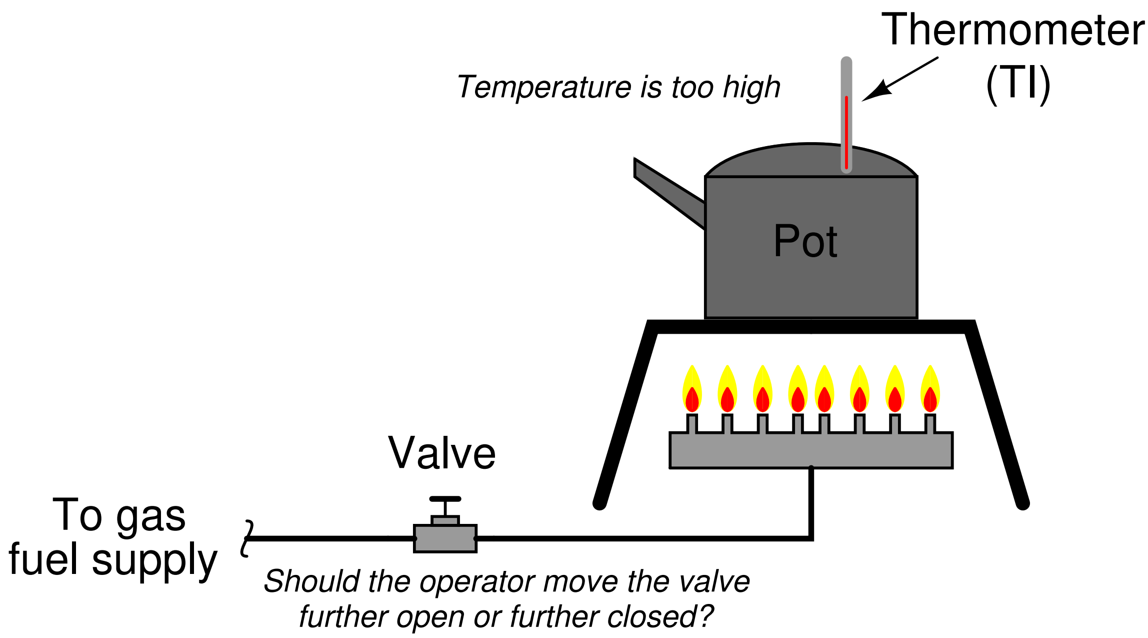
Grunnleggende reguleringsteknikk

Oppgaver

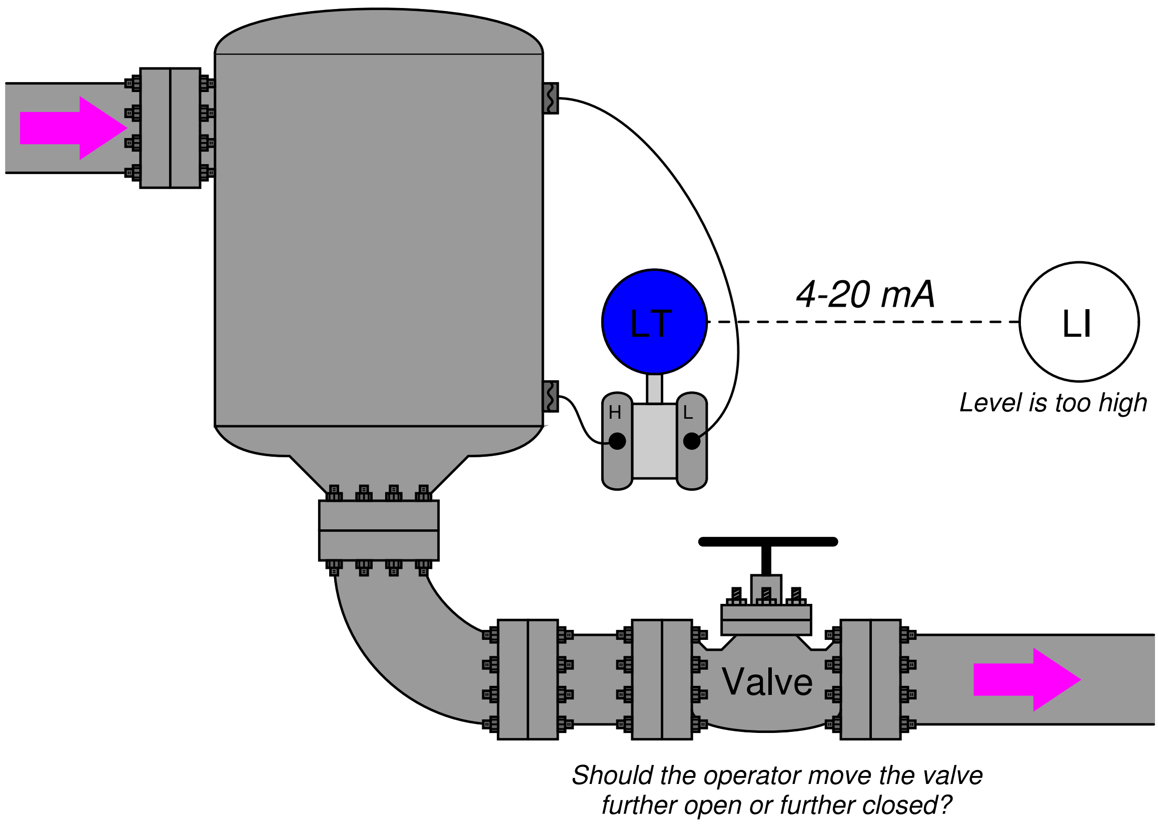
Oppgave 1

Suppose you were giving instructions to a human operator regarding which way to move a hand-operated control valve to maintain a process variable at setpoint. In each of these examples, determine which way the operator should move the valve to *counteract* an increase in the process variable resulting from some independent change in the process:

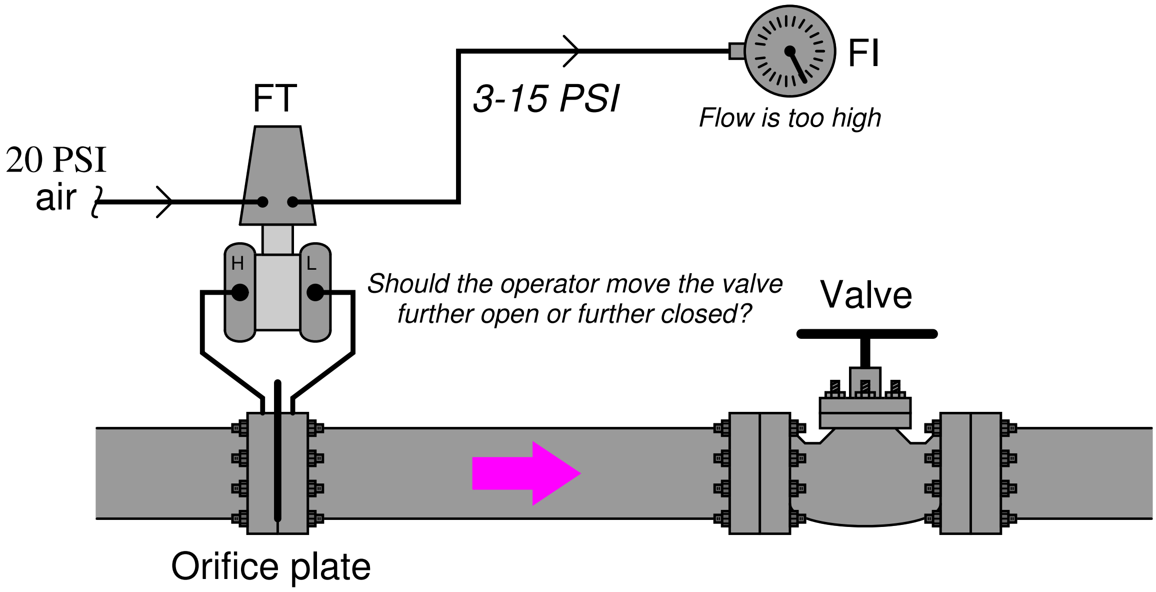
Example 1: Temperature control application



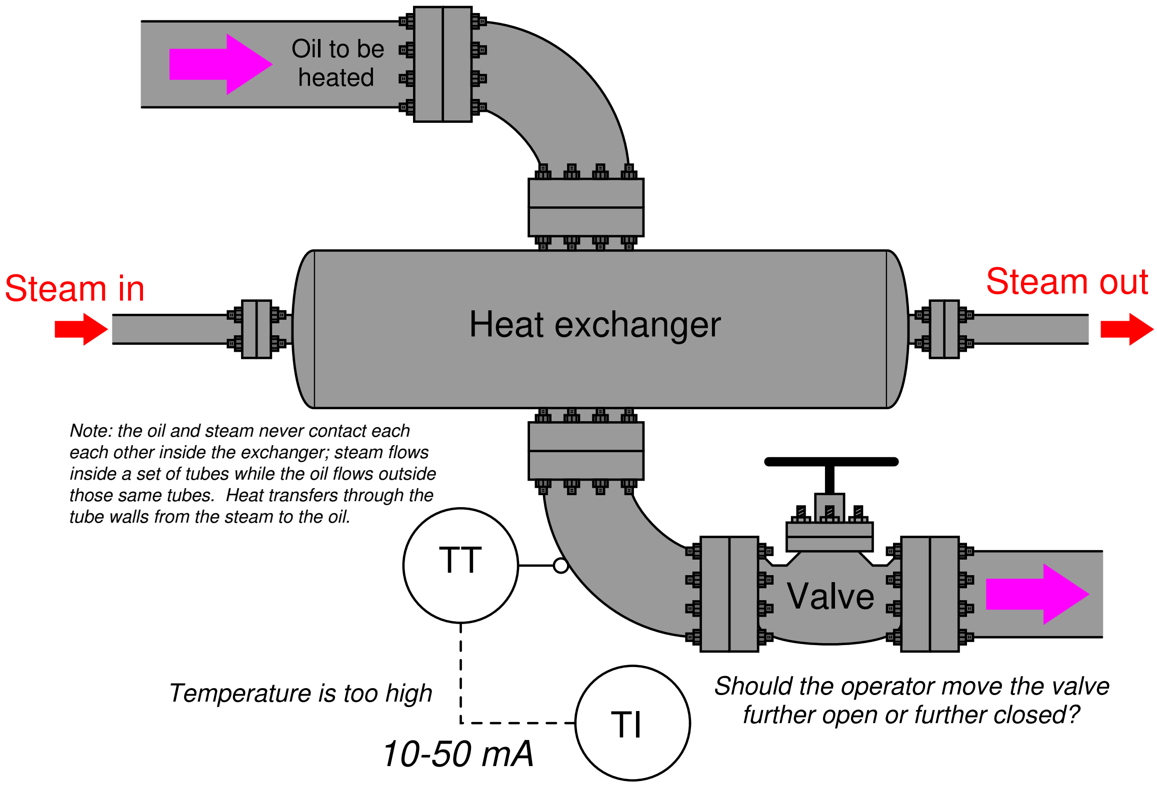
Example 2: Level control application



Example 3: Flow control application



Example 4: Temperature control application



Suggestions for Socratic discussion

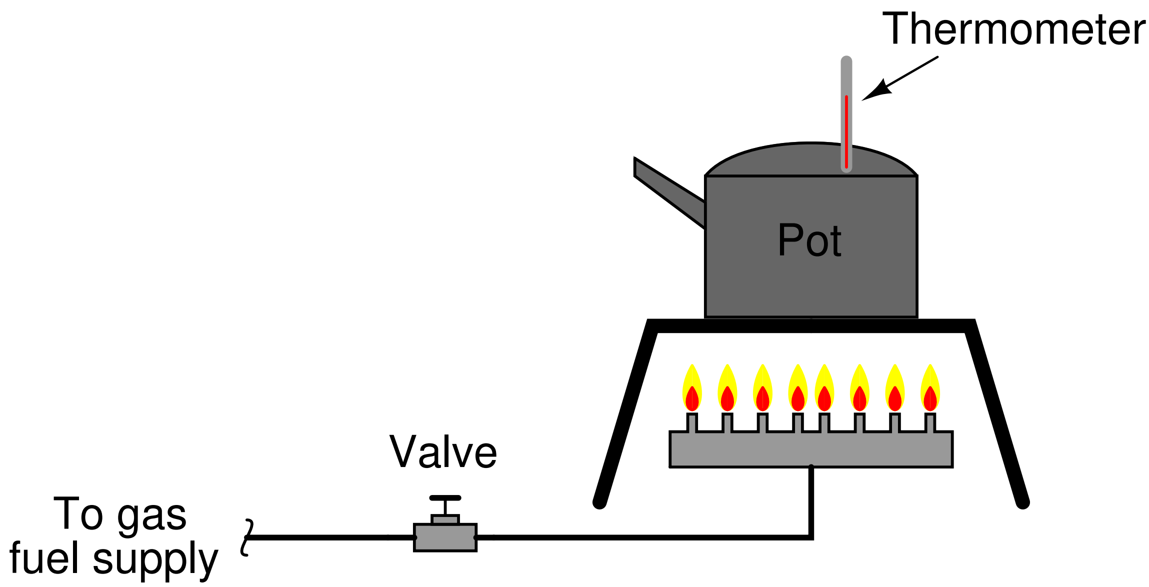
- Follow-up question: in which of these examples is the operator functioning as a *direct-action controller* and in which of these examples is the operator functioning as a *reverse-action controller*?

file i00109

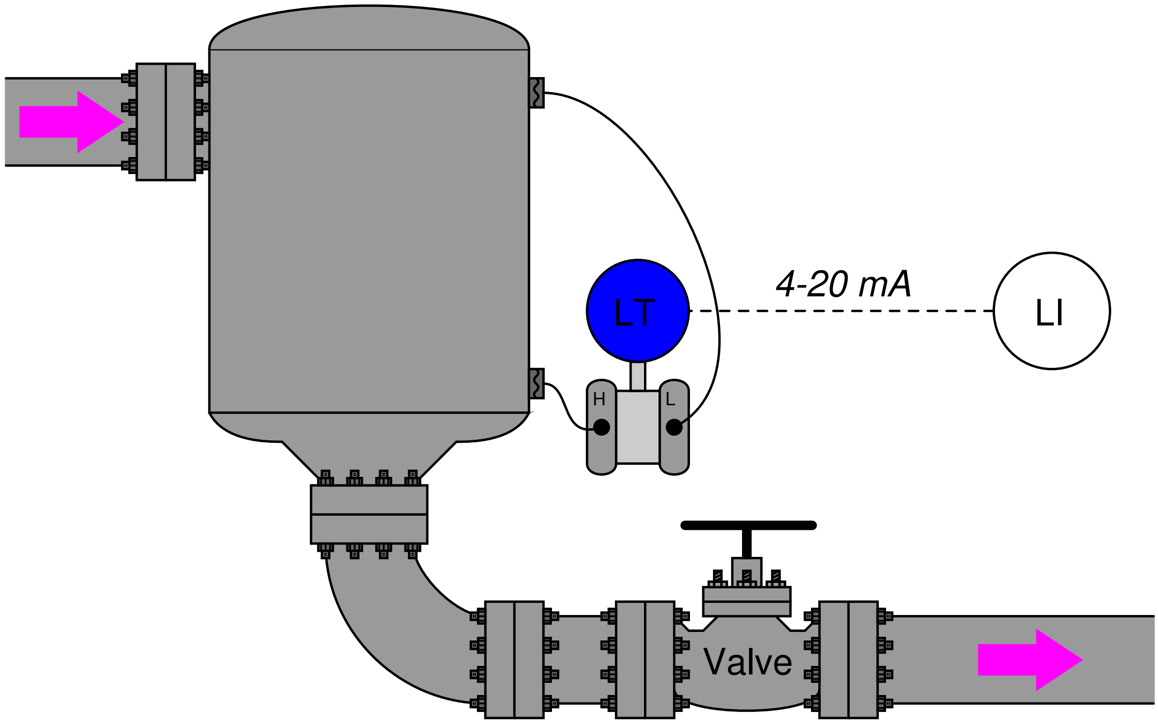
Oppgave 2

In any automated (controlled) system, there is a *process variable*, a *setpoint*, and a *manipulated variable*. There is also something called a *load*, which influences how well the control system is able to maintain setpoint. Provide a general description for a "load," and then identify the load(s) in each of the following manually-controlled processes:

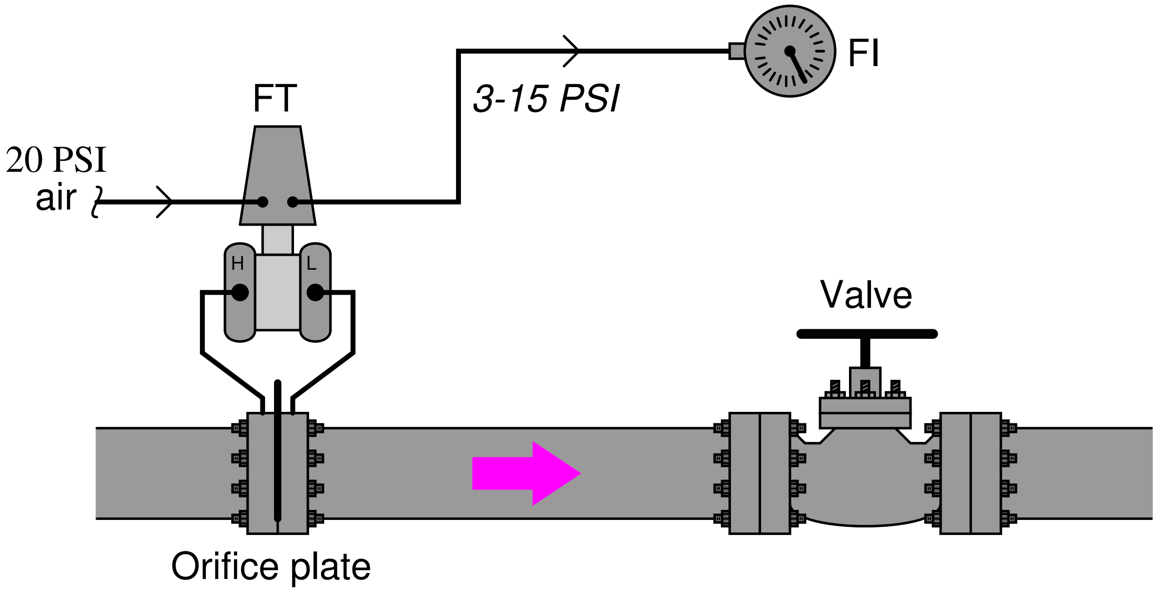
Example 1: Temperature control application



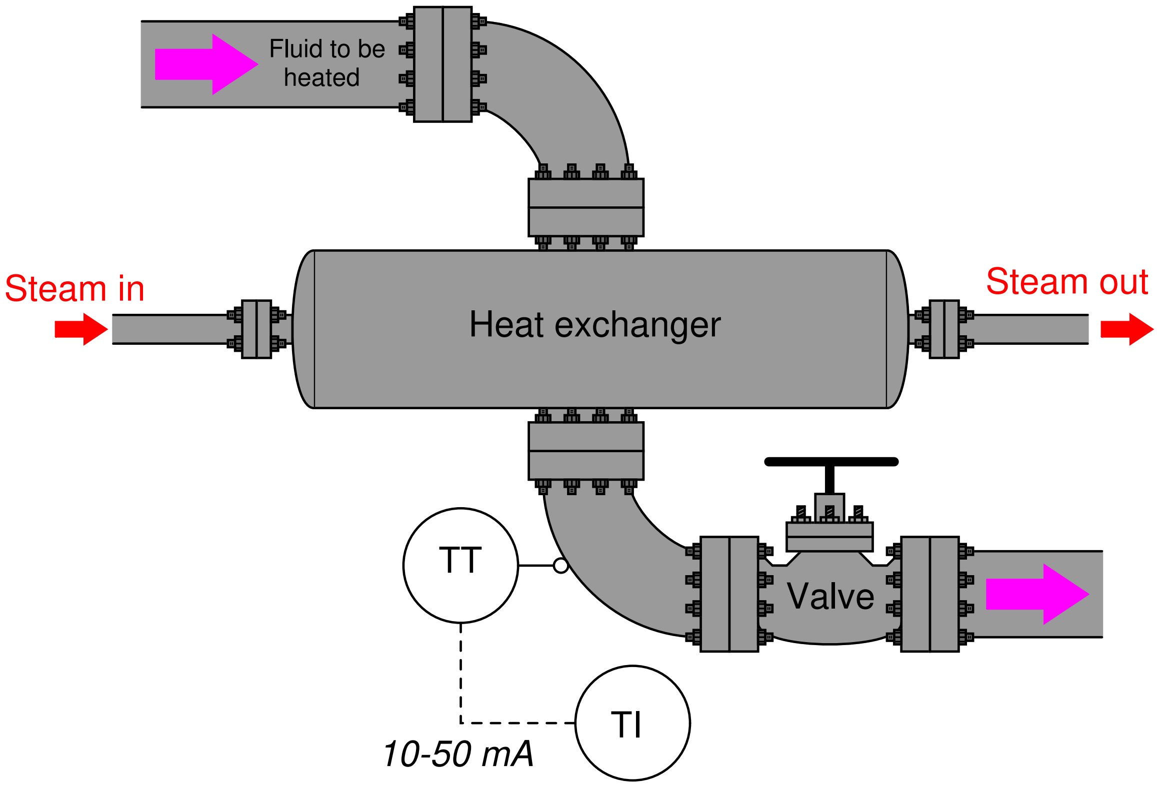
Example 2: Level control application



Example 3: Flow control application



Example 4: Temperature control application



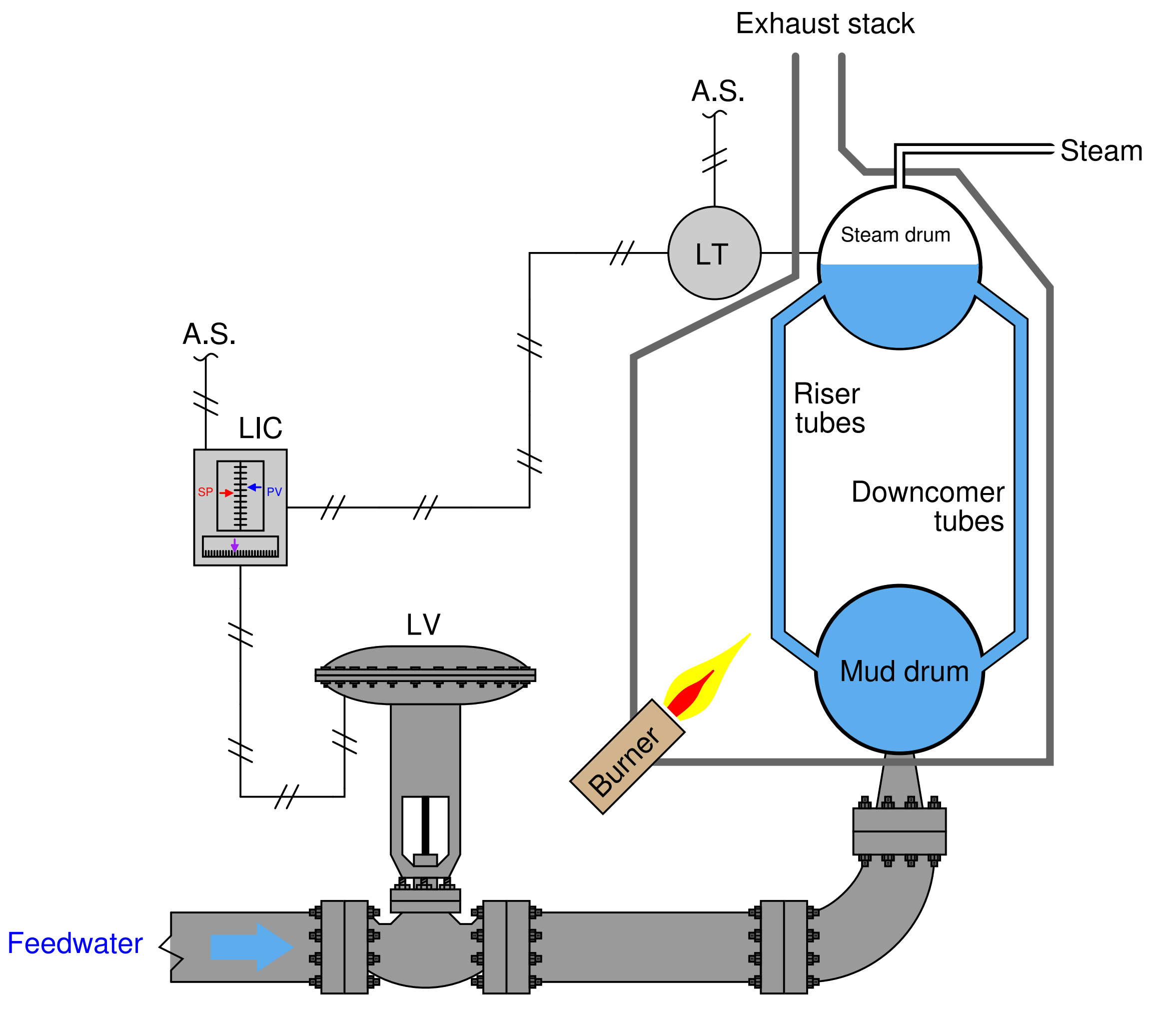
Suggestions for Socratic discussion

- Explain why ambient air temperature is considered a *load* to process example #4, but the insulation thickness on the heat exchanger is not.

file i01453

Oppgave 3

The following steam boiler is automated with a pneumatic water level transmitter, controller, and control valve. This system ensures the water level in the steam drum remains approximately constant regardless of changes in steam demand or burner firing rate, and it is called a *single-element feedwater control* because it bases the feedwater valve position on a single variable (steam drum level):

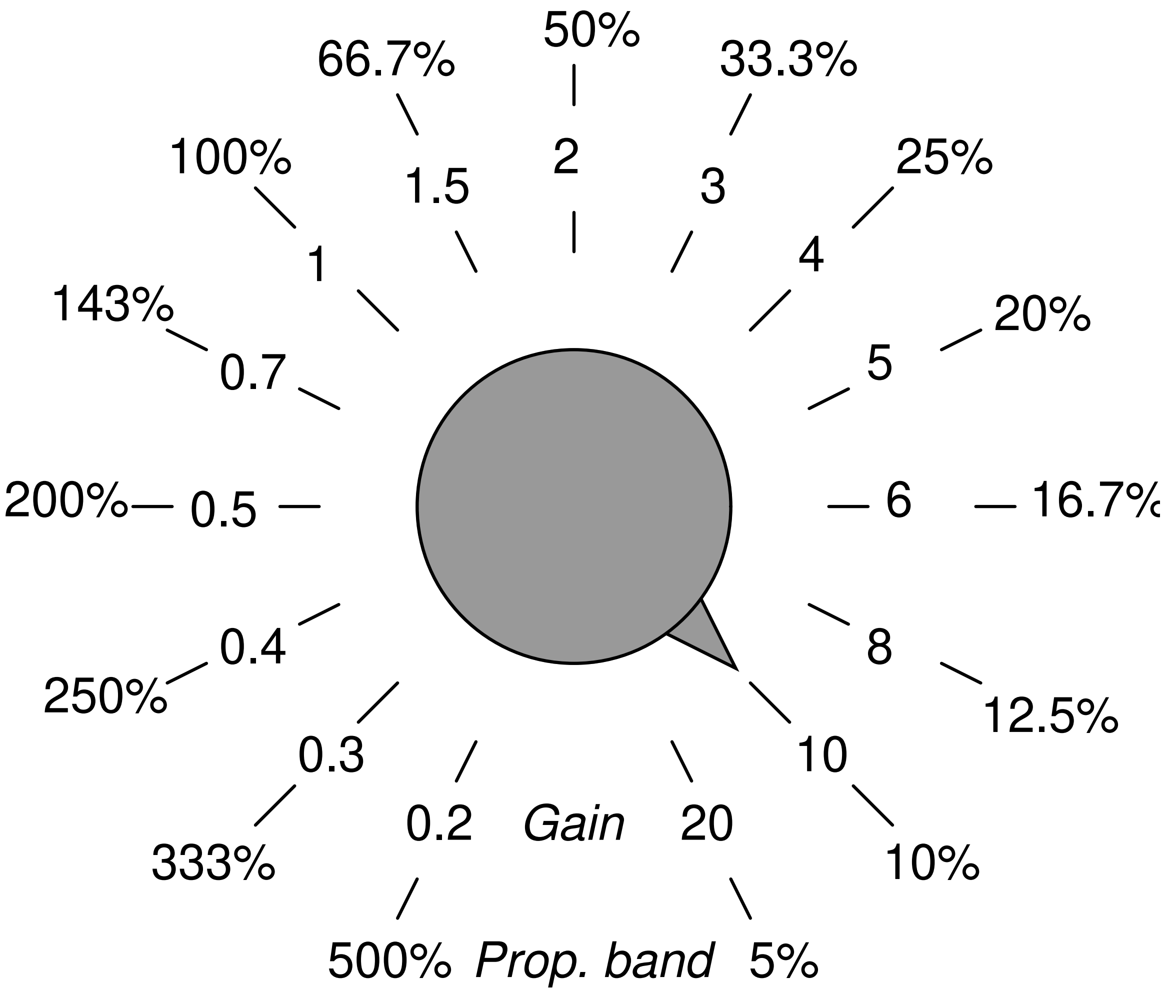


The process variable (PV), setpoint (SP), and output signals (manipulated variable, or MV) of the controller are recorded in a table at random time intervals:

PV (Process Variable)	SP (Setpoint)	MV (Output)
50%	50%	50%
48%	50%	70%
45%	50%	100%
49%	50%	60%
52%	50%	30%
51%	50%	40%
55%	50%	0%

Based on an examination of the values in this table, is the level controller configured for *direct* or *reverse* action?

Examining the controller, you notice there is a knob on its side for setting its gain. This knob is labeled "Gain / Prop. Band," and it has two sets of numbers describing its range of adjustment:



Explain how the two values shown for the knob's setting (Gain = 10 ; Prop. Band = 10%) relate to the percentages you see in the table. Particularly, define *proportional band* in a way that makes sense looking at the controller's behavior over time.

Suggestions for Socratic discussion

- Build a computer spreadsheet program to model the behavior of the proportional controller in this scenario. You will know you are successful when it is able to duplicate the table of values presented in the question (i.e. your spreadsheet will be able to exactly calculate each Output value corresponding to the PV and SP values given in different rows of the table.

file i01461

Oppgave 4

Convert the following controller gain settings into units of proportional band:

- Gain = 1; P.B. = ________
- Gain = 2; P.B. = ________
- Gain = 3.0; P.B. = ________
- Gain = 0.5; P.B. = ________
- Gain = 0.2; P.B. = ________
- Gain = 0.01; P.B. = ________
- Gain = 5.5; P.B. = ________
- Gain = 10.2; P.B. = ________

file i01462

Oppgave 5

Convert the following controller settings (in units of proportional band) into units of gain (K_p):

- P.B. = 150%; Gain = ________
- P.B. = 300%; Gain = ________
- P.B. = 40%; Gain = ________
- P.B. = 10%; Gain = ________
- P.B. = 730%; Gain = ________
- P.B. = 4%; Gain = ________
- P.B. = 247%; Gain = ________
- P.B. = 9.5%; Gain = ________

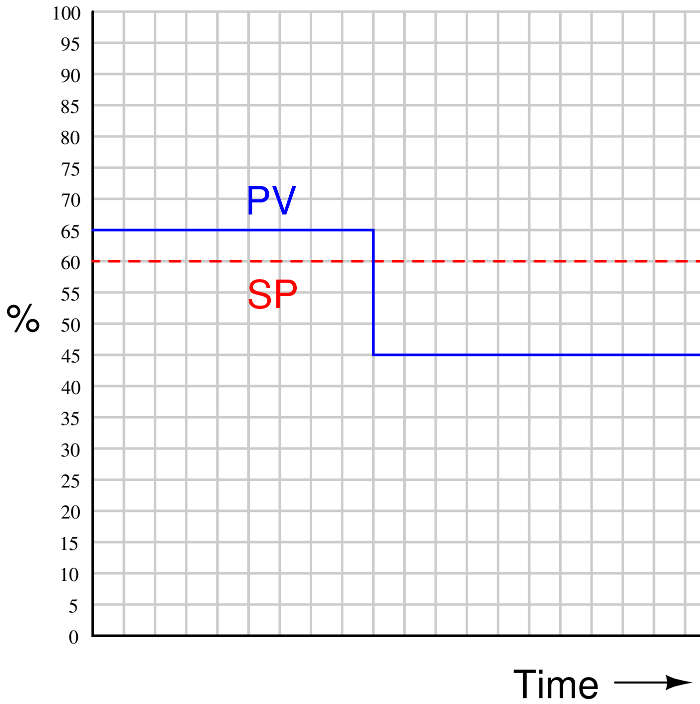
Suggestions for Socratic discussion

- Demonstrate how to estimate answers for these conversions without using a calculator.

file i01463

Oppgave 6

Graph the output of this proportional-only controller, assuming a gain (K_p) value of 2.0, a bias value of 50%, and a control action that is direct-acting:



Suggestions for Socratic discussion

- Explain why this trend graph of the PV is unrealistic for a real process, but nevertheless useful for learning how a proportional-only controller is designed to respond to changes in PV.
- How do you suppose the PV would *actually* respond in a real process to the conditions shown (or implied) in this trend? Sketch what you would think would be a more realistic response assuming a properly-tuned proportional-only controller running in automatic mode.

file i01468

Oppgave 7

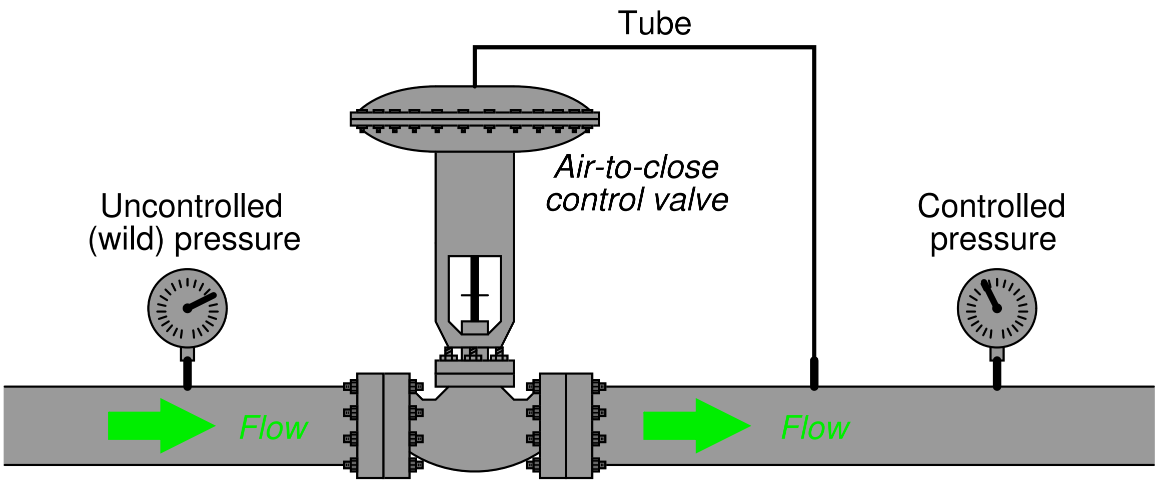
Suppose that a reverse-acting, proportional-only controller has a gain (K_p) setting of 2 and a bias (b) setting of 40%. What will its output be for the following input conditions?

- PV = 37%; SP = 50%; Output = ________
- PV = 92%; SP = 80%; Output = ________
- PV = 81%; SP = 75%; Output = ________
- PV = 33%; SP = 42%; Output = ________
- PV = 79%; SP = 76%; Output = ________
- PV = 15%; SP = 20%; Output = ________
- PV = 38%; SP = 38%; Output = ________
- PV = 0%; SP = 0%; Output = ________

file i01489

Oppgave 8

A control valve (all by itself!) may act as a crude proportional controller for controlling pressure of a gas or vapor:

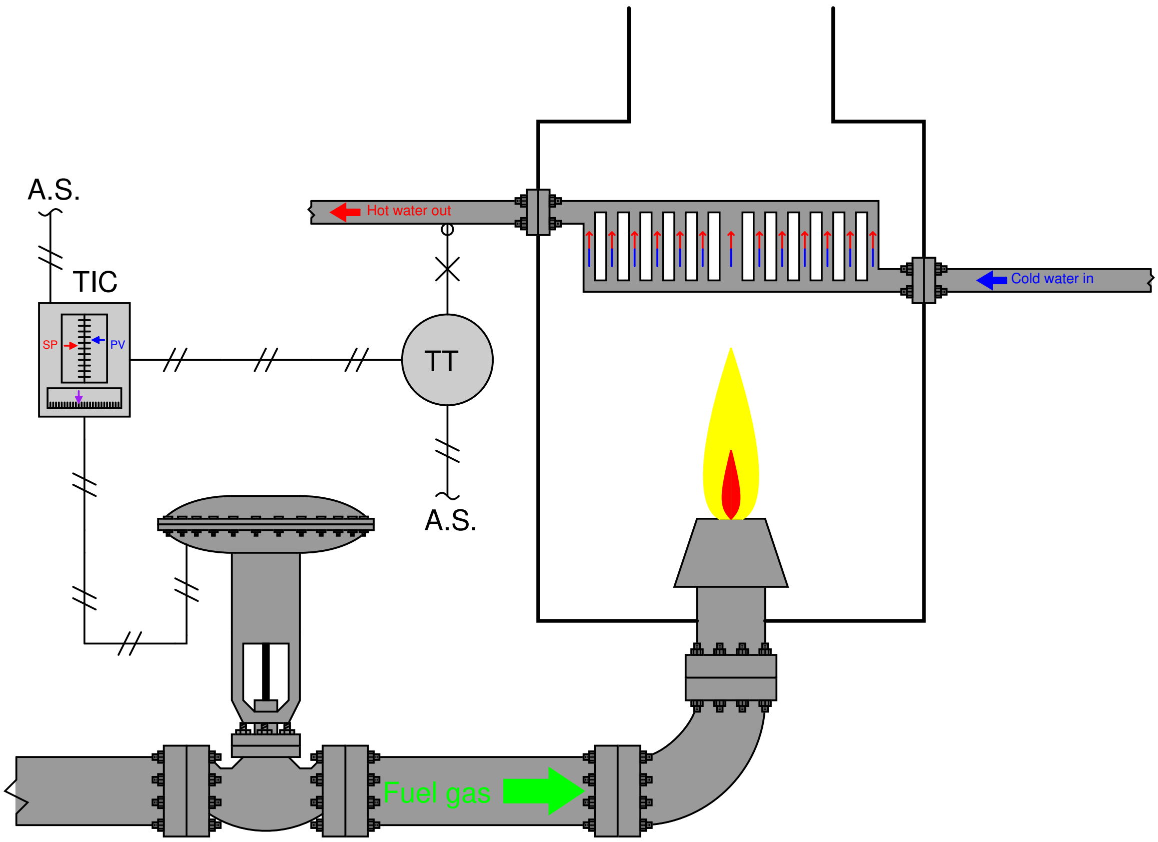


Identify how this constitutes a negative feedback system, and explain how it works to regulate downstream pressure. Then, identify what things you would have to change in this system to alter its gain (proportional band) and setpoint.

file i01483

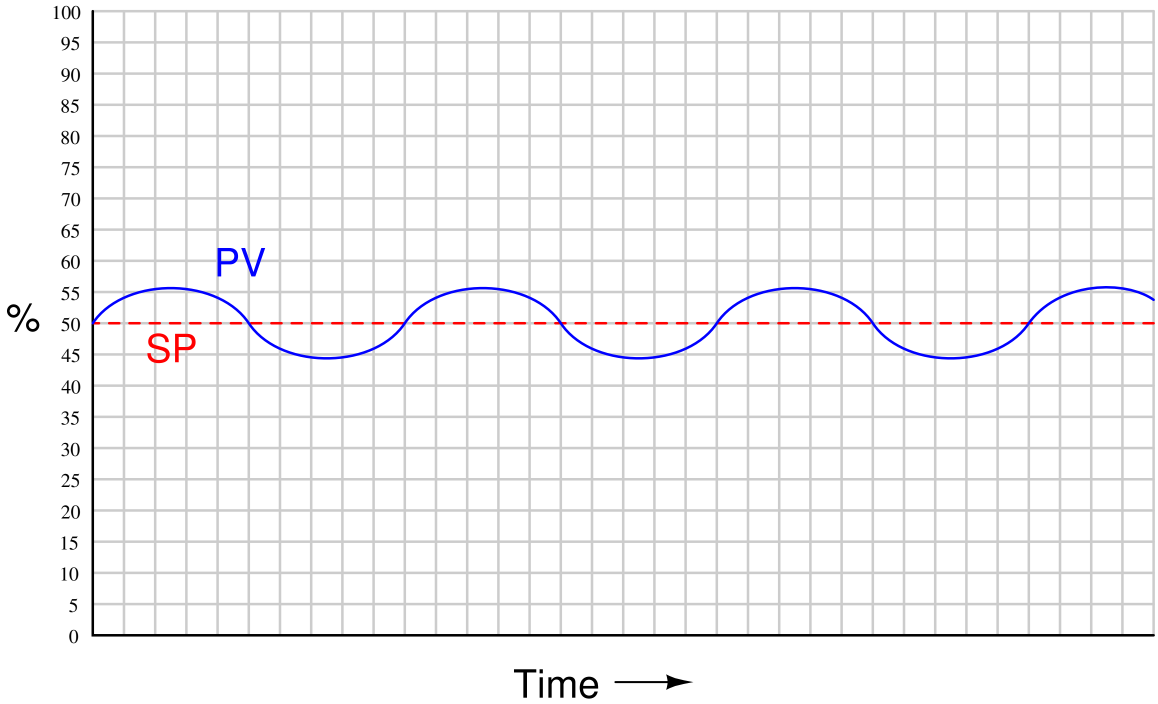
Oppgave 9

A pneumatic water heater control system uses a temperature transmitter calibrated to a range of 0 to 180^o F. The control system has worked adequately for many years:



It is then decided that the temperature range is too wide, since the water temperature never falls below 100^o F. A narrower calibrated range will make better use of the 3-15 PSI signal's dynamic range, and also make it easier to see changes in temperature on 3-15 PSI (input) indicators and chart recorders. An instrument technician re-calibrates the temperature transmitter to a narrower range: 100 to 180^o F, then re-labels all the indicators and chart recorders to reflect the new range. After doing this work, the operator places the control system back in service.

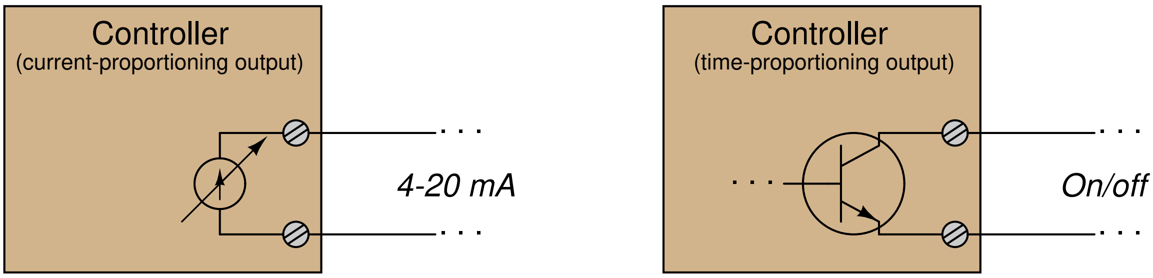
However, it quickly becomes evident that something is wrong. Instead of a smooth line on the chart recorder, the temperature is seen to cycle continuously:



Why is this now happening, when the control used to be stable before the re-calibration? Of course, we could fix the problem by returning the transmitter's calibration back to the way it was (0 to 180^o F), but is there any way we can maintain the narrower transmitter range (100 to 180^o F) *and* yet still have stable control, or are these two goals mutually exclusive?
file i01477

Oppgave 10

Some electronic controllers provide the option of a *time-proportioning* output instead of the customary *current-proportioning* output. With the time-proportioning output, the two output terminals of the controller connect (internally) to a relay contact or transistor, capable only of turning an electrical load fully on and fully off:

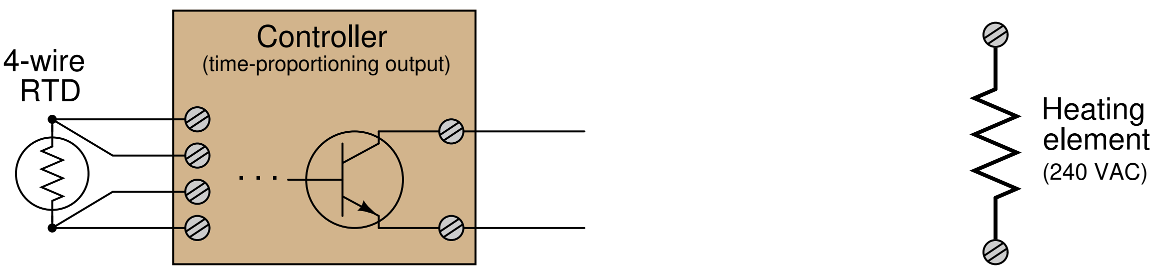


Time-proportional control is most often used when the final control element is an electric heater. Explain how time-proportional control works to maintain a process variable at setpoint while only being able to turn a heater on and off (and not in-between).

file i01487

Oppgave 11

Suppose you needed to control the temperature of an "incubation" vessel at a biopharmaceutical manufacturing facility, to ensure the bacteria were held at the correct temperature for optimum growth. The vessel is heated by an electric heater, and the only controller you have available is one with a time-proportioning output (transistor).
Unfortunately, the controller's transistor is not able to directly handle the 240 volt AC power required by the heater, partly because of the voltage and current limitations of the transistor, and partly because an NPN transistor can only switch DC, not AC.

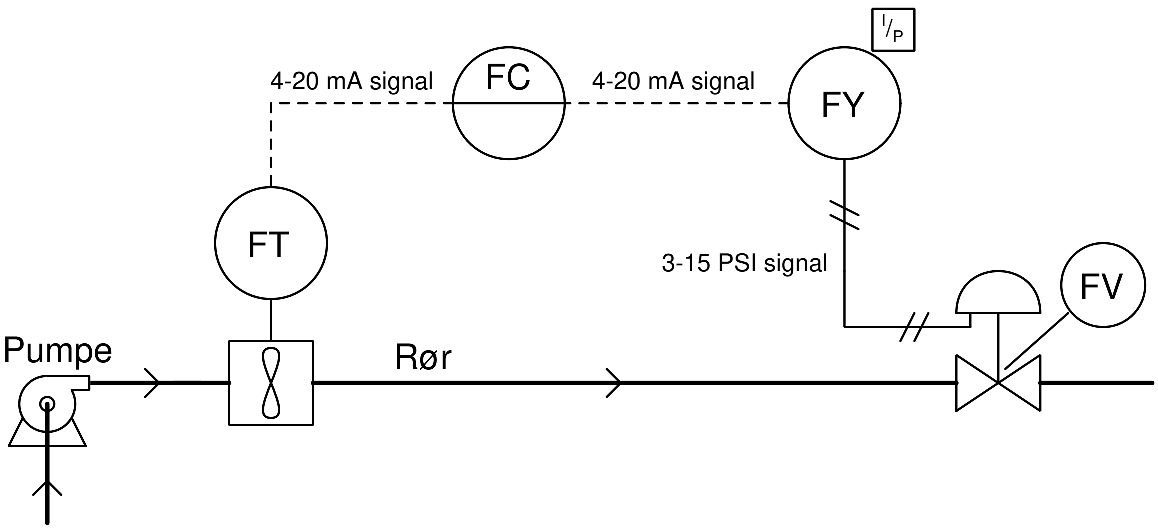


Sketch an "interposing" circuit between the controller and heating element that allows the controller to do its task.

file i01488

Oppgave 12

Her vises en P&ID (Prosess og instrumenteringsdiagram) for en væskestrøm reguleringssløyfe. Den består av en strømningsmåler (FT) som registrer strømningen i røret og sender et elektronisk signal på for stor strømning det er. En strømingsregulator (FC) mottar signalet og sammenligner dette med et settpunkt, for så å avgjør hvilken vei reguleringsventilen skal bevege seg. En strøm til luft omformer (*(FY) konverterer strømsignalet fra regulatoren til et lufttrykk som styrer posisjonen til reguleringsventilen(FV), som igjen styrer strømningen i røret.



Retningen på styresignalet for hvert instrument vises her:

- FT: Økende strømning = økende signal
- FC: Økende signal på inngang (PV) = minkende signal på utgang (MV)
- FY: økende strømsignal på inngang = økende pneumatisk signal på utgangen
- FV: økende pneumatisk signal = ventilen åpner mer.

Forklar hva som vil skje med alle signalene i denne reguleringssløyfen med regulatoren i "Auto" modus (Klar for å kompensere for variasjoner i strømningen) hvis pumpen plutselig roterer fortere og øsker strømningen.
Forklar også hva som vil skje med styresignalene i reguleringssløyfen med regulatoren i "manual" modus(styresignalet står fast på det som operatøren har stilt det på) dersom pumpen roterer fortere og forårsaker en økning i strømningen.

Suggestions for Socratic discussion

- Explain the practical benefit of having a "manual" mode in a process loop controller. When might we intentionally use manual mode in an operating process condition?

file i00124

Oppgave 13

The very simplest style of automatic control is known as *on-off* or more whimsically, *bang-bang* control. This is where the automatic controller only has two output signal modes: fully on and fully off. Your home's heating system is most likely of this sort, where a thermostat can either tell the furnace to turn on or to turn off.

Describe the advantages and disadvantages of "on-off" control, as contrasted against more sophisticated control schemes where a final control element such as a control valve may be proportionately positioned anywhere between fully open and fully closed according to the demands of the process.

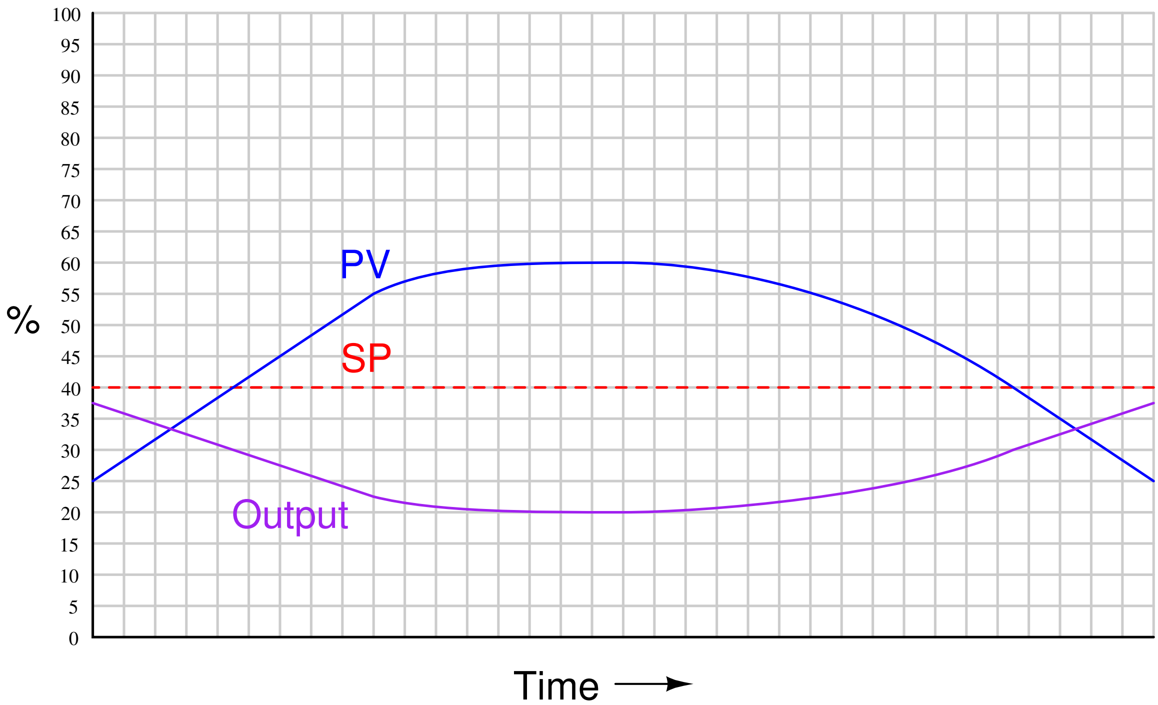
Suggestions for Socratic discussion

- What other control systems in common experience use the "bang-bang" strategy?

file i00125

Oppgave 14

An indispensible tool for process operators and instrument technicians alike is the *trend* graph, showing such control loop variables as PV, SP, and controller Output superimposed on the same time-domain plot. The following example shows the process variable, setpoint, and output for a proportional-only controller as it responds to changes in a control loop's PV while the setpoint remains at a constant value of 40%:



Based on an examination of this trend graph, determine the *bias* value of the controller and *gain* value of the controller, as well as its direction of action (*direct* or *reverse*).

A helpful analysis technique when relating trend graphs to controller equations is to sketch a vertical line on the graph to identify some particular point in time, then identify the values of PV, SP, and Output at that point in time. A proper equation for the controller will successfully predict the Output value from the PV and SP values at *any* point in time shown on the trend.

Suggestions for Socratic discussion

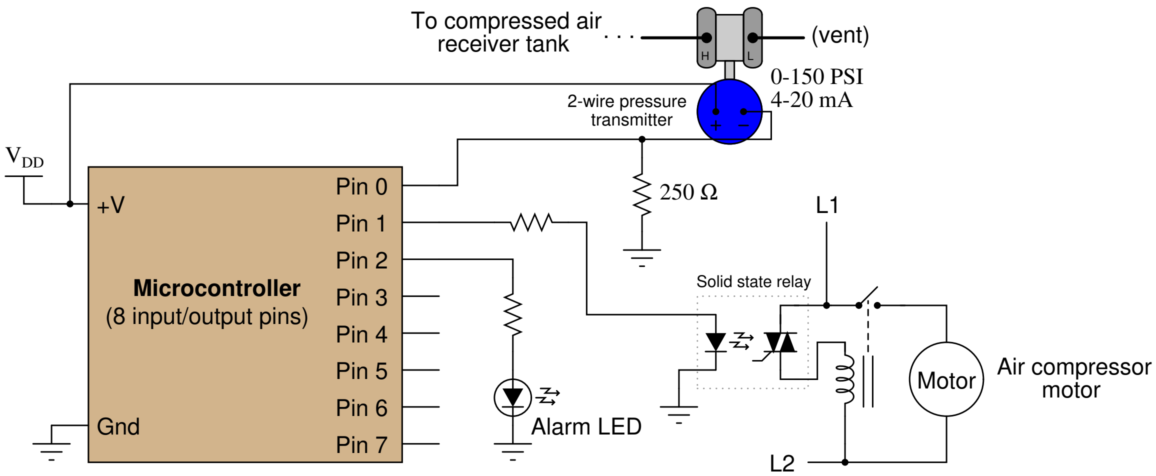
- Once you have calculated the gain of this loop controller, calculate its *proportional band* value as well.

- Build a computer spreadsheet program to model the behavior of the proportional controller in this scenario. You will know you are successful when it is able to duplicate any Output value shown on the trend graph at any particular point in time, corresponding to the PV and SP values at that same point in time.
- What would this trend look like if the controller were left in *manual* mode instead of *automatic* mode?

file i00715

Oppgave 15

A *microcontroller* is a single-chip digital computer with onboard I/O capable of receiving and transmitting different types of electrical signals, and a processor capable of executing a series of written instructions. This one is being used to control an air compressor:



Examine the following program (written in an informal programming language called "pseudocode") and explain how the microcontroller decides when to turn the motor on and off. Also determine the pressures at which the microcontroller turns on and shuts off the compressor:

Pseudocode listing

```
Declare Pin0 as an analog input (scale 0 to 5 volts = 0 to
1023)
Declare Pin1 as a discrete output
Declare Pin2 as a discrete output
Declare A as a constant = 805
Declare B as a constant = 750
Declare C as a constant = 700

LOOP
  // (Comment: Motor control points)
  IF Pin0 > A, SET Pin1 LOW
  ELSEIF Pin0 < B, SET Pin1 HIGH
  ENDIF

  // (Comment: Alarm LED control points)
  IF Pin0 < C, SET Pin2 HIGH
  ELSE SET Pin2 LOW
  ENDIF
ENDLOOP
```

Suggestions for Socratic discussion

- Which sections of the pseudocode program listing are executed repeatedly, and which sections are executed only once?
- How many bits of resolution does this microcontroller have for the analog input on pin #0, assuming that 0 to 1023 is the full range of the converter?
- Explain how the *solid state relay* device works to help control the compressor motor.
- Explain what would happen if you deleted the `LOOP` and `ENDLOOP` statements in the microcontroller program.
- Modify the pseudocode so that the alarm LED comes on if the pressure gets too high.
- Modify the pseudocode so that the alarm LED comes on if the pressure gets too high *or* too low.

file i01454

Oppgave 16

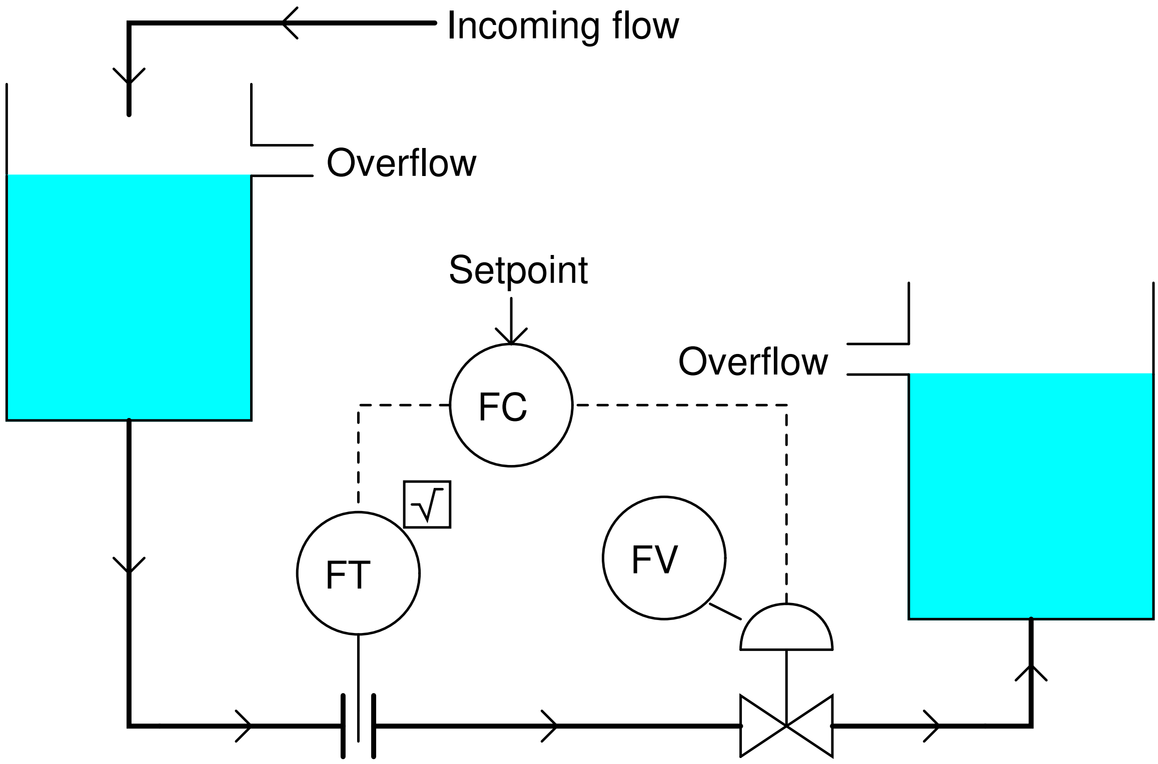
Imagine driving an automobile with very sensitive steering: just a few degrees of steering wheel motion at highway speeds is sufficient to quickly change lanes. Now imagine driving an automobile having significantly less sensitive steering: a whole quarter-turn of the steering wheel is needed to generate the same response as a few degrees of rotation in the first vehicle.

An important process quantity is its *gain*. How would you qualify the two automobile steering systems just described in terms of process gain, from the perspective of lane position as the process variable, steering wheel angle as the manipulated variable, and you (the driver) as the proportional controller? Which automobile has a high process gain, and which has a low process gain?

file i01457

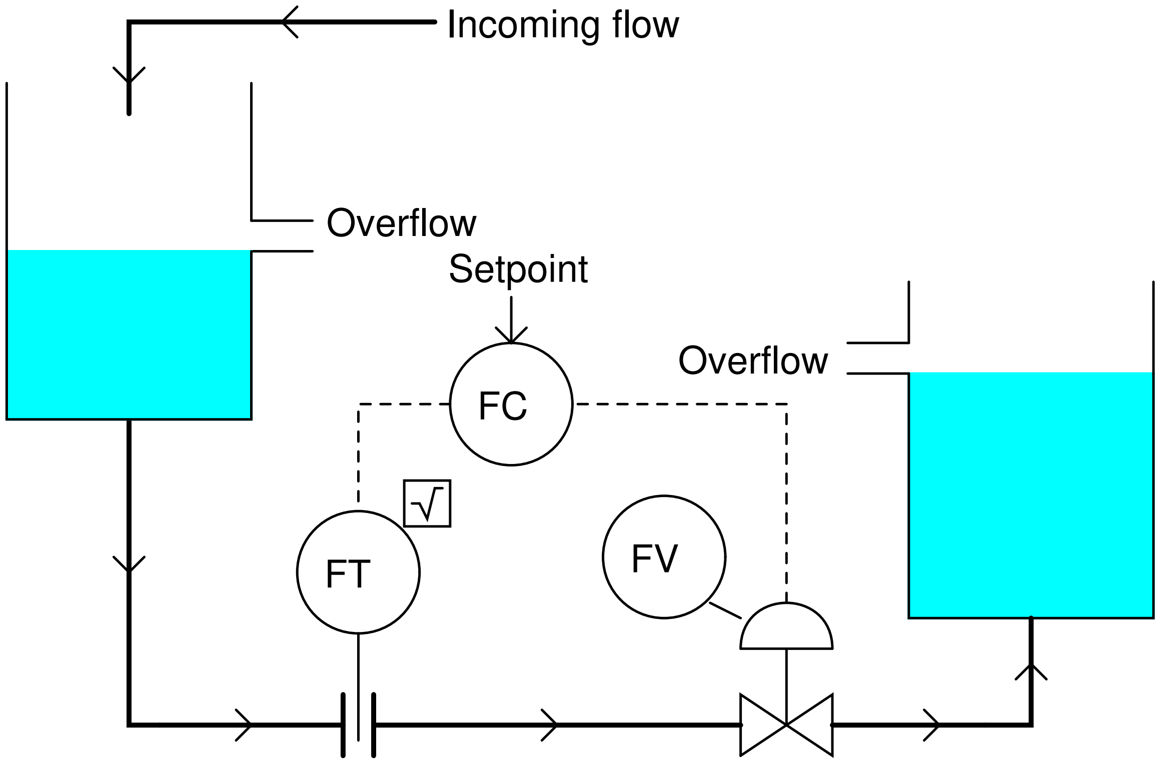
Oppgave 17

Examine this flow control system, where a valve controls the flow rate of liquid between two vessels:



Since each vessel has its liquid level controlled by an overflow pipe, the head pressure at the bottom of each will be constant. This means that the differential pressure across the valve will be constant as well.

Suppose now that the higher vessel has its overflow pipe moved to a lower location, thus reducing the controlled level in that vessel, and consequently the head pressure generated at the bottom:



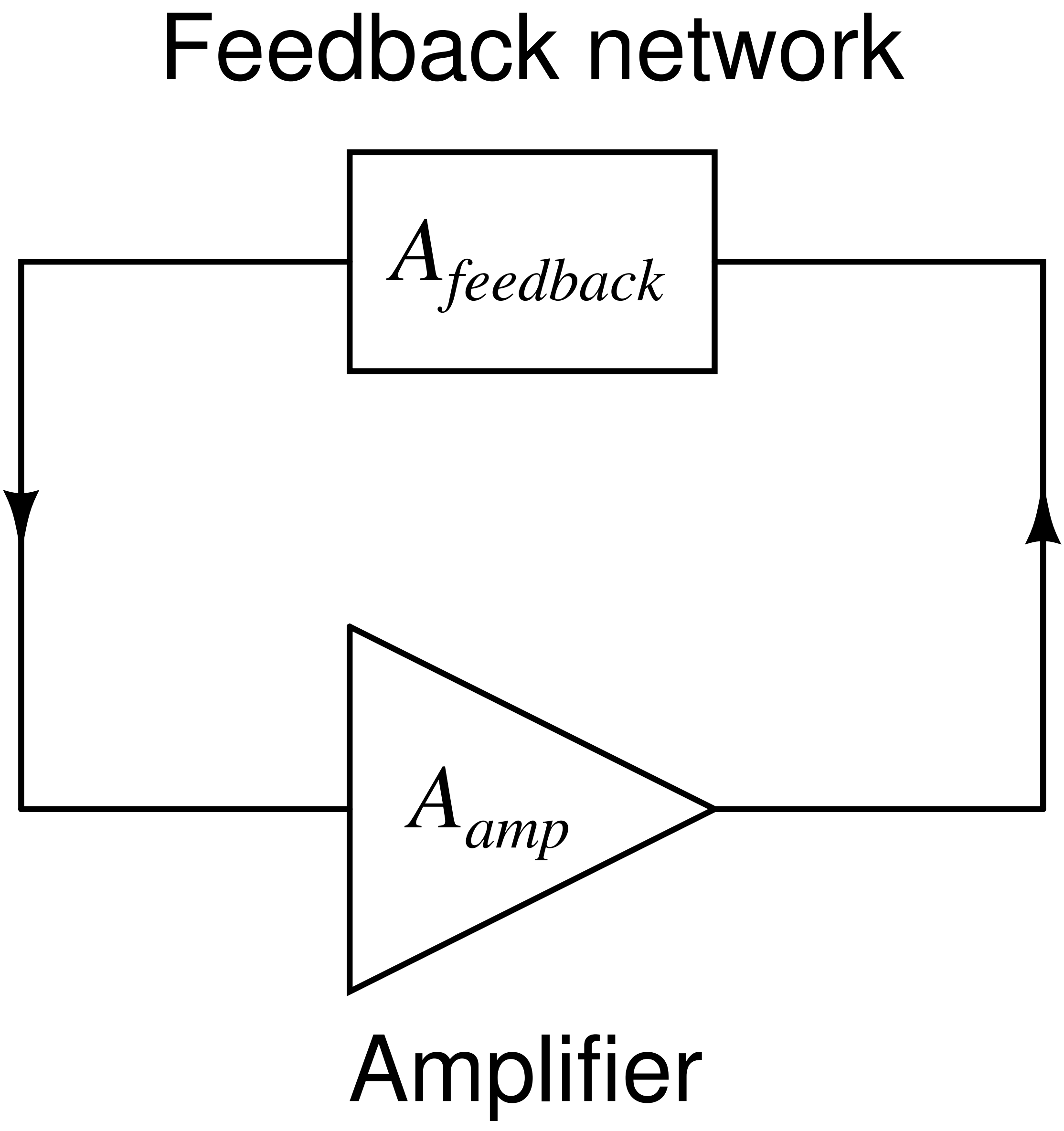
This change in head pressure, of course, reduces the amount of differential pressure across the valve. How will this affect the process gain, as it relates to flow control? In other words, will the flow rate become more or less sensitive to changes in valve position as a result of decreasing the pressure drop across the valve?

What will happen to the process gain if we then replace the control valve with one having a larger C_v value (a larger opening for fluid flow when fully open)?

Finally, what will happen to the process gain if we re-calibrated the flow transmitter for a smaller span (for example, from 0-120 GPM to 0-75 GPM)?
file i01458

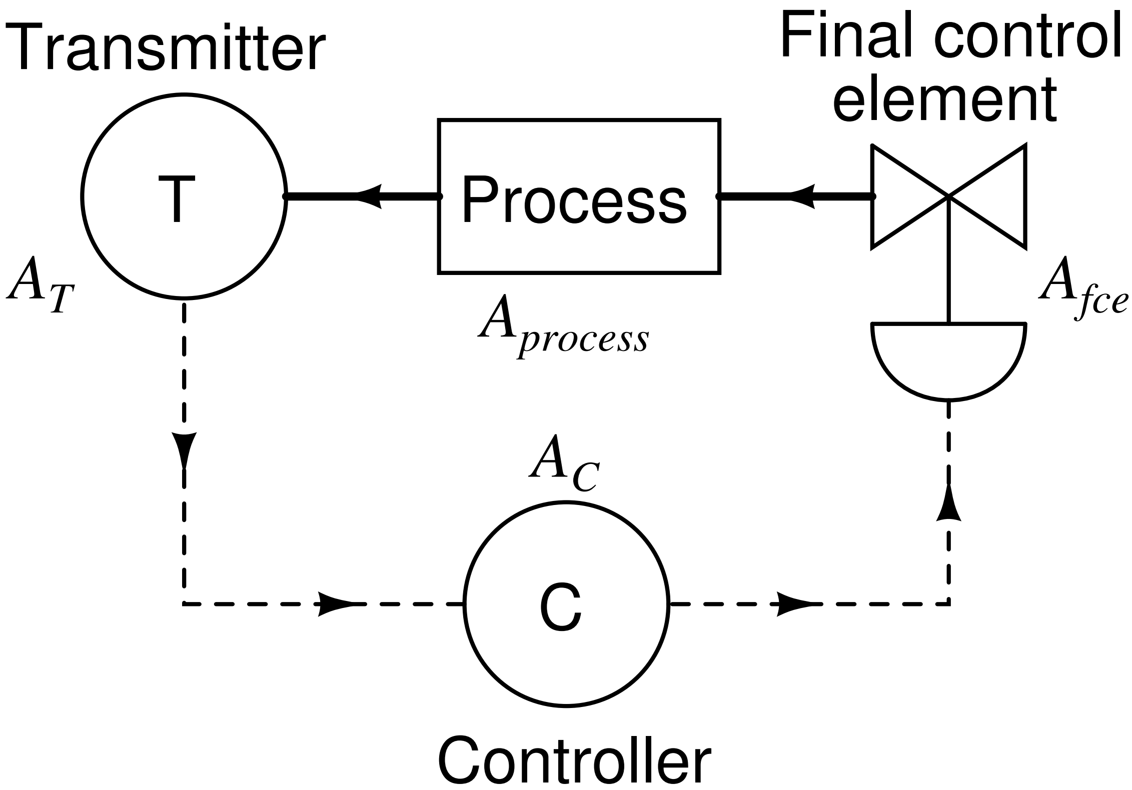
Oppgave 18

In your study of electronics, you probably learned that any amplifier can be turned into an *oscillator* by providing the right amount of phase-shifted feedback from output to input, with a minimum amount of total circuit gain. This principle even had a name: the *Barkhausen criterion*.



So long as the product of the two gains is at least unity ($A_{amp} \cdot A_{feedback} \geq 1$), there will be sufficient amplification to sustain oscillation in the circuit. One key to avoiding oscillation in such a circuit is to limit the total "loop" gain to less than unity.

A process control system using feedback is not much different from this, and it too may oscillate if the total "loop" gain is excessive:

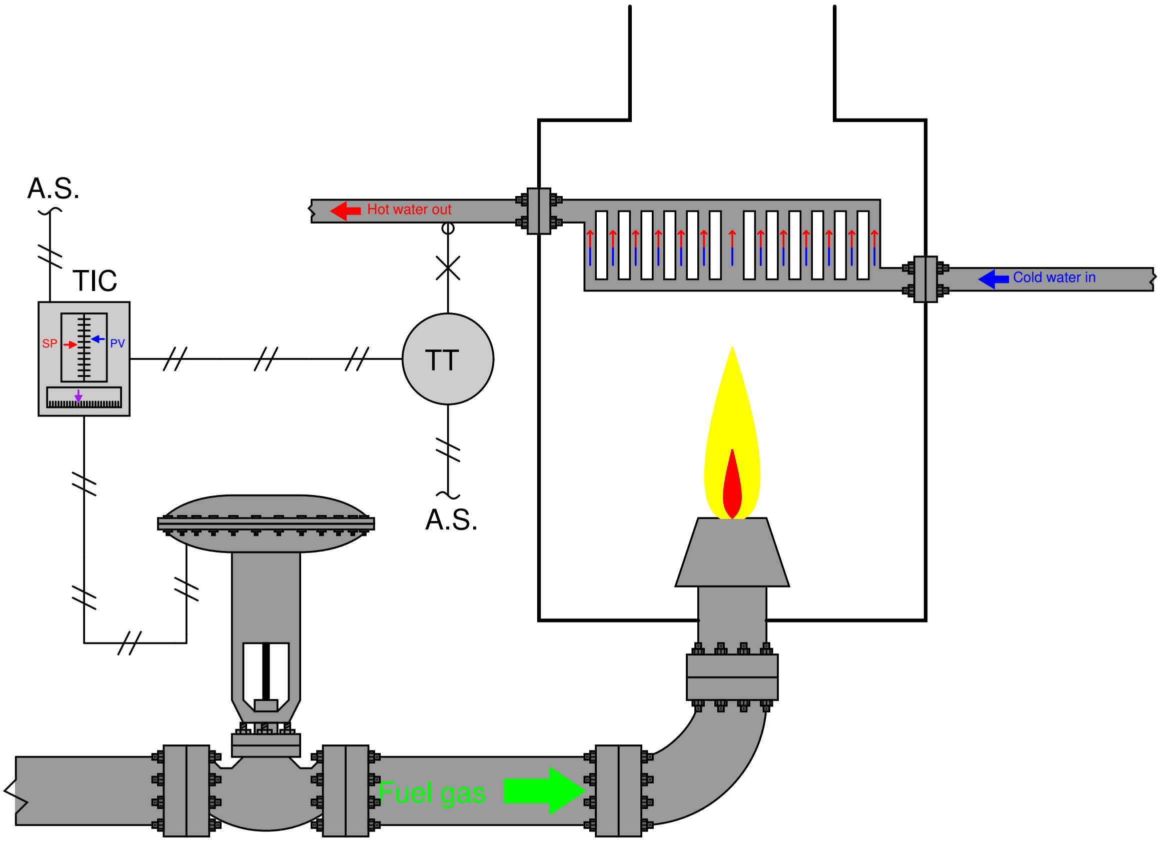


Describe what "gain" represents in each of the four components within the control system shown above (A_C, A_{fce}, $A_{process}$, and A_T), and identify which of these gains is easiest to alter. Finally, explain how that one (easy-to-set) gain should be adjusted. In other words, what criteria should determine its configured value?

file i01459

Oppgave 19

The following water heater process is automated with a pneumatic temperature transmitter, controller, and control valve:



The process variable (PV), setpoint (SP), and output signals (manipulated variable, or MV) of the controller are recorded in a table at random time intervals:

PV (Process Variable)	SP (Setpoint)	MV (Output)
50%	50%	50%
45%	50%	55%
30%	50%	70%
25%	50%	75%
65%	50%	35%
72%	50%	28%
50%	40%	40%
50%	71%	71%
80%	65%	35%
37%	42%	55%
40%	30%	40%

Develop a mathematical expression describing the data you see here in the table. Hint: it may be easier if you begin with a *qualitative* assessment of the figures (i.e. *"when the PV exceeds the SP, the MV . . ."*).
file i01460

Oppgave 20

Digital proportional controllers generate their output signal values using a microprocessor to repeatedly evaluate the proportional equation:

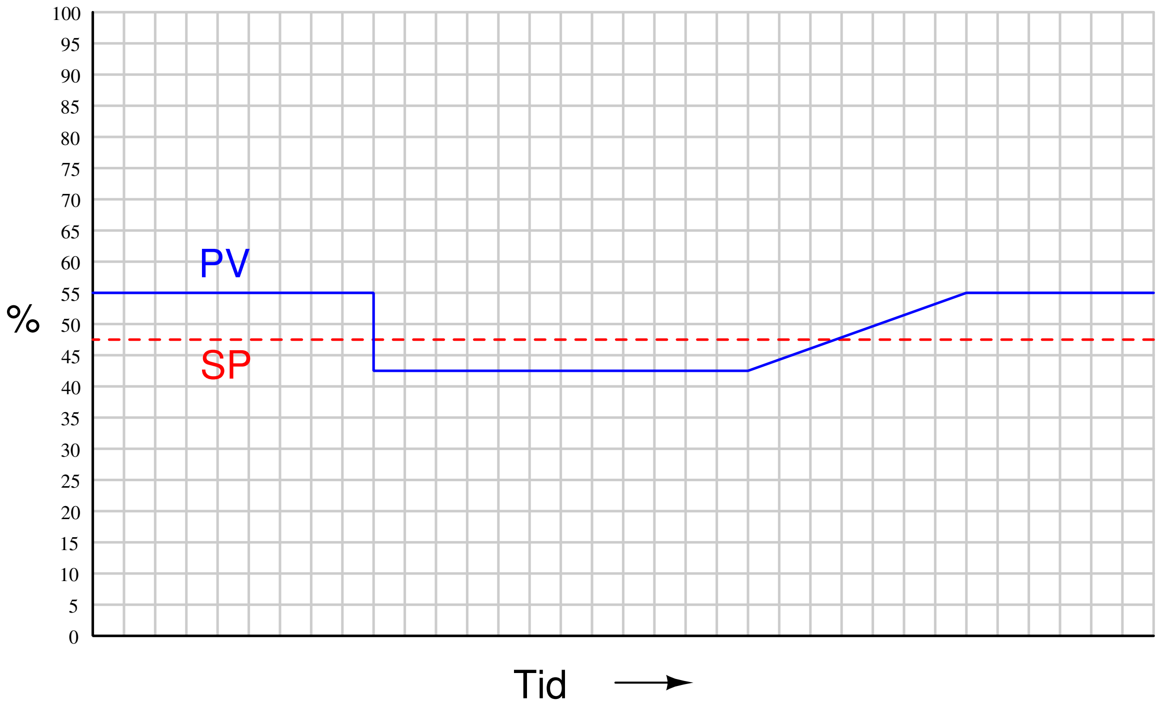
$$m = K_p e + b$$

What would happen if a *negative* value were entered for gain (K_p) into the digital controller's program?
file i01467

Oppgave 21

Tegn grafen for utgangen på denne regulatoren med bare p-ledd og direktevirkning. Den er stilt inn med følgende verdier:

- proporsjonalbånd 20%
- bias 50 %



Utregninger:

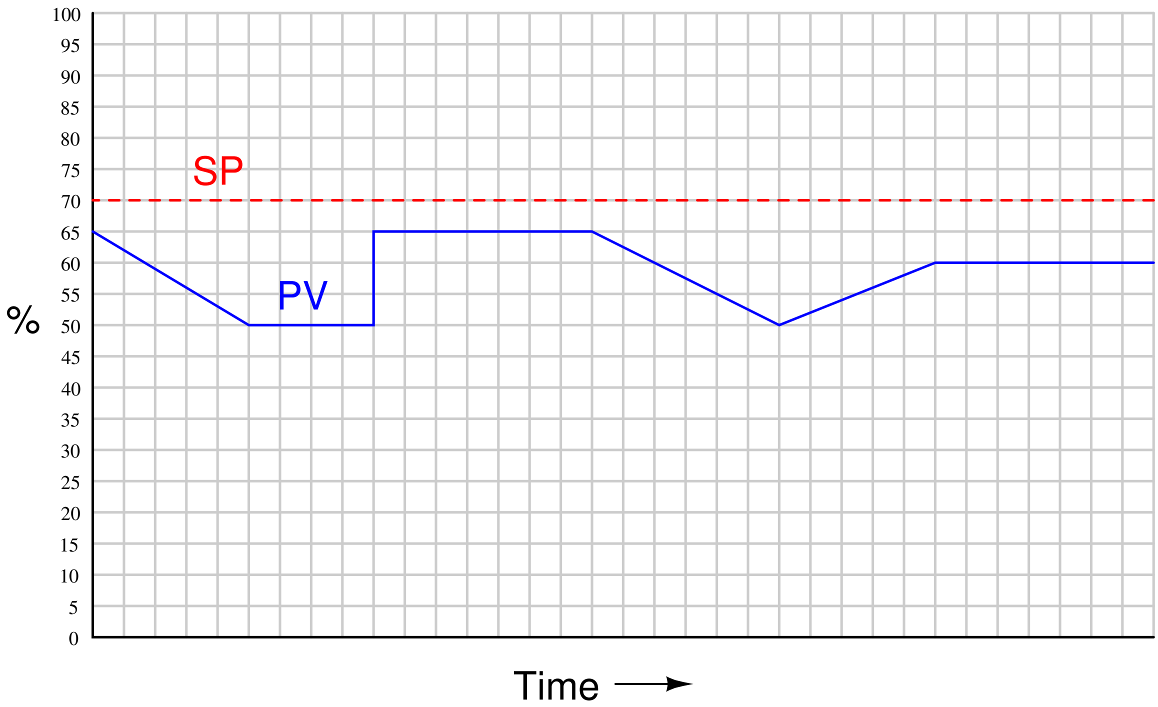
Suggestions for Socratic discussion

- Explain why this trend graph of the PV is unrealistic for a real process, but nevertheless useful for learning how a proportional-only controller is designed to respond to changes in PV.
- How do you suppose the PV would *actually* respond in a real process to the conditions shown (or implied) in this trend? Sketch what you would think would be a more realistic response assuming a properly-tuned proportional-only controller running in automatic mode.
- Identify points on the trend where the PV exhibits a positive rate of change.
- Identify points on the trend where the PV exhibits a negative rate of change.
- Identify points on the trend where the PV exhibits zero change.

file i01469

Oppgave 22

Graph the output of this proportional-only controller, assuming a proportional band value of 125%, a bias value of 30%, and a control action that is reverse-acting:



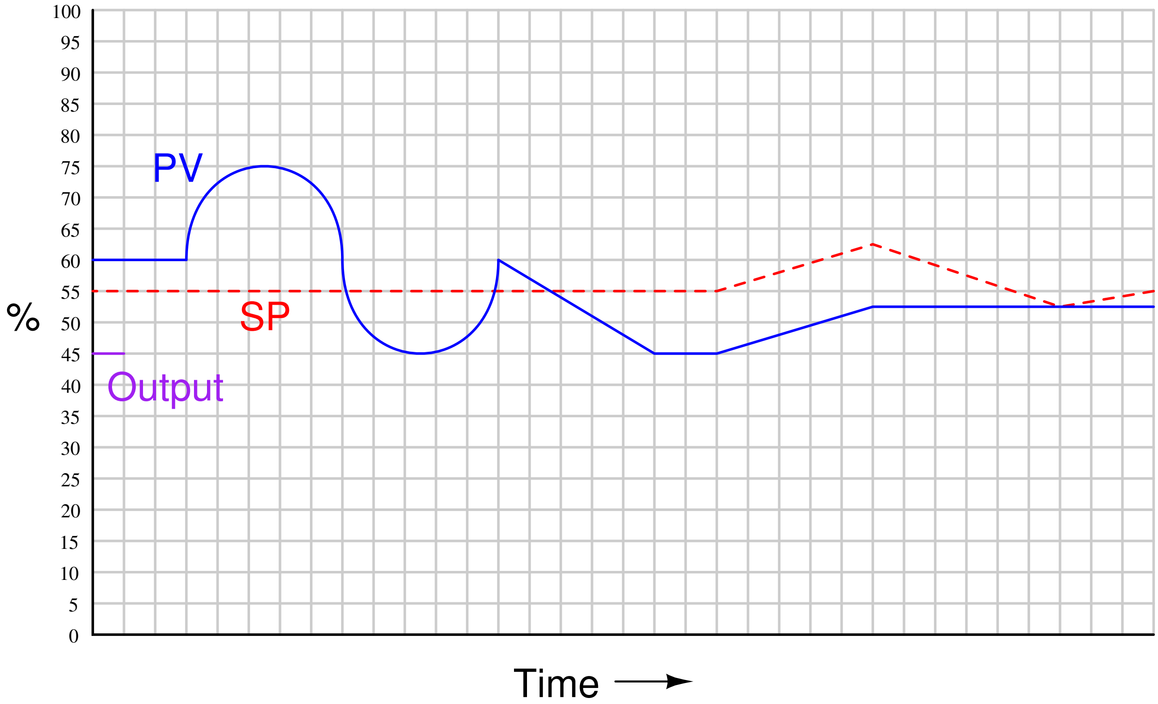
Suggestions for Socratic discussion

- Identify points on the trend where the PV exhibits a positive rate of change.
- Identify points on the trend where the PV exhibits a negative rate of change.
- Identify points on the trend where the PV exhibits zero change.
- How would the output signal trend be altered if the *gain* of this controller were increased?
- How would the output signal trend be altered if the *bias* of this controller were increased?
- How would the output signal trend be altered if the *action* of this controller were switched from reverse to direct?

file i01470

Oppgave 23

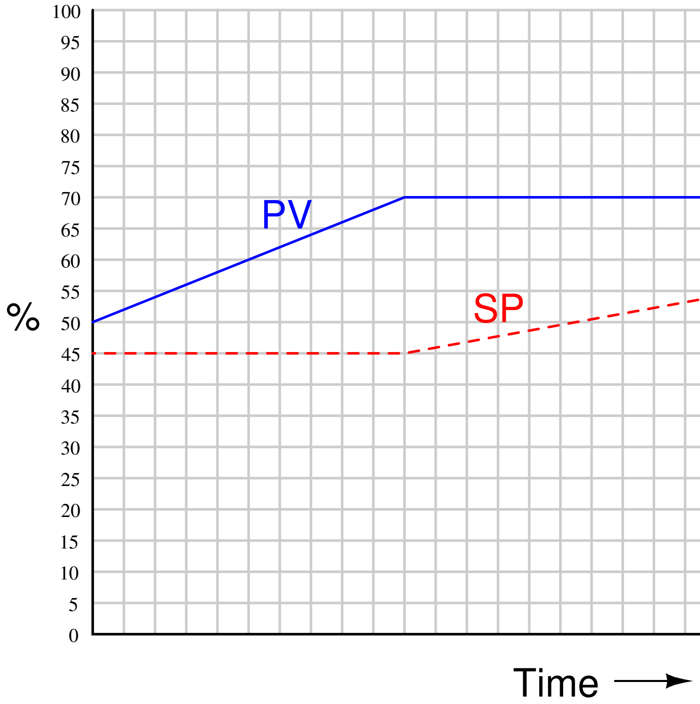
Graph the output of this proportional-only controller, assuming a proportional band value of 100% and a control action that is direct-acting:



file i01484

Oppgave 24

Graph the output of this proportional-only controller, assuming a gain (K_p) value of 0.5, a bias value of 40%, and a control action that is reverse-acting:



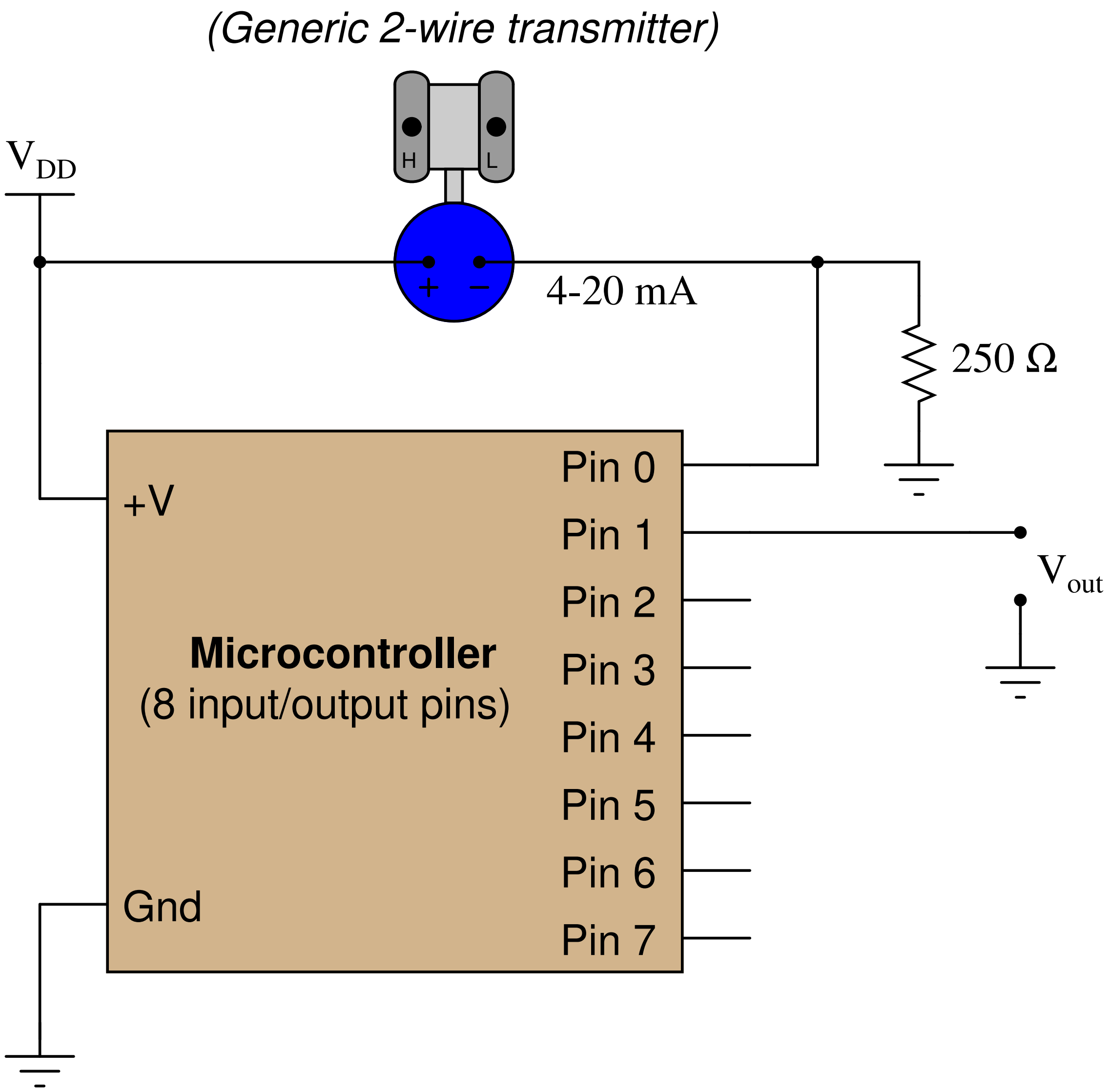
Suggestions for Socratic discussion

- Identify points on the trend where the PV exhibits a positive rate of change.
- Identify points on the trend where the PV exhibits a negative rate of change.
- Identify points on the trend where the PV exhibits zero change.
- How would the output signal trend be altered if the *gain* of this controller were decreased?
- How would the output signal trend be altered if the *bias* of this controller were decreased?
- How would the output signal trend be altered if the *action* of this controller were switched from reverse to direct?

file i01485

Oppgave 25

Examine this microcontroller circuit and program, designed to act as a general-purpose proportional controller:



Pseudocode listing

```
Declare Pin0 as an analog input (scale 0 to 5 volts = 0 to
1023)
Declare Pin1 as an analog output (scale 0 to 5 volts = 0
to 1023)
Declare SP as a variable, initially set to a value of 614
Declare GAIN as a variable, initially set to a value of
1.0
Declare ERROR as a variable
Declare BIAS as a constant = 614

LOOP
  SET ERROR = Pin0 - SP
  SET Pin1 = (GAIN * ERROR) + BIAS
ENDLOOP
```

Is this controller *direct* or *reverse* acting? What edit(s) to the program listing would be required to change the direction of the controller's action?

Suggestions for Socratic discussion

- Which sections of the pseudocode program listing are executed repeatedly, and which sections are executed only once?
- How many bits of resolution does this microcontroller have for the analog input on pin #1, assuming that 0 to 1023 is the full range of the converter?
- Does the speed of program execution (i.e. how fast the loop repeats itself) affect the controller's ability to control a process?
- Could all the "Declare" instructions be placed within the loop of this program? Why or why not?
- Explain what would happen if you deleted the `LOOP` and `ENDLOOP` statements in the microcontroller program.
- Modify this program to include a PV alarm, turning on an LED alarm lamp if the PV exceeds a certain value, and turning it back off when the PV drops below another value.

file i01486

Oppgave 26

A proportional-only controller in automatic mode has the following input and output values:

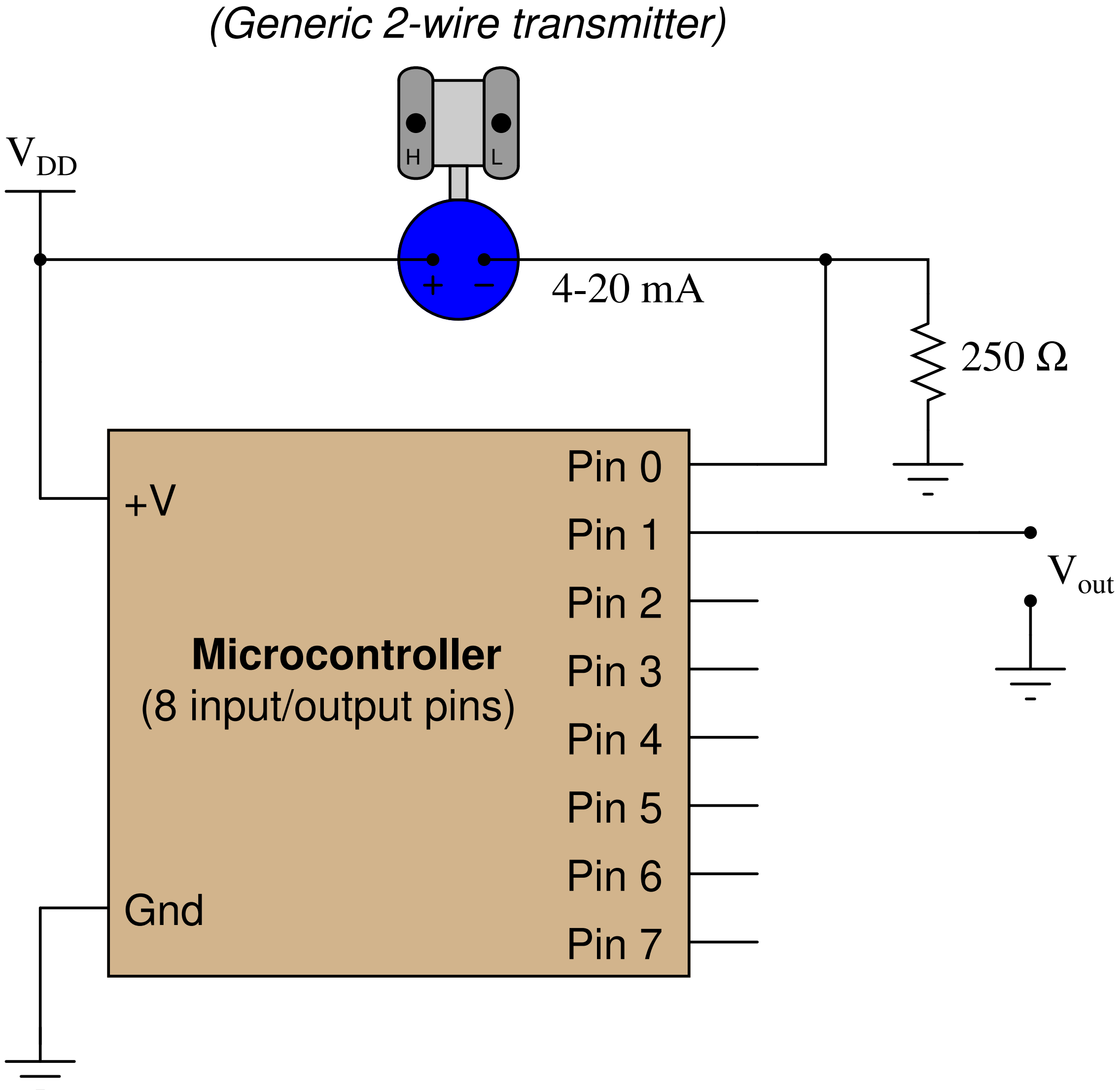
- PV = 65%
- SP = 62%
- Output = 48%

Suddenly, the operator changes the setpoint from a value of 62% to a value of 55%. The controller output immediately goes from 48% to 31%. Calculate the proportional band and the gain for this controller, and show all your work. Also, determine if this controller is *direct* or *reverse* acting.

file i01493

Oppgave 27

An instrumentation student programs a microcontroller to act as a proportional controller, but makes a mistake in writing his program:



Pseudocode listing

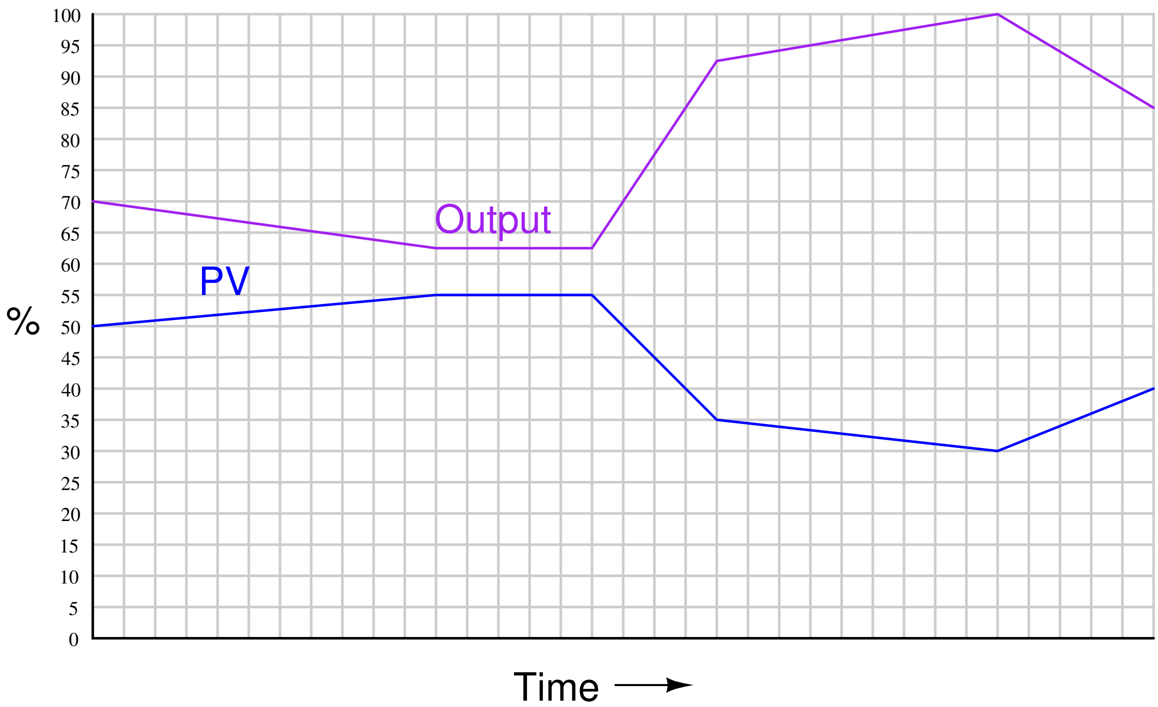
```
Declare Pin0 as an analog input (scale 0 to 5 volts = 0 to
1023)
Declare Pin1 as an analog output (scale 0 to 5 volts = 0
to 1023)
Declare SP as a variable, initially set to a value of 614
Declare ERROR as a variable
Declare GAIN as a variable, initially set to a value of
1.0
Declare BIAS as a constant = 614
Set ERROR = Pin0 - SP

LOOP
  Set Pin1 = (GAIN * ERROR) + BIAS
ENDLOOP
```

When executed, this program sets the output to a specific voltage value that never changes as the process variable changes (except when the microcontroller is re-started). Explain what is wrong with this program, and what is required to fix it. Also, identify whether this is programmed to be a *direct-acting* controller or a *reverse-acting* controller.

file i01497

Oppgave 28

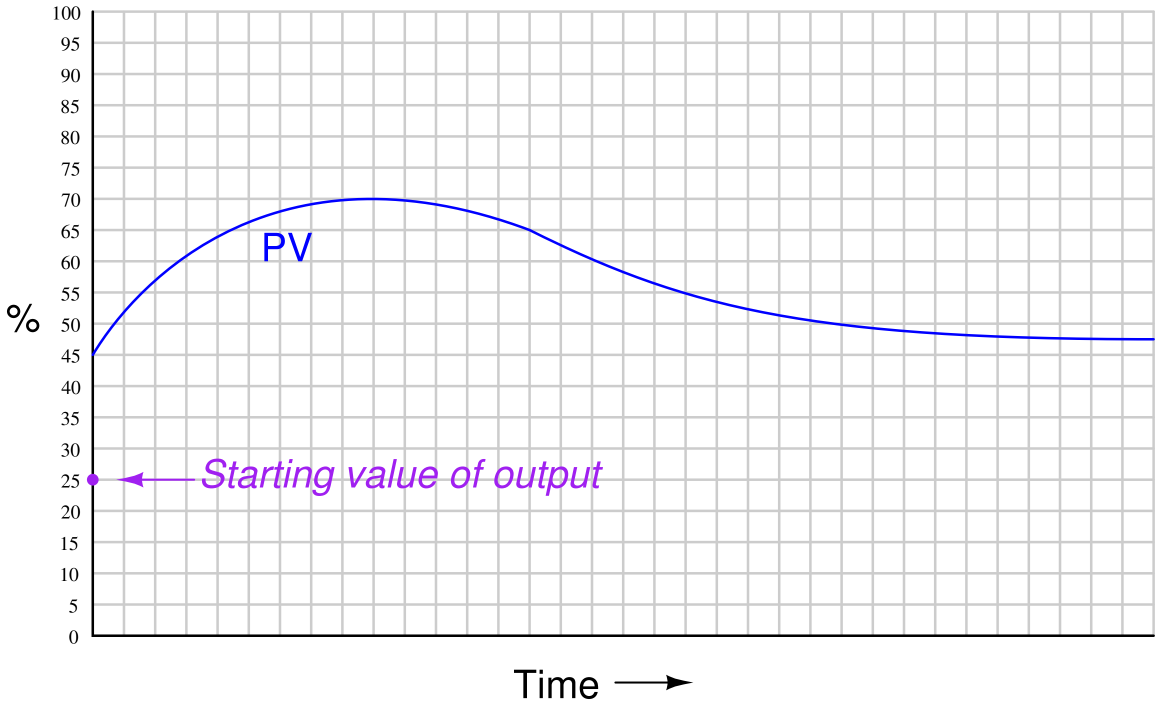
Assuming a constant setpoint, determine the proportional band setting of the proportional-only controller, as well as its control action (either *direct* or *reverse*) based on this chart recording of its behavior:



file i01499

Oppgave 29

Graph the output of this proportional-only controller, assuming a proportional band value of 40%, a constant setpoint, and a control action that is direct-acting:



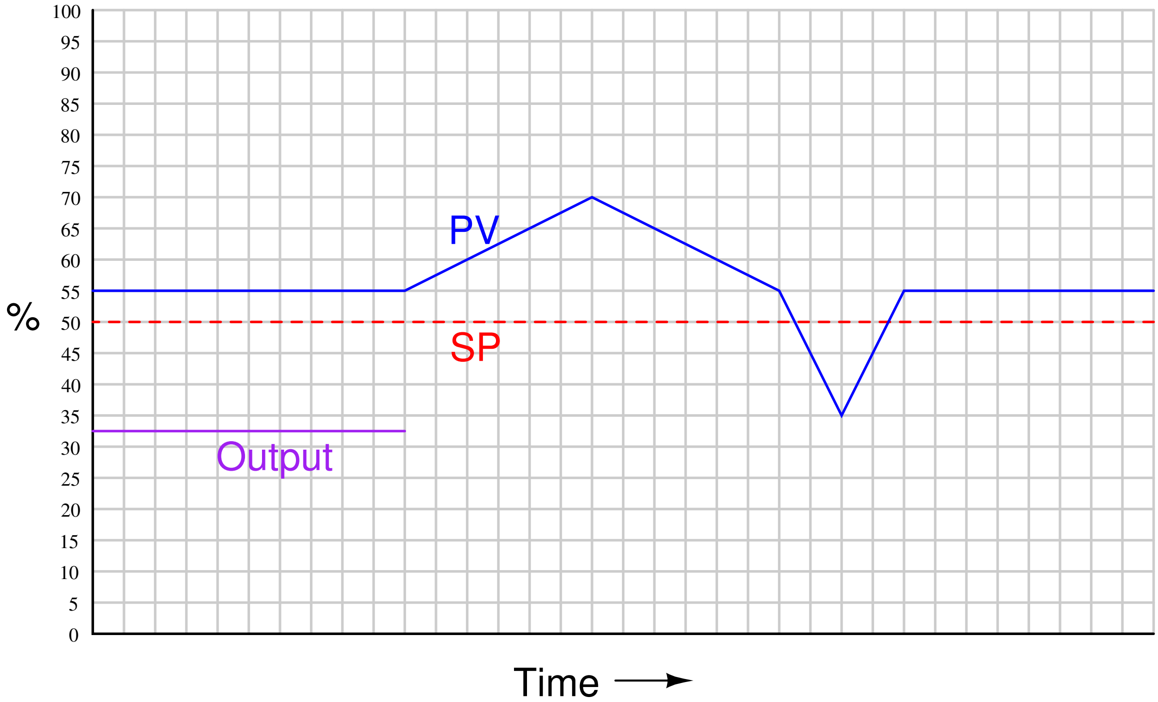
Suggestions for Socratic discussion

- Explain how it is possible to sketch an output trend without knowing the setpoint or bias values for this controller.

file i01500

Oppgave 30

Qualitatively graph the response of a proportional-only controller over time to the following changes in process variable:

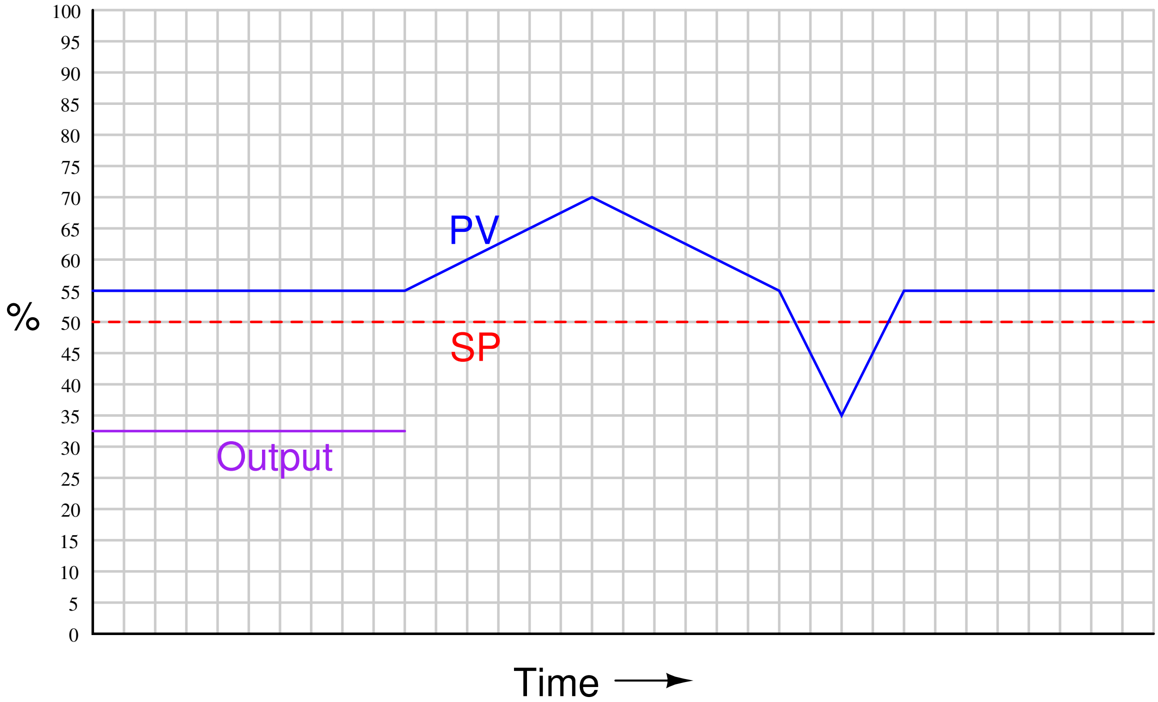


Assume *reverse* control action.

file i01536

Oppgave 31

Qualitatively graph the response of an hypothetical derivative-only controller over time to the following changes in process variable:

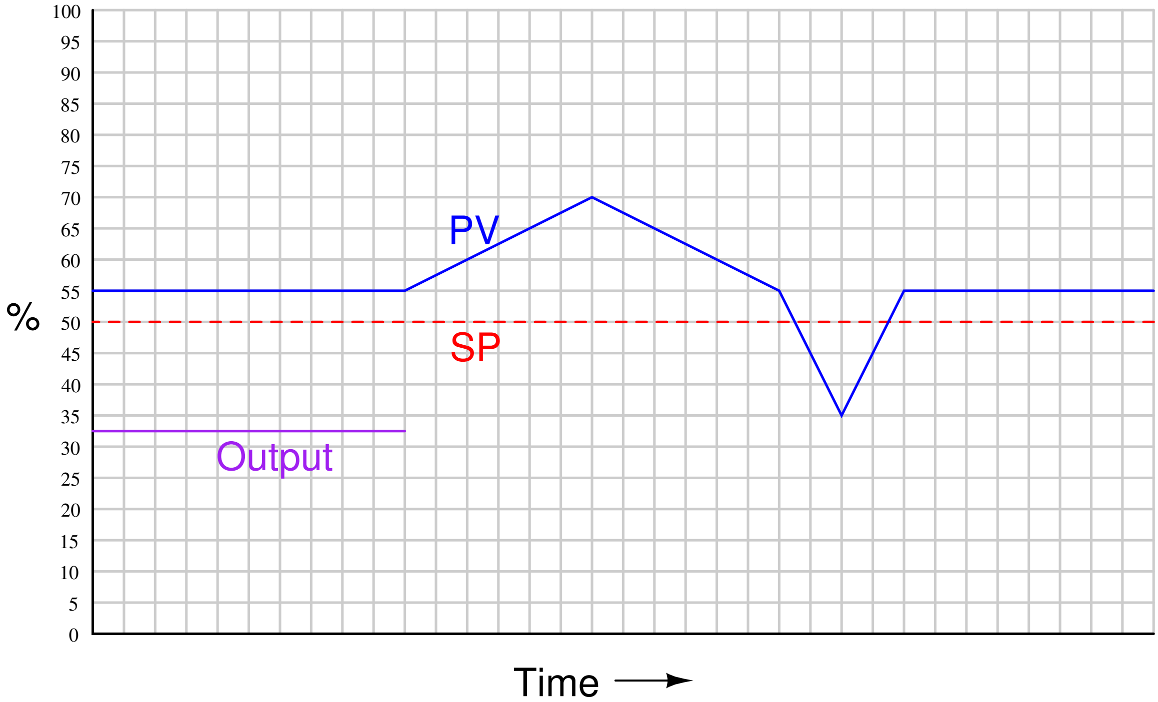


Assume *reverse* control action.

file i01537

Oppgave 32

Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:

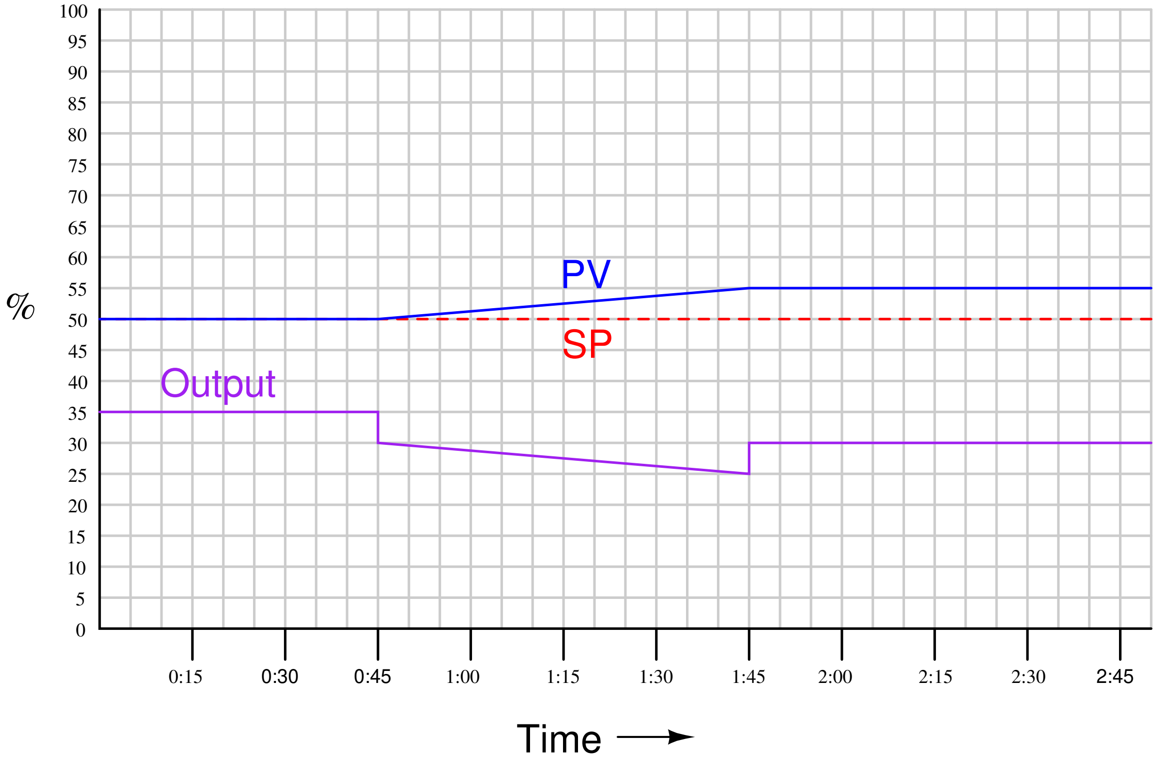


Assume *reverse* control action.

file i01540

Oppgave 33

Shown here is the response of a proportional+derivative controller to a ramping process variable (with a constant setpoint). Calculate the controller's proportional and derivative constant settings, based on what you see in the graph. Also, determine whether this controller is direct or reverse acting, and mark the features of the output plot corresponding to proportional action and to derivative action.

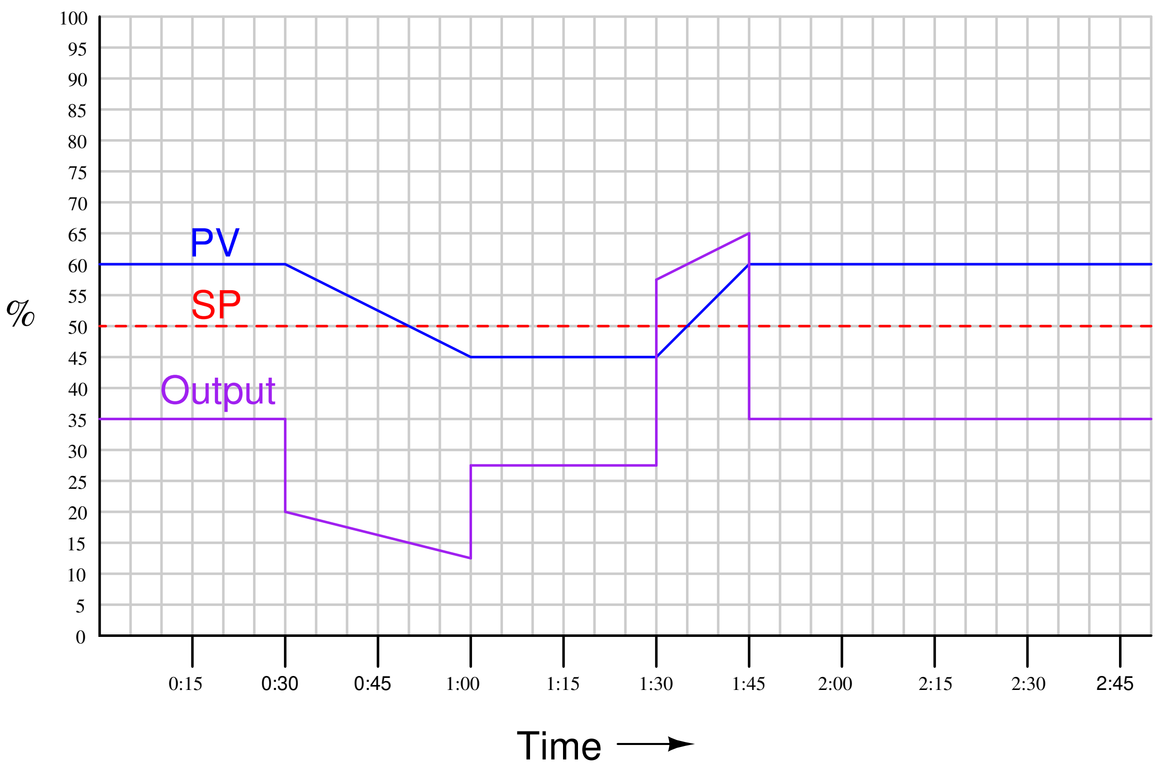


The time scale on the chart is minutes:seconds.

file i01543

Oppgave 34

Shown here is the response of a proportional+derivative controller to a ramping process variable (with a constant setpoint). Calculate the controller's proportional and derivative constant settings, based on what you see in the graph. Also, determine whether this controller is direct or reverse acting, and mark the features of the output plot corresponding to proportional action and to derivative action.



The time scale on the chart is minutes:seconds, and the P+D algorithm is as follows:

$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

Where,

m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (SP−PV or PV−SP)
τ_d = Derivative time constant
b = Bias

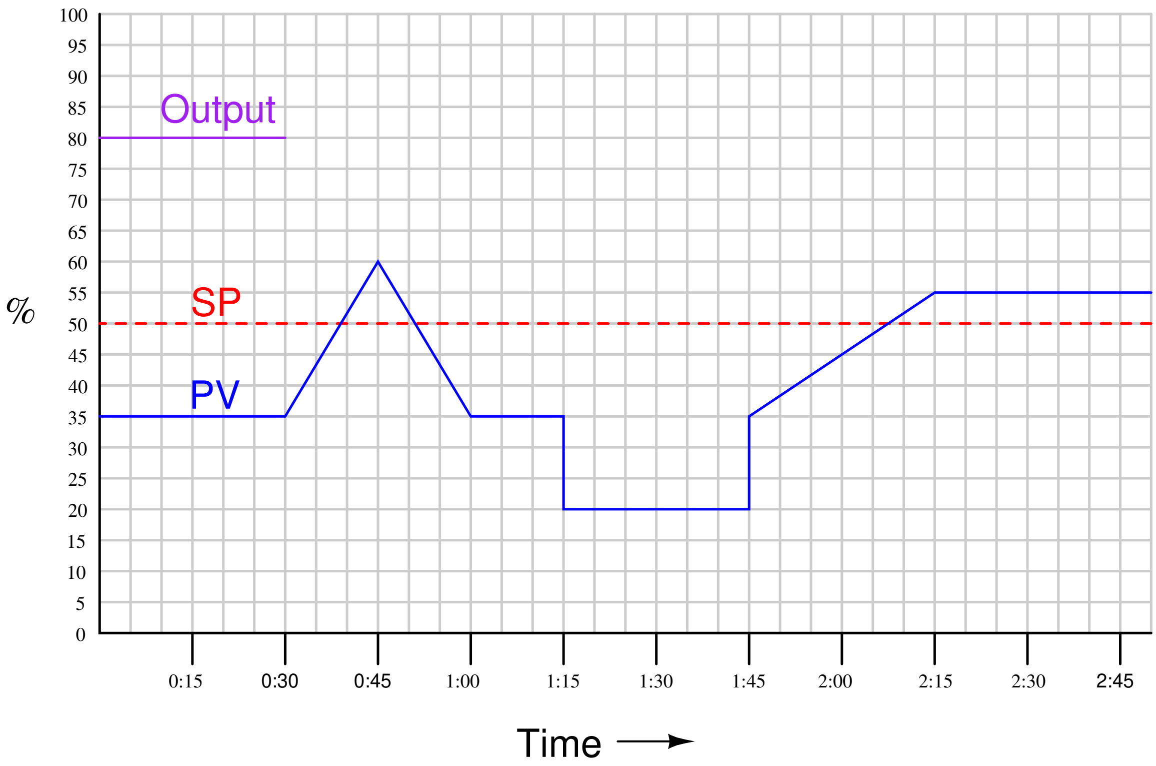
Also, determine the gain and derivative constant values if you were told the PD algorithm were this instead:

$$m = K_p e + \tau_d \frac{de}{dt} + b$$

file i01544

Oppgave 35

Graph the response of a proportional+derivative controller to the following input conditions, assuming a proportional band of 200% and a derivative constant of 15 seconds. The controller's action is *reverse*, and the algorithm it follows is shown below the graph:



The time scale on the chart is minutes:seconds, and the P+D algorithm is as follows:

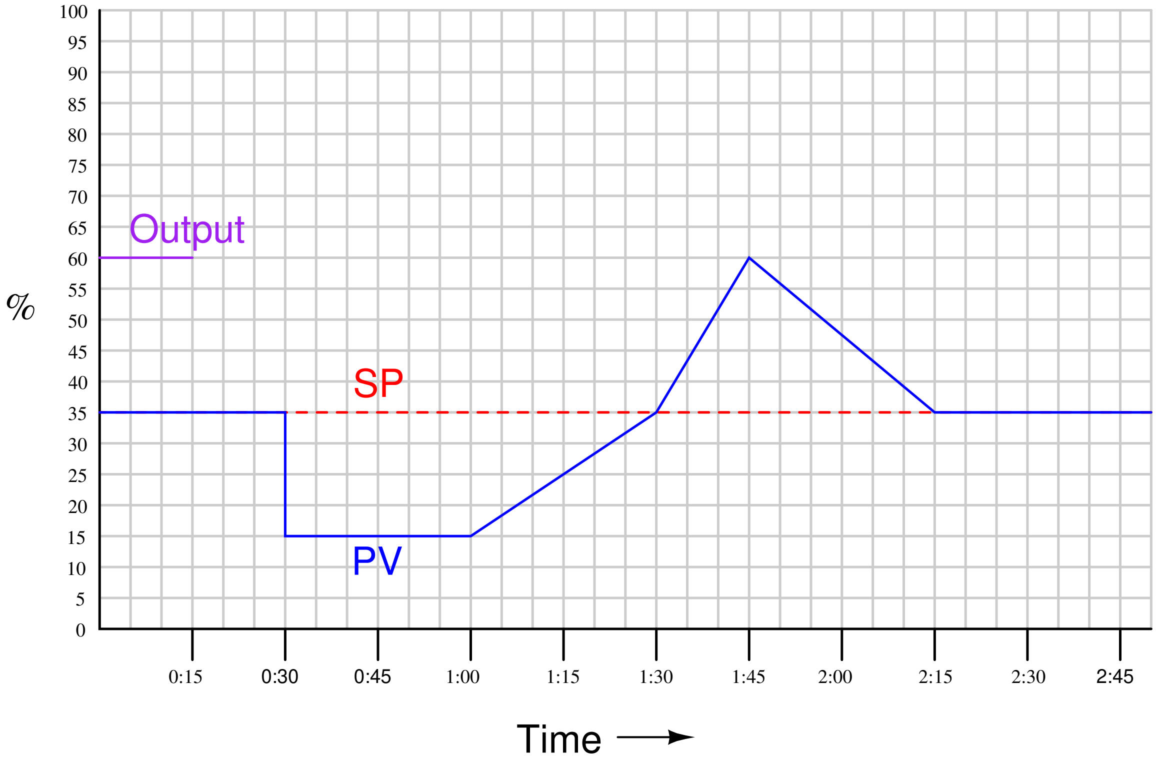
$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

Where,
m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (SP−PV)
τ_d = Derivative time constant
b = Bias

file i01546

Oppgave 36

Graph *just the derivative response* a proportional+derivative controller to the following input conditions, assuming a proportional band of 500% and a derivative constant of 1.5 minutes. The controller's action is *direct*, and the algorithm it follows is shown below the graph:



The time scale on the chart is minutes:seconds, and the P+D algorithm is as follows:

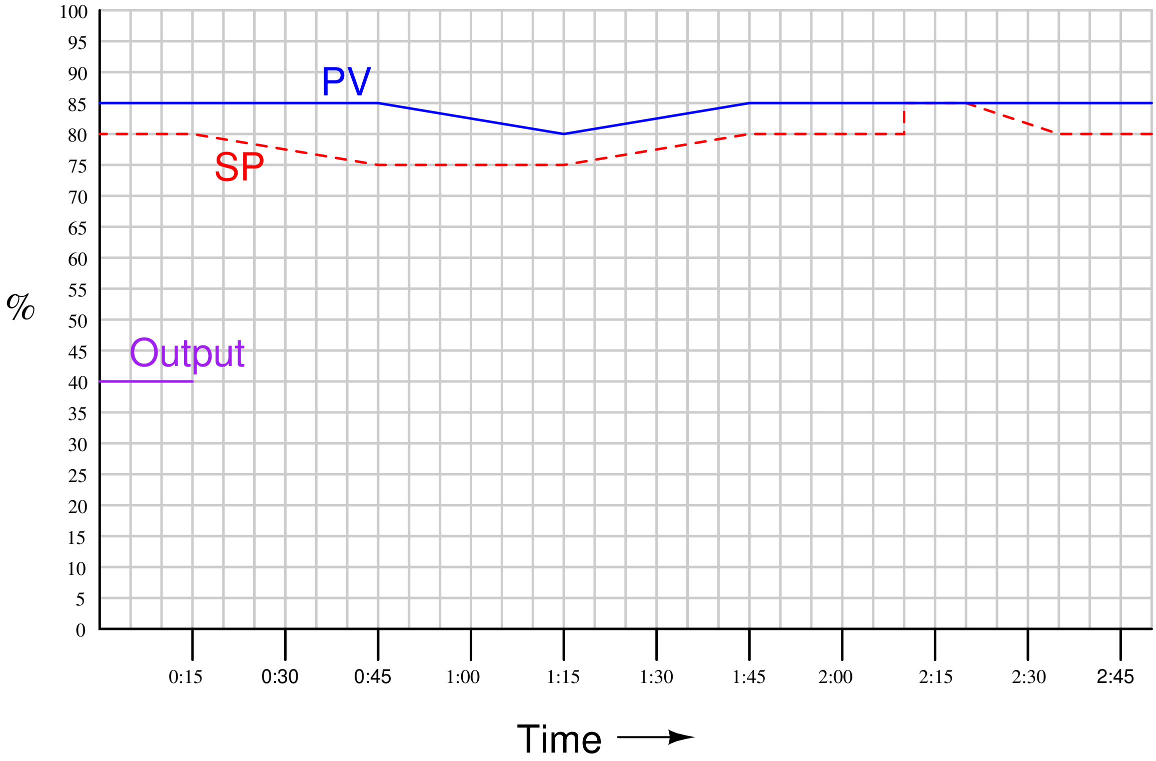
$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

Where,
m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (PV−SP)
τ_d = Derivative time constant
b = Bias

file i01547

Oppgave 37

Graph *just the derivative response* a proportional+derivative controller to the following input conditions, assuming a proportional band of 250% and a derivative constant of 4 minutes. The controller's action is *reverse*, and the algorithm it follows is shown below the graph:



The time scale on the chart is minutes:seconds, and the P+D algorithm is as follows:

$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

Where,

m = Controller output (manipulated variable)

K_p = Gain

e = Error signal (SP$-$PV)

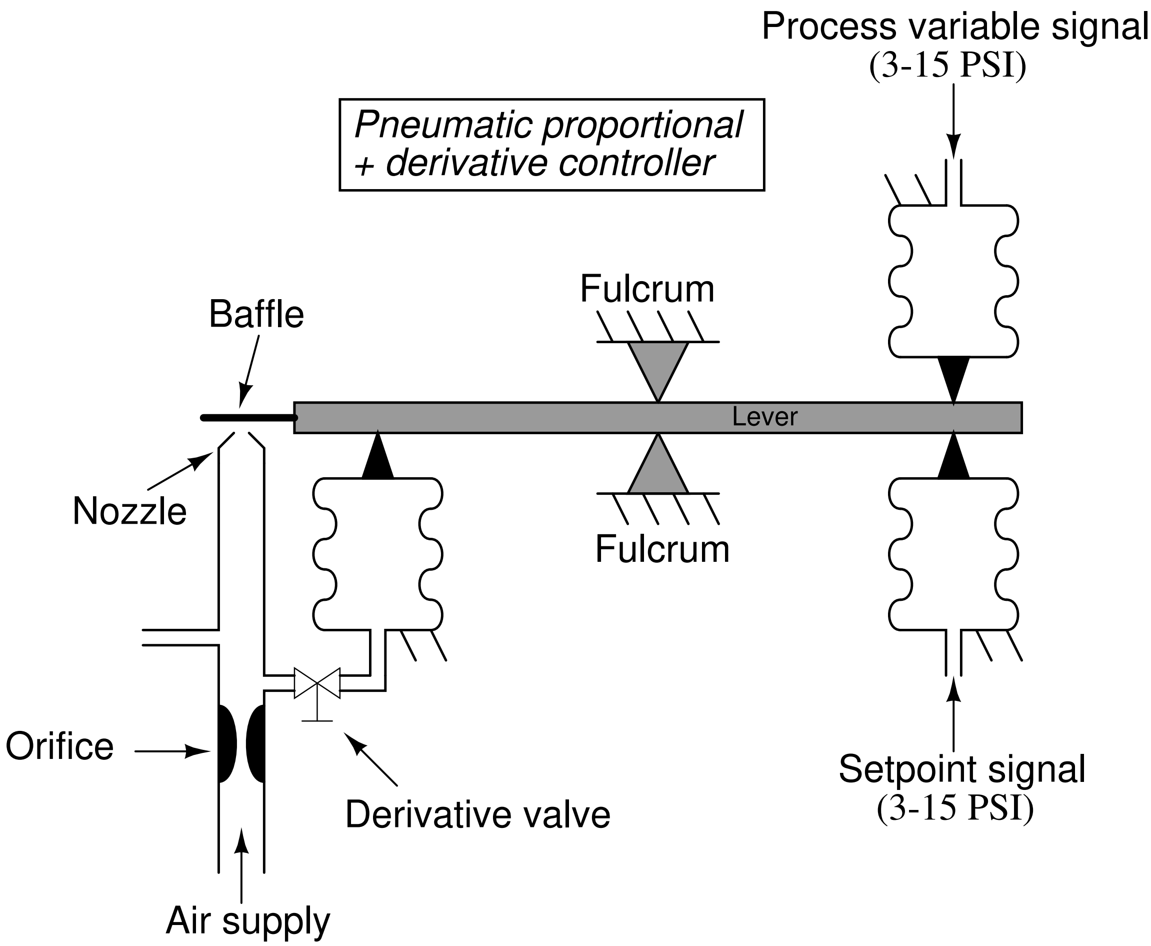
τ_d = Derivative time constant

b = Bias

file i01548

Oppgave 38

Explain what you would have to do to this pneumatic controller mechanism to *increase* the derivative time constant (τ_d) and also explain why it works:



file i01551

Oppgave 39

Digital controllers calculate the time-derivative of an input signal by sampling that signal (analog-to-digital conversion) repeatedly and performing mathematical analysis on it between samples. Here is a "pseudocode" algorithm that a digital computer might use in computing an input signal's rate-of-change over time:

Pseudocode listing

```
LOOP
  SET x = input   // (Sample input signal and set 'x' equal to that value)
  SET t = system_time   // (Sample system clock and set 't' equal to that value)

  SET delta_x = x - last_x
  SET delta_t = t - last_t

  SET rate = delta_x ÷ delta_t   // (Calculate the rate of change Δx/Δt)

  SET last_x = x   // (Set 'last_x' equal to the current value of 'x')
  SET last_t = t   // (Set 'last_t' equal to the current value of 't')
ENDLOOP
```

Explain how this algorithm works, calculating rate of change based on successive samples of the input variable and of the system clock (time).

Suggestions for Socratic discussion

- Suppose the order of the last two SET instructions were reversed. How will this change affect the operation of the program, if at all?
- Suppose the "t = system_time" SET instruction is deleted from the program. How will this change affect the operation of the program, if at all?
- Suppose the microprocessor were upgraded such that this program executed at twice its normal speed (i.e. it would "loop" through the algorithm twice as frequently as before). How will this change affect the calculation of rates of change, if at all?

file i01557

Oppgave 40

Suppose an integral-only (I-only) loop controller receives a process variable signal of 44%, a setpoint value of 50%, and is configured for reverse action. Assuming an integral coefficient of 1.6 repeats per minute and a constant error (i.e. PV and SP both remain constant over time), calculate the amount of time required for the output of this controller to change by 10%. Also, calculate how long it will take for the output to change by the same amount as the error (PV − SP).

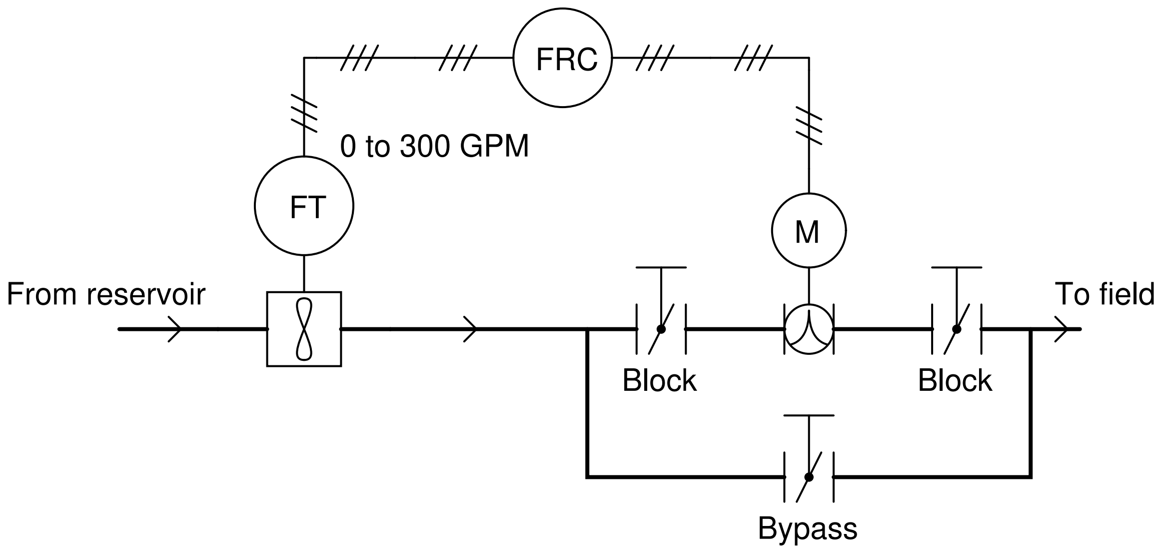
Suggestions for Socratic discussion

- In a real process, will the error hold constant as we are assuming it does in this question? Why or why not?
- Express the integration rate of this controller in units of *minutes per repeat*.
- Express the integration rate of this controller in units of *seconds per repeat*.
- Express the integration rate of this controller in units of *repeats per second*.

file i01583

Oppgave 41

Shown here is a simple flow control system for distributing water from an irrigation reservoir to a crop field at a controlled flow rate. The flowmeter is ranged from 0 to 300 gallons per minute:



The flow-recording controller (FRC) is a proportional-only unit with the following algorithm:

$$m = K_p(\mathrm{SP} - \mathrm{PV}) + 50\%$$

Where,
m = Manipulated variable (output)
K_p = Controller gain
SP = Setpoint
PV = Process Variable (water flow)

One day the controller is found to be working perfectly: the setpoint is set to 180 GPM, and the process variable reads exactly the same: 180 GPM. The controller's output is seen to be 50% in this condition. Then, the operator adjusts the setpoint to a new flow rate: 250 GPM. As expected, the controller's output automatically increases and the valve opens up to allow more flow through the pipe. As the flow rate approaches the new setpoint of 250 GPM, the valve begins to close off. This makes the flow rate approach setpoint slower and slower, like a capacitor slowly charging to a new voltage value over time. However, the operator notices something unexpected: the flow rate never makes it all the way to the new setpoint value of 250 GPM. Instead, it stabilizes at about 239 GPM and does not increase beyond that.

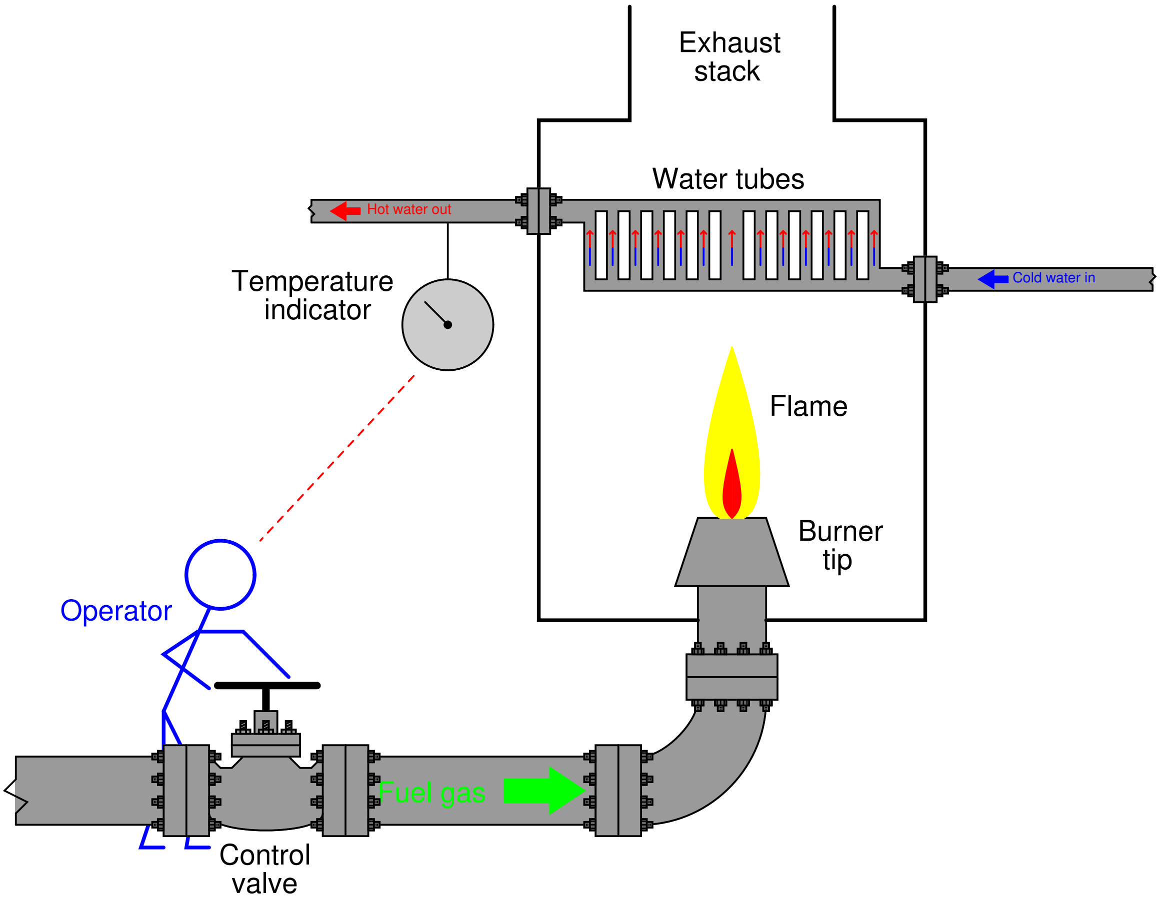
Confused as to why the controller does not reach the new setpoint of 250 GPM like it did the old setpoint of 180 GPM, the operator calls an instrument technician to investigate. "What is wrong with this controller?" the operator asks the technician. "It stops increasing the flow rate shy of its new setpoint." After a moment of investigation, the technician notices that this is a proportional-only controller. Seeing this, the technician just smiles and proceeds to explain to the operator why the controller *never will* reach the new setpoint like it did at 180 GPM. For that matter, it cannot perfectly reach any setpoint less than 180 GPM either! If it perfectly attained setpoint at 180 GPM, then that is the *only* setpoint value it will.

Explain, in your own words, why this is true.

file i01584

Oppgave 42

A human operator is charged with controlling the temperature of water in a gas-fired water heater. The "setpoint" (SP) is an ideal water temperature value held in the operator's mind, and the "process variable" (PV) of course is whatever the temperature gauge indicates:

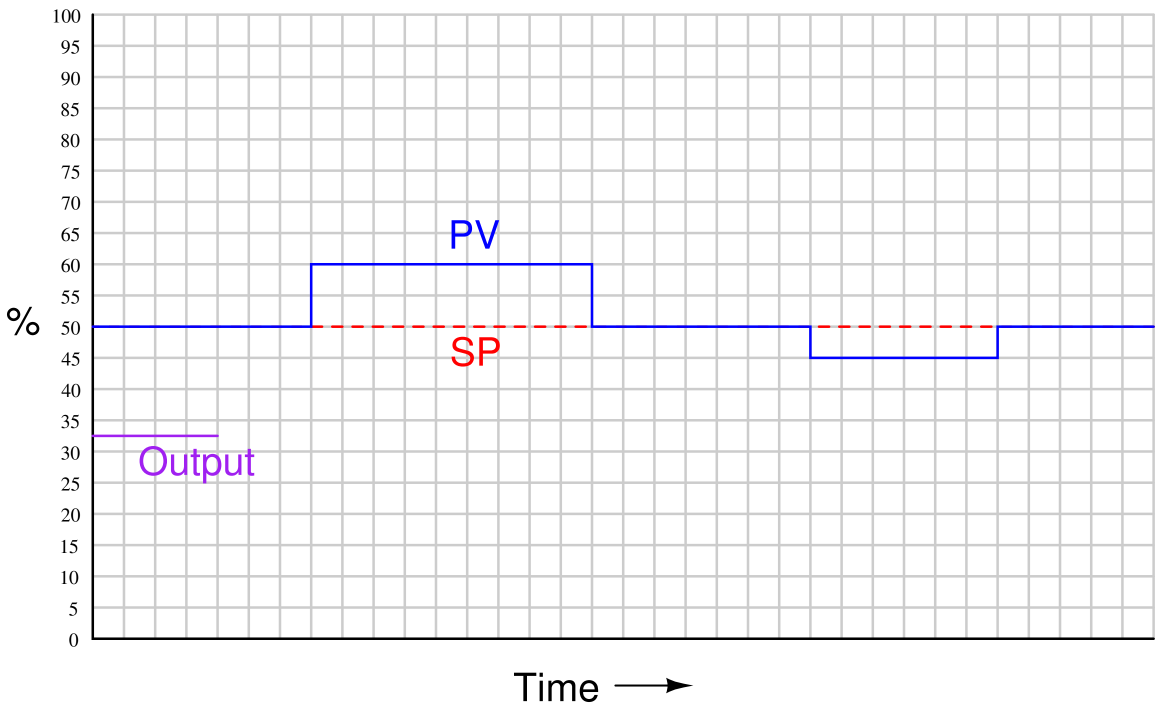


Imagine a situation where the water temperature is exactly at setpoint. The operator is standing next to the gas control valve, bored, because there is nothing to do. Then suddenly there is a demand for more hot water. As the water flow through the heater increases, the outlet temperature begins to fall. Noticing this decrease in PV, the operator opens the fuel valve by a proportional amount. This causes the temperature to slowly climb back up to setpoint. At some point in time, though, the water temperature settles at an equilibrium value that is less than setpoint. The operator recognizes this and begins to become impatient, opening the valve a little bit more with each minute of time that goes by. Eventually, after several additional "opening" motions of the valve, the water temperature rises to the setpoint value and stabilizes there. Happy with the new situation, the operator resumes his previous condition of boredom.

Now let us examine the operator's action in terms of how an automatic controller would handle the situation. The operator's initial response to open the valve proportional to the amount of temperature decrease can be easily accounted for by *proportional* control action – the name reveals it all. But the operator's actions after noticing the PV settling at a temperature less than setpoint – when he begins to feel impatient and opens the valve a little more each minute – is definitely not characteristic of proportional control. In fact, this action goes *against* what proportional control would do, by continuing to *increase* the valve's opening little by little even as temperature continues to *rise* to setpoint.
What the operator did was to examine how much error there was left between SP and PV, and also how long this condition of error persisted, and move the control valve accordingly. Explain how the operator's action in doing this could be described as *integration* in the calculus sense of the word.
file i01587

Oppgave 43

Qualitatively graph the response of a proportional-only controller over time to the following changes in process variable:



Assume *reverse* control action.

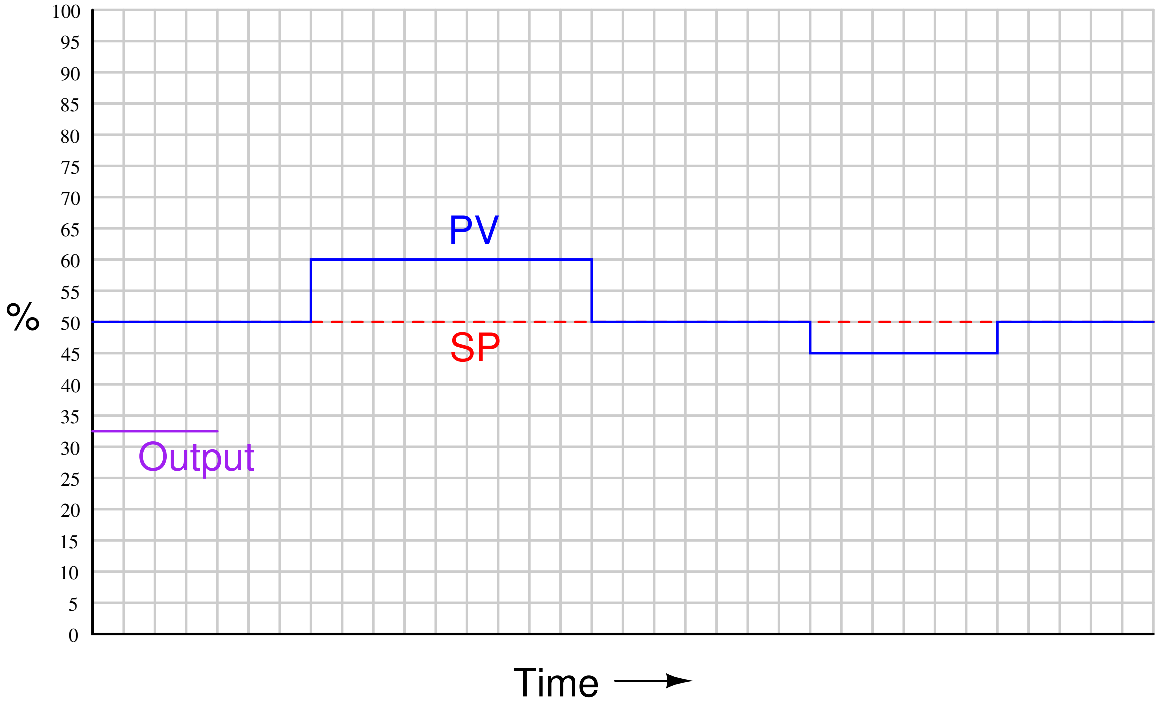
Suggestions for Socratic discussion

- What defines a "reverse" acting controller, in contrast to a "direct" acting controller?
- Explain why it would be highly unusual to see a trend like this in a real, working process loop. Why is this trend unrealistic, assuming a working process where all components are functioning properly?
- Given that this trend is unrealistic, why is it something we're studying? In other words, what value does a "toy" trend like this have for us?

file i01593

Oppgave 44

Qualitatively graph the response of a controller having *both proportional and integral* modes over time to the following changes in process variable, marking the features of the output plot corresponding to proportional action (P) and to integral action (I).



Assume *reverse* control action.

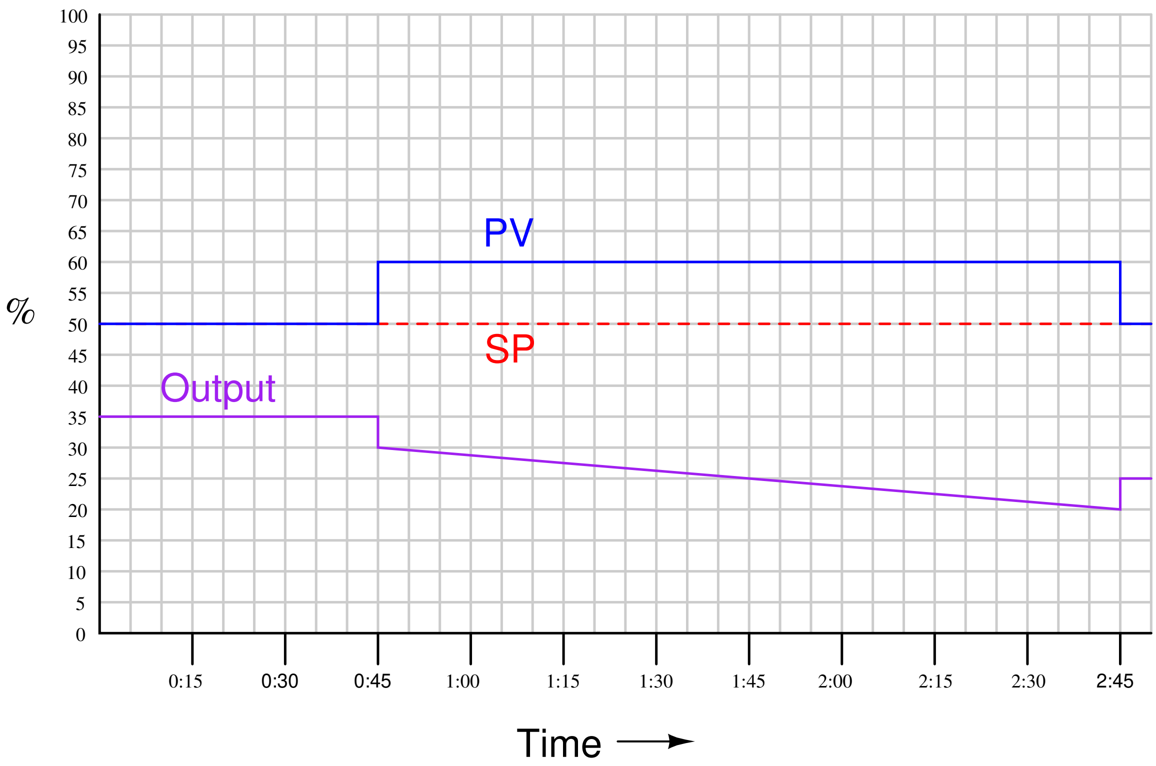
Suggestions for Socratic discussion

- A useful problem-solving strategy is to sketch the P and I actions separately (with their own trends) before combining them to make one final output trend. A subsection in the *Lessons In Industrial Instrumentation* textbook entitled "Note to Students Regarding Quantitative Graphing" illustrates this problem-solving technique.
- Why should any controller combine proportional and integral actions? What is wrong with just using one or the other action alone?

file i01595

Oppgave 45

Shown here is the response of a proportional+integral controller to a step-change in process variable (with a constant setpoint). Calculate the controller's proportional and integral constant settings, based on what you see in the graph. Also, determine whether this controller is direct or reverse acting, and mark the features of the output plot corresponding to proportional action and to integral action.



The time scale on the chart is minutes:seconds, and the PI algorithm is as follows:

$$m = K_p \left(e + \frac{1}{\tau_i} \int e \, dt \right) + b$$

Where,
m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (SP$-$PV or PV$-$SP)
τ_i = Integral time constant
b = Bias

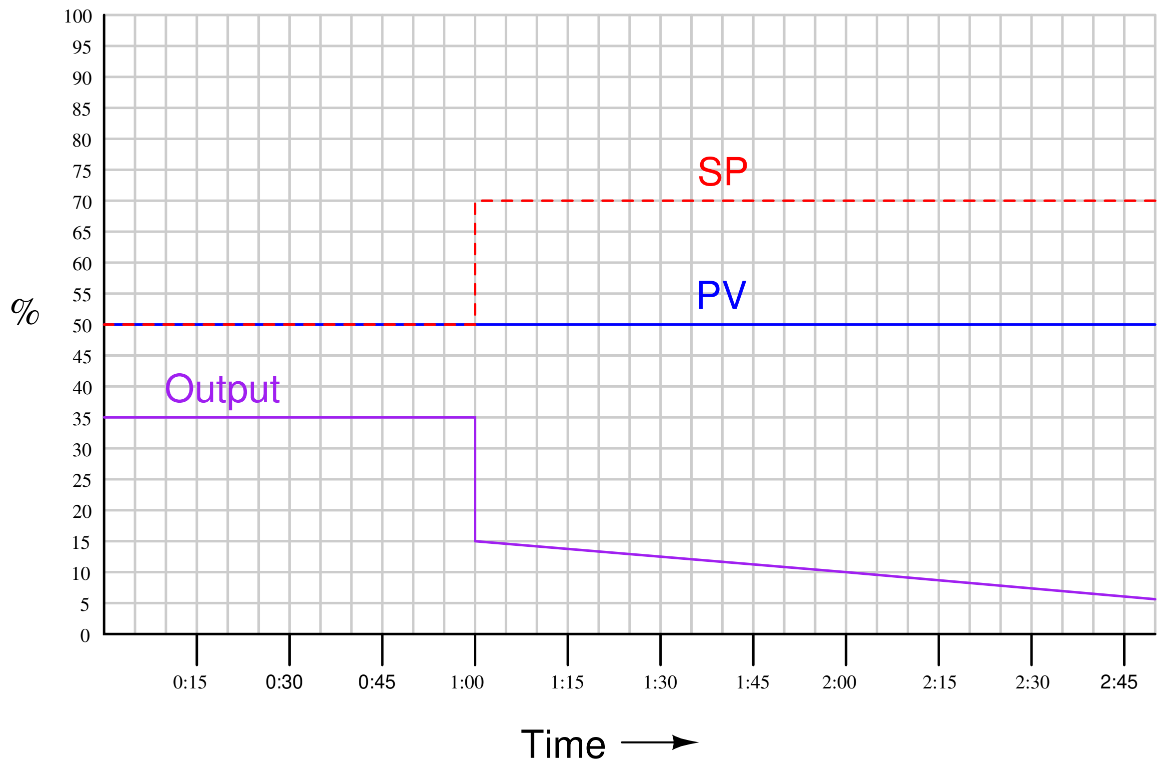
Suggestions for Socratic discussion

- When analyzing the output trend of a PI controller, the definition of the reset time constant as being "the number of minutes required to per repeat proportional action" is most useful. Identify the magnitude of proportional action in response to the PV step-change, and then explain how this value is helpful in identifying τ_i.
- Re-sketch what the output trend would look like if this controller's gain value (K_p) were doubled.
- Re-sketch what the output trend would look like if this controller's integral time constant (τ_i) were doubled.
- Re-sketch what the output trend would look like if this controller's bias value (b) were increased.

file i01601

Oppgave 46

Shown here is the response of a proportional+integral controller to a step-change in setpoint (with a constant process variable). Calculate the controller's proportional and integral constant settings, based on what you see in the graph. Express your answer for the integral constant both in units of "repeats per minute" and "minutes per repeat." Also, determine whether this controller is direct or reverse acting, and mark the features of the output plot corresponding to proportional action and to integral action.



The time scale on the chart is minutes:seconds, and the PI algorithm is as follows:

$$m = K_p \left(e + \frac{1}{\tau_i} \int e \, dt \right) + b$$

Where,
m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (SP−PV or PV−SP)
τ_i = Integral time constant
b = Bias

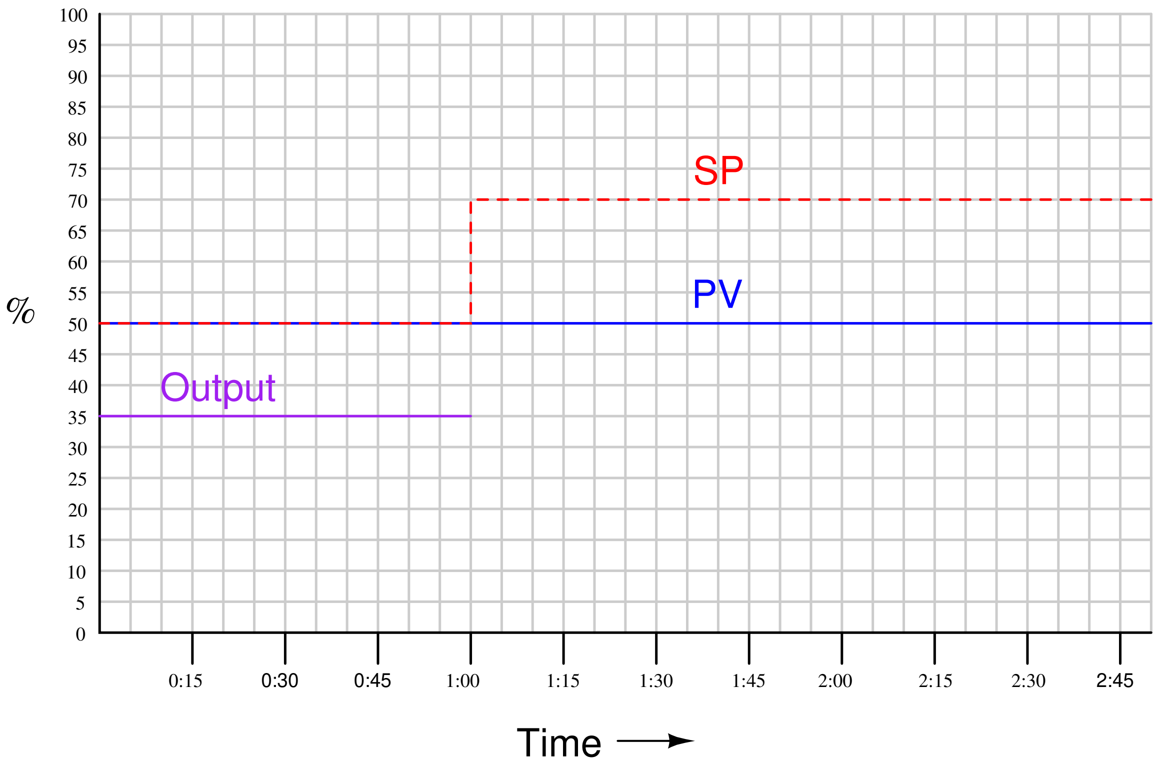
Suggestions for Socratic discussion

- When analyzing the output trend of a PI controller, the definition of the reset time constant as being "the number of minutes required to per repeat proportional action" is most useful. Identify the magnitude of proportional action in response to the PV step-change, and then explain how this value is helpful in identifying τ_i.
- If you really saw this type of response on a process controller trend (chart recorder), what might you suspect about the system? Hint: this type of trend is definitely *not* normal for a properly functioning control system!

file i01602

Oppgave 47

Graph the response of a proportional+integral controller to the following input conditions, assuming a proportional band of 100% and an integral constant of 8 minutes per repeat. The controller's action is *direct*, and the algorithm it follows is shown below the graph:



The time scale on the chart is minutes:seconds, and the PI algorithm is as follows:

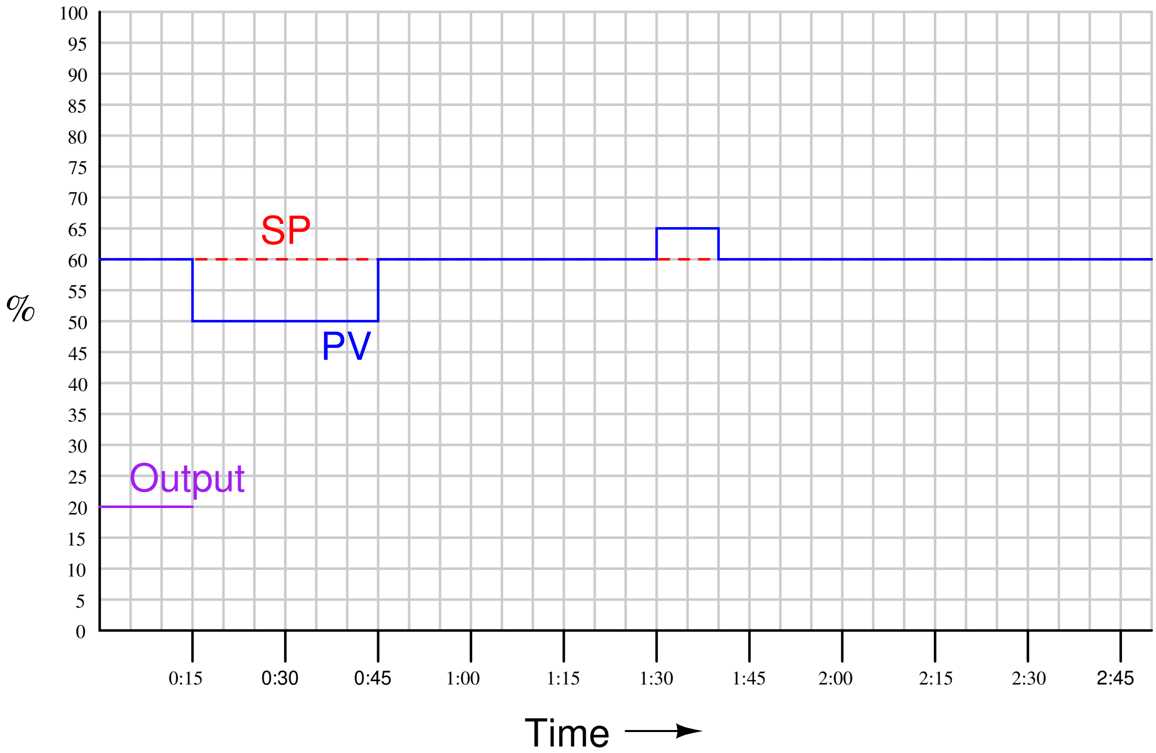
$$m = K_p \left(e + \frac{1}{\tau_i} \int e \, dt \right) + b$$

Where,
m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (PV−SP)
τ_i = Integral time constant
b = Bias

file i01603

Oppgave 48

Graph the response of a proportional+integral controller with a proportional band of 50% and an integral constant of 1.25 minutes per repeat to the following input conditions. Assume a control action that is *reverse-acting*:



The time scale on the chart is minutes:seconds, and the PI algorithm is as follows:

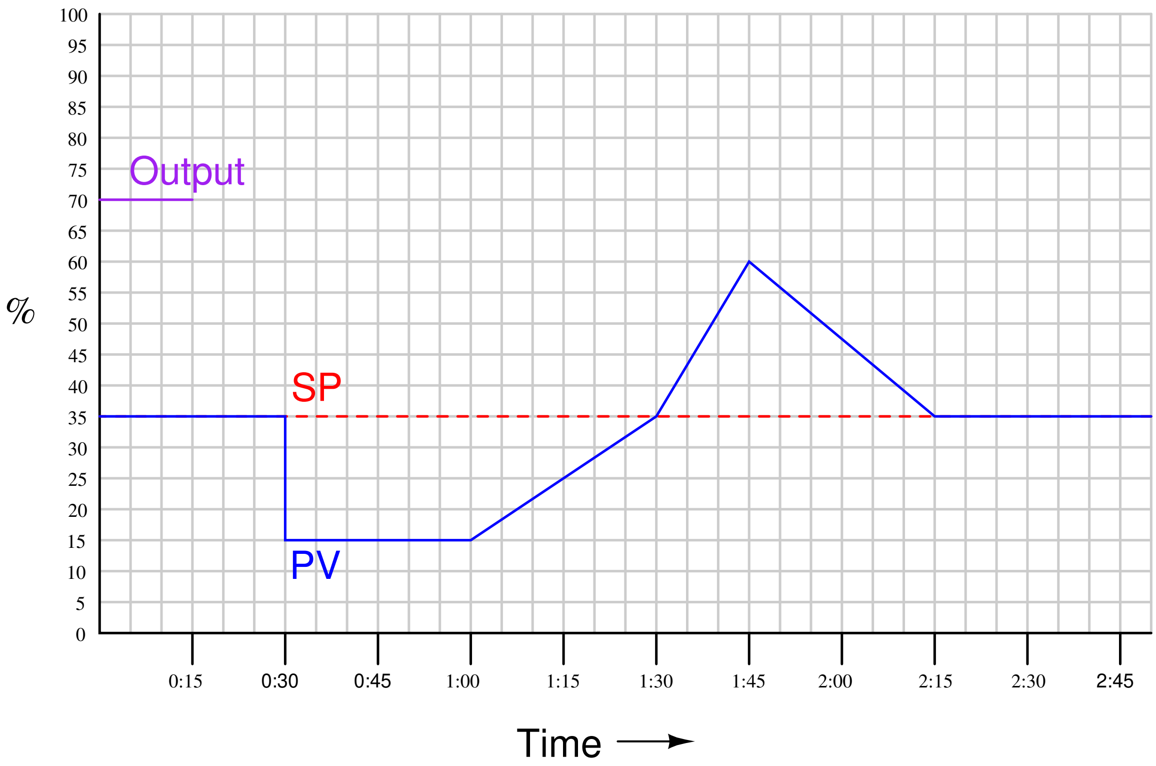
$$m = K_p \left(e + \frac{1}{\tau_i} \int e \, dt \right) + b$$

Where,
m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (SP$-$PV)
τ_i = Integral time constant
b = Bias

file i01604

Oppgave 49

Graph just the integral response of a *proportional+integral* controller with a proportional band of 75% and an integral constant of 2 minutes per repeat to the following input conditions. Assume a control action that is *direct-acting*:



The time scale on the chart is minutes:seconds, and the PI algorithm is as follows:

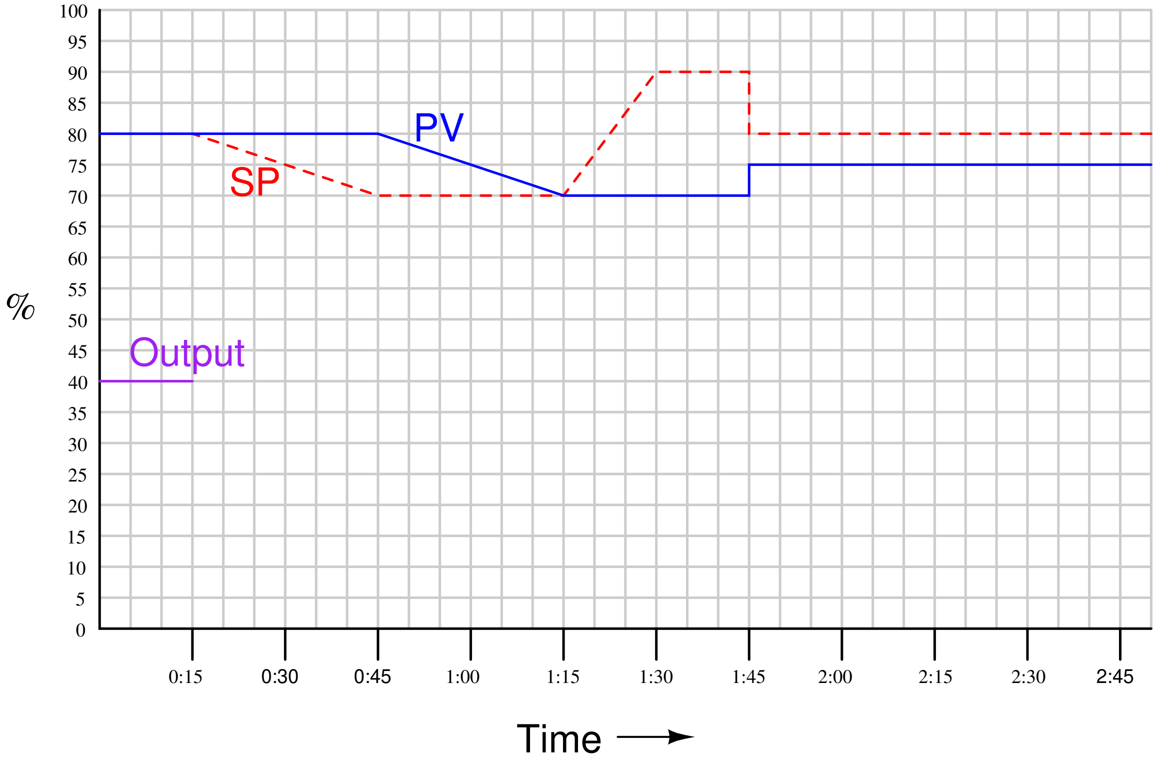
$$m = K_p \left(e + \frac{1}{\tau_i} \int e \, dt \right) + b$$

Where,
m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (PV−SP)
τ_i = Integral time constant
b = Bias

file i01606

Oppgave 50

Graph just the integral response of a *proportional+integral* controller with a proportional band of 50% and an integral constant of 4 minutes per repeat to the following input conditions. Assume a control action that is *reverse-acting*:



The time scale on the chart is minutes:seconds, and the PI algorithm is as follows:

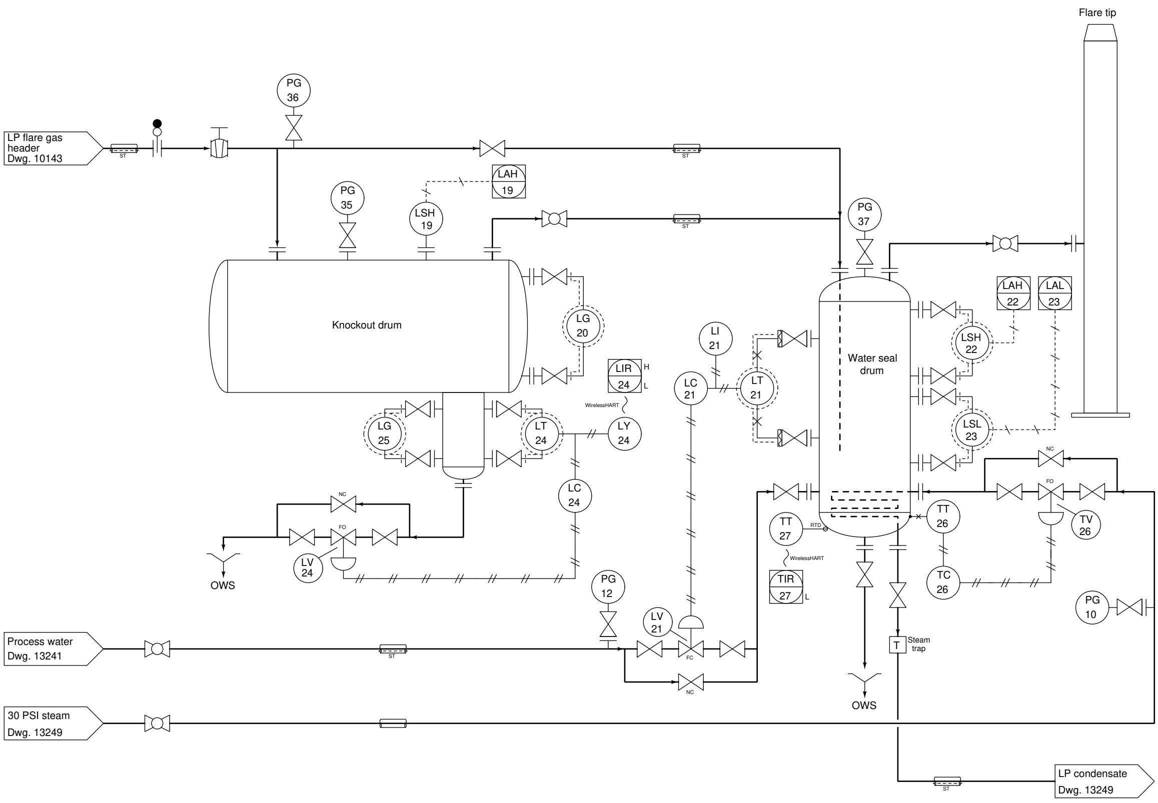
$$m = K_p \left(e + \frac{1}{\tau_i} \int e \, dt \right) + b$$

Where,
m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (SP$-$PV)
τ_i = Integral time constant
b = Bias

file i01607

Oppgave 51

Examine this process, where the temperature of water sitting at the bottom of a "water seal drum" vessel is regulated by passing hot steam through a heating tube immersed in the water:



Suppose that one day the 30 PSI steam supply boiler shuts down, ceasing the flow of steam to the TV-26. With no supply of steam to heat the seal drum, the water begins to cool down. What will controller TC-26 do in response to this event, assuming it is a proportional+integral (P+I) controller?

Now suppose that the steam "outage" lasts for a very long time. How will the controller's proportional and integral modes respond if left in the automatic mode the entire time? Is there a way to avoid this problem?

Suggestions for Socratic discussion

- Examining the diagram, what do you suppose the function of the water seal drum is, in the larger context of the flare process?

- Which is the worst-case scenario: the water in the seal drum becoming too cold or becoming too hot? How can we tell based on details found in this diagram?
- Suppose operations personnel approached you to install instrumentation to measure the total quantity of substance released to the flare each month, for emissions monitoring purposes. For those who have studied flowmeters, identify at least one practical solution to this problem, including the specific types of technologies used to sense the vapors going to the flare.

file i01608

Oppgave 52

A P+I controller is used to control the flow of a liquid through a pipe. The flow control valve, however, is undersized, and will not allow the flow to achieve a value greater than 70% of measurement range. What will the controller do if given a setpoint of 80%? Be as specific as you can in your answer.

What will happen if the setpoint is returned to some achievable value like 50% after it has been left at 80% for a long time?

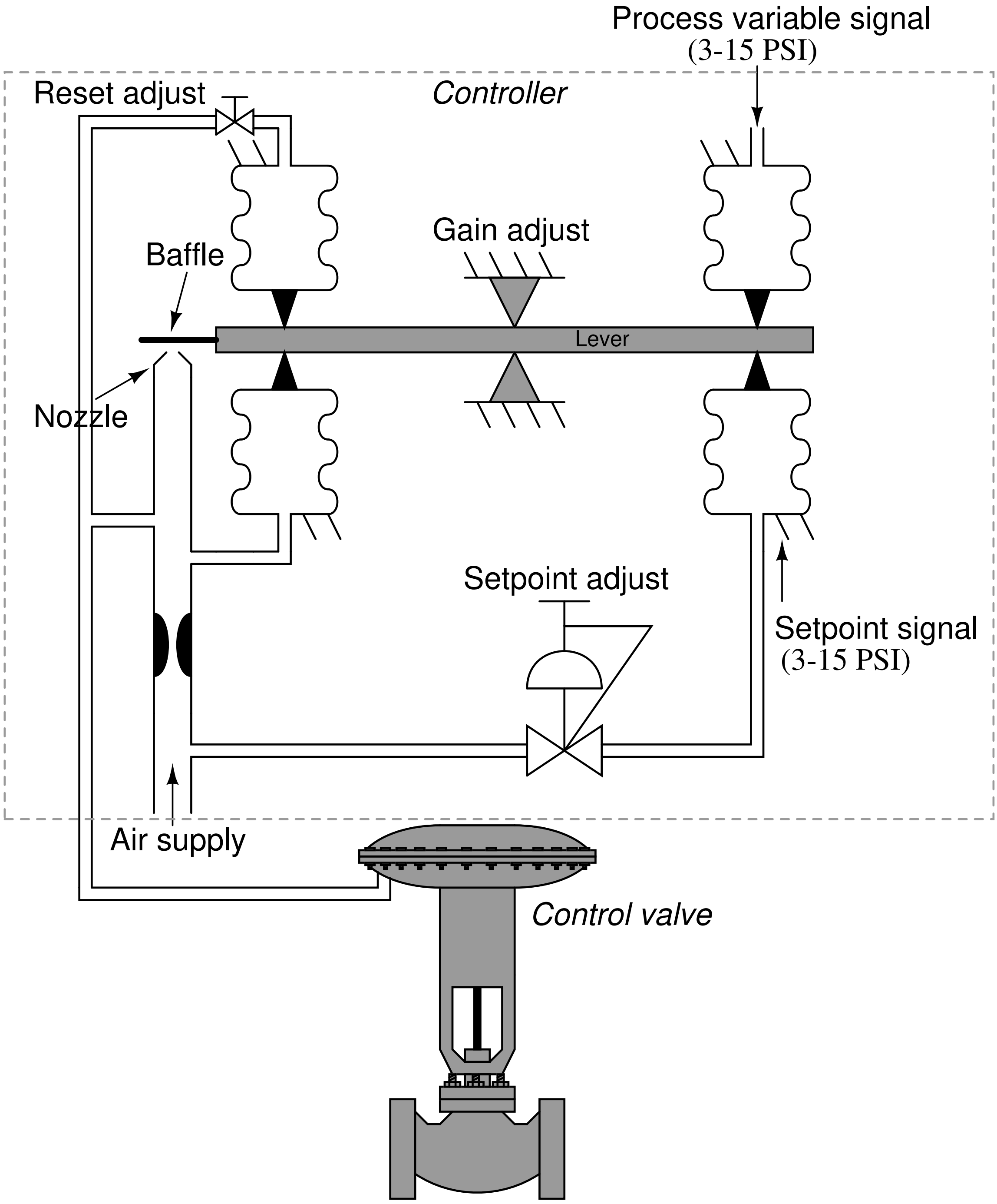
Suggestions for Socratic discussion

- How do you suppose a problem such as this manifest on a process trend (recording)? Are there any revealing clues on a trend to indicate such a problem exists?

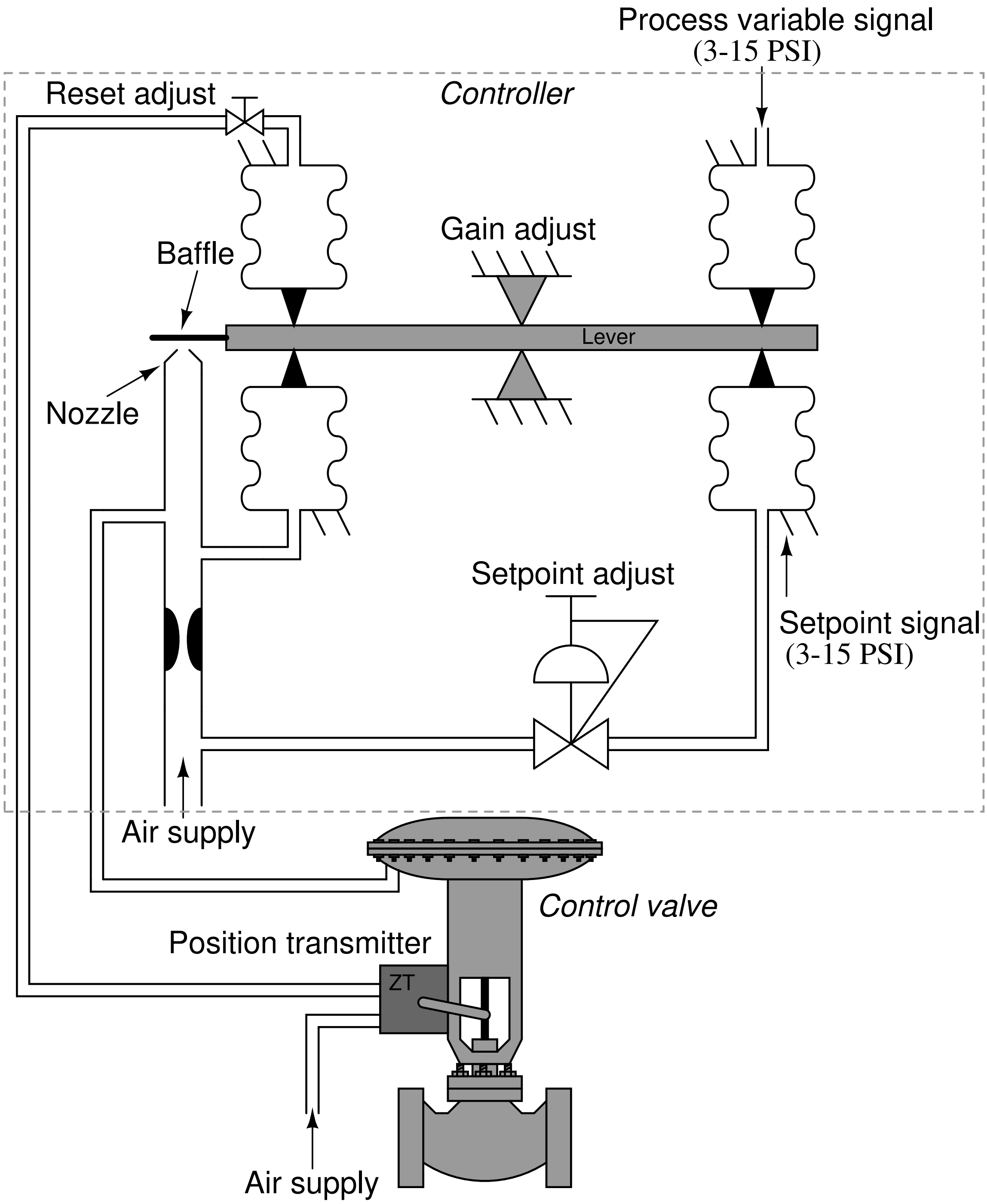
file i01609

Oppgave 53

Here is a pneumatic P+I controller mechanism, with reset (integral) action implemented in the standard way:


Process variable signal
(3-15 PSI)
Reset adjust
Controller
Gain adjust
Baffle
Lever
Nozzle
Setpoint adjust
Setpoint signal
(3-15 PSI)
Air supply
Control valve

This is called "internal reset" action. There is, however, an alternative method for implementing reset action in a pneumatic controller, and it involves the addition of a pneumatic position transmitter on the valve to signal valve stem position to the controller. This alternative method is called "external reset:"



The benefit of a controller with external reset is that the reset action has less of a tendency to "wind up." Explain why this is.

Hint: imagine the valve is equipped with a minimum-travel "stop" so that its furthest-closed position is 15%. Stops are sometimes used on flow-control valves where a certain minimum flow rate must be maintained for process safety reasons (e.g. flow control for process fluid in a combustion heater where zero flow might result in overheated and ruptured tubes). How would external reset help prevent the controller from winding down under certain low-setpoint conditions?

Suggestions for Socratic discussion

- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful "thought experiment" for this system, and how the results of that thought experiment are helpful to answering the question. If you find this system too complex, apply another problem-solving technique: *simplify* the system, then analyze the simpler system.
- How would this external reset scheme work on a control valve with really bad hysteresis (stiction)? Would the loop "cycle" as a normal internal-reset controller driving a sticky valve would exhibit a stick-slip cycle, or not?
- Identify how you could increase the gain of this controller without moving the fulcrum.

file i01610

Oppgave 54

Suppose an aging controller needs to be replaced, and its tuning constants are documented as such:

- Proportional band = 130%
- Reset = 2.7 minutes per repeat

The new controller destined to replace this old unit is also a proportional+integral controller, but its tuning constant units are different. Instead of "proportional band," the K_p constant is labeled as "gain." Instead of "minutes per repeat," the new controller bears the unit of "repeats per second" for its integral constant.
Convert the old tuning constants into the new units, so that when the new controller is installed, it does the same exact job as the old controller. Note: assume the use of the same algorithm type (P+I equation) in both controllers.

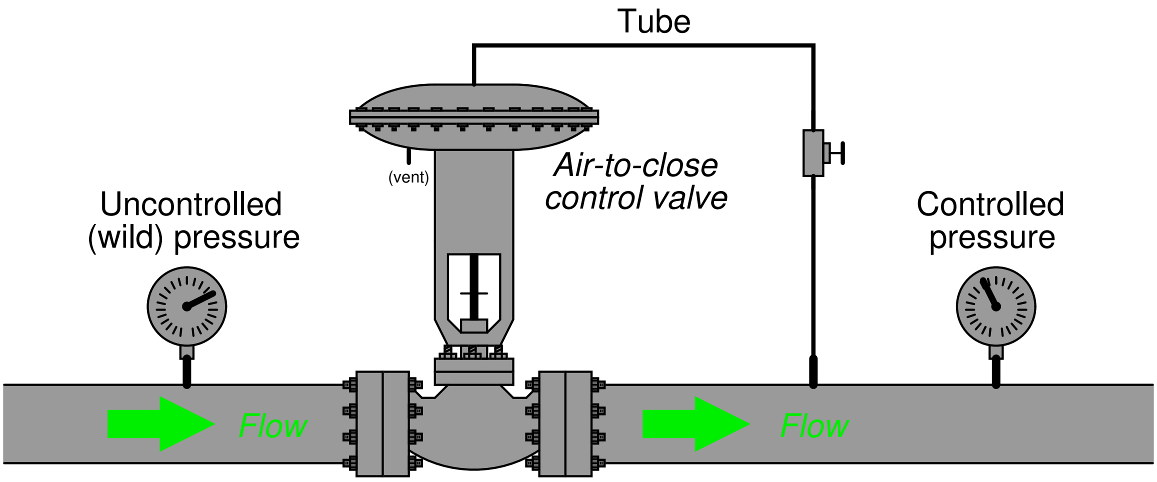
Suggestions for Socratic discussion

- Explain what would happen if the new controller were installed and programmed (by someone who didn't know better) with a gain of 1.30 for proportional action and 2.7 repeats per second for integral action.

file i01612

Oppgave 55

A control valve (all by itself!) may act as a crude proportional controller for controlling pressure of a gas or vapor in a pipe:



Unfortunately, this simple pressure-regulating system has a problem. The downstream pressure is much less than it should be, despite this system working just fine several days ago. Assume the control valve is a stem-guided, single-ported globe valve with an actuator ranged from 6 to 30 PSI. The setpoint for this system is 12 PSI, and that the temperature of the gas inside the pipe is 94 ^{o}F.

Identify the likelihood of each specified fault for this pressure-regulating system. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this system.

Fault	**Possible**	**Impossible**
Control valve stem jammed by metal debris between plug and seat		
Control valve stem jammed by metal debris between plug and bonnet		
Block valve downstream of control valve closed		
Block valve upstream of control valve closed		
Tear (leak) in actuating diaphragm		
Hand valve shut off		
Upstream pressure lower than normal		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

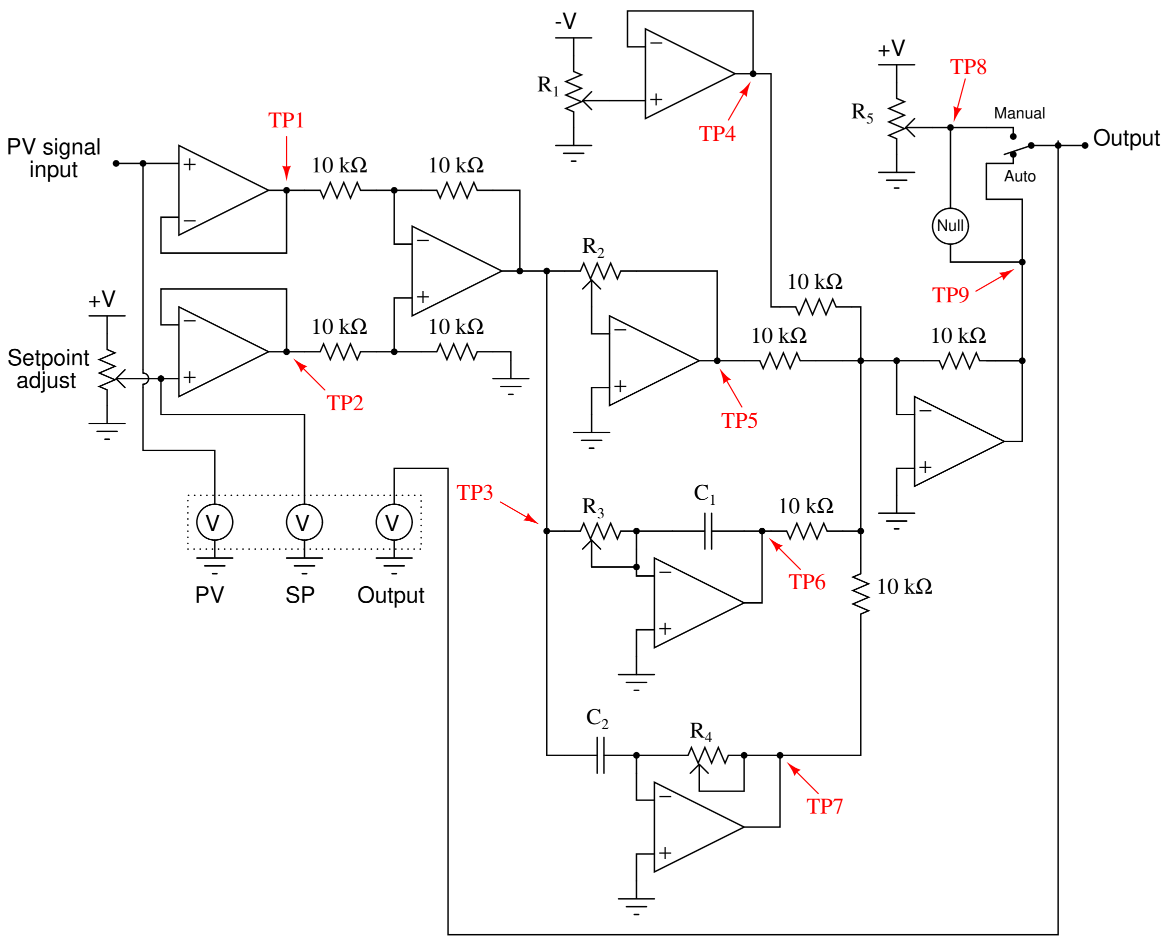
Suggestions for Socratic discussion

- Identify any advantages this pressure-control system enjoys over a control system based on a remote PID controller.
- Could this control strategy work just as well for a liquid application rather than a gas application? Explain why or why not.

file i01614

Oppgave 56

Shown here is the schematic diagram of a full "PID" analog electronic controller. Although it lacks the features of output and setpoint tracking, it does possess all three control terms: Proportional, Integral, and Derivative.



Based on your analysis of this circuit, answer the following questions:

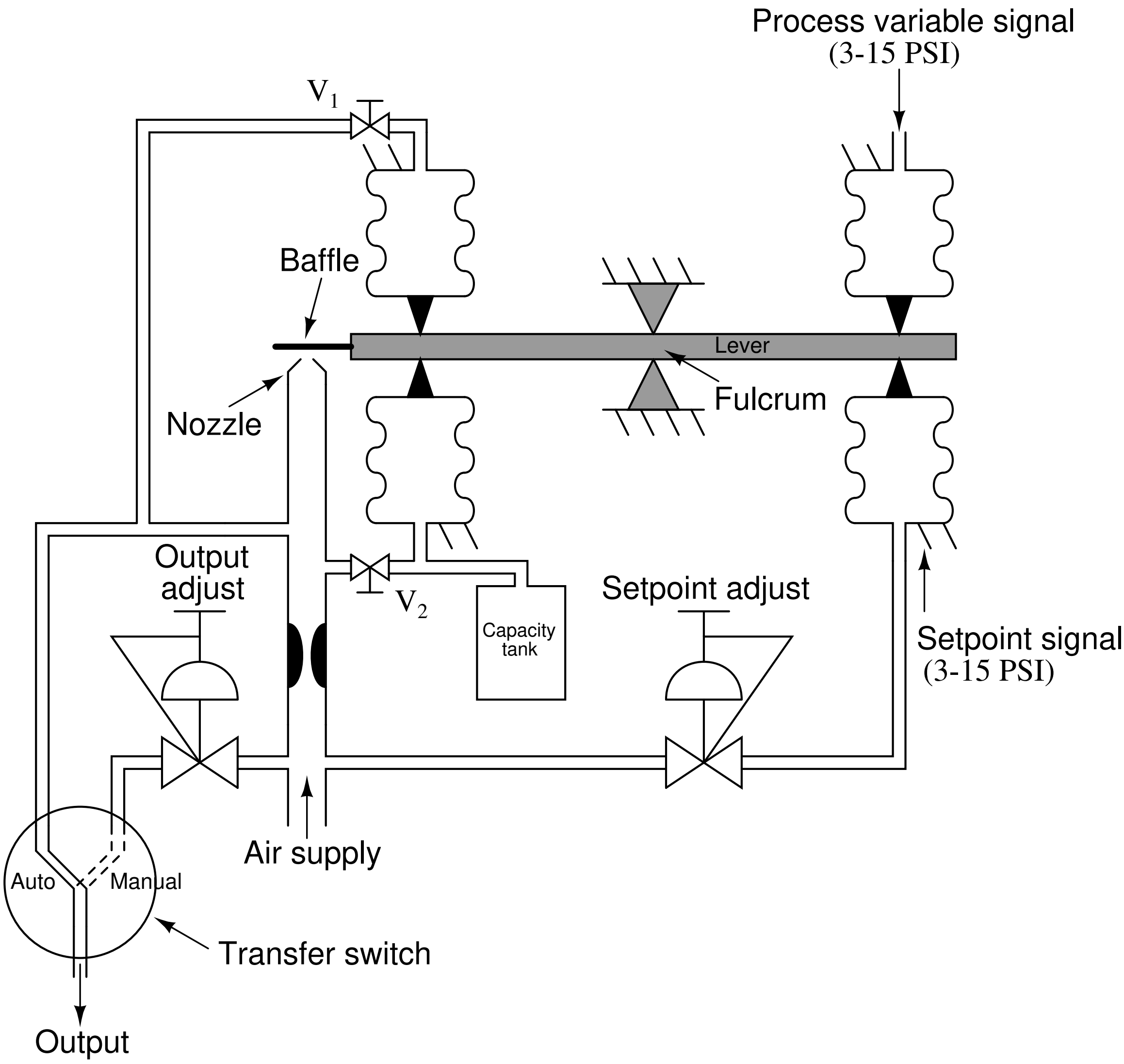
- At what test point would you measure the controller's derivative term signal?
- At what test point would you measure the controller's error signal?
- At what test point would you measure the controller's setpoint signal?
- Which potentiometer adjusts the integral constant (τ_i)?
- Which potentiometer adjusts the derivative constant (τ_d)?

- Which capacitor is used to calculate the integral term?
- Will adjustment of the proportional constant affect either the integral or derivative responses?

file i01635

Oppgave 57

Shown here is the schematic diagram of a full "PID" analog pneumatic controller. Although it lacks the features of output and setpoint tracking, it does possess all three control terms: Proportional, Integral, and Derivative.



Based on your analysis of this mechanism, answer the following questions:

- Is this controller reverse or direct acting?
- Which valve adjusts the integral constant (τ_i)?

- Which valve adjusts the derivative constant (τ_d)?
- What will a change in the capacity tank's volume affect?
- Will adjustment of the proportional constant affect either the integral or derivative responses?
- What would happen if valve V_2 were fully shut?

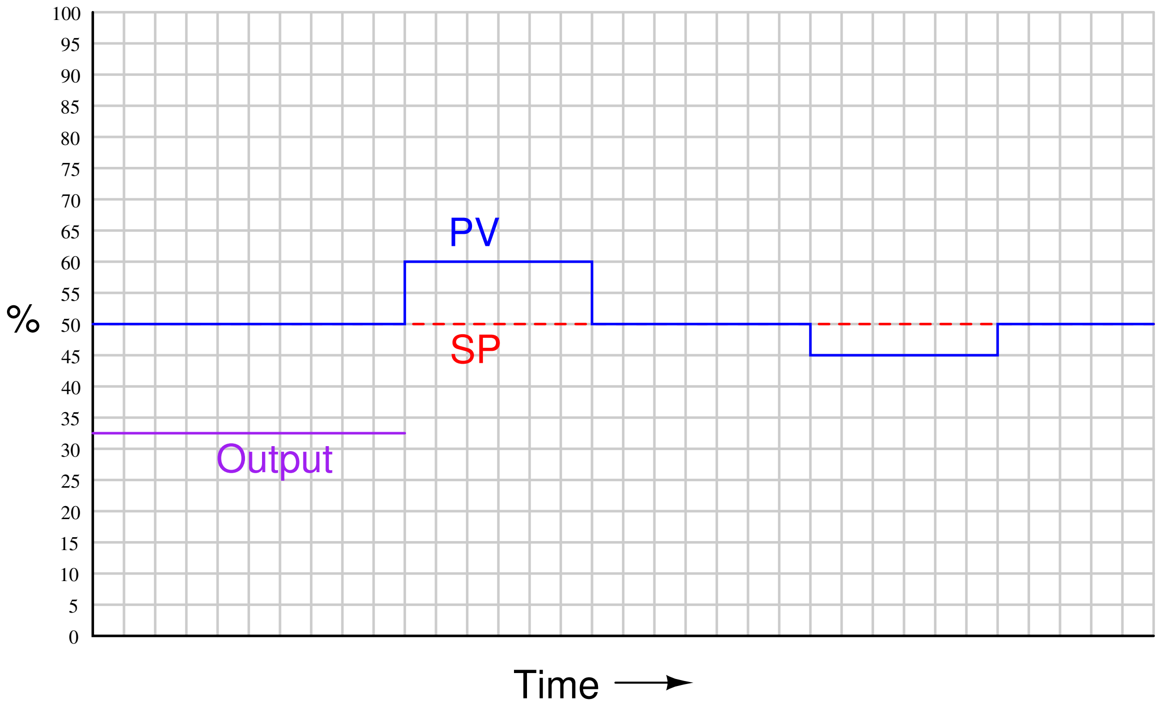
Suggestions for Socratic discussion

- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful "thought experiment" for this system, and how the results of that thought experiment are helpful to answering these questions.

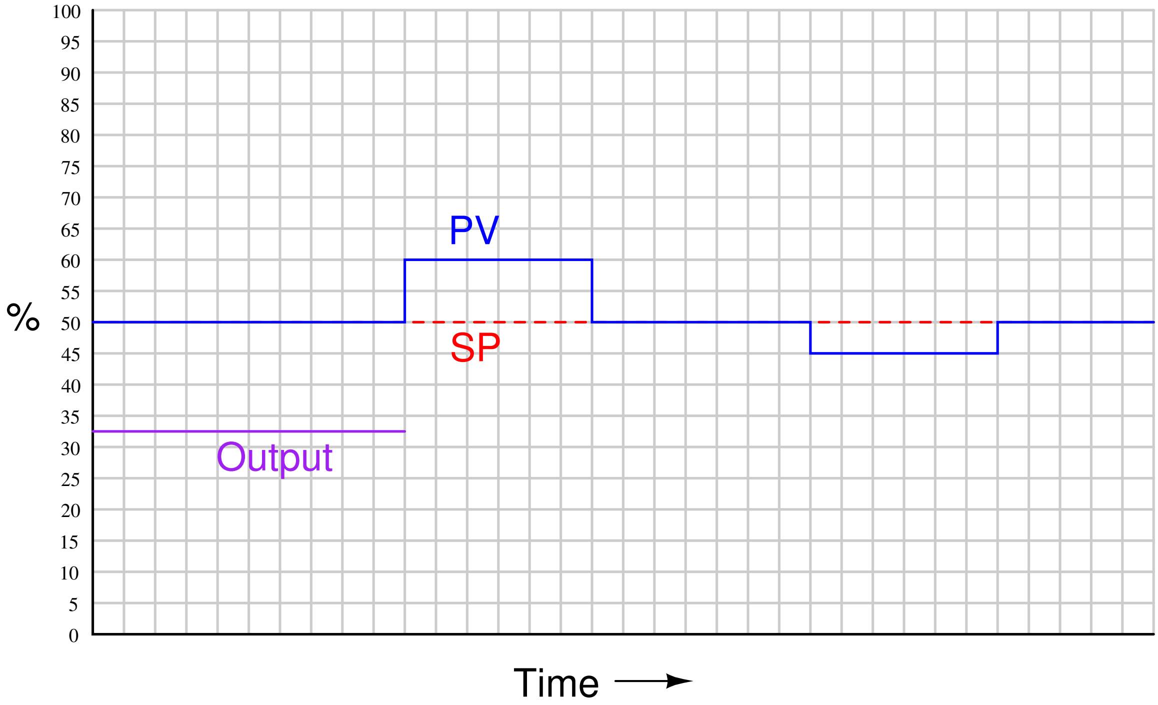
file i01636

Oppgave 58

Qualitatively graph the individual proportional, integral, and derivative responses of a PID controller to the following input conditions, assuming *direct* controller action. Use a solid line for proportional, a dashed line for integral, and a dotted line for derivative:



Then, draw a final graph of the controller's output, showing how the P, I, and D terms would combine to form a composite waveform:



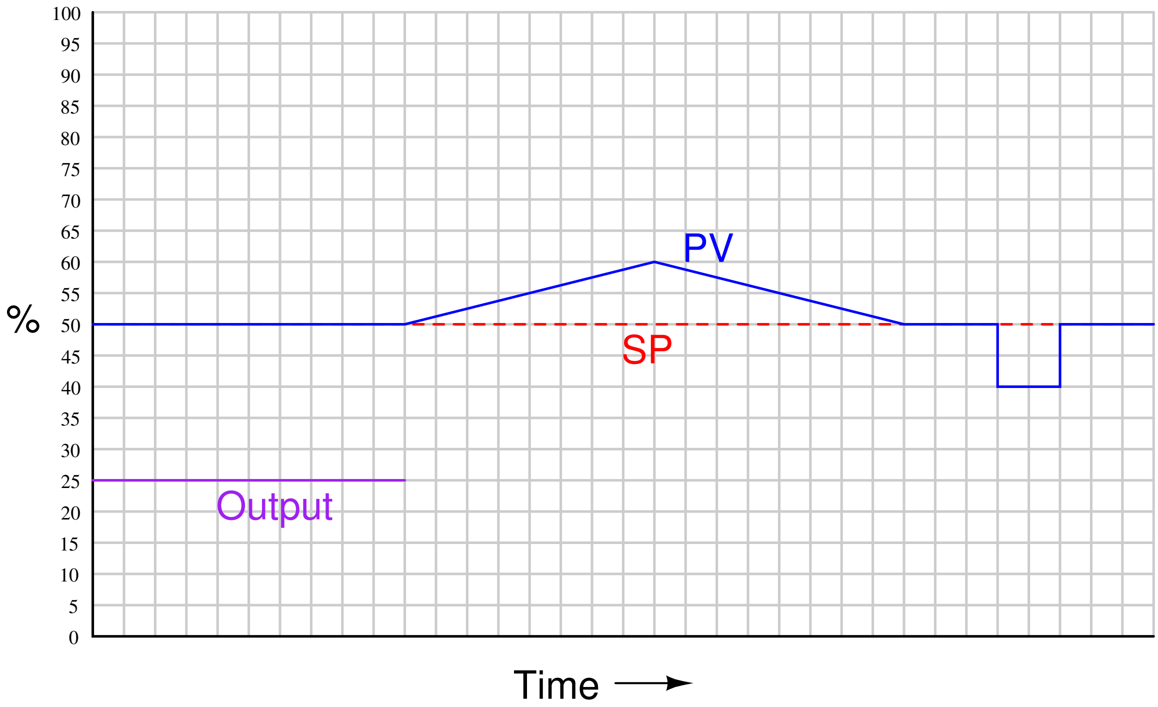
Suggestions for Socratic discussion

- Many students find the task of summing all three control actions together to be much more difficult than plotting any of the three responses separately. Devise a problem-solving strategy to ensure your summation will always be correct!

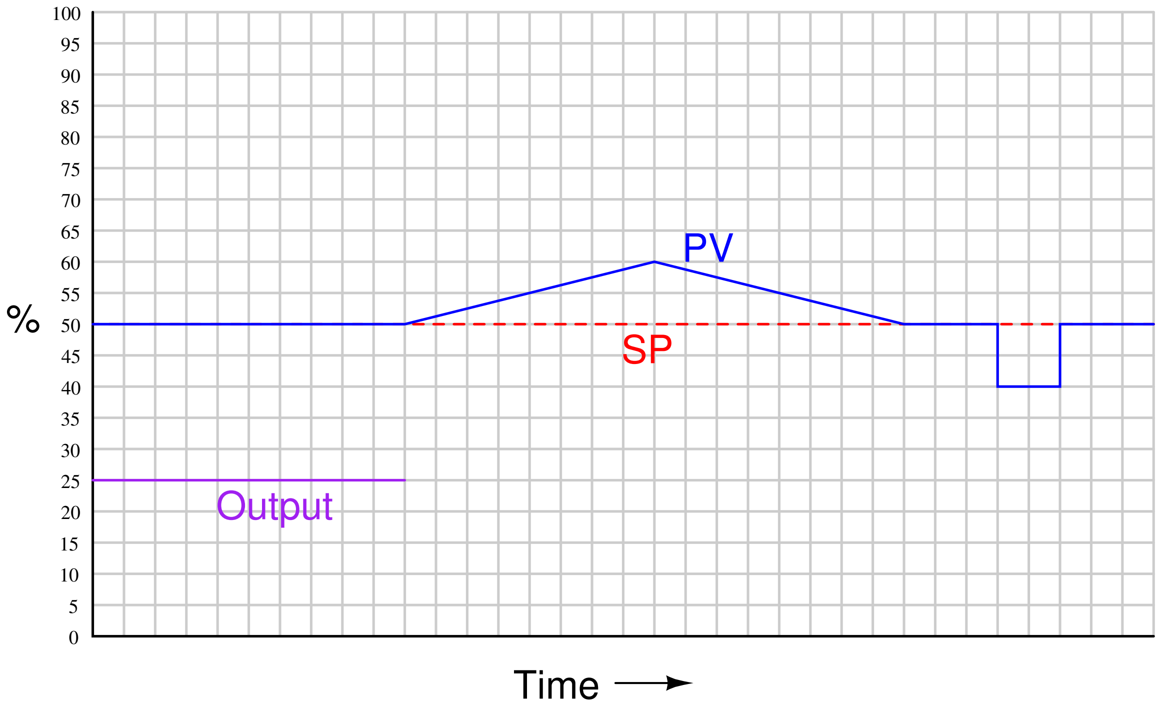
file i01637

Oppgave 59

Qualitatively graph the individual proportional, integral, and derivative responses of a PID controller to the following input conditions, assuming *direct* controller action. Use a solid line for proportional, a dashed line for integral, and a dotted line for derivative:



Then, draw a final graph of the controller's output, showing how the P, I, and D terms would combine to form a composite waveform:



Suggestions for Socratic discussion

- Many students find the task of summing all three control actions together to be much more difficult than plotting any of the three responses separately. Devise a problem-solving strategy to ensure your summation will always be correct!

file i01638

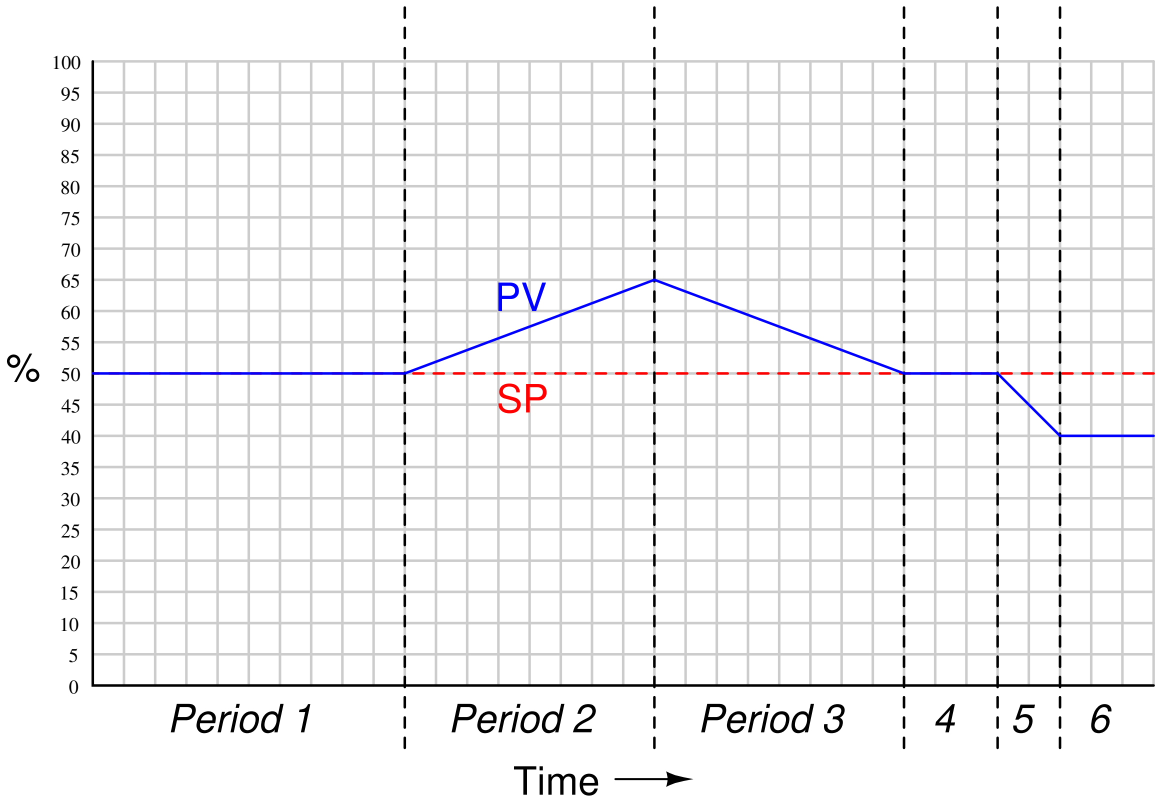
Oppgave 60

It is sometimes said that in a PID controller, proportional action works on the *present*, while integral action works on the *past* and derivative action works on the *future*. Explain what this means.

file i01639

Oppgave 61

Determine how each control action (P, I, and D) would react during the periods marked on this process trend by using the symbols ↑ (driving up), ↓ (driving down), + (steady positive), − (steady negative) or 0 (zero), compared to the actions of each at the beginning of the trend. Do this for P, as well as for I and D. Assume *direct action* for the controller.



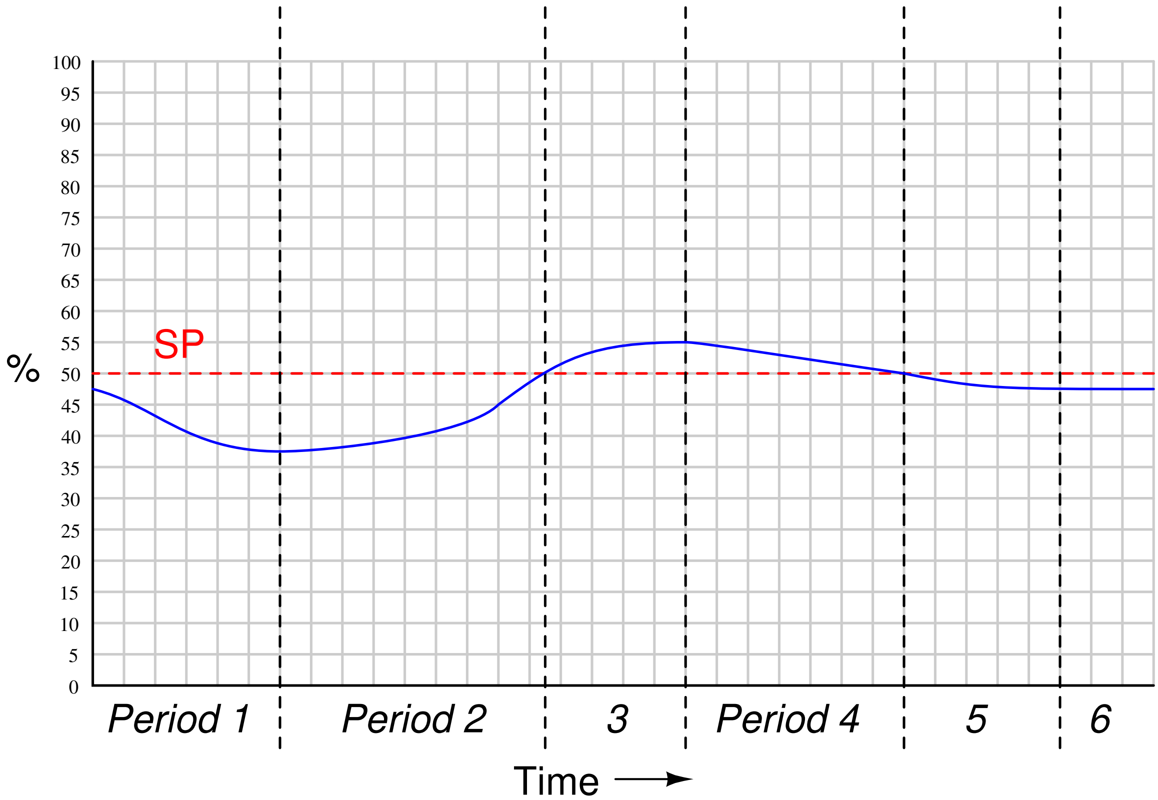
Suggestions for Socratic discussion

- Identify any good problem-solving strategies you might apply to this problem.
- Sketch a qualitative graph showing the output of a full PID controller given these PV and SP graphs.

file i01640

Oppgave 62

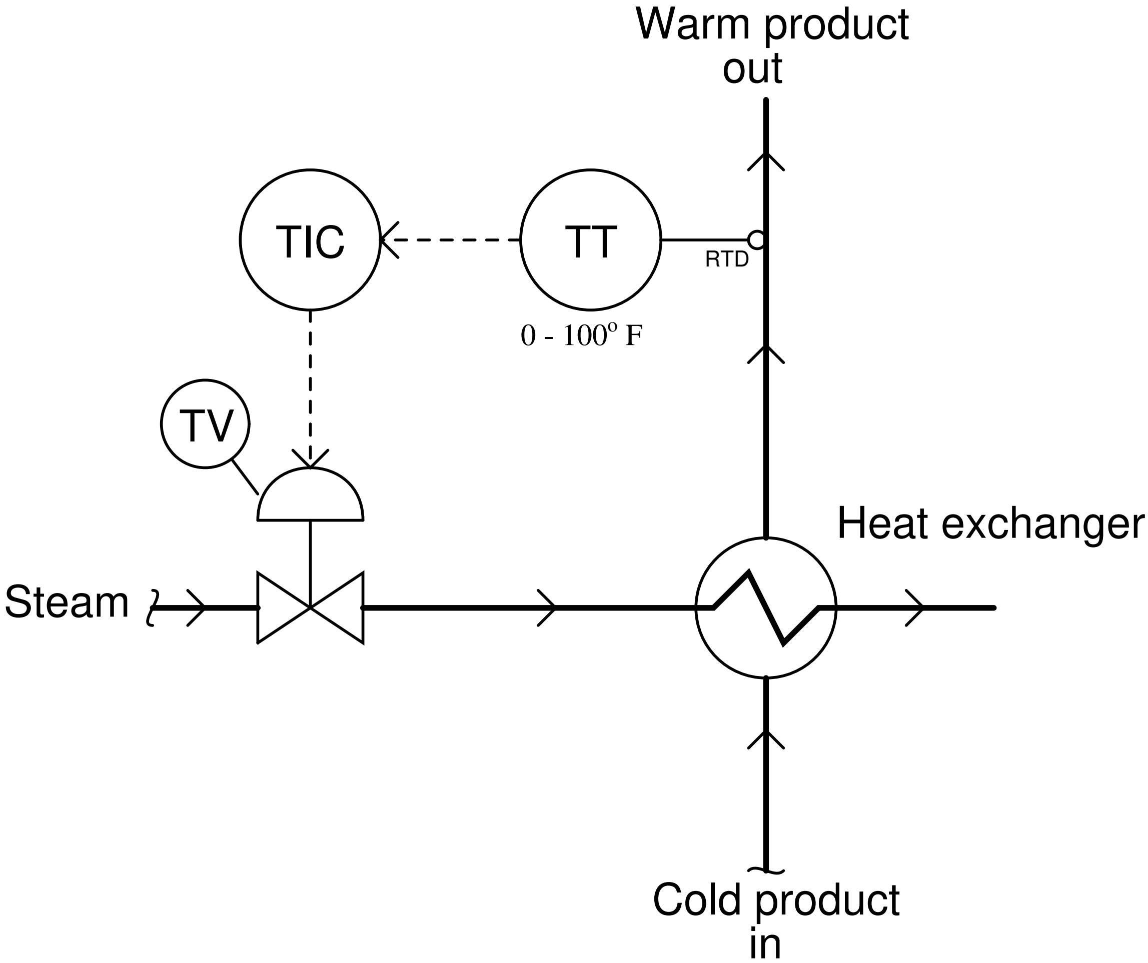
Determine how each control action (P, I, and D) would react during the periods marked on this process trend by using the symbols ↑ (driving up), ↓ (driving down), + (positive), − (negative) or 0 (zero), compared to the actions of each at the beginning of the trend. Do this for P, as well as for I and D. Assume *direct action* for the controller.



file i01641

Oppgave 63

Suppose this process is optimally tuned, with a measurement range of 0^o F to 100^o F:



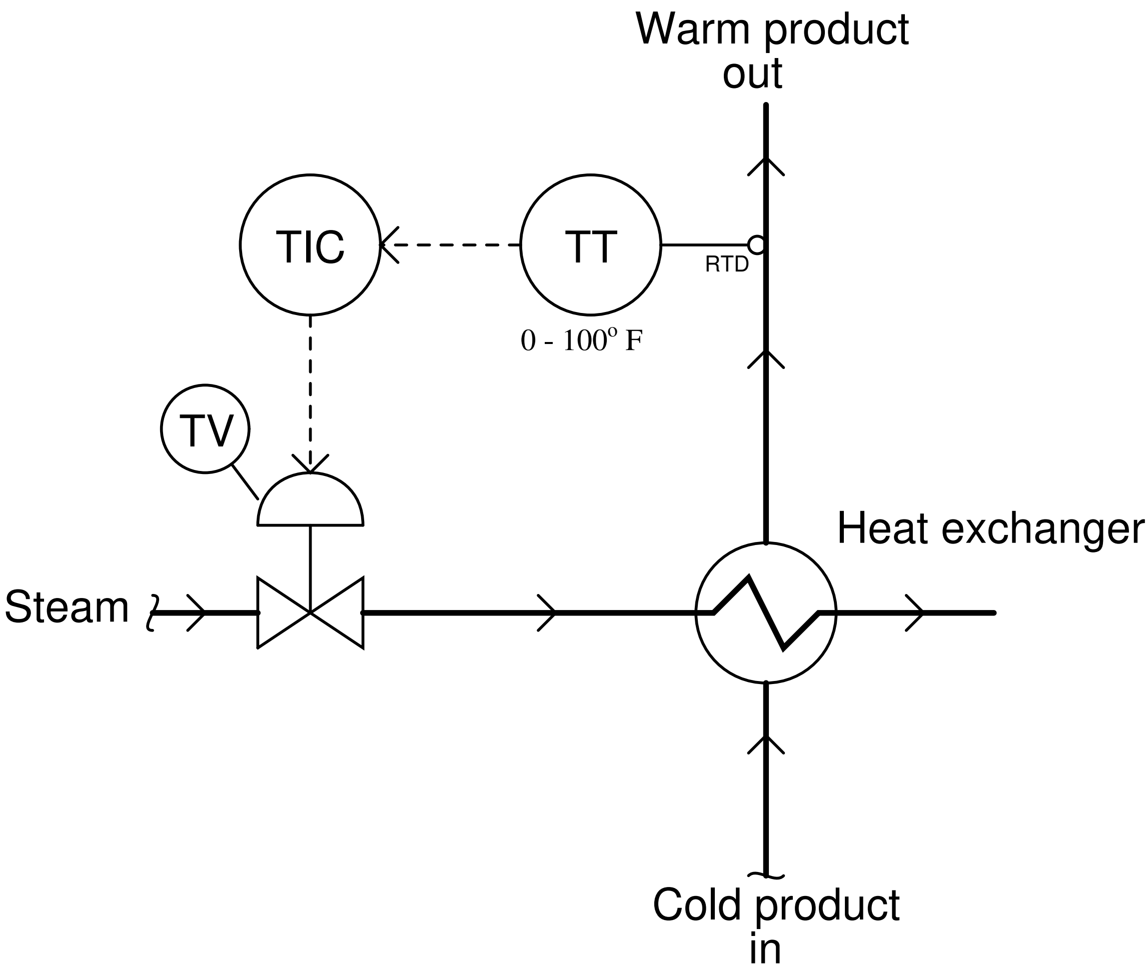
Then, one day the decision is made to re-range the temperature transmitter (TT) for greater resolution: 50^o F to 70^o F instead of 0^o F to 100^o F. As a result of this range-change, the process begins to oscillate around setpoint rather than hold steady at setpoint as it used to.

Explain why this range-change caused the process control to become unstable, and propose a solution that will restore the previous quality of control.

file i01643

Oppgave 64

Suppose this process is optimally tuned, with a measurement range of 0^o F to 100^o F:



Then, one day the decision is made to re-range the temperature transmitter (TT) for greater resolution: 50^o F to 70^o F instead of 0^o F to 100^o F. As a result of this range-change, the process begins to oscillate around setpoint rather than hold steady at setpoint as it used to.

Explain why this range-change caused the process control to become unstable, and propose a solution that will restore the previous quality of control.

file i01643

Oppgave 65

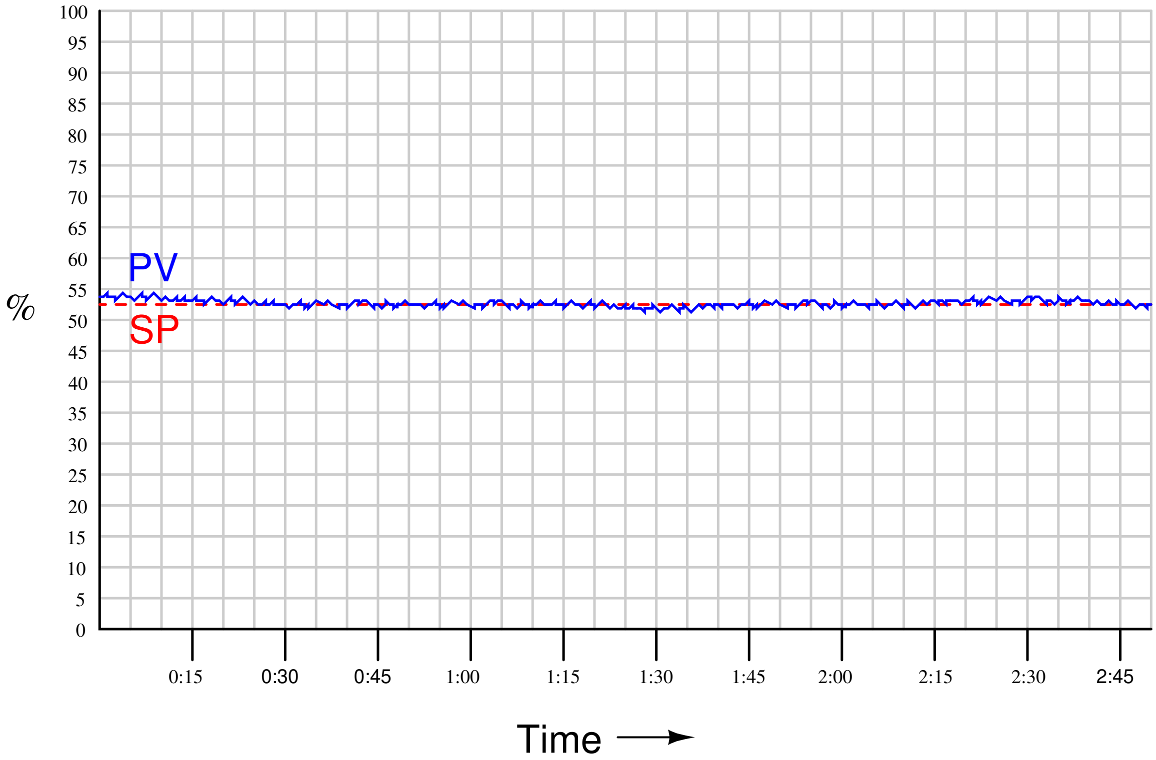
On some PID controllers, an option is given to allow derivative action to act on process variable (PV) changes only, or act on error (PV − SP) changes like integral action always does. What benefit would it be to have derivative action working on PV changes only and not SP changes?

file i01644

Oppgave 66

Derivative control action is especially useful in processes characterized by slow lag times, especially when the process has a natural tendency to "overshoot" the setpoint due to multiple lags. The purpose of derivative mode control is to make decisions based on how *quickly* the process variable changes over time, taking action in the present to avoid setpoint overshoot in the future.

However, derivative mode control cannot be used in processes where the PV signal is tainted with *noise*, as is the case in this trend:



It does not matter how well-suited the process may be for derivative control in any other regard, so long as the noise is there. Noise and derivative control are simply incompatible – explain why.

Also, identify whether or not *integral* mode control is affected by noise in the PV signal, and explain your answer.

Suggestions for Socratic discussion

- Observing the trend graph shown here, can we tell whether this controller is in manual mode or automatic mode? If so, identify its operating mode.
- Observing the trend graph shown here, can we tell whether this controller is direct-acting or reverse-acting? If so, identify its direction of action.
- Observing the trend graph shown here, can we tell anything about the P, I, and/or D settings of this controller? If so, identify what its dominant control action is (P, I, or D).

file i01671

Oppgave 67

What does it mean for a process (such as a temperature-controlled cookie oven) to have a *time constant*? I am referring here to the process itself (oven, heating element, and cookies), not the control system.
file i01678

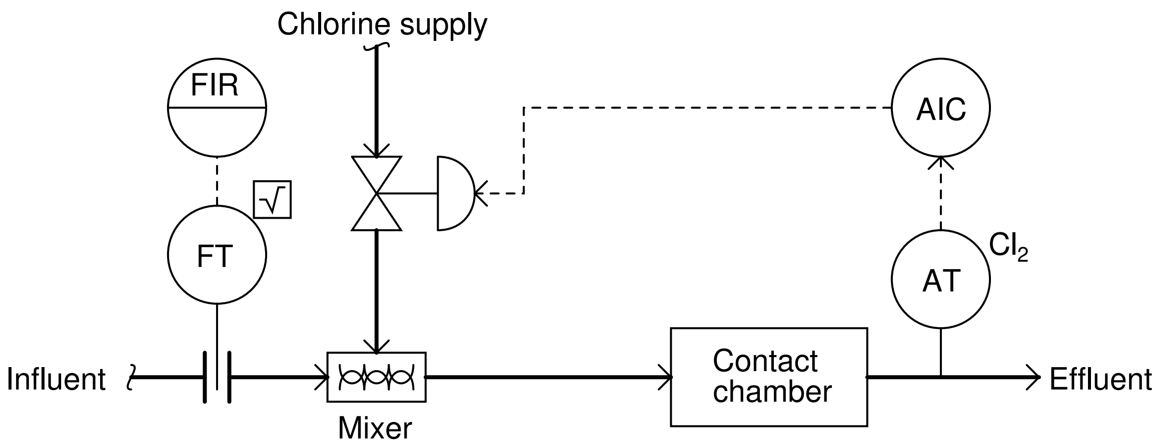
Oppgave 68

Explain what a *first-order* process is.
file i01679

Oppgave 69

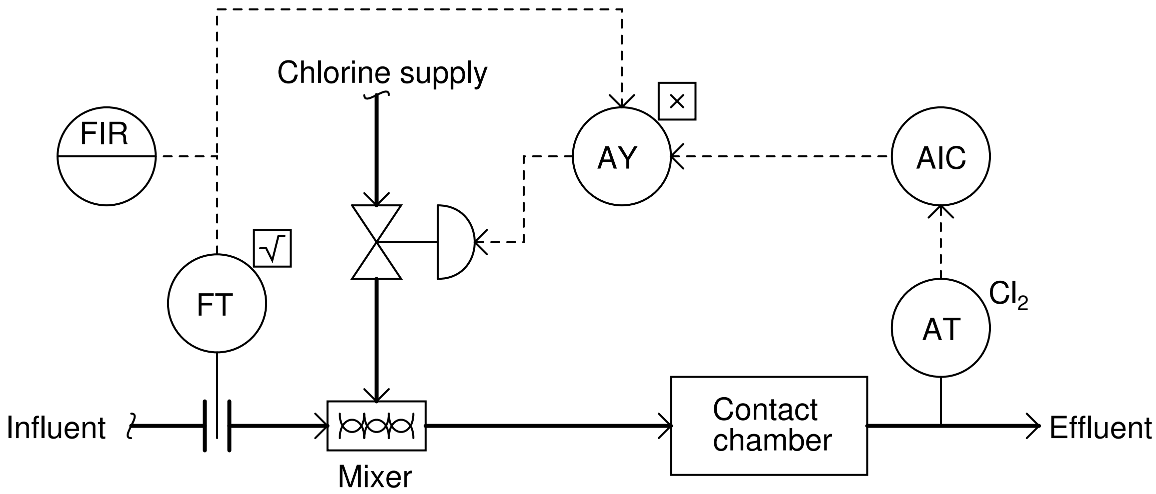
The following chlorine disinfection system (common to wastewater treatment systems) has a subtle problem the loop's stability changes with the weather. Influent in this case comes from the discharge of an open aeration lagoon, which collects rainwater during stormy weather but of course does not during dry weather.

When the influent water flow rate is low, the control system will oscillate. When the influent water flow rate is high, the system will respond sluggishly:

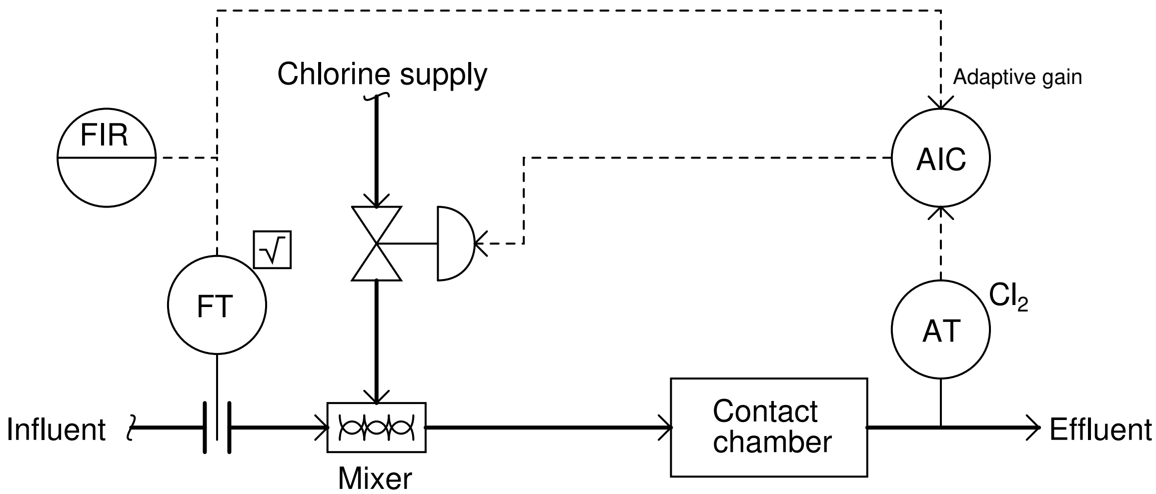


So far, instrument technicians' approach to solving this problem has been to re-adjust the PID tuning parameters seasonally. Identify how you think the controller's PID tuning parameters would need to be adjusted between the seasons and wet seasons, being as specific as you can. Explain *why* the process itself seems to control so differently based on influent flow rate.

Explain why the following modification will go a long way toward correcting this problem:



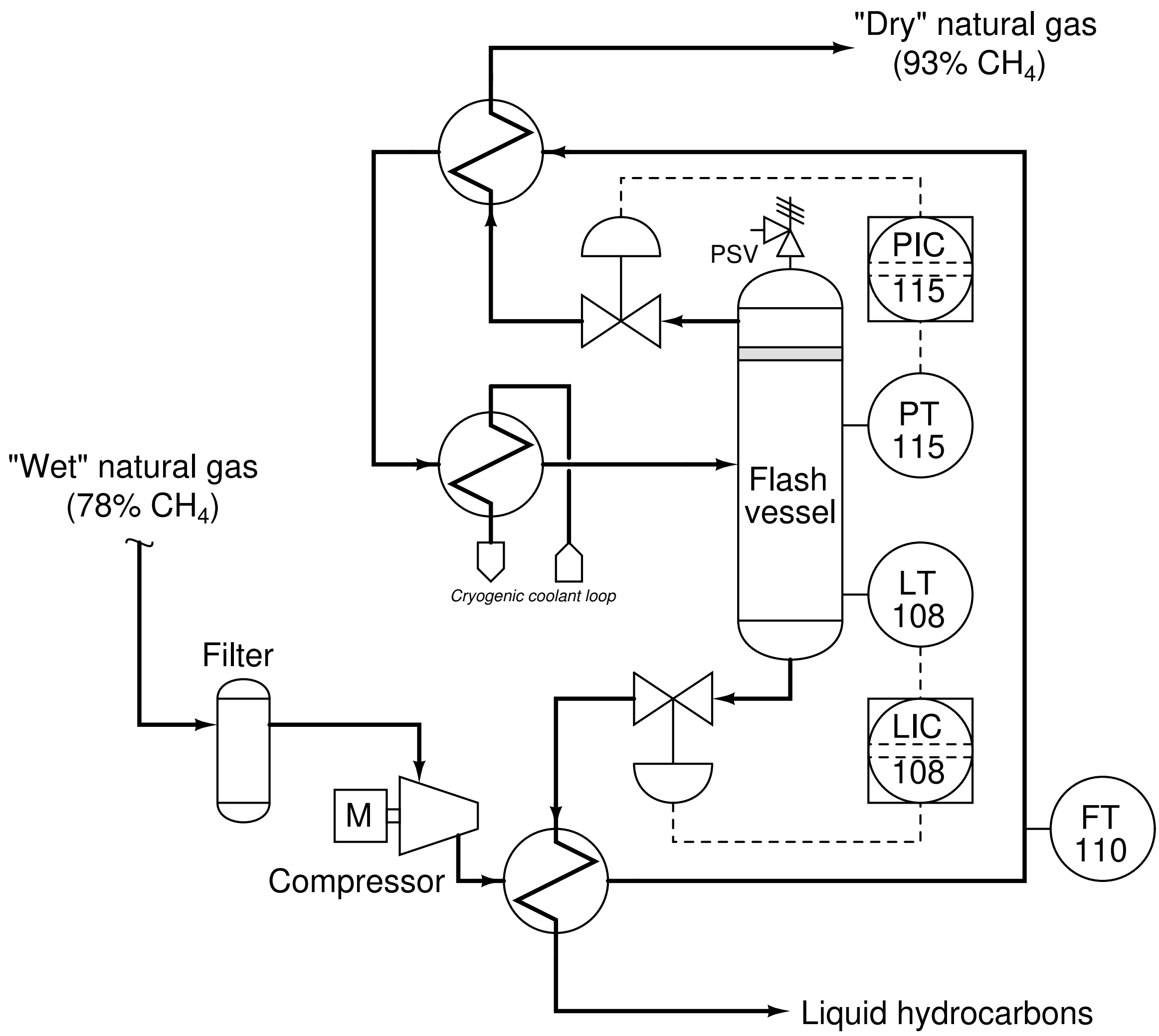
Explain why this next modification works as it does, being an alternative to the former solution:



file i01815

Oppgave 70

"Wet" natural gas is mostly methane (CH_4) mixed with significant amounts of heavier hydrocarbon species such as ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and pentane (C_5H_{12}) which condense into liquid at lower temperatures than methane. A process for separating these heavier hydrocarbons from the chief component (methane) using compression and cooling is shown here:



Chilled gases enter the flash vessel, where methane rises and escapes in gaseous form, while all the other (heavier) hydrocarbon molecules condense into liquid and exit out the bottom.

Suppose PIC-115 is a proportional-only controller, holding steadily and accurately to a setpoint value of 107 PSI with a valve position of 41%. How will this controller respond to a sudden change in natural gas composition that is much *drier* than usual, assuming the same total flowrate (as indicated by FT-110) as before? Be as specific as you can in your answer!

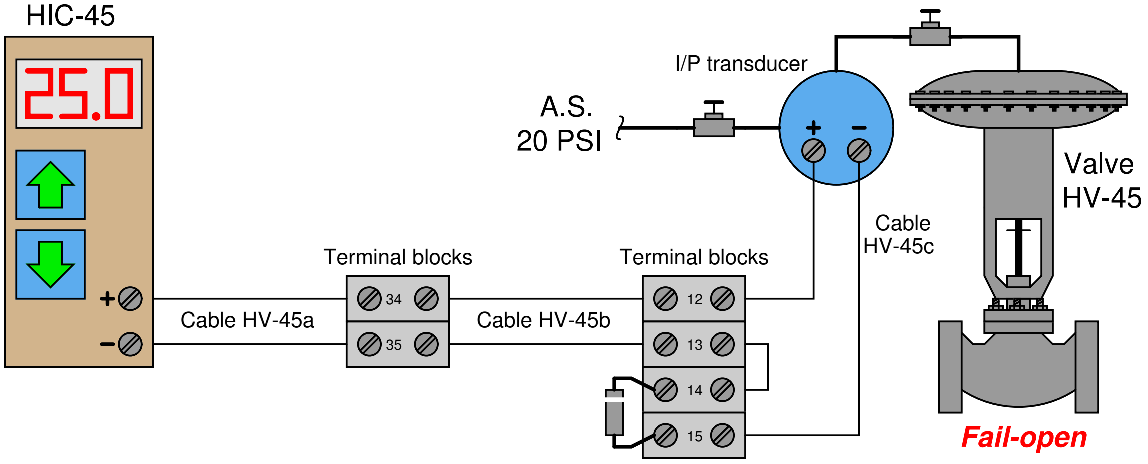
Suggestions for Socratic discussion

- Explain the purpose of the heat exchangers in this P&ID, especially the two exchanging heat between the incoming (compressed) gas and the products coming off the top and bottom of the flash vessel.
- Identify and explain the purpose of the "PSV" valve in this diagram.
- Suppose the operator of this process notices a consistent offset between PV and SP for controller PIC-115, with SP = 60% and PV = 65%. Describe steps the operator can take to eliminate this offset and get the PV equal to 60%.

file i01863

Oppgave 71

Den manuelle kontrolleren (HIC-45) gjør at den operatør kan kontrollere reguleringsventilen (HV-45) med å trykke pil opp og ned på regulatoren.



Som automatikker må du konfigurere kontrolleren sånn at displayet viser ventilens aktuelle posisjon. 0 på displayet skal tilsvare 0% åpen (helt lukket) og 100 på displayet skal tilsvare 100 % åpen. Dette for at displayet skal være så enkelt som mulig for operatører å betjene. Utfordringen er at ventilen er *air-to-close*, som betyr at den må fullt lufttrykk for å lukkes helt, og det den er helt åpen uten lufttrykk.

Det er to måter å oppnå dette målet på. Den første er å kalibrere I/P transduceren til å være reverserende (4 mA = 15 PSI : 20 mA = 3 PSI). Den andre måten krever at vi konfigurerer den manuelle kontrolleren til å være reverserende. (4 mA = 100% display ; 20 mA = 0% display). Anta du velger den andre metoden, der I/P kalibreringen er normal. (e.g. 4 mA = 3 PSI) og kontrolleren er reverserende. (e.g. 100% display = 4 mA). Gitt denne konfigurasjonen fullfør tabellen:

Controller display	Controller current	I/P pressure	Valve stem position
77.5%			
	17.9 mA		
		4.29 PSI	
			64% open

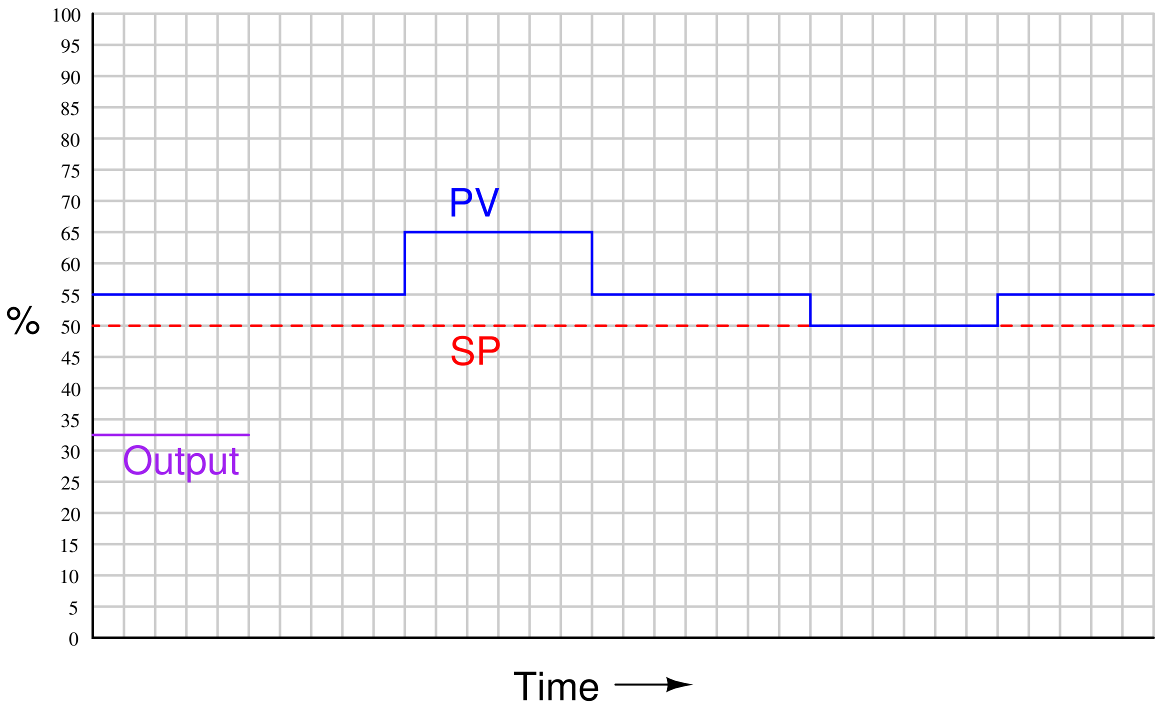
Suggestions for Socratic discussion

- Explain why anyone would choose to use an air-to-close (fail open) control valve.
- Explain why choosing to use a reverse-acting I/P might not be a good idea, considering fail-safe requirements of the system.
- Write a linear equation in the form $y = mx + b$ to describe the current signal output from the controller (y) in terms of its displayed percentage (x).
- Explain the distinction between a loop controller that is *reverse-acting* versus one that is merely *reverse-indicating*.
- Explain the purpose of the diode in the circuit.

file i02325

Oppgave 72

Proportional control action is where the output signal of a controller shifts in direct proportion to any shift in *error* (the difference between process variable and setpoint). Given this definition, identify how a proportional-acting controller would respond to the following process variable (PV) and setpoint (SP) values over time:

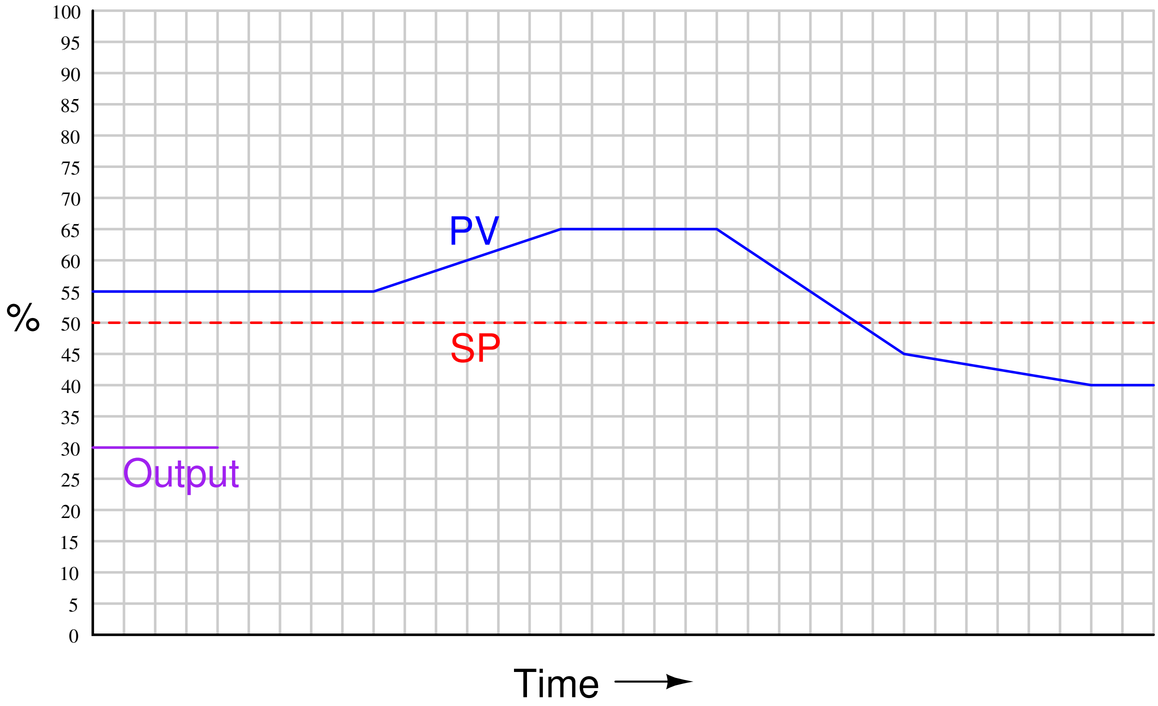


Assume *direct* control action.

file i02417

Oppgave 73

Derivative control action is where the output signal of a controller shifts in direct proportion to the rate that *error* (the difference between process variable and setpoint) changes. Given this definition, identify how a derivative-acting controller would respond to the following process variable (PV) and setpoint (SP) values over time:

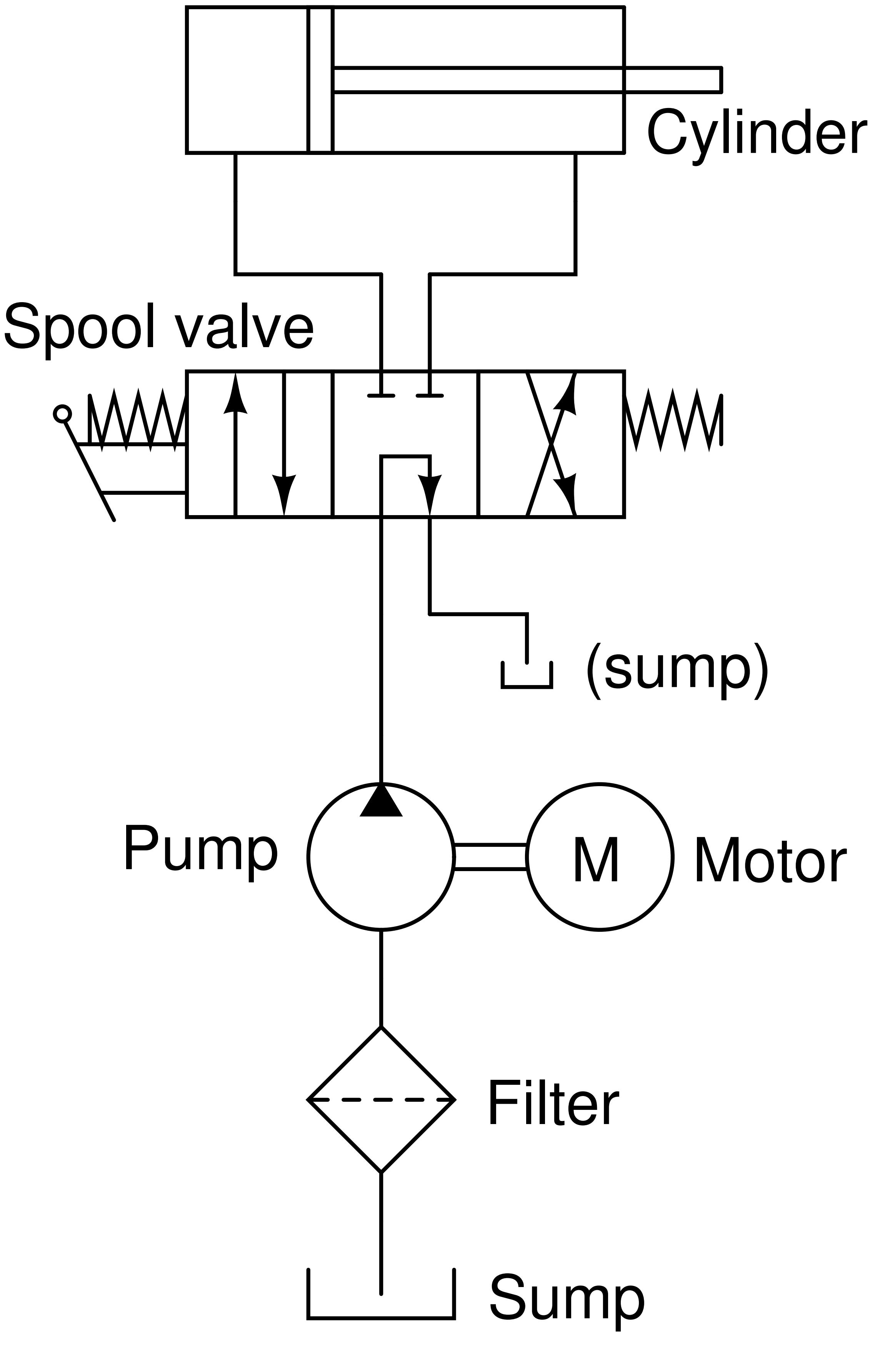


Assume *direct* control action.

file i02419

Oppgave 74

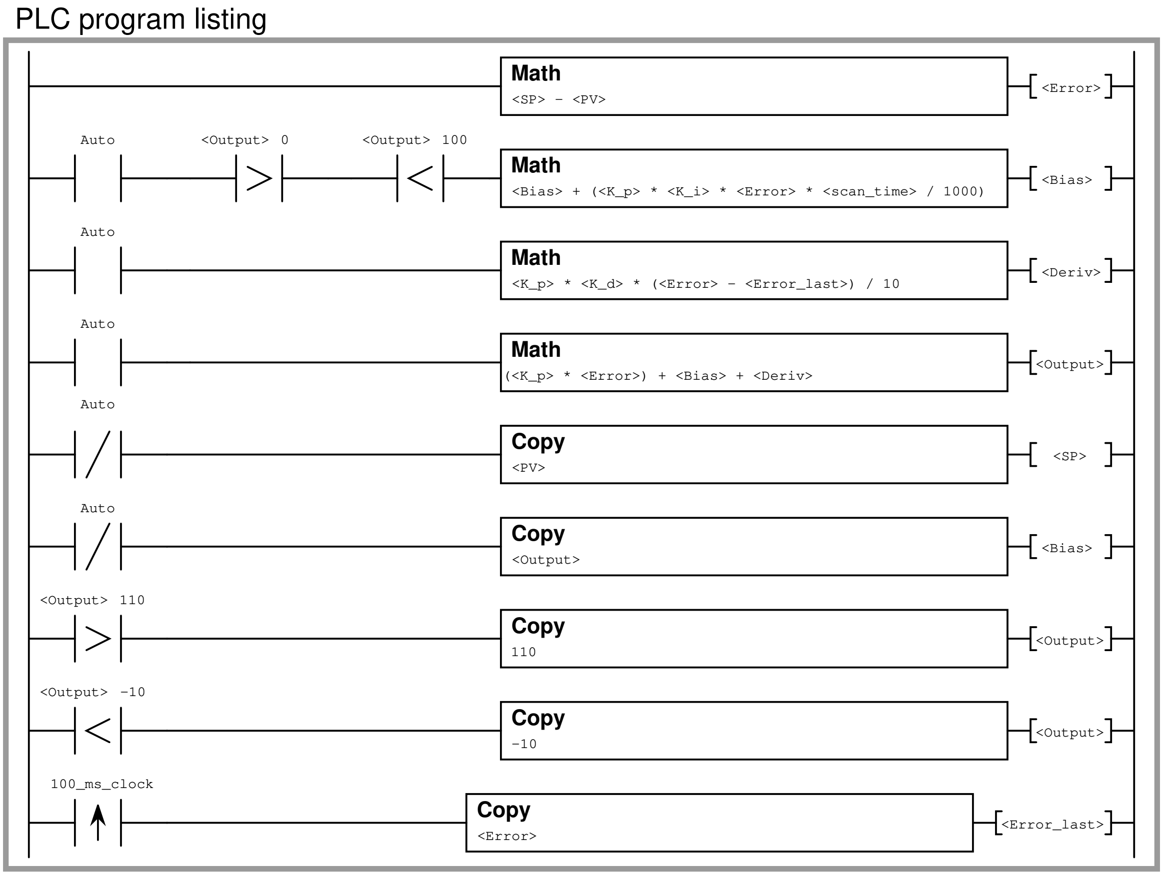
A hydraulic system consisting of a hand-actuated *spool valve* and a double-acting *cylinder* may be thought of as a sort of control system. Input (motion to the spool valve) results in a certain output (cylinder motion):


Cylinder
Spool valve
(sump)
Pump
M
Motor
Filter
Sump

Identify what the arrows mean inside the spool valve symbol, and then explain whether you think the action of this "control system" is more like *proportional* or more like *integral*.
file i02420

Oppgave 75

Some programmable logic controllers (PLCs) do not have a built-in PID instruction, and so to implement PID control in one of these PLCs the technician or engineer must build their own PID algorithm from math statements. Examine this ladder-logic program for a PLC implementing full PID control:



- Is this a *direct-acting* or a *reverse-acting* algorithm? Which instruction(s) in the program indicate this?
- Does this program implement the *Parallel*, *Ideal*, or *Series* PID equation? Which instruction(s) in the program indicate this?
- Where does the program implement the feature of *setpoint tracking*?
- Where does the program implement the feature of *output tracking*?
- Where is integral action (I) calculated in this program?

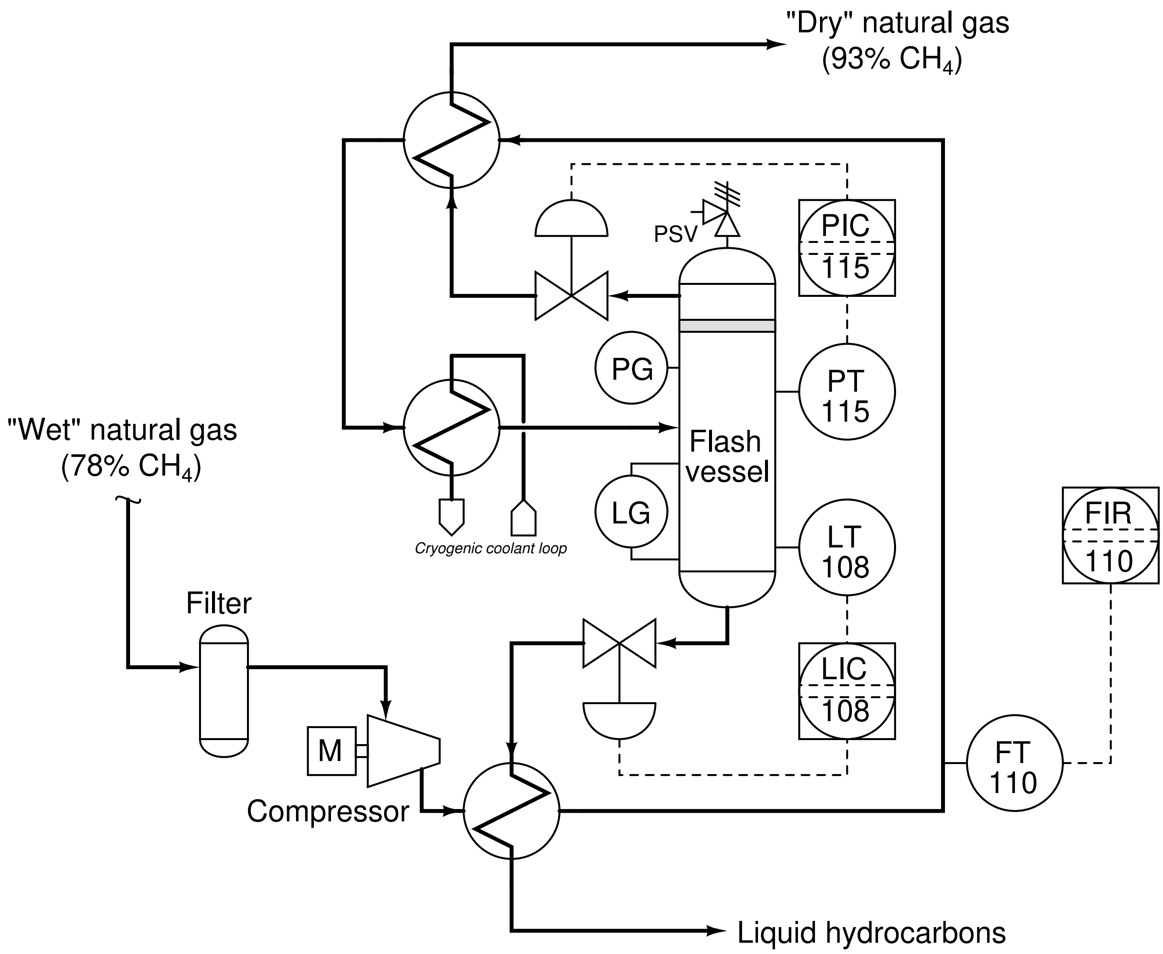
Suggestions for Socratic discussion

- Modify this PLC program so that it implements the *other* direction of action (i.e. reverse-action instead of direct-action, or vice-versa).
- Modify this PLC program so that it implements a different PID equation from the one it implements now.
- Modify this PLC program so that it implements a P+I equation (no derivative).
- Modify this PLC program so that it implements a P+D equation (no integral).
- Modify this PLC program so that it implements an I+D equation (no proportional).
- What is the significance of the "↑" symbol inside the 100_ms_clock contact?
- What is the significance of each "<" and ">" symbol inside some of the contacts?
- Where does this program implement *reset windup limiting*?
- Would it make any difference if the Error_last "copy" instruction were placed at the beginning of the program instead of the very end of the program? Hint: consider when a PLC typically scans its I/O to update any discrete and analog values – in the portion of the execution cycle *outside* the program scan.

file i02674

Oppgave 76

"Wet" natural gas is mostly methane (CH_4) mixed with significant amounts of heavier hydrocarbon species such as ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and pentane (C_5H_{12}). A process for separating these heavier hydrocarbons from the chief component (methane) using compression and cooling is shown here:



Chilled gases enter the flash vessel, where methane rises and escapes in gaseous form, while all the other (heavier) hydrocarbon molecules condense into liquid and exit out the bottom.

Suppose PT-115 is mis-calibrated, such that it falsely indicates a pressure lower than what is actually inside the flash vessel. How will this mis-calibration affect the control of flash vessel pressure? Will the operator be able to know anything is wrong by observing the DCS monitor screens for this process?

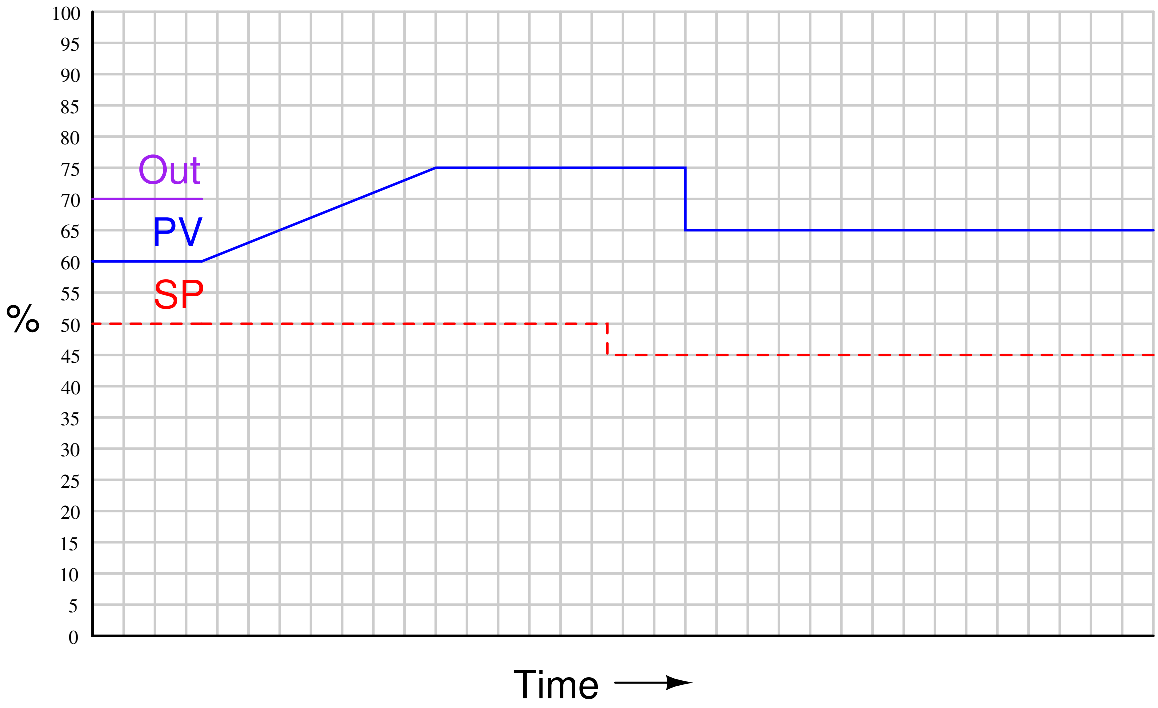
Suggestions for Socratic discussion

- Explain the purpose of the heat exchangers in this P&ID, especially the two exchanging heat between the incoming (compressed) gas and the products coming off the top and bottom of the flash vessel.
- Identify and explain the purpose of the "PSV" valve in this diagram.
- Assuming air-to-open control valves, identify the correct actions for each loop controller (direct or reverse).
- Identify the effect(s) of LV-108 failing shut.
- Identify the effect(s) of PV-115 failing shut.

file i03084

Oppgave 77

Complete the output graph for this proportional-only controller, assuming a gain (K_p) value of 3 and a control action that is reverse-acting:



A direct method of solving for the output graph is to re-calculate the output value using the proportional controller equation ($m = K_p e + b$), at every point where there is a unique PV and/or SP value. For example, you could use the equation to calculate the output value at PV=75% and PV=65%. This involves repeated calculations, which may be tedious for a complex graph.

As an aid to doing these repeated calculations, try setting up a computer spreadsheet (e.g. Microsoft Excel) to evaluate the proportional control equation for you, and then see if you can configure the spreadsheet to produce a graph of the same PV, SP, and Output trends as well!

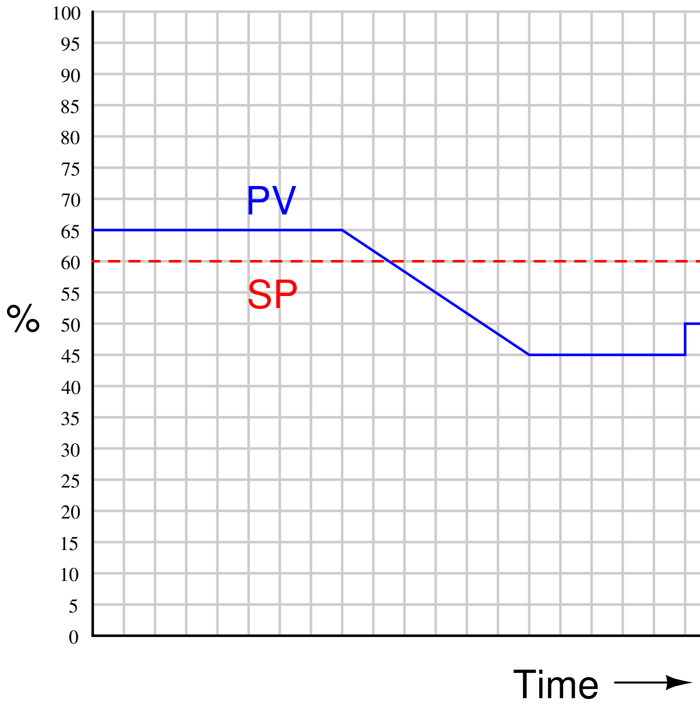
Suggestions for Socratic discussion

- Identify a way we could calculate the output trend without re-evaluating the reverse-acting controller formula, but just knowing the *gain* value of this controller.

file i03271

Oppgave 78

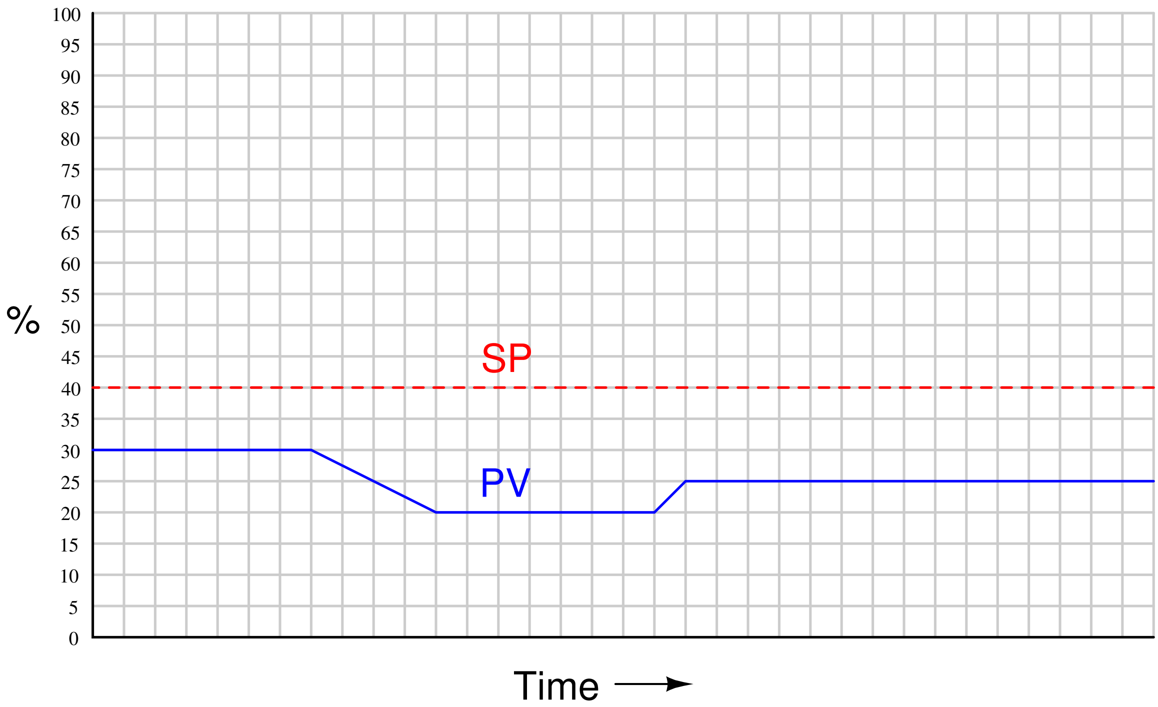
Graph the output of this proportional-only controller, assuming a gain (K_p) value of 1.0, a bias value of 50%, and a control action that is reverse-acting:



file i03272

Oppgave 79

Graph the output of this proportional-only controller, assuming a proportional band of 50%, a bias value of 30%, and a control action that is reverse-acting:



A direct method of solving for the output graph is to re-calculate the output value using the proportional controller equation ($m = K_p e + b$), at every point where there is a unique PV and/or SP value. For example, you could use the equation to calculate the output value at PV=30%, PV=20%, and PV=25%. This involves repeated calculations, which may be tedious for a complex graph.

As an aid to doing these repeated calculations, try setting up a computer spreadsheet (e.g. Microsoft Excel) to evaluate the proportional control equation for you, and then see if you can configure the spreadsheet to produce a graph of the same PV, SP, and Output trends as well!

Suggestions for Socratic discussion

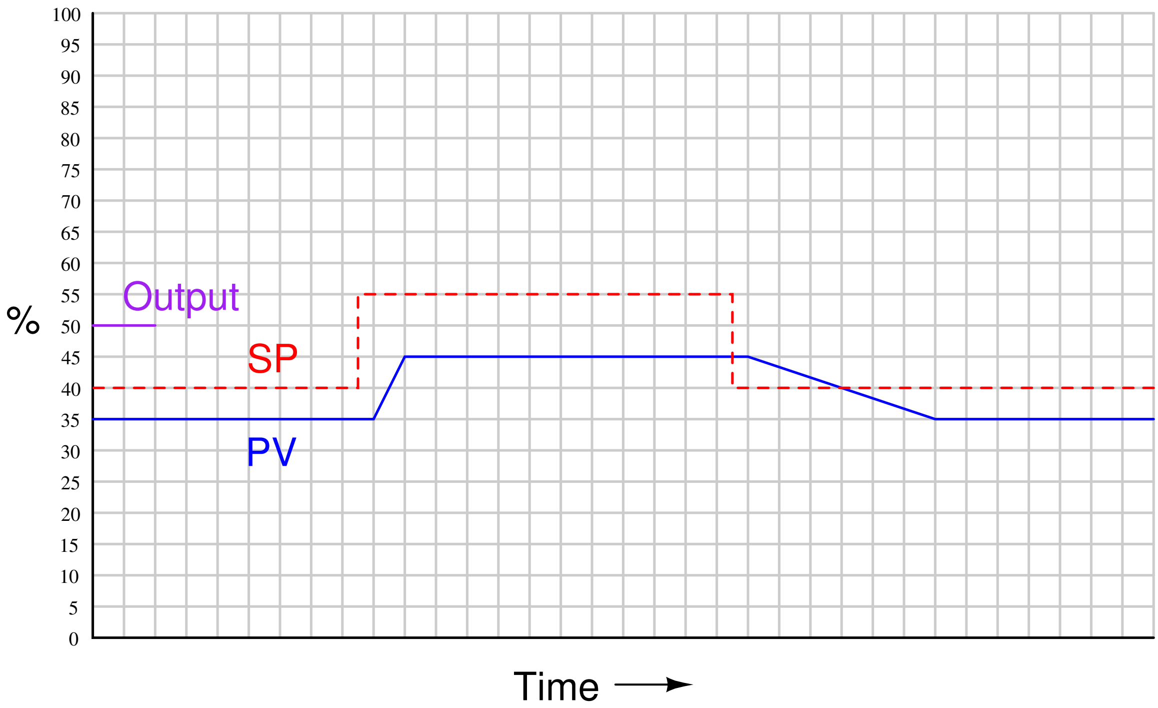
- How would the output signal trend be altered if the *proportional band* of this controller were increased?
- How would the output signal trend be altered if the *bias* of this controller were increased?

- How would the output signal trend be altered if the *action* of this controller were switched from reverse to direct?

file i03273

Oppgave 80

Graph the output of this proportional-only controller, assuming a proportional band of 25% and a control action that is direct-acting:

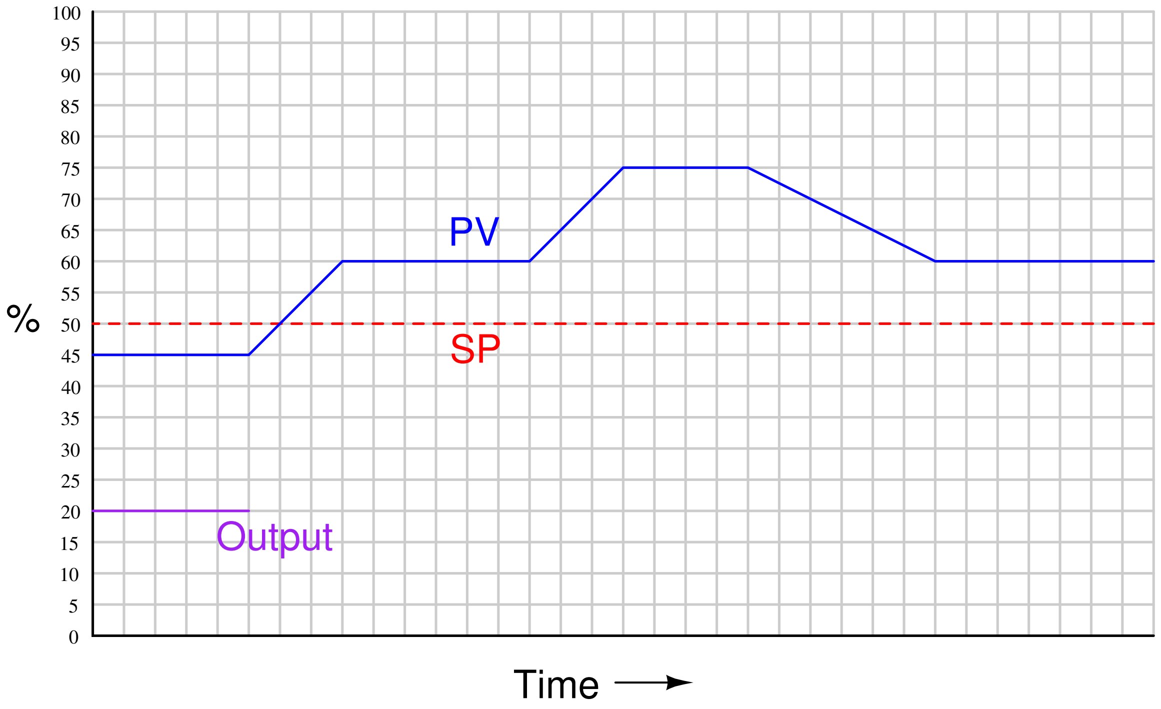


Also, calculate the *bias* value for this proportional-only controller, based on the data shown in the trend.

file i03274

Oppgave 81

Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:

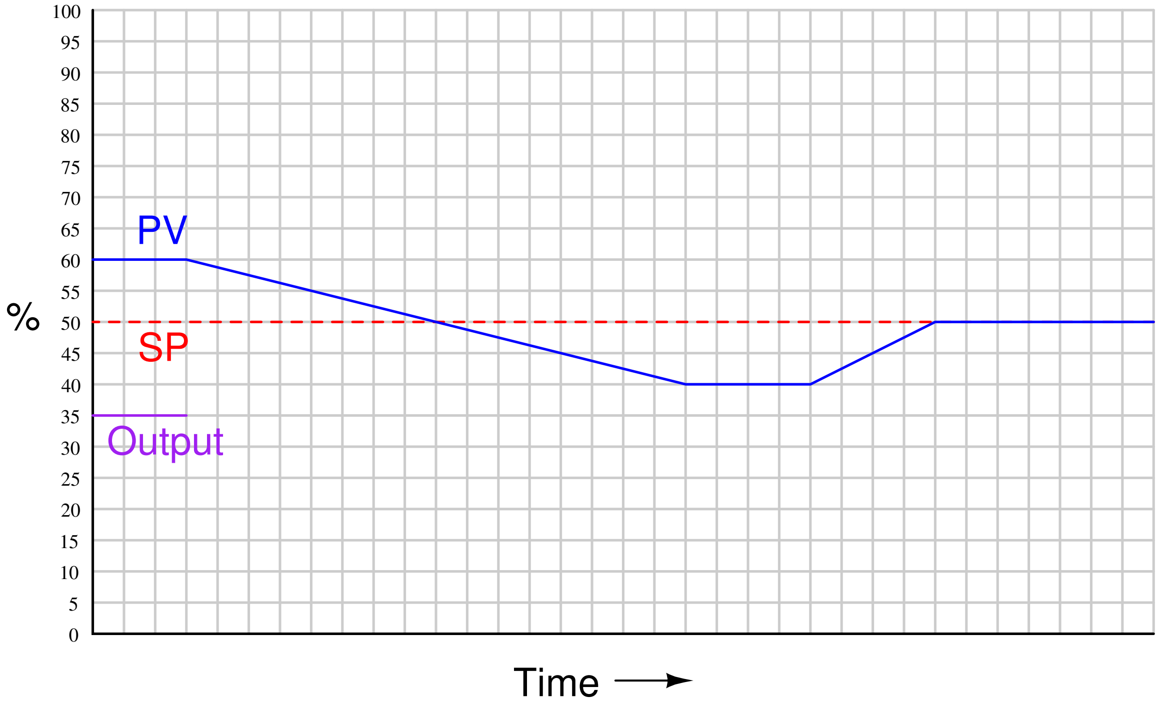


Assume *direct* control action.

file i03275

Oppgave 82

Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:

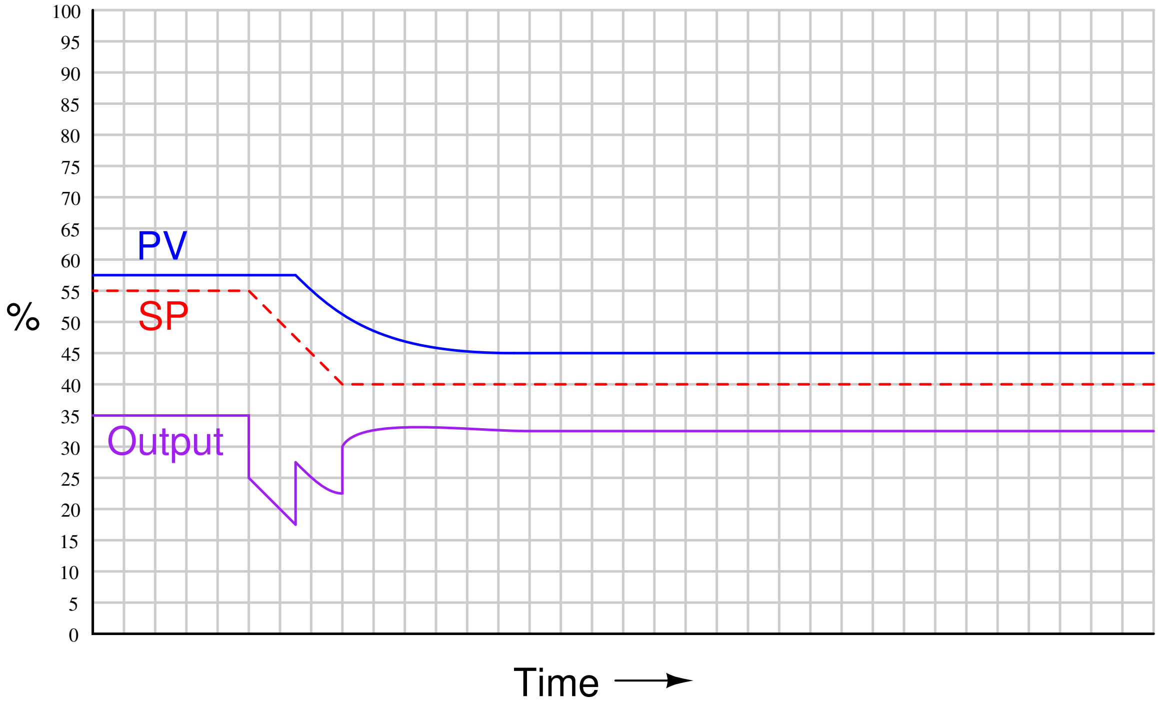


Assume *direct* control action.

file i03276

Oppgave 83

Examine this graphic trend of a proportional-plus-derivative controller's response to input changes over time:



Identify which of the following algorithms is being used in this P+D controller, and how you can tell:

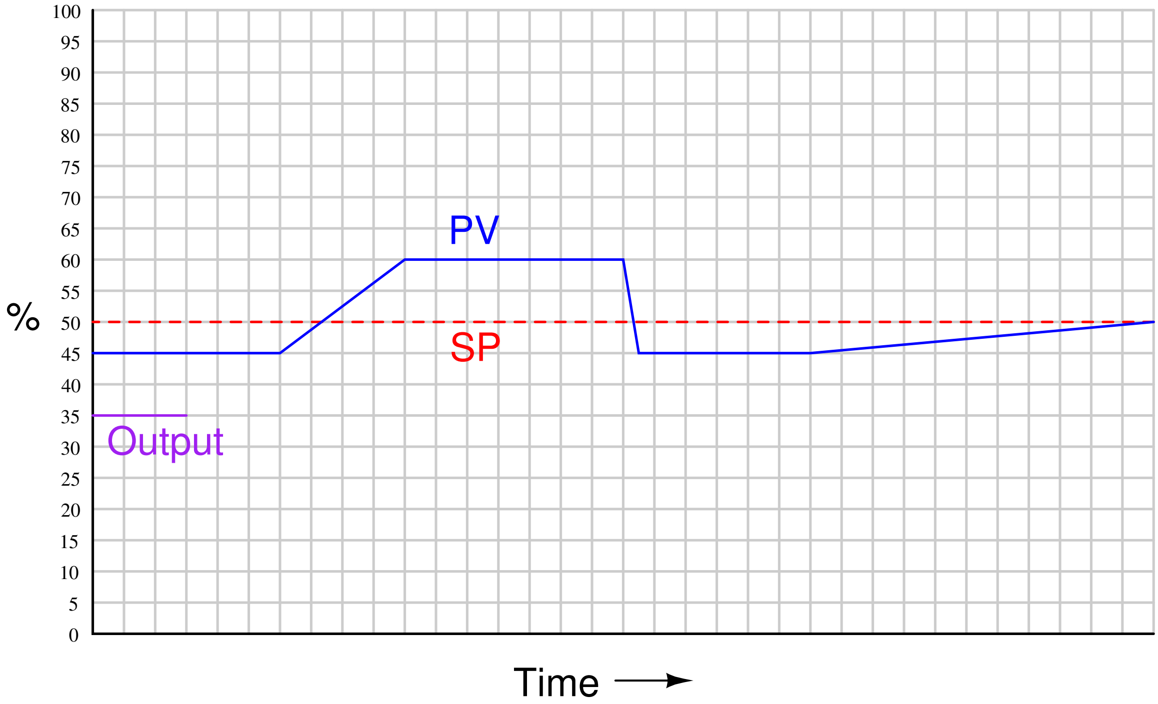
$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

$$m = K_p \left(e + \tau_d \frac{d(\text{PV})}{dt} \right) + b$$

file i03277

Oppgave 84

Qualitatively graph the response of a proportional-only controller over time to the following changes in process variable:

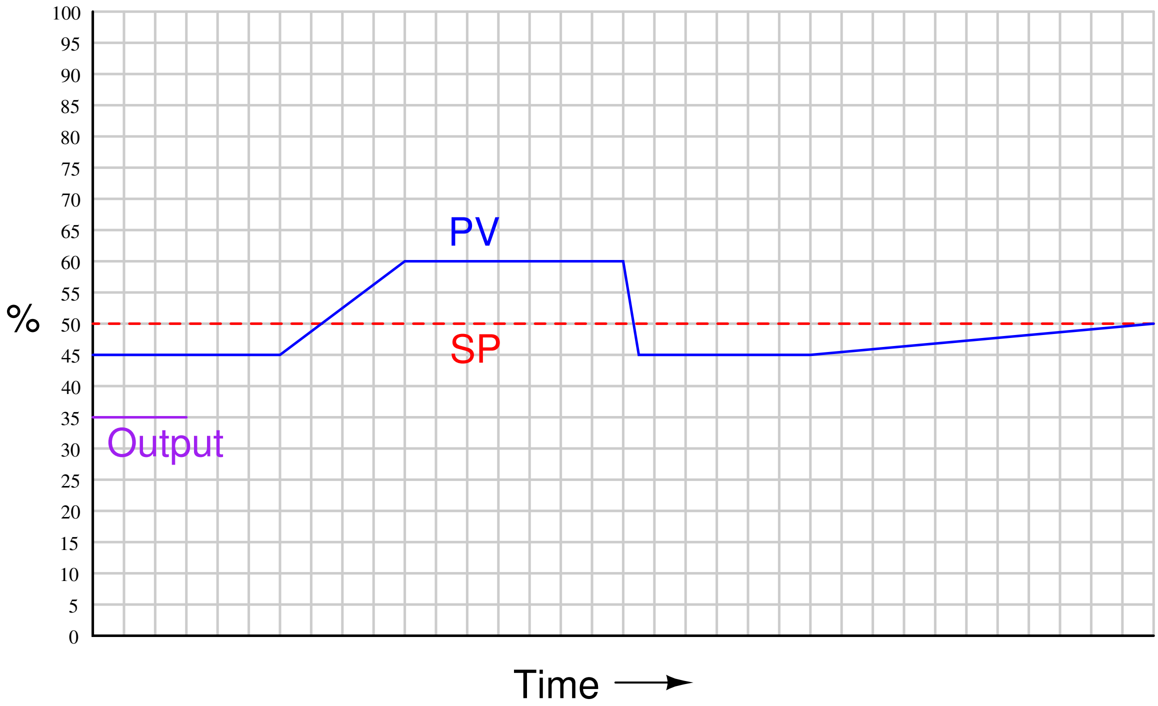


Assume *reverse* control action.

file i03278

Oppgave 85

Qualitatively graph the response of an hypothetical derivative-only controller over time to the following changes in process variable:

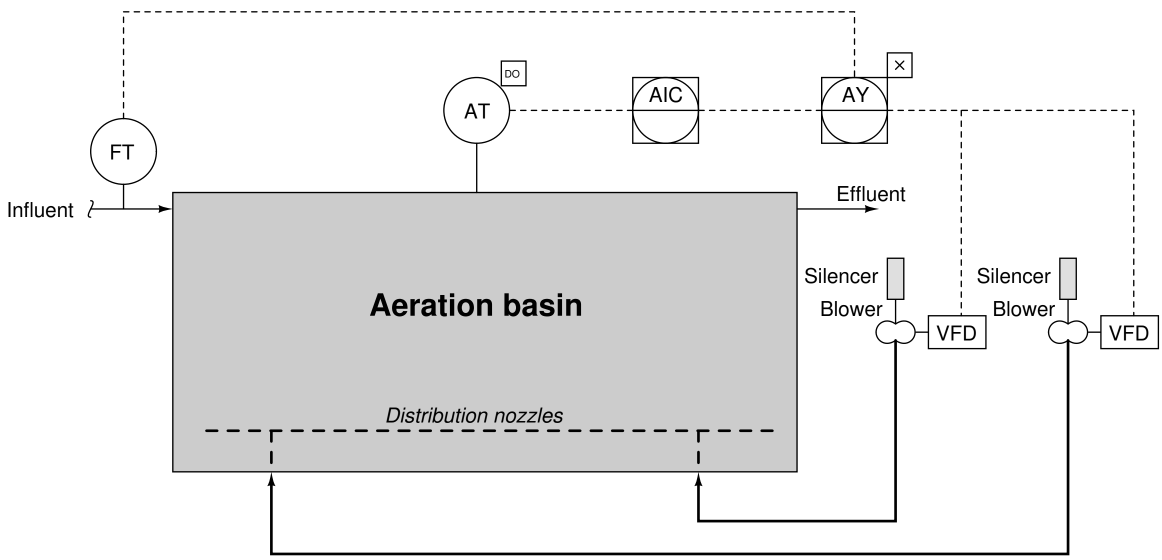


Assume *reverse* control action.

file i03279

Oppgave 86

One of the major processes used to treat municipal wastewater is *aeration*, where the dissolved oxygen concentration of the wastewater is enhanced by bubbling air through the water in an *aeration basin*. A dissolved oxygen ("DO") analyzer measures the oxygen concentration in the wastewater, and a controller varies the speeds of blowers pumping air into the basins using AC motors powered through variable-frequency drives (VFDs):



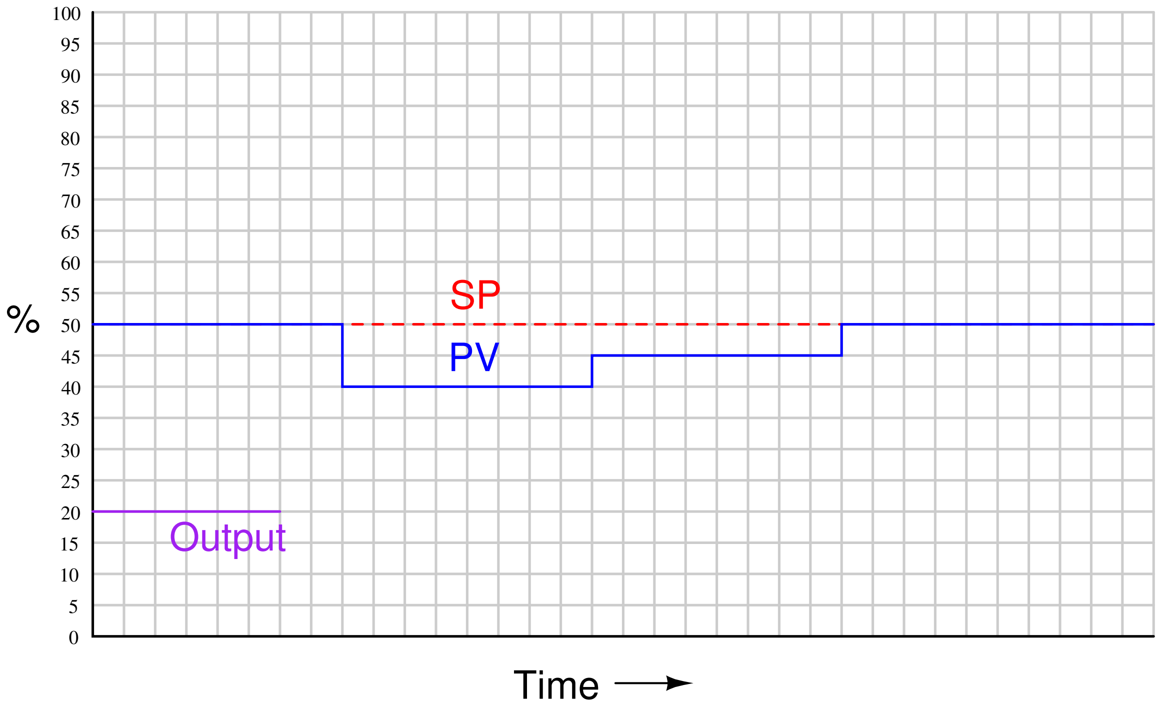
The control strategy used here is called *adaptive gain*. While similar in configuration to feedforward – where a load variable (in this case, influent flow rate) is used to alter the MV signal going to the final control element(s) of a feedback control loop – the relay used in this case is a *multiplier* rather than the more customary *summer* seen in conventional feedforward strategies.

Explain why a multiplying relay really is the most appropriate for this kind of application, "demonstrating" your explanation by posing a thought experiment of your own design.

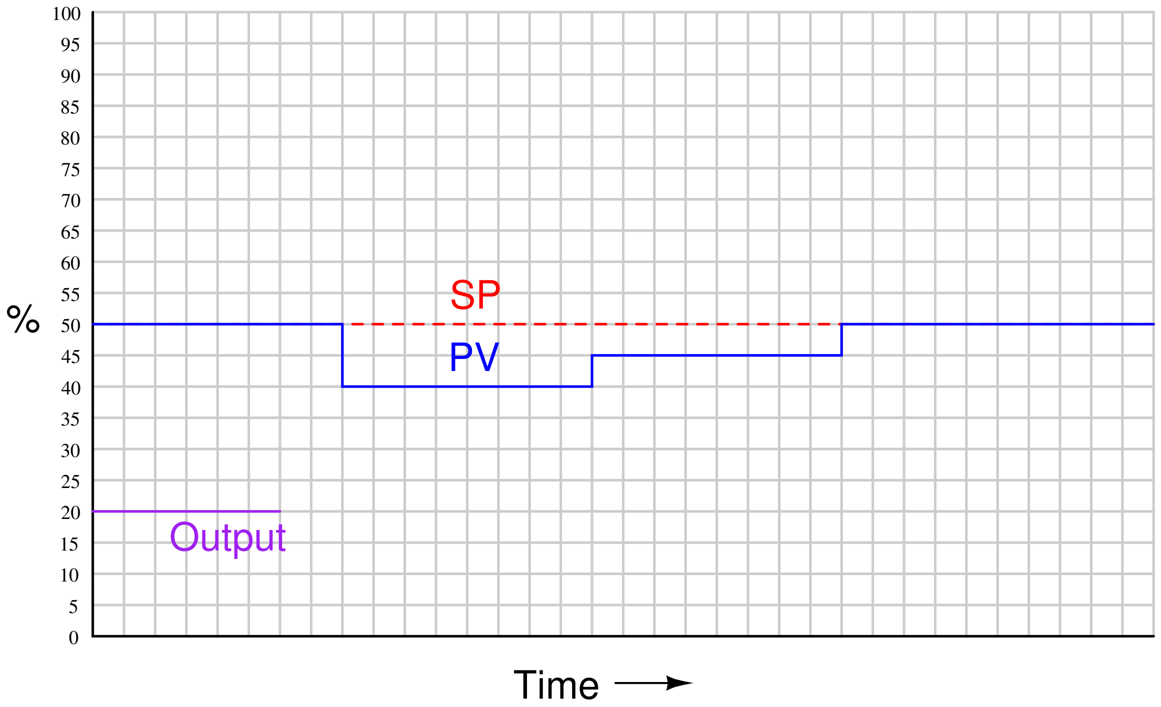
file i03291

Oppgave 87

Qualitatively graph the individual proportional, integral, and derivative responses of a PID controller to the following input conditions, assuming *reverse* controller action. Use a solid line for proportional, a dashed line for integral, and a dotted line for derivative:



Then, draw a final graph of the controller's output, showing how the P, I, and D terms would combine to form a composite waveform:


100
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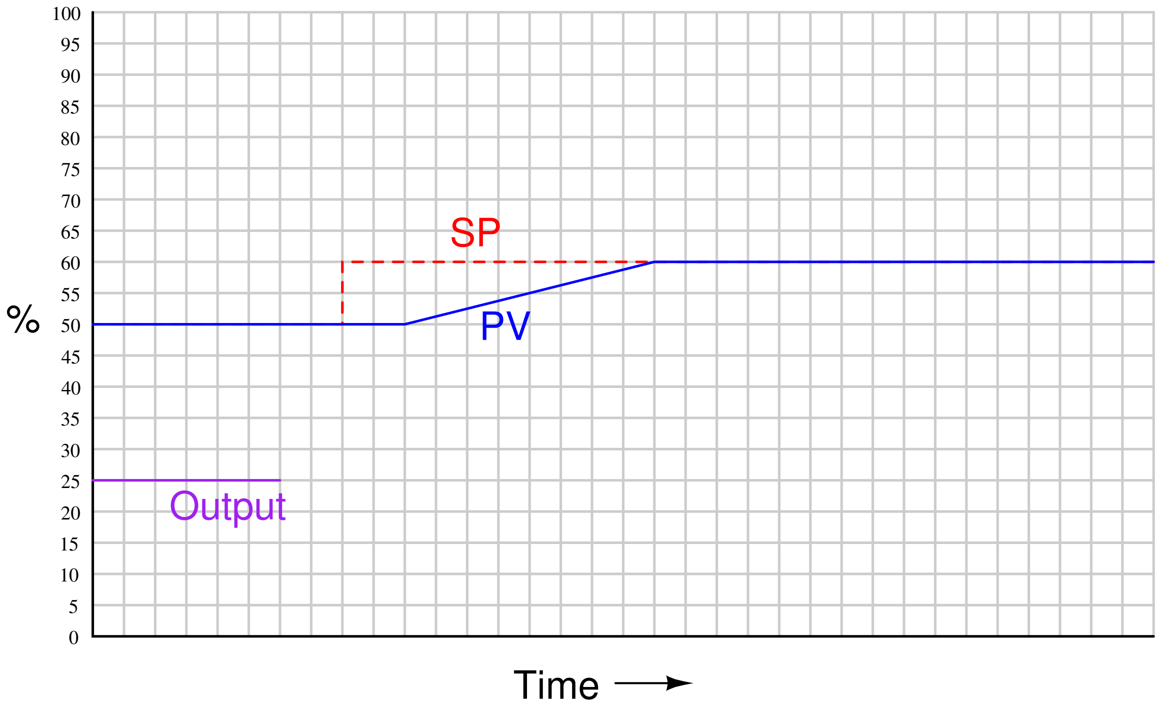
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
%
SP
PV
Output
Time

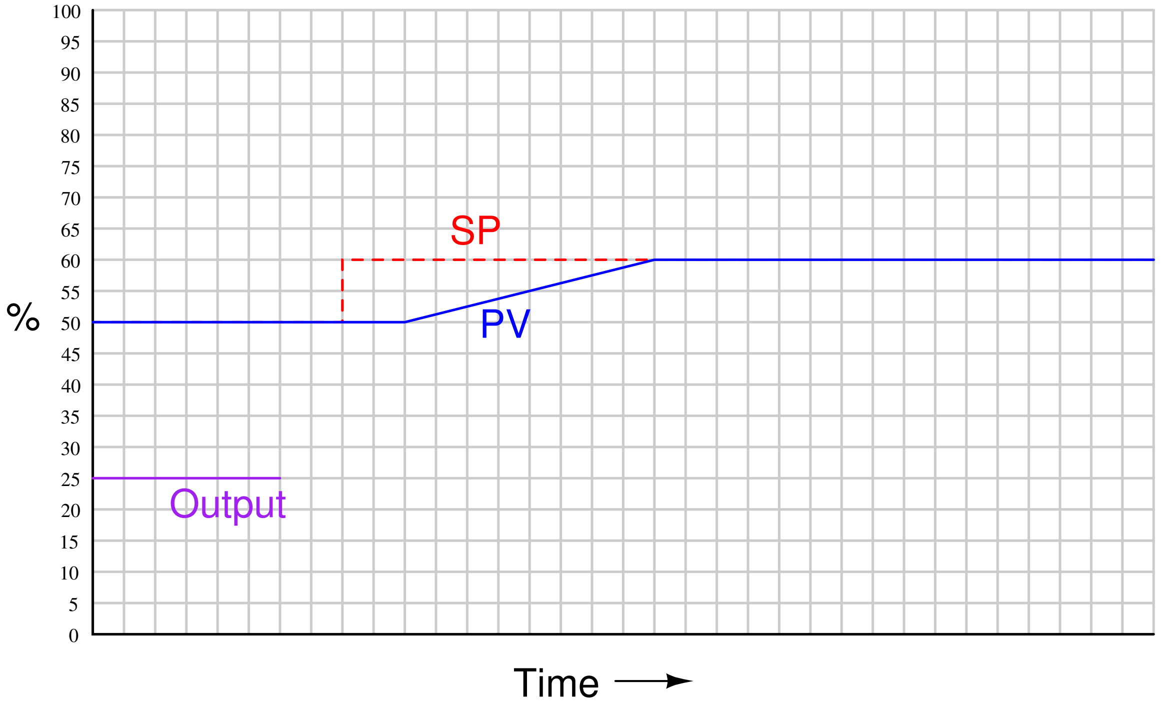
file i03303

Oppgave 88

Qualitatively graph the individual proportional, integral, and derivative responses of a PID controller to the following input conditions, assuming *reverse* controller action. Use a solid line for proportional, a dashed line for integral, and a dotted line for derivative:



Then, draw a final graph of the controller's output, showing how the P, I, and D terms would combine to form a composite waveform:


100
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20
15
10
5
0
%
SP
PV
Output
Time

file i03304

Oppgave 89

A computer spreadsheet program may be used as a simulator for a PID controller. By entering sets of values for Process Variable (PV), Setpoint (SP), Gain (K_P), Integral time constant (tau_I), Derivative time constant (tau_D), and Bias (B), we may program a spreadsheet to calculate the controller output values and even graph them.
Begin creating your own spreadsheet by following the format shown below:

	A	B	C	D	E	F	G	H	I
1	**Time (min)**	**PV**	**SP**	**Error**	**Derivative**	**Integral**	**Output**	**K_P -->**	2
2	0	50	50					**tau_I -->**	0.5
3	1	53	50					**tau_D -->**	5
4	2	56	50					**Bias -->**	50
5	3	59	50						
6	4	59	50						
7	5	57	50						
8	6	55	50						
9	7	53	50						

Assume a controller implementing the following P+D equation (note that our spreadsheet will calculate discrete steps rather than continuous change, hence the Δ notation instead of the more customary d notation, and the summation symbol Σ instead of the integration symbol $\int$):

$$\text{Output} = K_p e + \frac{1}{\tau_i}\Sigma(e\,\Delta t) + \tau_d \frac{\Delta e}{\Delta t} + b$$

Write equations for spreadsheet cells in columns `D`, `E`, `F`, and `G` so that the error term, derivative term ($\tau_d \frac{\Delta e}{\Delta t}$), integral term ($\frac{1}{\tau_i}\Sigma(e\,\Delta t)$), and total output values will be automatically calculated for any PV and SP values entered in columns `B` and `C`. Assume *direct action* for the controller.

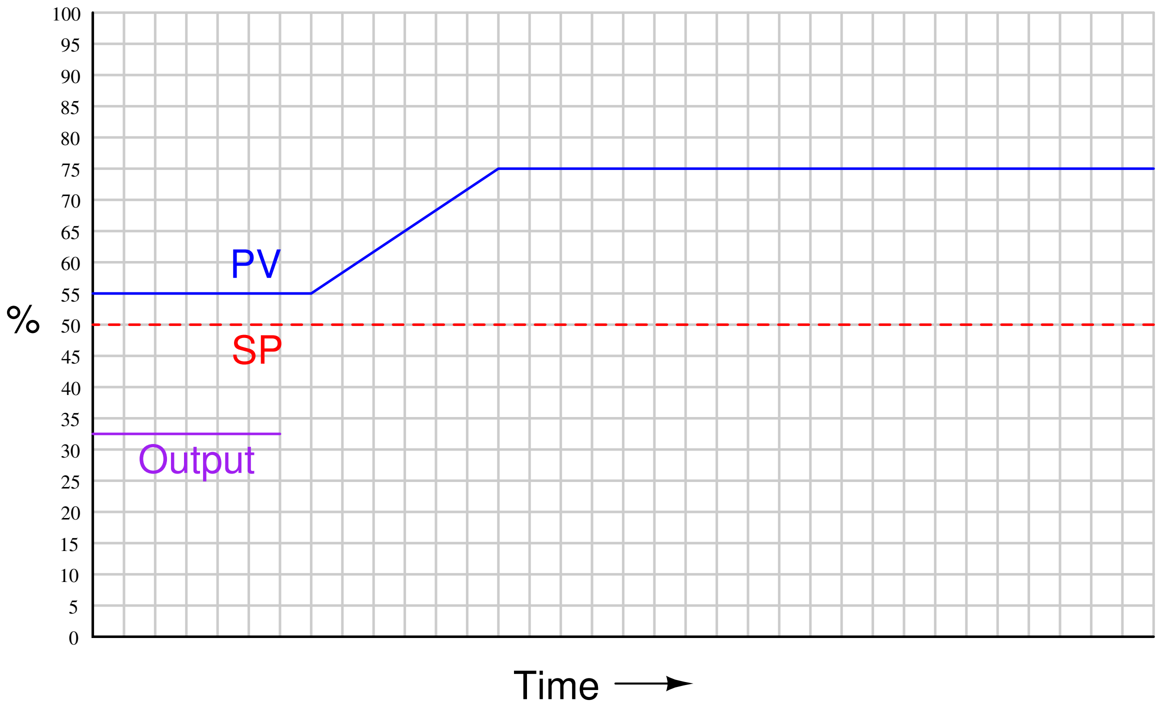
- Formula for cell `D3`:
- Formula for cell `E3`:
- Formula for cell `F3`:
- Formula for cell `G3`:

Note: your first formula begins on row 3 rather than row 2 because you need to compare two points in time (e.g. row 3 versus row 2) in order to calculate rates of change and

accumulated error-time products. Simply enter zero (0) for the derivative term value in cell `E2` as well as for the integral term value in cell `F2`.
file i03632

Oppgave 90

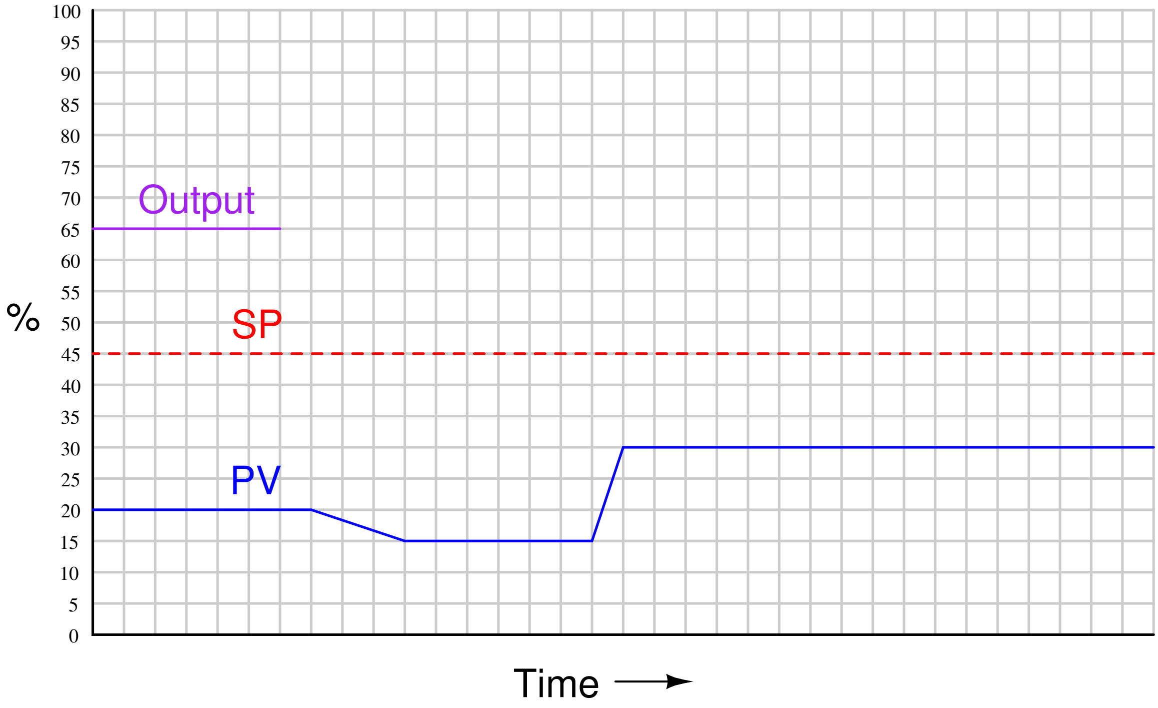
Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:



Assume *direct* control action.
file i03749

Oppgave 91

Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:

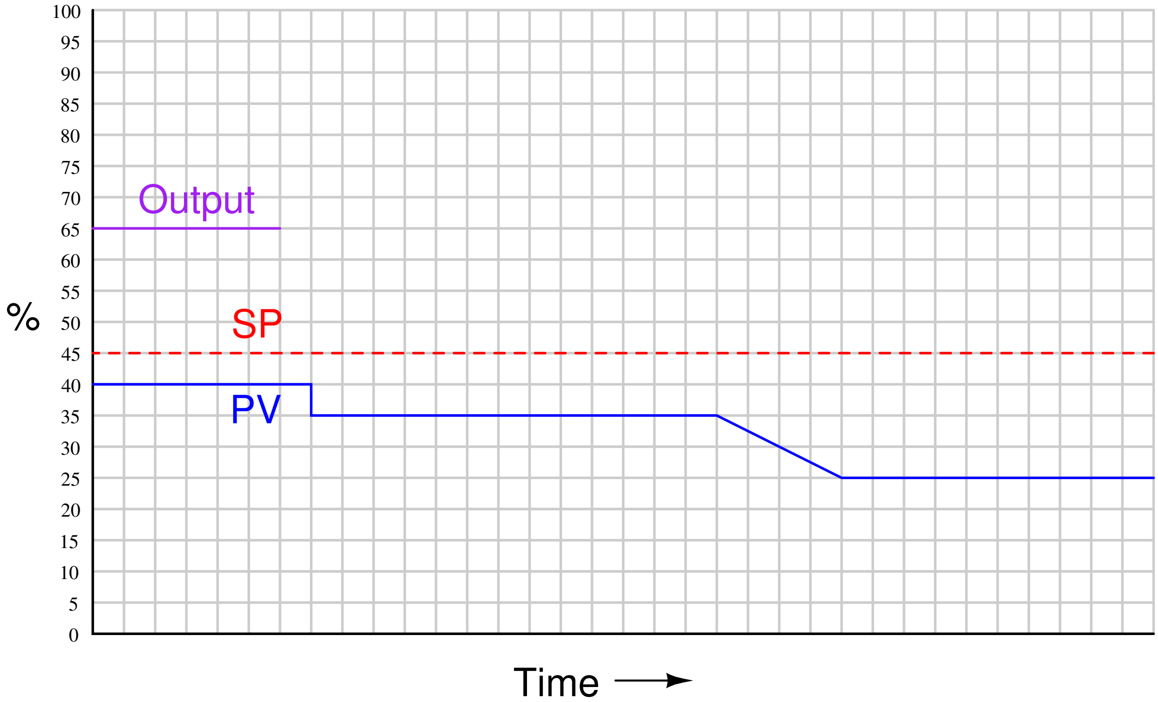


Assume *direct* control action.

file i03750

Oppgave 92

Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:

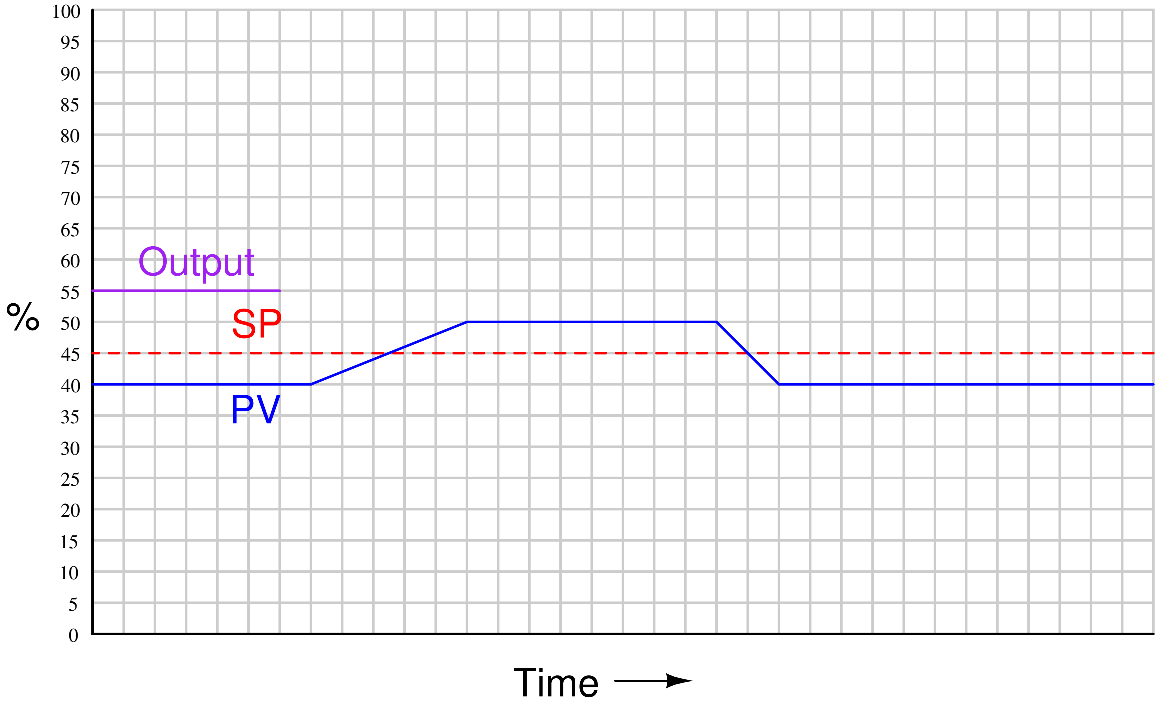


Assume *reverse* control action.

file i03751

Oppgave 93

Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:

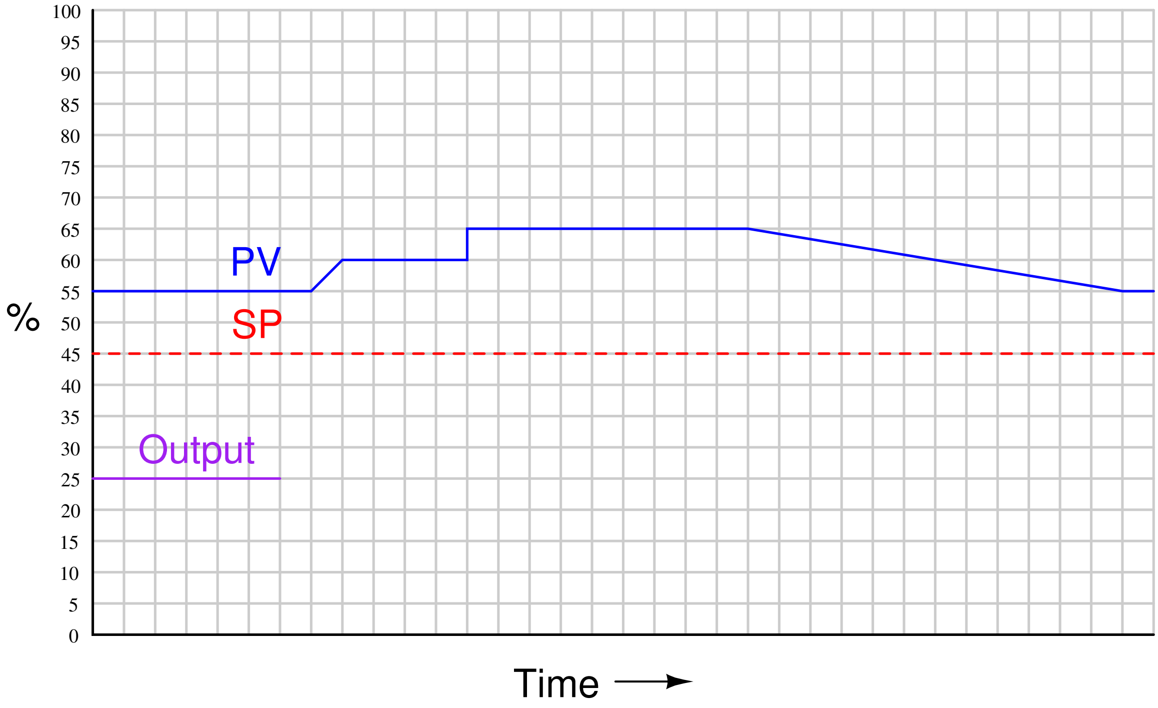


Assume *direct* control action.

file i03752

Oppgave 94

Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:

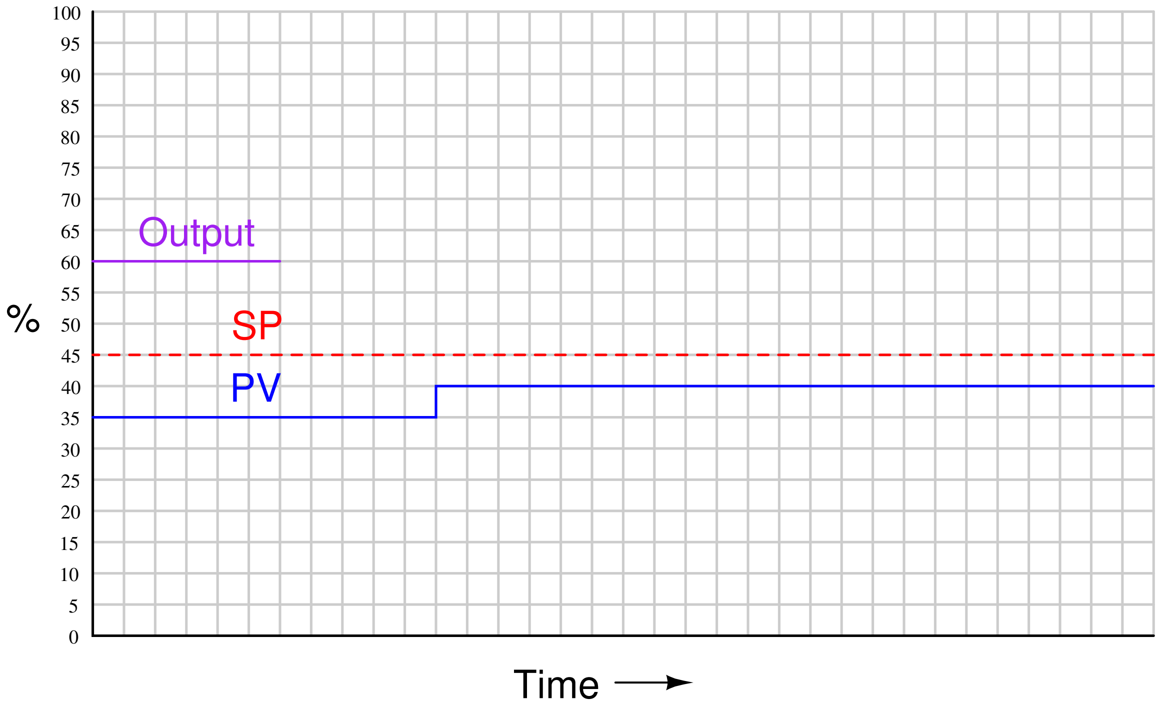


Assume *reverse* control action.

file i03753

Oppgave 95

Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:

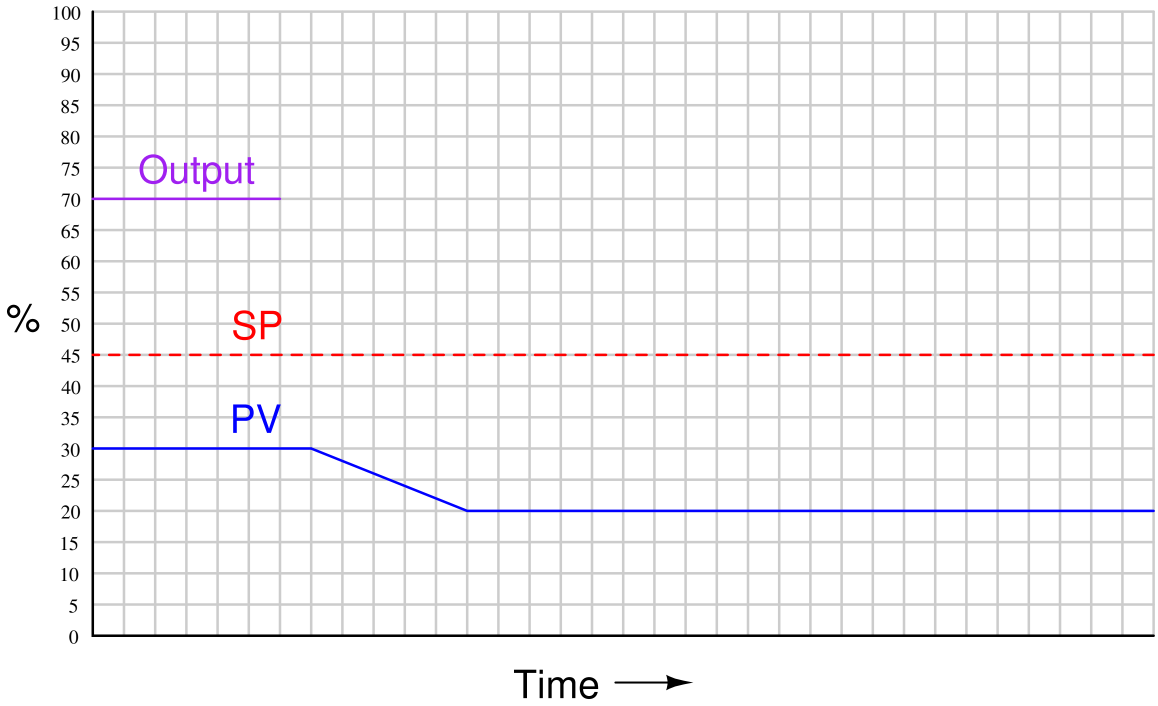


Assume *direct* control action.

file i03754

Oppgave 96

Qualitatively graph the response of a proportional-plus-derivative controller over time to the following changes in process variable:



Assume *reverse* control action.

file i03755

Oppgave 97

In their seminal 1942 paper *Optimum Settings for Automatic Controllers*, J.G. Ziegler and N.B. Nichols describe the compromise that must be struck when adjusting the gain ("sensitivity") of a controller having only proportional action:

"The rational adjustment of proportional-response sensitivity is then simply a matter of balancing the two evils of offset and amplitude ratio." (page 761)

Ziegler and Nichols used the phrase "amplitude ratio" to describe the severity of oscillations following a sudden change in setpoint or load. The "amplitude ratio" of an oscillation was a measure of each successive peak's height compared to the previous peak. A large amplitude ratio therefore referred to oscillations requiring many cycles to dampen, while a small amplitude ratio referred to oscillations dampening in very short order.

Describe this balancing act between the "two evils" of offset and oscillation while adjusting the gain setting on a process controller, making reference to your own experiences of adjusting gain settings on process controllers.

Suggestions for Socratic discussion

- Being that the solution to proportional-only offset is to use *integral* action in the loop controller in addition to proportional action, why do you suppose Ziegler and Nichols even bothered to suggest finding a compromise between low gain and high gain? Why not just suggest the use of integral action as a universal solution for the "two evils" of offset and amplitude ratio?

file i04288

Svar

Svar 1

- Example 1: increasing temperature, operator should close the valve more
- Example 2: increasing level, operator should open the valve more
- Example 3: increasing flow, operator should close the valve more
- Example 4: increasing temperature, operator should open the valve more

The goal with these questions is to think like an operator, in order to have a clear understanding of the process's needs. Only when one recognizes the required direction of valve operation to correct for an upset (off-setpoint) condition is it possible to properly and confidently configure an automatic controller to do the same. This is something every instrument professional needs to consider when designing and/or commissioning a control system: *which way does the final control element need to go, in order to stabilize the process variable if it deviates too high?*

In the first example, we would need to move the fuel gas valve further closed (toward the shutoff position) if ever the temperature got too high.

In the second example, we would need to move the drain valve further open to correct for a too-high liquid level in the vessel.

In the third example, we would need to move the flow control valve further closed (toward shutoff) if ever the flow rate measured too high.

In the fourth example, we would need to open the control valve further in order to reduce a too-high oil temperature exiting the heat exchanger. The rationale for this direction of valve motion is to increase the flow rate of the oil so that each molecule spends less time in the heat exchanger absorbing heat from steam and increasing in temperature.

Svar 2

A *load* is any variable in a process (besides the manipulated variable) that has influence over the process variable being controlled.

Note: the following answers are not exhaustive. In other words, there may be more loads than what is listed here for each process!

- Example 1: ambient air temperature
- Example 2: incoming flow rate
- Example 3: upstream and downstream pressures
- Example 4: steam flow rate, steam temperature

Svar 3

This is a *reverse-acting* level controller: the output rises when the PV input falls, and vice-versa.

"Proportional band" is the percentage that the controller input (SP − PV) must deviate in order to swing from 0% to 100% on the output. As you may have noticed, proportional band is the mathematical reciprocal of gain.

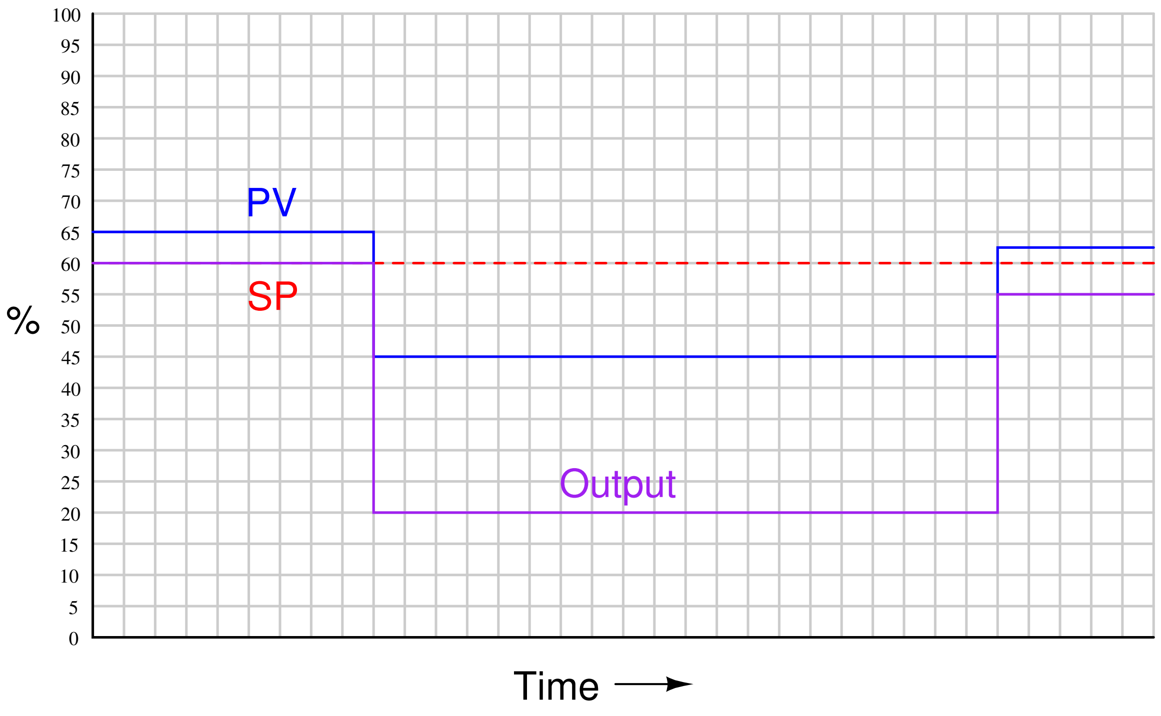
Svar 4

- Gain = 1; P.B. = 100%
- Gain = 2; P.B. = 50%
- Gain = 3.0; P.B. = 33.3%
- Gain = 0.5; P.B. = 200%
- Gain = 0.2; P.B. = 500%
- Gain = 0.01; P.B. = 10,000%
- Gain = 5.5; P.B. = 18.18%
- Gain = 10.2; P.B. = 9.804%

Svar 5

- P.B. = 150%; Gain = 0.667
- P.B. = 300%; Gain = 0.333
- P.B. = 40%; Gain = 2.5
- P.B. = 10%; Gain = 10
- P.B. = 730%; Gain = 0.137
- P.B. = 4%; Gain = 25
- P.B. = 247%; Gain = 0.4049
- P.B. = 9.5%; Gain = 10.53

Svar 6



Svar 7

- PV = 37%; SP = 50%; Output = **66%**
- PV = 92%; SP = 80%; Output = **16%**
- PV = 81%; SP = 75%; Output = **28%**
- PV = 33%; SP = 42%; Output = **58%**
- PV = 79%; SP = 76%; Output = **34%**
- PV = 15%; SP = 20%; Output = **50%**
- PV = 38%; SP = 38%; Output = **40%**
- PV = 0%; SP = 0%; Output = **40%**

Svar 8

The principle is fairly straightforward to figure out, but gain and setpoint are not as easy. To change gain, you could substitute a different-sized diaphragm in the valve actuator. Setpoint adjustments could be made by changing the *bench set* of the valve.

Svar 9

The problem is increased sensor gain with the new calibration range. The solution is to reduce the controller's gain (increase its proportional band) to compensate.

Svar 10

The controller outputs a *Pulse-Width Modulated* signal, the duty cycle of the on/off cycling modulating energy input to the process through the heating element.

Svar 11

This is a graded question – no answers or hints given!

Svar 12

In automatic mode:
Process flow rate (increase) $\rightarrow$ FT output signal (increase milliamps) $\rightarrow$ FC output signal (decrease milliamps) $\rightarrow$ FY output signal (decrease PSI) $\rightarrow$ FV position (moves further closed, pinching off liquid flow).

In manual mode:
Process flow rate (increase) $\rightarrow$ FT output signal (increase milliamps) $\rightarrow$ FC output signal (remains steady) $\rightarrow$ FY output signal (remains steady) $\rightarrow$ FV position (holds position).

The important part of this question is the difference in response between "automatic" and "manual" controller modes. In automatic control mode, the controller takes action to bring the process back to setpoint. In manual control mode, the controller just lets the process drift and takes no action to stop it.

At first, having a "manual" mode in a control system seems pointless. However, giving human operators the ability to manually override the otherwise automatic actions of a control system is important for start-up, shut-down, and handling emergency (unusual) conditions in a process system.

Manual mode is also a very important diagnostic tool for instrument technicians and operators alike. Being able to "turn off the brain" of an automatic control system and watch process response to manual changes in manipulated variable (final control element) signals gives technical personnel opportunity to test for unusual control valve behavior, process quirks, and other behaviors in a system that can lead to poor automatic control.

Svar 13

Svar 14

Gain = 0.5 and bias = 30%

Svar 15

`A` = `805` = 110 PSI (motor stop point)
`B` = `750` = 100 PSI (motor start point)
`C` = `700` = 90.8 PSI (low air pressure alarm point)

Svar 16

The automobile with "sensitive" steering has the greater process gain. As always, the "gain" of a system is a ratio of its output change to its input change ($\frac{\Delta \text{Out}}{\Delta \text{In}}$, or $\frac{d\text{Out}}{d\text{In}}$), and process gain is no exception.

Svar 17

Reducing the differential pressure drop across the valve will result in less flow when the valve is fully open. Of course, the flow rate will still be zero when the valve is fully closed. This means that the controllable flow *range* has been decreased as a result of decreased pressure drop across the valve.
With less of a controllable flow range, the flow will not change as much as it did before given the same change in valve position. That is to say, the process variable in this control system will be less sensitive to changes in valve position than before. In other words, we are faced with a *decreased* process gain.

Given a larger valve, the process gain will *increase*, because greater changes in flow rate will result from the same changes in valve position with a valve of greater size.
Technically speaking, the gain of the valve (ratio of valve coefficient, or C_v, versus position change) is a separate variable from the gain of the process itself (ratio of flow rate versus valve coefficient), and this is separate from the gain of the sensor (ratio of transmitter output percentage versus flow rate). However, here I use the term "process gain" to refer to the sensitivity of the whole control system, except the controller (the process vessels and piping, control valve, and flow transmitter).

Given a flow transmitter with a smaller range, the process gain will *increase*, because the same changes in valve position will now result in greater *percentage* changes in the transmitter output.

Svar 18

For each component in the control system, "gain" is defined in the same terms that gain is defined for any electronic component – the ratio of output change to input change:

$$\text{Gain} = \frac{\Delta\text{Out}}{\Delta\text{In}}$$

We may be more precise in our definition if we use calculus notation and express this ratio as a *derivative*:

$$\text{Gain} = \frac{d\text{Out}}{d\text{In}}$$

As for how and why to set the controller gain at a particular value, I will let you discuss this with your classmates and arrive at your own answer! I will say this, though: we do *not* want the system to break into oscillations!

Challenge question: as you may (should!) recall, a necessary condition for oscillation in a feedback system is that the feedback be *positive*. In other words, the phase shift from amplifier output to amplifier input needs to be 360^o, or else any oscillation will quickly die out due to interference, regardless of gain. This being said, how can a control system ever oscillate, because we know the feedback is normally *negative* in nature, not positive? Even if the controller gain were huge, shouldn't the inherently negative feedback of the system naturally prevent oscillation?

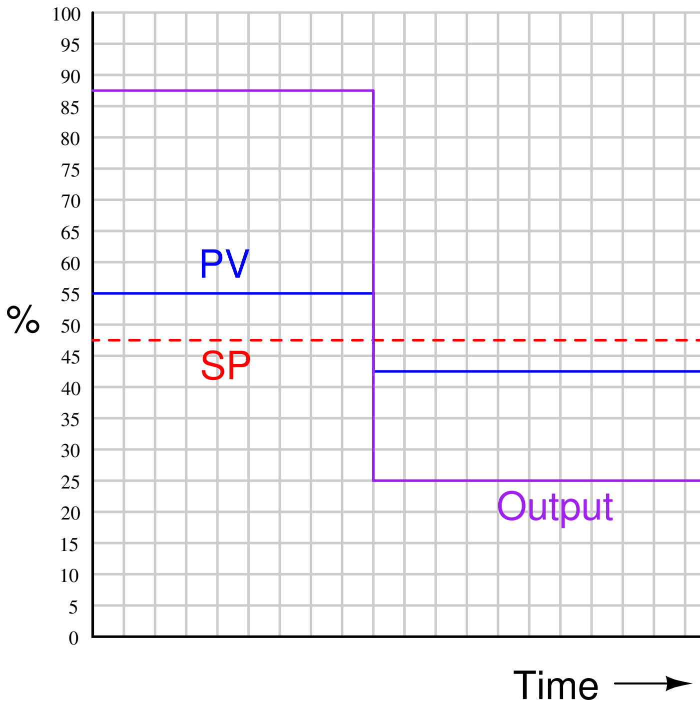
Svar 19

MV = SP − PV + 50%

Svar 20

The effect of a negative K_p value in a digital controller's algorithm would be to reverse the control action (from reverse-acting to direct-acting, or from direct-acting to reverse-acting), because a positive error would *decrease* the output, and vice-versa. This is assuming, of course, that the controller is programmed to accept such values. A wise programmer might make it impossible to enter negative tuning constant values, to avoid confusion from someone accidently entering one and unintentionally reversing the control action.

Svar 21


100
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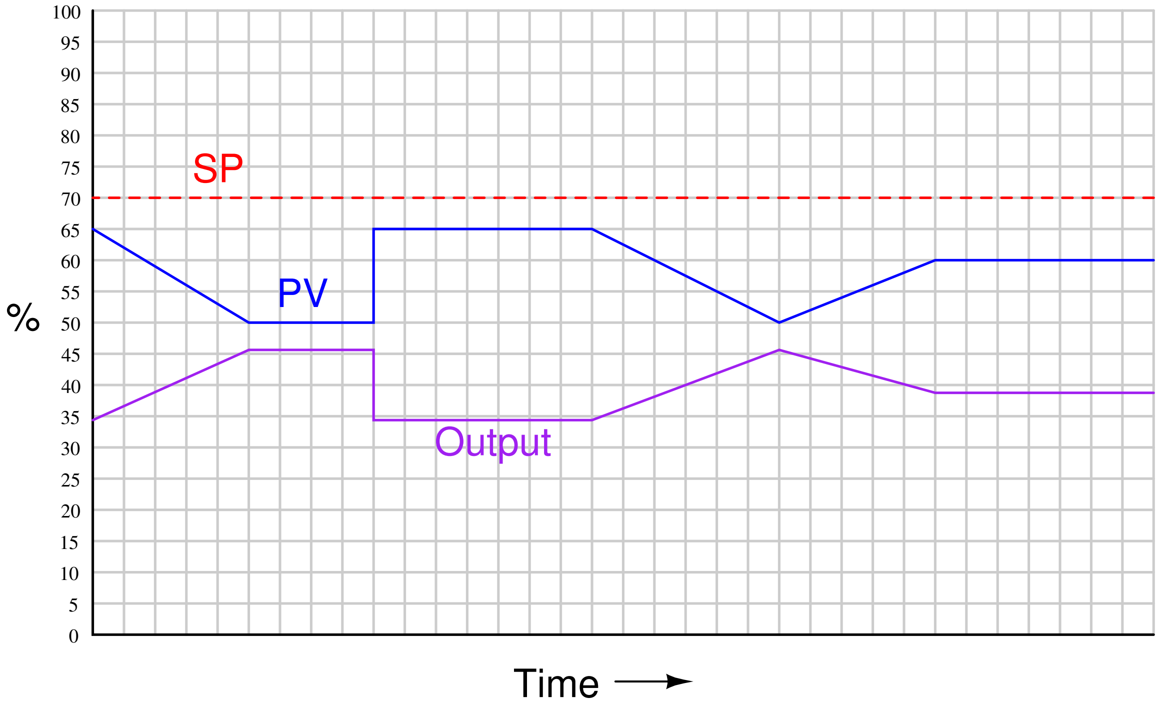
30
25
20
15
10
5
0
%
PV
SP
Output
Time

Svar 22

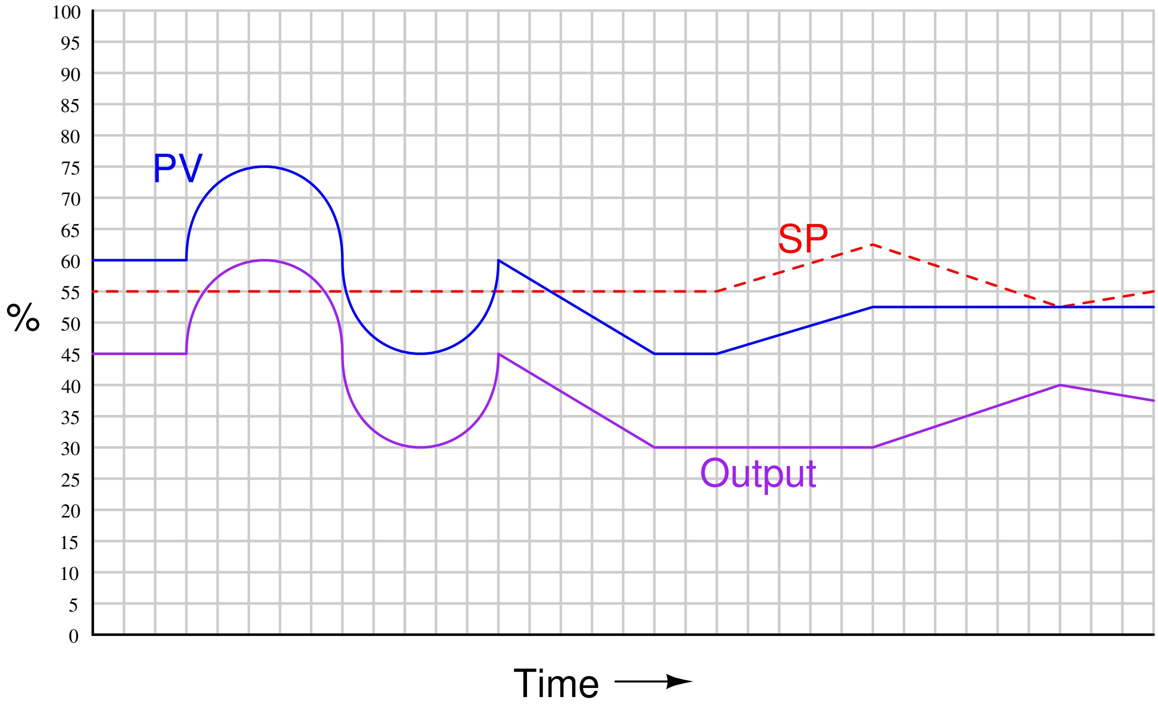


With a proportional band value of 125%, the gain will be equal to 0.8.

$$m = 0.8(\text{SP} - \text{PV}) + 30$$

PV	**SP**	**Output**
65%	70%	34%
50%	70%	46%
60%	70%	38%

Svar 23


100
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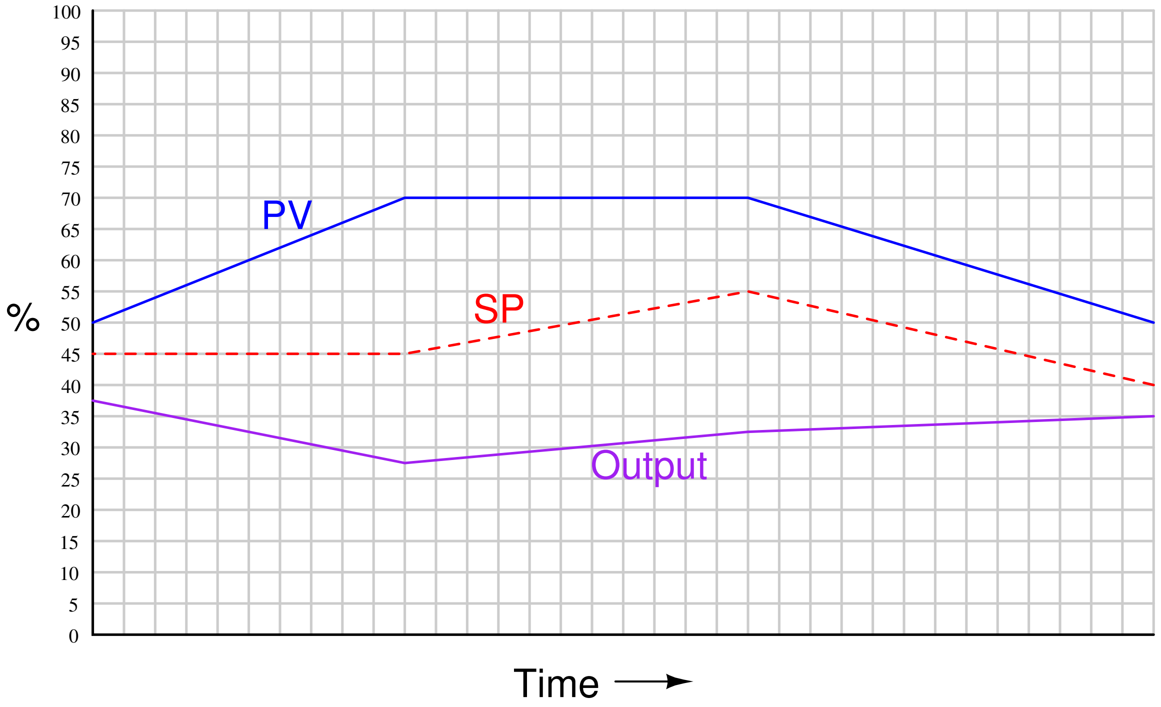
%
PV
SP
Output
Time

Svar 24



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50
45
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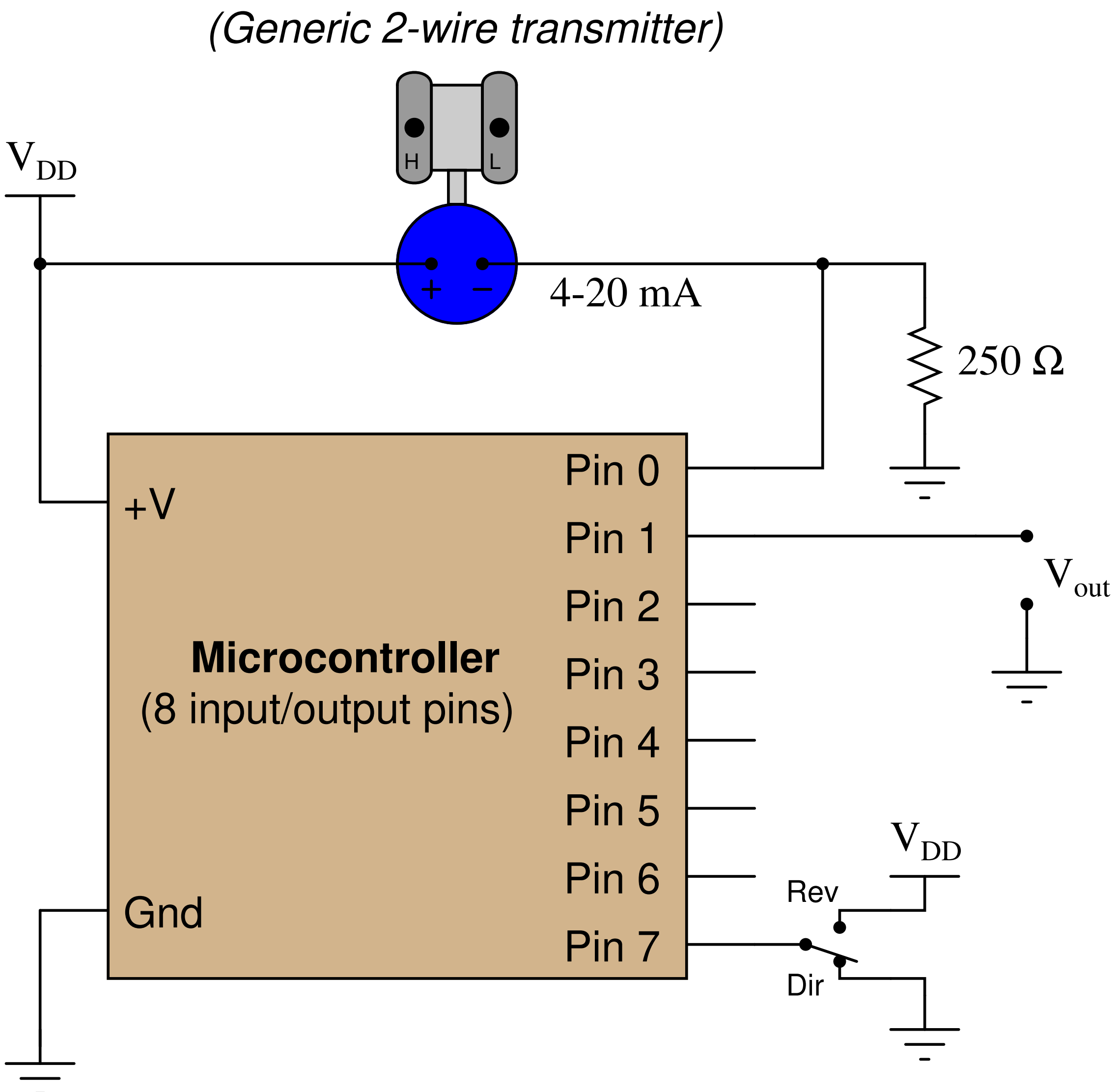
35
30
25
20
15
10
5
0
%
PV
SP
Output
Time

Svar 25

The controller code as shown implements *direct* action, since the error is calculated as PV − SP.

The following additions give this controller the ability to switch between direct or reverse control action:



Pseudocode listing

```
Declare Pin0 as an analog input (scale 0 to 5 volts = 0 to
1023)
Declare Pin1 as an analog output (scale 0 to 5 volts = 0
to 1023)
Declare Pin7 as a discrete input
Declare SP as a variable, initially set to a value of 614
Declare GAIN as a variable, initially set to a value of
1.0
Declare ERROR as a variable
Declare BIAS as a constant = 614

LOOP
  IF Pin7 = 0, SET ERROR = Pin0 - SP
  ELSE, SET ERROR = SP - Pin0
  ENDIF

  SET Pin1 = (GAIN * ERROR) + BIAS
ENDLOOP
```

While a very slow program execution time could be bad for control, it actually could serve a useful purpose in some processes. In processes with large dead times (transport delays), one control strategy to apply is called *sample-and-hold*, which is precisely what this program would be if a purposeful and substantial delay time were inserted into the loop.

Svar 26

This is a graded question – no answers or hints given!

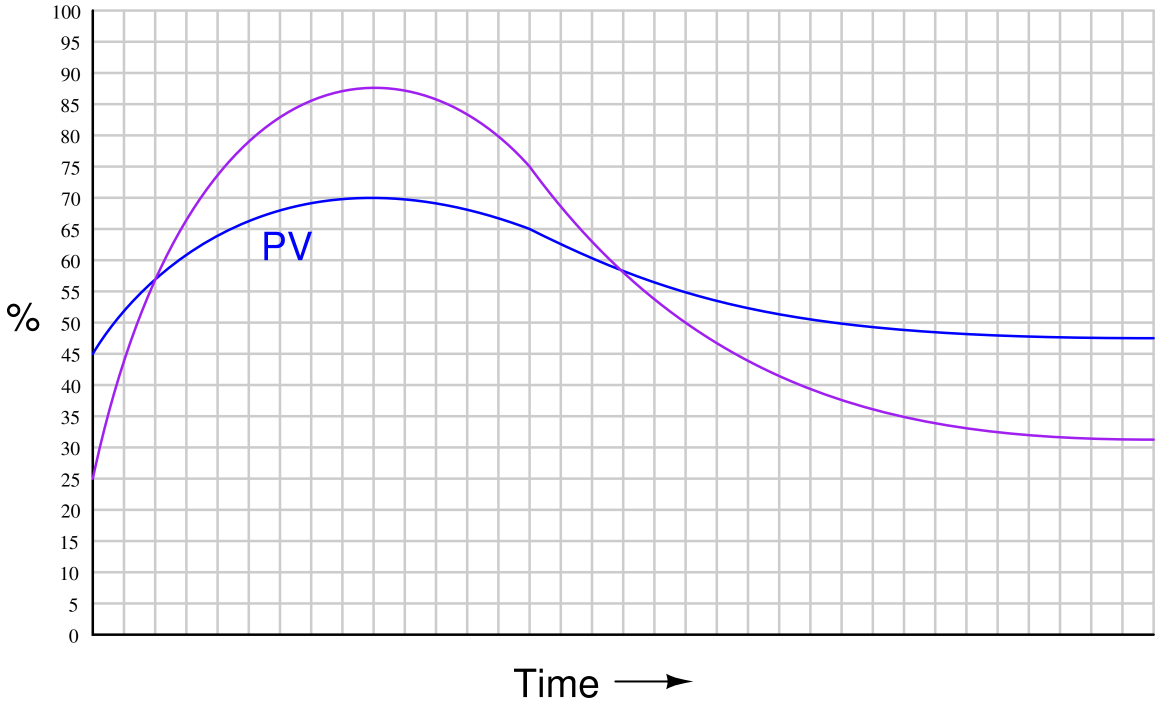
Svar 27

This will be a *direct-acting* controller, once the programming problem is fixed.

Svar 28

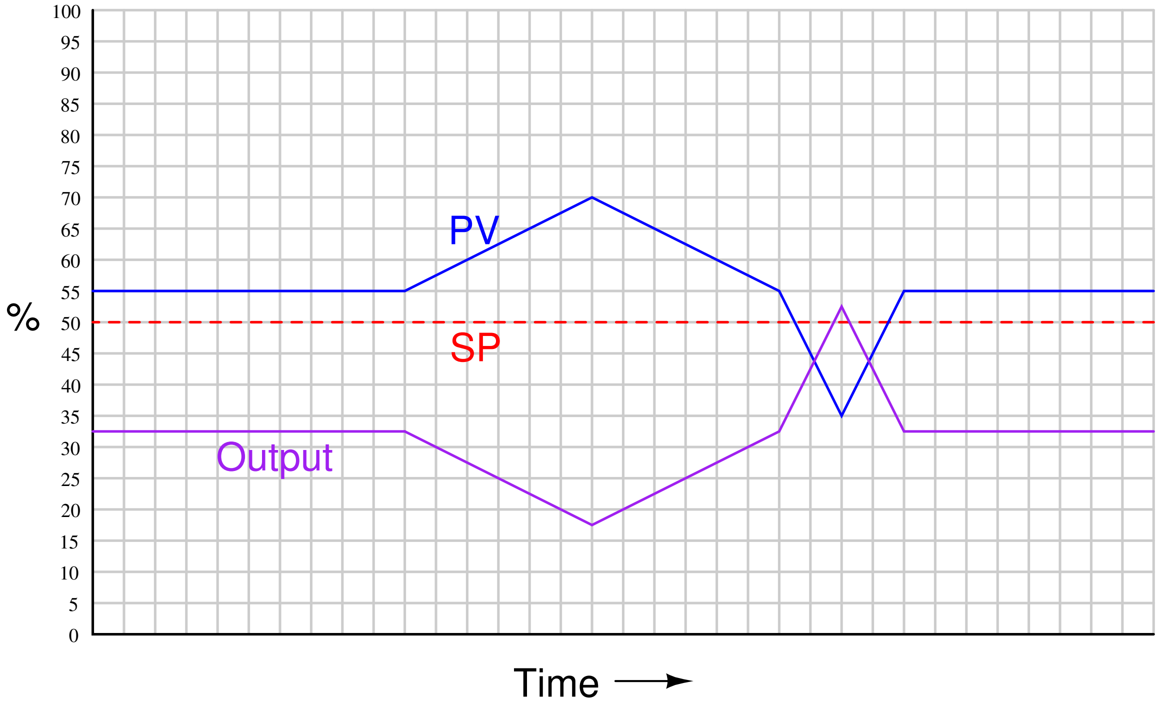
Proportional band = 66.67% ; reverse-acting control

Svar 29



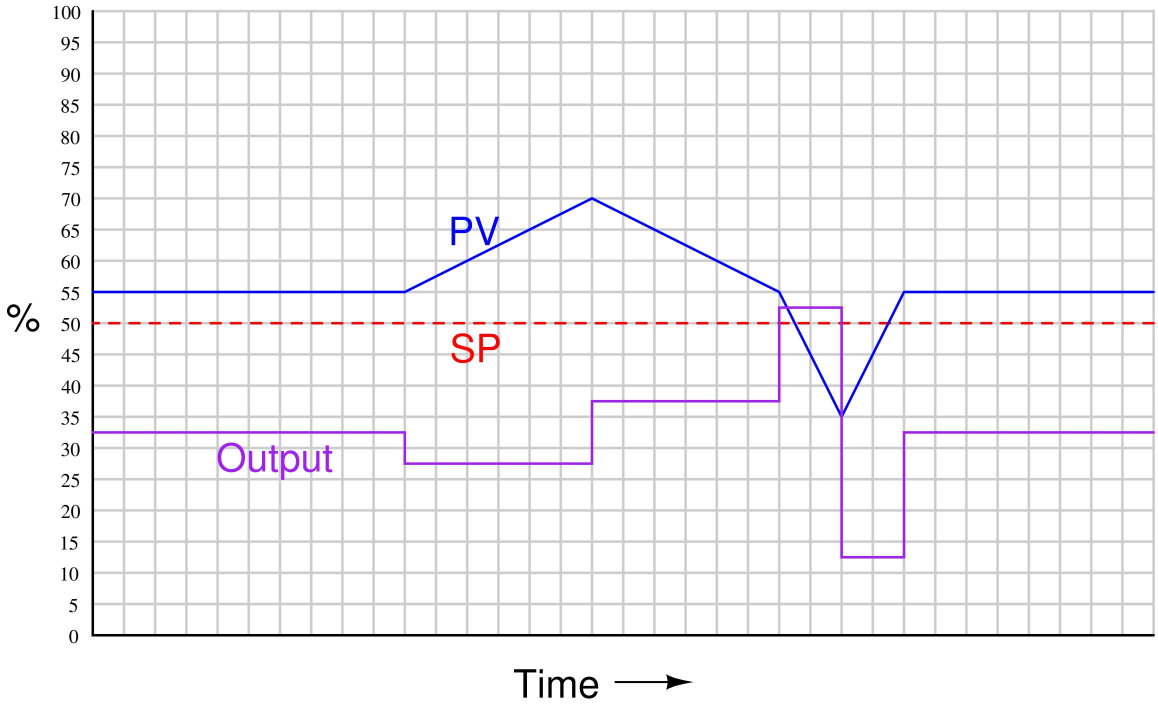
Svar 30

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Svar 31

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:

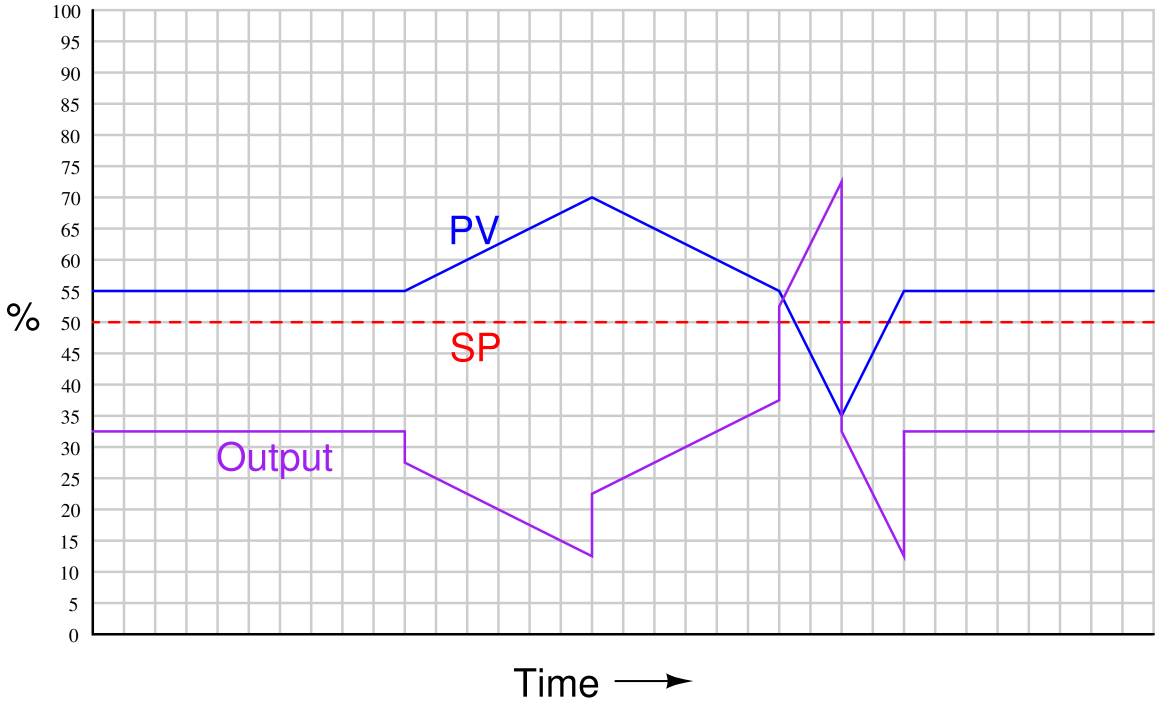


Derivative action looks only at the *rate-of-change* of the error signal. In this case, since the SP is constant, derivative acts only on the PV's *slope*. During the time period where the PV rises 15% over a run (time span) of 6 units, I plot the output as a constant 5% below the original output signal value (from 32.5% to 27.5%). When the PV falls the same amount (15%) over the same time span, the output goes to a value 5% above the original value (from 32.5% to 37.5%).

When the PV begins to fall at a faster rate (20% in 2 units), the rise/run slope ratio is 4 times as much as before. Thus, the output goes to a value 4 times as great as before (20% instead of 5%), from 32.5% to 52.5%. When the PV returns to SP at the same (steep) rate, the output drops 20% below the original starting value (from 32.5% to 12.5%).

Svar 32

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:

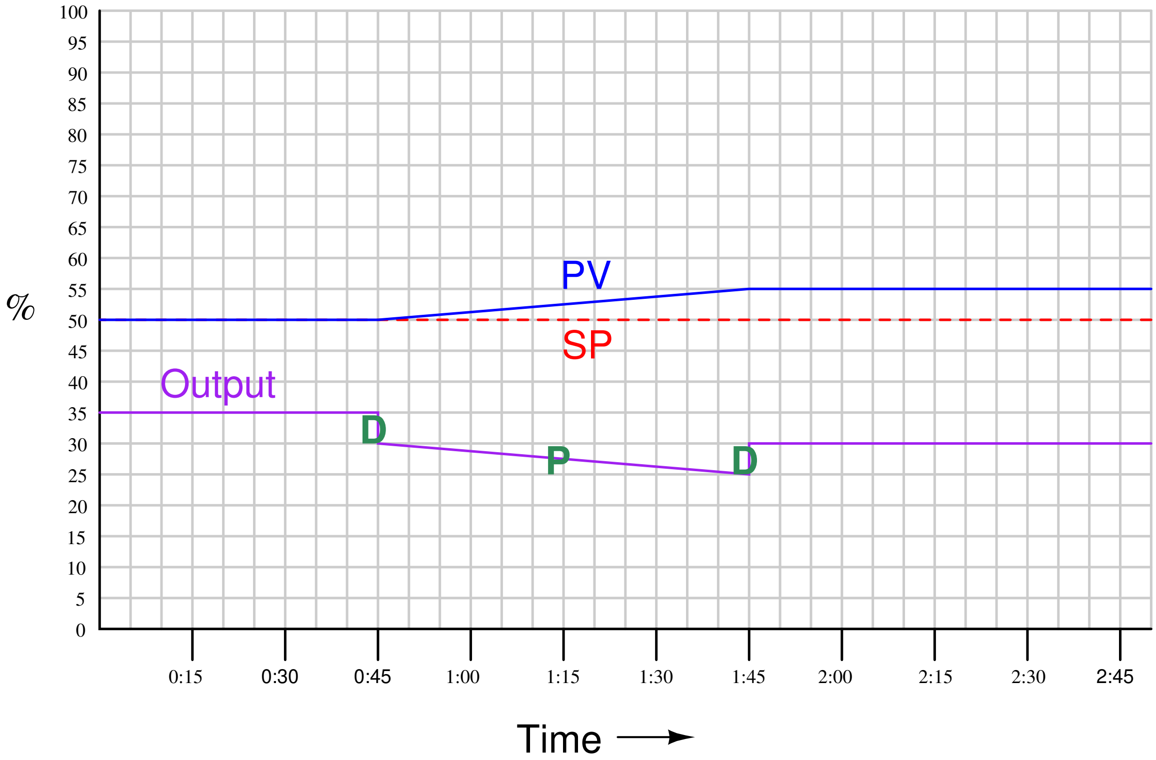


Svar 33

Controller action = *reverse*

$K_p = 1$

$\tau_d = 1$ minute = 60 seconds

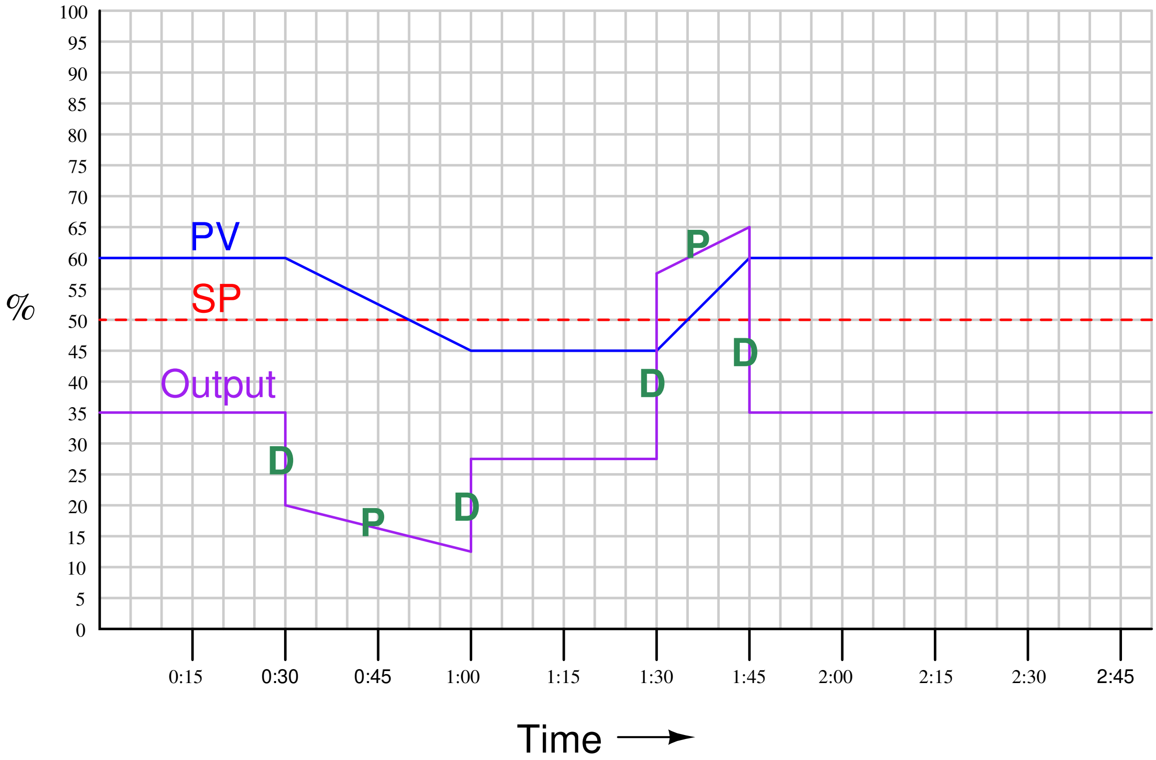


Svar 34

Controller action = *direct*

$K_p = 0.5$ (proportional band = 200%)

$\tau_d = 1$ minute = 60 seconds

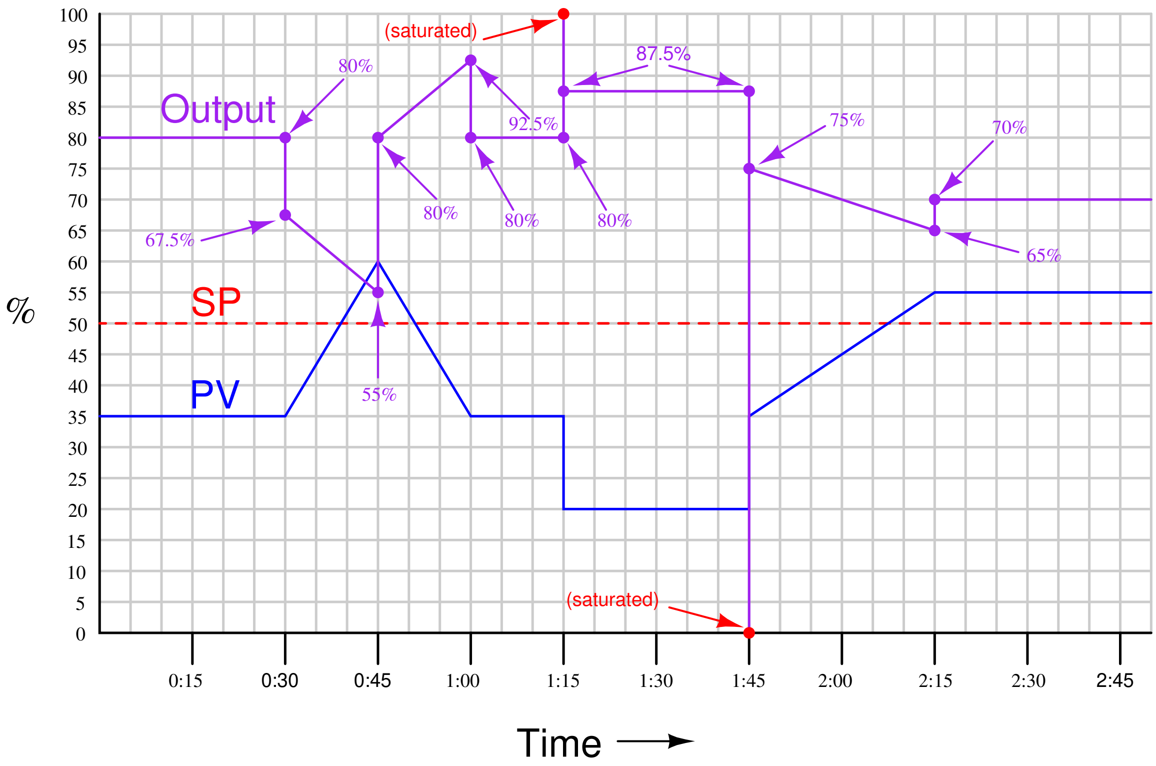


If the other algorithm were used, the gain and derivative constants would be:

$K_p = 0.5$ (proportional band = 200%)

$\tau_d = 0.5$ minute = 30 seconds

Svar 35

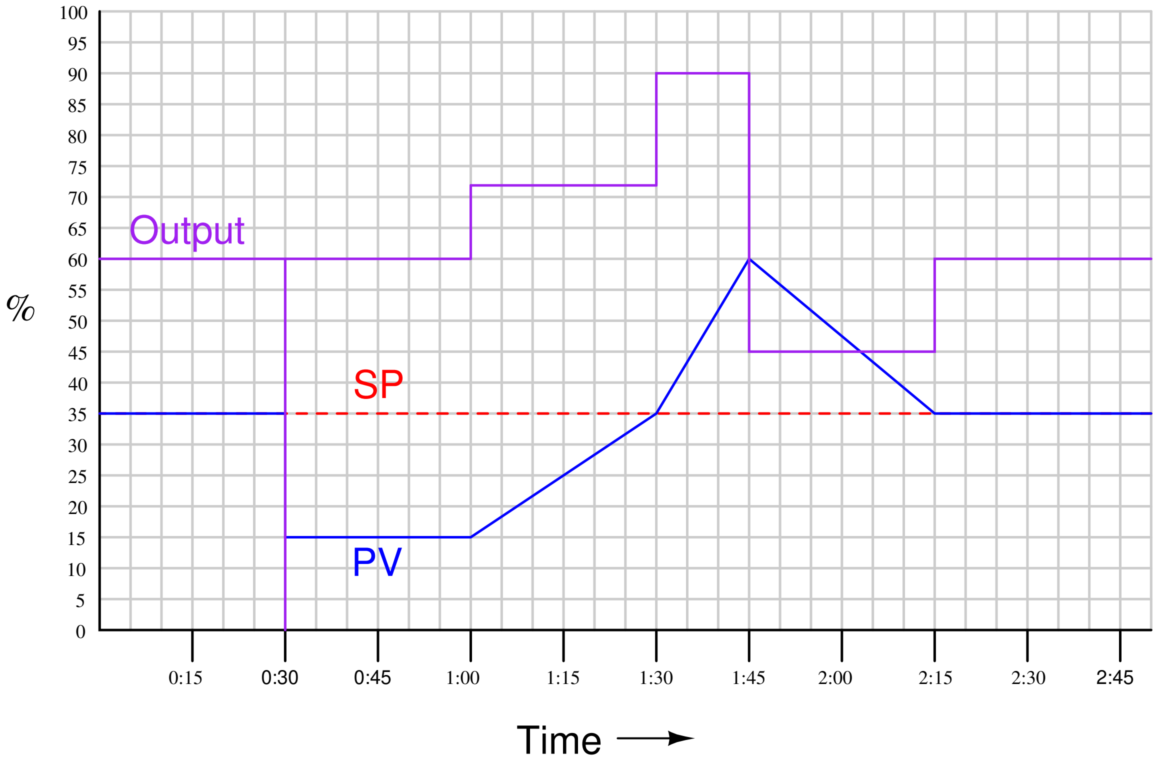


When the PV begins its initial upward ramp from 35% to 60%, it does so at a slope of 100% per minute (25% over a 15 second period of time). Since derivative action is the slope multiplied by the derivative constant (15 seconds, or 1/4 minute), multiplied by the gain (PB of 200% = gain of 0.5), the derivative term's action here is to step down 12.5%. Then, we see proportional action (with a gain of 0.5) ramp the output down at a slope 1/2 that of the PV's slope, to a point of 55%.

Then, when the PV ramp reverses direction and descends at the same rate it ascended previously, the derivative action stops *subtracting* 12.5% from the output and begins to *add* 12.5% to the output, for a total step-change in the output of 25% (from 55% to 80%). Proportional action, of course, ramps the output up 12.5% from time 0:45 to time 1:00 (from 80% to 92.5%) as the PV changes 25% in 15 seconds. When the PV levels off at 1:00, at the same value it stated at, the derivative action ceases, and the output returns to its original value of 80%.

At time 1:15, the 15% downward step-change taken by the PV causes derivative action to go "wild" and saturate the output at 100%. Proportional action steps up the output by 7.5%, so that after the transient rise of the PV the output settles at 87.5%. At time 1:45, the 15% upward step-change of the PV causes derivative action to saturate the output once more, this time in the downward direction at 0%. After this transient, the output settles at 75%: a combined effect of proportional action (driving the output down to 80%) and derivative action (driving the output down 5%, because the PV's upward slope is 40% per minute – 40%/min times 0.25 minutes times a K_p of 0.5). Proportional action ramps the output down 10% (from 75% to 65%) until time 2:15, when the ramping stops and derivative action ceases, allowing the output to step up by 5% (from 65% to 70%) to its final value.

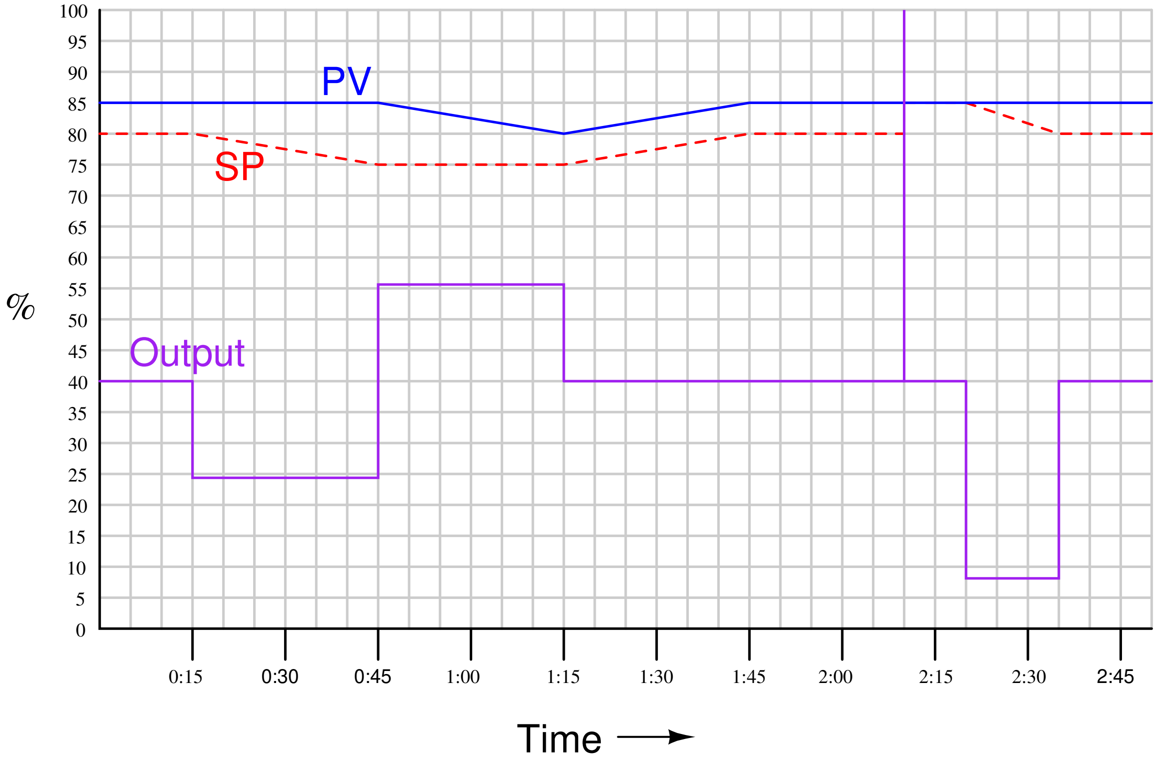
Svar 36



First, let us understand that a proportional band of 500% is equivalent to a gain of 1/5, or 0.2.

The downward step-change of the PV at time 0:30 causes the derivative to saturate the output to 0%. When the PV levels off, the derivative response goes to 0, leaving the output at the value where it started (60%).
From 1:00 to 1:30, the PV ramps from 15% to 35%, for a de/dt slope of +40% per minute. Multiplied by a τ_d constant of 1.5 and a gain (K_p) of 0.2, the derivative term's contribution is +12%. Thus, the output steps from 60% to 72%.
At 1:30, the PV ramp increases to a rate of 100% per minute (from 35% to 60% over 15 seconds), resulting in a derivative term output of +30%. Thus, the output steps to new level of 90% (original 60% value + 30% = 90%).
Between 1:45 and 2:15 the PV slopes negatively. This results in a negative derivative response (60% to 35% over 30 seconds = -50% per minute, times 1.5 times 0.2 = -15%). Thus, the output goes from 60% to 45%.
At 2:15, the PV levels off and the derivative response ceases, leaving the output at its original value of 60%

Svar 37



First, let us understand that a proportional band of 250% is equivalent to a gain (K_p) of 0.4. Also, we must realize that as a reverse-acting controller, the output will go in the same direction as the SP, but opposite that of the PV.

As the SP descends 5% between 0:15 and 0:45, it creates a de/dt slope of -10% per minute. This figure, times $\tau_d = 4$ and times $K_p = 0.4$ gives us a derivative term contribution of -16%. Thus, the output steps down from 40% to 24% during this time.
When the PV descends at the same rate between 0:45 and 1:15, derivative action drives the output up by the same amount (16%), from 40% to 56%.
Between 1:15 and 2:10, there is no change of error between PV and SP, even though ramping takes place between 1:15 and 1:45. At 2:15, the positive SP step-change causes the output to saturate at 100% momentarily, then return to 40%.
From 2:20 to 2:35, the SP slopes downward 5%, for a de/dt rate of -20% per minute. This gives a derivative response of -32%, stepping the output down from 40% to 8%. At time 2:35 when the SP stops ramping, the derivative action ceases and the output returns to 40%.

Svar 38

To increase τ_d, turn the "derivative valve" a bit further shut.

Svar 39

The trickiest part to understand is the relationship between `x` and `last_x`, and between `t` and `last_t`. This technique of declaring a variable pair and sequentially cascading a value from one variable to the next variable in each loop of execution, is commonly used in a lot of different algorithms. The point of this technique is to provide a means of measuring change in a variable (such as `x` and `t`) with every scan of the program. Once change in x and t are both known, the quotient (derivative) may be calculated by dividing one change by the other.

Svar 40

Given an error of 6%, and an integral coefficient of 1.6 repeats per minute, the controller output will change by 9.6% every minute of time. Use this ramping rate-of-change as the basis for all your calculations.

Svar 41

I will answer this question with another question: imagine if the controller actually *did* attain the new setpoint value of 250 GPM. If it did, what would the valve position be in this condition of equilibrium where both SP and PV are equal to 250 GPM? Now, compare this with the valve position when both SP and PV were equal to 180 GPM. Do you see now why PV = SP = 250 GPM is impossible?

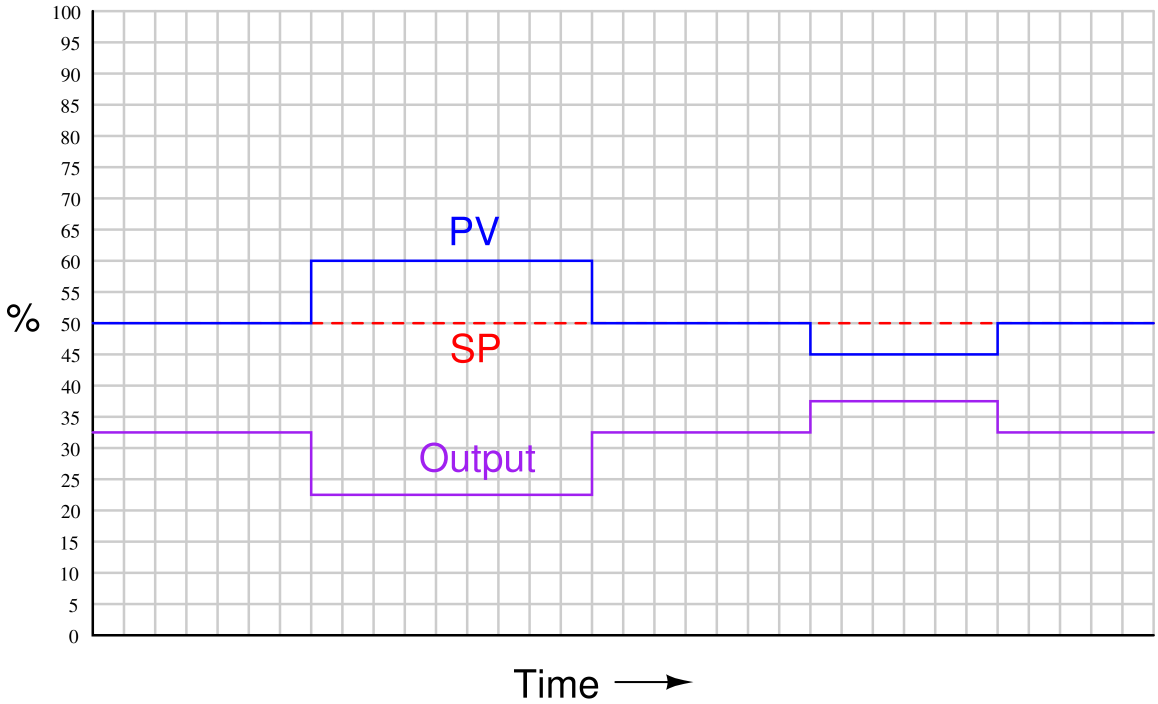
Challenge question: what effect does gain (K_p) have on the controller's inability to attain setpoint values other than 180 GPM?

Svar 42

I will let you discuss this with your classmates to arrive at an explanation!

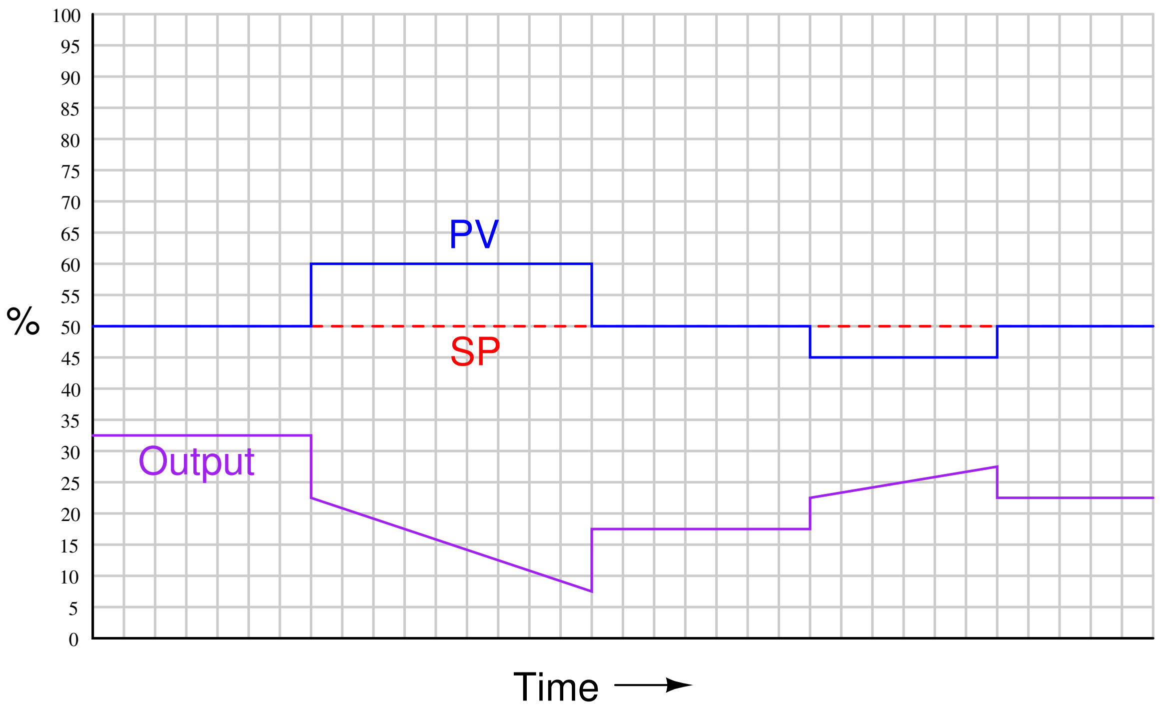
Svar 43

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Svar 44

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Svar 45

Controller action = *reverse*

Gain constant = 0.5

τ_i = 1 minute per repeat (K_i = 1 repeat per minute)

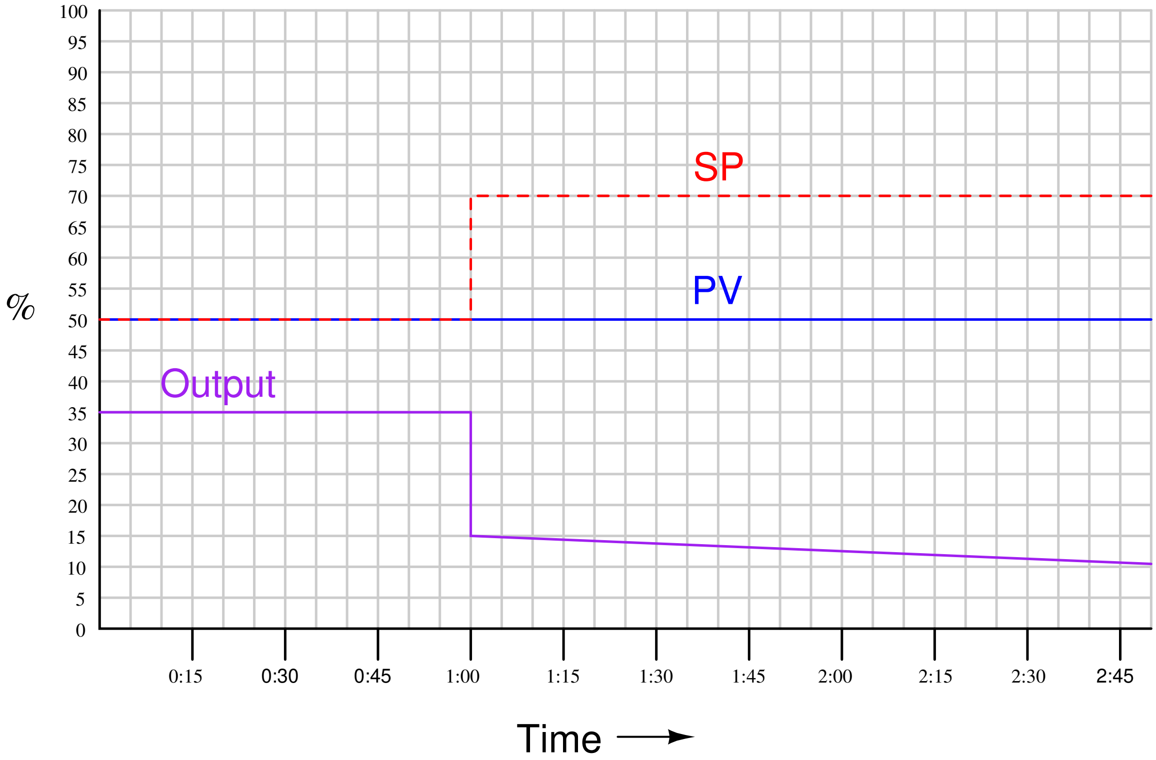
Svar 46

Controller action = *direct*

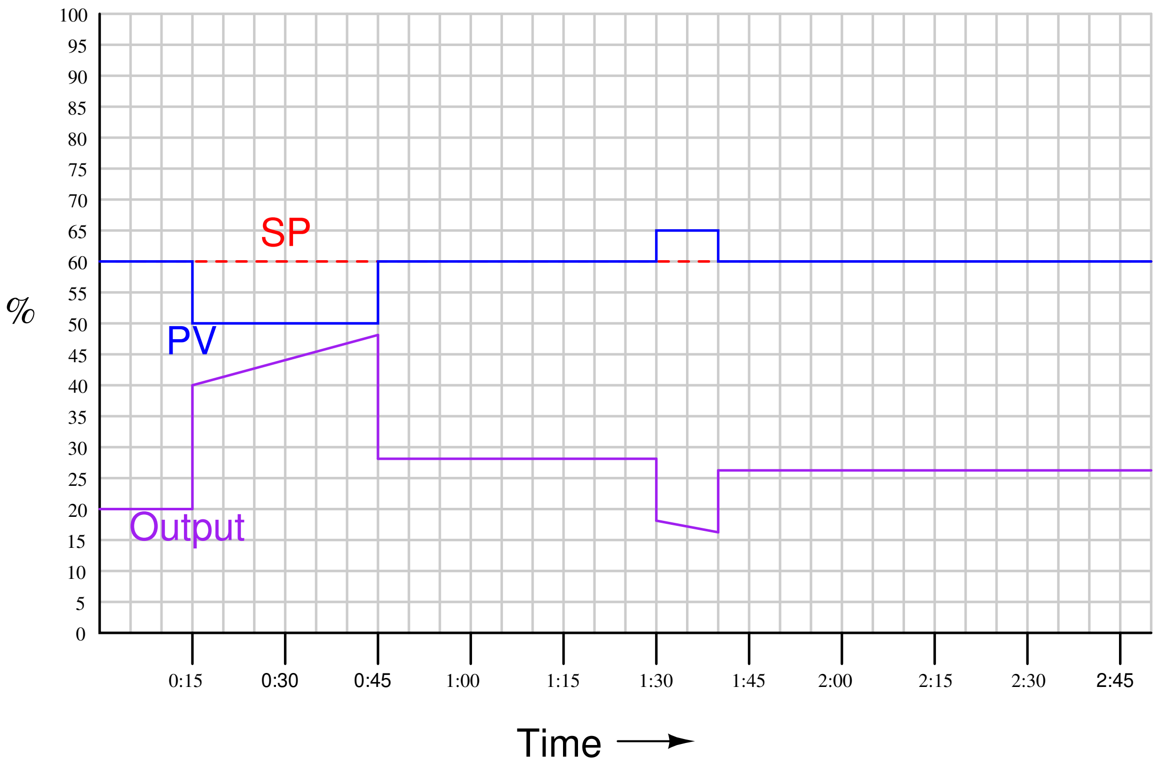
Gain constant = 1, or 100% proportional band

Integral constant = 0.25 repeats per minute (τ_i), or 4 minutes per repeat (K_i)

Svar 47


100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
%
SP
PV
Output
0:15
0:30
0:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
Time

Svar 48

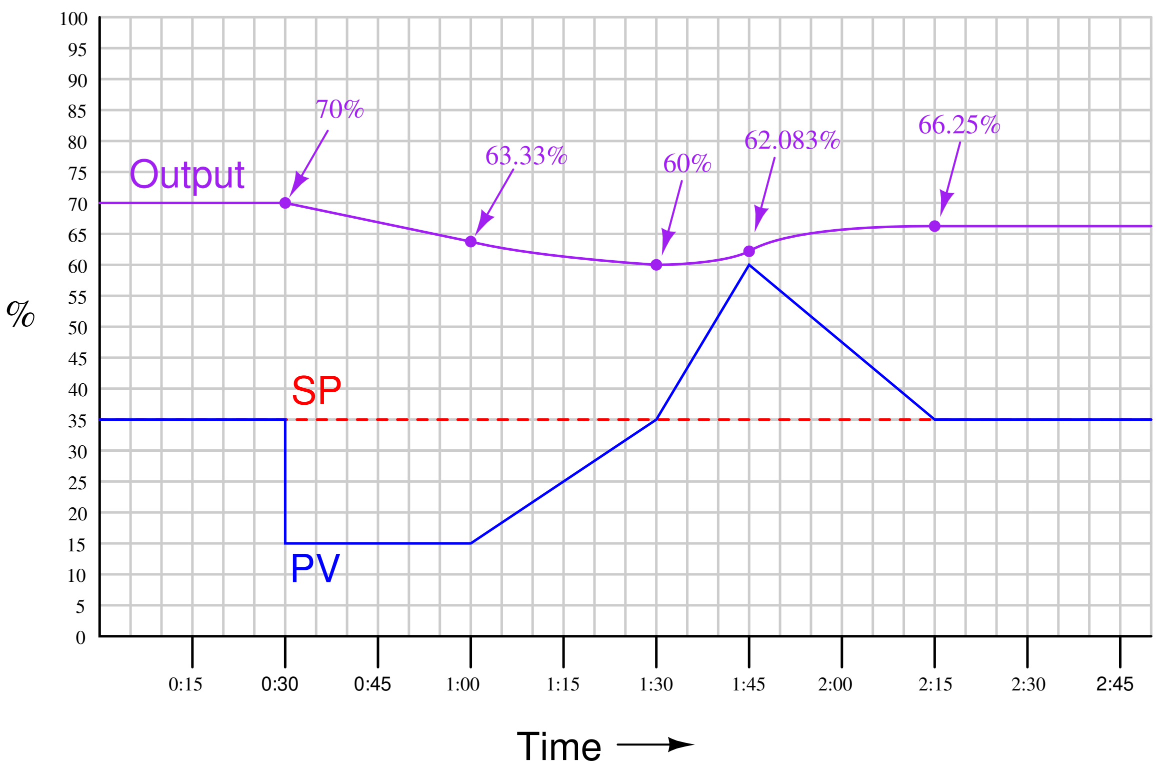


To the PV step-change of -10%, the controller immediately responds with an output step-change of 20% (the proportional band value of 50% is the same as a gain of 2), bringing the output from its original value of 20% to 40%. Then, the continuing error of -10% causes the integral action to ramp the output signal at a rate of 16% per minute (20% proportional response multiplied by 0.8 repeats per minute). Since the -10% deviation between PV and SP only lasts 30 seconds (between 0:15 and 0:45), the output signal only gets the chance to ramp up 8%, bringing the output to a value of 48% at the end of the first deviation period.

Then, when the PV returns to SP (a +10% step-change), the output jumps downward by 20%, leaving the output 8% higher than where it began (28%, from the original value of 20%).

When the next PV step-change arrives at 1:30, the +5% step upwards causes an immediate -10% step in output due to proportional action, bringing the output value to 18%. Integral action, working at a rate of 0.8 repeats per minute, takes the proportional response of -10% and produces an output slope of -8% per minute. Since this step-change period lasts only 10 seconds (1:30 to 1:40), the accumulated output change due to integral is -1.333%, bringing the output down to a final low value of 16.67%. When the PV returns back to SP (jumping down 5%), the output jumps up by 10%, leaving the final output value at 26.67% until the end of the graph.

Svar 49



First, let's convert the given tuning constants into direct-indicating units (gain instead of P.B., and rep/min instead of min/rep):

Proportional band = 75% ; Gain = 1.333

2 minutes per repeat = 0.5 repeats per minute

Now, calculating the accumulated area under each deviation period:

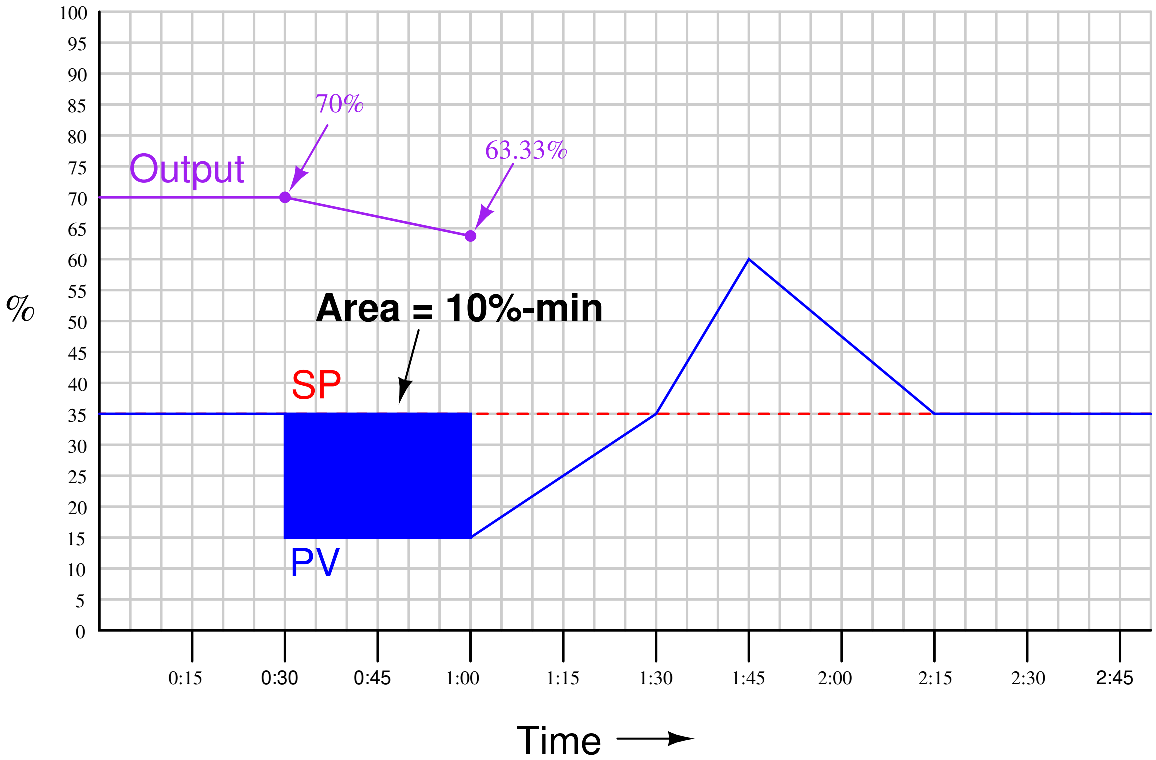
Integral action = $K_p \frac{1}{\tau_i} \int e \, dt$

Integral action = (gain)(repeats/min)(error-time product)

Integral action = (1.333)(0.5/min)(10%-min)

Integral action = 6.667%

Output goes from 70% to 63.33%



Output
70%
63.33%
Area = 10%-min
SP
PV
%
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0:15
0:30
0:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
Time

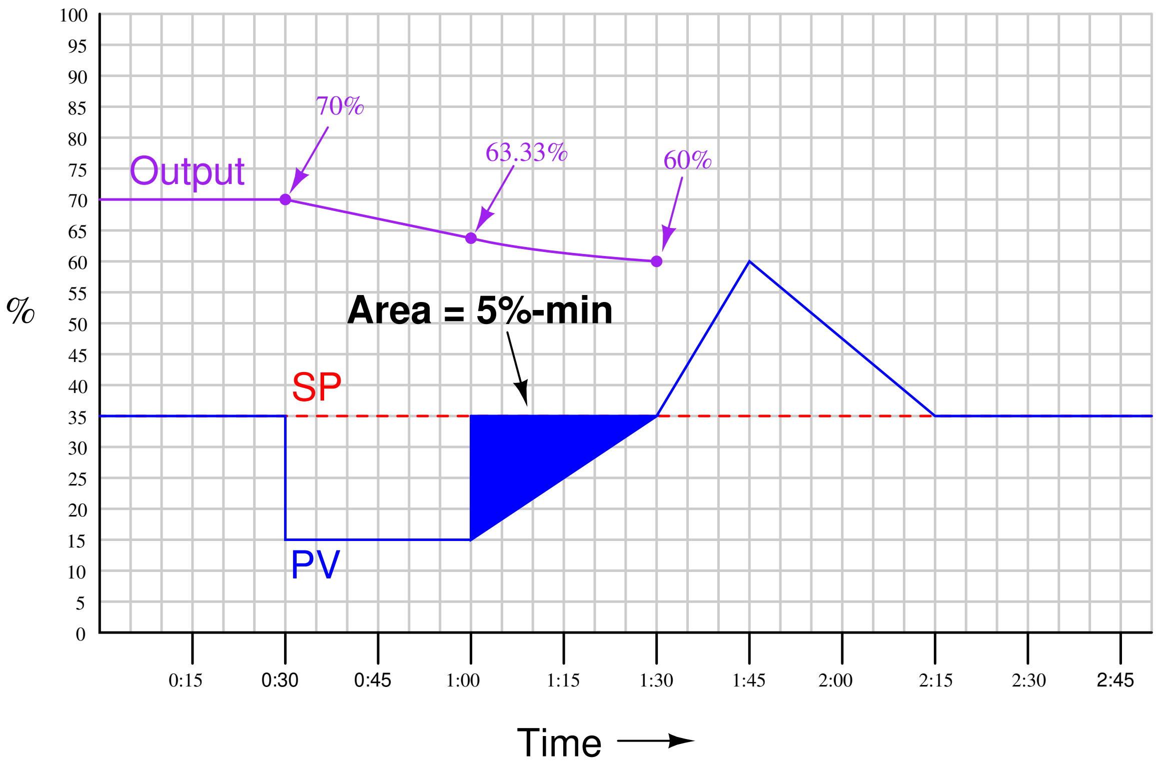
Integral action $= K_p \frac{1}{\tau_i} \int e \, dt$

Integral action = (gain)(repeats/min)(error-time product)

Integral action = (1.333)(0.5/min)(5%-min)

Integral action = 3.333%

Output goes from 63.33% to 60%



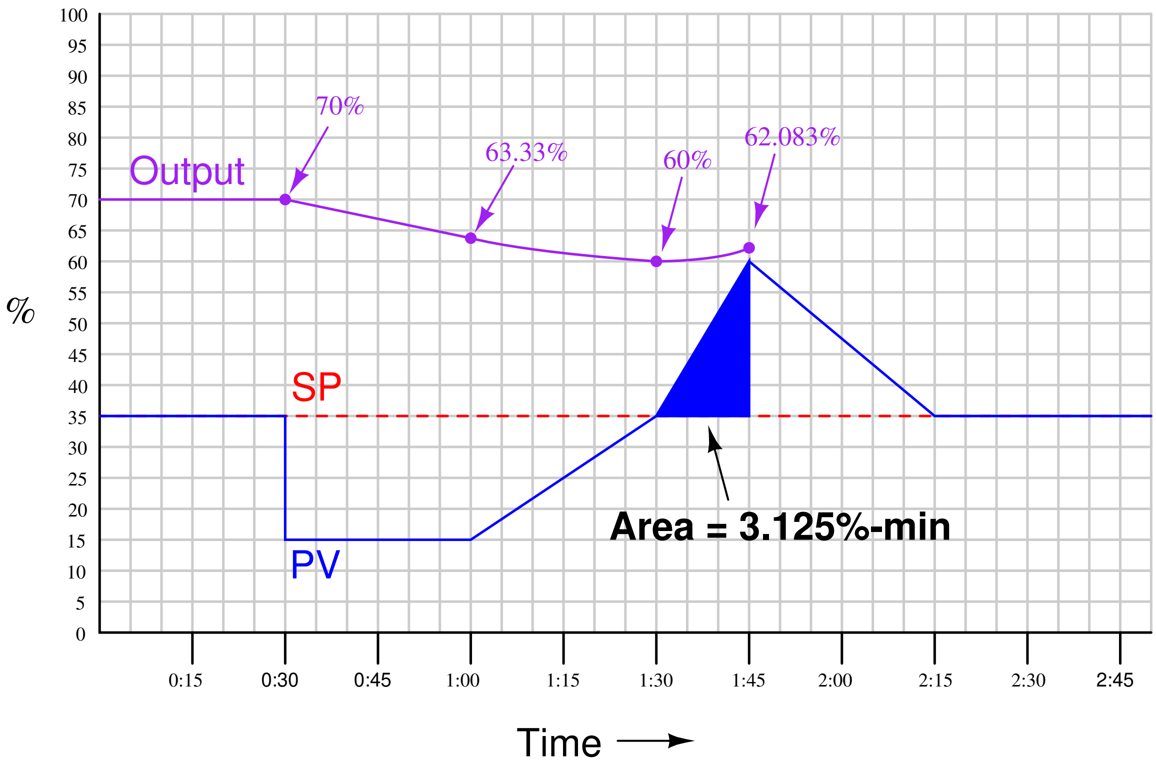
Integral action $= K_p \frac{1}{\tau_i} \int e \, dt$

Integral action $=$ (gain)(repeats/min)(error-time product)

Integral action $=$ (1.333)(0.5/min)(3.125%-min)

Integral action $=$ 2.083%

Output goes from 60% to 62.083%



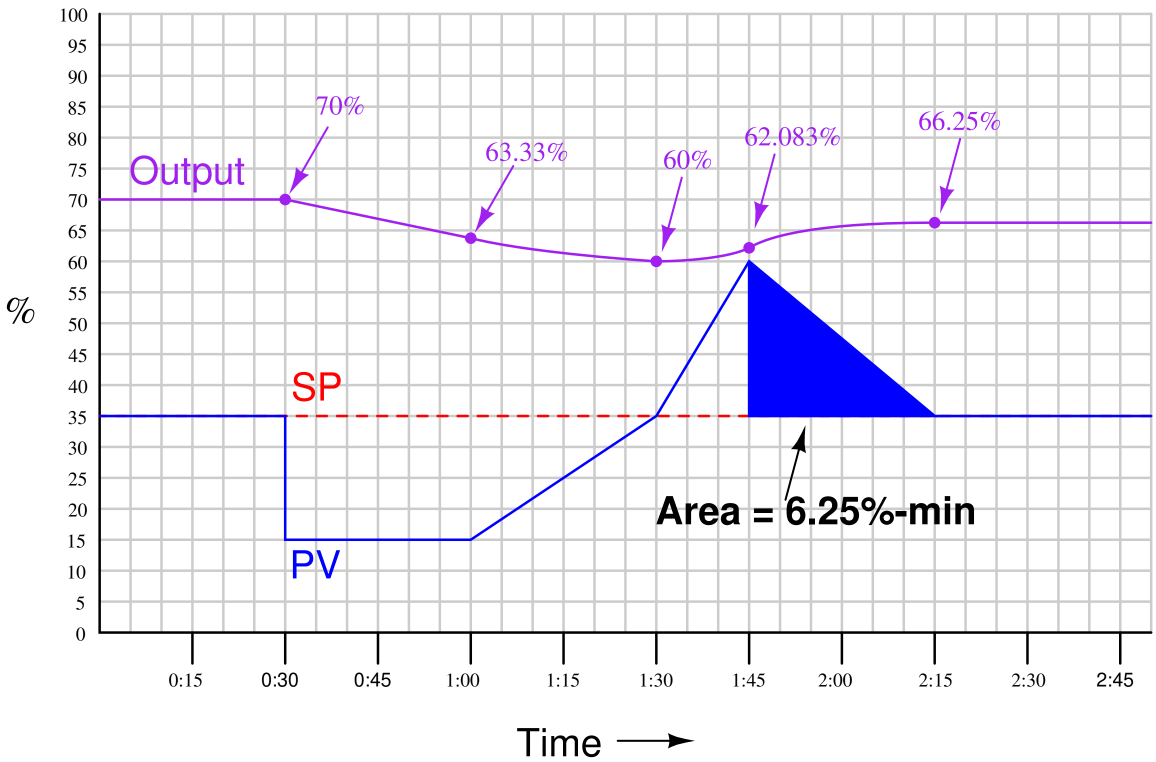
Integral action $= K_p \frac{1}{\tau_i} \int e \, dt$

Integral action = (gain)(repeats/min)(error-time product)

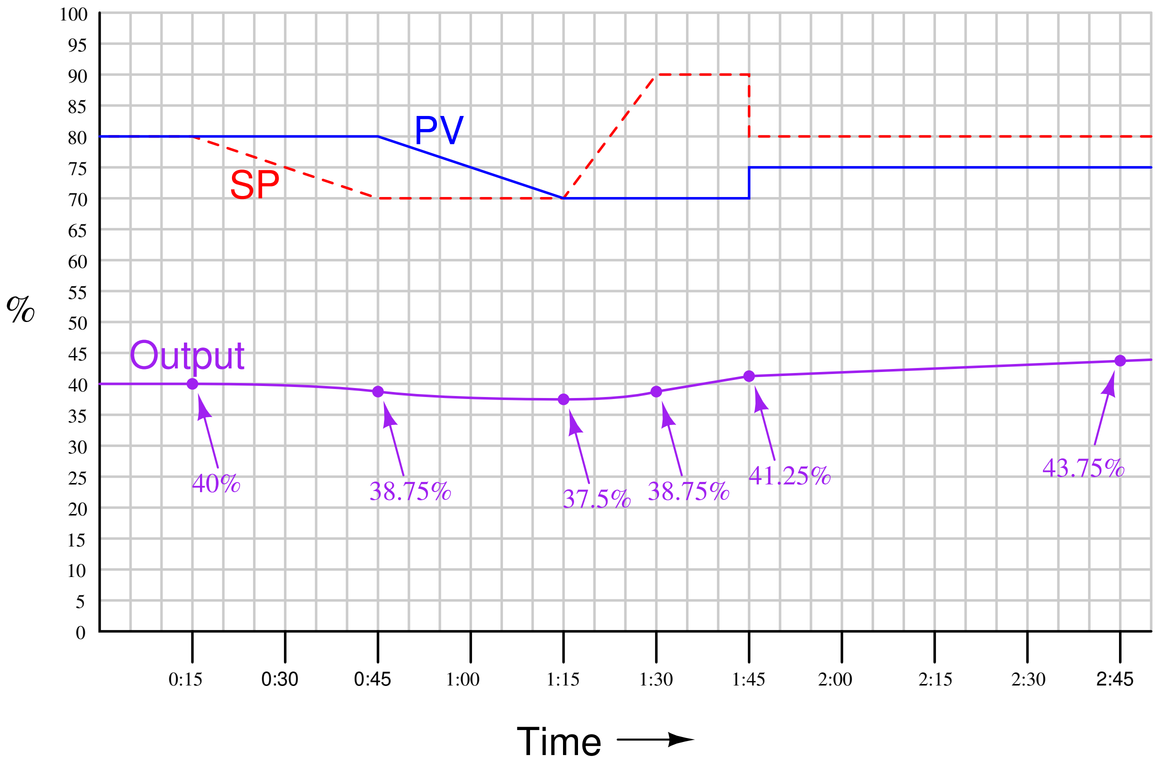
Integral action = (1.333)(0.5/min)(6.25%-min)

Integral action = 4.167%

Output goes from 62.083% to 66.25%



Svar 50



First, let's convert the given tuning constants into direct-indicating units (gain instead of P.B., and rep/min instead of min/rep):

Proportional band = 50% ; Gain = 2

4 minutes per repeat = 0.25 repeats per minute

Now, calculating the accumulated area under each deviation period:

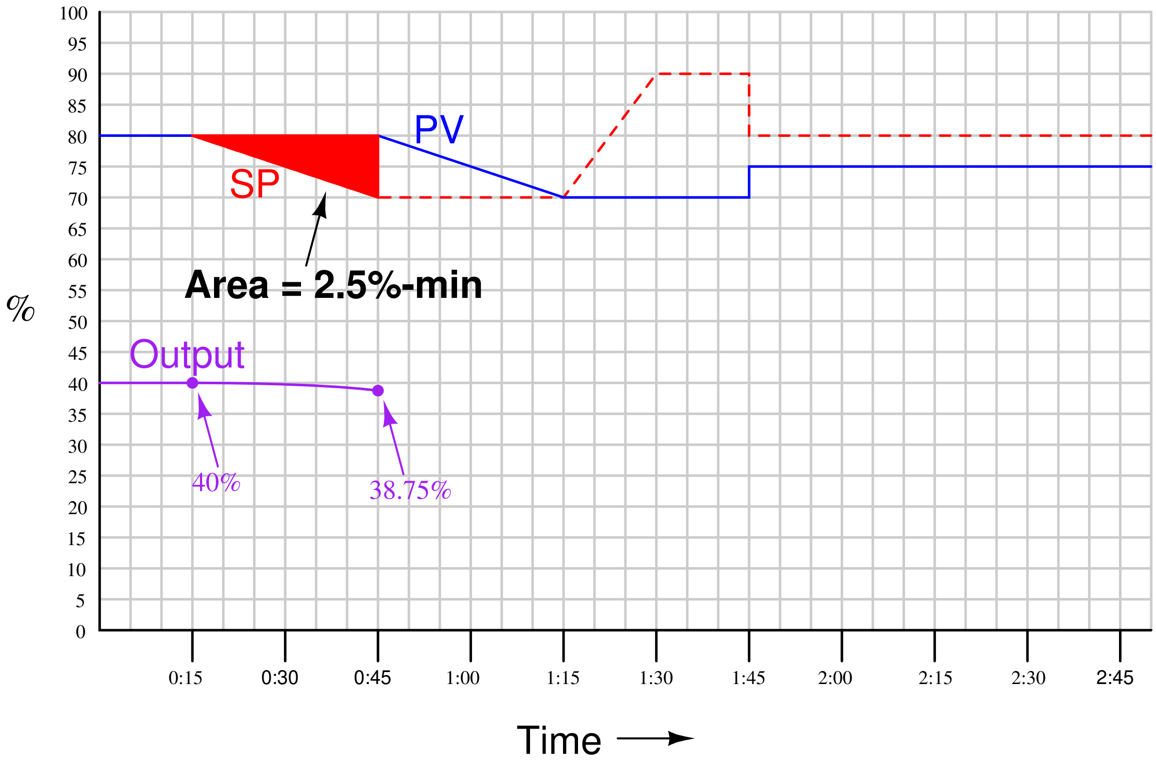
Integral action $= K_p \frac{1}{\tau_i} \int e \, dt$

Integral action = (gain)(repeats/min)(error-time product)

Integral action = (2)(0.25/min)(2.5%-min)

Integral action = 1.25%

Output goes from 40% to 38.75%


100
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70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
%
PV
SP
Area = 2.5%-min
Output
40%
38.75%
0:15
0:30
0:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
Time

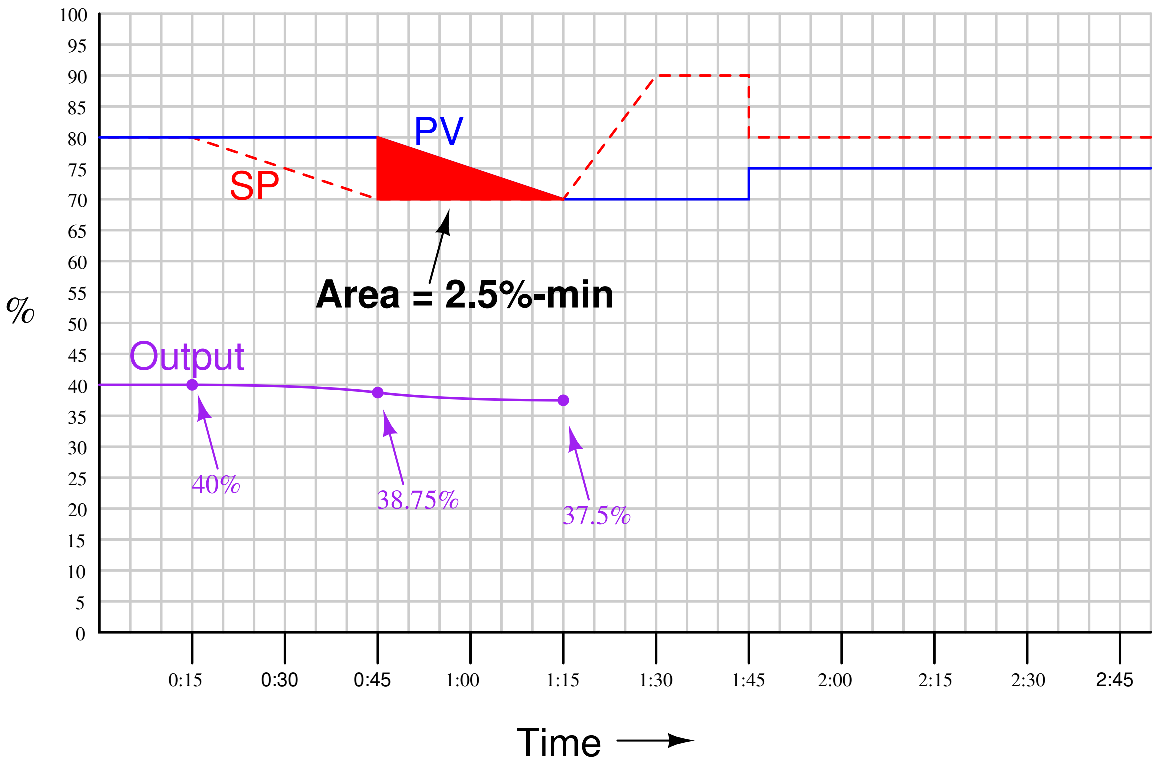
Integral action $= K_p \frac{1}{\tau_i} \int e \, dt$

Integral action = (gain)(repeats/min)(error-time product)

Integral action = (2)(0.25/min)(2.5%-min)

Integral action = 1.25%

Output goes from 38.75% to 37.5%



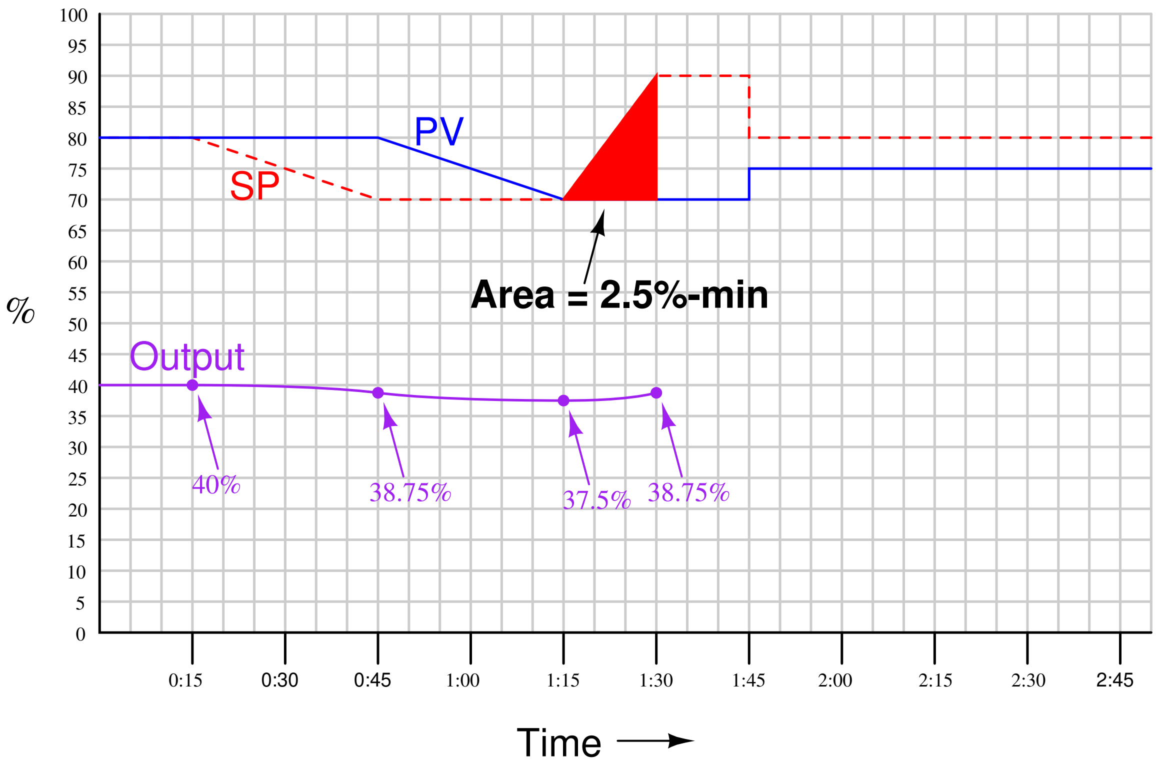
Integral action $= K_p \frac{1}{\tau_i} \int e \, dt$

Integral action = (gain)(repeats/min)(error-time product)

Integral action = (2)(0.25/min)(2.5%-min)

Integral action = 1.25%

Output goes from 37.5% to 38.75%



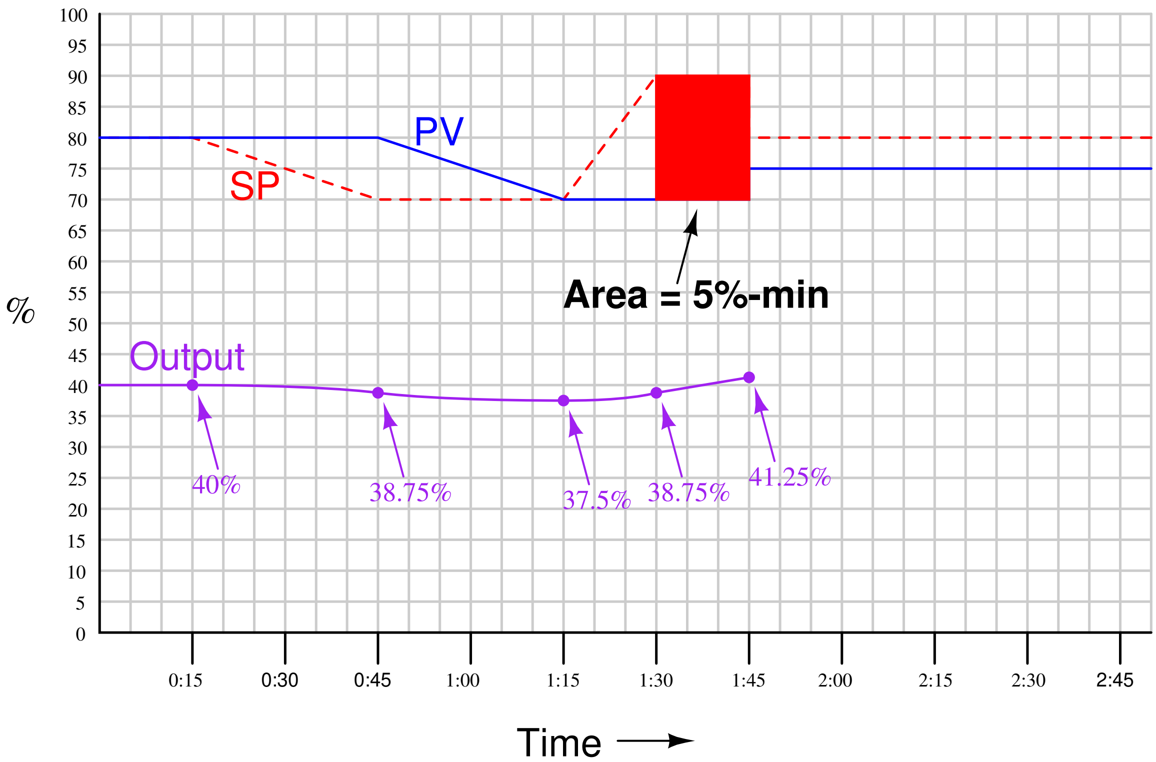
Integral action $= K_p \frac{1}{\tau_i} \int e \, dt$

Integral action = (gain)(repeats/min)(error-time product)

Integral action = (2)(0.25/min)(5%-min)

Integral action = 2.5%

Output goes from 38.75% to 41.25%



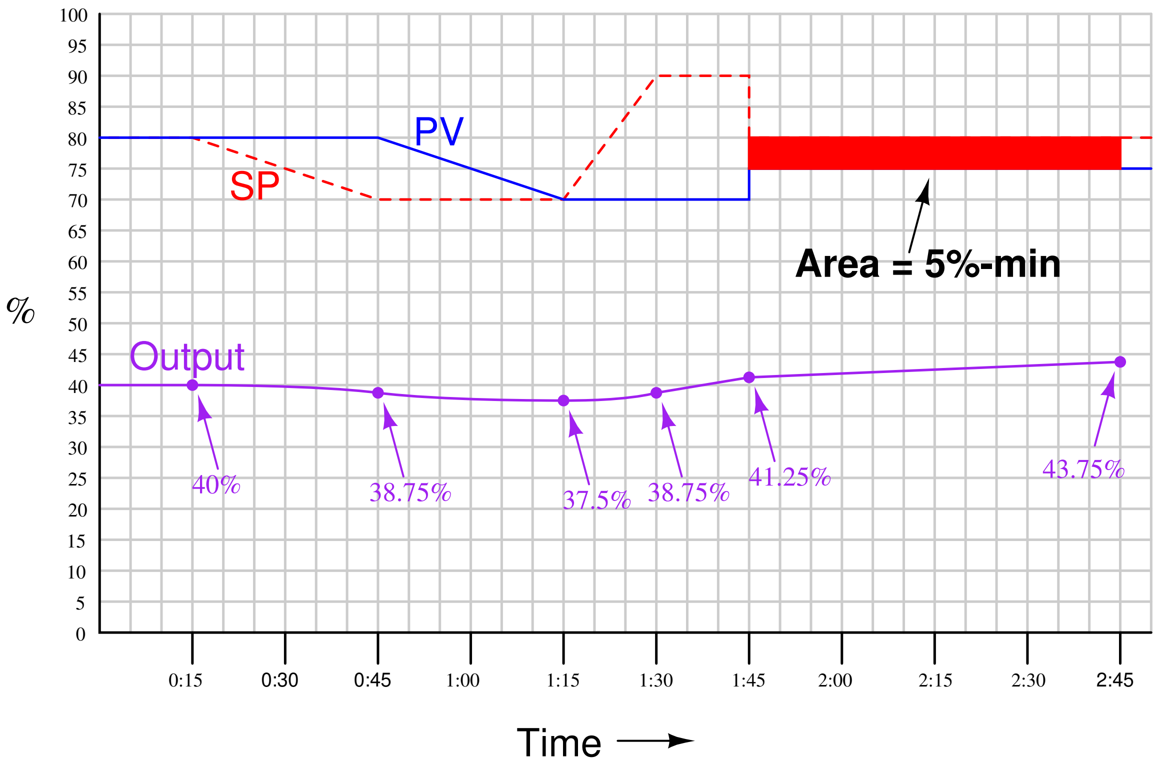
Integral action $= K_p \frac{1}{\tau_i} \int e \, dt$

Integral action = (gain)(repeats/min)(error-time product)

Integral action = (2)(0.25/min)(5%-min)

Integral action = 2.5%

Output goes from 41.25% to 43.75%



Svar 51

The controller will decrease its output signal as it tries to open the air-to-close valve. Both the proportional and integral terms of the controller will work to open the steam valve as the reactor temperature decreases. If there is no steam supply for an extended period of time, the controller's integral action will *wind* to a condition of saturation (3 PSI or less output signal pressure).

Svar 52

Since the flow cannot exceed 70% due to the undersized valve, the controller will continue to "see" an error of 10% and the controller output will eventually saturate at 100% (wide-open valve). The integral term of the algorithm will continue to increase (unless limited by a special feature of the controller designed to stop the integration process if and when the output signal reaches certain limits), even though it won't do any good because the valve is saturated wide open. This phenomenon is called *integral windup* or *reset windup*. When the setpoint is reduced to 50%, the controller output may remain saturated at 100% (valve fully open) rather than immediately decrease to reduce flow through the pipe like it's supposed to, because of the accumulated value ("windup") of the integral term.

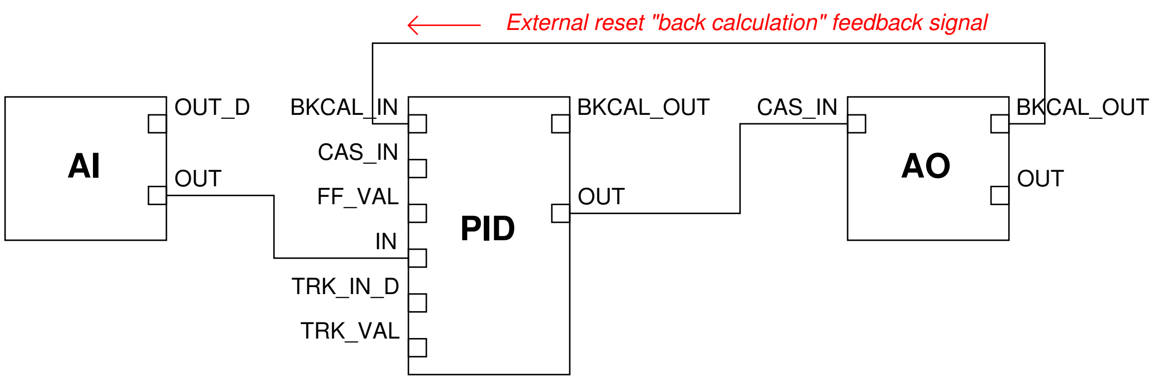
It should be noted that most modern (digital) loop controllers have anti-reset windup limits set by default at 100% and 0%, so that the integral accumulator will not wind past these limits. I have encountered controllers without this feature, though, where the controller's internal accumulator is able to go way past 100% even though the control valve of course cannot open any more than 100%.

Svar 53

External anti-reset windup is a feature available on some controllers for preventing "windup" of the integral (reset) term, by monitoring valve position or some other real-world indication of output saturation. It works by stopping integration whenever the actual final control element is saturated, rather than stopping integration based on a maximum or minimum set value programmed into the controller.

With integral action based on valve position rather than the controller's output signal magnitude, windup will be prevented over a wider range of conditions. For instance, if the valve were to become jammed or limited in travel by a "stop," integration would cease at that limit, rather than blindly progress until the actual controller output pressure reached saturation as would be the case with internal anti-reset windup.
This will not prevent all cases of reset windup, but it will help the controller recover from incidents of windup resulting from valve position saturation.

Interestingly, this very same technique is used in FOUNDATION Fieldbus PID loops, where the analog output function block provides a "back calculation" signal (BKCAL_OUT) for the input of the PID block. If the final control element cannot attain a certain state, for whatever reason, the PID block will know this and cease integrating, thus preventing needless windup:



Svar 54

- Gain = 0.769
- Reset = 0.00617 repeats per second

Svar 55

Partial answer:

Fault	**Possible**	**Impossible**
Control valve stem jammed by metal debris between plug and seat		
Control valve stem jammed by metal debris between plug and bonnet		
Block valve downstream of control valve closed		$\surd$
Block valve upstream of control valve closed		
Tear (leak) in actuating diaphragm		
Hand valve shut off	$\surd$	
Upstream pressure lower than normal		

Svar 56

This is a graded question – no answers or hints given!

Svar 57

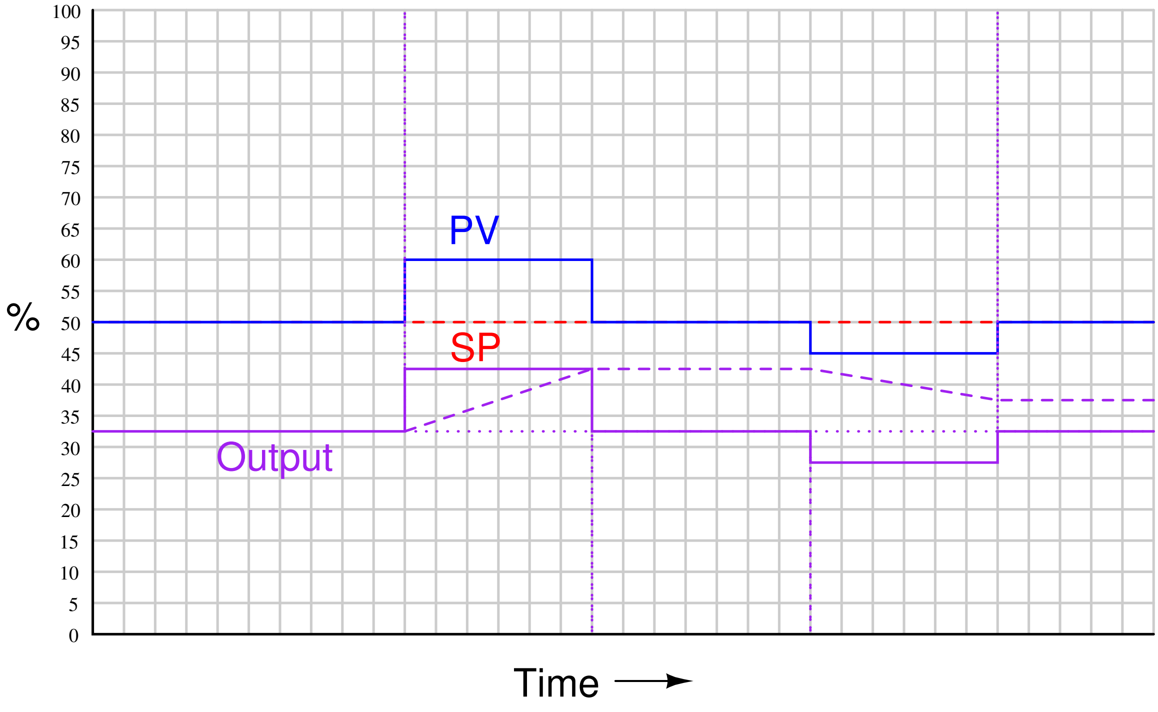
Partial answer:

- Which valve adjusts the derivative constant (τ_d)? $\mathbf{V}_2$
- Will adjustment of the proportional constant affect either the integral or derivative responses? **Yes!**

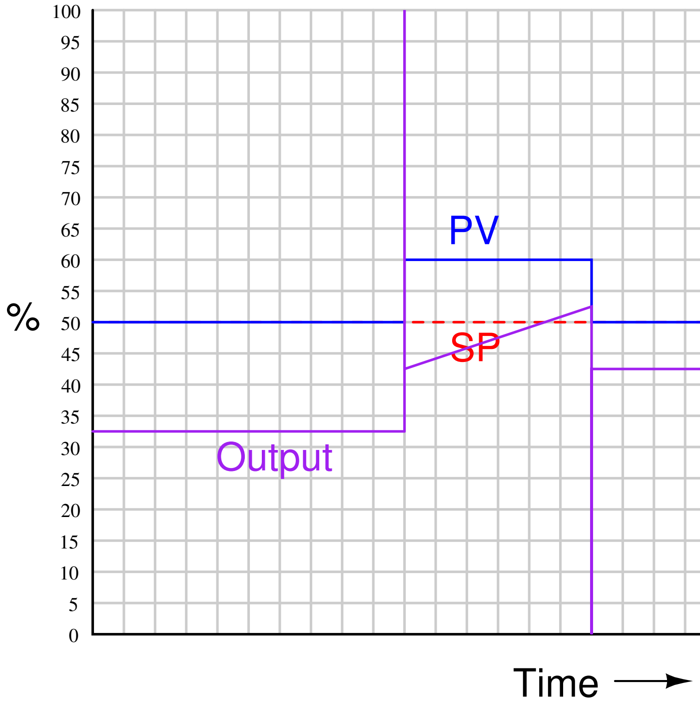
Svar 58

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:

Individual P, I, and D responses graphed:



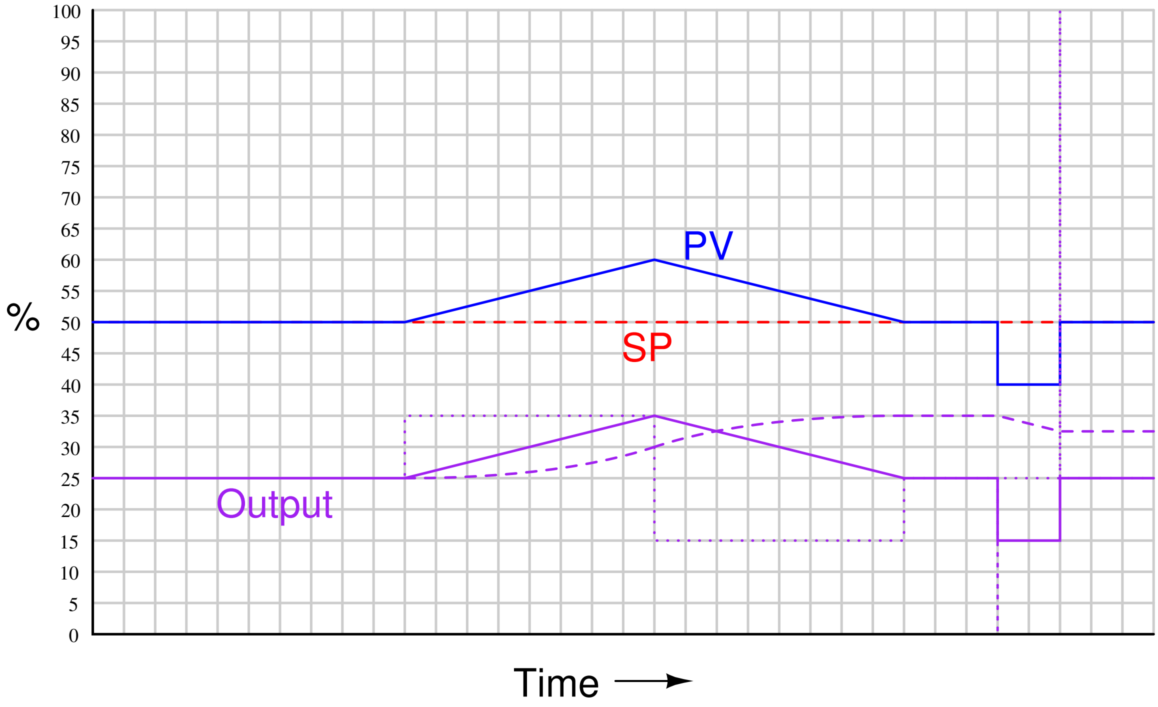
Final output signal graph:


100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
%
PV
SP
Output
Time

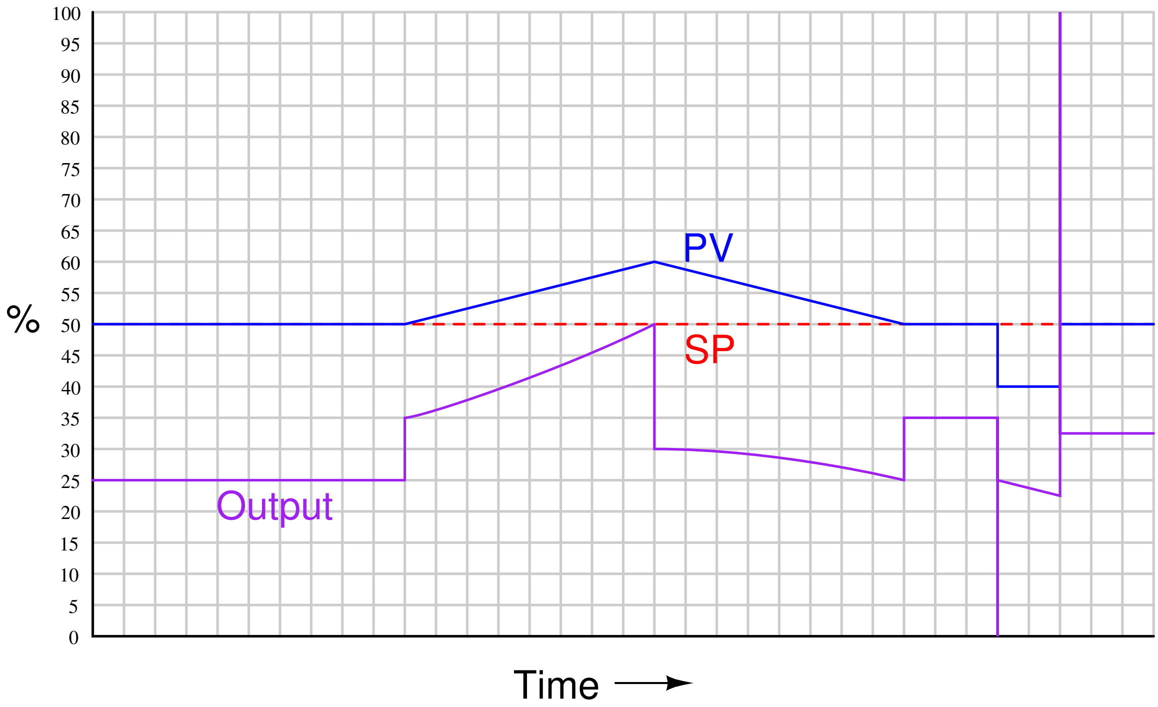
Svar 59

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:

Individual P, I, and D responses graphed:



Final output signal graph:



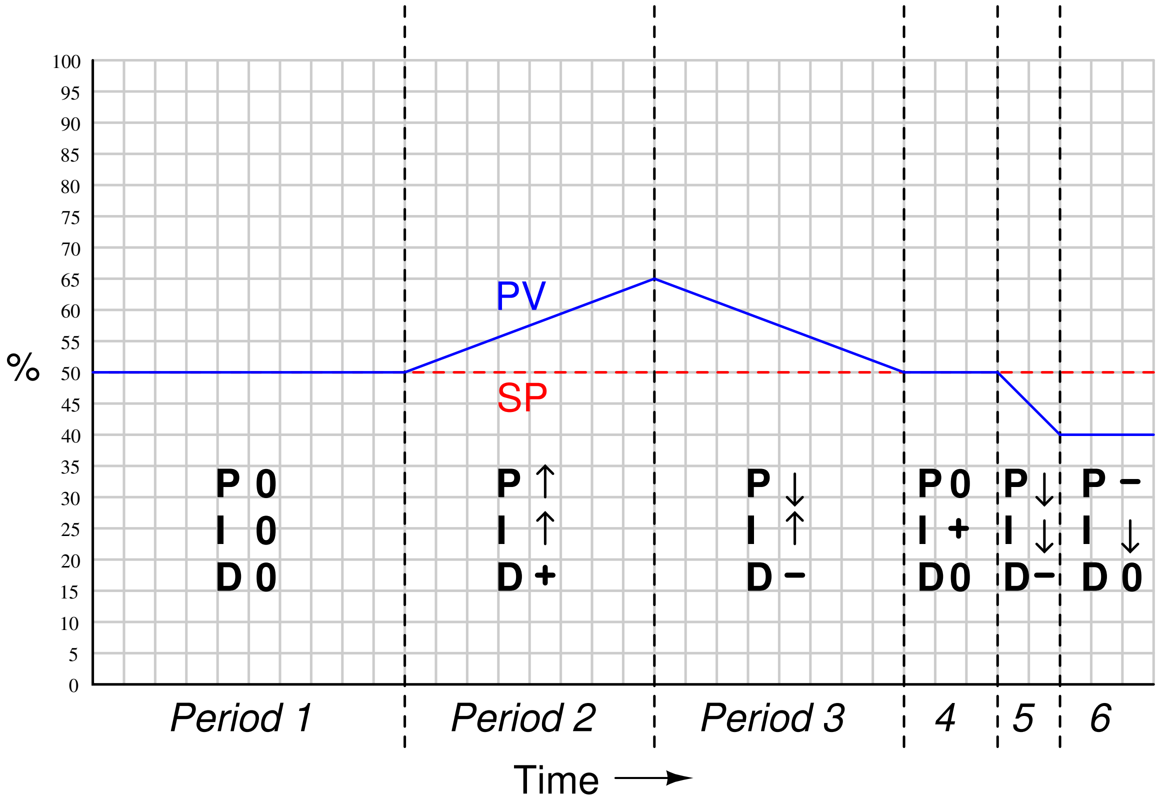
Svar 60

Proportional action is said to work on the present because its action is instantaneous and does not depend on time. The value of the proportional term in a PID controller is strictly a function of PV, SP, and gain, without any reference to time.

Integral action is said to work on the past, because its action is based on the amount of error (PV − SP) *accumulated over time*. Thus, the value of a PID controller's integral term is a function of past (accumulated) error.

Derivative action is said to work on the future, because its action is based on the rate-of-change over time of the PV, which is a good predictor of overshoot. This is why derivative action is sometimes called *preact*, because it preemptively acts to avoid overshoot of setpoint. This is analogous to a passenger in a fast-moving automobile, who can "predict" that the car's high speed will likely lead to "overshoot" of an intersection.

Svar 61



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Period 1
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Period 3
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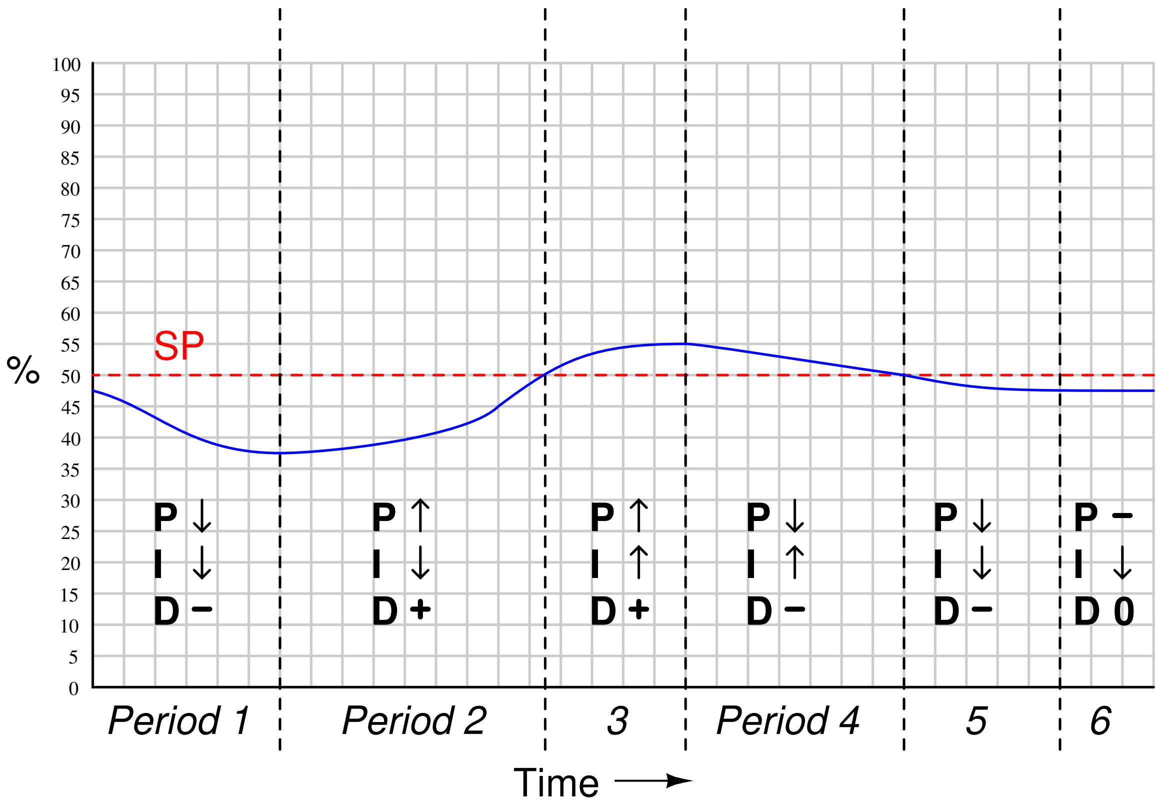
Svar 62



Svar 63

This is a graded question – no answers or hints given!

Svar 64

This is a graded question – no answers or hints given!

Svar 65

When derivative action works on the *error* signal, it responds to changes in setpoint (SP) and process variable (PV) equally. This will result in the controller output saturating (100% or 0%) upon step changes in setpoint, which can be a bad thing. That is why some controllers provide the option of having derivative action work only on PV changes only and not SP changes.

Svar 66

Svar 67

The time constant of a process is the amount of time it takes for the process variable to change by 63.2% from its initial value to its ultimate value, following a "step-change" in the final control element or any "load" in the process affecting the measured variable.

Svar 68

A first-order process is one having a single mode of storage (either of energy or of matter) and "resistive" element limiting the rate at which the storage element may be filled or unfilled. This leads to behavior like that of a simple RC circuit. In fact, first-order processes may be electrically simulated using nothing but a single capacitor and a single resistor.

Svar 69

The fundamental problem here is that the *process gain* varies inversely to flow rate. During the rainy seasons when the lagoon captures rainwater and the influent flow rate is high, it takes a big change in valve position to make a significant difference in chlorine concentration. When the weather is dry and the influent flow rate is low, even small moves in valve stem position generate large changes in chlorine concentration.

The multiplication relay (or adaptive gain controller) attempts to keep the overall *loop gain* constant despite changes in process gain.

Svar 70

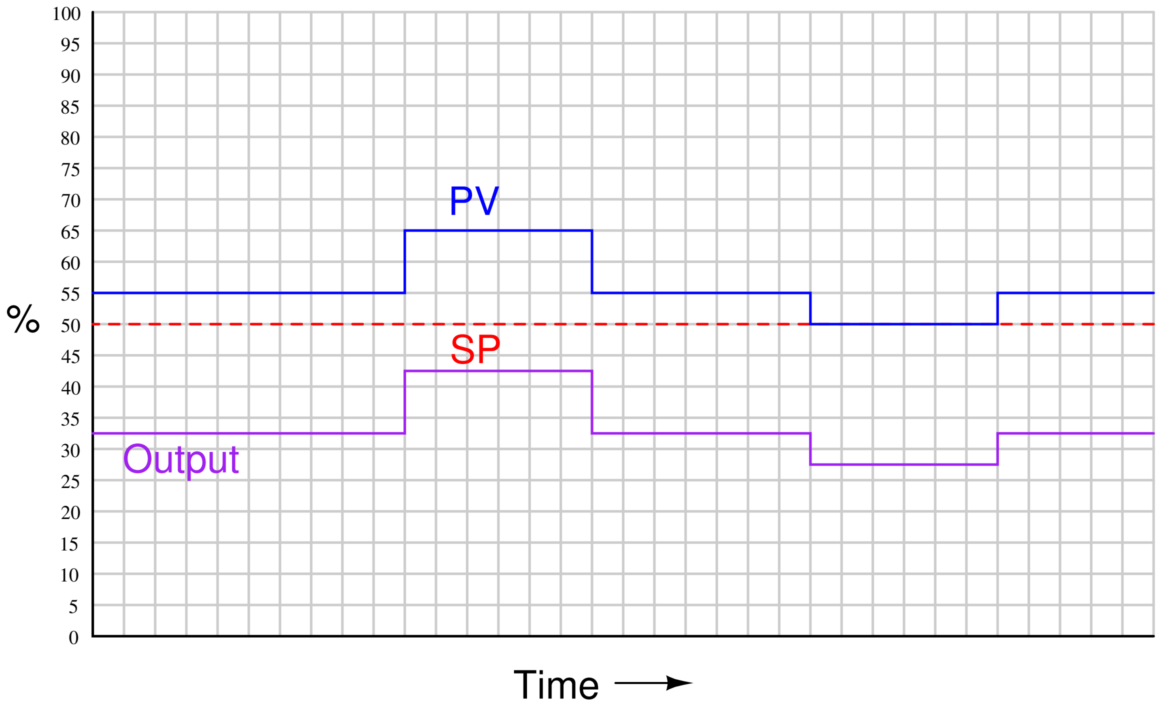
"Drier" natural gas entering this system means more methane and less of the heavier hydrocarbons. This will result in less liquid drained off the bottom of the flash vessel, and more methane gas vented off the top. In order to hold the flash vessel pressure steady, PIC-115 will have to "open up" its control valve just a bit to vent the additional methane gas. However, since it is a proportional-only controller, it will be incapable of settling exactly back on the setpoint value of 107 PSI and instead will settle at some higher value (i.e. proportional-only offset).

Svar 71

Controller display	**Controller current**	**I/P pressure**	**Valve stem position**
77.5%	7.6 mA	5.7 PSI	77.5% open
13.1%	17.9 mA	13.43 PSI	13.1% open
89.3%	5.72 mA	4.29 PSI	89.3% open
64%	9.76 mA	7.32 PSI	64% open

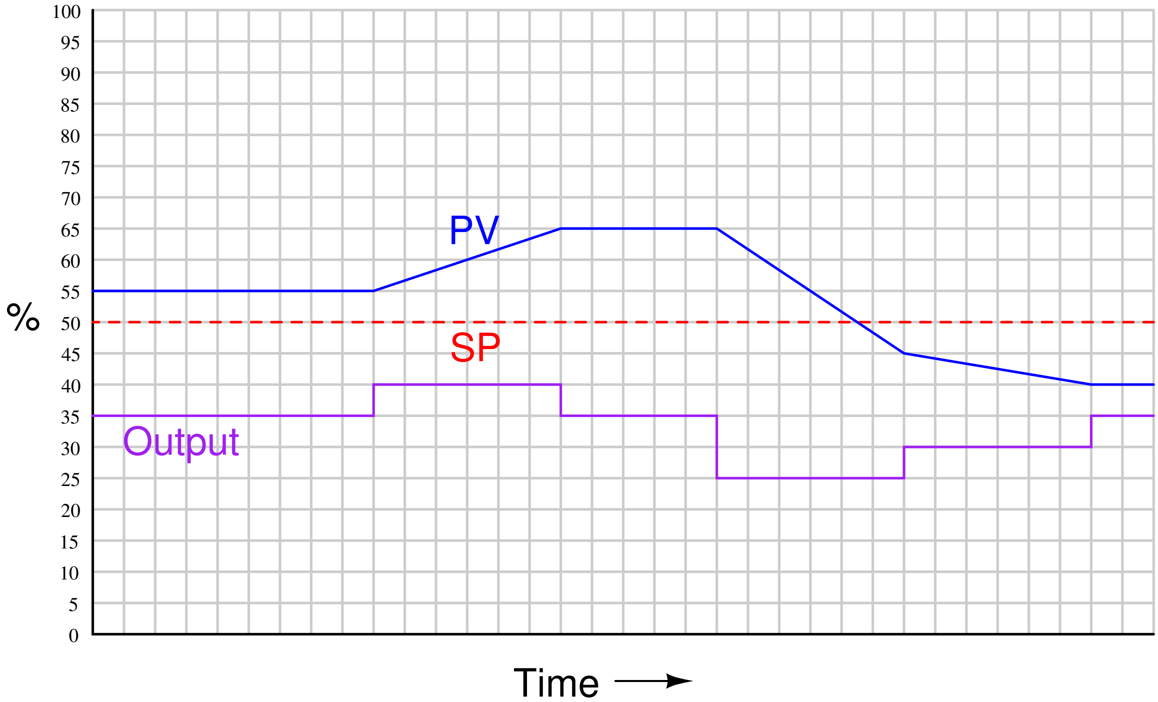
Svar 72

With proportional action, the amount of error tells the output how **far** to go:



Svar 73

With derivative action, the **rate** at which error moves tells the output how **far** to go:



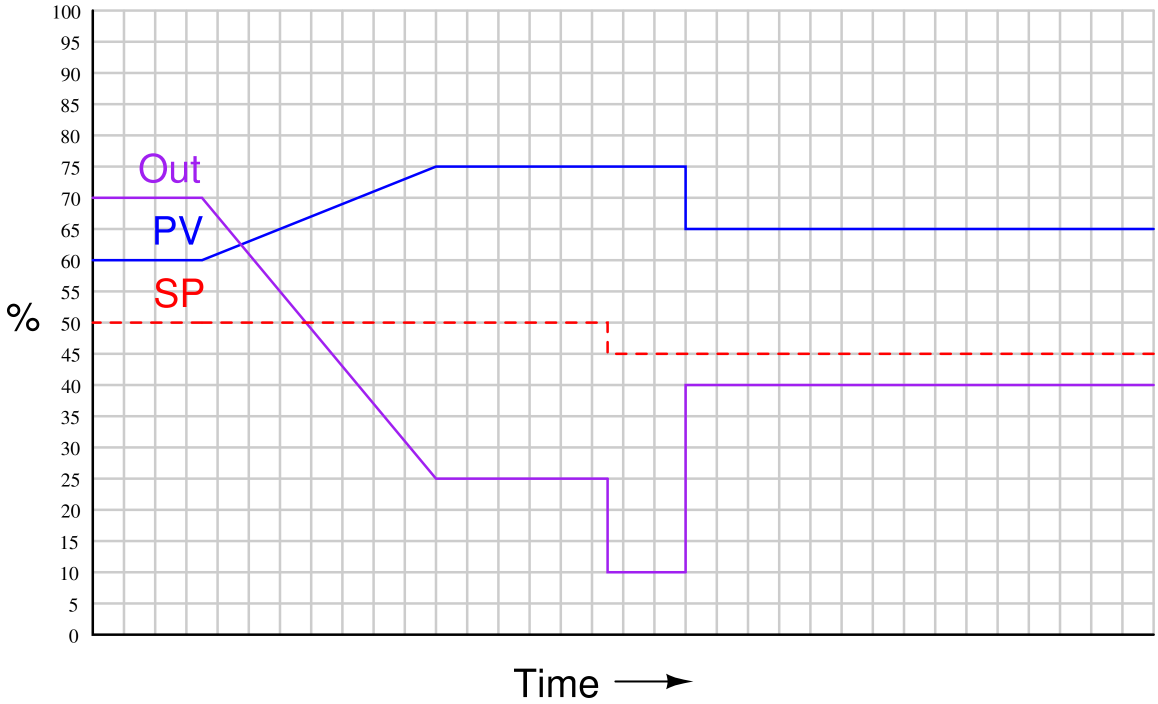
Svar 74

The arrows represent hydraulic fluid direction. Each of the three "boxes" in the spool valve symbol represents three different positions of the valve spool.

Svar 75

Svar 76

Svar 77



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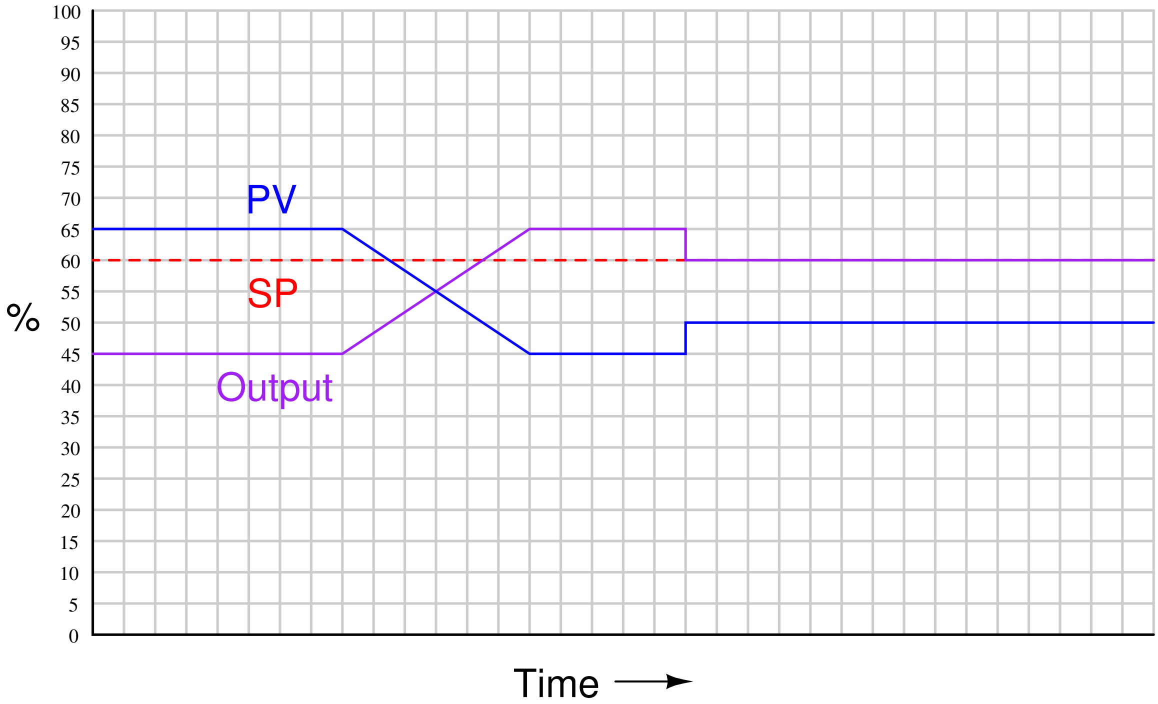
Svar 78



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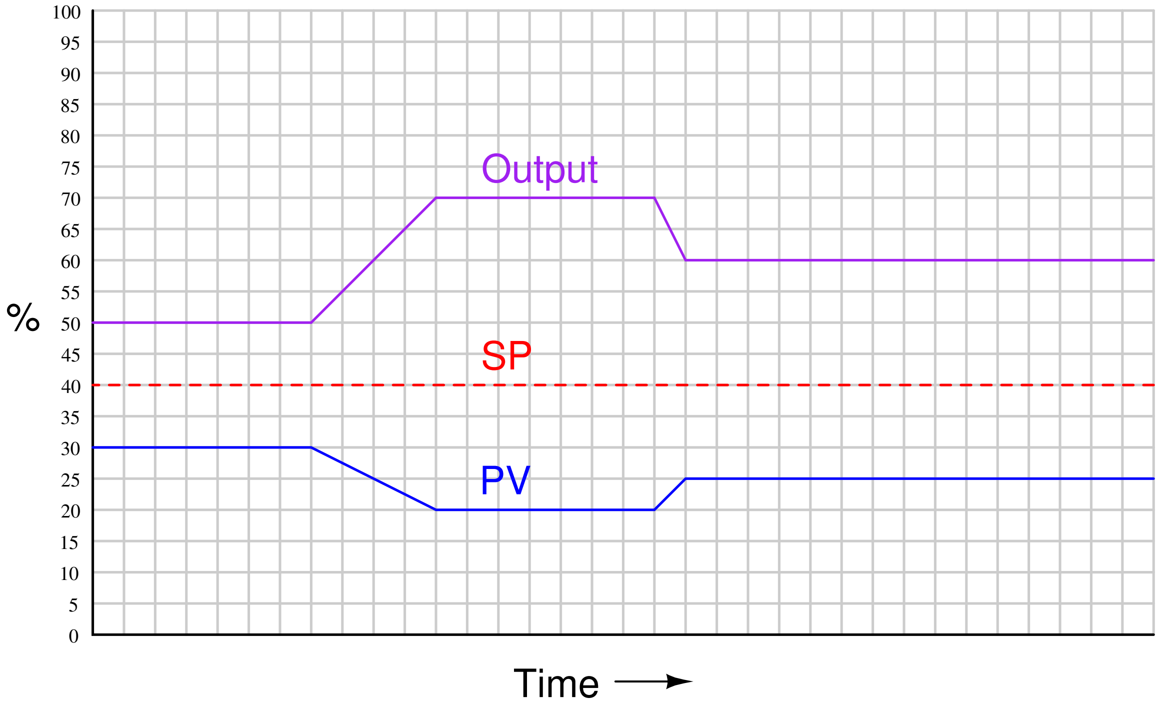
Svar 79

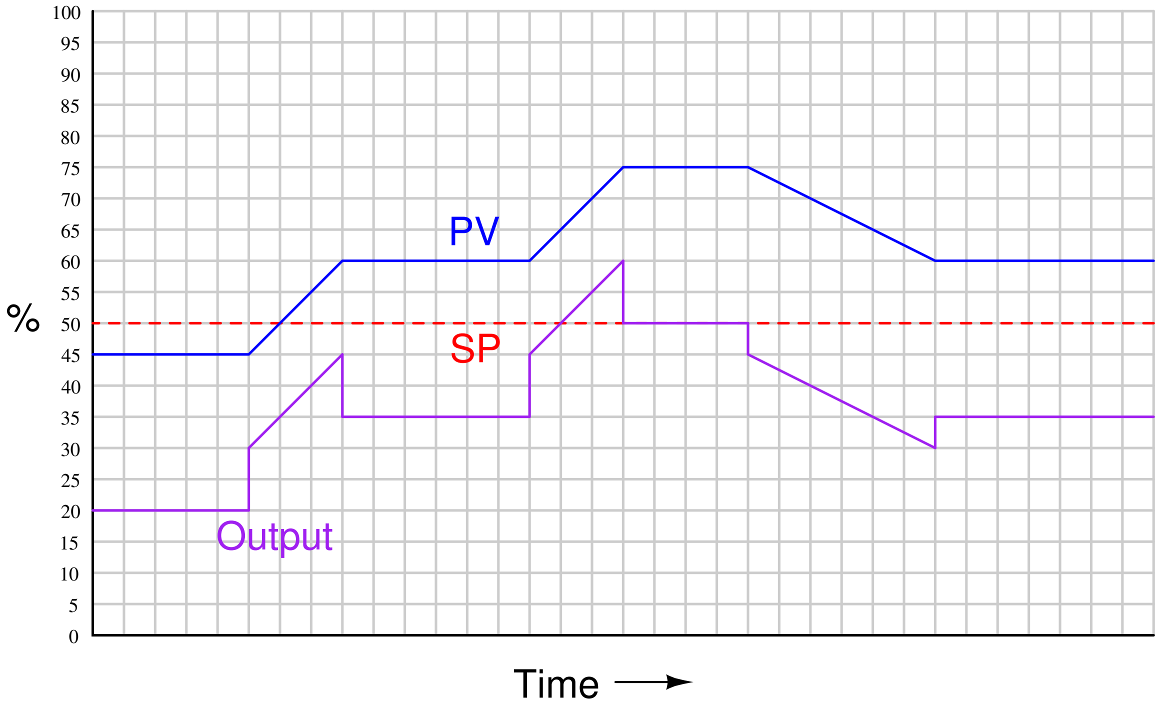


Svar 80

This is a graded question – no answers or hints given!

Svar 81

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Svar 82

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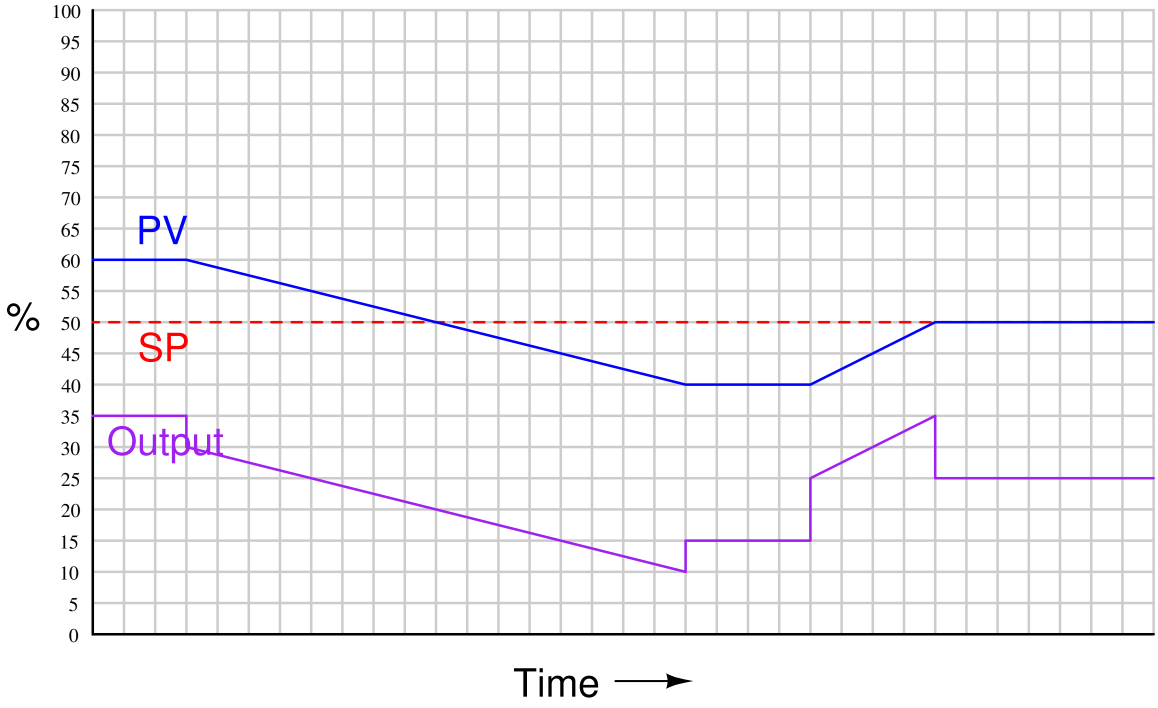


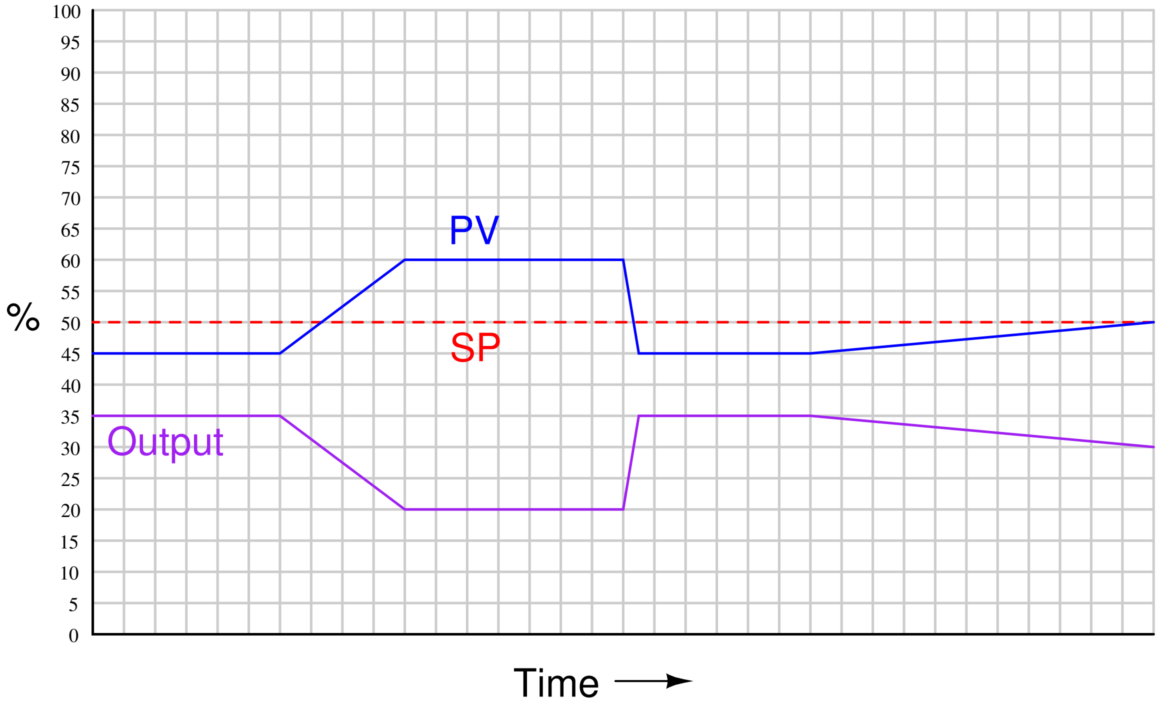
Svar 83

This P+D controller calculates derivative on error (e), not just the value of the process variable (PV), so it uses the following algorithm:

$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

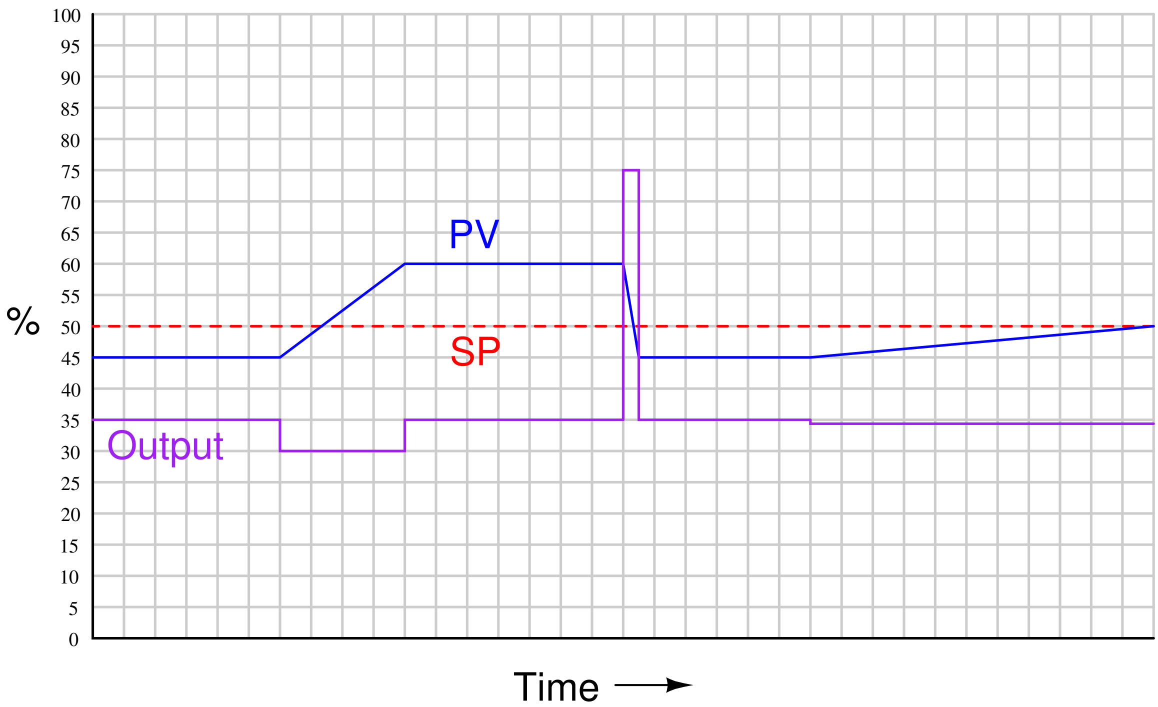
Svar 84

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Svar 85

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



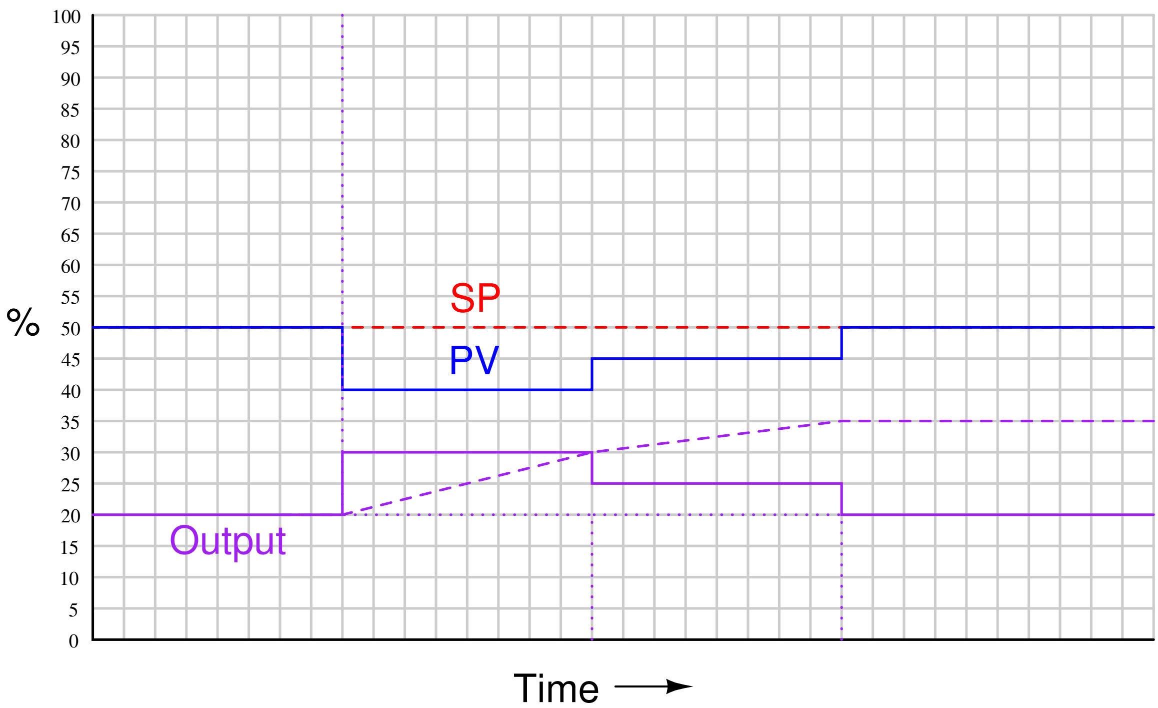
Svar 86

This is a graded question – no answers or hints given!

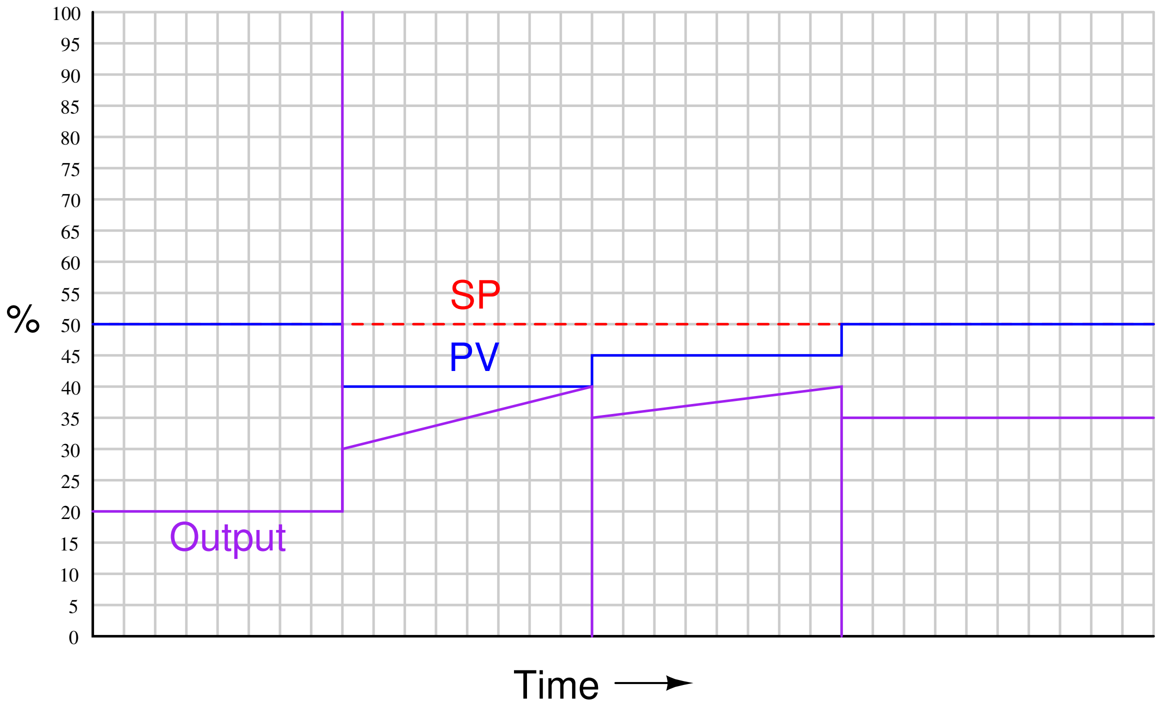
Svar 87

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:

Individual P, I, and D responses graphed:



Final output signal graph:



Svar 88

This is a graded question – no answers or hints given!

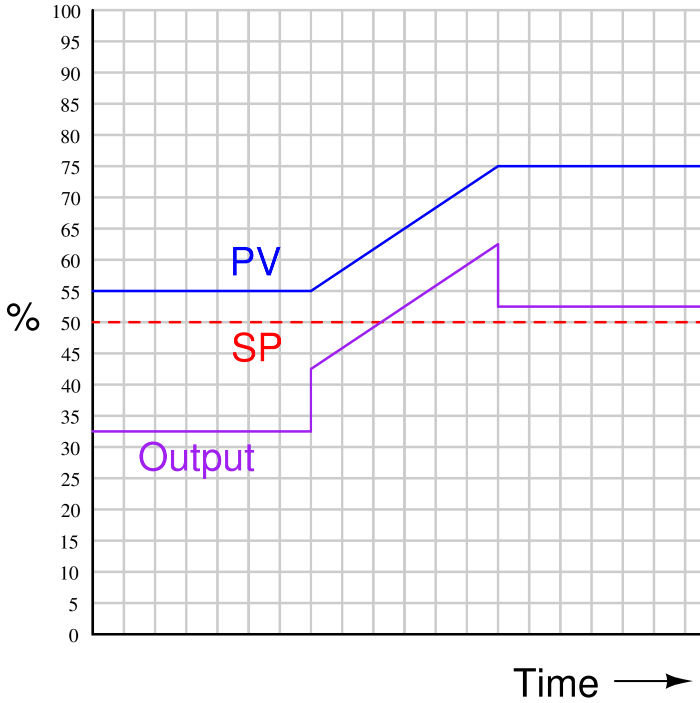
Svar 89

Partial answer:

- Formula for cell D3: = `B3 - C3`
- Formula for cell E3: = `$I$3 * (D3 - D2) / (A3 - A2)`
- Formula for cell F3: = `(D3 * (A3 - A2) / $I$2) + F2`

Svar 90

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Svar 91

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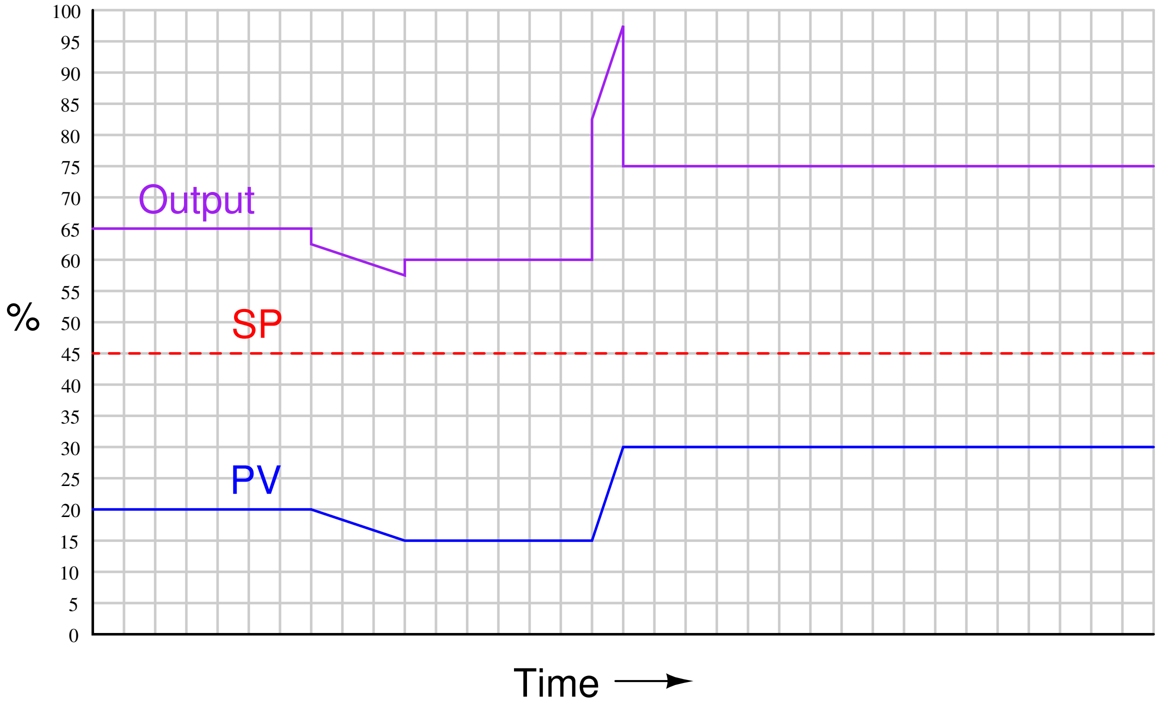
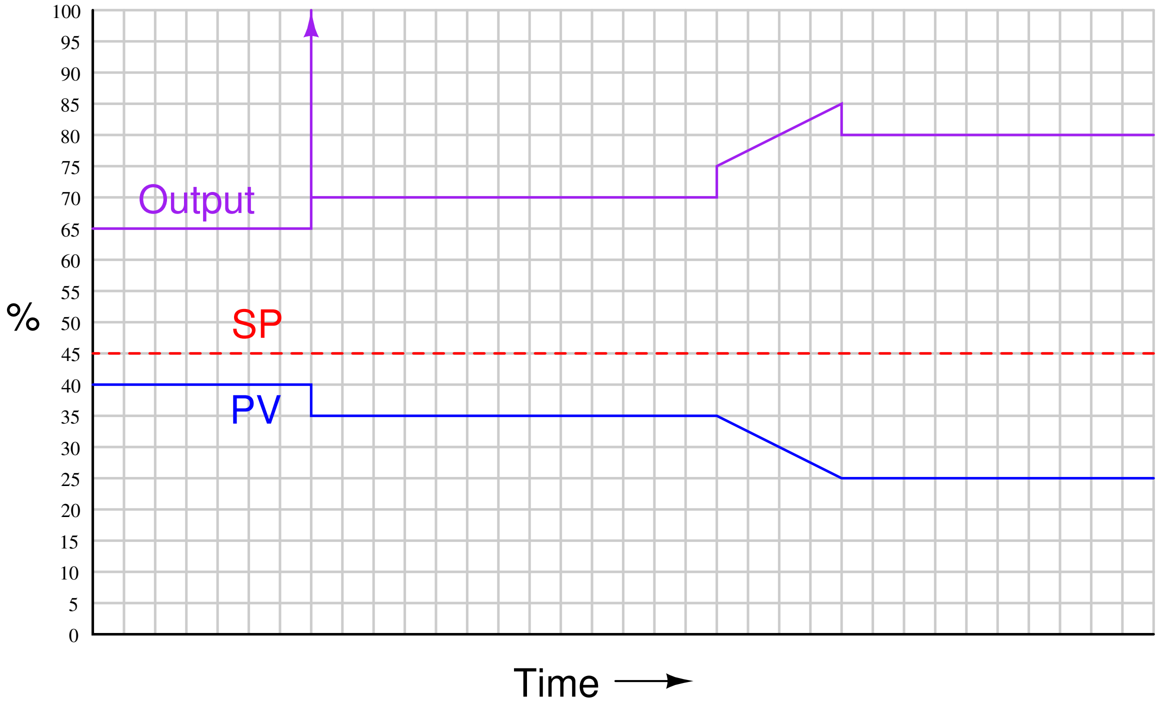


Svar 92

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Svar 93

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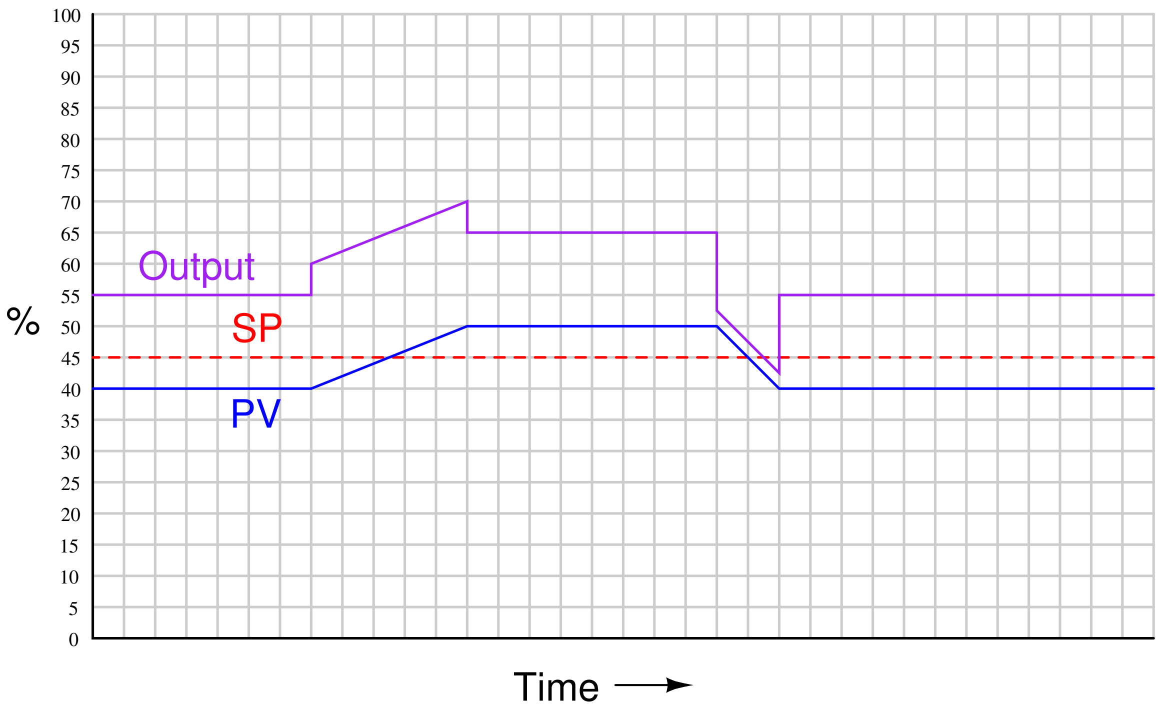
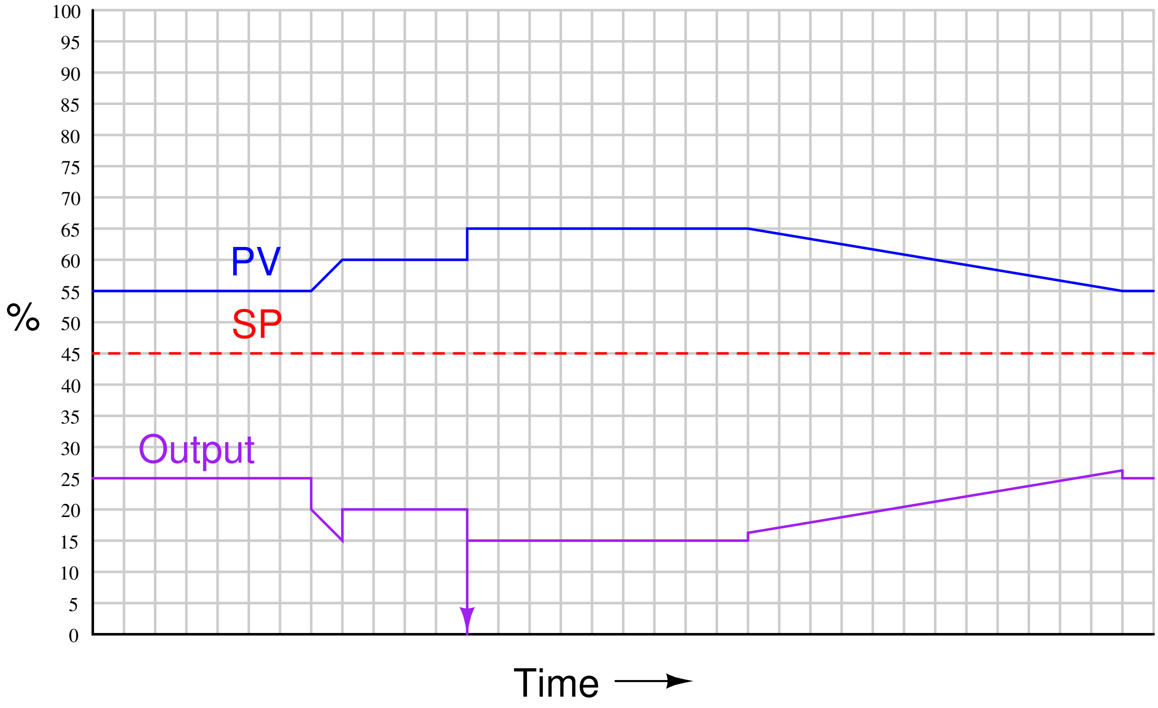


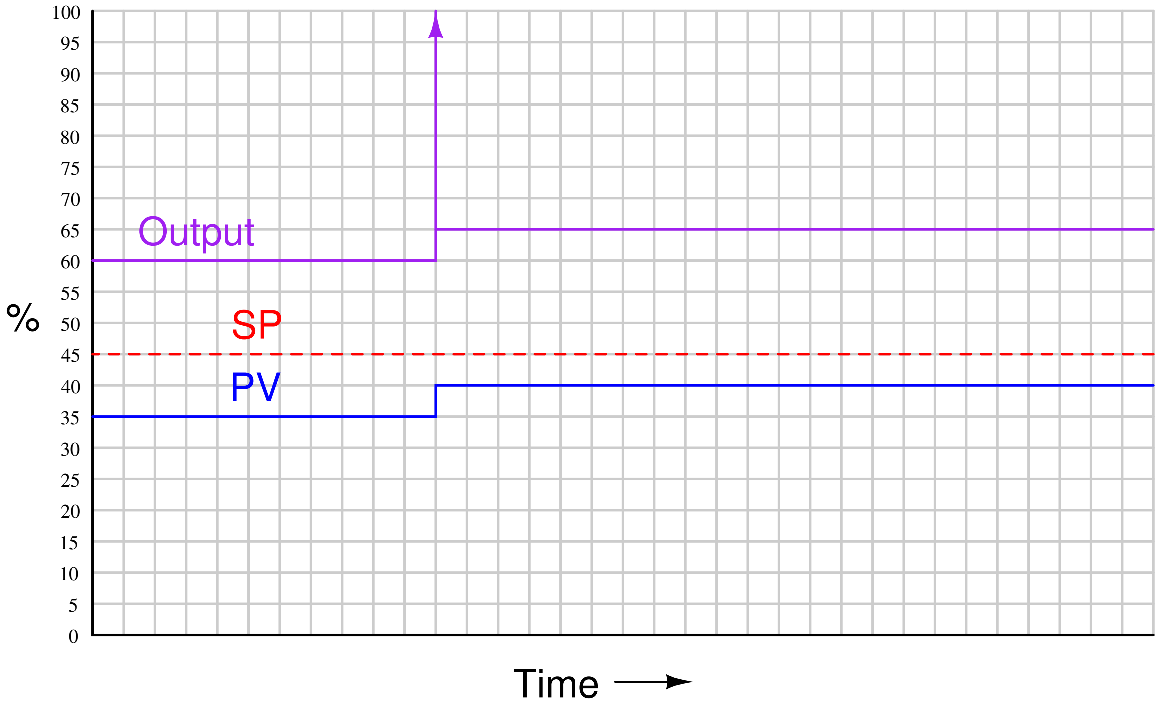
Svar 94

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



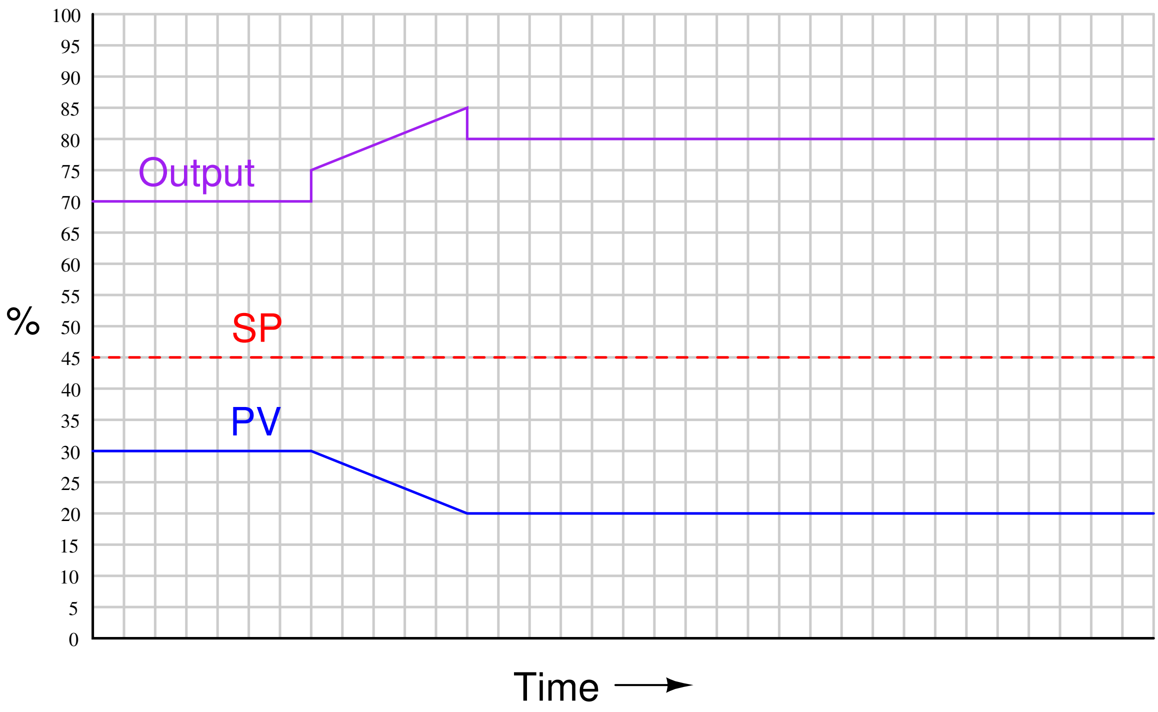
Svar 95

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Svar 96

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Svar 97