Table of Contents

Chapter 1: Introduction to Process Control
1.1 Why Process Control?
1.2 An Overview of the Technology
   1.2.1 Common Control Configurations
   1.2.2 Control Hardware
   1.2.3 The Mathematics of Feedback Control
   1.2.4 Control Technology Hierarchy
1.3 Historical Background
1.4 Uniqueness of Pulp and Paper Processes from a Control Perspective
1.5 The Status of Control in the Pulp and Paper Industry
   1.5.1 Control Loop Effectiveness
   1.5.2 Types of Control Technology
   1.5.3 Application of Control Loops
1.6 Important Control Concepts

Chapter 2: Summary of Conventional Process Control Concepts
2.1 Overview
2.2 Modeling for Control
   2.2.1 Types of Dynamic Processes
   2.2.2 Instantaneous or Steady-State Processes
   2.2.3 First-Order Lag
   2.2.4 Second-Order Processes
   2.2.5 Deadtime or Transport Delay
   2.2.6 Higher-Order Processes
2.3 Balances
   2.3.1 Mass and Energy
   2.3.2 Deviation from the Steady State
2.4 Laplace Transform
   2.4.1 Laplace Transforms of Important Functions
   2.4.2 Final Value Theorem
2.4.3 Initial Value Theorem
2.4.4 Laplace Transform of the Driving Force
2.4.5 Inverting the Transform
2.5 Solving the Dynamic Model
   2.5.1 Method of Partial Fractions
   2.6 First-Order Response
   2.7 Transfer Function
   2.8 Gain
   2.9 Nonlinearity
   2.10 Linearization and Decoupling
2.11 Second-Order Systems
   2.11.1 Roots of the Second-Order Polynomial
   2.12 the Characteristic Equation
   2.13 Higher than Second-Order Systems
   2.14 Process Disturbances
   2.15 Summary of Process Dynamics
2.16 Completing the Process Model
   2.16.1 Feedback Control
   2.17 PID Controllers
   2.17.1 Introduction to Controller Dynamics
   2.17.2 Basic Elements of PID Control
   2.17.3 Summary of PID Controls
   2.18 Difficult Control Situations
   2.18.1 Controllers for Processes with Deadtime
   2.18.2 Feedforward Control
   2.18.3 Cascade Control

Chapter 3: Field Devices: Sensors and Transmitters
3.1 Introduction
3.2 Brief History of the Evolution of Field Devices
3.3 Pressure Measurement
3.3.1 Mechanical Pressure Measuring Devices
3.3.2 Electrical Pressure Sensors
3.3.3 Capillary and Other Filled System Temperature Sensors
3.3.4 Installation of Temperature Sensors

3.4 Temperature Measurement
3.4.1 Thermocouples
3.4.2 Resistance Temperature Detectors (RTDs) and Thermistors
3.4.3 Infrared Temperature Sensors
3.4.4 Laser and Laser-Corrected Emissivity Sensors
3.4.5 Fiber Optic/Infrared Temperature Sensors
3.4.6 Ultrasonic Temperature Sensors
3.4.7 Filled Thermal Devices
3.4.8 Miscellaneous Temperature Sensors

3.5 Flow Measurement
3.5.1 Head Loss Flowmeters
3.5.2 Electromagnetic Flowmeters
3.5.3 Turbine Flowmeters
3.5.4 Vortex Flowmeters
3.5.5 Mass Flow (Coriolis Force) Flowmeters
3.5.6 Ultrasonic Flowmeters
3.5.7 Thermal Flowmeters
3.5.8 Positive Displacement Flowmeters
3.5.9 Target Flowmeters
3.5.10 Optical Flowmeters
3.5.11 Steam Flowmeters
3.5.12 Solids Flow Flowmeters

3.6 Level Measurement
3.6.1 Bubble Tube Level Devices
3.6.2 Flanged Differential Pressure Devices
3.6.3 Ultrasonic Devices
3.6.4 Nuclear Devices
3.6.5 Capacitance Devices
3.6.6 Radar and Microwave Devices

3.7 Common Miscellaneous Sensors
3.7.1 pH Sensors
3.7.2 Oxidation-Reduction Potential (ORP) Sensors
3.7.3 Conductivity Sensors
3.7.4 Consistency Sensors
3.7.5 Brightness Sensors

3.8 Measurement Technique

Chapter 4: from Instrumentation to Implementation
4.1 Process Block Diagrams (PBDs)
4.2 Process Flow Diagrams (PFDs)
4.3 Process and Instrumentation Diagrams (PIDs)
4.4 Instrumentation and Control Standards
4.5 Loop Diagrams
4.6 Instrument Index
4.7 Final Control Elements

Chapter 5: Review of Control Analysis Techniques
5.1 Introduction
5.2 the Control Loop Analysis
5.3 the Process Transfer Function
5.3.1 First-Order plus Deadtime Response
5.3.2 Second-Order Overdamped Response
5.3.3 Integrating Process Response
5.4 Modeling Deadtime
5.4.1 First-Order Taylor Series Approximation
5.4.2 Padé Approximation
5.5 the Controller Transfer Function
5.5.1 Sampled Data or Discrete Form Bump Test Method
5.5.2 Bump Test Method
5.6 Calculating the Loop Transfer Function
5.7 Root Locus Analysis to Predict Closed-
Loop Behavior from the Loop Transfer Function
5.7.1 Rules for Interpreting Root Locus Plots
5.7.2 Root Locus Examples
5.7.3 Root Locus Manual Sketching Rules
5.8 Frequency Response Design Criteria - Gain and Phase Margin
5.8.1 Stability - Gain Margin, Phase Margin, and the Bode Plot
5.8.2 Robustness - Gain Margin, Phase Margin, and the Bode Plot
5.8.3 Stability and Robustness
5.8.4 Setpoint Response and Load Response
5.8.5 Robustness
5.8.6 Robustness, Gain Margin, and Phase Margin Criteria
5.9 Calculation of the Setpoint Response
5.10 Calculation of the Load Response
5.11 Variability Analysis
5.11.1 the Nature of Noise and Disturbances
5.11.2 Statistics and Variability
5.11.3 Variability and the Power Spectrum
5.11.4 the Period Plot
5.11.5 Power Spectrum Log-Log Plot
5.12 Conclusion

Chapter 6: Controller Tuning Methods
6.1 Introduction
6.1.1 Types of PID Algorithms
6.1.2 Historical Methods of Loop Tuning
6.1.3 Modern Tuning Methods (Lambda Tuning)
6.1.4 PID Tuning Procedures
6.2 Simple Models
6.2.1 Obtaining Simple Models
6.2.2 Determining P, I, and D Parameters
6.2.3 Other Tuning Considerations
6.3 Specific Control Applications
6.3.1 Tuning Flow Control Loops
6.3.2 Tuning Temperature Control Loops
6.3.3 Tuning Level Control Loops
6.3.4 Tuning Control Loops for First Order Plus Deadtime Processes (Consistency Control)
6.3.5 Tuning Cascade Control Loops

Chapter 7: Control Objectives for Uniformity in Pulp and Paper Manufacturing
7.1 Introduction
7.1.1 Historical Perspective
7.2 Nature of Pulp and Paper Manufacturing Process
7.2.1 Pulp and Paper Agitation and Mixing
7.3 Process Related Variability and the Link to End-Use Performance
7.3.1 Competitive Position

7.3.2 Old Concepts of Variability
7.3.3 Process Variability Spectrum as Seen at the Paper Machine
7.3.4 Very High Frequency Furnish Mix
7.3.5 High Frequency Process Design/Maintenance Problems
7.3.6 Low Frequency Process Control Considerations and Problems
7.3.7 Very Low Frequency Pulp and Paper Tests

7.4 Sensors, Signal Filtering, and Interpretation
7.4.1 Digital Sampling and Aliasing
7.4.2 Data Averaging
7.4.3 Cross-Direction Data Points (Data Boxes)
7.4.4 Single-Point (Fixed-Point) Data
7.4.5 Scan-Average
7.4.6 2-Sigma Variability Analysis

7.5 Control Loop Characteristics
7.5.1 Closed-Loop Time Constant Lambda (\(\Lambda\))
7.5.2 Operational Motivation
7.5.3 Generic Characteristics of Regulatory Control Loops
7.5.4 Loop Cut-Off Frequency
7.5.5 Common Causes of Cycling and Variability
7.5.6 Variability Impact of Control Loop Tuning

7.6 Market Perspective - Variability Audit Results
7.6.1 Basis Weight Machine Direction (MD) variability
7.6.2 Causes of Variability on the Paper Machine

7.7 Pulp Mill Variability and its Impact on the Paper Machine

7.8 Paper Variability and Converting Equipment Runnability
7.8.1 Pressroom Operation
7.8.2 Converting Operations
7.8.3 Boxplants and Corrugators

7.9 Status of Control Loops in the North American Pulp and Paper Industry
7.9.1 Control Technology
7.9.2 Applications
7.9.3 Control Algorithms
7.9.4 Typical Process Variability
7.9.5 Impact of Process Variability on Product Uniformity
7.9.6 Control Engineering and the Human Dimension
7.9.7 Pulp and Paper Control Engineering Skills
7.9.8 Old Tuning Methods and Their Legacy
7.10.1 Fatal Flaws of the Quarter Amplitude damping method
7.11 Control Objectives for Pulp and Paper
12.2.7 Programmable Logic Controllers (PLCs)
12.2.8 Smart Sensor Measurement Network Interfaces
12.2.9 Other Distributed Control Interfaces
12.2.10 Controller Devices
12.2.11 DCS Consoles and Work Stations
12.2.12 Engineer's Work Station
12.2.13 Peripheral Devices
12.2.14 Distributed Control Service Tools

12.3 DCS Configuration
12.3.1 DCS System Configuration
12.3.2 DCS Controller Software
12.3.3 Alarm Configuration
12.3.4 Console Displays

12.4 Distributed Control and its Effect on Mill Operations

Chapter 13: Process Optimization
13.1 Introduction
13.2 Definitions
  13.2.1 Variables
  13.2.2 Model
  13.2.3 Objective Function
  13.2.4 Constraints
  13.2.5 Degrees of Freedom
  13.2.6 Math Program
13.3 Optimization Methods
  13.3.1 Analytical Methods
  13.3.2 Linearization
  13.3.3 Numerical Search Methods
13.4 Strategies and Examples
  13.4.1 Off-Line Optimization
  13.4.2 Real-Time Optimization
13.5 Summary

Chapter 14: Artificial Intelligence
14.1 Definitions and Background
14.2 Expert Systems
  14.2.1 Background
  14.2.2 Problem Selection
  14.2.3 Structure
  14.2.4 Predicate Calculus
  14.2.5 Production Rules
  14.2.6 Frames and Scripts
14.3 Fuzzy Logic Control (FLC)
  14.3.1 Background
  14.3.2 Basic Concepts of Fuzzy Logic Control
  14.3.3 Fuzzy Logic Control Design
  14.3.4 Comments on the Use of Fuzzy Logic
  14.3.5 Potential Applications of Fuzzy Logic in the Pulp and Paper Industry
  14.3.6 an Example of Fuzzy Consistency Control
  14.3.7 Tuning the Fuzzy Consistency Control
14.4 Neural Network Systems

Chapter 15: Economic Analysis and Justification
15.1 Introduction
15.2 Financial Analysis Concepts
  15.2.1 Depreciation
  15.2.2 Time Value of Money
15.3 Financial Analysis Methods
  15.3.1 Payback Period
  15.3.2 Net Present Value
  15.3.3 Internal Rate of Return
  15.3.4 Incremental Benefits
15.4 Process Areas
  15.4.1 Powerhouse Systems
  15.4.2 Woodyard
  15.4.3 Digesters
  15.4.4 Brown Stock Washers
  15.4.5 Bleach Plants
  15.4.6 Tower Level Control
  15.4.7 Paper Machines
  15.4.8 Coaters
  15.4.9 Supercalenders
  15.4.10 Roll Finishing and Shipping
  15.4.11 Information Systems
  15.4.12 Customer Information/Quality
  15.4.13 Continuous Improvement
15.5 Sample Economic Analysis Decision

Chapter 16: Case Study: the MWCS Project
16.1 Introduction
16.2 Project Description
16.3 Corporate Background
  16.3.1 Business Unit
  16.3.2 Technology Organization
  16.3.3 Corporate Engineering
  16.3.4 Management Information Systems Organization
16.4 Technology Transfer: Overcoming the Barriers
  16.4.1 Credibility of the Technology
  16.4.2 Organizational Changes
  16.4.3 Perceived Benefits
  16.4.4 Consensus
16.5 Project Results
  16.5.1 Quantifiable Benefits
  16.5.2 Mill Ownership
  16.5.3 Team Building
  16.5.4 Mill-Resident Technology Engineers
16.5.5 Cultural Change
16.6 Time Line
16.7 Summary
16.8 Conclusion

Chapter 17: the Marketplace and the Future
17.1 Introduction
17.2 Pulp and Paper Process Control - the Current Status
   17.2.1 Steady State Thinking and Variability
   17.2.2 Lessons Learned from Variability Audits
   17.2.3 the Manufacturing Team
   17.2.4 Process Control Competence of the Manufacturing Team
   17.2.5 Control Education and the Control Engineer
17.3 A View from the Chemical Industry
   17.3.1 Focus on Quality and SPC in the Chemical Industry
   17.3.2 Chemical Industry Algorithm Design - Trending Toward Generality
   17.3.3 The Chemical Industry's Control Strategy Focus
   17.3.4 Process Design and Process Control in the Chemical Industry
   17.3.5 Process Control Education in the Chemical Industry
17.4 Staffing, Organizations, and "Culture"
   17.4.1 Process Control Staffing Levels
   17.4.2 Organizations, Culture, and "Turf"
   17.4.3 Management Awareness
17.5 A View of the Future
17.6 Conclusion