Control Loop Foundation
Batch and Continuous Processes

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# Control Loop Foundation Short Course

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Control Loop Foundation Short Course

- Short Course will provide a summary of key points and examples from Control Loop Foundation.
- All workshops and application examples in the book are based on DeltaV control capability. This book is available at www.isa.org and this week at the ISA booth.
- The application section is designed to show how control techniques may be combined to address more complex process requirements.
- The book web site may be accessed to perform the workshops and to obtain hands-on experience using application example. Copies of the modules and trends may be downloaded from the web site and imported into a DeltaV system.
- A new class, Control Loop Foundation - Course 9025, is available through the education department.
Introduction

- Control Loop Foundation address the concepts and terminology that are needed to work in the field of process control.
- The material is presented in a manner that is independent of the control system manufacturer.
- Much of the material on the practical aspects of control design and process applications is typically not included in process control classes taught at the university level.
- The book is written to act as a guide for engineers who are just starting to work in this field.
- Experienced control engineers will benefit from the application examples on process control design and implementation of multi-loop control strategies.
Background - Different Construction Techniques

Figure 2-1. Plant with Enclosed Construction

Figure 2-2. Plant with Open Construction
Wiring Practices

Figure 2-14. Controller Termination Boards

Figure 2-15. Junction Box for Field Wiring

Figure 2-3. Cable Tray and Conduit for Instrumentation Wiring
Plant Organization

- Common terms used to describe plant organization are introduced.
- Plant Area – classification by name and area number
- Units within a process Area

Figure 2-4. Multiple Power Boilers in the Powerhouse Area

Build on Your Knowledge.
2010 Emerson Global Users Exchange

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Lab, Control Room, Lab and Rack Room

Figure 2-5. Lab Used to Provide Analysis of Quality-related Parameters

Figure 2-12. Custom Furniture Used in a Control Room

Figure 2-13. Rack Room for Distributed Control Equipment
Existing System – Electronic and Pneumatic

Figure 2-6. Panel-based Analog Electronic Control System

Figure 2-7. Circular Chart Recorder in a Control Panel

Figure 2-8. Control Panel Wiring
Impact of DCS Systems

Figure 2-9. Distributed Control System Overview

Figure 2-10. Operator Interface Graphical Displays
Integration of External System/Interface

Figure 2-16. Addressing Specialized Applications with a PLC

Figure 2-17. Vibration Monitoring System

Figure 2-18. Local Interface
Modern DCS Controller

Figure 2-19. Comparison of Multi-loop Controller Designs

Figure 2-20. Field Wiring and Terminations
Impact of Digital Communications

- Ethernet
- Fieldbus – Foundation Fieldbus, Profibus
- Wireless - WirelessHART

Figure 2-21. Field Wiring Using Bus Technology
Wireless Impact

- Wireless Field Devices
- Relatively simple - Obeys Network Manager
- Gateway and Access Points
- Allows control system access to WirelessHART Network Gateways
- Manages communication bandwidth and routing
WirelessHART Objectives

- Satisfy the end users concerns
  - Reliable & Secure
  - Fit for Industrial Environments

- Keep it simple
  - As simple as 4-20mA HART
  - Instruments should be Intelligent and easy to use

- Use Existing tools
  - Update DD for Handheld and Asset Management applications
  - Same tools – same procedures
Satisfy the end users concerns

- **Reliable**
  - Use Mesh for redundant paths (A – B)
  - Redundant Gateway to the Host
  - Multiple Network Access Points
  - Coexistence with neighbouring networks
    - Channel hopping
    - TDMA
    - Low Power

- **Secure**
  - Device Authentication
  - AES128 Encryption
  - Anti-Jamming
    - Channel Hopping
  - Verification at MAC Layer
  - Key Management
Device Types

- **Wireless Field Devices**
  - Relatively simple - Obeys Network Manager
  - All devices are full-function (e.g., must route)

- **Adapters**
  - Provide access to existing HART-enabled Field Devices
  - Fully Documented, well defined requirements

- **Gateway and Access Points**
  - Allows access to WirelessHART Network from the Process Automation Network
  - Gateways can offer multiple Access Points for increased Bandwidth and Reliability
  - Caches measurement and control values
  - Directly Supports WirelessHART Adapters
  - Seamless access from existing HART Applications

- **Network Manager**
  - Manages communication bandwidth and routing
  - Redundant Network Managers supported
  - Often embedded in Gateway
  - Critical to performance of the network

- **Handheld**
  - Supports direct communication to field device
  - For security, one hop only communication

- **All devices compatible with existing DD-enabled Applications**
Impact of Standard on Control

- ISA88 – Batch terminology
- IEC 61804 – Function blocks for the process industry.

Figure 2-22. Overview of ISA-88 Terminology

Figure 2-23. Function Blocks in Control Applications
Introduction to devices used for basic measurement
- Magnetic flow meter
- Vortex flow meter
- Differential pressure for flow measurement
- Coriolis flow meter
- Absolute and gauge pressure
- Temperature – RTD, thermocouple
- Level based on pressure/differential pressure
- Level - Radar
Device Calibration

- Concept of devices calibration and configuration is introduce.
- Role of hand held devices and EDDL is addressed

Figure 3-4. Hand-held Device to Check and Set Transmitter Calibration
Analyzers

- Difference between sampling and situ analyzers is addressed
- Impact of sampling system on maintenance and measurement delay is highlighted
A couple of common situ analyzers are addressed to show features and options
- Flue Gas O2
- pH/ORP

Calibration of analyzer and role of sample/hold when used in control is addressed.
Final Control Element

- Basic final control elements are addressed:
  - Sliding stem valve
  - Rotarty valve
  - Damper drive
  - Variable speed drive
  - Block valve

- Advantages and limitations are discussed
Final Control Element Terminology

- Common terms associated with final control elements are defined
  - Positioner
  - Actuator
  - Valve Body

Figure 5-2. Example of a Rotary Valve
Installed Characteristics

- Types of valve characteristics and their impact on installed characteristics is addressed

![Graph showing different valve characteristics](image)

**Figure 5-3. Valve Characteristic**
Field Wiring and Communications

- Installation of 2-wire vs 4-wire devices is addressed
- Common problems are addressed e.g. need for electric isolation when utilizing a 4-wire device

Figure 6-1. Wiring for Traditional Installation

Figure 6-2. Wiring for Four-wire Transmitters
Fieldbus Installation

- Special requirements for a fieldbus installation are addressed
- Common terminology is defined:
  - Multi-drop
  - Power conditioner
  - Terminator

Figure 6-4. Foundation Fieldbus Segment
Control System Documentation

- Documentation that is typically generated for a control system installation are addressed.
- The purpose of each document is explained.
- Reference provided to ISA-5.4 standard for Instrument Loop Diagrams
**Tag Convention – ISA S5.1**

**TYPICAL TAG NUMBER**
- TIC 103 - Instrument Identification or Tag Number
- T 103 - Loop Identifier
- 103 - Loop Number
- TIC - Function Identification
- T - First-letter
- IC - Succeeding-Letters

**EXPANDED TAG NUMBER**
- 10-PAH-5A - Tag Number
- 10 - Optional Prefix
- A - Optional Suffix

**ISA S5.1 Tag Number Convention**

<table>
<thead>
<tr>
<th>First Letters</th>
<th>Succeeding Letters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured/Initiating Variable</td>
<td>Variable Modifier</td>
</tr>
<tr>
<td>A</td>
<td>Analysis</td>
</tr>
<tr>
<td>B</td>
<td>Burner, Combustion</td>
</tr>
<tr>
<td>C</td>
<td>User's Choice</td>
</tr>
<tr>
<td>D</td>
<td>User's Choice</td>
</tr>
<tr>
<td>E</td>
<td>Voltage</td>
</tr>
<tr>
<td>F</td>
<td>Flow, Rate</td>
</tr>
<tr>
<td>G</td>
<td>User's Choice</td>
</tr>
<tr>
<td>H</td>
<td>Hand</td>
</tr>
<tr>
<td>I</td>
<td>Current</td>
</tr>
<tr>
<td>J</td>
<td>Power</td>
</tr>
<tr>
<td>K</td>
<td>Time, Schedule</td>
</tr>
<tr>
<td>L</td>
<td>Level</td>
</tr>
<tr>
<td>M</td>
<td>User's Choice</td>
</tr>
<tr>
<td>N</td>
<td>User's Choice</td>
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<td>O</td>
<td>User's Choice</td>
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<tr>
<td>P</td>
<td>Pressure</td>
</tr>
<tr>
<td>Q</td>
<td>Quantity</td>
</tr>
<tr>
<td>R</td>
<td>Radiation</td>
</tr>
<tr>
<td>S</td>
<td>Speed, Frequency</td>
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<td>T</td>
<td>Temperature</td>
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<tr>
<td>U</td>
<td>Multivariable</td>
</tr>
<tr>
<td>V</td>
<td>Vibration, Mechanical Analysis</td>
</tr>
<tr>
<td>W</td>
<td>Weight</td>
</tr>
<tr>
<td>X</td>
<td>Unclassified</td>
</tr>
<tr>
<td>Y</td>
<td>Event, State, Presence</td>
</tr>
<tr>
<td>Z</td>
<td>Position, Dimension</td>
</tr>
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</table>

*Figure 7-9. ISA-5.1 Identification Letters*
Representation of Signals and Instruments

- Instrument supply or connection to process
- Pneumatic Signal
- Electric Variable or Binary
- Communication Link

Figure 7-10. Excerpt from ISA-5.1 Instrument Line Symbols

Discrete Instrument, field mounted

Discrete instrument, accessible to operator

Visible on video display

Figure 7-11. Excerpt from ISA-5.1 General Instrumentation or Symbol Function
Symbols for Field devices and Elements

- General Symbol
- Ball Valve
- Globe Valve
- Damper

Figure 7-12. Excerpt from ISA-5.1 Valve Body and Damper Symbols

- Generic actuator, Spring-diaphragm
- Spring-diaphragm with positioner
- Linear piston actuator with positioner
- Rotary motor operated actuator
- Solenoid actuator for on-off valve

Figure 7-13. Excerpt from ISA-5.1 Actuator Symbols

- Restriction Orifice, With Flow Transmitter
- Hand Valve
- Inline Measurement
- Measurement Element

Figure 7-14. Excerpt from ISA-5.1 Symbols for Other Devices
Process Symbols

Vessel, Jacketed Vessel, Reactor
Atmospheric Tank, Storage

Heat Exchange

Agitator

Pump

Figure 7-15. Examples of Process Equipment Symbols
Figure 7-16. Example – Basic Neutralizer Control System
Figure 7-17. Basic Column Control System
Figure 7-18. Example – Batch Reactor Control
Symbol Example (Cont.)

Figure 7-19. Example – Continuous Feed and Recycle Tank
An operator interface design is addressed by Alarm Standard EEMUA 191

Advocates that alarms should be in alarm color. Pipes, pumps, valves, etc. should not be in alarm colors, or any other bright color.
Display Tools

- Basic tools for construction a display are discussed
  - Dynamos, dynamic elements, faceplates, links for creating a display hierarchy
Performance Metrics

- Example used to illustrate how operation metrics may be added to an operator display
- Benefits of integrating this type of information into the operator interface

Figure 8-6. Display for Monitoring Performance Indicators
Welcome to the Center for Operator Performance

WHO WE ARE
Operating safely requires redundancy of many components. Operating competitively requires lack of redundancy of the human component.

We are a diverse group of industry, vendor, and academia representatives addressing human capabilities and limitations with research, collaboration, and human factors engineering. Our mission to raise the performance level of our operators and improve Health, Safety, and Environmental effectiveness is accomplished through:

- Openly sharing knowledge and ideas
- Putting collaboration ahead of competition
- Including vendors in research decisions
- Teaming with leading human factors researchers and universities

http://www.operatorperformance.org/
Current Members

- Beville Engineering, Inc.
- Marathon Pipe Line LLC
- Flint Hills Resources
- Wright State University
- Suncor Energy
- Chevron
- Nova Chemicals
- bp
- Emerson
- ABB
Research Programs

- **Completed**
  - Nature of Expertise
  - Decision Making Exercises
  - Simulator Usage
  - Color Usage/Display Design
  - Alarm Rate & Presentation Impact

- **Current**
  - Quantify alarm actuation rates that operators can handle
  - Develop & evaluate effectiveness of decision-based operating graphics
  - Develop systematic approach to documenting “expertise? of senior operators before they walk out the door
  - Evaluate methods of early detection of off-normal operations
  - Data Mining of Near Miss Process Incidents
  - Human Performance Metrics
A plant may be thought of as being made up of a series of processes. A good understanding of these processes is required to design a control system for the plant.

Figure 9-1. Example – Gas Plant Process Flow Diagram

Figure 9-2. De-Iso-Butanizer Process Detail
Process Definition

Process – Specific equipment configuration (in a manufacturing plant) which acts upon inputs to produce outputs.
Process Terminology

- **Controlled output (controlled parameter)** – Process output that is to be maintained at a desired value by adjustment of process input(s).
- **Setpoint** – Value at which the controlled parameter is to be maintained by the control system.
- **Manipulated input (manipulated parameter)** – Process input that is adjusted to maintain the controlled parameter at the setpoint.
- **Disturbance input** – Process input, other than the manipulated input, which affects the controlled parameter.
- **Constraint output (constraint parameter)** – Process output that must be maintained within an operating range.
- **Constraint limit** – Value that a constraint parameter must not exceed for proper operation of the process.
- **Other input** – Process input that has no impact on controlled or constraint outputs.
- **Other output** – Process output other than controlled or constraint outputs.
Example – Application of Terminology

Figure 9-4. Example – Flow Process

Valve Position (Manipulated)
Upstream Pressure (Disturbance)

Flow Process

Flow (Controlled)
Downstream Pressure (Other)
Impact of Disturbance Input

Figure 9-5. Flow Process – Response to Input Change
Example – Lime Mud Filter Process

Figure 9-6. Process Example – Lime Mud Filter
Example – Lime Mud Filter (Cont.)

Value

Flow to Vat

Vat Level

Inlet Density

Pump Speed

Time

Figure 9-7. Lime Mud Filter – Response to Input Change
Pure Gain Process

When the process output tracks the process input except for a change in signal amplitude, the process is known as a pure gain.

The change in signal amplitude is determined by the process gain.

For a step change in process input, the process gain is defined as the change in the process output divided by the change in process input.

Gain = \( \frac{O_2 - O_1}{I_2 - I_1} \)

Note: Output and Input in % of scale

Figure 9-8. Pure Gain Process Response
Example – Pure Gain Process

- An example of a pure gain process is the jack shaft used in some boiler combustion control systems.
- Gain is determined by the length of the lever arms attached to the jack shaft.

Figure 9-9. Pure Gain Process Example
Pure Delay Process

- When the process output tracks the process input except for a delay in the output signal, the process is known as a pure delay process.
- For a step change in the process input, process deadtime is defined as the time from the input changing until the first effect of the change is seen in the process output.
Examples – Pure Delay Process

- Example of pure delay processes are a conveyor belt and a pipeline.
- Delay is the result of transport time and will vary with the speed of the belt or the flow rate through the pipe.
First Order Process

- When process output immediately begin to respond to a step change in a process input and the rate of change is proportional to its current value and the final value the output will achieve, the process is known as a first order process.

- The dynamic response is fully captured by identifying the process gain and the process time constant.
An example of a pure lag process is a tank with outlet flow determined by tank level and the outlet flow restriction caused by the orifice.

The level will settle at a value which results in an outlet flow that matches the inlet flow.

Figure 9-15. Example – Pure Lag Process
Most processes in industry can be approximated as first order plus deadtime processes.

A first order plus deadtime process exhibits the combined characteristics of the lag and delay process.

**Figure 9-16. First Order Plus Deadtime Process**

\[ \text{Gain} = \frac{O_2 - O_1}{I_2 - I_1} \]

\[ \text{Dead Time} = T_2 - T_1 \]

\[ \text{Time Constant} = T_3 - T_2 \]

Note: Output and input are in % of scale.
Example – Steam Heater

- An example of a first order plus deadtime process is a steam heater.
- The process lag is caused by the heating process.
- The process deadtime is caused by transport delay.

Figure 9-17. Heater Example – First Order Plus Deadtime Process
Higher Ordered Systems

• The dynamic response of a process is the results of many components working together e.g. I/P, Valve actuator, heat or fluid/gas transport, etc.

• The net process response of these higher order systems can be approximated as first order plus deadtime.

Figure 9-18. Addressing Higher Order Systems
Combined Impact of Process Dynamics

Figure 9-19. Approximating Higher Order Systems
Integrating Process

When a process output changes without bound when the process input is changed by a step, the process is known as a non-self-regulating or integrating process.

The rate of change (slope) of the process output is proportional to the change in the process input and is known as the integrating gain.

Figure 9-20. Integrating Process Response
Example – Integrating Process

- An example of a non-self-regulating process is tank level where outlet flow is established by a gear pump.
- If the inlet flow does not match the outlet flow, then level will continue to change until the tank overflows or runs dry.

Figure 9-21. Example – Integrating (Non-self-regulating) Process
For a few processes, the initial change in the process output to a step change in a process input will be in the opposite direction of the final output change.

Processes exhibiting this characteristic are said to have an inverse response.
Example – Inverse Response Process

- The level of a vertical thermosiphon reboiler in a distillation column may exhibit an inverse response to a rapid increase in heat input.
- The size or direction of the change in heat input may determine if an inverse response is obtained.
Process Linearity

Figure 9-24. Linear Process Criteria
Example – Non-linear Process

- Most processes may be approximated as linear over a small operating range. However, over a wide range of operation, processes may exhibit some non-linearity.

- A common cause of non-linearity is a change in process gain – reflecting the *installed characteristics of the final control element* i.e. valve acting with the other equipment making up the process, as illustrated in this example.

*Figure 9-25. Example – Process Non-linearity*
Workshop – Use of Process Simulation

Figure 9-26. Typical Control Loop

Figure 9-27. Simulated Process for Workshop Exercises
Three example processes are included in the workshop:
- First order plus deadtime
- Integrating
- Inverse response

Web site is accessed to perform step test. Only a web browser is needed – no software to install.
Control Objective

For the case, production is greatest when the band of variation is reduced to zero and the process parameter is maintained at the value corresponding to maximum production.
Impact of Operating Target

- To benefit from improvement in control, the loop must operate at the target that provides maximum production.

- The plant design conditions may be used as a guide in establishing setpoints for best operation.
For this case, maximum production is obtained by maintaining the process parameter at a limit determined by some plant limitation.

How close to the limit you can operate is determined by the quality of the control.
Impact of Reduced Variability

- Production improvement is obtained by operating closer to product specification or operating limit.
Example - Ammonia Plant

Figure 10-5. Ammonia Plant Example
Example - Ammonia Plant (Cont.)

Figure 10-6. Impact of Synthesis Bed Temperature on Plant Production
Example - Ammonia Plant (Cont.)

Figure 10-7. Synthesis Loop Pressure Control at a Limit
Other Control Objectives
Balancing Control Complexity and Benefits

- Various techniques may be used to improve the control of a process.
- As the complexity of the control system increases, so does cost for operator training and maintenance.
- The complexity (cost) of the control system should be balanced with the benefits provided.
- The benefits of control improvement may be influenced by market conditions i.e. value of product, cost of feedstock, energy cost.
Single Loop Control

- In some cases, manual control may be appropriate.
- Manual Loader Block may be used to implement manual control.

Figure 11-1. Example – Hand Indicator Control
Manual Control Implementation

Figure 11-2. Function Block Implementation of Hand Indicator Control
Processing of Analog Input Signal

Figure 11-3. Analog Input Card Processing
Impact of Aliasing

Value sampled by the control module
Aliased measurement as seen by the control module
Measurement (with noise removed)
Measurement with process noise

Figure 11-4. Aliasing of Measurement
Setup of Anti-aliasing Filter

Figure 11-5. Anti-aliasing Filtering at the Analog Input Card
Processing by Analog Input Block

Figure 11-6. Analog Input Block
Filtering Provided by Analog Input Block

Figure 11-7. Analog Input Filtering
Manual Loader Block

Figure 11-9. Manual Loader Function Block
Analog Output Block

Figure 11-10. Analog Output Block Rate Limiting of Analog Output
Analog Output Block - Rate Limiting

Figure 11-11. Rate Limiting of Analog Output
The *Increase to close* option should be set to account for field reversal (I/P, actuator) so that the SP value always indicates "implied" valve position.

Figure 11-12. IO_OPTS Parameter
Feedback Control

Figure 11-13. Basis of Feedback Control
Proportional Only Control

\[ \text{OUT} = K_p \times \text{Error} + \text{BIAS} \]

Where

- OUT = Output of Controller
- \( K_p \) = Proportional Gain
- Error = Difference between the Setpoint and the controlled parameter
- BIAS = Bias value, also known as manual reset

P-Only

Figure 11-14. Proportional-Only Control
Proportional Plus Integral (PI) Control

\[ \text{OUT} = K_p \left( \text{Error} + \frac{1}{K_I} \sum \text{Error} \times \Delta t \right) \]

Where

- **OUT** = Output of Controller
- **$K_p$** = Proportional Gain
- **Error** = Difference between the Setpoint and the controlled parameter
- **$K_I$** = Reset time, second per repeat
- **$\Delta t$** = Period of execution (sec)

Figure 11-15. Proportional-Integral Control (PI Control)
Proportional, Integral, Derivative (PID) Control

\[ \text{OUT} = K_p \left( \text{Error} + \frac{1}{K_i} \sum \text{Error} \times \Delta t + K_d \times \text{Rate of Change} \right) \]

Where:
- **OUT** = Output of Controller
- **PV** = Control measurement
- **K_p** = Proportional Gain
- **Error** = Difference between the Setpoint and the controlled parameter
- **K_i** = Reset time, second per repeat
- **K_d** = Rate, seconds
- **\Delta t** = Period of execution (sec)

*Figure 11-16. PID Control*
The selection of **PID structure** should be based on the process i.e. how the controlled parameter reacts to a change in the manipulated parameter.

**I-Only** - When the response of the controlled parameter to a change in the manipulated parameter is instantaneous – the process is a pure gain.

**PI** - The process can be adequately represented as a first-order lag. *The majority of industrial process fall into this category*

**PID** - The process is best represented as a second-order system and the control parameter contains little noise.

**P-Only** - If the process is best represented as an integrator.
A direct/reverse selection is normally provided with the PID to compensate for the relationship of the manipulated parameter to the controlled parameter.

1. Select **direct** if the manipulated parameter must be increased to correct for an increasing controlled parameter.

2. Select **reverse** if the manipulated parameter must be decreased to correct for an increasing controlled parameter.

*Note: The OUT parameter of the PID is normally considered to be the manipulated parameter.*

**Figure 11-18. Setting Controller Action**
PID Function Block

Figure 11-19. Feedback Control Connections

Figure 11-20. PID Block Implementation
PID Form – Standard and Series

Conventional Standard PID with feedforward
– Laplace (s domain) representation.

\[ \text{OUT}(s) = \text{GAIN} \times \left( 1 + \frac{1}{T_r s} + \frac{T_d s}{(\alpha T_d s + 1)} \right) E(s) + F(s) \]

Series PID with derivative filter applied only to derivative action, with feedforward – Laplace (s domain) representation.

\[ \text{OUT}(s) = \text{GAIN} \times \left( 1 + \frac{T_d s}{(\alpha T_d s + 1)} \right) \left( \frac{T_r s + 1}{T_r s} \right) E(s) + F(s) \]

where:

- \( \text{GAIN} \) = Proportional gain
- \( T_r \) = Reset time, seconds per repeat
- \( T_d \) = Rate, seconds
- \( E(s) \) = Error
- \( F(s) \) = Feedforward contribution

Figure 11-21. PID Form
Setting PID Form and Structure

Figure 11-22. Selection of PID Form

Figure 11-23. Selection of PID structure
Block Mode – Selection of Source of SP and OUT

Figure 11-24. PID Mode Parameter
## Target Modes of Block

<table>
<thead>
<tr>
<th>Mode</th>
<th>Source of SP</th>
<th>Source of OUT</th>
</tr>
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<tbody>
<tr>
<td>Out-of-Service (O/S)</td>
<td>Operator</td>
<td>Operator</td>
</tr>
<tr>
<td>Manual (Man)</td>
<td>Operator</td>
<td>Operator</td>
</tr>
<tr>
<td>Automatic (Auto)</td>
<td>Operator</td>
<td>Block</td>
</tr>
<tr>
<td>Cascade (Cas)</td>
<td>CAS_IN</td>
<td>Block</td>
</tr>
<tr>
<td>Remote Cascade (Rcas)</td>
<td>RCAS_IN</td>
<td>Block</td>
</tr>
<tr>
<td>Remote Output (Rout)</td>
<td>Operator</td>
<td>RCAS_OUT</td>
</tr>
</tbody>
</table>

Control and output blocks

Figure 11-25. Supported Operator Modes
## Other Actual Modes of Block

<table>
<thead>
<tr>
<th>Actual Mode</th>
<th>What it means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Override (LO)</td>
<td>Track or Auto-tuning is active and in control of the output value</td>
</tr>
<tr>
<td>Initialization Manual (IMAN)</td>
<td>The forward path to a physical output is broken and the output is tracking the downstream block</td>
</tr>
</tbody>
</table>

*Figure 11-26. Other Actual Modes*
Duty Cycle Control

Figure 11-27. Duty Cycle Control
Duty Cycle Control (Cont.)

Figure 11-28. Discrete Output Setup for Duty Cycle Control
Increase-Decrease Control – Motor Driven Actuator

Figure 11-30. Interfacing to Increase-Decrease Actuators
Workshop – Feedback Control

Figure 11-32. Process for Feedback Control Workshop

Figure 11-33. Feedback Control Workshop Module
### Tuning and Loop Performance – Default Setting

<table>
<thead>
<tr>
<th></th>
<th>Gain</th>
<th>Reset</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>0.3</td>
<td>5</td>
<td>--</td>
</tr>
<tr>
<td>Temperature</td>
<td>1.3</td>
<td>300</td>
<td>60</td>
</tr>
<tr>
<td>Level</td>
<td>2</td>
<td>600</td>
<td>--</td>
</tr>
<tr>
<td>Gas Pressure</td>
<td>3</td>
<td>600</td>
<td>--</td>
</tr>
</tbody>
</table>

*Figure 12-1. Initial PID Tuning*
Manual Tuning Technique

Tuning of a PI controller applied to a self-regulating process can be quickly establish as follows:

1. Place the controlled and manipulated parameters on trend.
2. Place the controller in manual and allow the process to reach steady state.
3. Impose a step change in OUT and observe the response.
4. Set the RESET to match the sum of the process deadtime plus the time constant.
5. Place the loop on automatic control using conservative GAIN.
6. Make small changes in Setpoint and observe the response. Adjust only the GAIN to achieve the desired response.

Figure 12-2. Manual Tuning Technique
Tools to Automate Tuning

- Example base on DeltaV Insight On-demand Tuning

Figure 12-3. Auto-Tune Interface

Figure 12-4. Simulation of Loop Response
Impact of Sticky Valve

Figure 12-5. Impact of Sticky Valve on Automatic Control
Use of Signal Characterizer to Compensate for Non-linearity

Figure 12-7. Signal Characterization in Control Path
Characterizer Setup

Figure 12-8. Example of Characterizer Setup
Multi-loop Control - Feedforward Control

Figure 13-1. Basis of Feedforward Control
Feedforward Control Implementation

*Figure 13-2. Feedforward Dynamic Compensation*

*Figure 13-3. Dynamic Compensation in Feedforward Path*
Commissioning Dynamic Compensation

Figure 13-4. Step Test to Determine Process Dynamics

\[ FF_{lead} = T_m \]
\[ FF_{lag} = T_d \]
\[ FF_{gain} = \left( \frac{Gain_{disturbance\ input}}{Gain_{manipulated\ input}} \right) \]

Figure 13-5. Step Test to Determine Process Deadtime

\[ FF_{dt} = DT_2 - DT_1 \]
Workshop – Feedforward Control

Figure 13-9. Process for Feedforward Control Workshop

Figure 13-10. Feedforward Control Workshop Module
Figure 13-11. Basis of Cascade Control
Example – Boiler Steam Temperature

Figure 13-12. Example – Control of Outlet Steam Temperature
Cascade Control Implementation

- Selecting FRSI_OPT for dynamic reset in primary loop and CONTROL_OPTS for Use PV for BKCAL_OUT in secondary loop can often improve dynamic response.

Figure 13-13. Cascade Control Implementation
Workshop – Cascade Control

Figure 13-15. Cascade Control Workshop Module
Override Control

Figure 13-16. Basis – Override Control
Example – Override Control

Figure 13-17. Example – Clarifier Control
Workshop – Override Control

Figure 13-21 Override Control Workshop Module
Control Using Two Manipulated Parameters

Three methods Addressed:
- Split Range Control
- Valve Position Control
- Ratio Control

Figure 13-22. Control Using Two Manipulated Parameters
Split Range Control Implementation

Figure 13-29. Split-range Control Implementation

Figure 13-30. Splitter Block Calculation
Split Range Setup

Figure 13-31. Splitter Block Characterization

Figure 13-32. Configuring the IN_ARRAY and OUT_ARRAY
Example – Split Range Control

Figure 13-24. Steam Header Example

Figure 13-25. Split-range Output (FY196)
Workshop – Split Range Control

Figure 13-35. Process for Split-range Control Workshop

Figure 13-36. Split-range Control Workshop Module
Valve Position Control

Figure 13-37. Valve Position Control
Valve Position Control Implementation

Figure 13-40. Valve Position Control

Figure 13-41. Configuring PID for I-only Control
Example – Valve Position Control

Figure 13-38. Example – Boiler BTU Demand
Workshop – Valve Position Control

Figure 13-42. Process for Valve Position Control Workshop Module

Figure 13-43. Valve Position Control Workshop Module
Ratio Control

Input = SP or PV of independent loop

SP = (Ratio * Independent Loop Input)

Figure 13-44. Basis – Ratio Control
Ratio Control Implementation

Figure 13-48. Ratio Control

Figure 13-49. RATIO Block Function
Example – Ratio Control

- In this example the ratio setpoint is adjusted using feedback control based on a downstream analysis of the blended material.

Figure 13-46. Automatic Ratio Adjustment
Workshop – Ratio Control

Figure 13-50. Process for Ratio Control Workshop

Figure 13-51. Ratio Control Workshop Module
Figure 13-52. Process Simulation for Ratio Control Workshop
Model Predictive Control (MPC)

Figure 14-2. MPC Configuration for Single Loop

Figure 14-10. Example MPC Implementation for One Measured Disturbance Input

Figure 14-12. MPC Constraint Control

Figure 14-14. MPC Implementation for Interactive Process
MPC May be Layered on Existing Control

Figure 14-16. Layering MPC onto an Existing Strategy
Figure 14-19. Module MPC Workshop – PID versus MPC
Figure 15-4. Breaking P&ID into Small Processes
Simulation Diagram

Figure 15-5. Diagram Showing Processes for Recycle Tank
Simulation Module

Figure 15-6. Simulation Module
Example – Process Simulation Composite

Figure 15-9. FLOW_VALVE Composite
<table>
<thead>
<tr>
<th>Multi-loop Workshop</th>
<th>Process Simulation Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cascade Control</td>
<td></td>
</tr>
<tr>
<td>Feedforward Control</td>
<td></td>
</tr>
<tr>
<td>Valve Position Control</td>
<td></td>
</tr>
<tr>
<td>Split Range Control</td>
<td></td>
</tr>
<tr>
<td>Override Control</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 15-11. Simulation for Multi-loop Workshop**
Figure 15-19. Spray Dryer Process
Application – Boiler Drum Level

Figure 16-4. Three Element Drum Level Control

Figure 16-5. Inventory Control Workshop Module
Figure 16-8. Batch Chemical Reactor Control
Batch Reactor - Processing

Figure 16-9. Batch Chemical Reactor Cycle
Batch Reactor - Control

Figure 16-13. Batch Control Workshop Module
Continuous Reactor

Figure 16-14. Continuous Chemical Reactor
Continuous Reactor - Control

Figure 16-17. Continuous Control Workshop Module
Single Fuel Power Boiler

Figure 16-20. Power Boiler – Single Fuel
Figure 16-22. Combustion Control Workshop Module
Distillation Column

Figure 16-23. Distillation Column Control
Distillation Column Control

Figure 16-24. Distillation Control Workshop Module
Ammonia Plant H/N Ratio Control

Figure 16-25. Ammonia Plant H/N Control
Ammonia Plant H/N Ratio Control (Cont.)

Figure 16-27. Unit Coordination Workshop Module
Control Loop Foundation Web Site

Figure A-1. Web Site Home Page
Exercise and Process Information

This feedback control workshop may be used to explore control of a temperature process using the PID block.

Step 1. In the feedback control workspace, set the model to simulate the process response.

Step 2. Set the PID mode to Auto and change the set point.

Step 3. Introduce an unmeasured process disturbance block to return the temperature to its setpoint.

Step 4. Reduce the PID GAIN by a factor of 2, then replot changes.

Figure A-4. Process – Feedback Control
Workspace – Dynamic Simulation/Control

Figure A-5. Workspace – Feedback Control
Chart and Solution Selections

Figure A-9. Chart – Feedback Control

Figure A-10. Solution – Feedback Control
Summary

- Feedback on the book can be provide through the Control Loop Foundation website
- Questions?
- Drawing for books
How to Get More Information

- Emerson Education Class
  - Control Loop Foundation, Course 9025  CEUs: 3.2
  - This course is for engineers, managers, technicians, and others that are new to process control or need a refresher course. This course includes the practical aspects of control design and process applications that course developers personally learned through years of hands on experience while designing and commissioning process control applications.

Overview
- This 4-1/2 day course covers the concepts and terminology that are needed to understand and work with control systems. Upon completion of this course the student will be able to effectively work with and commission single and multi-loop control strategies. Interactive workshops allow the student to apply what they learn in the class.

Prerequisites
- Windows experience.

- Control Loop Foundation - ISA Book
  - May be purchase through the ISA web site - http://www.isa.org/

- Book Web Site