PALO VERDE
NUCLEAR GENERATING STATION

Instrumentation & Controls Training

Classroom Lesson

I&C Program	**Date: 5/8/2007**
LP Number: NIA02L000401	**Rev Author: Christopher A. Mahar**
Title: Loop Control	**Technical Review:** Reynolds, James J(Z78347) Digitally signed by Reynolds, James J(Z78347) DN: cn=Reynolds, James J(Z78347), email=James.Reynolds@aps.com Reason: I have reviewed this document Date: 2007.05.10 11:33:16 -07'00'
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INITIATING DOCUMENTS:

Site Maintenance Training Program Description

REQUIRED TOPICS

NONE

CONTENT REFERENCES

Comprehensive Dictionary of Measurement and Control; WH Cuberly, Editor: Instrument Society of America

MDG 36PRG-005 Calibration of Instrument Loops

Lesson Plan Revision Data

May 03, 2007 Chris Mahar Record created

Tasks and Topics Covered

The following tasks are covered in Loop Control:

Task or Topic Number*	Task Statement
Lesson:	Loop Control
PRO40	Tune a loop
FOX07	Calibrate dynamic compensators
FOX08	Calibrate control cards/stations
PRO35	Maintain electrical/pneumatic controller

Total tasks or topics: 4

TERMINAL OBJECTIVE:

1.1 Given the necessary tools, equipment, and references,, the I&C Technician will calibrate control loops. Mastery will be demonstrated by successful completion of all in class exercises, Laboratory Practical Evaluations and scoring 80% or better on an end of course exam

1.1.1 Discuss the following terms:
Measured Variable
Controlled Variable
Manipulated Variable
Final Control Element
Set-point
Error
Controller Output
Self Regulation
Time Constant
Process Gain
Dead Time
Rise Time
Settling Time
Feedback
Feedforward
Cascade Control
Split Range Control
Closed Loop
Open Loop
Supply Disturbance
Demand Disturbance

1.1.2 Identify the process response criteria for the quarter wave dampened tuning method

1.1.3 Describe on-off control systems to include the effects of varying the neutral zone and the primary causes of undershoot and overshoot

1.1.4 Describe "Proportional Control" to include offset error and the relationship between proportional band (PB) and gain

1.1.5 Describe "Integral Control" to include reset wind-up and the relationship between Integral Constant and Integral Time.

1.1.6 Define Derivative Control

1.1.7 Describe the operation of a Foxboro model 43AP pneumatic controller.

1.1.8 Describe bumpless transfer as it applies to electronic controllers

1.1.9 Describe the operation of Foxboro SPEC 200 electronic controllers

1.1.10 State the function of a dynamic compensator

1.1.11 Describe the operation of a Dynamic Compensator

1.1.12 State the function and describe the operation of a Control Station Simulator

1.1.13 Tune an electronic or pneumatic control loop

1.1.14 Calibrate and tune a loop with a Foxboro SPEC 200 electronic controller

1.1.15 Calibrate a Dynamic Compensator

1.1.16 Utilize a Control Station Simulator

Lesson Introduction: Loop Control

The following items are things to consider in your Lesson Introduction. They are not mandatory. You should develop your own introduction and place that material in the Program Hierarchy in the Lesson Introduction Tab or appropriate Training Unit.

CLASSROOM GUIDELINES

- If applicable, remind students of class guidelines as posted in the classroom.
- Pass the attendance sheet around and have it signed in Dark ink.
- Ensure that student materials needed for the class are available for each student.
- Emphasize student participation and remind them of your philosophy on asking and answering questions, if applicable.

ATTENTION STEP

- Give a brief statement or story to get student concentration focused on the lesson subject matter.

LESSON INTRODUCTION

- Give a brief statement that introduces the specific lesson topic. Should be limited to a single statement.

MOTIVATION

- Focus student's attention on the benefits they derive from the training. At Instructor's discretion. The need for motivation in each succeeding lesson must be analyzed by the Instructor and presented as necessary.
- Instructor should include how the STAR process can be used to improve or enhance Operator Performance, if applicable.
- Read and discuss lesson terminal objective and review lesson enabling objectives, if desired.
- If applicable, briefly preview the lesson topic outline and introduce the major points to be covered. The objective review may have been sufficient.
- REINFORCE the following PVNGS management expectations as opportunities become available:

  Nuclear Safety
  Industrial Safety Practices
  STAR and Self-Checking
  Procedure Compliance
  Communication Standards
  ALARA
  Prevent Events

[Introduction]

T.Obj 1.1	**Given the necessary tools, equipment, and references,, the I&C Technician will calibrate control loops. Mastery will be demonstrated by successful completion of all in class exercises, Laboratory Practical Evaluations and scoring 80% or better on an end of course exam**

EO 1.1.1	**Discuss the following terms:** **Measured Variable** **Controlled Variable** **Manipulated Variable** **Final Control Element** **Set-point** **Error** **Controller Output** **Self Regulation** **Time Constant** **Process Gain** **Dead Time** **Rise Time** **Settling Time** **Feedback** **Feedforward** **Cascade Control** **Split Range Control** **Closed Loop** **Open Loop** **Supply Disturbance** **Demand Disturbance**

1.1.1.1 Main Idea

A. Measured Variable	Methods & Activities: Optional
A quantity, property, or condition that is measured.	Refer to PPT presentation
B. Controlled Variable	
A process variable that is to be controlled at some desired value by means of manipulating another process variable. The controlled variable is often the measured variable	
C. Manipulated Variable	
A quantity or condition that is varied as a function of the actuating error signal so as to change the value of the controlled variable.	
D. Final Control Element	

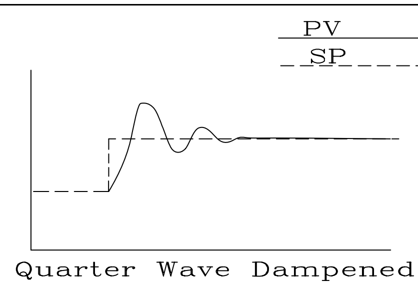
The hardware device used to regulate the Manipulated Variable.	
E. Set-point	
The desired value for the Controlled Variable.	
F. Error	
The difference between the Set-point and the actual Controlled Variable	
G. Controller Output	
The signal output to the Final Control Element as a result of the generation of an error signal	
H. Self-regulation	
The ability of the process to which permits attainment of equilibrium, after a disturbance, without the intervention of a controller.	
I. Time constant	
The time required for the output of the instrument to reach 63.2% of the final steady-state value following a step change at the input.	
J. Process Gain	
The change in the process output, divided by the change in the process input.	
K. Dead Time	
The time between initiation of an input change and the start of the resulting observable response.	
L. Rise Time	
The time required for the leading edge of a pulse to rise from one-tenth of its final value to nine-tenths of its final value.	

M. Settling Time	
The time interval between the step change of an input signal and the instant when the resulting variation of the output signal does not deviate more than a specified tolerance from the steady state value.	
N. Feedback Control	
Control in which a measured variable is compared to its desired value to produce an actuation device error signal that is acted upon in such a way as to reduce the magnitude of the error.	
O. Feedforward Control	
Control in which information containing one or more conditions that can disturb the controlled variable are converted, outside any feedback loop, into corrective actions to minimize deviations of the controlled variable.	
P. Cascade Control	
Control in which the output of one controller is the set-point of another controller.	
Q. Split-Range Control	
Action in which two or more signals are generated or two or more final control elements are actuated by an input signal, each one responding consecutively, with or without overlap, to the magnitude of that input signal	
R. Open Loop Control	
A system in which no comparison is made between the actual value and the desired value.	
S. Supply Disturbance	
An undesired change into the process that tends to affect adversely the controlled variable.	
T. Demand Disturbance	

An undesired change on the output of the process that tends to affect adversely the controlled variable.	

EO 1.1.2	**Identify the process response criteria for the quarter wave dampened tuning method**

1.1.2.1 Main Idea

A. There are several different criteria for loop performance in the I&C industry. The criteria accepted at Palo Verde is quarter wave dampened.	Methods & Activities: Optional Refer to PPT slides
B. Quarter wave dampened is where the amplitude of the deviation of the controlled variable, following a disturbance, is cyclic so that the amplitude of each peak is one quarter the amplitude of the preceding peak.	

EO 1.1.3	Describe on-off control systems to include the effects of varying the neutral zone and the primary causes of undershoot and overshoot

1.1.3.1 Main Idea

Advantages of on-off control · Cheap · Simple · Reliable · Good for systems which can not be throttled Disadvantages of on-off control · Process never stabilizes at setpoint · System and equipment cycling Constant overshoots and undershoots	Methods & Activities: Refer to PPT slides for on-off control
A. On-off control is the simplest form of process control. The control device can be in one of two conditions, on or off.	
B. In the example, the level controller would monitor the level of the tank. When the level of the tank increases to a pre-determined set-point, the controller would start the pump to lower the level in the tank. When the level decreases to the reset value, the pump would stop.	
C. Other examples of on-off control would be float switches, bistables, pressure switches, and bimetallic switches.	
D. In on-off control, the period between the set-point and reset is the neutral zone. The larger the neutral zone, the more the process variable would vary. The smaller the neutral zone, the more the equipment will cycle	
E. Delays in the system will cause overshoot and undershoot of the set-point and reset	

F. Consider the neutral zone, equipment cycling, undershoots and overshoots and system limitations when determining the set-point and reset of on-off controllers.	

EO 1.1.4	Describe "Proportional Control" to include offset error and the relationship between proportional band (PB) and gain

1.1.4.1 Main Idea

A. While on-off control is acceptable for use in a sump, it would not work very well in a system that requires fine control of the process variable. When finer control of the process variable is required, a proportional controller can be used. Proportional control provides a throttling signal to the final control element.	Methods & Activities:
B. There are two terms used to describe the amount of proportional action that the controller provides: 1. Proportional Band - The change in the input required to produce a full range change in the output due to proportional control action. 2. Proportional Gain - The ratio of the change in the output, due to proportional action, to the change in the input.	*Relationship:* $Gain = \frac{1}{PB}; PB = \frac{1}{Gain}$ C. The equation to determine the amount of proportional action is: $Output = (e \times g) + b$ 1. Where: e = error = set-point - measured variable 2. g = gain 3. b = the output of the controller with a zero error condition, usually 50% of the controller output
D. The only way for the controller to provide an output other than the bias setting is for an error to exist. This will result in the process variable being offset from the setpoint. This is referred to as <u>offset error</u>. The magnitude of the offset error will vary with the gain of the controller. As the gain of the controller is increased, the amount of the offset will decrease.	

EO 1.1.5	Describe "Integral Control" to include reset wind-up and the relationship between Integral Constant and Integral Time.

1.1.5.1 Main Idea

A. Integral control is used to eliminate the offset error associated with a proportional controller. Integral control is sometimes referred to as reset since it "resets" the process variable to setpoint. The magnitude of the error signal will determine the rate of change of the output signal.	Methods & Activities:
B. The amount of integral action in a controller is expressed with one of two terms: 1. Integral Time(T_i) The amount of time required to repeat the proportional action on an open loop response. Integral time is measured in Minutes per Repeat (MPR) 2. Integral Constant(K_i) The inverse of integral time $K_i = \frac{1}{T_i}$. Integral constant is measured in Repeats per Minute (RPM)	Integral Control equation: $Output = K_i eg\Delta t + O_o$ P+I Equation $Output = eg + K_i eg\Delta t + O_o$ 1. Where: K_i = Integral Constant 2. e = error 3. g = gain 4. Δt = change in time 5. O_o = Initial controller output (time=0)
C. Integral action is usually used in conjunction with proportional control.	

D. Integral control action can be thought of as the amount of area under the error curve.. 1. If a constant error is applied, the open loop response of the integral action will ramp the output.. 2. If the error was larger, the ramp would be steeper 3. If the error was smaller, the ramp would not be as steep	
E. Reset windup is the saturation of the integral mode of control during times when control cannot be achieved. This usually is the result of operation during system startup and shutdown periods. Reset windup results from a long lasting error signal causing the integral component to saturate. Reset windup usually results in excessive overshooting once control action starts.	

EO 1.1.6	Define Derivative Control

1.1.6.1 Main Idea

A. Proportional and integral both require an error signal to be present prior to beginning control action. Derivative action responds to the rate-of-change of the error signal. The actual error does not need to be large, it just needs to begin to change.	Methods & Activities:
B. Derivative action anticipates the magnitude of the error if the error continues to change at the same rate.	Formula for controller output with Derivative $Output = g\frac{de}{dt}\Delta t + g\frac{de}{dt}T_d + O_o$ Where a. g = gain b. $\frac{de}{dt}$ = rate of change of error c. Δt = change in time d. T_d = derivative time e. O_o= initial output (time = 0)
C. It is usually used in systems with slow or sluggish response (such as temperature loops).	Often process engineers will put lag filters on process inputs to eliminate noise, thus allowing derivative to be used.

D. Because derivative action responds to rate-of-change, it is not used in noisy or rapidly changing systems (such as flow loops).	The derivative of a noisy signal is a noisy signal
E. Derivative action is measured in units of time. Derivative Time is the time that the proportional action is advanced.	The unit for Derivative is usually seconds or minutes

EO 1.1.7	**Describe the operation of a Foxboro model 43AP pneumatic controller.**

1.1.7.1 Main Idea

A. One of the most common pneumatic controllers used in the plant is the Foxboro Model 43AP.	Methods & Activities:
B. A standard Foxboro measuring element positions the measurement pointer in proportion to the measurement	
C. A SET KNOB positions the peripheral set-point arrow	
D. The difference between the measurement and set point (error signal) moves the PROPORTIONING LEVER which pivots at its center on the end of a FLAT SPRING	
E. As the proportioning lever travels, it contacts a PIN/STRIKER BAR/FLAPPER assembly which varies the nozzle pressure.	
F. Through a CONTROL RELAY, the nozzle pressure is applied to the proportioning bellows	
G. This provides negative feedback to re-balance the flapper and the nozzle at new relative positions	
H. There is a proportional change in output pressure with every change of the error signal for any given proportional band setting	
I. The Proportional Band is determined by the angle between the proportioning lever and the striker bar.	

J. The flapper/nozzle assembly is mounted on the same shaft as the PROPORTIONAL DIAL.	
K. When the dial is rotated so that the striker bar is parallel with the proportioning lever, on-off control action is obtained	
L. At the other extreme, when the striker bar is 90 degrees from the proportioning lever, the proportional band setting becomes infinite	
M. Control action is reversed when the proportional dial is moved 90 degrees to change the sector in which the striker bar operates	
N. The white part of the proportional dial is used if an increasing measurement is to decrease the output pressure	
O. The black striped part of the dial is used if an increasing measurement is to increase the output.	
P. For integral control action, the output pressure is transmitted though a restrictor to a second feedback bellows called the INTEGRAL BELLOWS which opposes the proportional bellows	

Q. Integral control causes the output pressure to change until the error signal is reduced to zero (measurement corresponds to set point). This is possible because an error signal change immediately causes an unbalance between the two bellows and an up-or-down movement of the proportional lever pivot point	
R. This affects the flapper/nozzle relationship and changes the output pressure. The output pressure changes at a rate proportional to the feedback unbalance (error signal)	
S. The rate of output pressure change falls to zero when the error signal becomes zero, and the output is held constant	
T. The derivative section involves the use of an adjustable restrictor and a DERIVATIVE CAPACITY TANK interposed in the feedback line between the output and the proportioning bellows	
U. Air flowing to or from the proportioning bellows due to changes in measurement or setpoint causes a pressure drop to occur across the derivative restriction	
V. Output pressure is greater or less than that in the proportioning bellows by the amount of this pressure drop.	

W. Hence the valve position is determined by the combined proportional (and integral, if any) effects plus or minus the derivative effect	
X. To limit the amount of derivative gain, a SMALL BELLOWS extending into the derivative capacity tank is provided	
Y. With a sudden change in output, the bellows changes the volume and pressure of the derivative tank. This instantly provides some feedback to the proportioning bellows	

EO 1.1.8	Describe bumpless transfer as it applies to electronic controllers

1.1.8.1 Main Idea

Transfer of control mode between "Manual" and "Automatic" with no step change in controller output even if a mismatch in signals is present. This is accomplished by ramping the controller output from the current manual signal to the new automatic signal	Methods & Activities: Optional
Without bumpless transfer, the controller could produce a large output step change upon mode transfer. This could cause:	
Final control element moving to an extreme position	
Large upset in the process being controlled.	
In extreme cases, could produce continuing instabilities.	

EO 1.1.9	Describe the operation of Foxboro SPEC 200 electronic controllers

1.1.9.1 Main Idea

A. Receives measurement and setpoint inputs and provides a control signal output as a function of the error, varying at a rate determined by the control mode.	Methods & Activities
B. Code Designations 1. 2AC+A2 Proportional Only 2. 2AC+A4 Proportional + Integral 3. \2AC+A5 Proportional + Integral + Derivative	
C. Units of Measure 1. Proportional Action - Proportional Band (PB) 2-500% 2. Integral Action - Integral Time (Minutes per Repeat) a. X1 0.01 - 0.60 MPR b. X10 0.10 - 6.00 MPR c. X100 1.00 - 60.0 MPR	

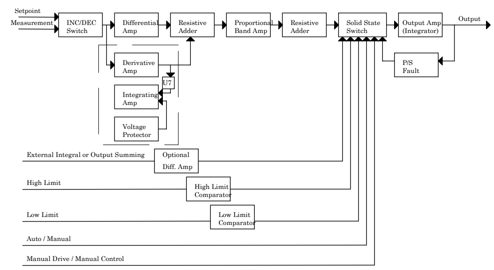
3. Derivative Action - Derivative Time (Minutes)

    a. X1 0.01 - 0.60

    b. X10 0.10 - 6.00

    c. X100 1.00 - 60.0

D. Block Diagram



1. Inputs are the measurement and setpoint

2. INCREASE / DECREASE Switch

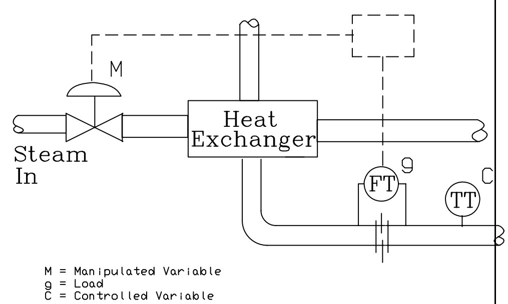
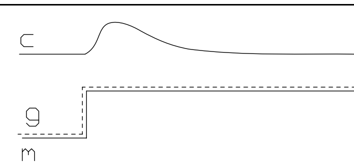
    a. Provides polarity reversing of both signals. This allows the controller action to be reversed. When INC is selected, control action is a function of Measurement minus Setpoint (increasing measurement causes an increasing output). When DEC is selected, control action is a function of Setpoint minus Measurement (decreasing measurement causes an increasing output).

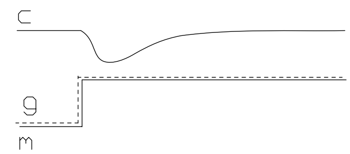
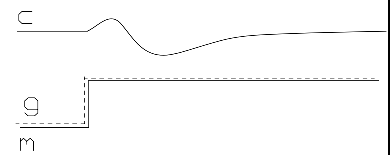
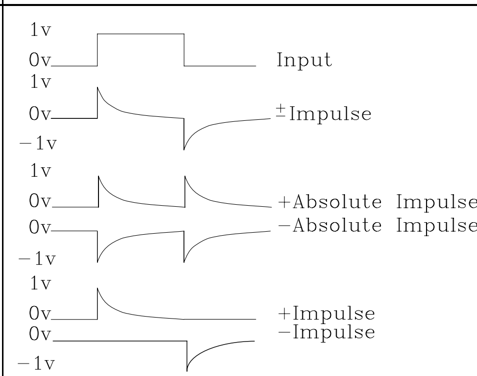
3. Differential Amplifier a. The measurement and setpoint are compared to each other as specified by the increase/decrease switch. The output is the deviation signal.	
4. Derivative Action Section a. Only the measurement signal is applied to the derivative section. This section performs the derivative action of the controller	
5. Resistive Adder a. The resistive adder combines the deviation signal and the derivative action signal	
6. Proportional Band Amplifier a. The proportional band amplifier is a variable gain amplifier whose gain is controlled by the front panel PB adjustment.	

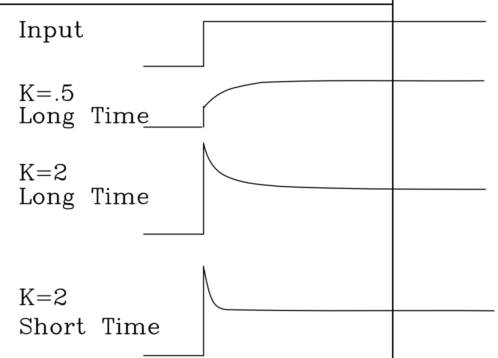
7. Solid State Switch a. The solid state switch performs the final summing and switching. The switch is operated by the Auto/Man signal from the control station. b. In auto, the automatic signal passes through. c. In manual, the manual drive signal passes through. The manual drive signal is a DC voltage from the control station. d. The switch also controls the hi/low limits and power supply fault recovery. e. The solid state switch is a network of FETs and resistors.	
8. Output Amplifier a. The output amplifier is an integrating amplifier. The amount of integral action is controlled by a voltage dividing network at the input of the integrating amplifier.	

EO 1.1.10	State the function of a dynamic compensator

1.1.10.1 Main Idea

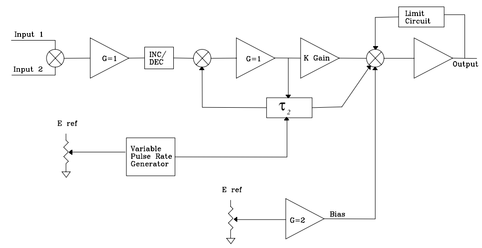
A. The dynamic compensator can be configured to provide lead, lag, and impulse functions for dynamic compensation within a control system.	Methods & Activities: Optional
1. Lead/Lag	
a. Lead/Lag is usually used on feedforward control systems to compensate for the dynamic response of the system.	
b. The figure shows a feed forward system with water temperature as the controlled variable, water flow as the load on the system, and the steam valve as the manipulated variable. The need for dynamic compensation can be observed by simultaneously changing the manipulated variable and the system load. If the controlled variable does not change, there is no need for dynamic compensation. If there is a perturbation of the controlled variable, there is a need for dynamic compensation	
c. The following graphs show examples of resulting transients	
1) . The graph shows the controlled variable overshooting then returning to normal. To correct this dynamic response, the dynamic compensator would be set up for <u>lag</u> operation. That is we want the manipulated device to ramp into its new position	

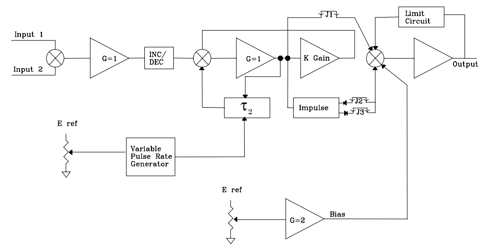
2) The graph shows the controlled variable undershooting then returning to normal. To correct this dynamic response, the dynamic compensator would be set up for lead operation. That is we want the manipulated device to open farther initially then ramp into it's new position.	
3) The graph shows the controlled variable initially overshooting then undershooting before returning to normal. To correct this dynamic response, the dynamic compensator would be set up for lead / lag operation. That is we want the manipulated device to initially respond slower, then open the manipulated device farther, then ramp into it's new position.	
4) These responses are a result of how fast the changes in load and supply affect the overall system response with respect to each other. If the manipulated variable has the faster effect, the controlled variable would increase initially then when the effect of the load was felt, the controlled variable would then return to normal. If the load has the faster effect, the controlled variable would decrease initially, then when the effect of the manipulated variable was felt, the controlled variable would then return to normal.	
2. The impulse function is used to monitor for rate-of-change. Impulse acts like pure derivative control.	
a. Five different set-ups	
1) ± Impulse - When a rate-of-change is detected an output pulse is generated in the same direction of the input.	

2) + Impulse - When any input rate-of-change is detected a positive output pulse is generated	
3) – Impulse - When any input rate-of-change is detected a negative output pulse is generated	
4) + Absolute Impulse - When positive rate-of-change is detected a positive output pulse is generated	
5) - Absolute Impulse - When negative rate-of-change is detected a negative output pulse is generated	
3. Adjustments	
a. The adjustments on a dynamic compensator are τ_1, τ_2, and K	
1) τ_1, τ_2 Time constant adjustments, adjusts the decay time of the curve	
a) It takes five time constants to stabilize	
2) K Gain (or Lead/Lag ratio), Adjusts the height of the initial pulse	
a) With a K<1 the output lags. With a K>1 the output leads	
b. High and Low Limits	
1) Hi +0.5 to 10.5 vdc	
2) Lo -0.5 to 9.5 vdc	
3) Bias -10.0 to +10.0 vdc	

EO 1.1.11	Describe the operation of a Dynamic Compensator

1.1.11.1 Main Idea

A. Lead / Lag Operation	Methods & Activites: optional 
1. Two inputs are applied to a comparator	
2. τ_1 is only included on full DYC cards. It performs the initial Lag for the Lag and Lead/Lag function. The DYC-L does not have a τ_1 function.	
3. The INC/DEC jumpers determine the input/output relationship. In the increase position, the output increases with an increasing input. In the decrease position, the output decreases with an increasing input	
4. The τ_2 circuit performs the lag portion of the lead/lag function. What this means is that it controls the time constant based decay	
5. The K variable gain section performs the Lead portion of the Lead/Lag function. That is it takes the input signal and applies it to a variable gain amplifier. The output of the amplifier is the initial step seen on the output	
6. The K and τ_2 signals are then summed with the bias and limit circuit outputs to develop the card output	

B. Impulse Operation	
1. The signal is processed the same as the Lead/Lag through the INC/DEC jumpers	
2. The output of the K gain amplifier is sent as feedback to the unity gain amplifier. The τ_2 portion is also fed back to the input of the unity gain amplifier.	
3. Jumpers J1, J2, and J3 positions will determine the impulse output	
4. The output always returns to zero. This is accomplished by the τ_2 section offsetting the input to the unity gain amplifier	

EO 1.1.12	State the function and describe the operation of a Control Station Simulator

1.1.12.1 Main Idea

Functions	Methods & Activities: optional
Designed for use when testing SPEC 200 control cards	
Used in conjunction with the Card Test Module (CTM)for bench tests	
May be used in the nest area by unplugging the connector at the top of the 2AC module and inserting the CSS.	
Provides adjustment and switch functions found on control stations	
CSS Controls	
P, I, D and bias adjustments for Station Tuned Control Cards	
Local Setpoint adjustment	
Local/Remote setpoint selection	
Auto/Man switch	
Manual Drive Switch	
Test jacks are also included for monitoring measurement and setpoint	

EO 1.1.13	Tune an electronic or pneumatic control loop

1.1.13.1 Main Idea

Refer to LPE on calibrating electronic or pneumatic control loop

EO 1.1.14	Calibrate and tune a loop with a Foxboro SPEC 200 electronic controller

1.1.14.1 Main Idea

Refer to LPE on calibrating and control loop tuning

EO 1.1.15	Calibrate a Dynamic Compensator

1.1.15.1 Main Idea

Refer to LPE on calibrating a dynamic compensator

EO 1.1.16	Utilize a Control Station Simulator

1.1.16.1 Main Idea

Refer to LPE on using the control station simulator

SUMMARY OF MAIN PRINCIPLES

The following items are things to consider in your lesson summary. They are not mandatory. You should develop your own summary.,

Objectives Review

Review the Lesson Objectives

Topic Review

Restate the main principles or ideas covered in the lesson. Relate key points to the objectives. Use a question and answer session with the objectives.

Questions and Answers

Oral questioning

Ask questions that implement the objectives. Discuss students answers as needed to ensure the objectives are being met.

Problem Areas

Review any problem areas discovered during the oral questioning, quiz, or previous tests, if applicable. Use this opportunity to solicit final questions from the students (last chance).

Concluding Statement

If not done in the previous step, review the motivational points that apply this lesson to students needs. If applicable, end with a statement leading to the next lesson.

You may also use this opportunity to address an impending exam or practical exercise.

Should be used as a transitional function to tie the relationship of this lesson to the next lesson. Should provide a note of finality.