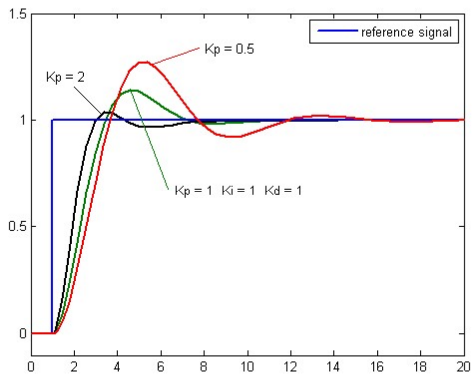
MECH 10
Fundamentals of Electronics

Class 29
Process Controls



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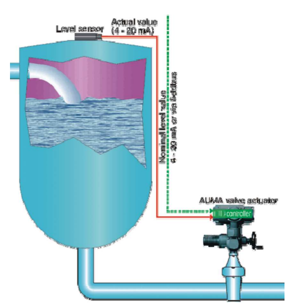
Fundamentals of Electronics

- Process Controls
  - **Process** – a mechanical, electrical, chemical or thermal operation used to change or preserve useful material properties
  - **Control** – to influence or direct a process



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- Process Controls
  - **Process Variables**
    - Pressure, Temperature, Level, Flow, Position, Strain, Velocity, Acceleration, Vibration
  - **Analytical Variables**
    - Conductivity, dissolved oxygen, chemical constituent, combustion quality, density, viscosity, pH, fluoride

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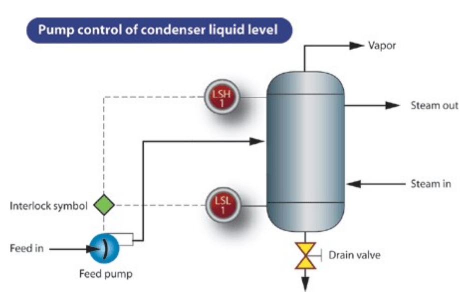
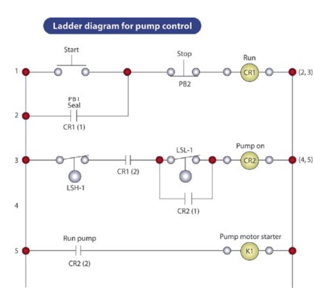
- Process Controls
  - Control Types
    - **On-Off** – discrete control element with two conditions, fully on or fully off
    - **Continuous** – analog control element with infinite conditions, from fully on to fully off





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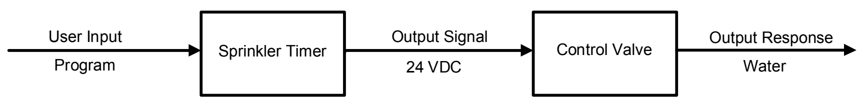
- Process Controls
  - Continuous Controls
    - **Open Loop** – a control system where the control action is independent of the system response - ***no feedback!***
    - Used for simple, easily modeled systems where precise control is not required



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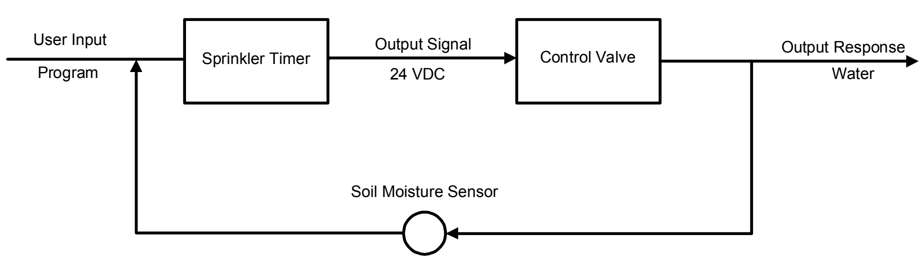
- Process Controls
  - Continuous Controls
    - **Closed Loop** – a control system where the control action is dependent on the response ***feedback***
    - Used for complex, transient, critical automation systems where precise control is required



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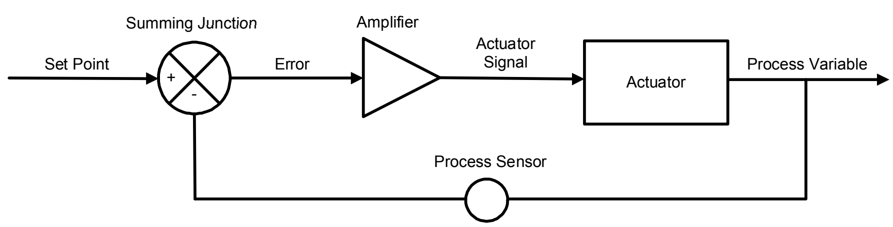
- Process Controls
  - Closed Loop
    - Primary components
      - Process sensor (measures the process variable)
      - Summing junction
      - Error amplifier
      - Actuator



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- Process Controls
  - Closed Loop Error Correction
    - **Proportional** – produces an output response proportional to the error
    - **Integral** – produces an output response proportional to time and the error magnitude
    - **Derivative** - produces an output response proportional to the error rate of change

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- Process Controls
  - Closed Loop Error Correction
    - **Proportional** – produces an output response proportional to the error

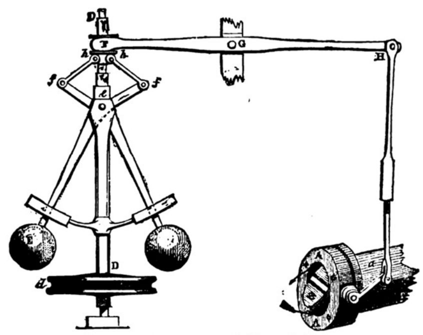

FIG. 4.—*Governor and Throttle-Valve.*

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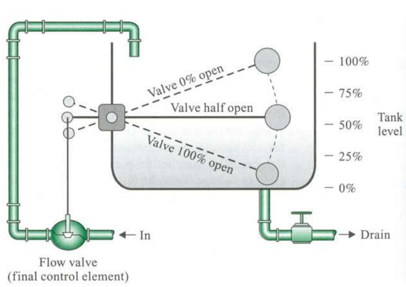
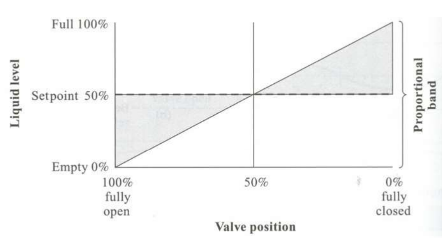
- Process Controls
  - Closed Loop Error Correction
    - **Proportional Gain** – the change in output divided by the change in input





Gain = 1

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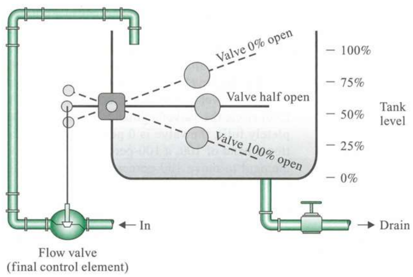
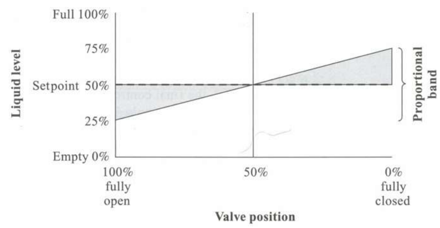
- Process Controls
  - Closed Loop Error Correction
    - **Proportional Gain** – the change in output divided by the change in input





Gain = 2

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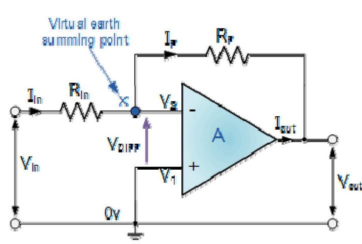
$$V_{out} = V_{in} \times \frac{R_F}{R_{IN}}$$

- Process Controls
  - Closed Loop Error Correction
    - **Proportional Gain** – the % change in output divided by the % change in input
    - **Proportional Band (%)** – the % change in output that causes a 100% change in input

$$Gain = \frac{\Delta Output(\%)}{\Delta Input(\%)}$$

$$PB = \frac{1}{Gain} \times 100$$



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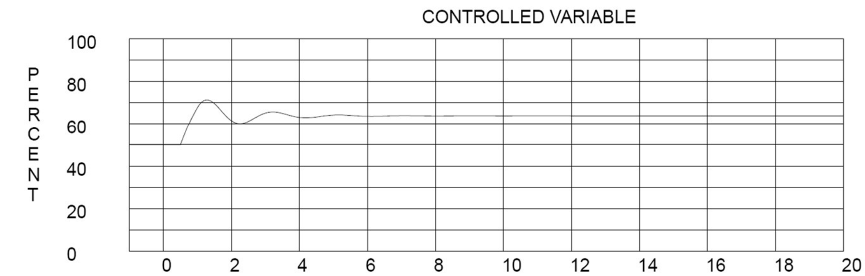
- Process Controls
  - Closed Loop Error Correction
    - **Proportional Offset** – the continuous difference between the set point and the process variable



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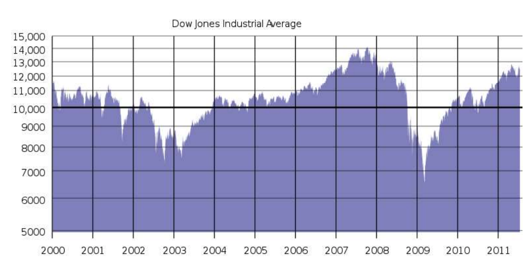
- Process Controls
  - Closed Loop Error Correction
    - **Proportional Offset** – the continuous difference between the set point and the process variable
      - Market Crash = (8,000 – 10,000) / 10,000 = 20%
      - Full recovery = (10,000 – 8,000) / 8,000 = 25%



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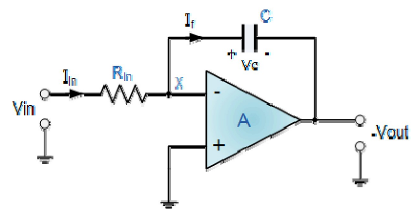
$$V_{out} = V_{in} \times \frac{1}{2\pi fRC}$$

- Process Controls
  - Closed Loop Error Correction
    - **Integral Gain** – the change in output proportional to the magnitude and duration of the error
    - **Reset Rate** – Full range corrections per minute
      - Example Reset Rate = 2 minutes
        - 20% set point change (50 to 70) $\longrightarrow$ 20% output change
        - Full recovery = (50 - 70) / 70 = 28.6% = 8.6% offset
        - Correction time = reset rate x offset

$$t = \frac{8.6\%}{1} \times \frac{2\,\text{min}}{100\%} = 0.172\,\text{min}$$



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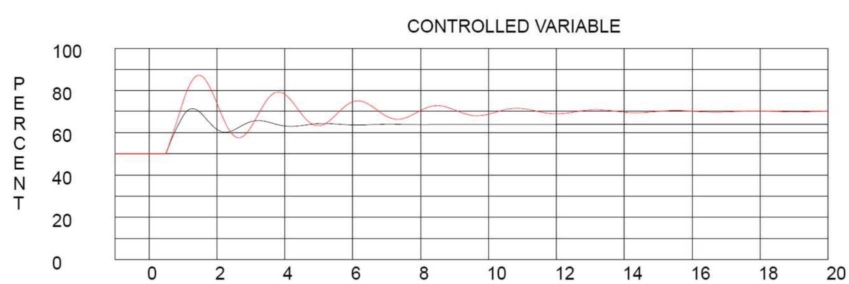
$$V_{out} = V_{in} \times \frac{1}{2\pi fRC}$$

- Process Controls
  - Closed Loop Error Correction
    - **Integral Gain** – the change in output proportional to the magnitude and duration of the error
    - **Reset Rate** – Proportional action corrections per minute



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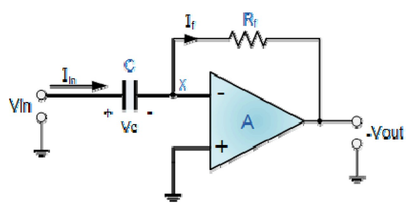
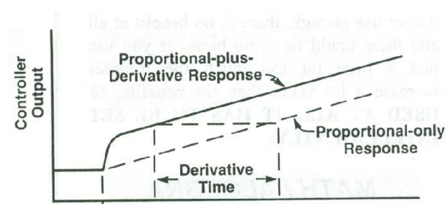
$$V_{out} = \frac{\Delta V_{in}}{\Delta t} \times RC$$

- Process Controls
  - Closed Loop Error Correction
    - **Derivative Gain** – the change in output proportional to the error rate of change
    - **Derivative Time** – the advance in time of the output over proportional only control





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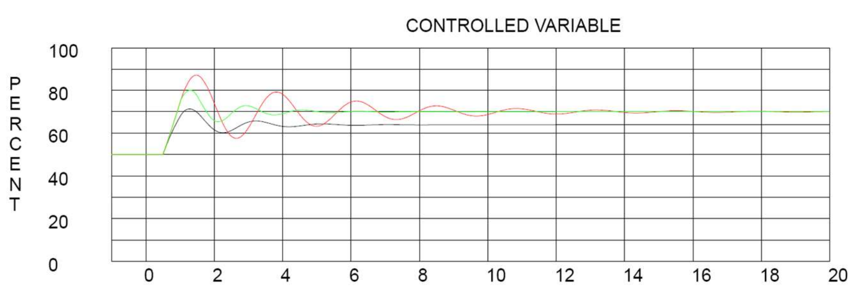
- Process Controls
  - Closed Loop Error Correction
    - **Derivative Gain** – the change in output proportional to the rate of error change
    - **Derivative Time** – the advance in time of the output over proportional only control



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Fundamentals of Electronics

- Process Controls
  - Closed Loop Error Correction
    - Combined Mode Function & Application

Mode Combination	Function	Application
Proportional	Provide gain	Small set point or load changes
Proportional + Integral	Eliminate offset	Large and slow set point & load changes
Proportional + Integral + Derivative	Fast response, minimize overshoot, eliminate offset	Large & sudden set point or load changes in slow response system

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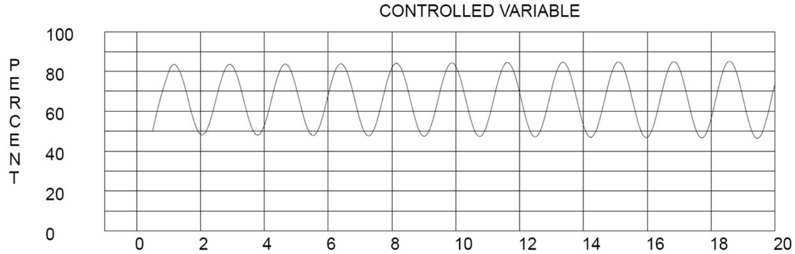
- Process Controls
  - Closed Loop Tuning Methods
    - Ziegler-Nichols Continuous Cycling
      - Step 1 – set integral time to max & derivative time to zero
      - Step 2 – increase proportional gain until output oscillates with constant amplitude, record ***ultimate gain*** $\boldsymbol{K_U}$
      - Step 3 – record oscillation period as $\mathbf{P_u}$

CONTROLLED VARIABLE



Proportional Gain = 0.75

- Process Controls
  - Closed Loop Tuning Methods
    - Ziegler-Nichols Continuous Cycling
      - Step 4 – Apply gain factors from table
      - Step 5 – Test system response & stability

Control Type	Proportional Gain (K_p)	Integral Time (T_i)	Derivative Time (T_D)
Proportional	$0.50K_u$	-	-
Proportional + Integral	$0.45K_u$	$1.2K_p$ / P_u	-
Proportional + Integral + Derivative	$0.60K_u$	$2K_p$ / P_u	K_p x P_u / 8

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- Process Controls
  - Example
    - PID control, K_u = 0.75, P_u = 2 minutes
    - Find K_p, K_i, & K_d

$$K_p = 0.6 \times K_u = 0.45$$

$$K_i = \frac{2 \times K_u}{P_u} = 0.75$$

$$K_D = \frac{K_u \times P_u}{8} = 0.19$$

Control Type	Proportional Gain (K_p)	Integral Time (T_i)	Derivative Time (T_D)
Proportional	$0.50K_u$	-	-
Proportional + Integral	$0.45K_u$	$1.2K_p$ / P_u	-
Proportional + Integral + Derivative	$0.60K_u$	$2K_p$ / P_u	K_p x P_u / 8

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- Process Controls
  - Closed Loop Tuning Methods
    - Ziegler-Nichols Continuous Cycling
      - Step 3 – reduce proportional gain to 60% of ultimate gain
      - Step 4 – decrease integral time until unbounded oscillation starts
      - Step 5 – increase integral time just until unbounded oscillation stops
      - Step 6 – increase derivative time until unbounded oscillation starts
      - Step 7 – decrease derivative time just until unbounded oscillation stops.

Proportional Gain = 0.75

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- Lab 29 – Closed Loop Controls