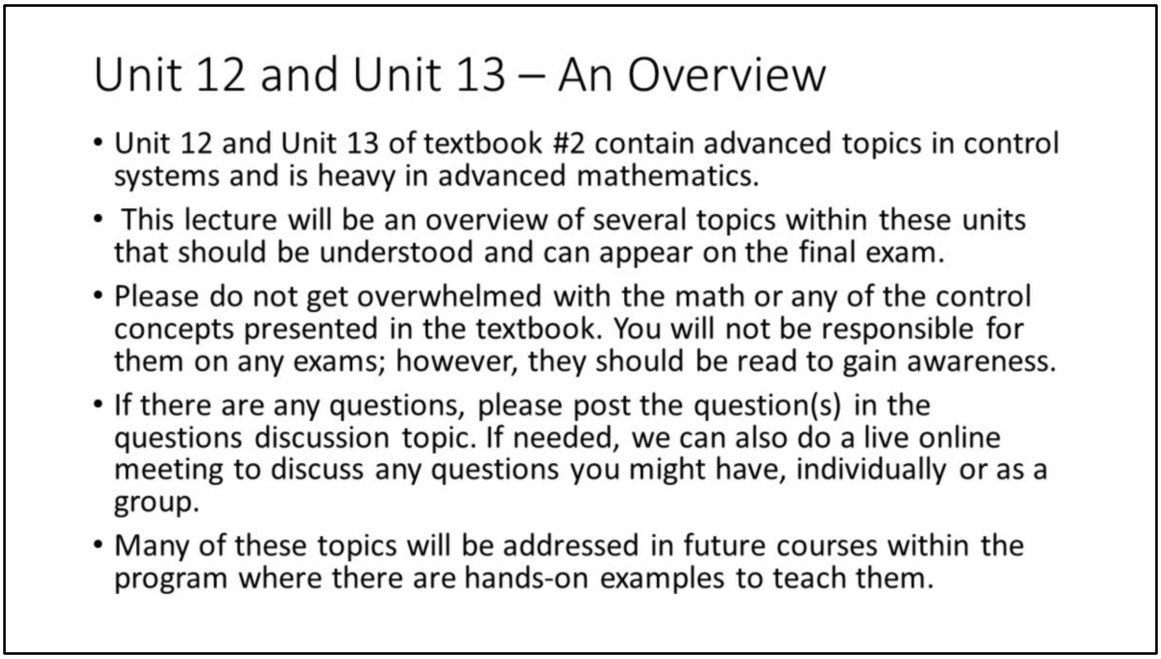
Special – Purpose Concepts Dead Time

Unit 12 & Unit 13

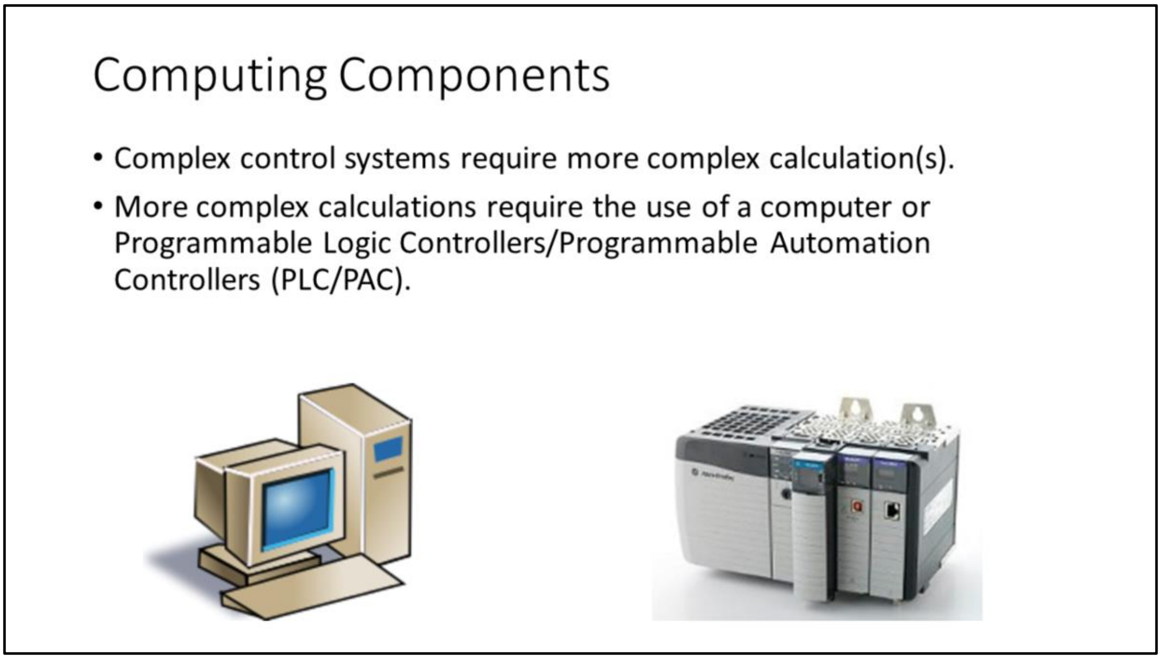
An Overview

Textbook #02



Unit 12 and Unit 13 – An Overview

- Unit 12 and Unit 13 of textbook #2 contain advanced topics in control systems and is heavy in advanced mathematics.
- This lecture will be an overview of several topics within these units that should be understood and can appear on the final exam.
- Please do not get overwhelmed with the math or any of the control concepts presented in the textbook. You will not be responsible for them on any exams; however, they should be read to gain awareness.
- If there are any questions, please post the question(s) in the questions discussion topic. If needed, we can also do a live online meeting to discuss any questions you might have, individually or as a group.
- Many of these topics will be addressed in future courses within the program where there are hands-on examples to teach them.

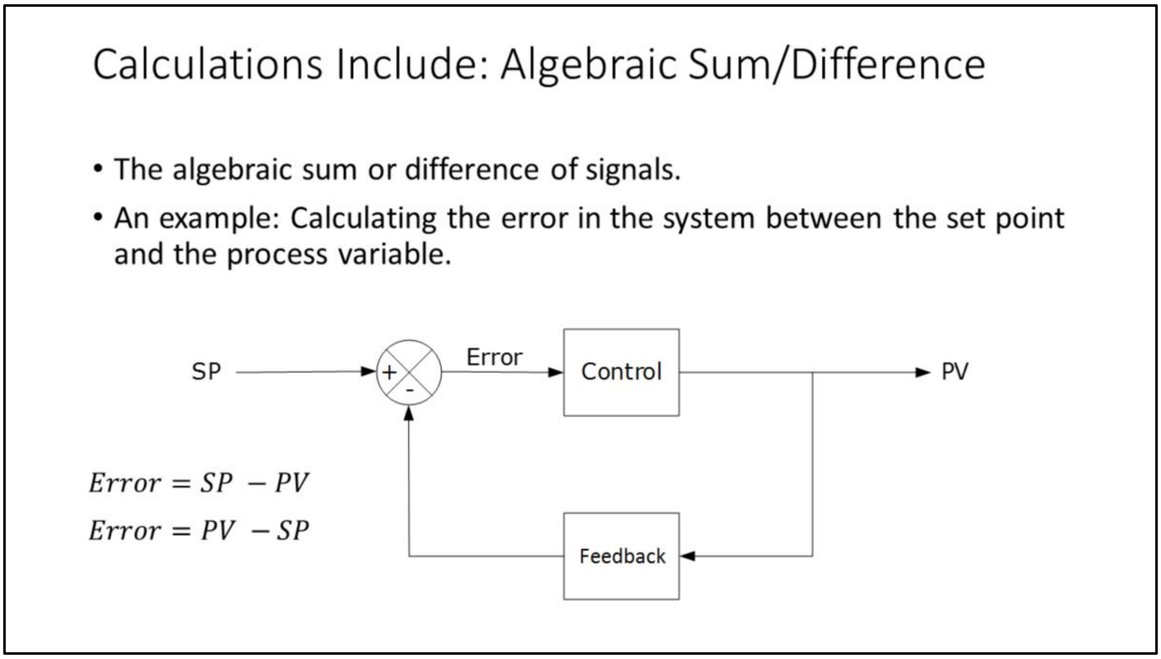


Computing Components

- Complex control systems require more complex calculation(s).
- More complex calculations require the use of a computer or Programmable Logic Controllers/Programmable Automation Controllers (PLC/PAC).

As control systems and process become more complex, the control concepts and calculations that need to be made also become more complex.

More complex systems that require more complex computation require the use of PC’s and/or PLC’s/PACs. Programmable Automation Controllers provide a good solution that uses industrial controls with the power of a PC.



Calculations Include: Algebraic Sum/Difference

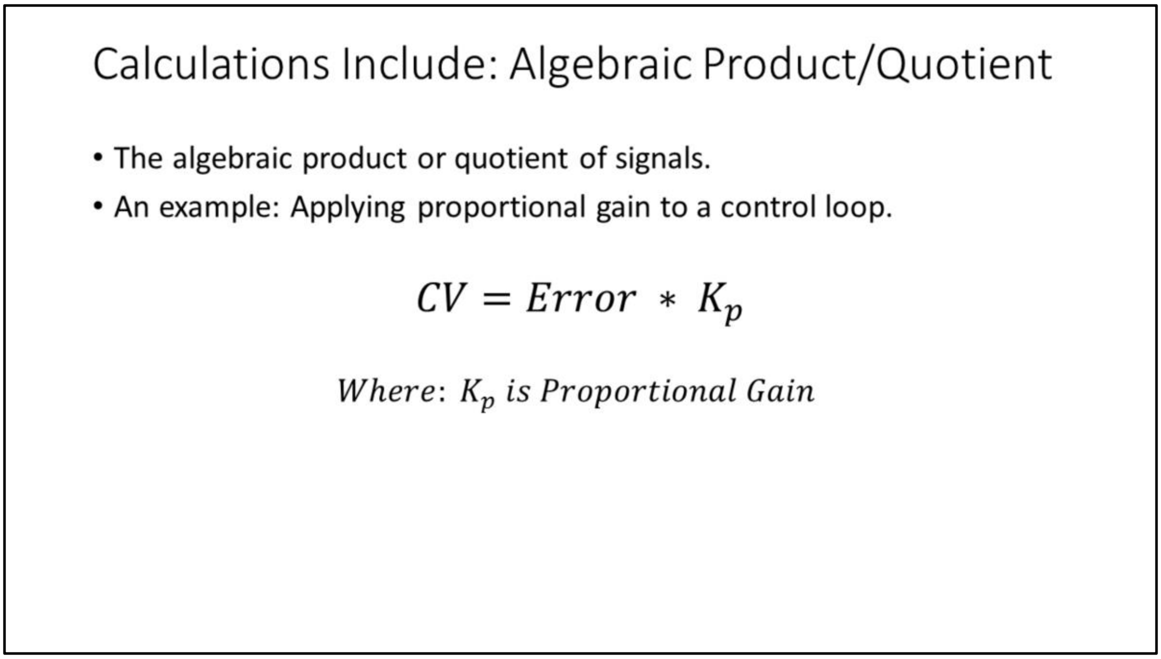
- The algebraic sum or difference of signals.
- An example: Calculating the error in the system between the set point and the process variable.

$$Error = SP - PV$$

$$Error = PV - SP$$

Algebraic sums and differences are very common in all control systems. The algebraic function is depicted by the summing junction on this block diagram and is calculating the amount of error in the system.

Here the Error signal = SP – PV. This form of the error equation is used for heating applications. If the PV is less than the SP the Error is positive and the system requires more heating. PV – SP is for cooling applications. If the PV is greater than the SP the Error is positive and the system is too warm and requires more cooling.



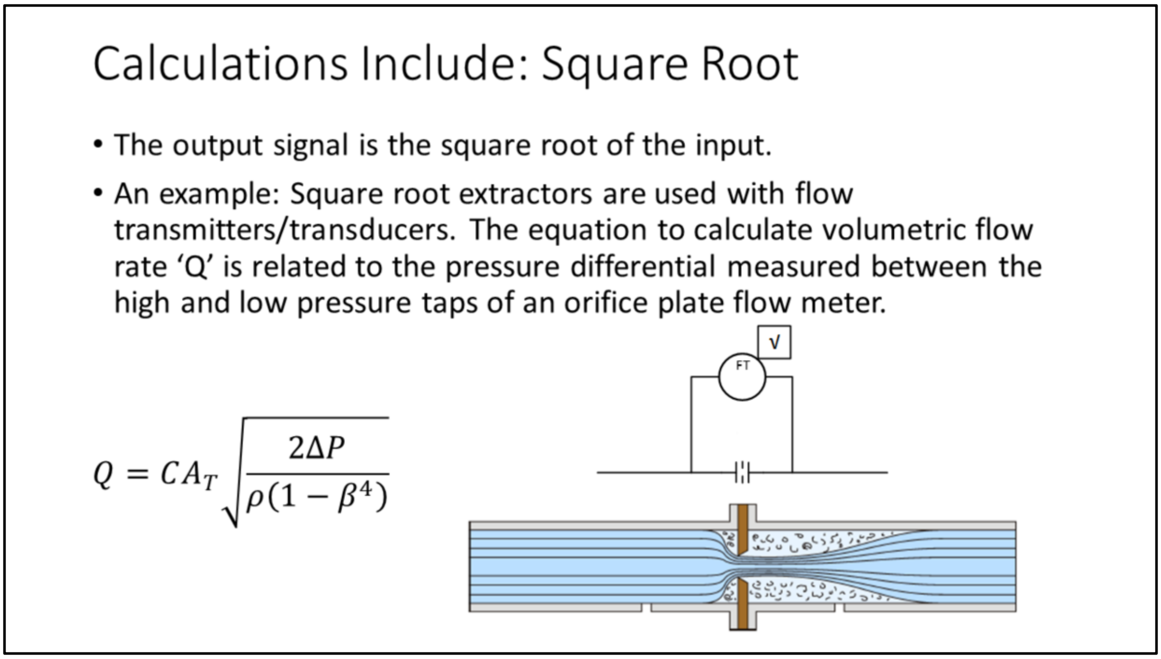
Calculations Include: Algebraic Product/Quotient

- The algebraic product or quotient of signals.
- An example: Applying proportional gain to a control loop.

$$CV = Error \; * \; K_p$$

$$Where\colon K_p \; is \; Proportional \; Gain$$

Algebraic multiplication and division are also very common calculations in process control systems. The equation shown; CV = Error * Kp is a simple form of amplifying the error signal so that it makes a large change to the CV. The Kp term is a tuning parameter that is adjusted as part of the looping tuning process. Too much Kp will make the system unstable and overshoot the SP. Not enough gain will make the system sluggish and the process may never reach the SP.



Calculations Include: Square Root

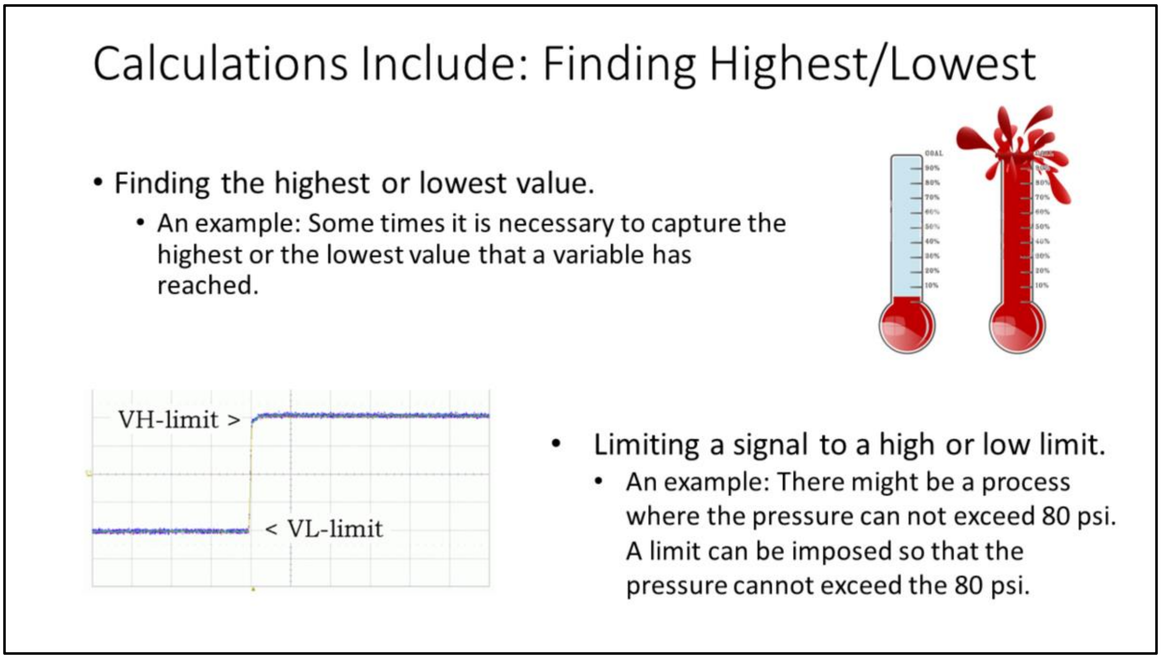
- The output signal is the square root of the input.
- An example: Square root extractors are used with flow transmitters/transducers. The equation to calculate volumetric flow rate ‘Q’ is related to the pressure differential measured between the high and low pressure taps of an orifice plate flow meter.

$$Q = CA_T\sqrt{\frac{2\Delta P}{\rho(1-\beta^4)}}$$

In a differential pressure flow meter (orifice + DP Cell), pressure is measured before the orifice and after it. This pressure difference is used to measure the flow of the liquid in the pipe. If the pressure difference is more, the flow is more and vice a versa. The problem with this method is that the pressure difference is not proportional to the flow so if the velocity (flow) of the liquid increases, the pressure increases but at a different rate. If you were to plot this on a graph you would get a curve. This curve is not much good for automatic control requirements. We have to make this curve straight or linear so that we can get a linear signal from the meter. A square root extractor is used to do this.

Flow is directly proportional to the square root of the differential pressure. The equation shown can be used to calculate the flow rate where:

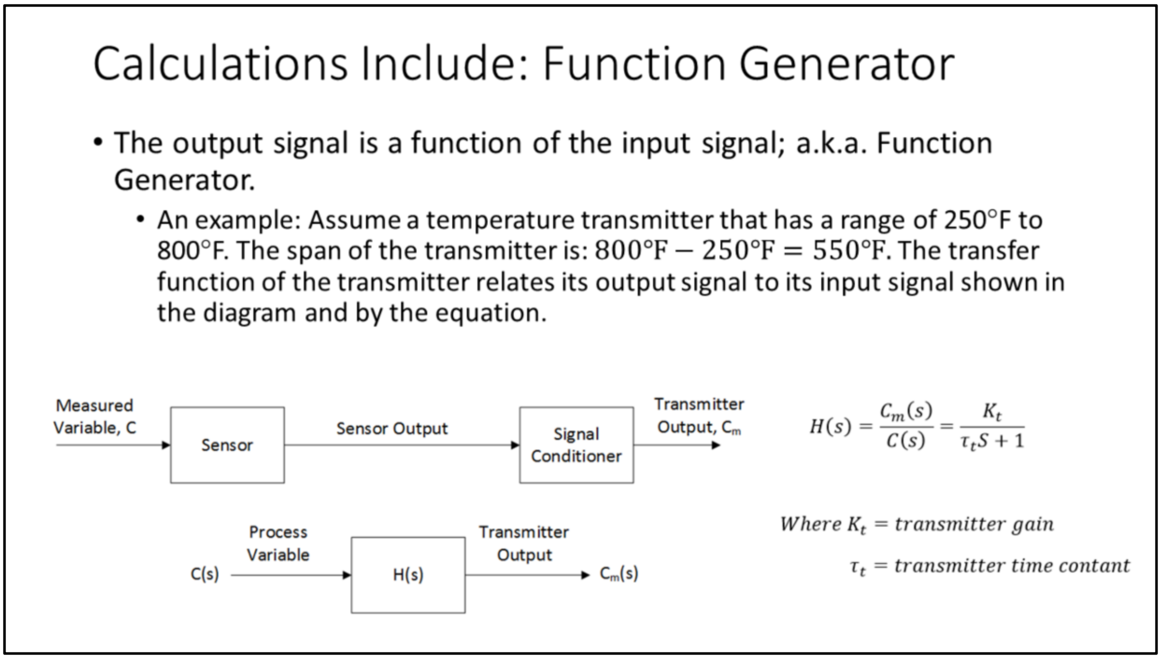
Q	is the volumetric flow rate
C	is the discharge coefficient found in the manufacturers table
A_T	is the area of the aperture facing upstream
ΔP	is the pressure differential between the high and low pressure taps
ρ	is the fluid density
B	is the aperture diameter-to-pipe internal diameter ratio (d/D)



Calculations Include: Finding Highest/Lowest

- Finding the highest or lowest value.
  - An example: Some times it is necessary to capture the highest or the lowest value that a variable has reached.

- Limiting a signal to a high or low limit.
  - An example: There might be a process where the pressure can not exceed 80 psi. A limit can be imposed so that the pressure cannot exceed the 80 psi.



Calculations Include: Function Generator

- The output signal is a function of the input signal; a.k.a. Function Generator.
  - An example: Assume a temperature transmitter that has a range of 250°F to 800°F. The span of the transmitter is: $800°\text{F} - 250°\text{F} = 550°\text{F}$. The transfer function of the transmitter relates its output signal to its input signal shown in the diagram and by the equation.

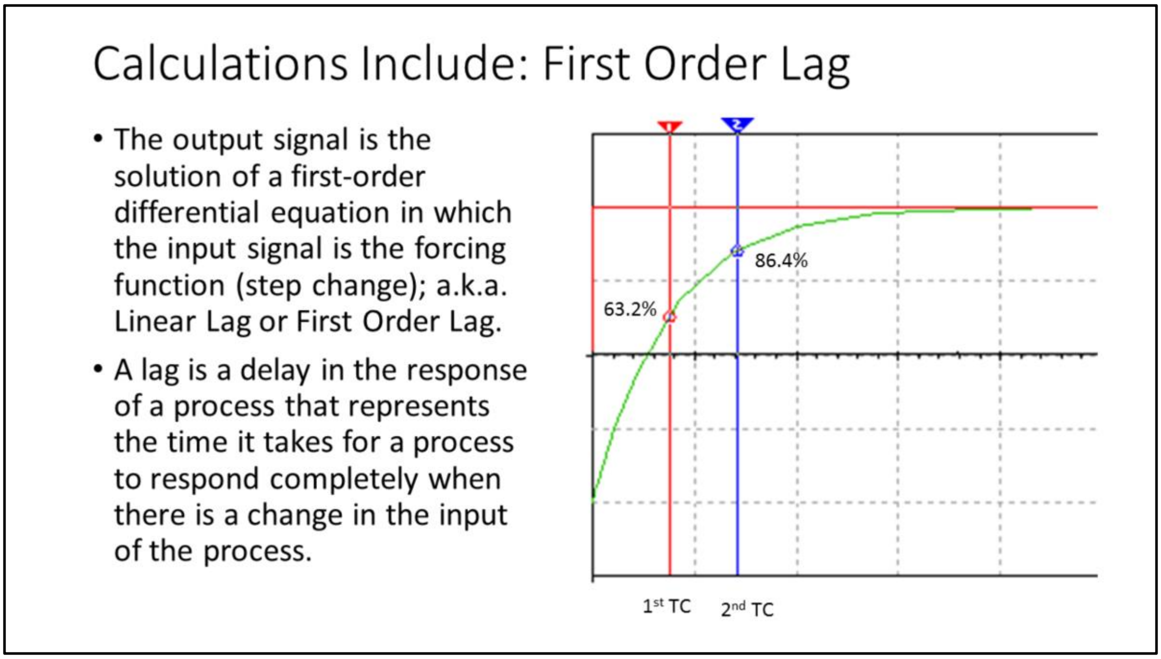
$$H(s) = \frac{C_m(s)}{C(s)} = \frac{K_t}{\tau_t S + 1}$$

$$Where\ K_t = transmitter\ gain$$

$$\tau_t = transmitter\ time\ contant$$

Automation system and process control use devices that create an output signal that is a function of the input signal. The devices are called sensors in conjunction with at transmitter/transducer. The sensor signal is converted into a different form that is compatible with the controller input. As an example, a temperature sensors that consists of the thermocouple will convert the mV signal generated by the T/C into a 4-20mA or 0-10Vdc signal. The block diagram on this slide depicts the sensor with a measured variable ‘C’ going to a signal conditioner. The signal conditioner is what converts the sensor signal to either a 4-20mA or 0-10Vdc signal or whatever signal is required for the controller.

Therefore, the sensor measures the PV and produces a signal that is converted by the signal conditioner (transmitter/transducer) that is required as the output to make it compatible with the input of the controller. The device is called a transmitter if the output is current and a transducer if the output is a DC voltage. Thus, the output of a transmitter/transducer is a function of the input signal.



Calculations Include: First Order Lag

- The output signal is the solution of a first-order differential equation in which the input signal is the forcing function (step change); a.k.a. Linear Lag or First Order Lag.
- A lag is a delay in the response of a process that represents the time it takes for a process to respond completely when there is a change in the input of the process.

The first order lag basically states that when the input of a process is subjected to a step change, the output begins to respond at time = 0, or at the time that the step occurs.

The graph on this slide depicts a first order lag. The step change is shown with the red trace as being a square wave step. The green trace is the process system response to the step change. The first time constant occurs at 63.2%. The response time remaining is 36.8%. Taking 63.2% of the time remaining gives the 2nd time constant which is 86.4%. The next time constant would be 63.2% of what remains therefore the 3rd time constant would be 95%. After the 5th time constant the process should be at 99.32%. The process will repeat, theoretically, without mathematical limit. The response will never actually reach 100%; however, it does approach it to a point where the difference does not matter.

1st TC = 63.2%   Response remaining 100% - 63.2% = 36.8%   36.8 * 0.632 = 23.2%
63.2% + 23.2% = 86.4%
2nd TC = 86.4%
3rd TC = 95.0%
4th TC = 98.16%

5th TC = 99.32%

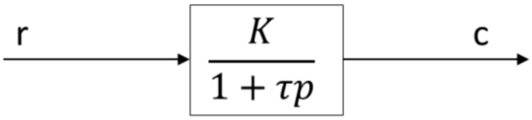
You read about this in Unit 8 – Process Dynamics, in textbook #2.

Calculations Include: First Order Lag

- First Order Lag is described by the equation:

$$\tau \frac{dc}{dt} + c = Kr$$

$$Where\ c = output, r = input, K = gain, \tau = time\ constant$$



r

$$\frac{K}{1 + \tau p}$$

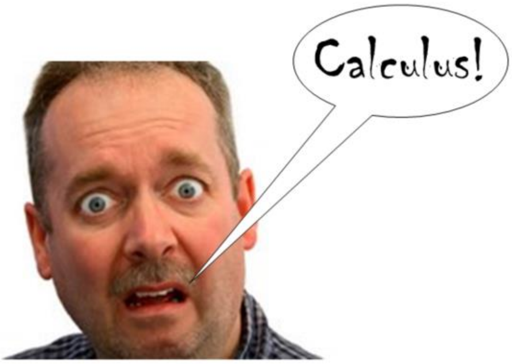
c

$$where\ p\ is\ the\ Heaviside\ operator\ \frac{d}{dt}$$

Calculations Include: First Order Lag

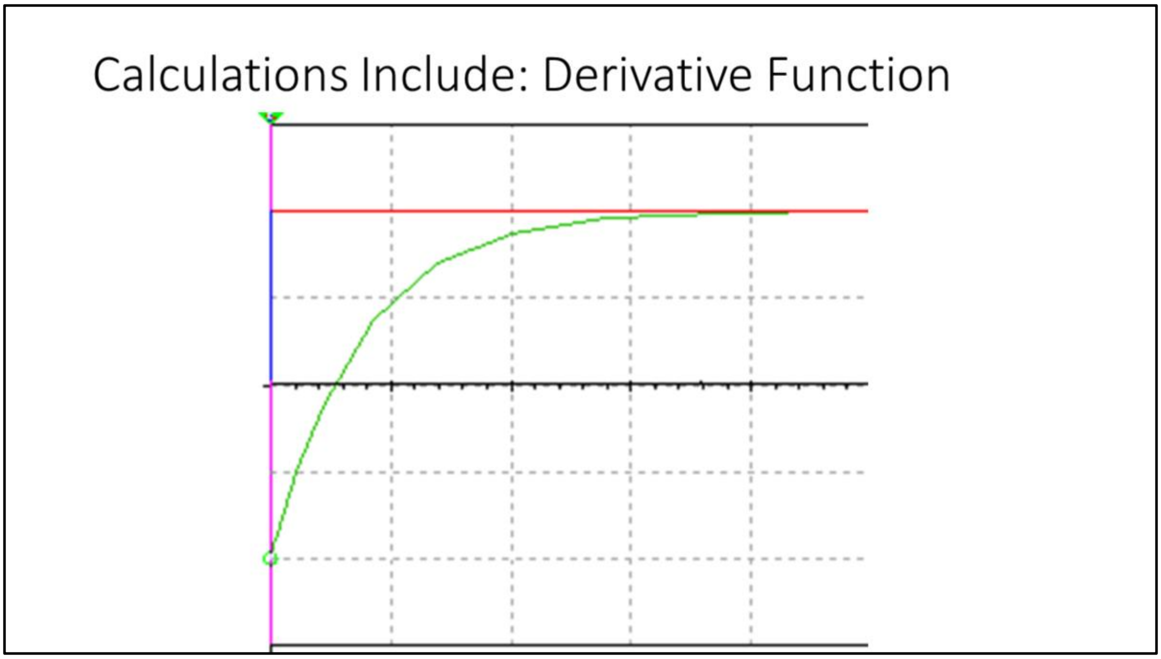
- What is a Heaviside operator?
- A Heaviside operator is Calculus.

- Don’t worry…if you never had calculus, you will not have to do any. However, you should know that there is a lot of calculus in process control and you should understand what some of the terms mean.



Calculations Include: First Order Lag

- First Order Lag and the Heaviside Operator.
- The Heaviside Operator d/dt is a calculus term called a derivative.
- In process control, when a loop is tuned using Proportional Integral Derivative (PID), the derivative term is also referred to as, rate.
- Derivative (Rate) is nothing more than the rate of change of a process signal with respect to time, d/dt. Where t is time.



Calculations Include: Derivative Function

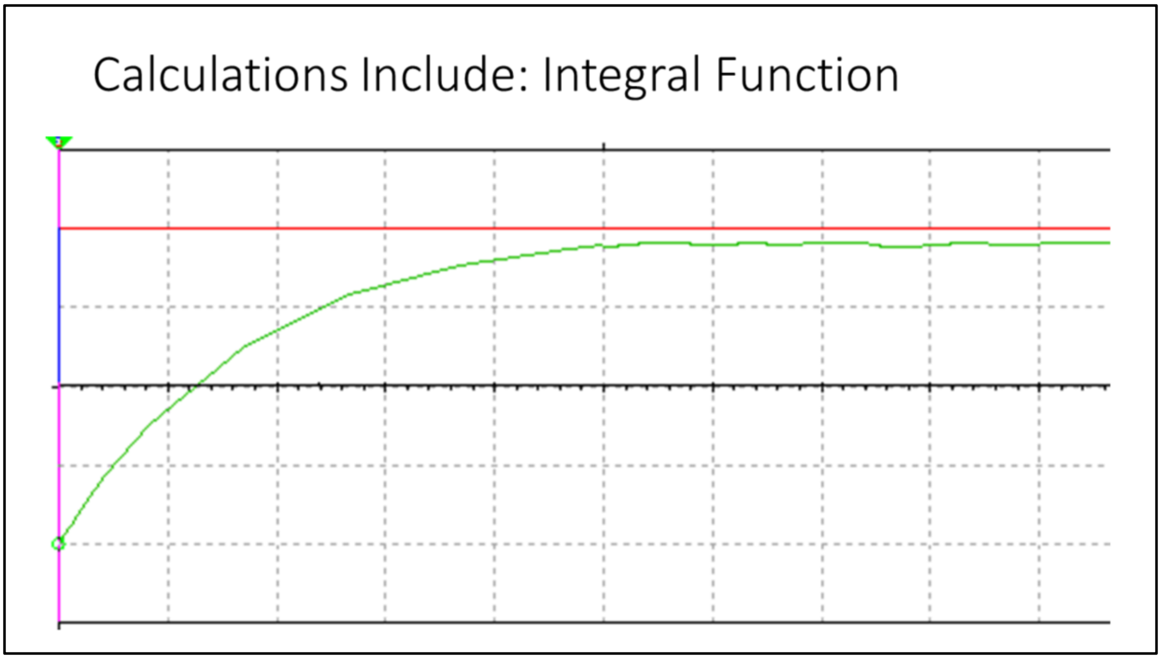
Use this graph to explain error and rate of change. Also show the tangent line at a point so that it will be an introduction to what a derivative is. Reference the Khan Academy for anyone wanting further knowledge with derivatives

Calculations Include: Integral Function

- An output or input signal that is the time integral of the other, a.k.a. integrator (Integral) or totalizer.
- Integral is another calculus term and is the ‘I’ term in a PID control loop.
- The integral portion is used to change the output of a process by an amount proportional to an error over time. It can be represented mathematically by:

$$E + \frac{1}{T_i}\int_0^t Edt$$

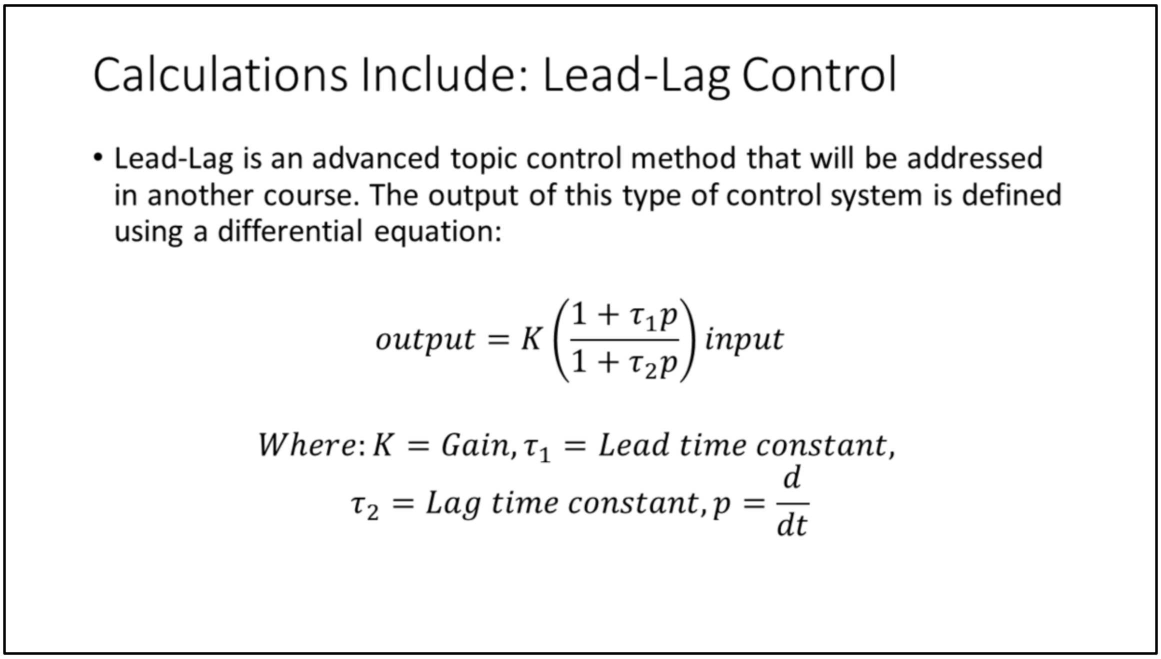
$$Where\ E\ is\ the\ error, T_i\ is\ time\ and$$
$$\int_0^t Edt\ is\ an\ integral\ of\ error\ over\ time$$



Calculations Include: Integral Function

Use this graph to show the Integral term by showing the error over a period of time.

The Integral term looks at the error over time and adjusts the process output accordingly.



Calculations Include: Lead-Lag Control

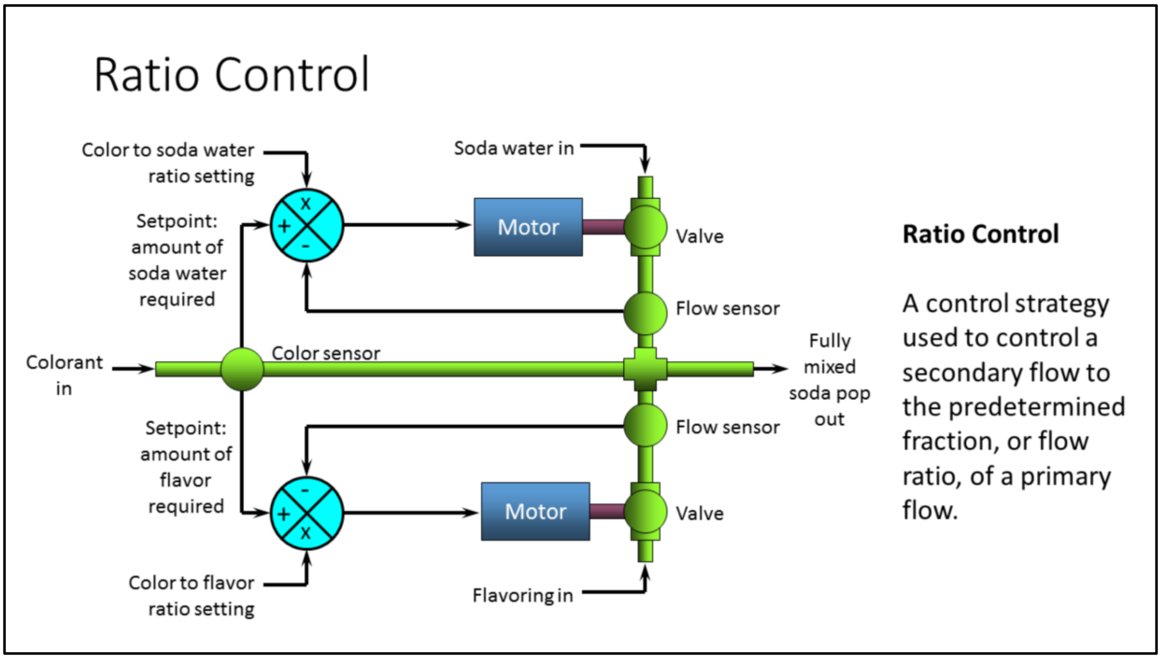
- Lead-Lag is an advanced topic control method that will be addressed in another course. The output of this type of control system is defined using a differential equation:

$$output = K\left(\frac{1+\tau_1 p}{1+\tau_2 p}\right) input$$

$$Where: K = Gain, \tau_1 = Lead\ time\ constant,$$
$$\tau_2 = Lag\ time\ constant, p = \frac{d}{dt}$$

A Lead-Lag system is often used in air-fuel control systems where increases in combustion-air flow lead increases in fuel flow and decreases in combustion-air flow lag decreases in fuel flow.

This topic will be covered in detail in NCC course, EMEC225 – Instrumentation II.



Ratio Control

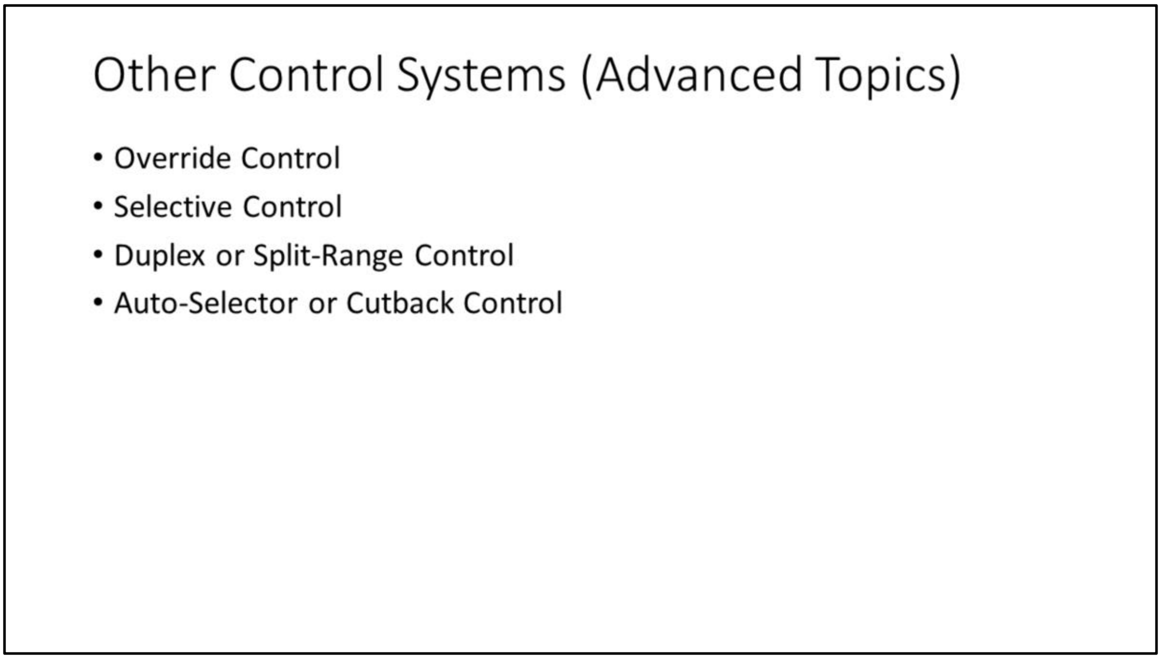
Ratio Control

A control strategy used to control a secondary flow to the predetermined fraction, or flow ratio, of a primary flow.

The ratio controller’s sensor measures the concentration of colorant, but not to control the flow of the colorant. Instead, the sensor provides a setpoint to two parallel fluid streams (soda water and flavor), so that the output from the mixing tank is the correct ratio to color, flavor and soda water.

Ratio of colorant : soda water : flavoring

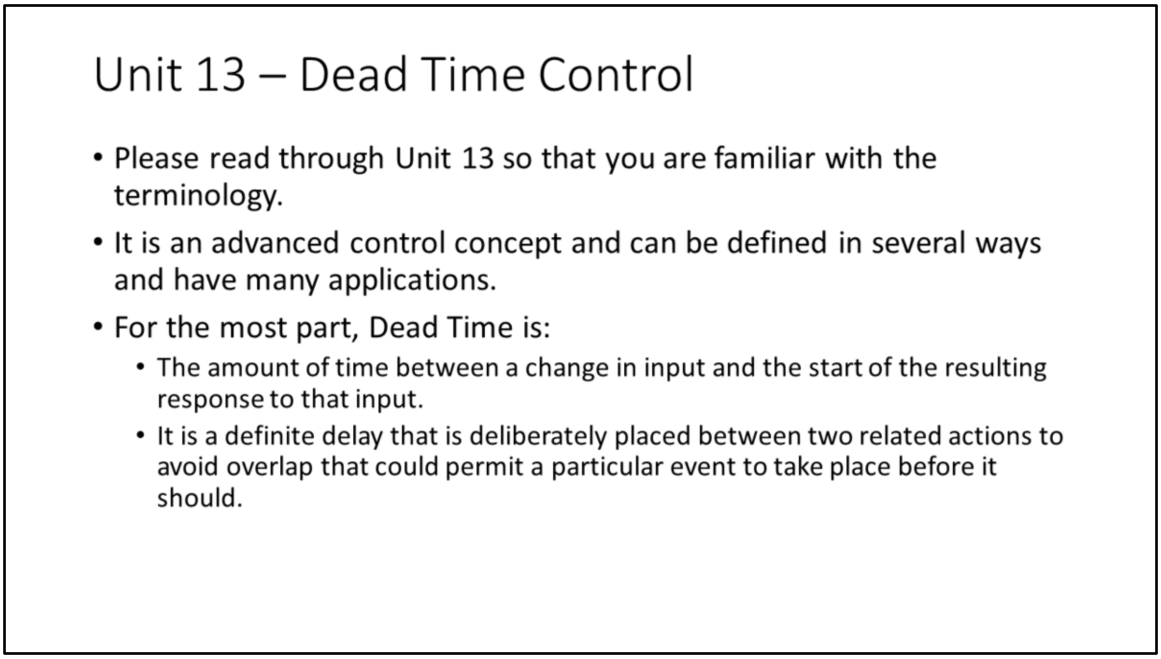
This topic will also be covered in detail in NCC EMEC225 – Instrumentation II.



Other Control Systems (Advanced Topics)

- Override Control
- Selective Control
- Duplex or Split-Range Control
- Auto-Selector or Cutback Control

These are advanced topics and will be discussed in future courses. They are mentioned here and in your textbook as an FYI.



Unit 13 – Dead Time Control

- Please read through Unit 13 so that you are familiar with the terminology.
- It is an advanced control concept and can be defined in several ways and have many applications.
- For the most part, Dead Time is:
  - The amount of time between a change in input and the start of the resulting response to that input.
  - It is a definite delay that is deliberately placed between two related actions to avoid overlap that could permit a particular event to take place before it should.

Talk a furnace that uses the Bang-Bang method of controlling the heating element and that without dead time, the contactor could start cycling on-and-off when the temperature of the furnace reaches the set point.