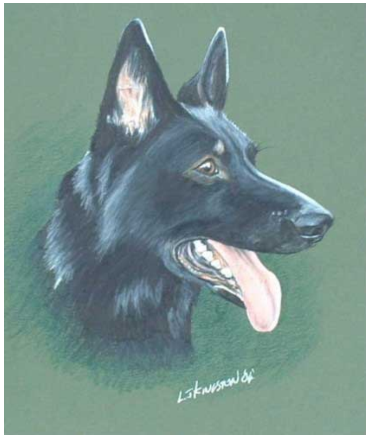
Control 101
The Process Control Loop
Controllers, Types of control



Dan Weise, presenting

Process industry vs discrete manufacturing

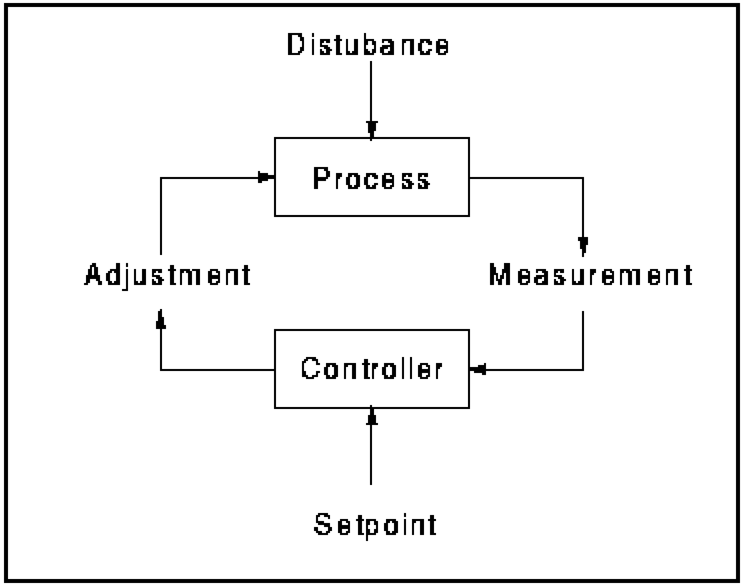
- Discrete manufacturing makes ‘things’, do assembly
  - iPhones, cars, pencils, clothing,
  - Package stuff

- 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

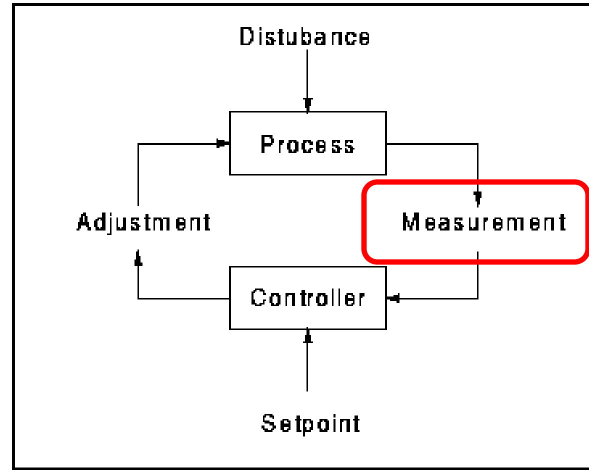
Control is done in a control loop

- 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



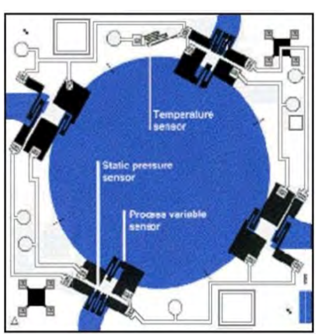
Start with a measurement

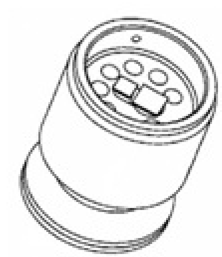
- To control anything you need to start with a measurement
- Process is measured by
  - Sensor
  - Transducer
  - Transmitter

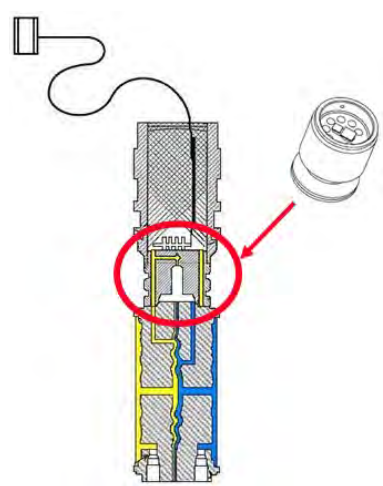


What is a transducer ?

- 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’



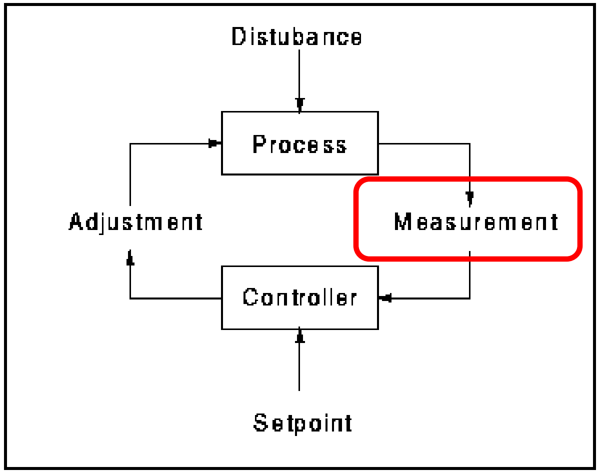




What is a transmitter ?

- 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

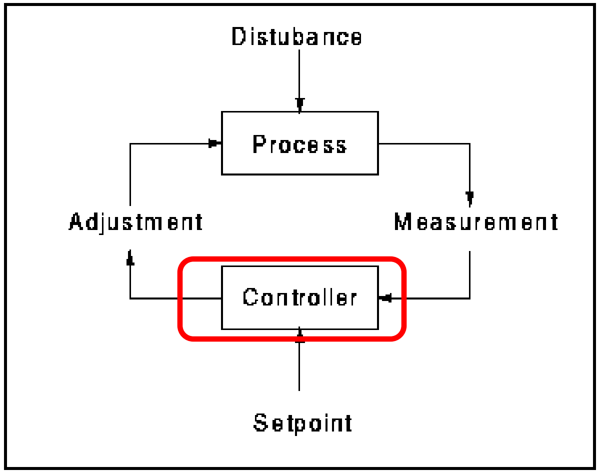
What is a process variable?

- 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?

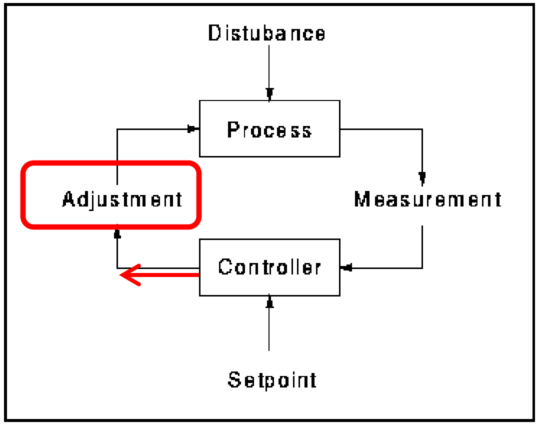
- Setpoint (abbreviated 'SP')
  - The desired result of control
  - It's where you set the thermostat
- Dan calls it 'What you want'
  - 500 gpm, 1000 Deg F, 8in w.c.
- The value in the lower display
  - Happens to be labeled SP on this controller

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

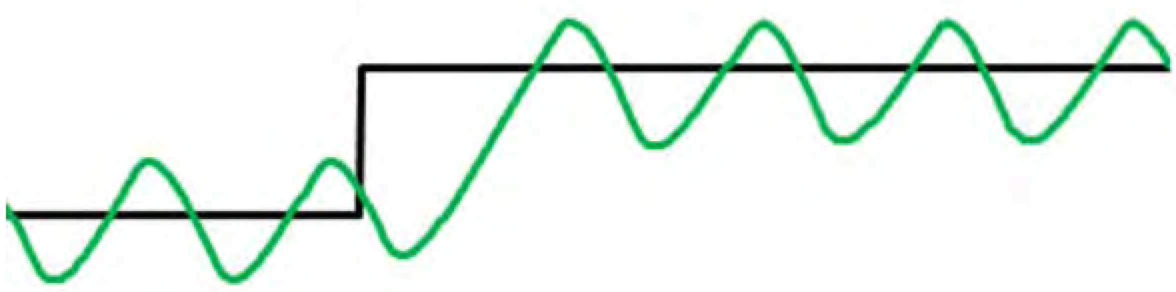
- Automatic control has 2 main control types
  - On-off
  - Proportional
- On-off
  - Final control element has only 2 states
    - 2 positions
    - On or Off
    - Open or closed
- Proportional
  - Final control modulates

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

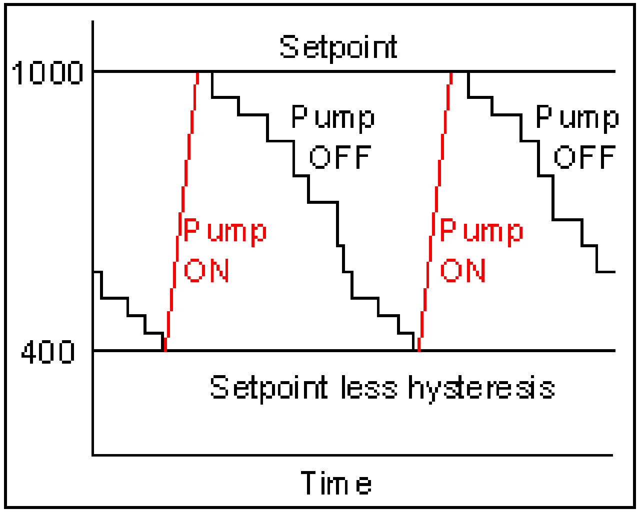
- What characterizes on-off control?
  - Simple control, no tuning
  - 2 states: either on or off
  - Sawtooth response over time – overshoot, undershoot



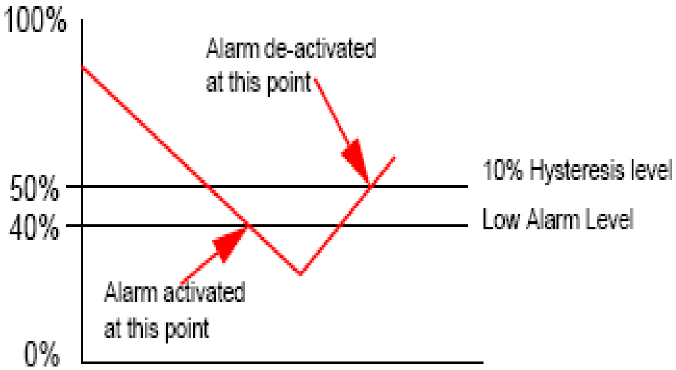
  - Hysteresis/deadband
    - Gap between when output turns on and when it turns back off again.
    - Prevents “chattering”, turning on and off in quick sequence
  - ‘deadband’ size can be critical
    - Pump action is wide deadband, alarm action is narrow deadband

Deadband

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

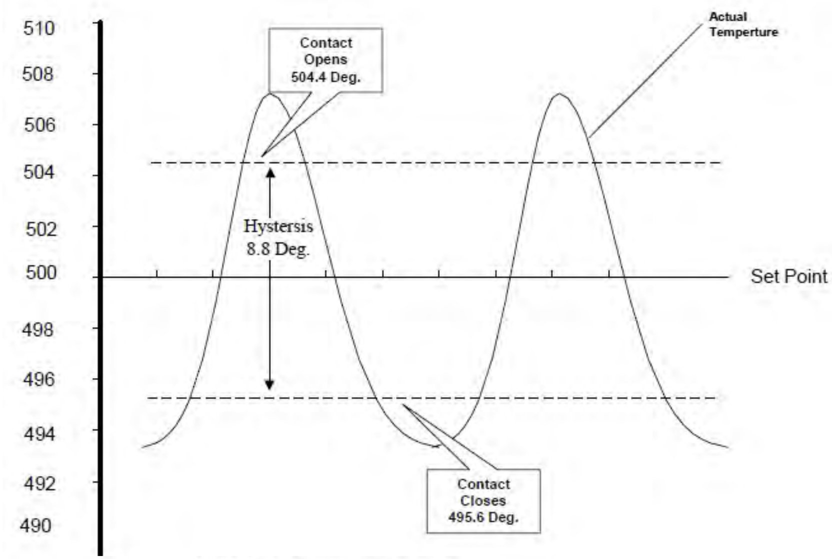


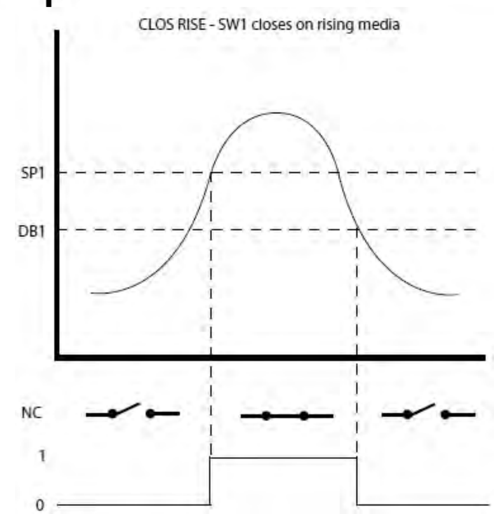
- Narrow deadband for alarm action



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

ATTENTION

Alarm relays are designed to operate in a failsafe mode (that is, de-energized during alarm sate). This results in alarm actuation when power is OFF or when initially applied, until the unit completes self diagnostics. If power is lost to the unit, the alarms will de-energize and thus the alarm contacts will close.

Table 2-3 Alarm Relay Contact Information

Unit Power	Alarm Relay Wiring	Variable NOT in Alarm State		Variable in Alarm State	
		Relay Contact	Indicators	Relay Contact	Indicators
Off	N.O.	Open	Off	Open	Off
	N.C.	Closed		Closed	
On	N.O.	Closed	Off	Open	On
	N.C.	Open		Closed	

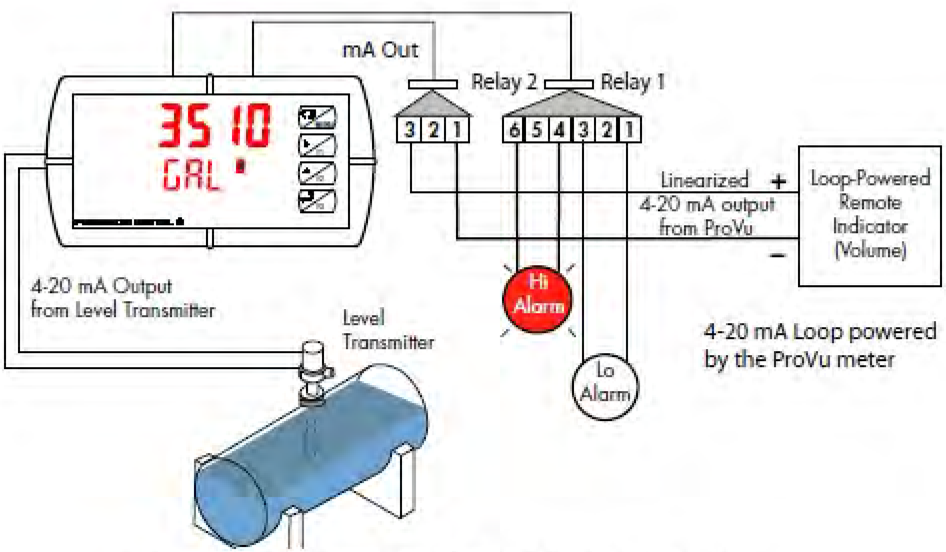
On-Off controllers

- 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

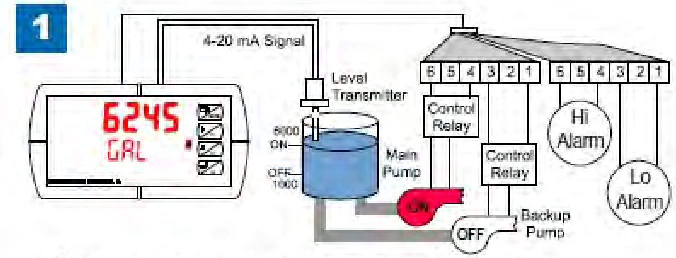
- Pump staging, alternating
- Tank level control
- Good illustrated descriptions



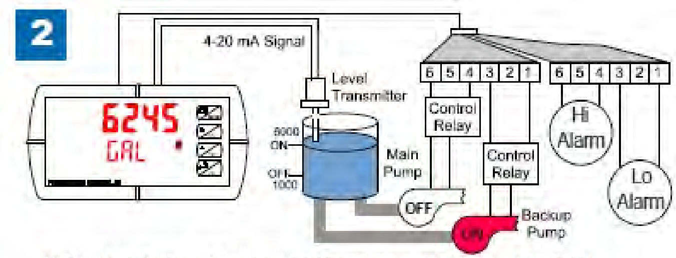
Round Horizontal Tank Math Function

MULTI-PUMP ALTERNATION

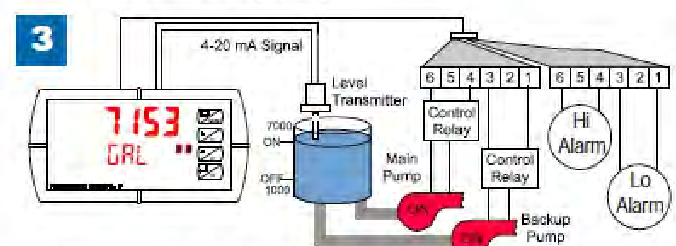
Up to 8 pumps can be alternated/sequenced.



Relay #4 turns the main pump on at 6000 gallons and turns it off at 1000 gallons.



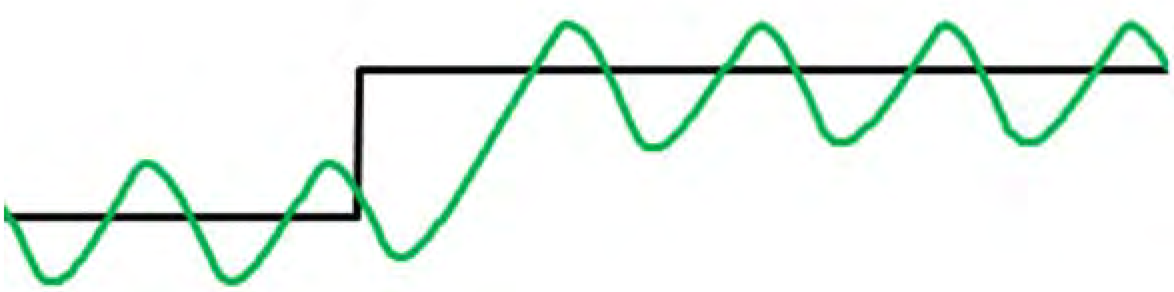
With the Pump Alternation feature activated, the next time the level reaches 6000 gallons, relay #3 transfers and starts the backup pump.



If the backup pump is not able to keep up, and the level reaches 7000 gallons, relay #4 transfers and starts the main pump as well.

On-Off Control

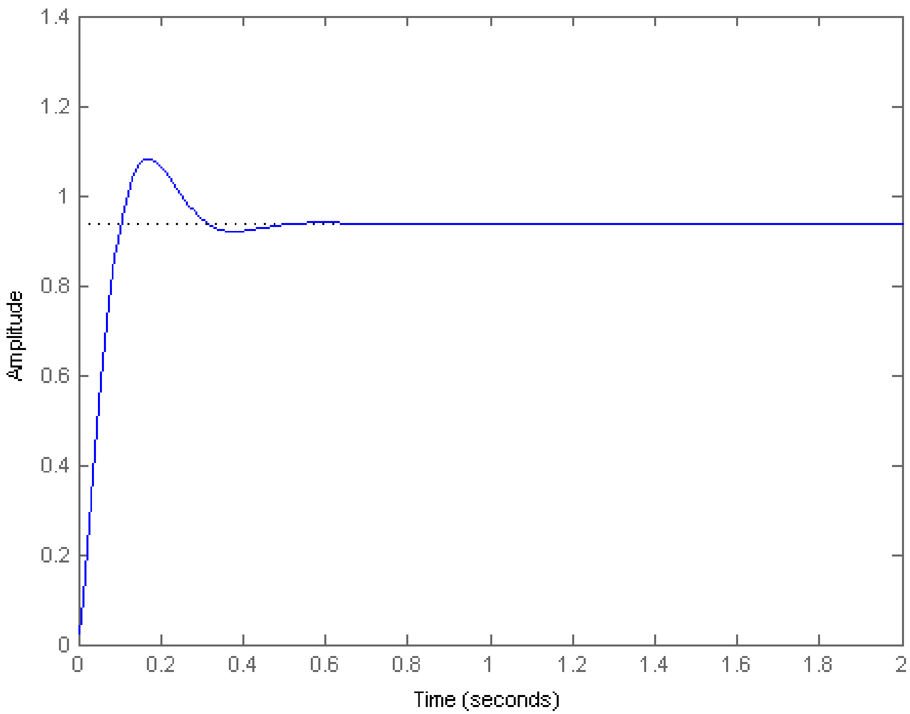
- It's simple, but it causes oscillations; sawtooth action
  - – overshoot, undershoot, overshoot, undershoot



- 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

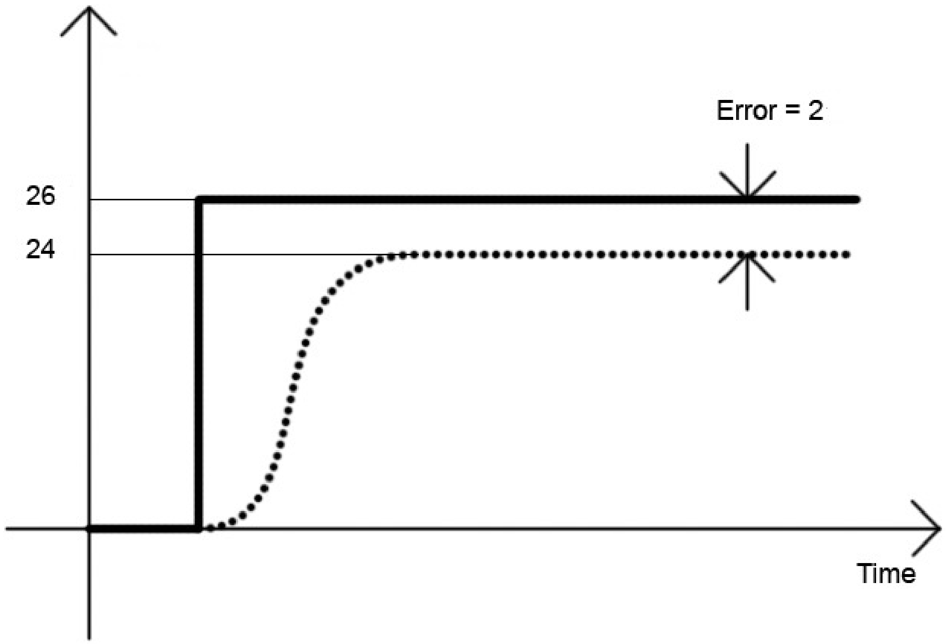


Output Modulation

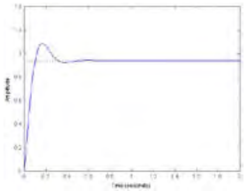
- Modulate: adjusts or regulates by incrementally varying the output
- Proportional output modulates continuously between 0% to 100%
  - not just 2 on/off states of on/off control
- An incremental response provides
  - Just the right amount
  - rather than full on (too much) or full off (too little)
- 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?

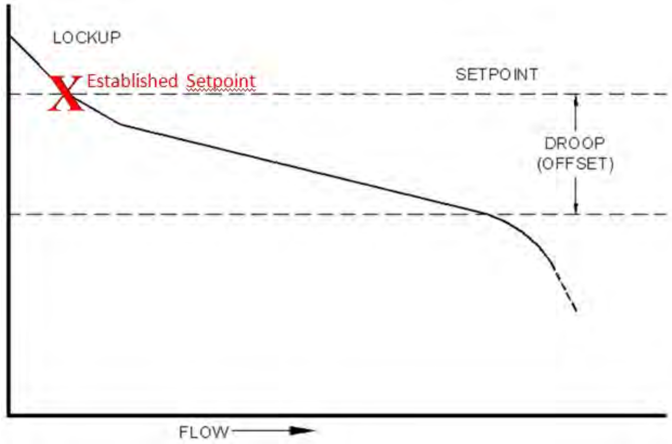
- PID looks at the *error*
- Error is difference between what you want (SP) and what you got (PV)
  - SP minus PV
- Goal is zero error, when PV = SP



How does PID work?

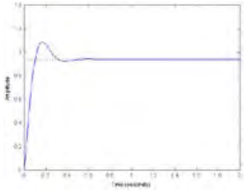


- PID has 3 modes
  - P: Proportional gain– response proportional to magnitude of error
  - I: Integral time – accounts for how long the error has existed
  - D: Derivative – accounts for how fast the error is changing
- P-only (proportional only) control
  - mechanical pressure regulator
  - P-only always has 'droop'

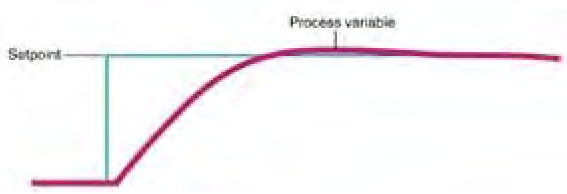


  - Reset (I term) corrects for droop in 2 mode PI control

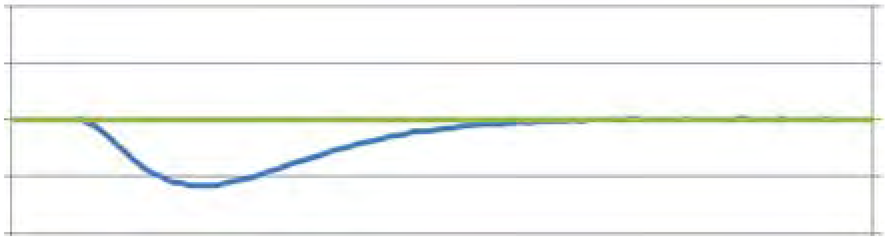
How does PID work?



- 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

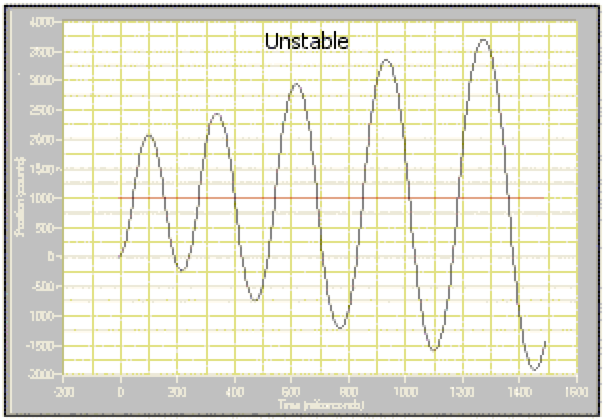


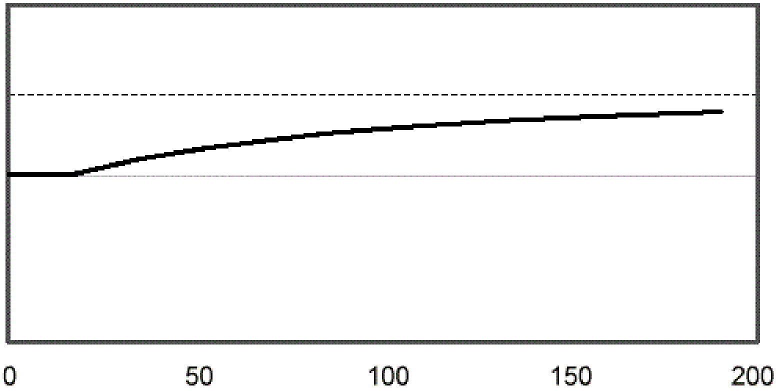
  - Adds more response when PV drops from setpoint



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

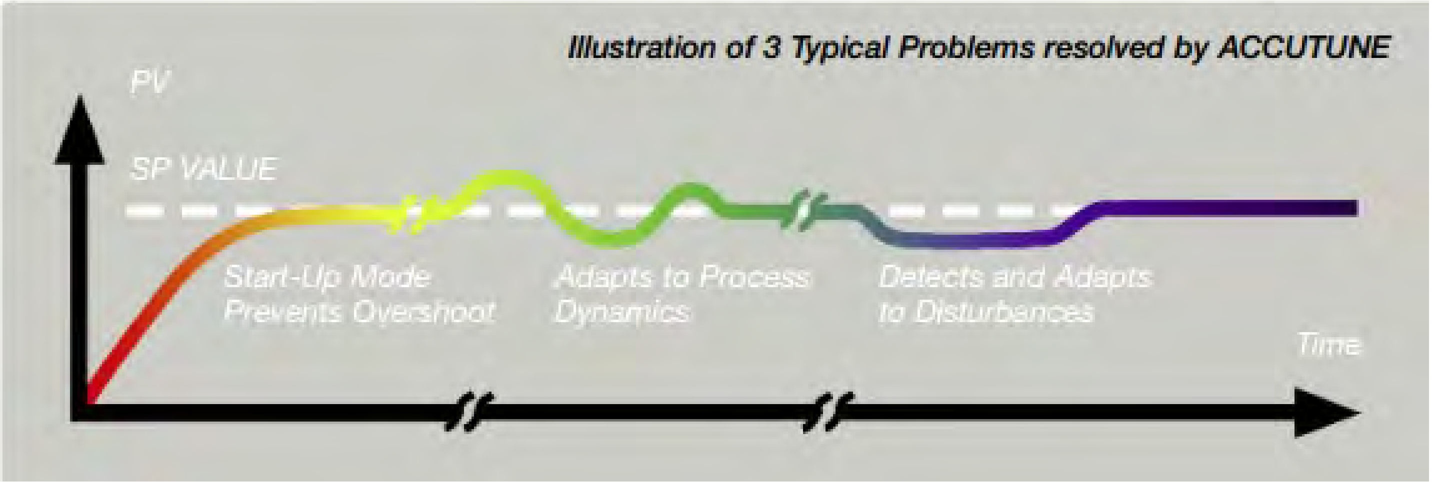
- Generally control loop types have an inherent ‘capacity’
- Tuning constant rules of thumb (based on generalities)

Control loop	*Proportional band*	*Time constant*	*Derivative*
Flow	High (250%)	Fast (1 to 15 sec)	Never
Level	Low	Capacity dependent	Rarely
Temperature	Low	Capacity dependent	Usually
Analytical	High	Usually slow	Sometimes
Pressure	Low	Usually fast	Sometimes

- 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?

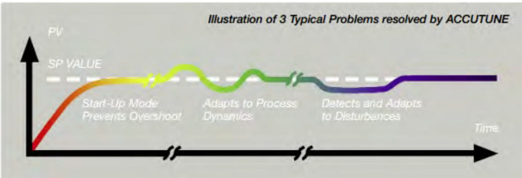
What is autotune or accutune?

- 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?



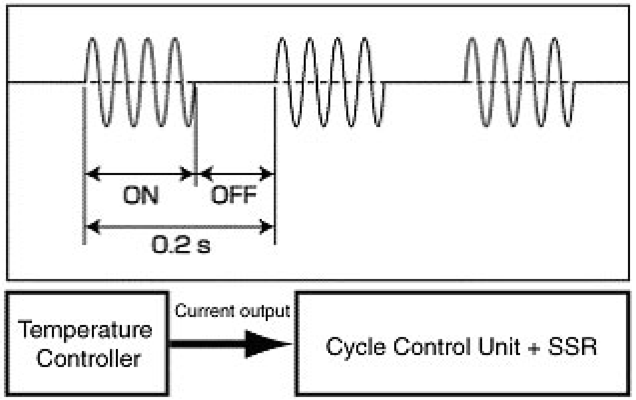
- Push a button to start it running
- Output goes to 100%, then 0%, then 100%, then 0%
  - Introduces an upset in the process
- Controller observes the response to output changes
- Determines the tuning constants from the process response
- Saves new tuning constants, exits Accutune
- Controller resumes 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

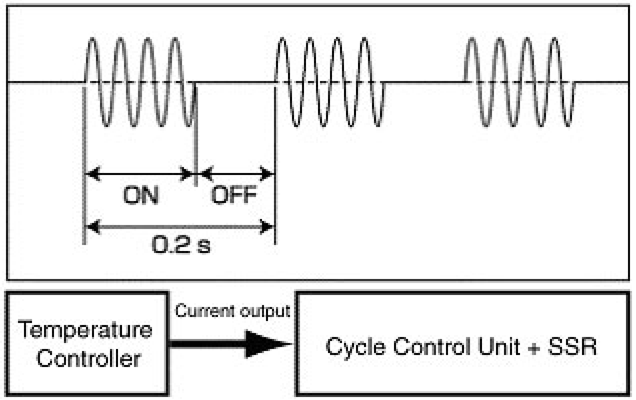
- AC power is cycled/switched on or off over a ‘duty cycle’
- The duty cycle has a fixed time period
  - .2 seconds, 5 seconds, 20 seconds



- 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

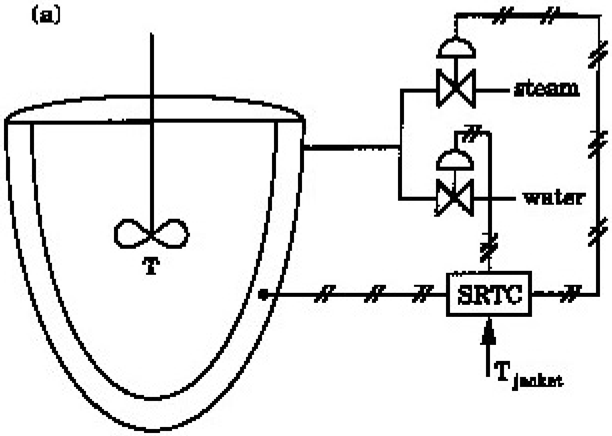
- Packaged SCR/thyristor controllers
- Control input 4-20mA
- Package switches the high voltage, high current



- 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

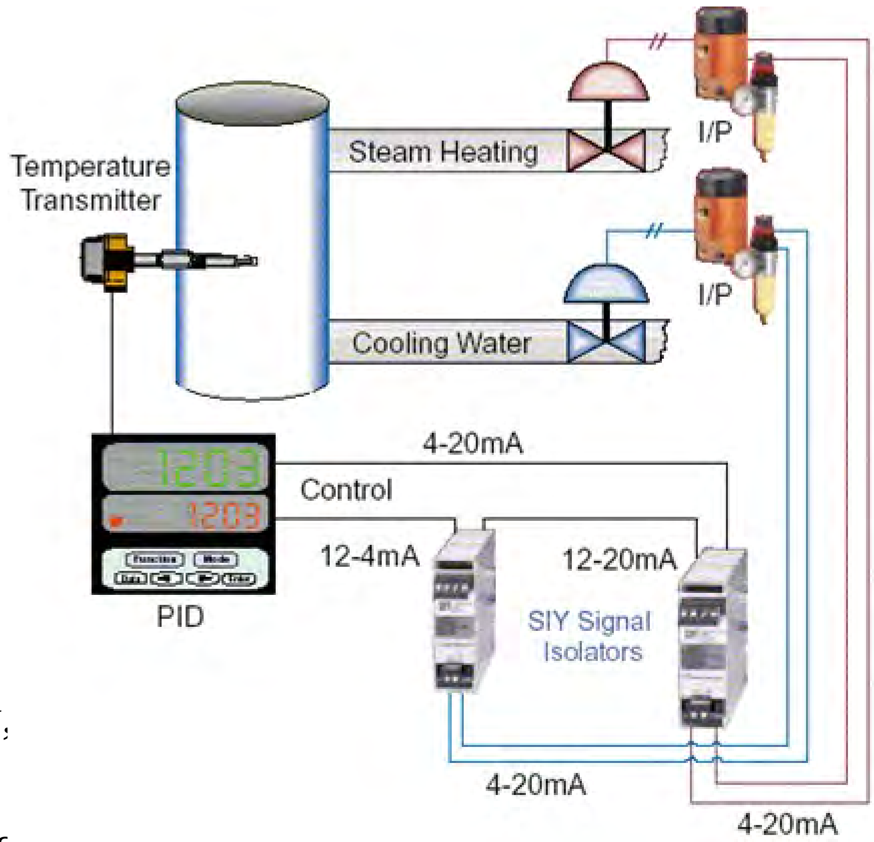
- A controller that automatically switches between heating and cooling
- Heat-cool controllers: 1 loop with 2 control outputs
  - Only one control loop (only one output is active at a time)
  - One output for heat
  - One output for cooling
  - Home thermostat has to be manually switched from heat to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



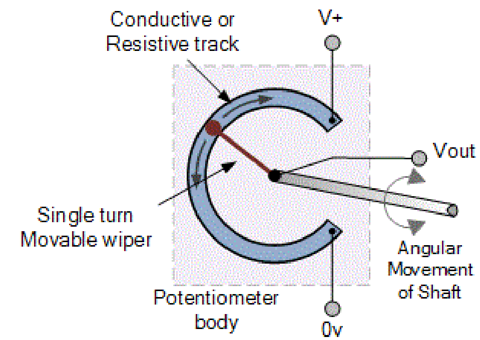
Split Range control

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



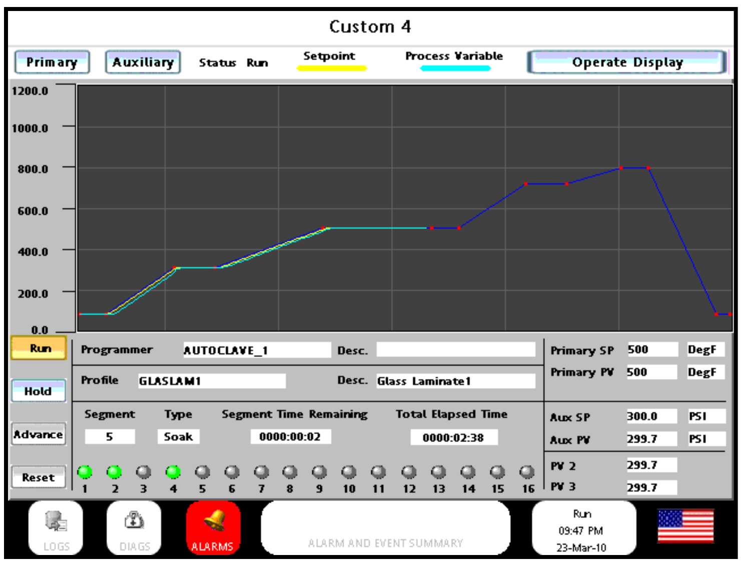
- Position Proportional Output
  - Output to drive a electric actuator
  - Slidewire feedback for precision positioning
    - Slidewire tracks the rotation position of the motor shaft
  - Controller output, 2 relays
    - One relay drives motor Clockwise (CW)
    - Other relay drives motor counter-clockwise (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

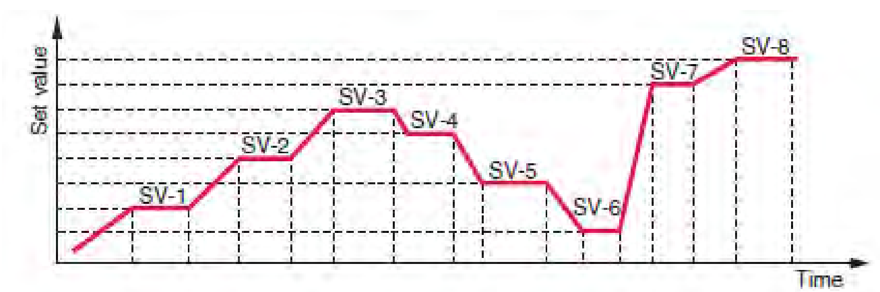
Three Position Step Control (TPSC)

- 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



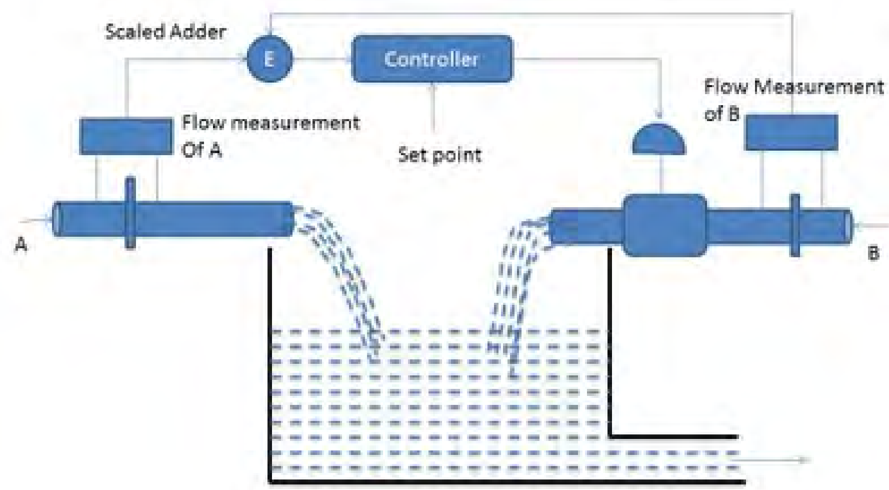


Ratio Control

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

Example of Ratio Control System

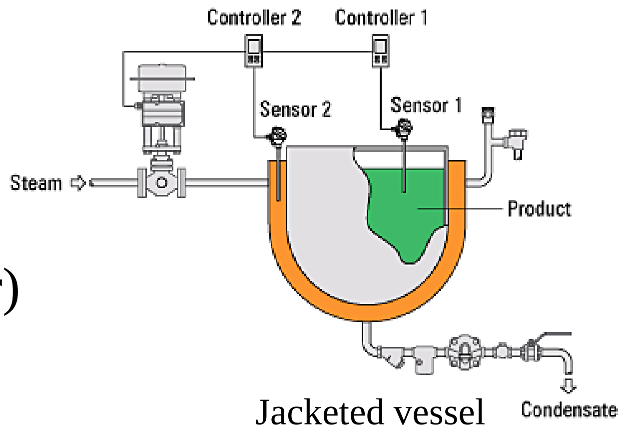


Batch Control

- 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

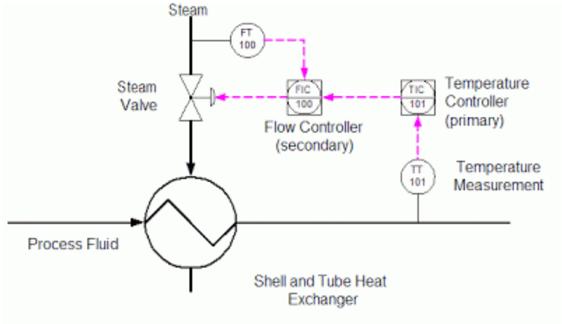
Cascade Control

- 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



Jacketed vessel

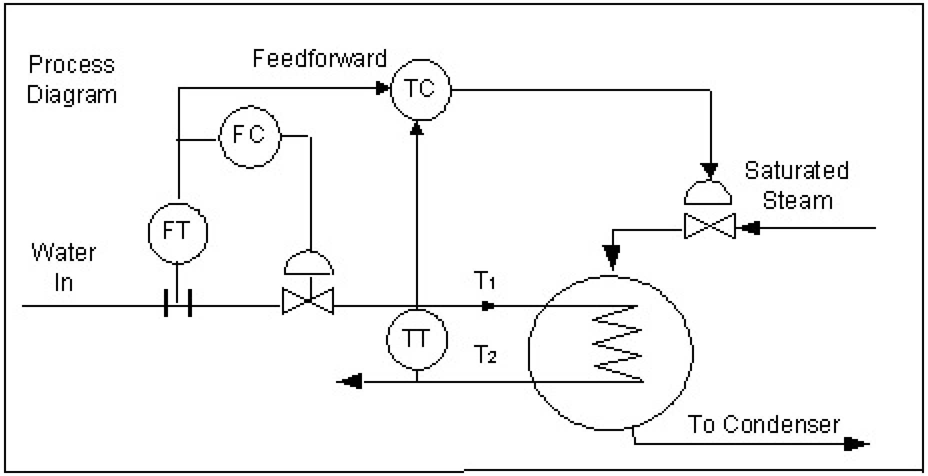
annealing



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

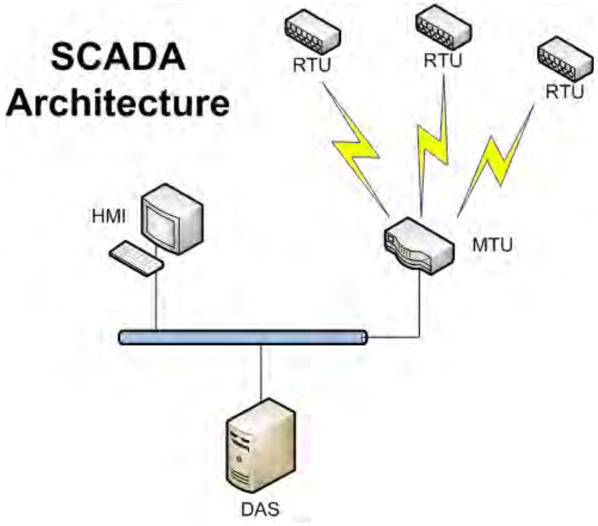


PLC control

- 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)

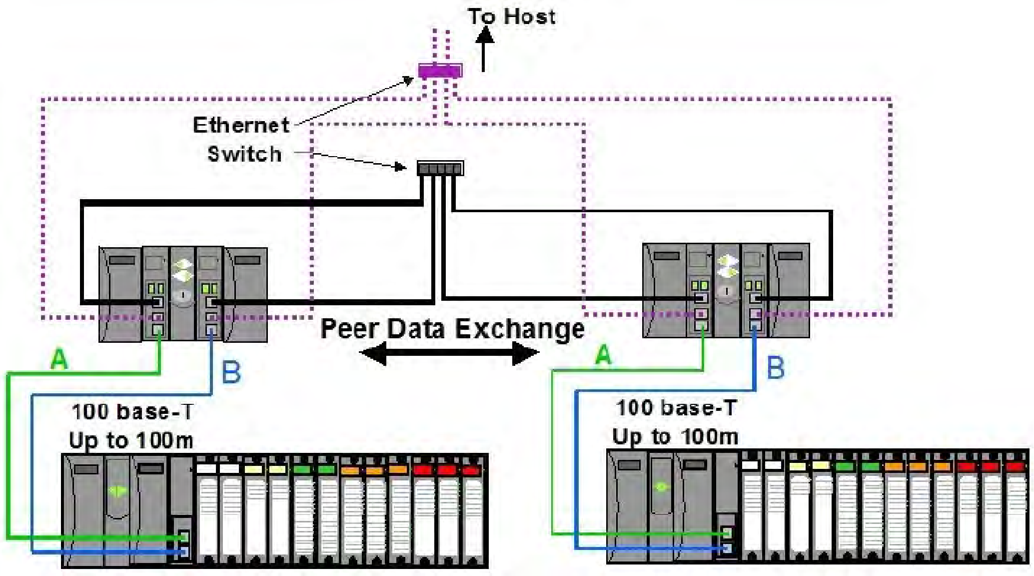
SCADA Control

- 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



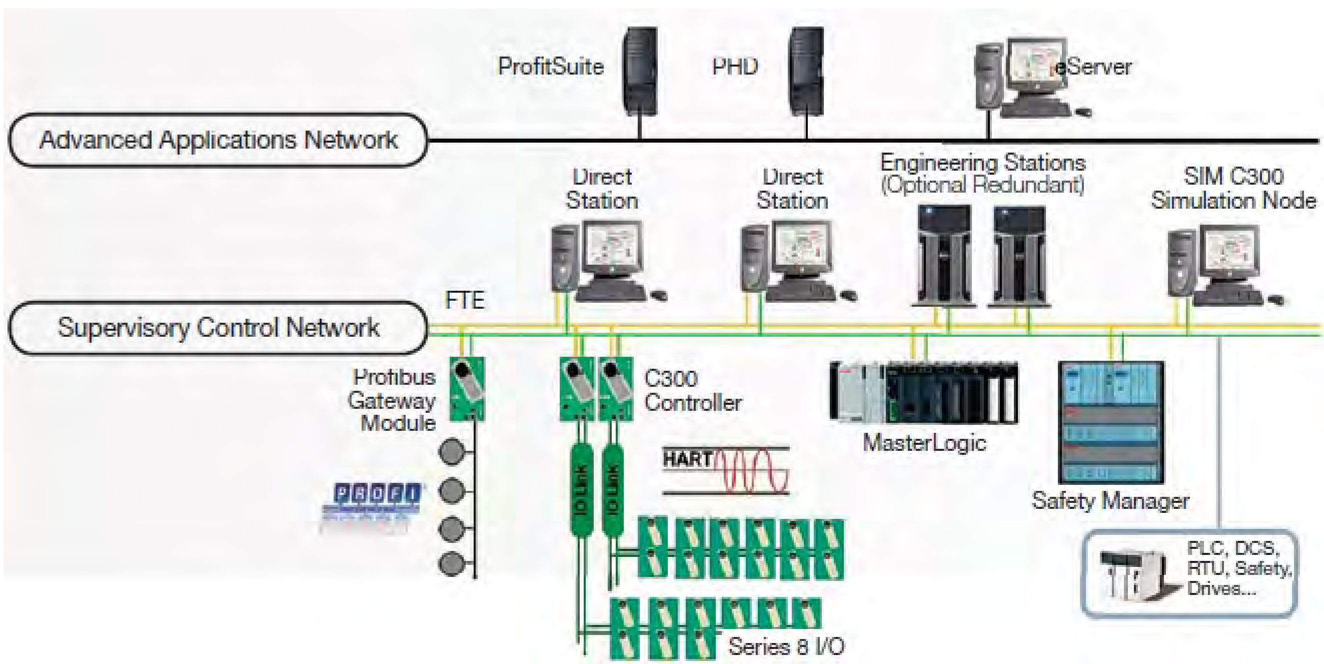
Hybrid/PAC/multiloop Control

- 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

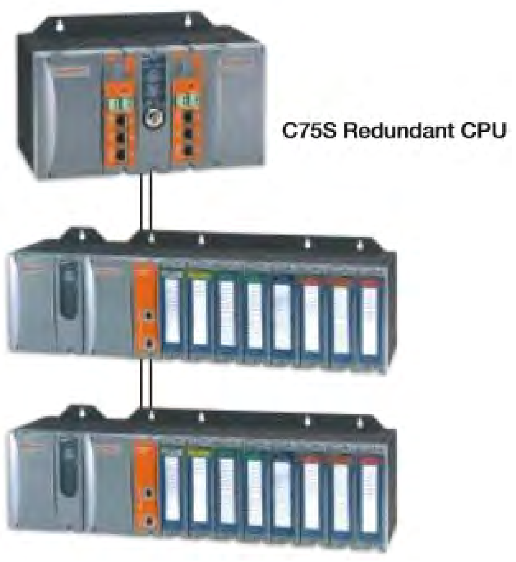
- Control: air-fuel ratio combustion
  - Boiler/furnace/kiln/oven
  - Excess air
- Safety: FM approved Flame Safety
  - Flame detection (FM)
    - UV, IR, flame rod,
    - Multi-burner UV discriminator
  - Single burner controls (FM)
  - Multiburner controls (FM)
  - Safety Shutoff valves (FM)
  - Vent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

Safety Instrumented Systems (SIS)

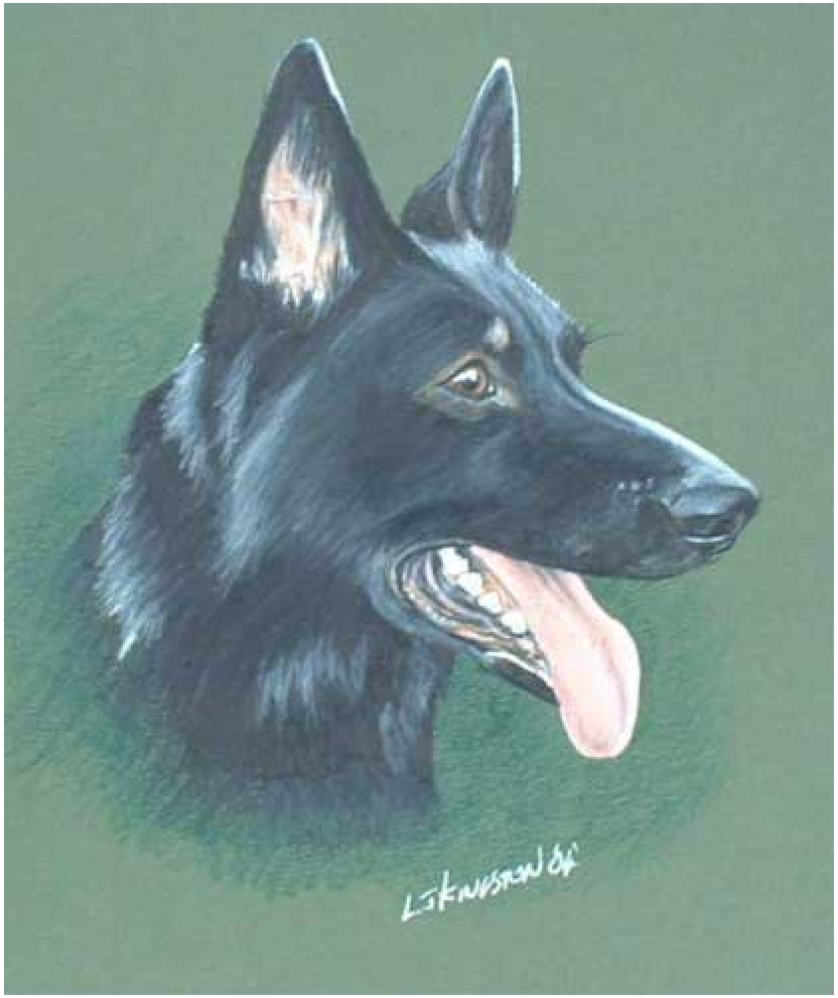
- Insurance and liability is driving process loop safety design
- Standards IEC 61511 and ISA84.01 outline how to analyze, design, realize, install, commission and maintain SIS loops in the process industries.
- Risk factor for a process loop is analyzed.
  - Result is a SIL (Safety Integrity Level) 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