Control 101

The Process Control Loop

Controllers, Types of control

Dan Weise, presenting
What is a process?

Process industry vs discrete manufacturing

- Discrete manufacturing makes ‘things’, do assembly
  - iPhones, cars, pencils, clothing,
  - Package stuff
- Process industries make ‘stuff’
  - Chemicals, steel, medicines, ferment beer, process sewage
  - Process material into something else
  - Spouse’s cooking
- Can overlap
  - Automotive plant, primarily discrete manufacturing
    - Process loops in the paint booths:
      - controls temperature, humidity, air flow, positive pressure
What is a control loop?

Control is done in a control loop

• Control Loop is a “management system” to regulate the process
• Process: whatever you’re making/processing
• Measure the process value
  – Tells us whether process condition is too high or too low
• Controller decides whether to make an adjustment (sometimes, how much)
• The adjustment change affects the process
Start with a measurement

• To control anything you need to start with a measurement
• Process is measured by
  – Sensor
  – Transducer
  – Transmitter
What is a transducer?

- Transducer converts physical phenomenon into some other form of energy
  - Pressure sensor converts pressure to electrical signal
  - Thermocouple – converts heat to millivolts
  - RTD – changes resistance with temperature
  - Transducers are always the core of an industrial ‘transmitter’
What is a transmitter?

- Transmitter converts a weak, low level transducer signal into a robust, conditioned signal
  - Pneumatic signal (air)
  - Electronic signal (mV, volts, 4-20mA)
- Hardened for industrial environments
  - Useable over long distances (mile), relatively noise resistant
What is an indicator?

- Indicator
  - displays a measurement
  - analog – pressure gauge
  - Digital - numerical values
- Can be part of transmitter
- Can be part of a controller
- Can display only
- Might or might not be part of a control loop
What is a process variable?

• Process Variable (abbreviated ‘PV’)
  – Whatever’s being measured and controlled in the control loop
  – Signal coming from the field transmitter
  – Examples: Temperature, pressure, flow, level, pH, relative humidity, conductivity

• Dan calls it ‘What you got’
  – 485 gpm, 1005 Deg F, 105in w.c.

• The value in the upper display
  – Happens to be labeled PV on this controller
What is a setpoint?

- Setpoint (abbreviated ‘SP’)
  - The desired result of control
  - It’s where you set the thermostat

- Dan calls it ‘What you want’
  - 500 gpm, 1000 Deg F, 8in w.c.

- The value in the lower display
  - Happens to be labeled SP on this controller
The controller

- Reads the measured Process Variable
  - What you got
- Knows what you want
  - setpoint
- Compares what you got (PV) to what you want (SP)
- Makes a decision based on the comparison
  - Hold steady
  - Increase
  - Decrease
- Holds or changes its output
Process controller’s output

- Signal to the final control element
- Means of making an adjustment
- output is the manipulated variable (MV)
  - textbook word
  - commonly called ‘Output’ (everyday word)
  - common expression: ‘the output is calling for heat’
Final Control Element

- Physically controls a desired output variable (flow, electricity)
- Puts more or less energy or more or less stuff into the process
- Controller’s output signal drives a ‘final control element’
  - Tells Final Control Element
    - To Turn ON
    - To Turn OFF
    - Defines the magnitude of change the final control element should make
Final Control Element

- Examples of final control elements:
  - Electrical motors driving a pump
  - Variable speed drive or variable frequency drive to an electric motor
  - Contactor which turns pump’s motor on
  - Control valve
  - SCR/thyristor unit (industrial grade light dimmer)
Feedback

• What is feedback?
• Information that tells you how you’re doing
• Automatic controller uses feedback
  – Difference between the Process Variable and the Setpoint (the error) tells the controller how well it’s doing.
  – The less the error, the better the performance
• Open loop control does not use feedback
  – Example: timed lawn sprinkler system
    • Even if it rains, the sprinkler turns on because it has no feedback that tells it that the soil already has sufficient moisture
• Closed loop control depends on feedback
2 Control modes: Manual vs Auto

• Manual control
  – A person
    • makes the decision
    • makes the change

• Automatic
  – Unattended
  – automatic correction for disturbances
Auto/Manual

- Industry surveys say 35% of all control loops are manual loops
- Process tend to want to automate
  - Cut cost
  - Ensure consistency and quality
- automatic control systems generally have provision for ‘manual mode’
  - Hand-Off-Auto or Auto/Manual switch
  - Troubleshooting
  - Start-up
Types of Automatic Control

- Automatic control has 2 main control types
  - On-off
  - Proportional
- On-off
  - Final control element has only 2 states
    - 2 positions
    - On or Off
    - Open or closed
- Proportional
  - Final control modulates
Types of Control

• Why on-off control?
  – Simplicity – controlled by a switch
  – For many applications, it works well enough
    • Thermostat on your home furnace

• Fits like a glove
  – Staged pump control
  – Limit/safety control:
    • Flame safeguard controller and safety shutoff valve
    • High level shutdown
  – Thermostatic control like heat trace, ovens
  – Level control: pump up/pump down
  – Solid and liquid flow switches
  – Pressure control on simple compressors
On-Off Control

What characterizes on-off control?

- Simple control, no tuning
- 2 states: either on or off
- Sawtooth response over time – overshoot, undershoot

- Hysteresis/deadband
  - Gap between when output turns on and when it turns back off again.
  - Prevents “chattering”, turning on and off in quick sequence
- ‘deadband’ size can be critical
  - Pump action is wide deadband, alarm action is narrow deadband
Deadband

- Wide deadband between turn-on and turn-off points for pump-up sump level control
  - Single control relay output

- Narrow deadband for alarm action
How is deadband implemented?

- Honeywell on-off controller:
  - splits deadband above and below the setpoint:

- UE One Series Electronic pressure switch
  - Trips exactly at SP and deadband
Output: failsafe or normal?

- Normal or failsafe output actuation
- Failsafe: coil deenergized during alarm state
  - N.C. contact is closed in alarm state

**Table 2-3 Alarm Relay Contact Information**

<table>
<thead>
<tr>
<th>Unit Power</th>
<th>Alarm Relay Wiring</th>
<th>Variable NOT in Alarm State</th>
<th>Variable in Alarm State</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Off</strong></td>
<td>N.O.</td>
<td>Open</td>
<td>Off</td>
</tr>
<tr>
<td></td>
<td>N.C.</td>
<td>Closed</td>
<td></td>
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On-Off controllers

- Electromechanical temperature and pressure switches
- Thermostatic mechanical regulators
- Electronic pressure switches
- Ultrasonic level switches
- Electronic on-off controllers
- Solids level switches
- pH analytical controller
On-Off controllers

Precision Digital indicator/controllers
- Pump staging, alternating
- Tank level control
- Good illustrated descriptions
On-Off Control

- It’s simple, but it causes oscillations; sawtooth action
  - overshoot, undershoot, overshoot, undershoot

- How do we get straight line control?
**Straight Line Control**

- Some processes require straight line control
  - Not the sawtooth oscillating control inherent in on-off control
- Proportional control, known as PID, offers straight-line control

![Graph showing straight line control](graph.png)
Output Modulation

- Modulate: adjusts or regulates by incrementally varying the output
- Proportional output modulates continuously between 0% to 100%
  - not just 2 on/off states of on/off control
- An incremental response provides
  - Just the right amount
  - rather than full on (too much) or full off (too little)
- A typical modulating output is a 4-20mA signal
- Final control element (valve) provides incremental response
  - Controller output = 62% output. Valve goes to 62% open.
  - An On-off controller output is either on or off, nothing in between
How does PID work?

- PID looks at the error
- Error is difference between what you want (SP) and what you got (PV)
  - SP minus PV
- Goal is zero error, when PV = SP
How does PID work?

- PID has 3 modes
  - P: Proportional gain– response proportional to magnitude of error
  - I: Integral time – accounts for how long the error has existed
  - D: Derivative – accounts for how fast the error is changing
- P-only (proportional only) control
  - mechanical pressure regulator
  - P-only always has ‘droop’
- Reset (I term) corrects for droop in 2 mode PI control
How does PID work?

- **D term**
  - D: Derivative – accounts for how fast the error is changing
  - Also called ‘rate’
  - Backs off output more rapidly when approaching SP than P/gain

- Adds more response when PV drops from setpoint
**PID can do straight-line control**

- Sounds great, straight line control with PID. What’s the catch?
- The controller has to produce an ‘appropriate’ *response* to the error: not too much, not too little
- The wrong response produces fluctuations or sluggish response
  - Bad tuning can cycle worse than on-off control
Process capacity: tuning

- Each process load has a unique capacity to absorb or release energy or mass
- The task of matching the controller response to the process capacity is tuning
- Each mode, P, I, D has a numerical term associated with it
  - Tuning constants
  - Wrong tuning constants result in bad (not straight line) control
- Everyone wants to know what numbers or values to enter
  - It’s different for every process
  - We’re not withholding secret information, it’s just that it varies from process to process
Tuning constants

- Generally control loop types have an inherent ‘capacity’
- Tuning constant rules of thumb (based on generalities)

<table>
<thead>
<tr>
<th>Control loop</th>
<th>Proportional band</th>
<th>Time constant</th>
<th>Derivative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>High (250%)</td>
<td>Fast (1 to 15 sec)</td>
<td>Never</td>
</tr>
<tr>
<td>Level</td>
<td>Low</td>
<td>Capacity dependent</td>
<td>Rarely</td>
</tr>
<tr>
<td>Temperature</td>
<td>Low</td>
<td>Capacity dependent</td>
<td>Usually</td>
</tr>
<tr>
<td>Analytical</td>
<td>High</td>
<td>Usually slow</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Pressure</td>
<td>Low</td>
<td>Usually fast</td>
<td>Sometimes</td>
</tr>
</tbody>
</table>

- But it all depends on the particulars
  - Way over-capacity gas fired temp loop with a 650% PB, 2 sec I, no D
    - Opposite of temperature on the chart above
- Is there an alternative to learning how to tune a loop?
**What is autotune or accutune?**

- Method of letting a PID controller determine its tuning constants
- A self-tuning algorithm that’s part of a PID controller
- Most stand-alone PID controllers have some form of autotune
- Honeywell’s Accutune:
  
  - Demand action, manually started each time
How does Accutune work?

– Push a button to start it running
– Output goes to 100%, then 0%, then 100%, then 0%
  – Introduces an upset in the process
– Controller observes the response to output changes
– Determines the tuning constants from the process response
– Saves new tuning constants, exits Accutune
– Controller resumes control using new tuning constants
– Caveats
  • Load has to be typical – it does no good to tune to an uncharacteristic load
  • Output swings might damage some loads – use a dummy load
How is electricity ‘modulated’?

• How is AC power modulated to electric heating elements for proportional straight line control?

• Vacuum furnaces use electric power (not gas) to keep products of combustion from polluting the load

• 3 techniques
  • Time proportional control
  • SCR/thyristor
    • Uses either time proportional or PWM
  • Variable Frequency drives
**PID Time proportional control**

- AC power is cycled/switched on or off over a ‘duty cycle’
- The duty cycle has a fixed time period
  - .2 seconds, 5 seconds, 20 seconds

- The On period is a proportion of the full time period
  - 0% is no power
  - 50% is power on for half the cycle, off for half the cycle
  - 100% is power on for the full time period
Time proportional control

- Packaged SCR/thyristor controllers
- Control input 4-20mA
- Package switches the high voltage, high current

- Choice of zero cross or phase angle
  - Phase angle chops each cycle (noise/harmonics)
  - Zero cross turns on or off when cycle starts at 0 or ends at 0 (little noise/harmonics)
- Sometimes referred to a PWM, or Pulse Width Modulation
Heat/Cool control

- A controller that automatically switches between heating and cooling
- Heat-cool controllers: 1 loop with 2 control outputs
  - Only one control loop (only one output is active at a time)
  - One output for heat
  - One output for cooling
  - Home thermostat has to be manually switched from heat to cool
- Jacketed vessel
**Split Range control**

Split Range control

- Single 4-20mA output splits to two final control elements (FCE)
  - Sometimes single operation (heat/cool)
  - Other times, staged operation
- Need
  - PID Controller with 1 linear output
  - Two final control elements (valves with positioners or E/I/P)
  - I/P or positioners ranged differently, 3-9 and 9-15 psi
  - Sometimes a loop repeater/splitter is needed (diagram) due to positioner loading
Position Proportional Control

- Position Proportional Output
  - Output to drive a electric actuator
  - Slidewire feedback for precision positioning
    - Slidewire tracks the rotation position of the motor shaft
  - Controller output, 2 relays
    - One relay drives motor Clockwise (CW)
    - Other relay drives motor counter-clockwise (CCW)
    - Slidewire feedback tells controller when to stop driving
  - Requires 6 wires CW, CCW, common, 3 wires for slidewire
    - Controller uses slidewire card
  - Adapter modules convert 4-20mA to position prop
  - Controllers: UDC3200, Truline, HC-900
Three Position Step Control (TPSC)

- Position Proportional minus the slidewire
  - Slidewire is the weak link, breaks first
  - Open feedback control, no slideware feedback
  - Uses the 2 relay, CW, CCW action
  - Times the duration the drive motor is on
  - Initializes first time by stroking full open, full closed
  - West calls is VMD (valve motor drive)
  - Requires setting the stop-to-stop time (30 seconds, 90 seconds)
  - UDC: can be configured and used when the slidewire fails
    - Relay output wiring is identical to position proportional
  - Costs less then Pos Prop (no slidewire card)
  - Better reliability (no slidewire to fail)
  - Assumes PI integral action makes up for minor position error
Setpoint Programming (SPP)

- Setpoints, dwell times entered, saved and recalled
  - *Profile, recipe or program*
- Continuous PID control with SPP
- Discrete output ‘Events’ synchronized to specific segments
- Improved batch processing capabilities and efficiencies
Ratio Control

Typical ratio control application - blending

• Single ratio controller
  – 2 PV inputs, wild flow and controlled flow

• Controls one flow rate as a ratio of the other
  – Wild flow X (A) (outside demand factor determines its flow rate)
  – Controlled flow (B) at x% of A
**Batch Control**

- Supplies exact amounts of material for batch
- “Make it easy for my operators”
- Operator enters a *preset* on the numerical keypad
- Hits *start* button
- Batch controller
  - reads the output of a flow meter
  - totalizes the flow
  - Shuts off when total reached
  - Dribble or bleed option
Cascade Control

- 2 interconnected control loops
  - 2 measured PVs, one for each control loop
  - Only ONE control output (4-20mA) to a final control element
  - 2nd loop’s output becomes setpoint of 1st loop
- Typically used when
  - primary PV is slow responding (relatively)
  - Secondary PV is fast responding (3-10x faster)
- One sensor is typically sensing the load

Annealing

Heat Exchanger
Feed Forward Control

- Disturbance is measured (upstream flowrate)
- Feedforward bypasses PID, doesn’t wait for disturbance effect on PV and resulting ‘error’
- Ratioed disturbance value is summed into PID output
  - Feedforward component added directly to PID output
- Comprehensive understanding of disturbance required
- below: heat exchanger: inflow rate fed forward to Temp controller
**PLC control**

- Originally discrete based, now most PLC’s do analog control in some form
- Modular I/O
- Can be Networked
- Ubiquitous (everywhere)
- Not Lesman’s strength (MasterLogic PLC/LX DCS)
**SCADA Control**

- SCADA means different things to different people
  - “collect lots of remote points” from remote RTU’s
  - Any data transferred over wireless or phone line
  - A HMI software package with great graphics
  - A remote I/O rack that talks digital back to a local processor
  - Data Concentrator

- Today’s RTUs do local control
Hybrid/PAC/multiloop Control

- **Process Automation Controller**
  - Modular like a PLC, but process based, not discrete based
  - Slower scan time, but deterministic (fixed certainty for timed events)
  - Hundreds of I/O: AI, AO, DI, DO, frequency/pulse points
  - Can be networked
  - Redundant power, control, networking
  - a Lesman strength – Honeywell HC-900
**DCS control**

- Distributed Control
  - The total integrated control solution
  - Server based, connects to enterprise level software
  - Advanced control algorithms, include existing PLC, SCADA, RTUs
**FM Limit Control**

- Limit control is a safety function
  - High Limit required by NFPA 86 (furnaces, kilns)
  - Prevents overheating and potential fire hazard
    - Controls against run-away conditions
  - Intended to protect the heater/furnace, not the load
  - Does NOT control the process variable (temperature)
- Control output (relay) enables/disables
  - the safety shutoff valve
  - Shunt trip circuit breaker upstream of an SCR
- FM Limit controller ‘latches out’
  - When tripped, requires a manual reset to re-enable the output
- Secondary, independent safety control
  - Does not share a temperature sensor (thermocouple)
  - Is separate from the primary temperature controller
Burner Management Control

- Control: air-fuel ratio combustion
  - Boiler/furnace/kiln/oven
  - Excess air
- Safety: FM approved Flame Safety
  - Flame detection (FM)
    - UV, IR, flame rod,
    - Multi-burner UV discriminator
  - Single burner controls (FM)
  - Multiburner controls (FM)
  - Safety Shutoff valves (FM)
  - Vent valve, Hi/Lo pressure switches (FM)
  - Limit control (FM)
Safety Instrumented Systems (SIS)

• Insurance and liability is driving process loop safety design
• Standards IEC 61511 and ISA84.01 outline how to analyze, design, realize, install, commission and maintain SIS loops in the process industries.
• Risk factor for a process loop is analyzed.
  – Result is a SIL (Safety Integrity Level) rating
• The higher the SIL level, the greater the impact of a failure and the lower the failure rate that is acceptable
• Implementation involves concepts like
  – Analysis of past performance
  – Redundancy – multiple sensors, voting logic
  – Diversity – using a different technology to avoid common mode failures
Safety Instrumented Systems

- Field instruments can have SIL ratings
  - Agency certified (Exida, TuV)
- A safety controller is a ‘logic solver’
  - Designed to not fail, but when it does fail, to fail predictably and safe
  - Fault tolerant
  - Incorporate fail-safe diagnostics
  - Voting logic to analyze redundant sensors
  - Designated by a SIL rating
Questions?
2 control modes

- **Manual control**
  - A person
    - makes the decision
    - makes the change

- **Automatic Control**
  - A controller controls the process variable
    - Reads the process variable = measures
    - Compares PV to SP = compares
    - Makes a decision: how much to change or not = computes
    - Changes output (manipulated variable) = changes
Regulating a process

• Manual control
  – Manually set the light dimmer

• Automatic
  – Unattended
  – automatic correction for disturbances