Instrumentation and Controls

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Instrumentation and Controls

7 contact hours
9 CC10 hours

Operators of water and wastewater plants use instrumentation to control and monitor many plant processes. The course examines from an operator's perspective systems that automatically open and close valves, control pump speeds, and pace chemical feed dosages. The class introduces the fundamentals of measuring, displaying, and controlling important operating parameters such as levels, pressures, and flows.

1. Demonstrate techniques used to troubleshoot system components;
2. Explain fundamentals of measuring, and controlling important operating parameters;
3. Evaluate techniques used to maintain system components; and
4. Identify feedback and feed –forward techniques.

8:00 am - Course Introduction
- Section 1: The Basics
  - Benefits & Frustrations of Control Systems
  - The Role of the Operator
  - Fundamental Terms

10:00 am - Break
10:15 am - Section 2: On/ Off Control
- Process Disturbances
- Choosing the Correct Sensor
- Intro to Automation

12:00 am - Lunch
1:00 pm - Hands on Exercise
- Section 3: Distance Monitoring & Control
  - Intro to Telemetry Systems
- Section 4: Continuous Control
  - Intro to the Feedback Control Loop

2:45 pm - Break
3:00 pm - Section 4: Continuous Control
- Tuning Functions
- Cascade Control
- Feed-forward Control

4:00 pm - Course Review
- Evaluations
- Concluding Remarks

Instrumentation and Controls

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Process Training Sessions

Before class starts, please:
- Sign in on Attendance Sheet

During classes, please:
- **Asks questions**
- Feel free to get up and leave the classroom at any time (i.e., rest rooms, phone calls, etc.)
- **Answer questions** on worksheets and exercises

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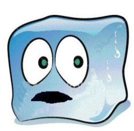
Ice Breaker



- Before we start, let's…
  - Name one thing you know or want to know about:
    - SCADA
    - PLC's
    - Analyzers
    - Loop control

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Housekeeping

- Start class - 6:30 am
- Please mute/silence cell phones
- 10-minute Breaks – every hour
- Lunch – 30 minutes; Between 10:00 am ~ 11:00 am
- End class ~ 2:30 to 3:00 pm

Instructor Expectations

- Begin and end class on time
- Be interactive
- Share experiences and needs
- ***Make this an enjoyable and informative experience!***

Groundrules

- Participate at your own comfort level
- Use terms we all understand
- Everyone is different, so please show respect for others
- Listen with an open mind
- Express opinions
- Maintain confidences

Introduction

Objectives, Focus, and Agenda

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Objectives

- To discuss reasons for instrumentation control for WWTP processes
- To discuss the fundamentals of instrumentation control
- To discuss the interaction between:
  - Plant processes and operator work stations
  - Remote facilities and plant work stations
  - Setpoints, process variables, and loop controls
  - Process sensors, analyzers, and PLCs

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Objectives

- To discuss importance of instrumentation controls in a wastewater treatment system
- To discuss performances of:
  - PLCs and loop controls
  - Sensors and controllers
  - Setpoints and process variables
  - Processes and “disturbances”

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Participant Focus

- What information can you use at your work location?
  - Current **instrumentation technologies**
  - PLCs – **practical process controls**
  - Loop controls – Feedback and Feedforward
- What information can you contribute to the discussion?
  - Problems with **plant automated controls**

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OUTLINE

1. Background – process instrumentation and computers
2. Loop control fundamentals
3. PLCs (and a few RTUs)
4. SCADA – Supervisory Control And Data Acquisition
5. Sensors/analyzers
6. PID Controls
7. Summary and conclusions

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Learning Objectives

- Objective 1 - to discuss fundamentals of loop control:
  - Feedback
  - Feedforward
- Objective 2 - To discuss use of common instrumentation and automation systems for process control and information sharing:
  - Computers
  - Sensors
  - Controllers
- Objective 3 –to discuss programmable controller devices
  - Operator Work Stations
  - PLCs
  - RTUs

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Instrumentation - Overview

- Loop control
  - Sensors/analyzers
  - Controllers
  - Setpoints
  - Process variable
- PLCs - Programmable Logic Controllers
- RTUs – Remote Terminal Units
- PID Controllers

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Participant Focus

- What information can you use at your work location?
  - Loop control fundamentals
  - Information of PLCs and RTUs
- What information can you contribute to the discussion?
  - On-site practices
  - Processes that are automated

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Expected Learning Outcomes

Participants will be able to discuss:

- Fundamentals of loop control
- Basic equipment needed for loop control of a process
- Common sensors and analyzers used at WWTPs
- Use of programmable logic controllers for process control

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Our Focus Today

- Loop control
  - Feedback
  - Feedforward
- Sensors/analyzers
- Programmable logic controllers
  - PLCs
  - RTUs
- SCADA

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Introduction

Definitions and Acronyms

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Definitions

- **Input Variable** – This variable shows the effect of the surroundings on a process and normally refers to factors that influence the process.
  - *Manipulated inputs:* variable in the surroundings that can be controlled by an operator or the control system in place.
  - *Disturbances:* inputs that can not be controlled by an operator or control system. Measurable and immeasurable disturbances exist.
- **Output variables**- Also known as *control variables,* these are variables that are outputs of the process.

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Definitions

- **Closed control loop** exists where a process variable is measured, compared to a setpoint, and action is taken to correct any deviation from that setpoint
- **Setpoint** is a value for a process variable that is desired to be maintained
- **Error** is the difference between the measured variable and the setpoint
- **Algorithm** is a step-by-step (usually involving math) procedure used in automating process control, processing data, and reasoning

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Acronyms

- PSC – Process Control System
- DCS – Distributed Control System
- SCADA – Supervisory Control and Data Acquisition system
- PLC – Programmable Logic Controller
- RTU- Remote Terminal Units
- CMMS – Computerized Maintenance Management System
- LIMS – Laboratory Information Management System

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Abbreviations/Acronyms

- RAS – return activated sludge
- WAS – waste activated sludge
- BNR – biological nutrient removal
- FMCW – frequency modulated continuous wave
- GWR – guided wave radar
- TDR – time domain reflectometry

Abbreviations/Acronyms

- RTD – resistance temperature detector
- ORP – oxidation reduction potential
- DO – dissolved oxygen
- LED – light emitting diode
- NTU – nephelometric turbidity unit

Instruments in the Water Industry

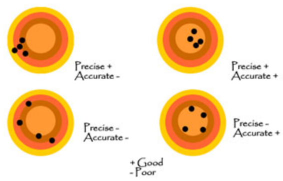
- Want to know basic information about the system
- Eliminate manual measurements
- Transmit information for use in controlling the system
- Save time, save money, and increase efficiency
- Allows us to operate facilities at the limits of technology

Instrumentation Terms

- Range: The values that the instrument can read, minimum to full scale.
- Span: The currently set upper range limit of the instrument.
- Turndown:
  - The ratio between the maximum value (full scale) and the set upper range limit of the span, or
  - The range of values it can accurately read.

Instrumentation Terms

- Accuracy: How close is it to the actual reading?
- Repeatability: Does it provide the same answer each time?



Introduction

Signal Transmission Techniques

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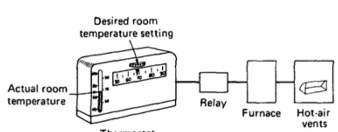
Signal-Transmission Techniques

- Analog
- Digital
- Telemetric



Home heating control system.

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Analog Signal Transmission

- A continuous and proportional output converted to another form
- Pre-electronic forms:
  - Pneumatic and hydraulic transmission system converted mechanical displacement to pressure
- Electronic analog transmission systems
  - Low voltage/low amperage
  - Continuous signal proportional to sensor output

Analog Signal

- Continuous range of values
- Have a scale (gpm, psi, feet, pH, %, etc.)
- Current-based 4-20 mA signal
- Signal carried by a twisted pair of wires with a shield

Digital Signal Transmission

- Process information like computers…binary number system
- Numerical data: combinations of zeros and ones; electrically, presence or absence of electrical voltage
- To transmit analog data, analog-to-digital converters are used
- Large amounts of data can be processed at high speeds

Telemetry

- Both analog and digital signal transmission techniques link remote facilities (lift stations) to centralized facilities
- Telemetry systems use radio, telephone, microwaves, or lasers as communication media
- Typically combined with computers

Introduction

Automatic Controllers

How Instruments Communicate

- Visual display
  - Indicator => Instantaneous Reading (gpm)
  - Totalizer => Totalized Reading (1,000 gal)
  - Recorder => Chart/Trend (x:y plot of gpm over time)
- Discrete signal – switch closure
- Analog signal – smooth range of values
- Digital communication – HART (Highway Addressable Remote Transducer), Profibus, Foundation Fieldbus, etc.

Visual Displays


Transmitter


Circular Chart Recorder

Totalizer


Strip Chart Recorder

Automatic Controllers

- Prepackaged devices that accept input signals from sensors and send output signals to a control element
  - On-off
  - Proportional (P)
  - Reset Control or Proportional-Integrated (PI)
  - Three-mode – Proportional-Integrated-Derivative (PID)

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Discrete Signal

- On or off
- Discrete signals – High, Low, Failed, Opened, Closed, etc.
- Often called digital
- Signal carried by two wires
- Two kinds:
  - Momentary – close and release
  - Maintained – stays closed

On-off

- **Widely used**
- Used for tight control
- Control is based on a specific band of values rather than just one
- Examples:
  - On-off control in a thermostat
  - Level controls in a wet well of a lift pump station to turn pumps on and off

Proportional (P)

- Continuous control; wide operating band of variable is not acceptable
- Based on a linear mathematical relationship
- Controller output equals the error between set point and actual process variable value multiplied by a constant adjustable factor (gain)
- As error increases, controller output increases
- Not commonly used by itself

Reset Control

- A mathematical integration of the error signal, allowing controller output to change at a rate matching the change of the error signal over time
- Usually combined with proportional control
- Proportional-Integral (PI) action
- **Most commonly used controller combination**

Three-mode

- PID – Proportional-Integral-Derivative controller
- Most sophisticated; least used and not required
- Can be used to add a lead action on a PI control loop

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What have you learned…

- List two types of signals used with instrumentation…

…Analog

…Digital

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What have you learned…

- List two automated controllers commonly used in instrumentation control systems…

…On-off

…Reset Control or Proportional-Integrated (PI)

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Introduction

Process Control

Process Control Fundamentals

- Focus is on the process
- Dynamic behavior of individual processes and the plant as a whole needs to be understood
- Best to utilize the simplest control system that will achieve desired objectives
- Process control design determines how well it will respond dynamically and how it can be controlled

PROCESS CONTROL LAWS

- **FIRST LAW**: The best control system is the simplest one that will do the job
- **SECOND LAW**: A process must be understood before it can be controlled
- **THIRD LAW**: Automated control is difficult if mathematical models and algorithms can not be developed

What does a Control System do?

Control: To maintain desired conditions in a process by adjusting selected variables in the system.

In control Systems:

- A specific value or range is used as a desired value for the controlled variable
- The conditions of the system are measured
- Each system has a **control calculation or algorithm**
- The results of calculation are implemented by a final control element

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Why is Control Necessary?

Two reasons for control:

1. To maintain the measured variable at its desired value when disturbances occur
2. To respond to changes *in t*he "desired value" set point

Desired values are determined by control objectives

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How is Control Achieved?

- A process can be controlled manually by operators or automatically with instrumentation (Sensors, controllers, and control elements)
- Most automatic control is implemented with electronic equipment which uses levels of current or voltage to represent values of variables to be communicated
- Sensors should be calibrated and accurate

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How is Control Achieved?

- Generally the plant never operates on "automatic pilot" and an operator is always present:
  - to perform tasks not automated
  - to optimize operations
  - to interfere with situations when an unusual or dangerous situation occurs

Process Control Design

- Key factors in automated process control systems:
  - Responsiveness
  - Ability to deal with disturbances
- "A responsive control system" means the controlled variable responds quickly to adjustments in the manipulated variable
- Frequency and magnitude of disturbances should be minimum

Sensors

- Selection and location of sensors in process is critical
- "one can control only what is measured"
- Sensors measure important variables rapidly, reliably, and with sufficient accuracy

What have you learned…

- List two reasons for process controls…

… to maintain the measured variable at its desired value when disturbances occur

…to respond to changes in the “desired value” set point

What have you learned…

- List two factors in automated process controls…

…responsiveness

…ability to deal with disturbances

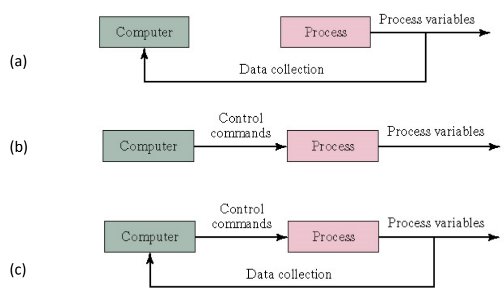
Introduction

Programmable Controls

Computer Use Milestones

- 1950's to 1960's - Origins
  - Mainframe computers – slow and expensive
  - Set point control
  - 1962 - Direct digital control (DDC) systems
- Late 1960's - Minicomputers introduced
- Early 1970's - Microcomputers introduced
  - Programmable logic controllers (PLC) introduced for discrete process control
  - Distributed control starting around 1975
- Early 1990's - PCs for process control

Computer Use Milestones



Remote Terminal Unit (RTU)

- A direct interface between field sensors, actuators, and a central control unit
- A device to control multiple processes, without direct intervention from a controller or master

Programmable Logic Controller (PLC)

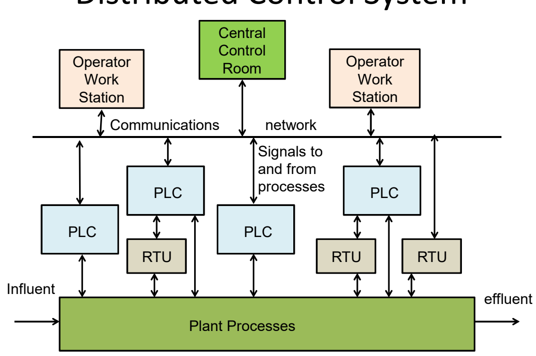
Microprocessor-based controller that executes a program of instructions to implement logic, sequencing, counting, and arithmetic functions to control equipment and processes

- Introduced around 1970 to replace electromechanical relay controllers
- Today's PLCs perform both discrete and continuous control

PCs in Process Control

1. Operator interface – PC is interfaced to one or more PLCs or other devices that directly control the process
   – PC performs certain monitoring and supervisory functions, but does not directly control process
2. Direct control – PC is interfaced directly to the process and controls its operations in real time
   – Traditional thinking is that this is risky

Distributed Control System

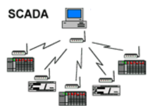


Supervisory Control

Denotes a control system that manages the activities of a number of integrated unit operations

A control system that directs and coordinates the activities of several interacting pieces of equipment

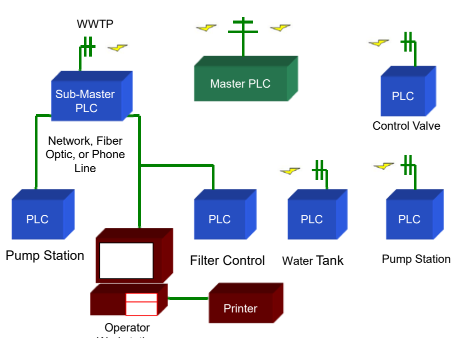
- SCADA
- CMMS - Avantis



SCADA Defined

- What is SCADA?
  - **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition
  - One Supervisory Controller (Master)
  - Multiple Sub-Controllers
  - Possible Sub-Master Controllers

SCADA System Architecture

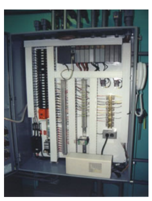


SCADA System Architecture

- Goals:
  - Graphical Representation of Entire System
  - Continuous Information at Operator Workstations
  - Automatic Control
  - Remote Control
  - Alarming/Paging
  - Trending/Reporting
  - Easily Expandable

Typical Hardware – PLC's

- Programmable Logic Controllers (PLC's) - Standardized on Allen-Bradley and Micrologix controllers

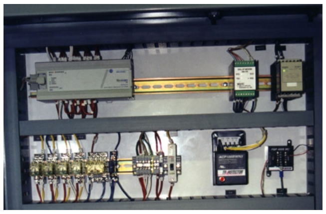



Typical Hardware – Radio Communication

- MAS/MDS radios and modems for Radio Communication


Typical Hardware – Phone Line Communication

- Mille Research modems for Phone Line Communication



Typical Software

- Standardized on Rockwell Software:
  - RSLogix for programming
  - RSLinx for communications
  - RSView for Operator Interface
  - RSMessenger for Alarm Paging
- LapLink Software allows connection to operator workstation from a remote computer through a dial-up modem

SCADA Economic Advantages

- Implementation of “On-Call” shifts
- Reduced Operator Travel Time

SCADA Economic Advantages

- Greater Speed, Accuracy, and efficiency
- Increased Reliability
- Reduced Maintenance
- Safety and Security

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What have you learned…

- What do RTU and PLC stand for?

…RTU – Remote Terminal Unit

…PLC – Programmable Logic Controller

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What have you learned…

- What does SCADA stand for?

…SCADA – Supervisory Control and Data Acquisition

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Process Control

Loop Control

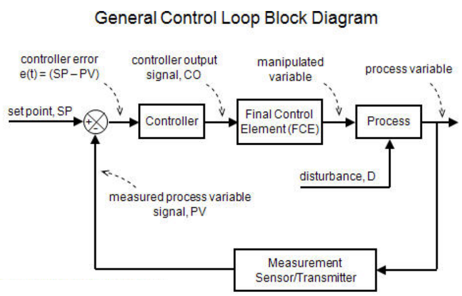
Process Control "Loops"

- Monitoring and control of a process
- WWTP relies on four building blocks:
  - A process model concept
  - Monitoring and control strategies
  - Sensors that provide on-line data to controllers
  - Actuators or control elements that implement controller output

Control Types

- **Feedback Control**: uses direct measurements of the controlled variables to adjust the values of the manipulated variables
- **Feedforward Control**: uses direct measurement of the disturbances to adjust the values of the manipulated variables
- **Compound Control**: different combinations of the two types
- Control objective - to keep control variables at desired levels

Feedback Process Control "Loop"



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Feedback Process Control "Loop"

- Feedback control is a common control strategy; its simplicity accounts for its popularity.
- The feedback controller works with minimum knowledge of the process; it needs only to know which direction to move
- How much to move is usually adjusted by trial and error

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Feedback Process Control "Loop"

- Disadvantage of feedback control: it compensates for a disturbance only after the controlled variable has deviated from the set point
- Disturbance must propagate through the entire process before the feedback control scheme can initiate action to compensate

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Feedforward Control

- Objective - anticipate the effect of disturbances that will upset the process by sensing and compensating for them before they affect the process
- If applied correctly, the controlled variable deviation would be minimum
- Mathematical model captures the effect of the disturbance on the process

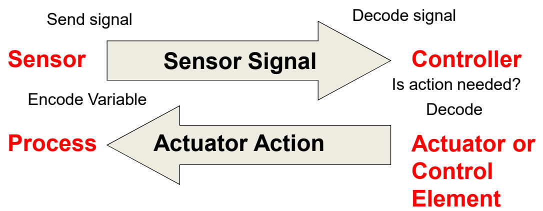
Feedforward Control

- Complete compensation for disturbances is difficult due to variations, imperfections in mathematical models, and imperfections in the control actions
  - Usually combined with regulatory control
- Regulatory control and feedforward control are more closely associated with water and wastewater utilities

Process Control "Loop"

- Three physical properties are monitored in wastewater:
  - Liquid flow: Wastewater, sludge quantities, chemical addition
  - Concentrations: MLSS, nutrients, sludge solids
  - Gases: air, digester gas

Simple Communication Loop



Control Concepts

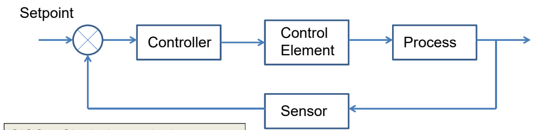
- Manual
- Feedback
- Feedforward
- Compound
- Advanced Control

Manual Control

- Operator observes problems and takes corrective action
- Sometimes, nothing more than a guess
- "Open-loop" control
  - No direct connection between desired output (setpoint) and process variable
  - Operator may have to constantly observe and change manipulated variable to ultimately correct problem

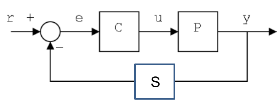
Feedback Control

- Output information is used to adjust process controls
- Feedback controller receives sensor output on process variable and compares it to setpoint



SISO – Single-input single-output

Feedback Control



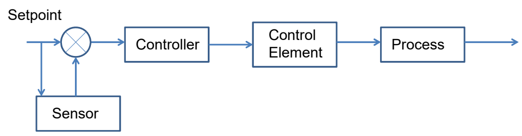
- Output of the system $y(t)$ is fed back to the reference value $r(t)$ through measurement of a sensor, S
- Controller *C* takes the difference between the reference and the output and determines the error *e*
- Controller C changes the inputs *u* to Process under control *P* by the amount of error *e*

Feedback Control

- Limitations on feedback control:
  - Feedback control is after the fact, not predictive
  - Requires operators to change set points to optimize system
  - Changes can bring instability into system
  - Optimization of many input and output variables are difficult
  - Most processes are non-linear and change according to process environment

Feedforward Control

- Input information is used to adjust process controls
- Controller receives sensor output on process variable and compares it to setpoint

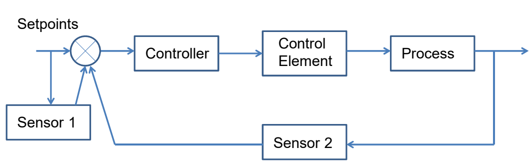


Feedforward Control

- Feedforward control avoids delays of feedback control
- Input disturbances are measured and accounted for before they have time to affect the system
- Difficulty with feedforward control:
  - Effects of disturbances on process must be anticipated
  - No surprises

Compound Control

- Input and output information is used to adjust process controls
- Controller receives sensor outputs on process variables and compares it to setpoints



Compound Control

- Benefits of feedback control:
  - Controlling unknown disturbances
  - Not having to know exactly how a system will respond
- Benefits of feedforward control:
  - Responding to disturbances before they can affect process

Cascade control – Feedback as primary with a feedforward secondary loop

Advanced Control

- Use of computers and microprocessors
- Control logic (algorithms) includes feedforward and feedback control concepts
- Compare process conditions with pre-programmed conditions
- Best applied where multiple, parallel treatment units are used
- Monitors dozens of sensors
- Manipulates several pieces of equipment

Advanced Control

- Most complex processes have many control variables
- To control multiple variables, multiple control loops are used
  - Example: bioreactor with at least three control loops: Carbon feed, D.O., and flow splitting
  - Multiple control loops often interact causing process instability
- Multivariable controllers account for loop interaction
- Models can be developed to provide feedforward control strategies applied to all control loops simultaneously

Data Issues

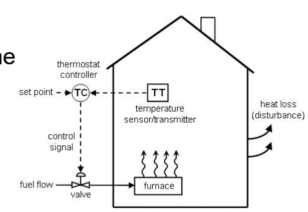
- Inputs to advanced control systems require accurate, clean, and consistent process data
  - "Garbage in-garbage out
- Many key process parameters cannot be measured on-line requiring laboratory or maintenance analyses
  - LIMS
  - CMMS
- Sensors may have to be filtered to attenuate noise
- With many variables to manipulate, control strategy is critical to limit control loop interaction

Analogies

- Before discussing instrumentation and sensor details, let's look at two familiar feedback process control loops:
  - Home heating system
  - Car cruise control

Feedback Control Loop – Analogy I

Heating your home



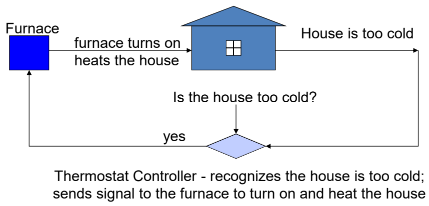
•Temperaturere of the room is determined by a thermostat

•Temperature is compared with a desired temperature

•If the temperature falls below desired amount, furnace turns on; if the temperature is above, the furnace turns off

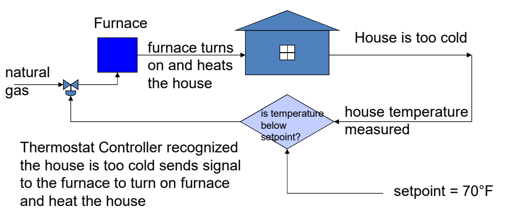
Feedback Control Loop – Analogy I

- Process control loop: control component monitors desired output results and changes input variables to obtain the result.
- Example: thermostat controller



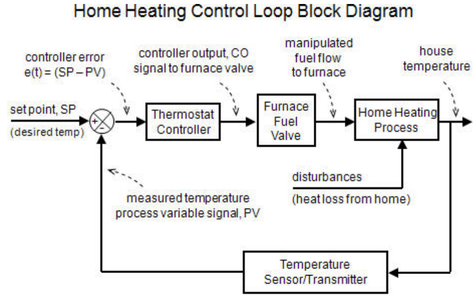
Feedback Control Loop – Analogy I

- Controlled variable: temperature (desired output)
- Input variable: temperature (measured by thermometer in theromostat)
- Setpoint: user-defined desired setting (temperature)
- Manipulated variable: natural gas valve to furnace (subject to control)



Feedback Control Loop – Analogy I

Home Heating Control Loop Block Diagram



Feedback Control Loop – Analogy I

- As the furnace turns on and off, home temperature increases or decreases
- Feedback loops are operative
- Elements of a home heating control system:
  - Control Objective: *maintain house temperature at SP in spite of disturbances*
  - Process Variable: *house temperature*
  - Measurement Sensor: *thermistor; or bimetallic strip coil on analog models*
  - Measured Process Variable (PV) Signal: *signal transmitted from the thermistor*

Feedback Control Loop – Analogy I

- More elements of home heating controls:
  - Set Point (SP): *desired house temperature*
  - Controller Output (CO): *signal to fuel valve actuator, furnace blower, furnace burner*
  - Final Control Element (FCE): *solenoid valve for fuel flow to furnace*
  - Manipulated Variable: *fuel flow rate to furnace*
  - Disturbances (D): *heat loss from doors, walls and windows; changing outdoor temperature; sunrise and sunset; rain...*

Feedback Control Loop – Analogy II

- Cruise control in a car
  - Cruise control is enabled with a push button on the car steering wheel
  - Once on the open road and at a desired cruising speed, a second button switches the controller from manual mode (where car speed is adjusted by our foot) to automatic mode (where car speed is adjusted by the controller)
  - Cruise control monitors transmission drive shaft rotation than vehicle speed…!

Feedback Control Loop – Analogy II

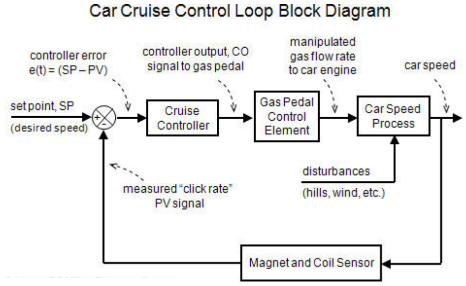
- Elements of cruise control:
  - Control Objective: *maintain car speed at SP in spite of disturbances*
  - Process Variable: *car speed*
  - Measurement Sensor: *magnet and coil to clock drive shaft rotation*
  - Measured Process Variable (PV) Signal: *"click rate" signal from the magnet and coil*

Feedback Control Loop – Analogy II

- Other elements of cruise control:
  - Set Point (SP): *desired car speed, recast in the controller as a desired transmission click rate*
  - Controller Output (CO): *signal to actuator that adjusts gas pedal (throttle)*
  - Final Control Element (FCE): *gas pedal position*
  - Manipulated Variable: *fuel flow rate*
  - Disturbances (D): *hills, wind, curves, passing trucks…*

Feedback Control Loop – Analogy II

Car Cruise Control Loop Block Diagram



input output

Input refers to a variable that causes an output.

- Driving example;
  - input: gas fuel rate
  - output: car speed
- Heated room example;
  - input: fuel to the furnace
  - output: room temperature

What have you learned…

- List three loop control configurations…

…feedback

…feedforward

…compound; combinations of feedback and feedforward

Process Control

Sensors and Analyzers

Physical-Chemical Analyzers

- Specific chemical ion analyzers
  - DO, pH, ammonia, ORP
- Group of chemical analyzers
  - Total chlorine, total oxidized nitrates
- Type of substance analyzers
  - TSS, SS
- Effect analyzers
  - BOD, COD

Sensors

- Flow measurement
- Pressure measurement
- Level
- Temperature
- Weight
- Speed
- Proximity sensors
- Physical-chemical analyzers
- Solids concentration

FLOW MEASUREMENT

Flow Measurement Uses - Wastewater

- Influent/effluent flow measurement
- Flow distribution
- Reactor control
  - Aeration air flow
  - RAS rate
  - WAS rate
- Flow pacing of chemicals
- Digester gas flow

Flow Measurement Uses - Water

- Water supply, production, & delivery
- Flow pacing of chemicals
- Customer billing
- Check pump efficiency
- Monitor for leaks
- Help control or limit water delivery

Flow Measurement Basics

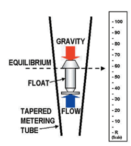
- To measure flow, must know:
  - Velocity
  - Area
  - $Q = V \times A = ft/sec \times ft^2 = ft^3/sec$
- To know mass flow, multiply by specific weight
  - $\gamma \times Q = lb/ft^3 \times ft^3/sec = lb/sec$
- In an open channel or partially full pipe, must measure both or have a device that compensates for this

Flow Measurement Basics

- Incompressible fluids
  - Volume doesn't change with pressure
  - Water
  - Liquid chemicals
  - We get to simplify our flow equations
- Compressible fluids
  - Volume changes with pressure
  - Gas flow (air, steam, etc.)
  - PV = nRT (ideal gas law)
  - Must measure temperature and pressure to get accurate mass flow

Variable Area Flow Meters

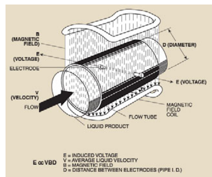
- Generally called rotameters
- Fluid velocity moves shaped float within tapered tube
- Read flow via graduations on clear tube
- Magnetically-coupled pointer on solid tubes
- Often used for:
  - Chlorination gas flow
  - Seal water flow
  - Bubbler air flow



Rotameters

Magnetic Flow Meters

- Any conductor moving within an electromagnetic field will have an induced voltage in that conductor
- The magnitude of the voltage (volts) is proportional to the speed of the movement.



Magnetic Flow Meters

- Used for liquids and sludge in closed pipes
- No obstruction to flow
  - No head loss
  - Unaffected by solids
- Must be conductive fluid

Magnetic Flow Meters

- Highly accurate – 0.25%
- Wide flow range – >10:1 turndown
- Good immunity to flow line distortion
- Needs full pipe flow

Flow Measurement

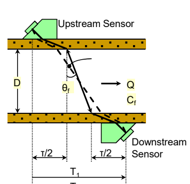
- Open-channel flow
  - Parshall flume
- Closed-pipe flow
  - Venturi meters
  - Magnetic flow meters
  - Ultrasonic

Magmeters

- Magnetic flow metering is based on Faraday's law of electromagnetic induction
- Magmeters can detect the flow of conductive fluids only

Ultrasonic Flowmeters

- Doppler Effect Ultrasonic Flowmeter
- Transit Time Difference Ultrasonic Flowmeter



PRESSURE MEASUREMENT

Pressure Measurement

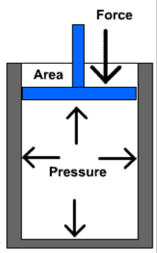
- Mechanical pressure gauges
- Pneumatic pressure transmitters
- Electronic pressure transmitters
- Differential pressure transmitters

Pressure Measurement Uses

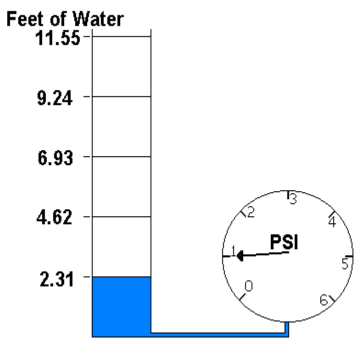
- Pump/blower performance
- Force main pressure
- Aeration system header pressure
- Differential pressure for flow measurement, filter status
- Level measurement
- Distribution system pressures
- Pressure in tanks, etc.

Pressure Measurement Basics

- Pressure = force per unit area
- Measured in:
  - pounds per square inch – lbs/in^2
  - kilonewtons per square cm – kN/cm^2 (kPa)
- Can also express as height of liquid:
  - feet of water – ft w.c.
  - inches of water – in w.c.
  - millimeters of mercury – mm Hg

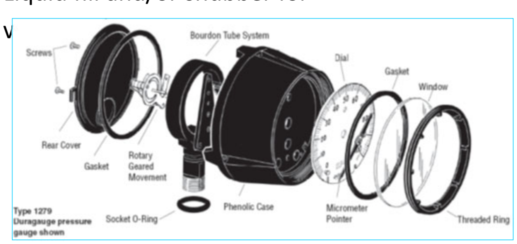


Water Column to PSI



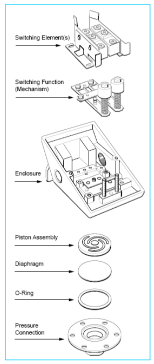
Pressure Gauges

- Simple pressure indication
- Bourdon tube geared to pointer
- Liquid fill and/or snubber for v



Pressure Switches

- Tells us of high or low pressure
- Diaphragm/spring operated snap action switch
- Deadband: Amount of pressure change before switch releases

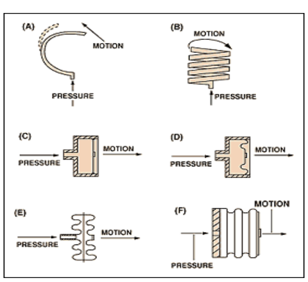


Pressure Transmitters

- Continuous pressure readings
- Transmit analog signal
- Loop powered
- Gauge/differential pressure, flow or level
- Incredibly accurate: 0.04% or 0.025%

Pressure Sensing Units

A. C- shaped Bourdon tube
B. Helical Bourdon tube
C. Flat diapragm
D. Convoluted diaphragm
E. Capsule
F. Bellows



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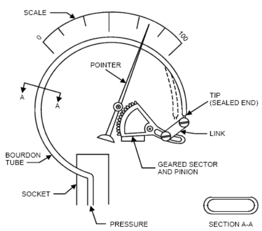
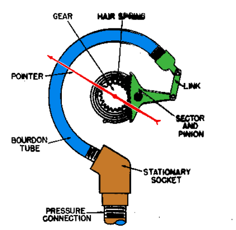
Bourdon Tube





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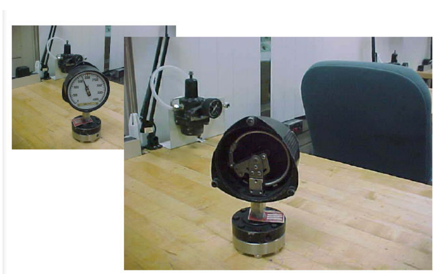
Bourdon Tube



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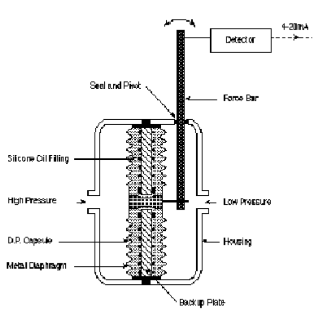
Differential Pressure Cell



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LEVEL MEASUREMENT

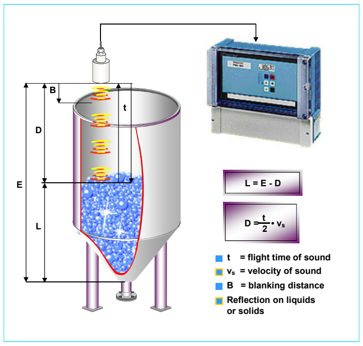
Level Measurement

- Floats
- Ultrasonic
- Electrical methods
- Head pressure
  - Bubbler tube system
  - Diaphragm bulb system

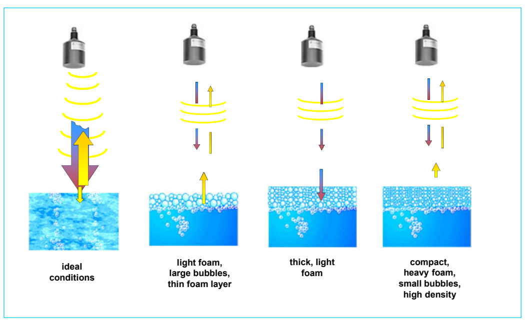
Ultrasonic Level Instruments

- Accurate and reliable
- Non-contacting
- Must eliminate interferences
  - Obstructions
  - Surface scum/ice/foam
  - Wind
  - Air temperature must be compensated

Ultrasonic Level Measuring Principle



Effects of Foam



Radar Level Instruments

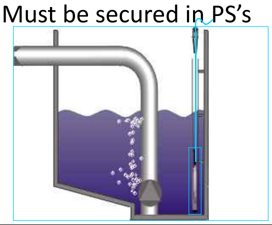
- Uses electromagnetic wave propagation
- Depends on dielectric constant of material surface – water is fine
- Eliminates interference by wind, temperature, and some foam

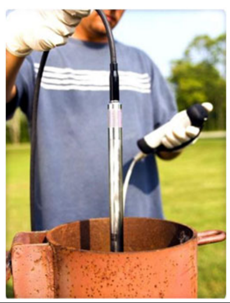

Types of Radar Level Instruments

- Free Space
  - Frequency Modulated Continuous Wave (FMCW)
  - Pulse Time-of-Flight (similar principle to ultrasonic)
- Guided Wave Radar (GWR)
  - “Radar on a rope” or Time Domain Reflectometry (TDR)
  - Time pulse along cable or rod

Submersible Pressure-Type Level Instruments

- Cheap – $500-1,000
- Accurate – 0.2%
- Works in tight spaces
- Must be secured in PS’s

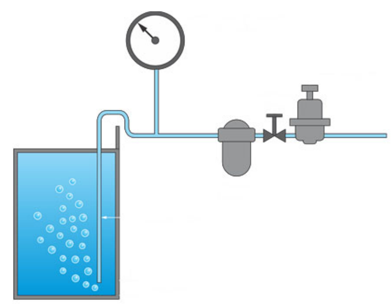




Bubbler Level Measurement

- Components
  - Gas Compressor & Receiver Tank
  - Flow Regulator
  - Tube into Water
  - Pressure Instrument(s)
- Good for Tight Quarters
- Moving Parts Can Fail
- Widely Used

Bubbler Tube Level Measurement

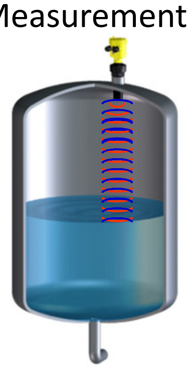


Float Level Switches

- Classic pump control solution
- Used to be mercury switches, now mechanical switches
- Contacts open or close on rising or falling water
- Can be fouled in wet wells or damaged by scum layer

Ultrasonic Level Measurement

- Time of Flight Technology
- Short ultrasonic impulses emitted from transducer
- Bursts are created from electrical energy applied to piezeo electric crystal inside the transducer
- The transducer creates sound waves (mechanical energy)
- With longer measuring ranges a lower frequency and higher amplitude are needed to produce sound waves that can travel farther
- The longer the measuring range the larger the transducer must be



TEMPERATURE MEASUREMENT

Temperature Measurement

- Thermal bulb
- Thermocouple
- Resistance temperature detectors
- Thermistors

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Temperature Measurement Uses

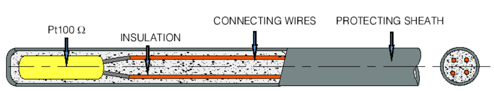
- Wastewater influent/effluent temperature
- Digester sludge temperature
- Raw/finished water temperature
- Motor bearing/winding temperature
- Air temperature for mass air flo measurement

Temperature Sensors

- Thermometers
  - Liquid or capillary
  - Bimetallic
- RTDs
  - Pure metal - stable, accurate, repeatable
  - Most often used
- Thermocouples
  - Versatile
  - Good for temps > 800 C (engine exhaust)
- Thermistors
  - Like RTDs but made of ceramic or polymer
  - Most sensitive – low stability but fast response

Temperature Transmitters

- Need a measuring device (RTDs, etc.)
- Generally use a transmitter to give us a 4-20 mA signal
- Protect element with thermowell



RTD – Resistance Temperature Detector

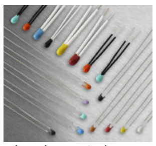
Thermocouple Applications

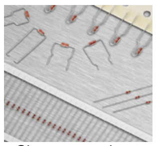
- Plastic injection molding machinery
- Food processing equipment
- Deicing
- Semiconductor processing
- Heat treating
- Medical equipment
- Industrial heat treating
- Packaging equipment

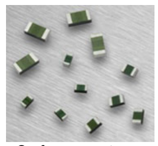
Thermistors
THERMal resISTORS

•A thermistor is a type of resistor used to measure temperature changes, relying on the change in its resistance with changing temperature

•Thermistor is a combination of the words thermal and resistor.


Leads, coated


Glass encased

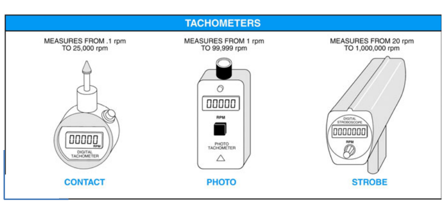

Surface mount

Speed Measurement

- Tachometer generations
- Noncontact frequency generators

Tachometers

- The speed of a rotating object can be measured using a contact tachometer, photo tachometer, or strobe tachometer.



Weight Measurement

- Weigh beam
- Hydraulic load cell
- Strain gauge

PROCESS ANALYZERS

Physical-Chemical Analyzers

- Ion-selective electrodes
  - Dissolved Oxygen
  - pH
  - Ammonia
  - ORP
- Group chemical analyzers
  - Total Chlorine
  - Total NO_x - Nitrate and Nitrite

pH/ORP Analyzers

- pH = negative log of H^+ concentration (acid/base)
- ORP = oxidation-reduction potential
- Two methods – differential and combination
  - Differential electrodes
    - Longer lasting
    - Replaceable parts
    - Resists poisoning

Typical ORP Probes

Several typical ORP probes. The one on the left is designed for high chlorine applications.

NOTE: Each has a thin glass bulb or membrane at the tip. These are VERY fragile.

pH/ORP Analyzer Uses

- Each process has its own favorable range
- Wastewater process contains many oxidation-reduction reactions
- BNR process changes pH and ORP

ORP Ranges for Processes

Biochemical Reaction	ORP, mV
Nitrification	+100 to +350
cBOD degradation with air (O_2)	+50 to +250
Denitrification	+50 to -50
Acid formation (fermentation)	-100 to -225
Methane production	-175 to -400

Residual Chlorine Analyzers

- “Chemist in a Box”
- Measures either free **or** combined chlorine
- Uses colorimetric measurement process
- Replace reagents monthly
- Latest amperometric devices use no reagents, but have limitations

Chlorine Measurement Uses

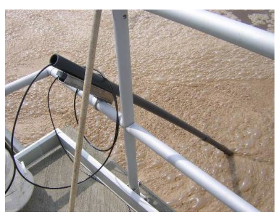
- Control chemical addition
- Ensure disinfection residual in distribution system
- Confirm dechlorination

Dissolved Oxygen Analyzers

- Historically problems with membrane probes
- Zullig electrode probes solved some of these but had high O&M
- Improved membrane probes worked pretty well
- New optical units are much better

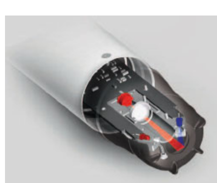
DO Analyzer Uses

- DO is most important W/W process monitor
- Maintain aerobic conditions for biological treatment
- Automatically control aeration systems
  - Save energy
  - Save money



Optical Dissolved Oxygen Sensor

- End cap coated w/ luminescent material
- LED emits blue light
- Coating gets excited
- Emits red light
- Measure time to disappear
- More O_2 - “quenches” faster
- Red LED for reference



Optical DO is Not Perfect

- Optical device in wastewater
- Requires clean surface
- Wipe end cap as maintenance
- Use air blast cleaning - maybe

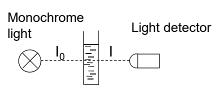
MEASUREMENT OF POLLUTANTS IN WATER

Optical methods

Colorimetry

Visual tests

Photometer



Chemical Analysis

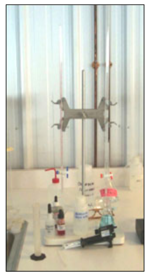
Test Kits and Colorimeters

Chemical Analysis - Alkalinity

Titration Method

Titration with 0.02 N Sulfuric Acid
with methyl orange indicator end point (4.5 pH)

1 ml titrant equals 10 mg/L $CaCO_3$.

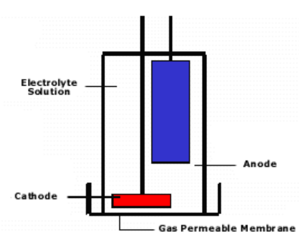


Chemical Analysis – D.O.

Winkler Method:

- manganous sulfate, potassium iodide, sodium hydroxide
- manganous ion + oxygen → manganous dioxide (proportional to dissolved oxygen concentration)
- sulfuric acid causes the oxidation of iodide to iodine by the manganous dioxide.
- Titration with sodium thiosulfate with starch indicator (iodine concentration proportional to DO concentration

DO Probe



Measurements - pH

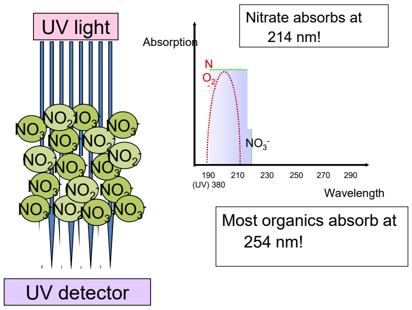
Both laboratory and field instruments readily available

Measuring pH using ion selective electrodes (ISE)

Chemical Analysis – Ammonia, Nitrite and Nitrate

Ammonia:	colorimetric Nesslerization ion specific electrodes
Nitrite:	colorimetric
Nitrate:	reducing to nitrite with cadmium catalyst, measure nitrite. ion specific electrode

NO_3 Absorption measurement



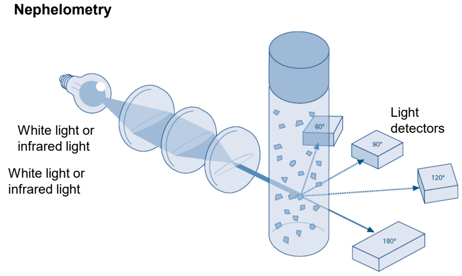
Solids Concentrations

- Nephelometers
- Turbidimeters
- Ultrasonic solids meters
- Sludge blanket sensors

MEASUREMENT OF POLLUTANTS IN WATER

Optical methods

Nephelometry



Ultrasonic sludge blanket level

Primary clarifiers / Thickeners

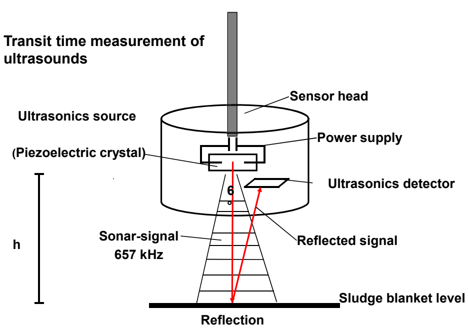
- Ultrasonic detection
- To moniter blanket level
- Prevent sludge overflow

Sand Filter

- Bed expansion during backwash

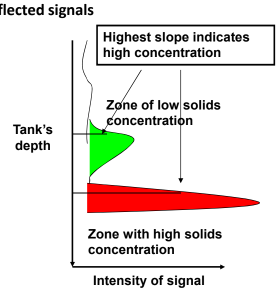
Measuring principle

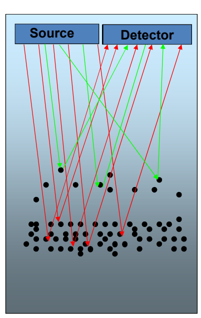
- **Transit time measurement of ultrasounds**



Measuring principle

- **Sludge concentration profile, derived from the distribution of intensity of reflected signals**





What have you learned…

- List two flow measurement devices…

…parshall flume

…magmeter

…venturi meter

…ultrasonic meter

What have you learned…

- List two types of pressure gauges…

…mechanical

…pneumatic

…electrical

What have you learned…

- List two level measuring devices…

…floats

…ultrasonic

…bubbler

What have you learned…

- List two temperature measuring devices…

…thermocouples

…thermistors

What have you learned…

- List four specific chemical ion measuring analyzers…

…dissolved oxygen

…pH

…ammonia

…ORP

What have you learned…

- List one group of chemical analyzer…

…Total chlorine

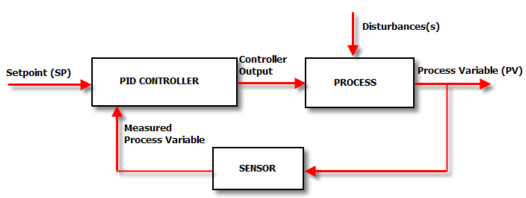
…Total nitrogen oxides (NO_x)

Process Control

PID Control

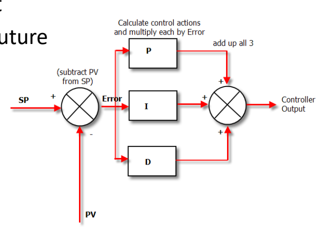
PID Control

Typical loop control:



PID Control

- Modes of PID controller
  - Proportional (P) – present
  - Integral (I) – past
  - Derivative (D) - future



PID Control

- **Proportional** - To handle the present, the error is multiplied by a negative constant *P* and added to the controlled quantity
  - Note that when the error is zero, a proportional controller's output is zero

PID Control

- **Integral** - To handle the past, the error is integrated (added up) over a time period, multiplied by a negative constant *I* and added to the controlled quantity
- *I* finds the process output's average error from the setpoint
  - A simple proportional system oscillates around the setpoint
  - The average difference between the process output and the setpoint is always reduced and the process output will settle at the setpoint.

PID Control

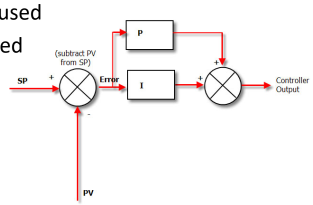
- **Derivative** - To handle the future, the first derivative (slope) of the error is calculated, multiplied by negative constant *D*, and added to the controlled quantity
- The larger the derivative term, the more rapidly the controller responds to changes in the process output.
  - The *D* term dampens a controller's response to short term changes.

PID Control

- The PV is subtracted from the SP to create the Error
- The error is simply multiplied by one, two or all of the calculated P, I and D actions (depending which ones are turned on)
- The resulting "error x control actions" are added together and sent to the controller output.

PID Controls

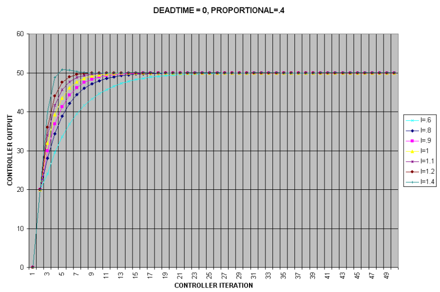
- The 3 PID modes are used in different combinations:
  - P – Sometimes used
  - PID – Sometimes used
  - PI - Most often used
  - PD – rarely used



PID Control - Goals

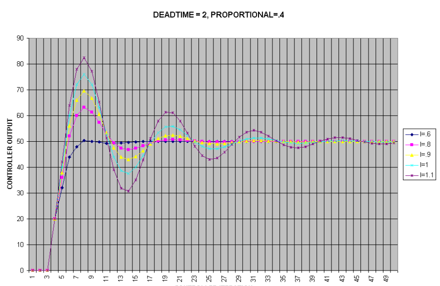
- Quickly respond to changes in setpoint
- Stability of control
- Dampen oscillation
- Problems:
  - Deadtime—lag in system response to changes in setpoint
  - Deadtime can cause significant instability in the system controlled

PI Control – Example 1



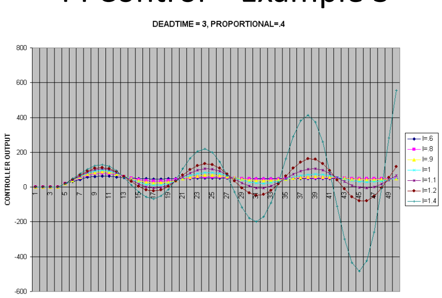
I = 1.4 gives the best response: quickly brings controller to setpoint without oscillation

PI Control – Example 2



I = 0.6 gives the best response
I = 1.1 borders on instability

PI Control – Example 3



I = 0.6 gives the best response
I = 1.2 & 1.4 unstable

Summary

Helpful Hints/Conclusions

Questions?

Thank You

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"Anyone who can solve the problems of water will be worthy of two Nobel prizes – one for peace and one for science."

- John F. Kennedy