Faculty of Enigeering

Cairo University

PID Single Loop Control

PID CONTROLLER CHARACTERISTICS

Presented for ELC 4046 Lab 8

Presented to:

Dr. Ahmed Ismail

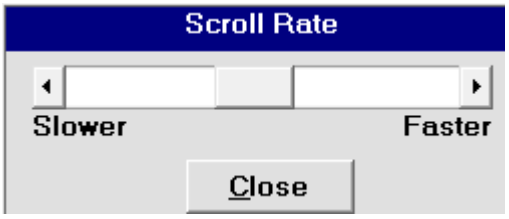
T.A: Mohamed nade

TEAM MEMBERS (4th Year Electronics and Electrical Communication Engineers)	
مجدي أحمد عباس عبد الحميد الابرق	Sec: 3 / I.D: 9210899 / BN: 32
محمد إبراهيم محمد على	Sec: 3 / I.D: 9210906 / BN: 34

LABORATORY EXERCISE 8
(PID CONTROLLER CHARACTERISTICS)

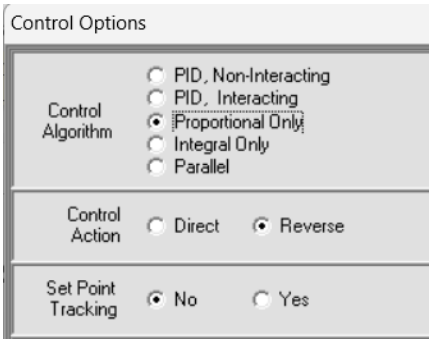
OBJECTIVE: To demonstrate the characteristics of the proportional, integral (reset) and derivative control modes in open loop operation, including definitions of the tuning parameters.

1. RUNNING THE PROGRAM



Run **PC – ControLAB**.

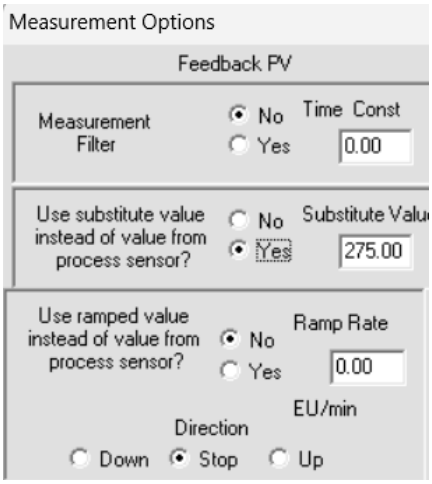
Slow down the simulation speed via **View | Scroll Rate** and select a mid-value, to have more practical experience.



2. PROPORTIONAL MODE DEMONSTRATION

2.1 Set Up

- Check the top line of the display. Be sure that you are using the **GENERIC** process model, the **FEEDBACK** control strategy. Be sure that the controller is in **MAN**.



- From the Menu Bar, select **Control** | **Control Options**. For Control Algorithm, select **Proportional Only**.
- While you still have the Control Options box on display, be sure the following options are selected:
- Control Action > **REVERSE** & Set Pt Tracking > **NO**
- Press **Close** to remove the Control Options box.

- Select **Control | Measurement Options**.
- Select **Yes** for "Use substitute value instead of value from process sensor?"
- Press **Close** to remove the Measurements Option box.

- Select **View | Display Range | Percent of Span**.
- Select **View | Display Proportional Band**. (An auxiliary bar display will appear between the strip chart and the instrument faceplate. Its use will be explained later.)

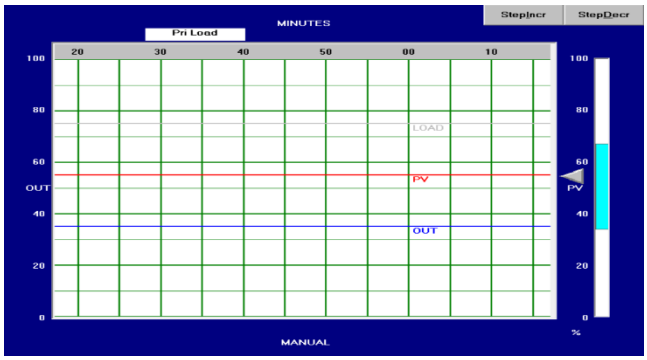


Figure 1: Display range in percent & PB

2.2 Gain and Proportional Band Features

- Press **TUNE**. Set or confirm the following values:
- GAIN 2.0
- MANUAL RESET 35
- Click on the **Options** tab and select "Display proportional tuning parameter as" Prop **Band**.
- Return to the **Tuning** tab.

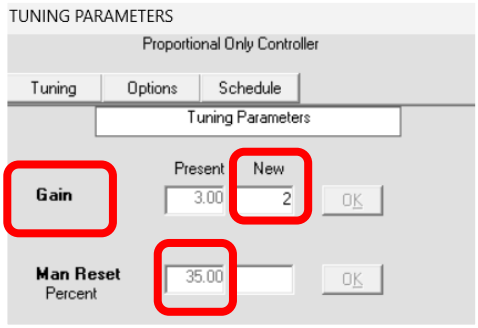


Figure 2: Gain & bias new values

Q1: What value and what name do the Tuning Display now show in place of GAIN?

- **Value** = 50%
- **Name:** is Proportional Band Percentage.

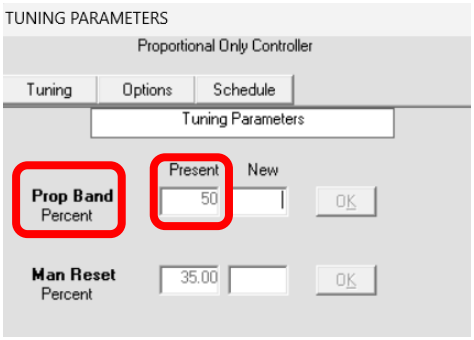


Figure 3: Display proportional tuning parameter as" Prop Band "

- Press **Close** to remove the Tuning dialog box.
- Select **View** | **Data Monitor**.

Q2: Record the following present values?

- **Process variable:** 55
- **Setpoint:** 55
- **Controller output:** 35

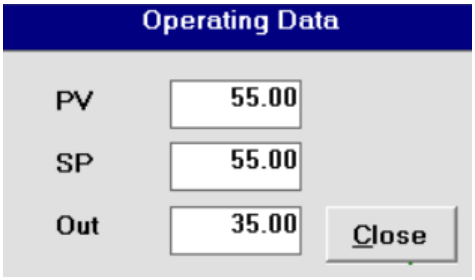


Figure 4: Monitor operating data

- For a **Reverse Acting** controller, the controller error is calculated as:
- **ERROR = SP - PV**
- and the top and bottom of the proportional band can be calculated from the present values of setpoint (SP), manual reset (MR) and gain (or PB).
- **PBtop = SP + MR × (PB / 100) & PBbot = PBtop – PB**

Q3: Calculate the PB_{top} and PB_{bot} and confirm the figures from viewing the PB bar (CYAN colored) at the right of the strip chart?

P.O.C	Calculated	Observed
PB_{top}	$= 55 + 35 * \frac{50}{100}$ $= 72.5\ \%$	$= 72.5\ \%$
PB_{bot}	$= 72.5 - 50$ $= 22.5\ \%$	$= 22.5\ \%$

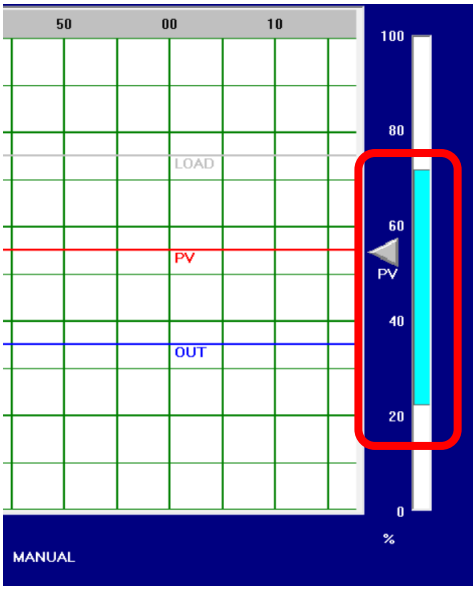


Figure 5: PB Limits

- Put the controller in **AUTO**. Change the Set Point to 65.

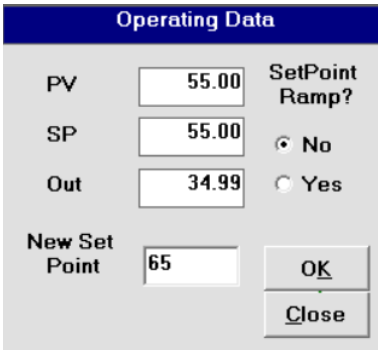


Figure 4: Changing SP

Q4: Did the PB bar move as expected?

- **Yes**, it moves **upwards** as expected, because the SP increase and according to the equations:
  PBtop =**SP** + MR × (PB / 100) & PBbot =PBtop – PB
- increasing in SP will **increase** the **PBtop** & **PBbot**
- But **PB value remains as it is** (only shifted)

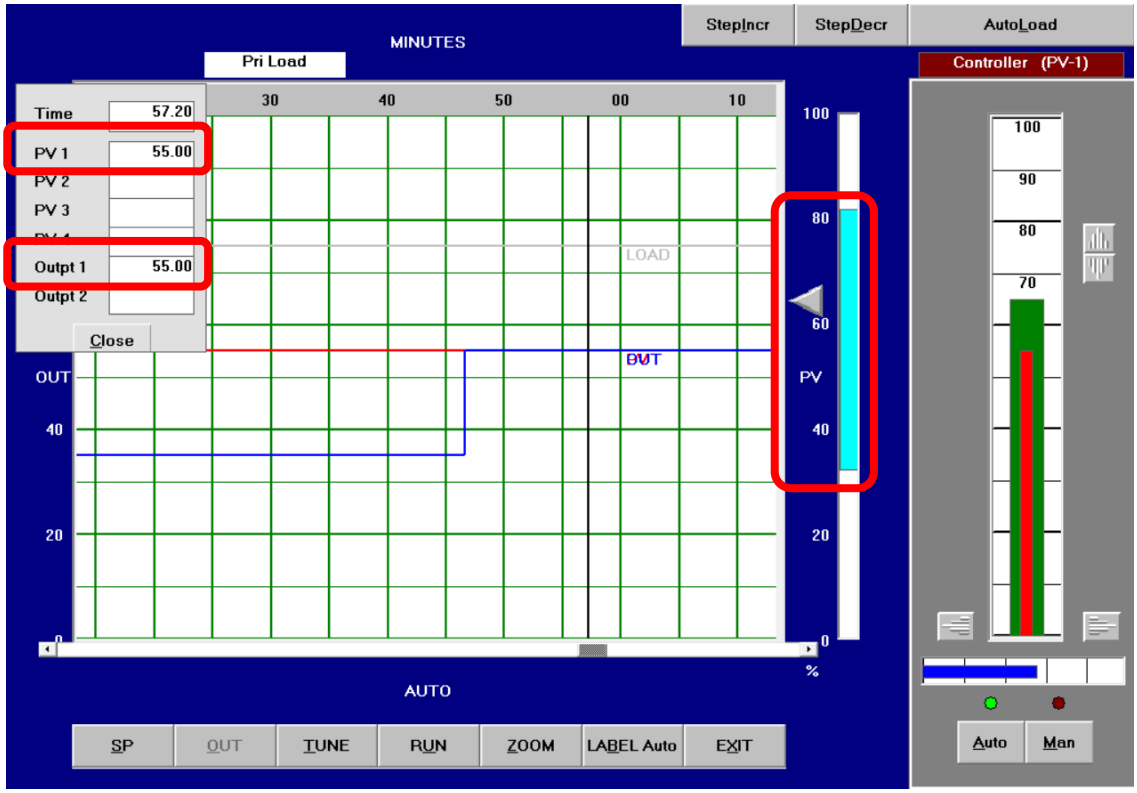


Figure 5: PB bar shift after changing PV

Q5: Calculate the theoretical controller output (m)?

- Since m = gain * (error) + MR, and the controller is reverse-acting, so error = SP-PV
- Therefore, m = 2 * (65 - 55) + 35 = **55 % (all in percentage except Kc)**

Q6: Does the theoretical output agree with the observed output?

- **Yes**, it agrees, **Output 1 = 55 %** as shown in fig. (7) above

Q7: From an observation of the Proportional Band bar, what value of PV would cause the controller output to go to zero?

- Since the controller is **reverse-acting**, so as PV increases the controller decreases, therefore when PV goes to its **max** value in PB range which is **PBtop**, the controller output becomes **zero** % (PB value doesn't change)
- **PV value** = PBtop = SP + MR × (PB / 100) = 65 + 35 × (50 / 100) = **82.5 %** as shown in fig. (7)

Q8: From an observation of the Proportional Band bar, what value of PV would cause the controller output to go to 100%?

- Since the controller is **reverse-acting**, so as PV decreases the controller increases, therefore when PV goes to its **min** value in PB range which is **PBbot**, the controller output becomes **100** % (PB value doesn't change)
- **PV value** = PBbot = PBtop - PB= 82.5 - 50 = **32.5 %** as shown in fig. (7)

- Select **Control** | **Measurement Options**. Enter a substitute PV value of **82.5**.

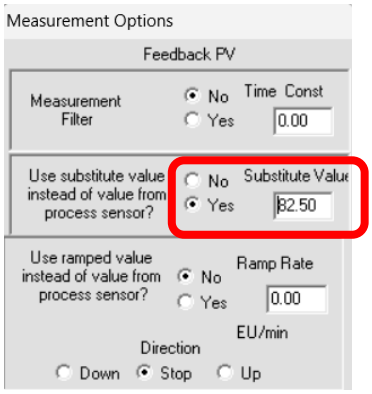


Figure 6: PV changed to PB_top

Q9: What is the Controller Output?

- **Zero** %

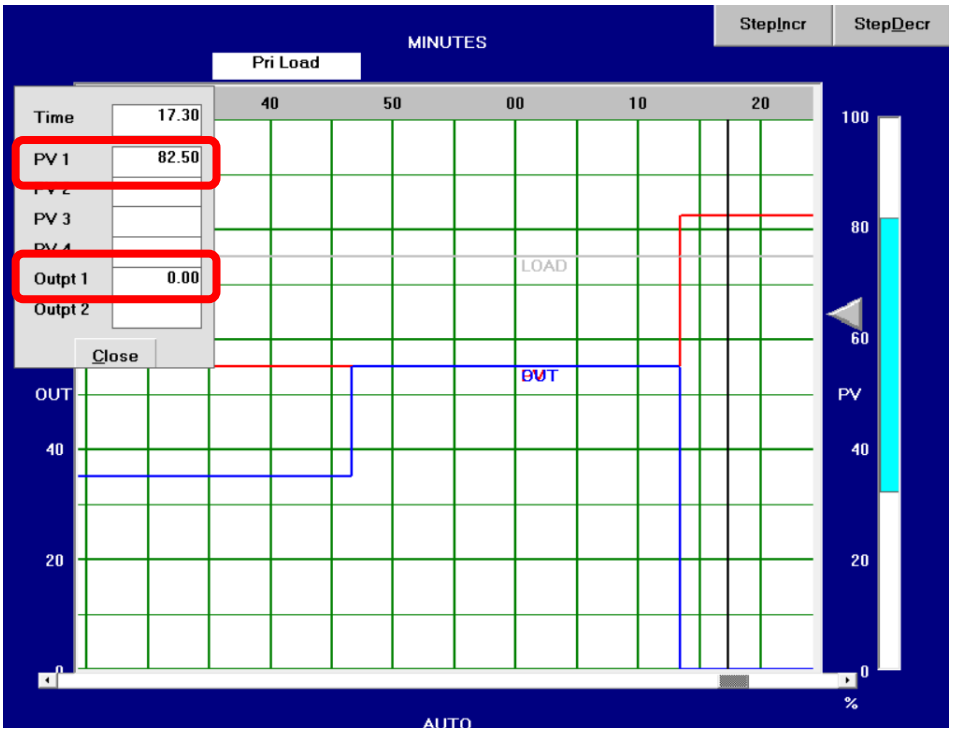


Figure 7: Controller output @ PV = 82.5%

- Now enter a substitute PV value of **32.5.**

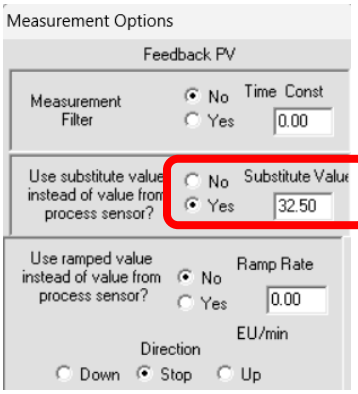


Figure 8: PV changed to PB_bottom

Q10: What is the Controller Output?

➢ **100** %

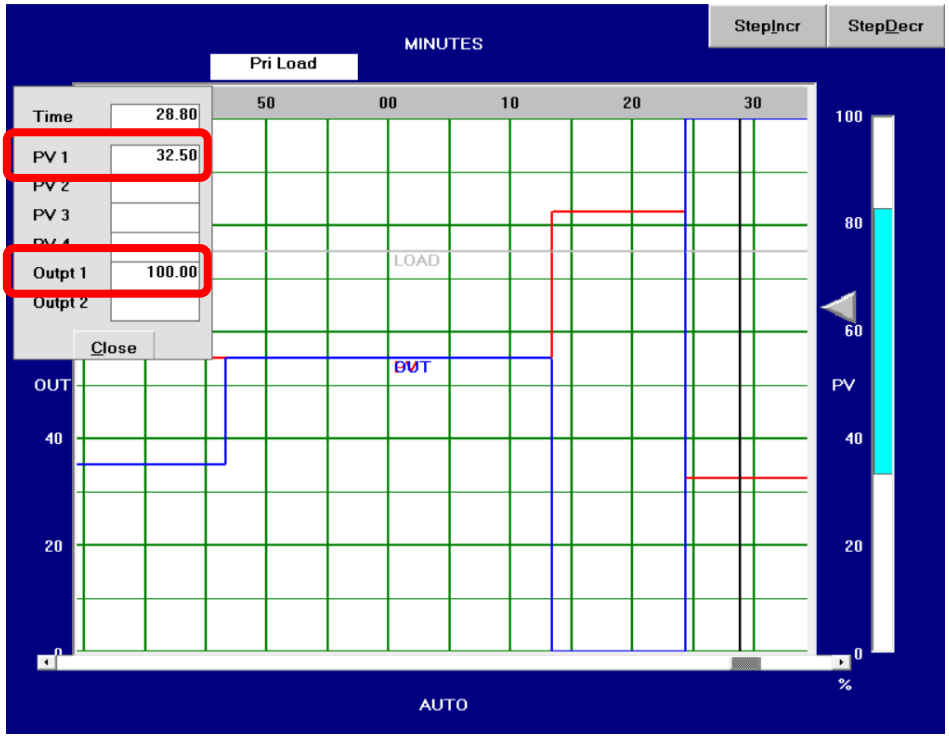


Figure 9: Controller output @ PV = 32.5%

- Select **Control** | **Measurement Options**. Enter a substitute PV value of **70.0**.
- Observe the PB bar and the present value of the PV.

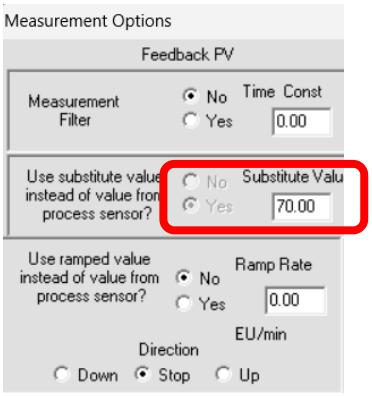


Figure 10: PV changed to 70

Q11: Make a visual estimate of the fraction of PB down from PBtop to the PV value?

➢ $\frac{82.5-70}{50} * 100 = 25\%$

➢ So, the decrease in **PV** value is **25%** fraction from PB

➢ Therefore, the **controller output** increase by **25%**

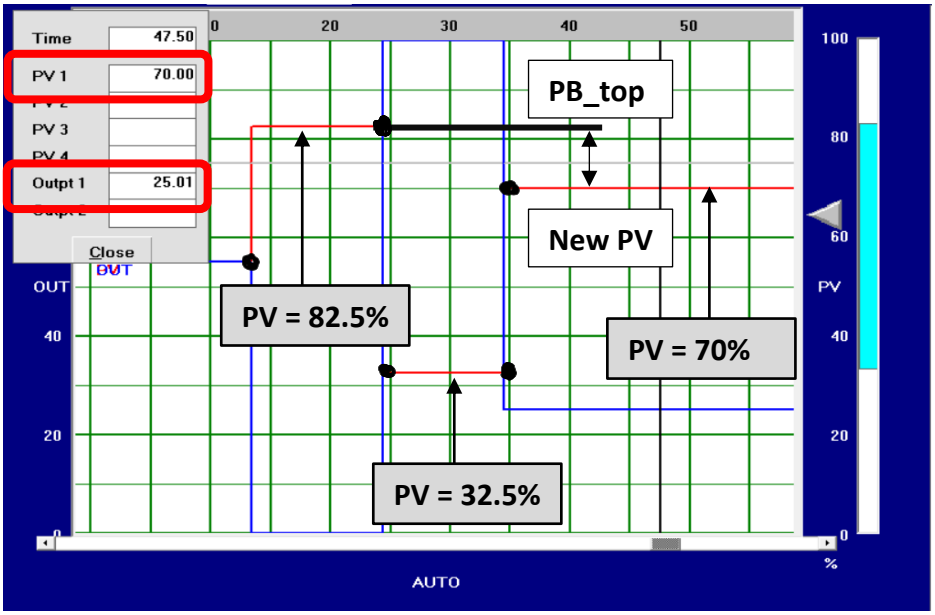


Figure 11: Controller output @ PV = 70%

Q12: Does this (approximately) agree with the controller output?

- **Yes**, it agrees because the controller output goes to **25.1 %** as shown in fig. () above
- m = gain * (SP – PV) + MR = 2 * (65 -70) + 35 = **25 %** (theoretically)

2.3 Closed Loop Proportional Mode Response

- Put the controller in **MAN**. Change the Set Point to 55.
- Change the controller output to 35.0. Change the substitute PV value to 55. Then select **Control** | **Measurement Options** and select **NO** for "Use substitute value …?" (Now we will be using process feedback.)

  Now put the controller in **AUTO**
- Change the Set Point to 65.

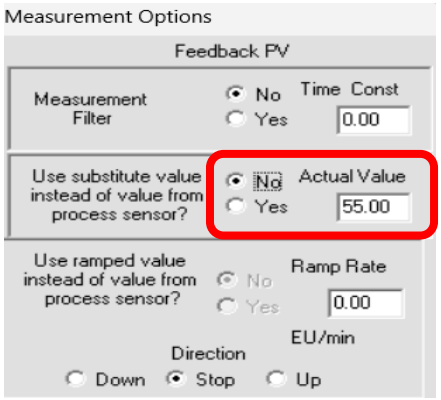


Figure 12: New PV = 55

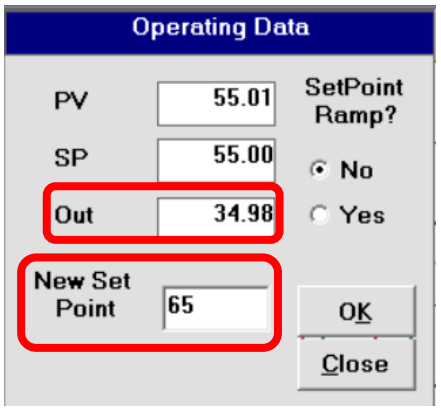


Figure 13: New SP = 65

Q13: When the control loop comes to equilibrium, note:

- **Process variable:** 62.47
- **Setpoint:** 65
- **Controller output:** 40.07

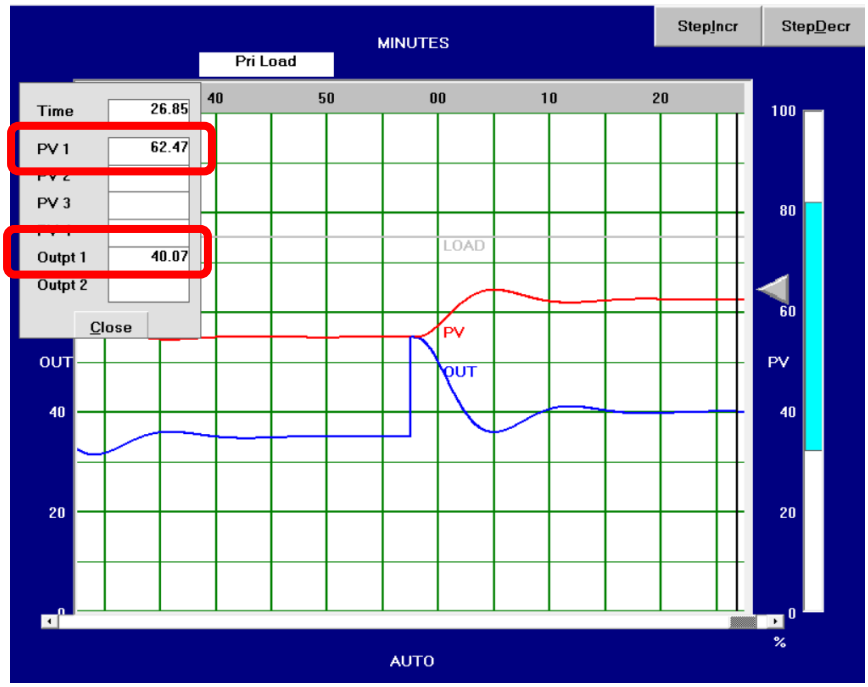


Figure 14: Controller Output & PV Response

Q14: Calculate the error?

- ERROR = SP - PV = 65% - 62.47% = **2.53%**

Q15: Calculate the theoretical controller output from the equation given previously. Does this agree with the observed output?

- OUTPUT = GAIN * ERROR + MR = 2.0 * 2.53% + 35% = **40.06%**
- **Yes**, it agrees with the observed output (only 0.01 % difference between them)

Q16: The PV and SP do not agree. Which way, increase or decrease, should the Manual Reset be adjusted to bring the PV into agreement with the SP?

- Since the error is **positive** and the controller is **reverse acting**, then the pv may **increase** and manual reset must **increase** to eliminate the offset
- **Yes**, it agrees with the observed output (only 0.01 % difference between them)

Q17: Experimentally adjust the Manual Reset until the PV matches the SP.

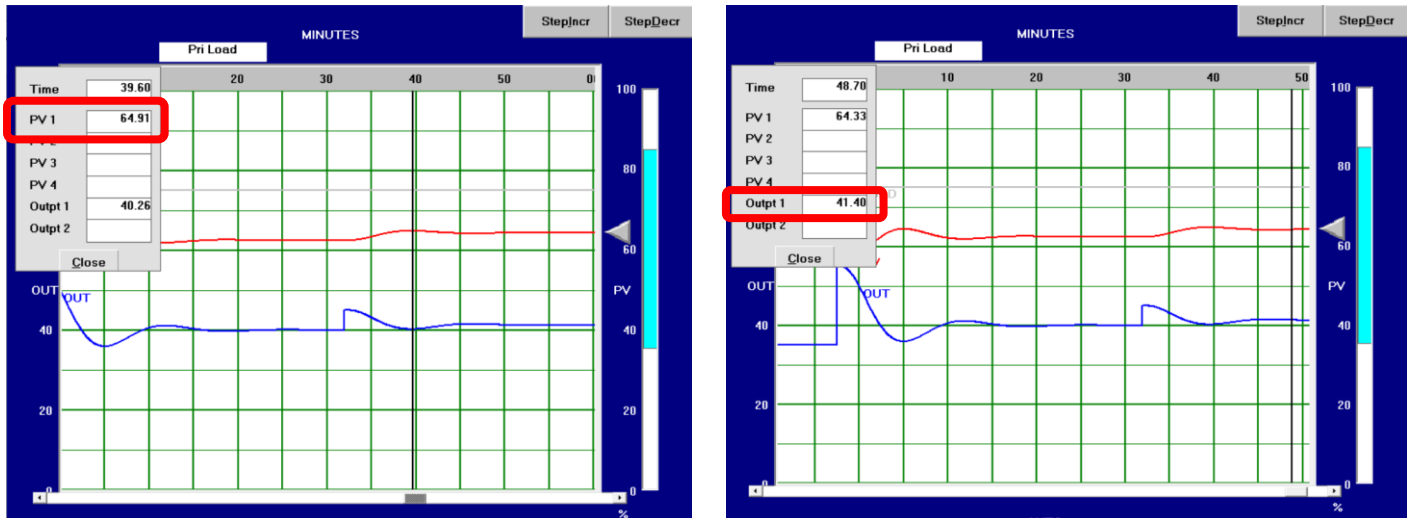


Figure 15: PV Response when increasing Manual Reset (Bias) to 40.06

- Final value of **Manual Reset**: 40.06 %
- Final value of **Controller output**: 41.40 %

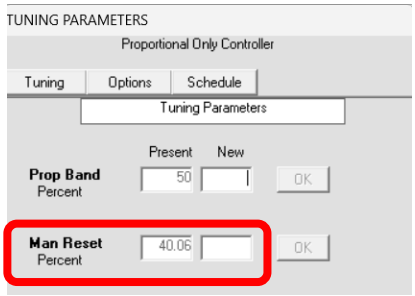


Figure 16: Changing Manual Reset to 40.06

Q18: Did the PB bar move as you adjusted the Manual Reset?

> ➢ **Yes**, it moves **upwards** as expected, because the **bias increased** from 35 % to 40.06% due to **positive error** or offset between the SP % PV.

---

3. INTEGRAL MODE DEMONSTRATION

3.1 Set Up

- Select **View** and click on **Display Proportional Band** (to remove it).
- Put the controller in **MAN**.
- Select **Control** | **Control Options** and set or check the following options:
- Control Algorithm: PID, Non-Interacting
- Action, Direct or Reverse: Reverse
- Set Point Tracking? No
- Deriv on Error or Meas: Meas
- Prop on Error or Meas: Error
- Go to **Control** | **Measurement Options** and set:
- Use substitute value: YES
- Substitute measurement value: 50
- Press **Tune** | **Options** and set the following:
- Display the proportional tuning parameter as GAIN
- Return to the **Tuning** tab and set

  Gain: 1.0
  Reset, Min/Repeat: 5.0
  Deriv, Mins: 0.0

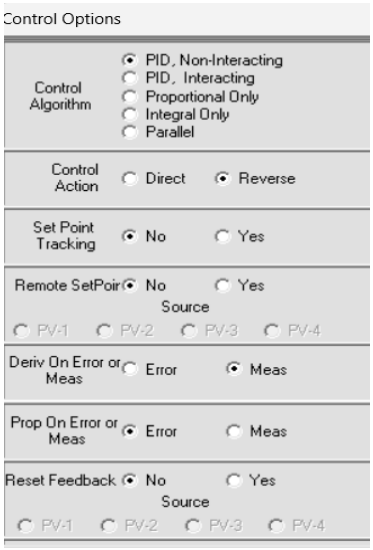


Figure 13: Control Options

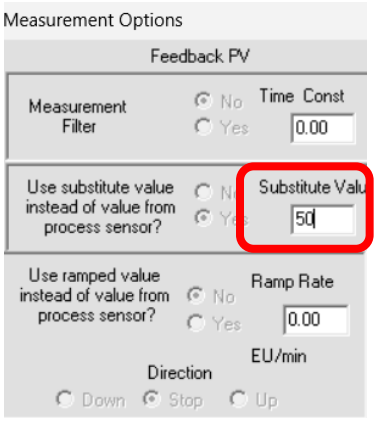


Figure 14: First change of PV to 50

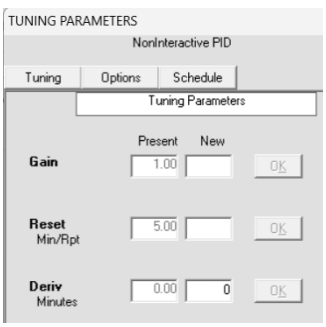


Figure 15: Controller Parameters

- Set the following:
- Set Point: 50
- Controller Output: 40
- Change to **AUTO**.
- (You should now see the control loop simulation in stable operation with **measurement** and **setpoint** both at **50**% and the **valve** signal at **40**%.)

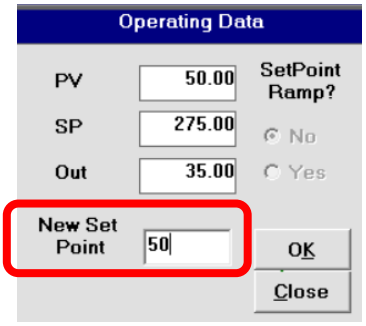


Figure 20: New SP

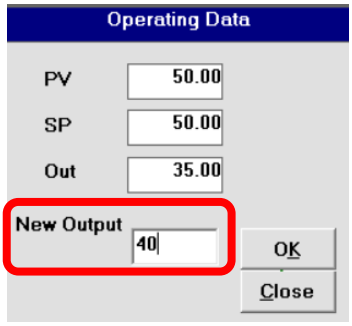


Figure 216: New Controller out

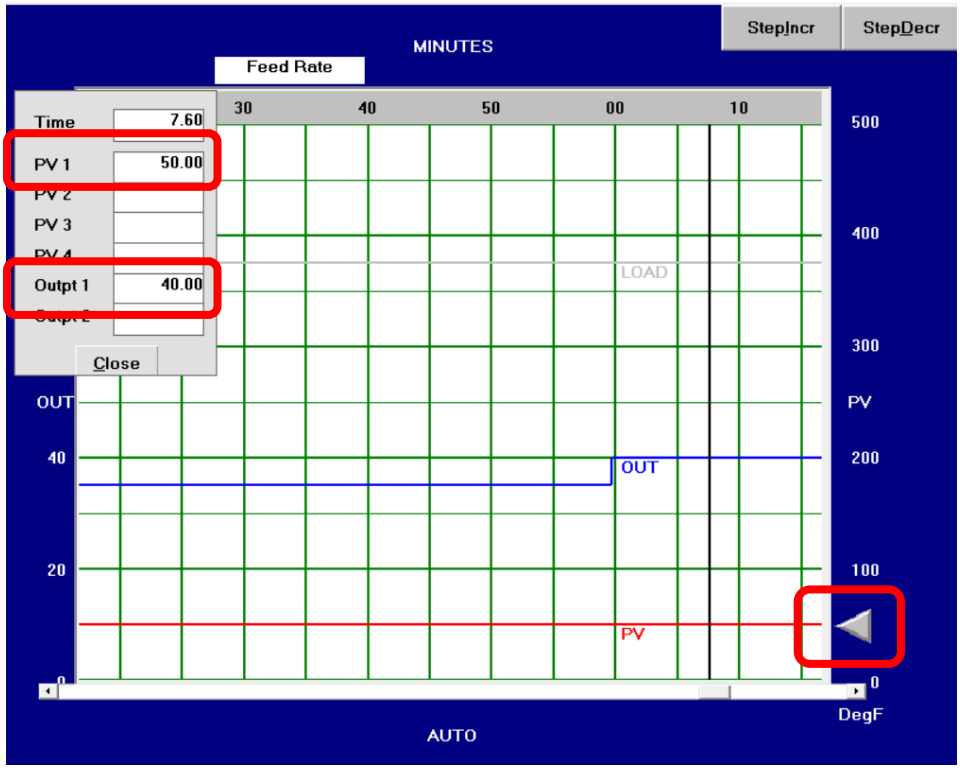


Figure 22: Stable operation of SP, PV and OUT

3.2 Integral Mode Response

- Go to **Control** | **Measurement** Options and enter:
- Substitute measurement value: 60
- Observe: The **controller output** signal immediately drops from **40**% to **30**%.
- The controller's output then begins to **ramp downward**, at the rate of **2% per minute**.

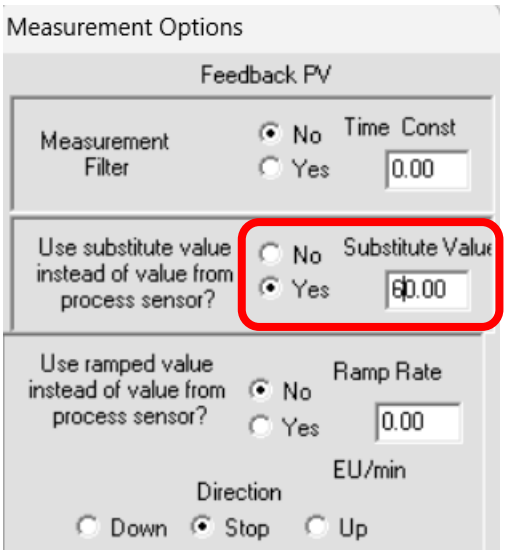


Figure 23: Second change of PV to 60

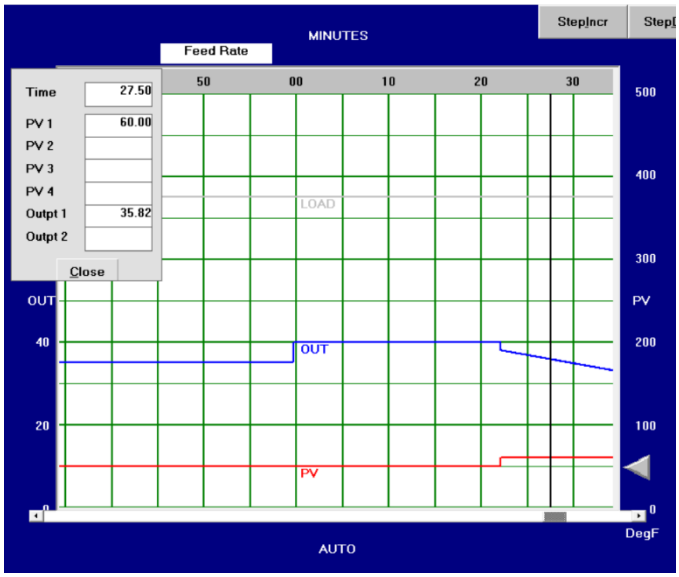


Figure 24: Controller out response due to second change of PV to 60

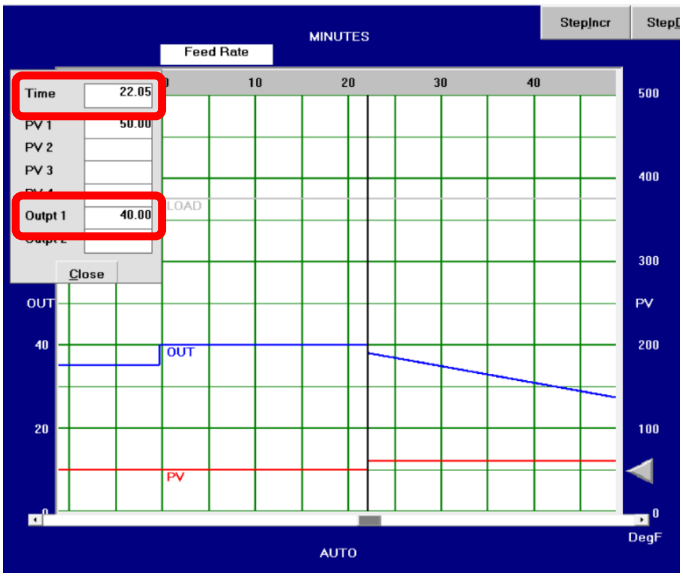


Figure 25: Start time of prop kick (start of Ti)

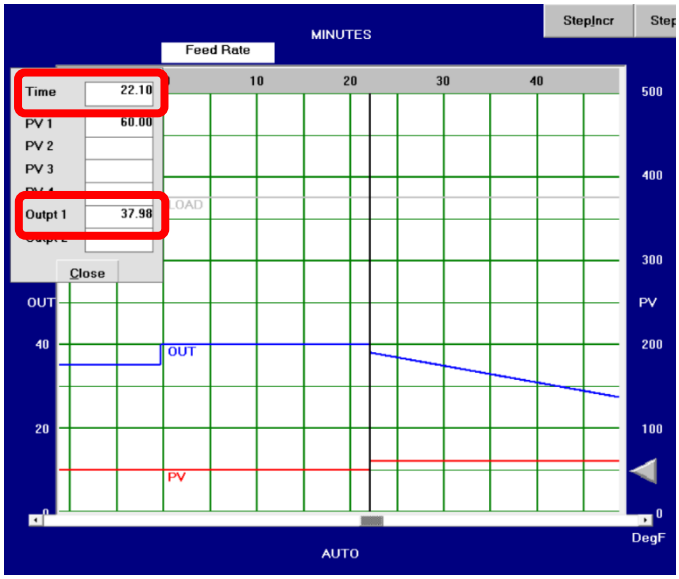


Figure 26: Value of Controller out just after the Prop kick

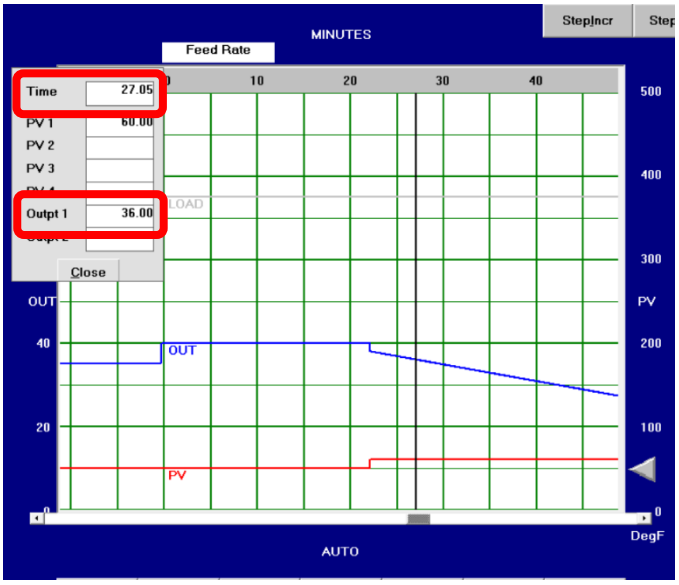


Figure 27: Repeat time of prop kick effect (end of Ti)

- As shown in fig. (26), the controller **goes down** by **2%** due to a prop kick = gain * change in error $= 1 * \left(\frac{50-60}{500} \times 100 - 0\right) = -2\%$, so the OUT = 37.98 ≅ **38 %**
- Then the integral action takes place, and as we know $\boldsymbol{I = k_c \frac{1}{T_i} \int e\, dt = 1 * \frac{1}{5} * (-2)\, t = -0.4\, t}$ → therefore the OUT **decrease** by rate 0.4% every minute
- $T_i = time\ in\ fig.(27) - time\ in\ fig.(25) = 27.05 - 22.05 = \mathbf{5\ min}$
- As we expected, the integral component repeats the prop action after integral time (it moves **from 37.98 to 36**) as shown in fig. (27)

3.3 Integral Mode Response, A Second Example

- Put the controller in **MAN**.
- Enter a substitute measurement value of **50%**.
- Enter a controller output of 40.
- Put the controller in **AUTO**.
- Be sure the controller is in a steady state condition, with the **measurement** at **50**% and **controller output** signal at **40**%

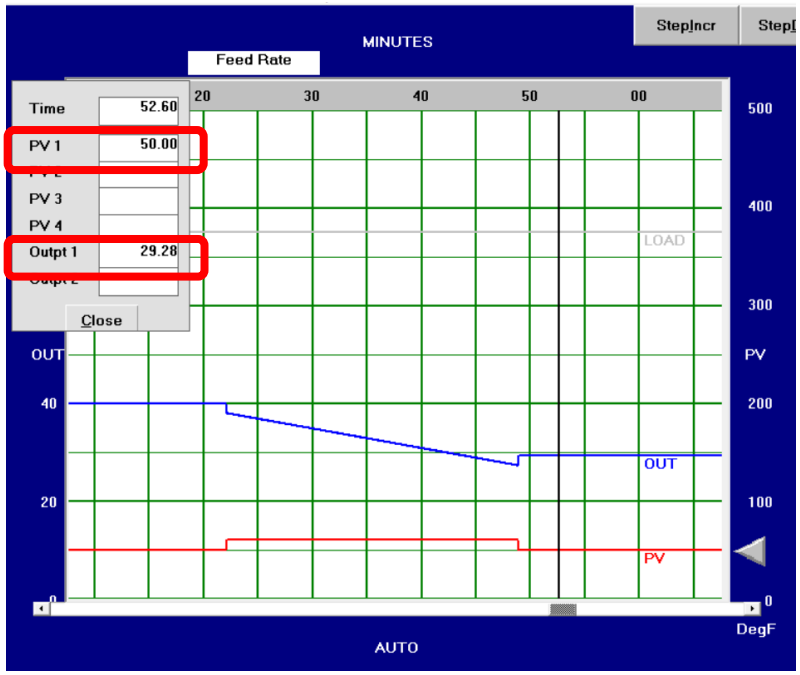


Figure 30: Controller out response due to Fourth change of PV

- Now, enter a substitute measurement value of **55**%.

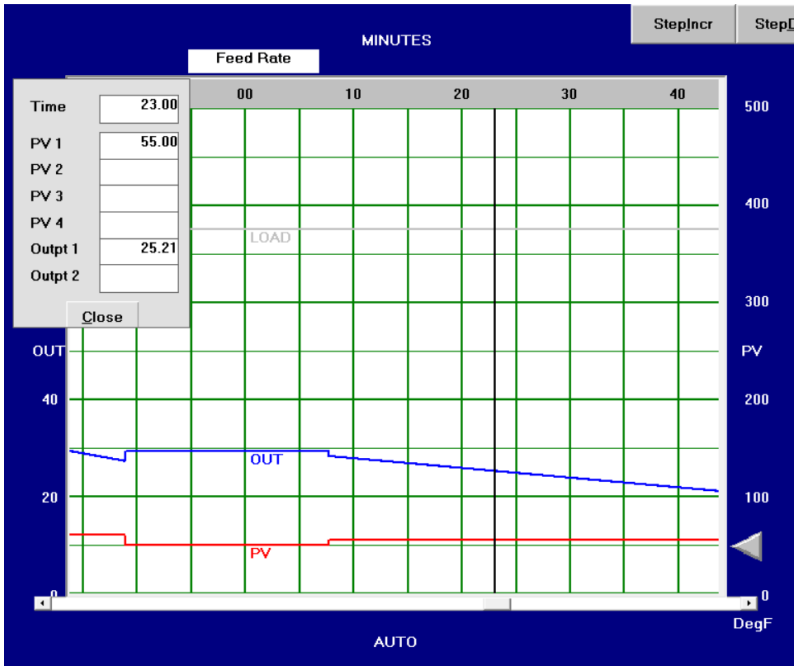


Figure 32: Controller out response due to third change of PV

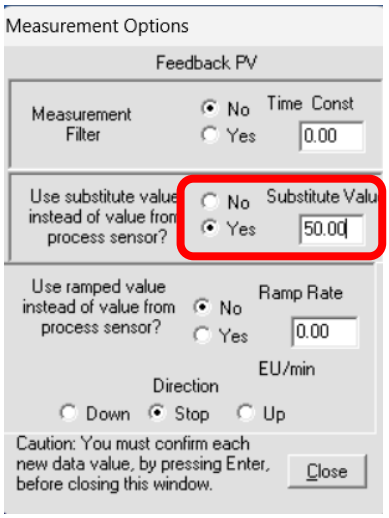


Figure 28: Third change in PV to 50

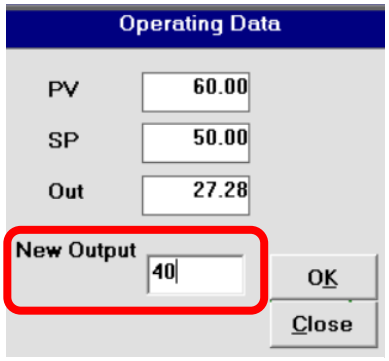


Figure 29: New Controller out

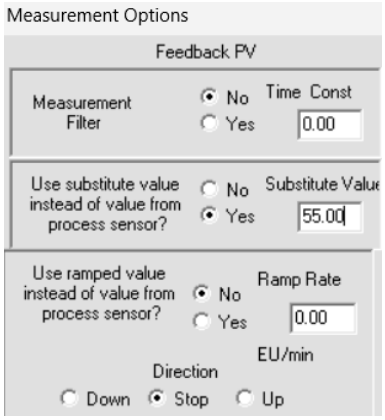
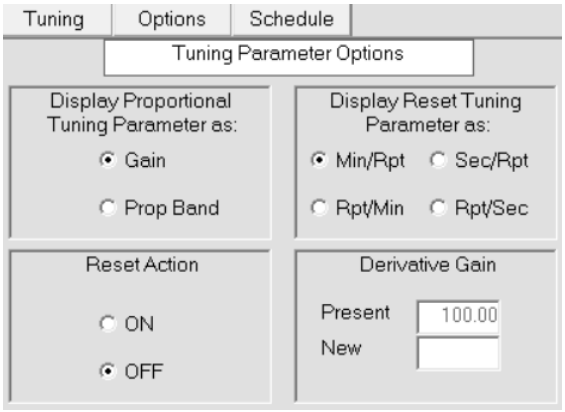


Figure 31: Fourth change in PV to 55

4. DERIVATE MODE DEMONSTRATION

4.1 Set Up



- Put the controller in MAN.
- In the **Tune | Options** tab, set the following:

Reset Action	OFF
Derivative Gain	100.0

Enter the following tuning values:

Gain:	0.5
Reset, Min/Repeat:	Not applicable (it's OFF)
Deriv, Min:	0.0

Enter the following operational values:

Set Point:	50
Controller output:	40

- In the **Control | Measurement Options**, select **Yes** for "Use substitute value …?",
- then enter a substitute measurement value of 50
- Change the controller mode to AUTO.
- Verify that the controller is in stable operation with setpoint and process variable at 50, and controller output signal at 40.

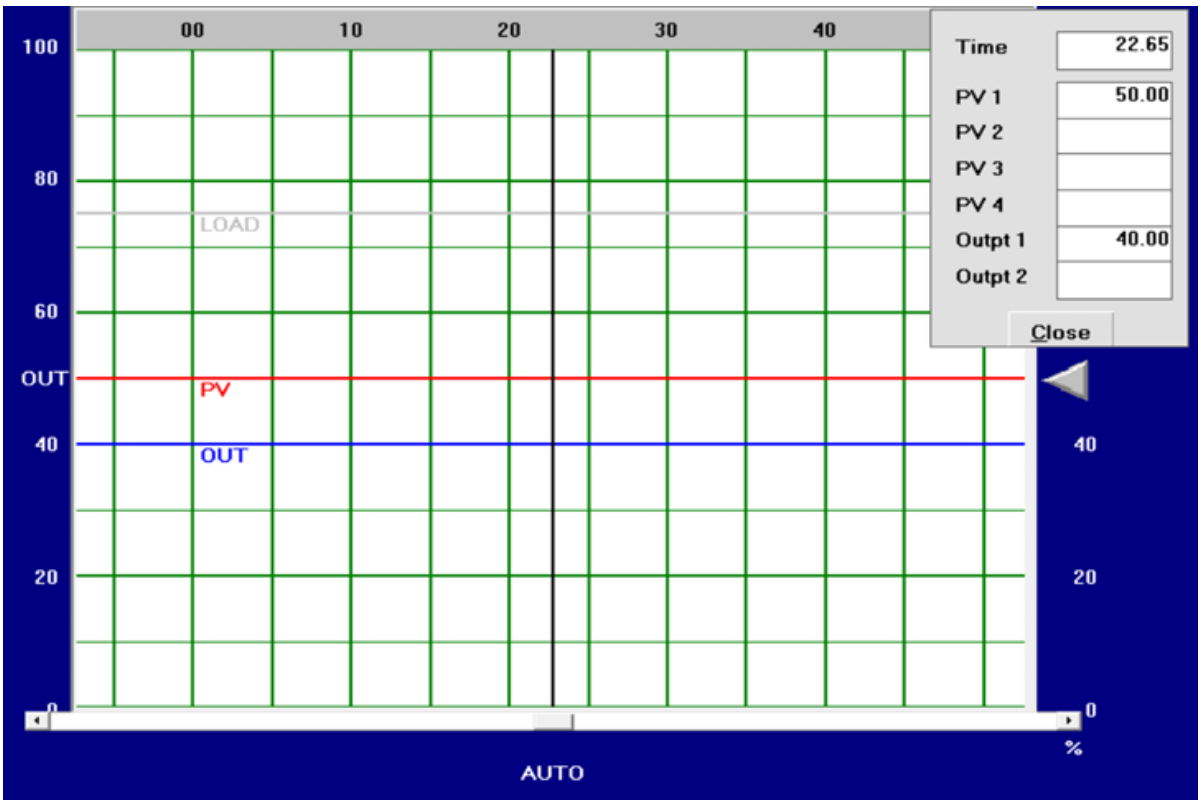


Figure 33: Controller Output = 40 & PV = 50 After setting the parameters up for Proportional Mode only

4.2 Ramp Response with Proportional Mode Only

- Under **Control | Measurement Options**, select **Yes** for "Use ramped value instead of value from process sensor?"
- Enter a ramp rate of 4%/minute.
- Select **Up**.
- Observe:
- The process variable ramping upward from its initial value of 50% at the rate of 4%/minute.
- The controller output ramping downward from its initial value of 40% at 2%/minute, stopping at 15% when the measurement reaches 100%.
- *(Reason: It is a reverse acting controller, so as measurement increases, the controller output decreases. The Gain is 0.5, so the controller output drops half as fast as the measurement rises.)*

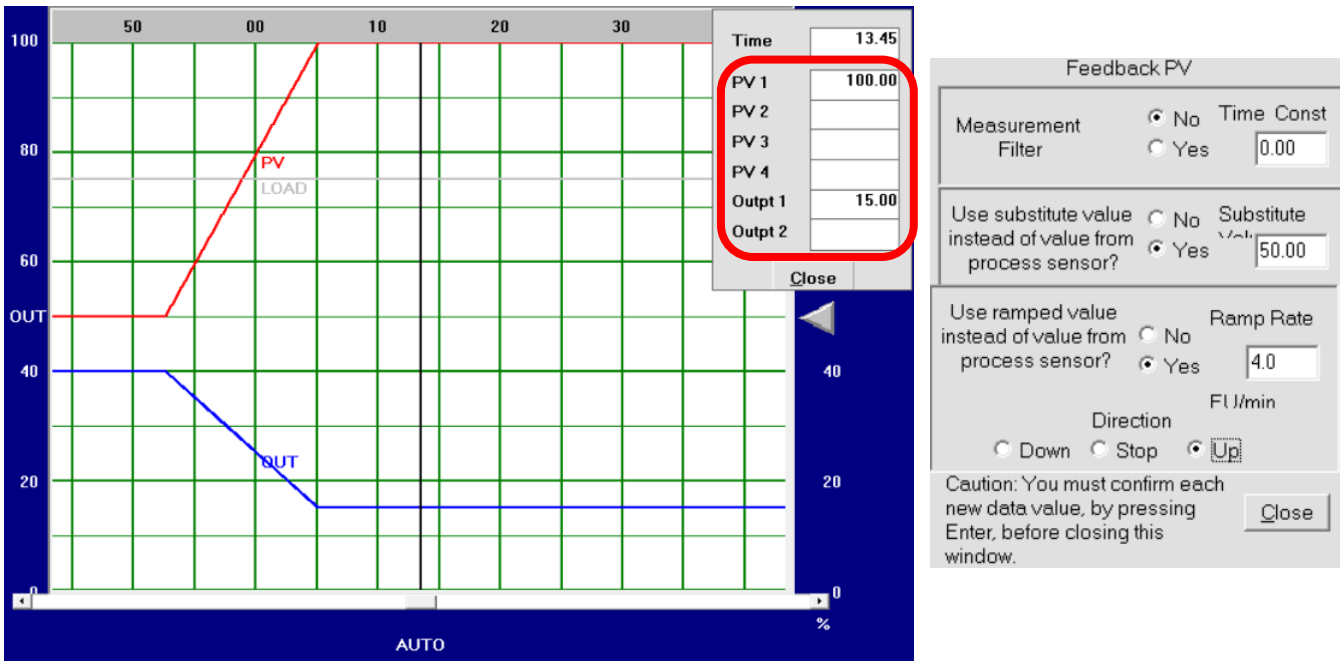


Figure 34: Controller Output stopped at 15 % when PV = 100 % Ramp Response with Proportional Mode only

Comments:

From the controller output equation: m = $K_c\, e$, where e = $SP - PV$.
Given that over time, e = $-4t$ and m = $-2t$, the controller output will continue decreasing linearly until the process variable (PV) reaches its saturation limit at 100%. Thus, even before running the simulation, we can anticipate that the controller output will keep ramping down until the PV saturates at t = 12.5 minutes from the start time. At that point, the final controller output will settle at 15%.

4.3 Ramp Response with Proportional and Derivative Modes

- In **Control | Measurement Options** select **No** for "Use ramped value …?"
- Change the controller mode to MAN.
- Enter a controller output signal of 40
- In **Control | Measurements Options** enter a substitute measurement value of 50
- Change the controller mode back to AUTO.

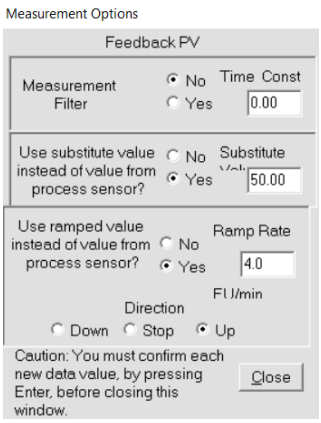
- Press **Tune** and change the Deriv setting to 5 minutes.
- Verify stable operation at a measurement of 50 and controller output signal of 40
- In **Control | Measurement Options**, enter the same ramp parameters as before:

  Rate: 4%/minute
  Direction: UP
  then select **Yes** for Use ramped value…?"
  Observe:
  The measurement ramping as before.

- The controller output signal makes an almost immediate change from 40% to 30% then ramps downward at the rate of 2% per minute to 5%, when the measurement has reaches 100%. As soon as the measurement ramp stops, the controller output signal makes an almost immediate change from 5% to 15%, then remains constant.
- *Reason: The derivative contribution is*
  $= -$ Gain × Deriv time × Meas ramp rate $= -0.5 \times 5$ minutes $\times$ 4 %/minute $= 10$ %

- *If the controller had no derivative (as in the first trial), you can estimate approximately how long, from the initiation of the ramp, was required for the controller output signal to change from its initial value (40%) to some chosen value (say, 20%). Your estimate should be approximately 10 minutes, with proportional control only.*
- *With derivative (as in this trial), estimate the time required for the controller output signal to change from its initial value (40%) to the same point (20%). Your estimate should be approximately five minutes.*
- ***Conclusion**: With a derivative time of 5 minutes, the controller output signal should lead (or get to the same chosen point) by 5 minutes its behavior with proportional control only.)*
- Repeat this part of this laboratory exercise, this time with a measurement ramp rate or a derivative time of your choice. You should observe:
  Derivative mode Rate of change contribution to = – Gain X Deriv time X of controller output measurement.

*The " – " sign is due to the fact that the derivative contribution is always in a direction which **opposes** the direction of measurement change.*



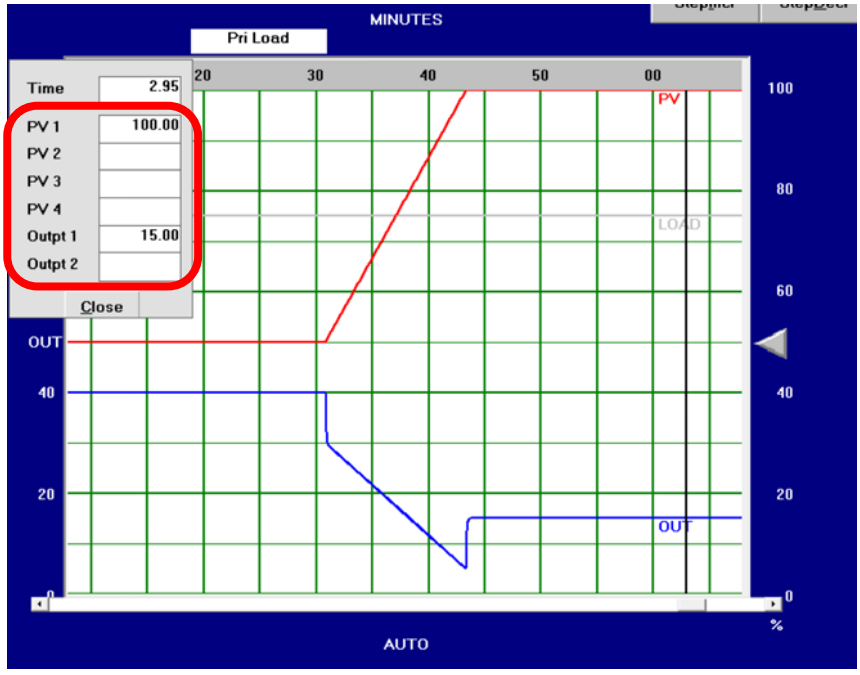


Figure 35: Controller Output stopped at 15 % when PV = 100 %
Ramp Response with Proportional and Derivative Modes

Comments:

- Like the previous scenario, the controller output eventually saturates at **15%** because the proportional response also reaches its limit. Additionally, the derivative action diminishes once the error stabilizes.
- The key difference lies in the **derivative response**, which actively influences the system before saturation. Since it detects the decreasing rate of error, it further reduces the controller output by **10%** until the error rate becomes constant, at which point its effect fades away.

Repeated Experiment:

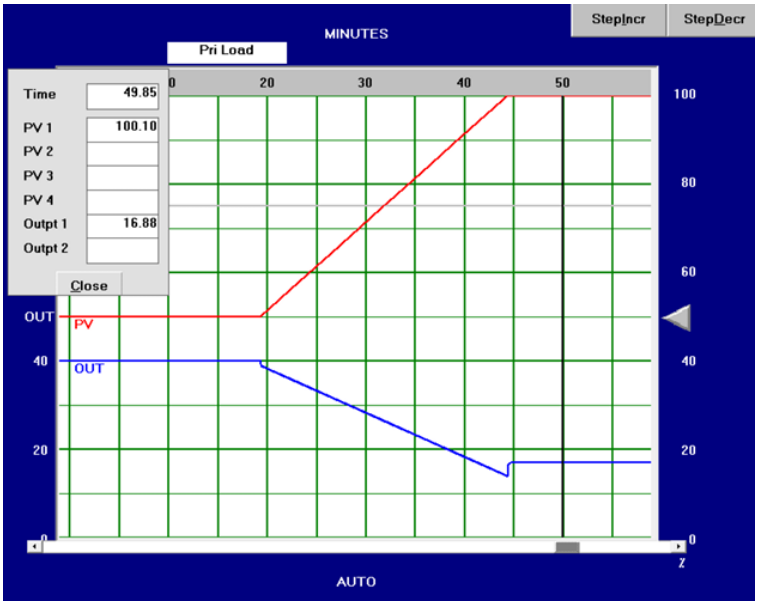


Figure 36: Controller Output stopped at 16.88 % when PV = 100 %

Comments:

After adjusting the ramp rate to **2 EU/min** and setting the derivative time to **3 minutes**, the derivative component contributes a response of **-3%** (calculated as **-0.5 × 2 × 3**). As a result, the controller's output experiences an abrupt drop from **40% to 37%** due to this derivative action. Following this initial step change, the output continues to decline linearly at a rate of **1% per minute**. Once the measurement ramp stabilizes at **100%**, the controller output eventually saturates near **17%**.