, 2nd Ed., K. Astrom and T. Hagglund, ISA Press, 1995, ISBN 1-55617-516-7, 343 pp.

Note: can be purchased as an e-book in Adobe Acrobat Reader (.pdf) format from ISA.

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References (Cont’d)

B. Useful Reference Texts – Process Control Basics

- (1) Process Control – A Primer for the Non-specialist and the Newcomer, 2^{nd} Ed., George Platt, ISA Press, 1998, ISBN 1-55617-633-3, 216 pp.
- (2) Measurement and Control Basics*, 3^{rd} Ed., Thomas A. Hughes, ISA Press, 2002, ISBN 1-55617-764-X, 375 pp.
- (3) Fundamentals of Process Control Theory, 3^{rd} Ed., Paul W. Murrill, ISA Press, 2000, ISBN 1-55617-683-X, 333 pp.
- (4) Regulatory and Advanced Regulatory Control: System Development, Harold L. Wade, ISA Press, 1994, ISBN 1-55617-488-8, 261 pp.
- (5) Design and Application of Process Control Systems, Armando B. Corripio, ISA Press, 1998, ISBN 1-55617-639-2, 319 pp.
- (6) Process Control Systems-Application, Design, and Tuning, 4th Ed., F. G. Shinskey, 1996, McGraw-Hill, ISBN 0-0705-7101-5, 439 pp.

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References (Cont'd)

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C. Relevant Articles

- (1) *"How To Tune Feedback Controllers*,"* Armando B. Corripio, ISA Press, 27 pp.
- (2) *"Feedback Controllers*,"* Armando B. Corripio, ISA Press, 32 pp.
- (3) *"Tuning Cascade Control Systems*,"* Armando B. Corripio, ISA Press, 21 pp.
- (4) *"Feedforward and Ratio Control*,"* Armando B. Corripio, ISA Press, 27 pp.
- (5) *"Adaptive and Self-Tuning Control*,"* Armando B. Corripio, ISA Press, 26 pp.
- (6) *"PI and PID Controller Tuning Rules for Time Delay Processes: a Summary,"* Aidan O'Dwyer, School of Control Systems and Electrical Engineering, Dublin Institute of Technology, May 2000, 205 pp., Website Download URL: http://citeseer.nj.nec.com/dwyer00pi.html
- (7) *"PID Compensation of Time Delayed Processes: a Survey,"* Aidan O'Dwyer, School of Control Systems and Electrical Engineering, Dublin Institute of Technology, May 2000?, 9 pp., Website Download URL: http://citeseer.nj.nec.com/398682.html
- (8) *"Time Delayed Process Model Parameter Estimation: a Classification of Techniques,"* Aidan O'Dwyer, School of Control Systems and Electrical Engineering, Dublin Institute of Technology, July 2000, 9 pp., Website Download URL: http://citeseer.nj.nec.com/398869.html
- (9) *"One Size Does Not Fit All: Tuning a Controller for Your Specific Process*,"* George Buckbee, ISA Press, 9 pp.

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References (Cont'd)

- **C. Relevant Articles (Cont'd)**

  - (10) *"Achieving Huge ROI Through Controller Tuning and Optimization*,"* George Buckbee, ISA Press, 4 pp.
  - (11) *"A Simple Method to Determine Control Valve Performance and Its Impact on Control Loop Performance*,"* Michel Ruel, ISA Press, 10 pp.
  - (12) *"The Control Valve and Its Effect on Process Performance*,"* Mark Henson, ISA Press, 10 pp.
  - (13) *"Control Loop Tuning with Smart Positioner*,"* Janne Laaksonen & Jouni Pyotsia, ISA Press, 7 pp.
  - (14) Source for many relevant online articles and presentations: *"ExperTune Process Control Articles and Software Reviews,"* ExperTune, Inc., Website URL: http://www.expertune.com/articles.html
  - (15) *"Tuning PI Controllers for Integrator/Dead Time Processes,"* Bjorn D. Tyreus and William L. Luyben, Industrial Engineering Chemistry Research, 1992, 31(11), 2625-2628.
  - (16) *"Identification and Tuning of Processes with Large Deadtime,"* S.G. Sain and C. Özgen, Control and Computers, 1992, 20(3), 73-78.
  - (17) *"On-line PI Controller Tuning for Integrator/Dead Time Processes,"* I.K. Kookos, A.I. Lygeros, K.G. Arvanitis; European Journal of Control, 1999, 5, 19-31.

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Appendix 1

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Default and Typical Tuning Settings – Ref. A.1*

Table 2 – Default and Typical PID Settings (scan in sec, reset in rep/min, and rate in minutes; λ = Lambda, CLM = Closed-loop method; SCM = Shortcut method)

Application Type	Scan (seconds)	Gain	Reset (repeats)	Rate (minutes)	Method
Liquid Flow/Press	1 (0.2-2)	0.3 (0.2-0.8)	10 (5-50)	0.0 (0.0-0.02)	λ
Tight Liquid Level	5 (1.0-30)	5.0 (0.5-25)*	0.1 (0.0-0.5)	0.0 (0.0-1.0)	CLM
Gas Pressure (psig)	0.2 (0.02-1)	5.0 (0.5-20)	0.2 (0.1-1.0)	0.05 (0.0-0.5)	CLM
Reactor pH	2 (1.0-5)	1.0 (0.001-50)	0.5 (0.1-1.0)	0.5 (0.1- 2.0)	SCM
Neutralizer pH	2 (1.0-5)	0.1 (0.001-10)	0.2 (0.1-1.0)	1.2 (0.1-2.0)	SCM
Inline pH	1 (0.2-2)	0.2 (0.1-0.3)	2 (1-4)	0.0 (0.0-0.05)	λ
Reactor Temperature	5 (2.0-15)	5.0 (1.0-15)	0.2 (0.05-0.5)	1.2 (0.5-5.0)	CLM
Inline Temperature	2 (1.0-5)	0.5 (0.2-2.0)	1.0 (0.5-5.0)	0.2 (0.2-1.0)	λ
Column Temperature	10 (2.0-30)	0.5 (0.1-10)	0.2 (0.05-0.5)	1.2 (0.5-10)	SCM

* An error/square algorithm or gain scheduling should be used for level loops with gains < 5

*Excerpted from Ref. A.1 by Gregory K. McMillan, p. 45, © 2000 Instrument Society of America (ISA.) Table note: first constant is a default, while the constants in parentheses represent a typical range of values. SCM is an Open Loop Tuning Method.

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Appendix 2

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- **Default and Typical Tuning Settings – Ref. C.14***

Initial Settings For Common Control Loops For Some Ideal and Series Controllers

Loop Type	*PB %*	*Integral min/rep*	*Integral rep/min*	*Derivative min*	*Valve type*
Flow	50 to 500	.005 to .05	20 to 200	none	Linear or Modified Percentage
Liquid Pressure	50 to 500	.005 to .05	20 to 200	none	Linear or Modified Percentage
Gas Pressure	1 to 50	.1 to 50	.02 to 10	.02 to .1	Linear
Liquid Level	1 to 50	1 to 100	.01 to 1	.01 to .05	Linear or Modified Percentage
Temperature	2 to100	.2 to 50	.02 to 5	.1 to 20	Equal Percentage
Chromatograph	100 to 2000	10 to 120	.008 to .1	.1 to 20	Linear

These settings are rough, assume proper control loop design, ideal or series algorithm and do not apply to all controllers.

Use ExperTune PID Tuner to find the proper PID settings for your process and controller.

***Excerpted from Ref. C.14 (near bottom of web page) by John Gerry, © 2002 ExperTune, Inc. Table note: PB % = Controller Proportional Band in % = 100/Controller Gain.**