Skill practice 7: Loop tuning (single variable)

Suggested duration
2½ hours

Task
- To tune a feedback control loop to provide QAD (Quarterly Amplitude Decay) response using at least, two different tuning methods.
- To retune the loop to the minimum disturbance response.

Equipment
- Suitable process plant with feedback control loop (flow, level, pressure etc.)
- Chart recorder
- Digital multimeter
- Wires and connectors
- Tuning notes and handouts

Procedure

Part A Tuning by systematic trial

1. Provide a sketch of the control loop.

2. Connect the chart recorder to record the process variable.

3. Check the operation of the loop on manual. Check that all the loop components are functioning correctly. Set up the recorder to record the process variable.

4. Describe the systematic trial tuning method.

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5. Tune the loop to give QAD response using the systematic trial method.

1st try	*2nd try*

6. Record your PID settings:

   P __________ I __________ D __________

   Attach a copy of the response curve.

7. Retune the loop to give a minimum disturbance response.

8. Record your PID settings:

   P __________ I __________ D __________

   Attach a copy of the response curve.

Part B Tuning by ultimate cycling

1. Adjust the controller gain to provide an ultimate cycle. (*Note:* I and D must be off).

2. (a) Calculate the PID settings.

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   (b) P = __________ I = __________ D = __________

   Attach the ultimate cycling response curve.

3. (a) Set the PID settings as calculate above and check the control loop response. Do these settings provide a satisfactory QAD response? *(Circle the correct answer)*

   Yes / No

   (b) Fine tune the control loop using the calculated PID settings as your starting point. Has the control loop response improved?

   Yes / No

4. Record your new PID settings:

P ____________ I ____________ D ____________

Attach a copy of the response curve.

1st try	*2nd try*

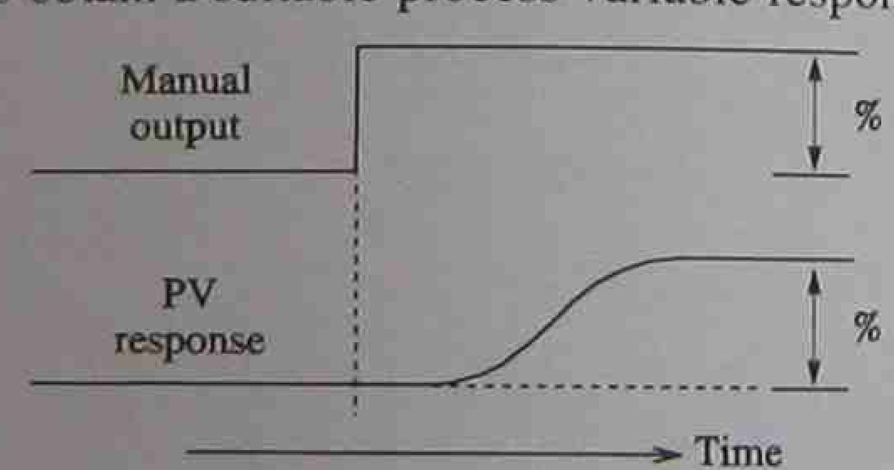
5. How would you proceed to retune the loop to give a minimum disturbance response?

Part C Tuning by open loop process response

Note: You must record both the manual output change and the process variable response.

1. (a) Step change the manual output to obtain a suitable process variable response.

You will obtain a chart record similar to that shown on the right.



(b) Remove the response curve obtained from the chart recorder.

2. (a) Construct the tangent on the PV response graph to obtain the time lag.

(b) With the data obtain from the graphs, use the appropriate equations to determine the PID settings.

(c) The PID settings as calculated are:

P ____________ I ____________ D ____________

(d) How do these settings compare to these obtained using the ultimate cycling method?

3. (a) Set the PID settings that you have calculated from the graphs and check the control loop response.

(b) Explain how this response compares to that obtained from the ultimate cycling PID values.

4. Explain why its necessary to fine tune the control loop to obtain a satisfactory control response?

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Part D Automatic tuning
If equipment and time is available retune the system using either an auto self-tuning type of controller or a loop analysis type package.

Observations/conclusion

1. Which tuning method was the most effective?

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2. Which tuning method caused the least process disturbance during the tuning procedure?

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Skill practice 8: Multi-variable loop tuning

Suggested duration
2½ hours

Task
To tune a multivariable loop, (such as cascade or feedforward etc.), using the systematic trial method auto-tuning methods.

Equipment
- Suitable process plant with appropriate control loop, or process simulator
- Chart recorder/VDU
- Wires and connectors
- Tuning notes and handouts.

Procedure

1. Provide a sketch of the control loop.

2. Briefly outline the principle of operation of this loop.

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3. Outline, in step form, the tuning procedure for this loop. (For example, the basic procedure for a cascade loop would be:
   - tune the slave with the master on manual,
   - then, tune the master.)

Teacher check	

4.

Explain to the teacher how this control loop operates and how you will proceed with this task.

5. Tune the control system to provide QAD response using the systematic trial method.

Teacher check	

6.

7. If equipment and time is available return the system using either an auto self-tuning type of controller or a loop analysis type package.

Observations/conclusions

1. Was the systematic trial tuning procedure a satisfactory method for tuning this loop?

2. Would another tuning procedure be more suitable for tuning this loop?

3. Did the auto tuning system have any advantages or disadvantages?

Review questions

These questions will help you revise what you have learned in Section 3.

1. Sketch a graph of the three main control valve inherent flow characteristics. (Quick opening, linear, equal percentage.)

2. Comment on the difference between the inherent and the installed characteristic of a control valve.

3. Define the terms rangeability and turndown.

Rangeability

Turndown

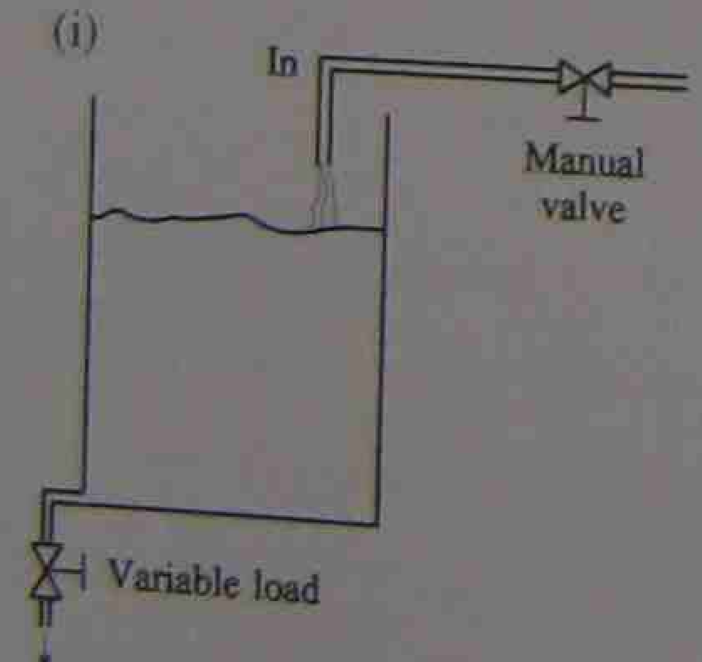
4. Comment on the effect of an incorrectly sized valve on control loop performance.

(a) Undersized valve

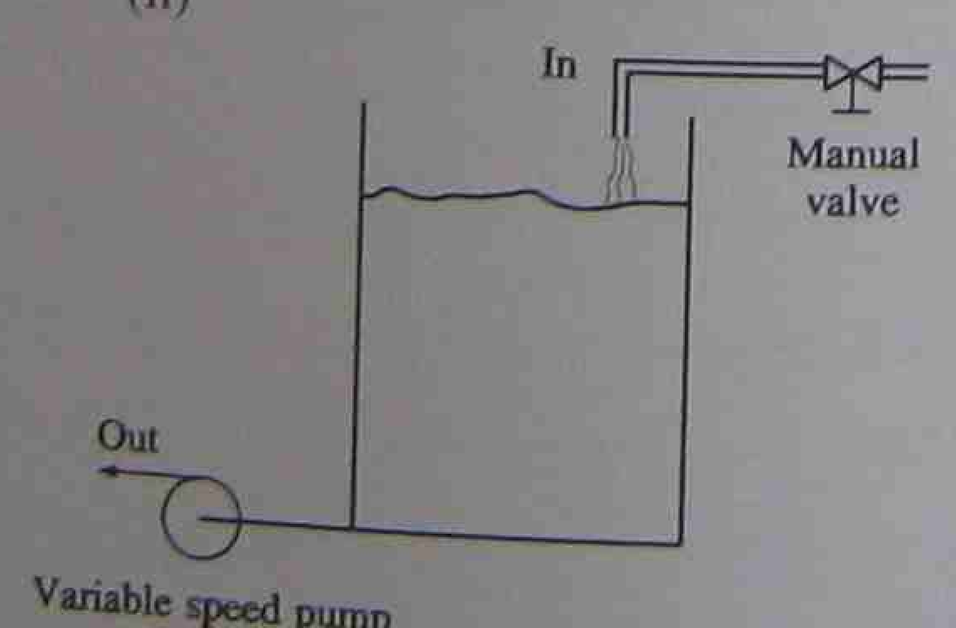
(b) Oversized valve

5. Refer to the diagrams below and answer the following questions.

(i)



(ii)



(a) Which process is self regulating (i) or (ii)? Why?

(b) Which process is not self regulating? Why?

(c) Which process has a linear response? Why?

(d) Which process has a non-linear response? Why?

(e) A feedback control loop is to be installed on process (i).

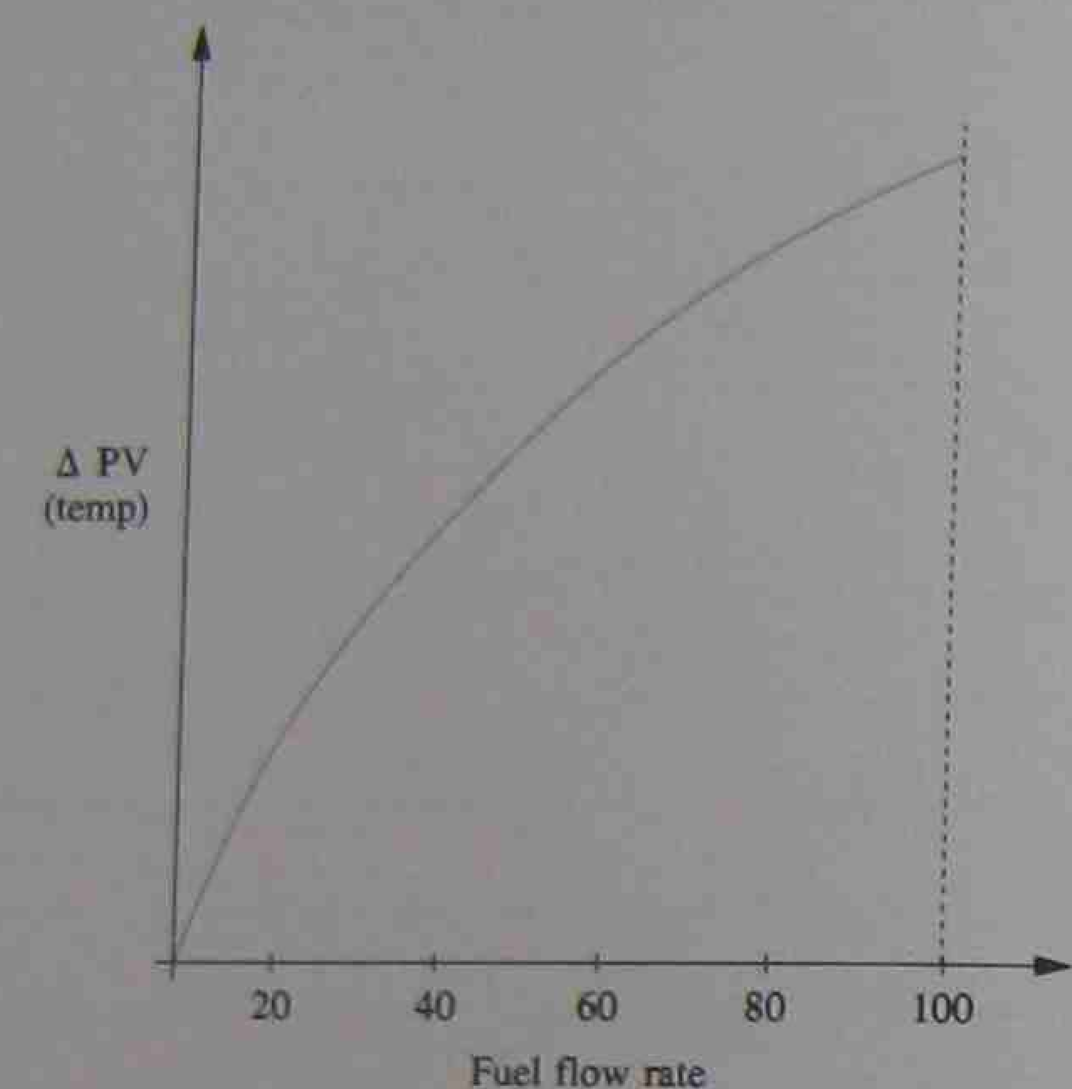
- Comment on the performance of a linear control valve on this process.

- Comment on the effect of an equal percentage control valve on this process.

6. (a) A typical equal percentage control valve has a rangeability of 50:1. A process requires a control valve rangeability of a minimum of 200:1. Discuss how this may be achieved.

(b) Explain how cavitation and flashing affect the performance of a control loop.

7. A temperature process has a gain that varies as shown below.



Comment on the performance of:

(a) A linear control valve used on the above process.

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(b) An equal percentage control valve used on the above process.

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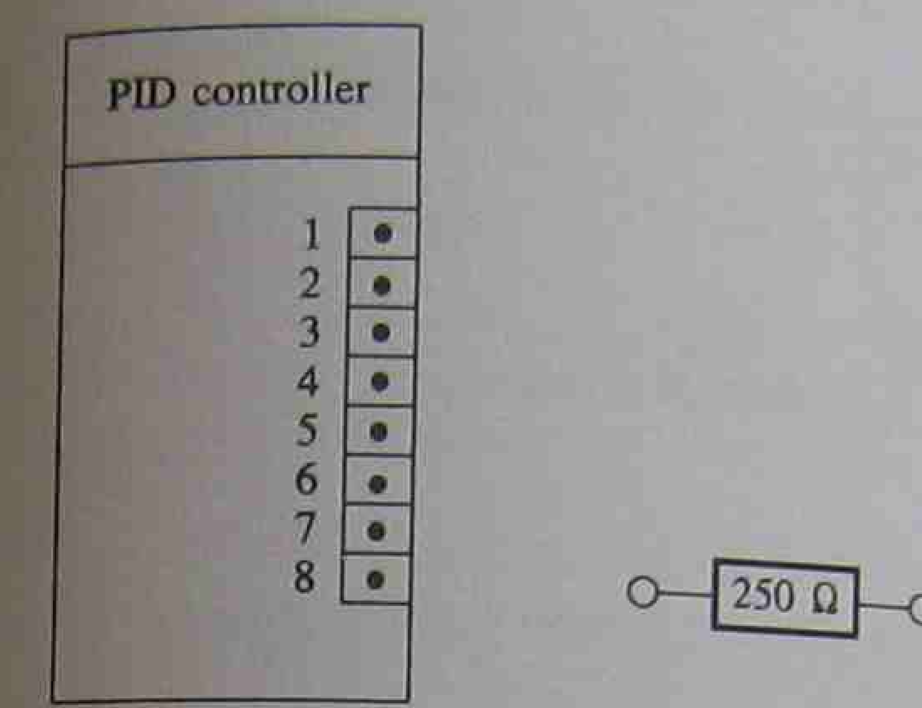
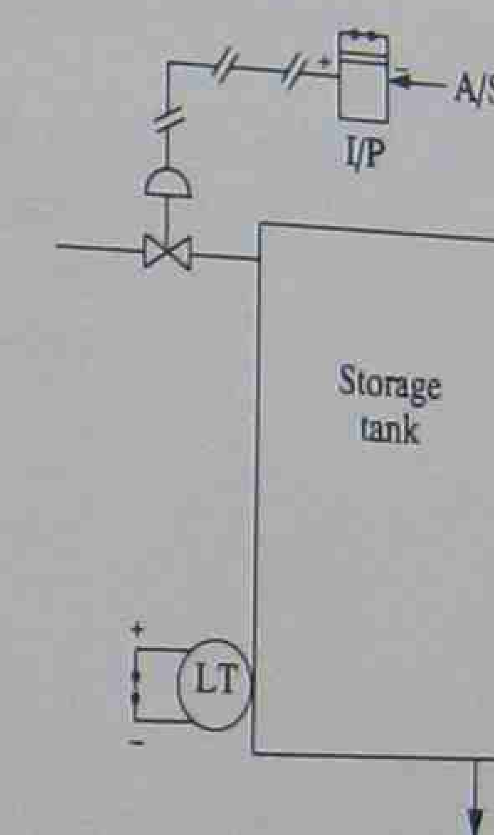
8. (a) Refer to the diagram below and connect the components to provide feedback control of the tank level.

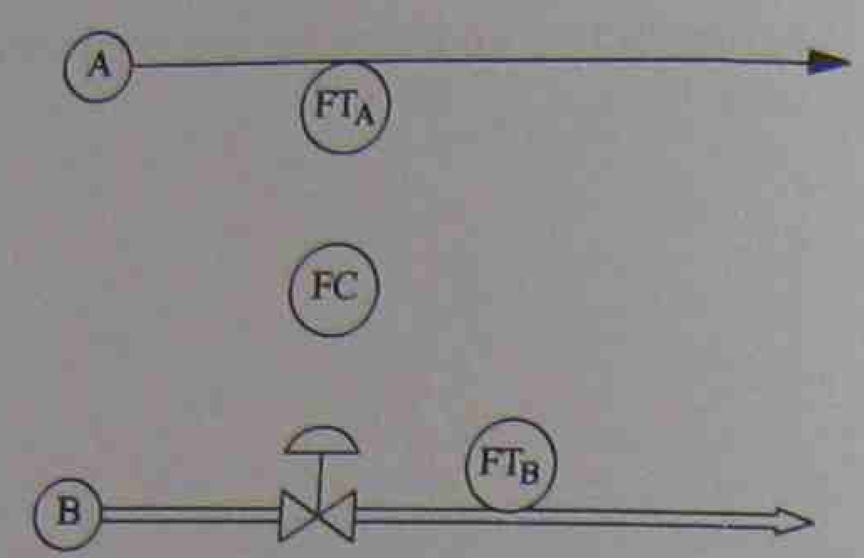




1. +26 V DC transmitter supply
2. Digital O/P 1
3. Digital O/P 2
4. Analogue O/P (+)
5. Analogue O/P common (-)
6. Analogue input 2 (+)
7. Analogue input 1 (+)
8. Analogue input common (-)

(b) Sketch below a simplified schematic diagram, using symbols, of the level control loop shown above.

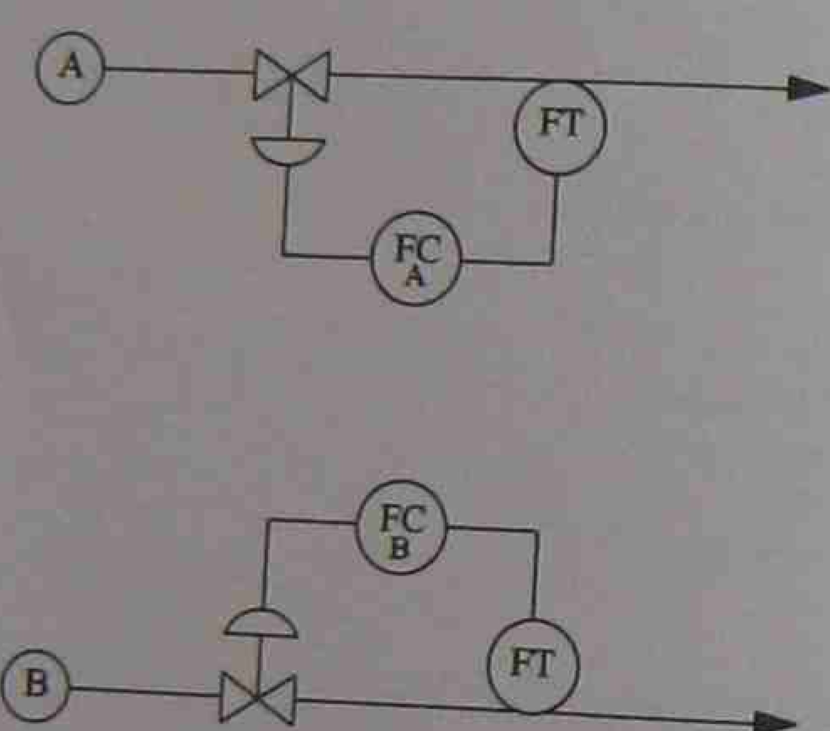
9.



(a) Complete the diagram above, to provide a ratio control system.

(b) Label the wild flow and the controlled flow.

10.



(a) Complete the diagram above, so that flow (B) is controlled in a 2:1 ratio to flow (A). ((B) is to 'follow' (A)).

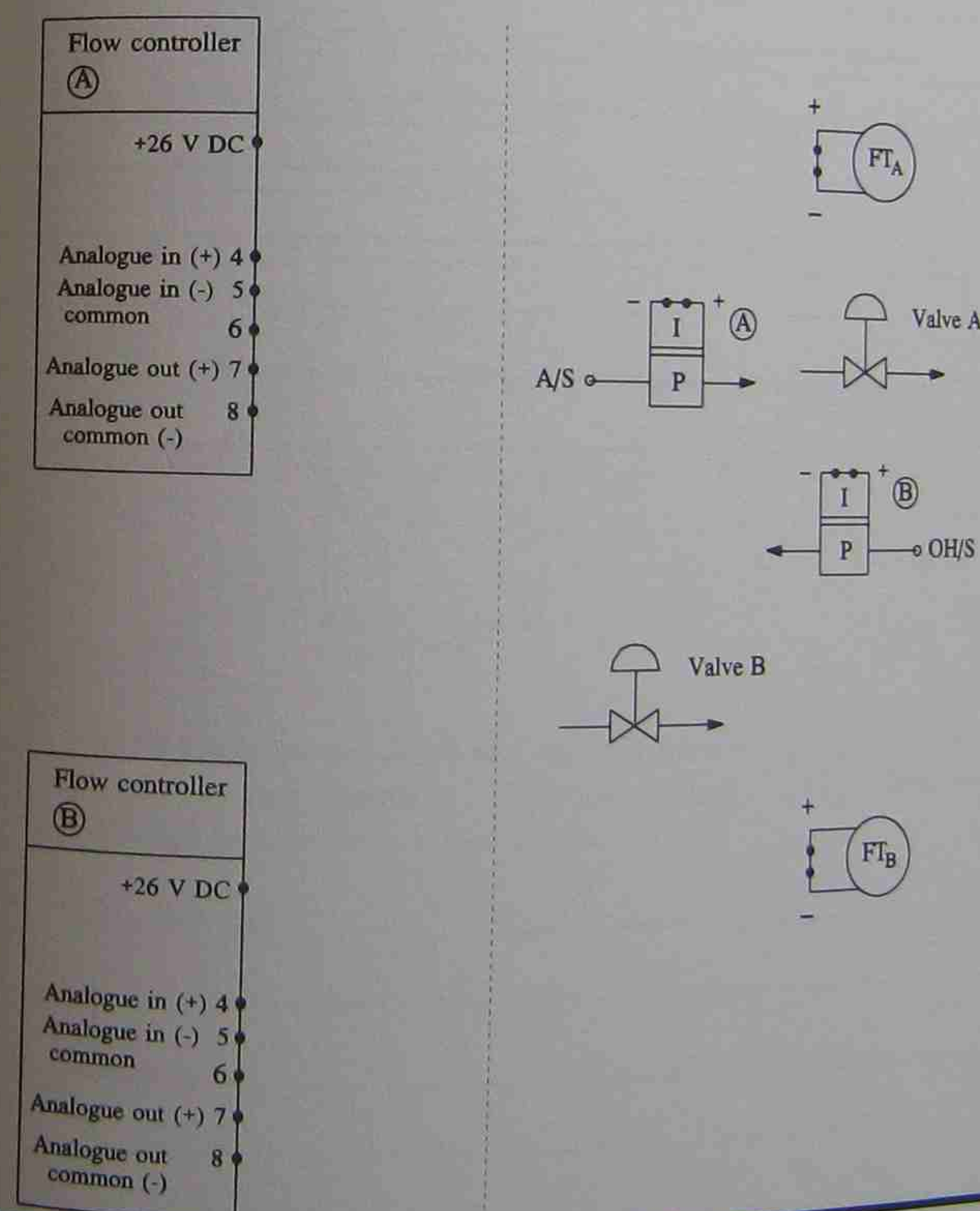
(b) Why are there two flow control loops?

(c) Which controller is the ratio controller?

(d) Are the set points for the flow controllers local or remote? Explain.

11. Connect the components below to provide ratio control as shown in question 10.

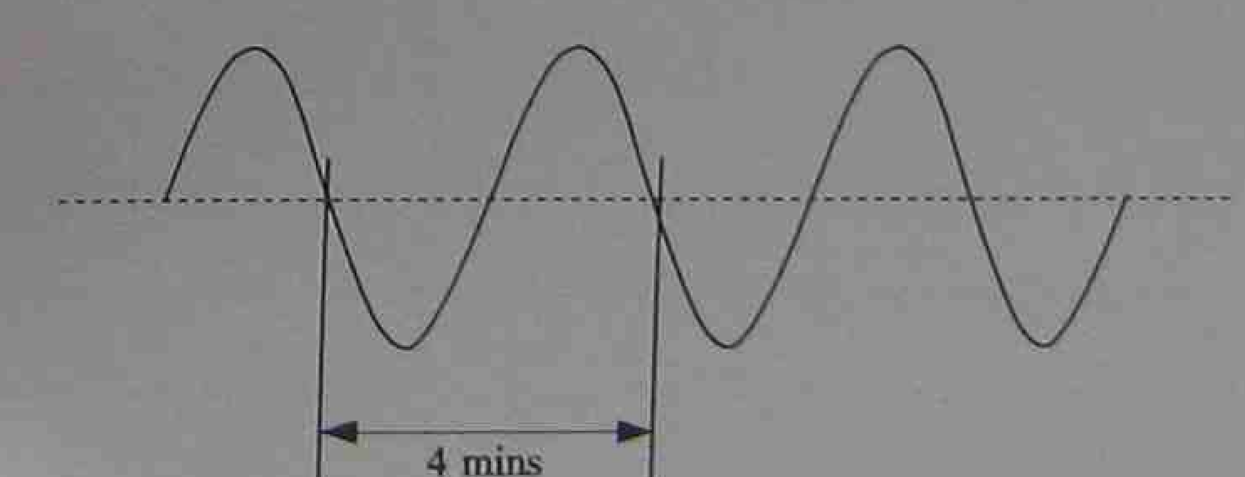
Control room *Field*



12. (a) Explain the method of tuning a P and D controller, using the systematic trial method.

(b) How is this procedure varied for a PID controller?

13.



(a) The PV cycle shown above was obtained when tuning a controller using the ultimate cycling method. (Controller gain, $K_u = 1.8$). Determine the controller settings for a PID controller.

Controller gain

Integral time

Derivative time ______________________________

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(b) Explain the procedure involved in tuning a controller using the ultimate cycling method.

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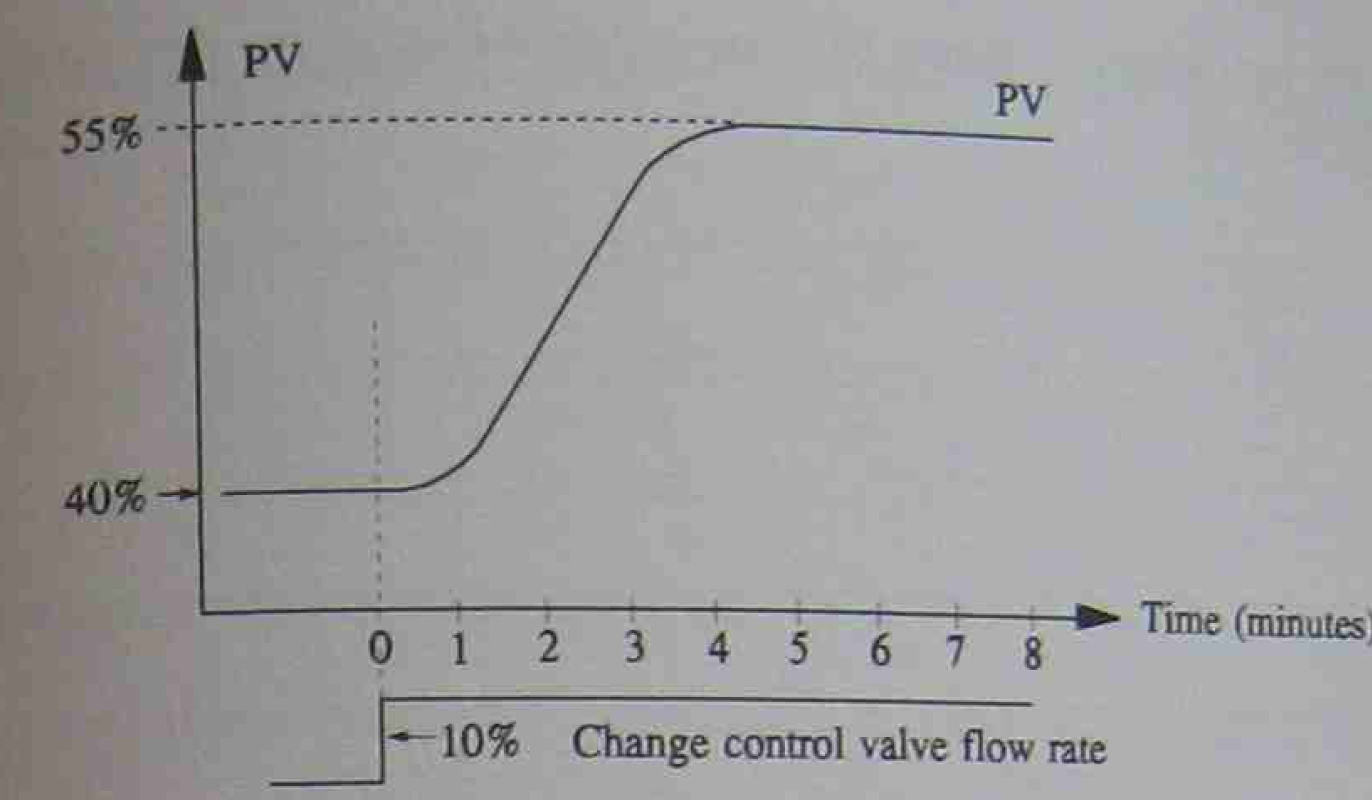
14.



The graph above shows the process response obtained from a step response (open loop) tuning procedure. Calculate the P and I settings required for this loop, to obtain QAD control response.

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15. Explain the procedure required to tune a controller using the open loop (step response) method.

16. Sketch graphs showing the QAD and minimum disturbance responses.

17. Explain the application of the QAD (minimum area) and the minimum disturbance response.

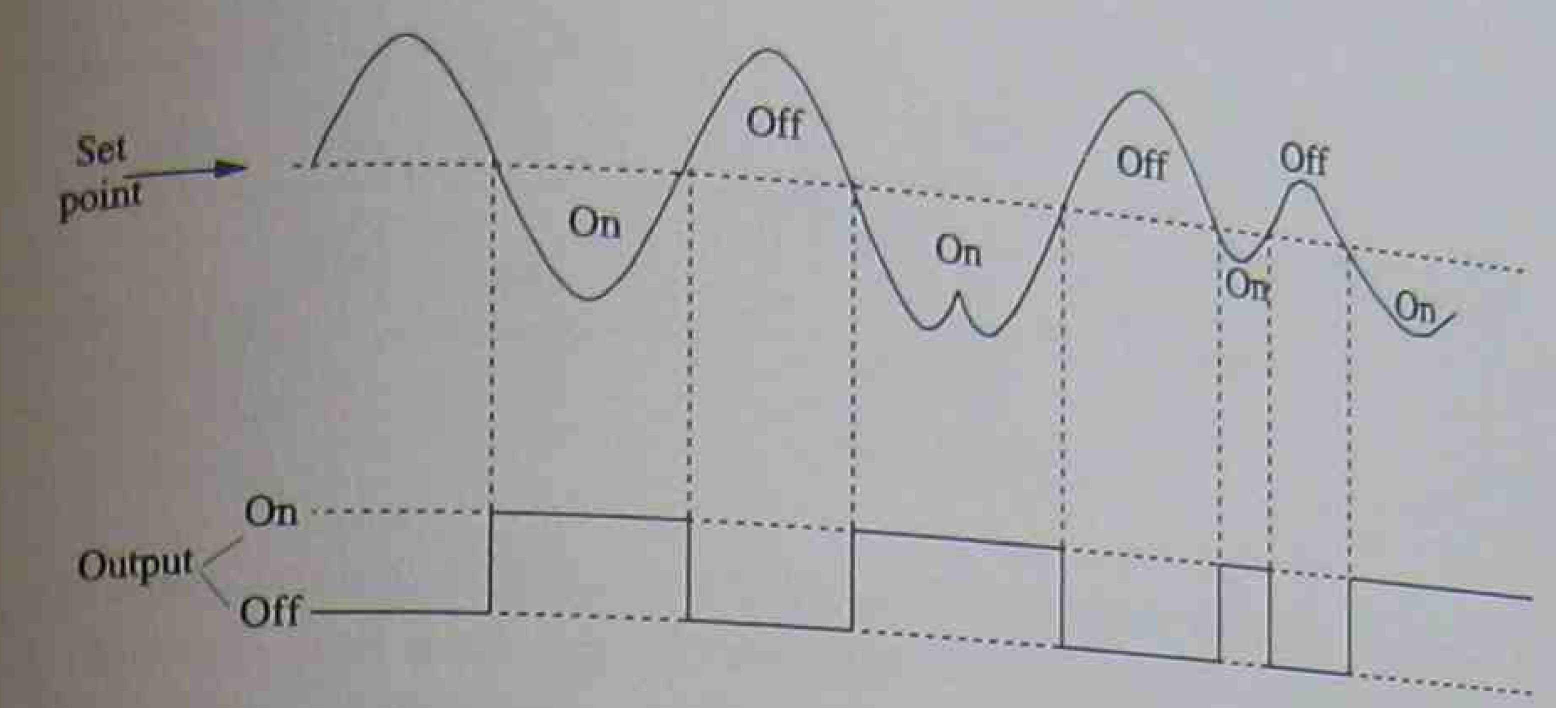
Review questions

18. Simply explain the principle used by self tuning controllers to 'self tune'.

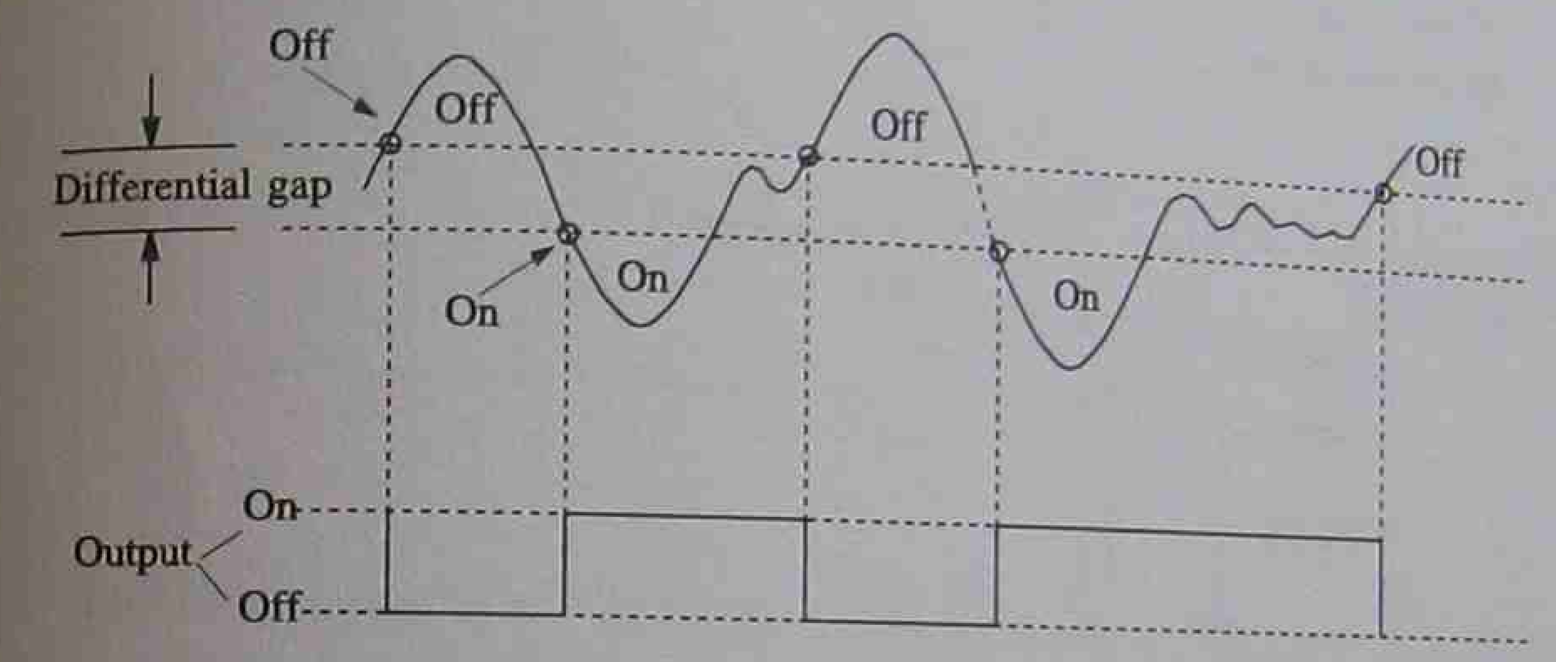
ANSWERS TO REVIEW QUESTIONS

Section 1

1.



2.

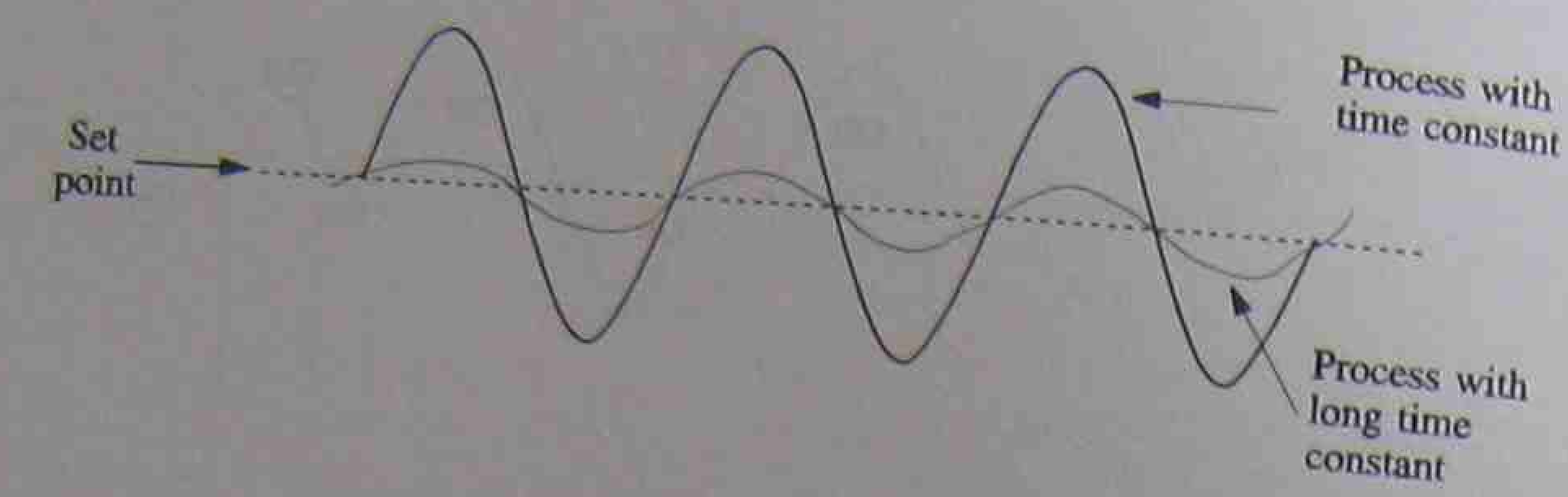


3. The period of the PV cycle is proportional to the deadtime in the loop. Thus a short deadtime will result in a short period and a long deadtime will result in a long period.

4. The time constant of the process will influence the amount of overshoot and undershoot of the set point that will occur during the period of the PV cycle. Processes with a short time constant (fast processes) will have large amplitude, long time constant processes will have a small amplitude for the same period of angle.

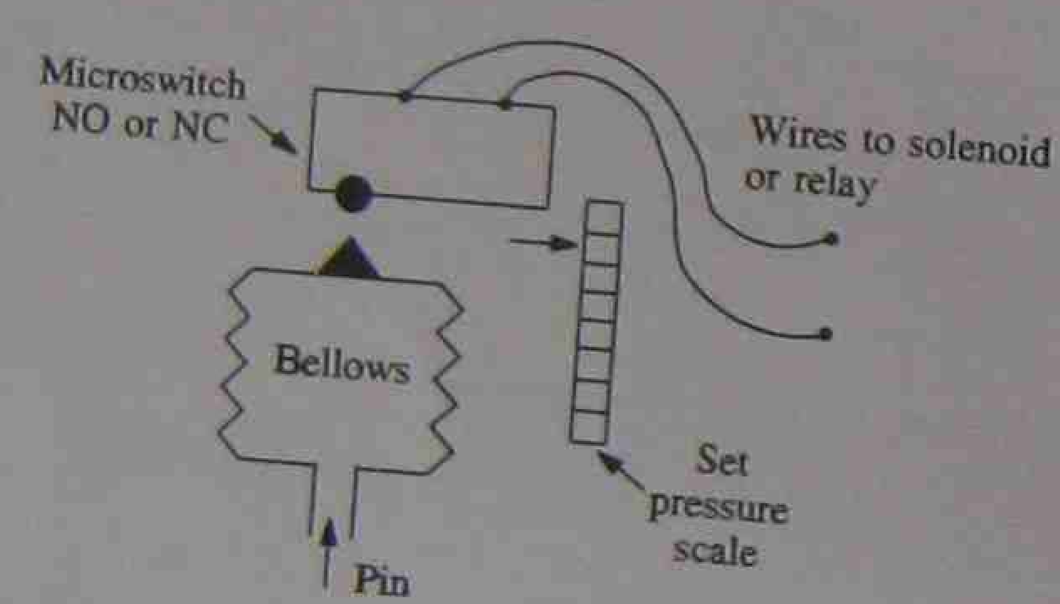
5. Deadtime causes a delay in the corrective action taken by the controller. It follows that the greater the delay in correction, the longer it will take the process to return to the set point, (which thus results in a longer process cycle, i.e. a longer period).

6. (a) For a given period of a process cycling under automatic control, the time constant will affect the amount of overshoot and undershoot of the set point, i.e. the amplitude of the cycle, as shown below.



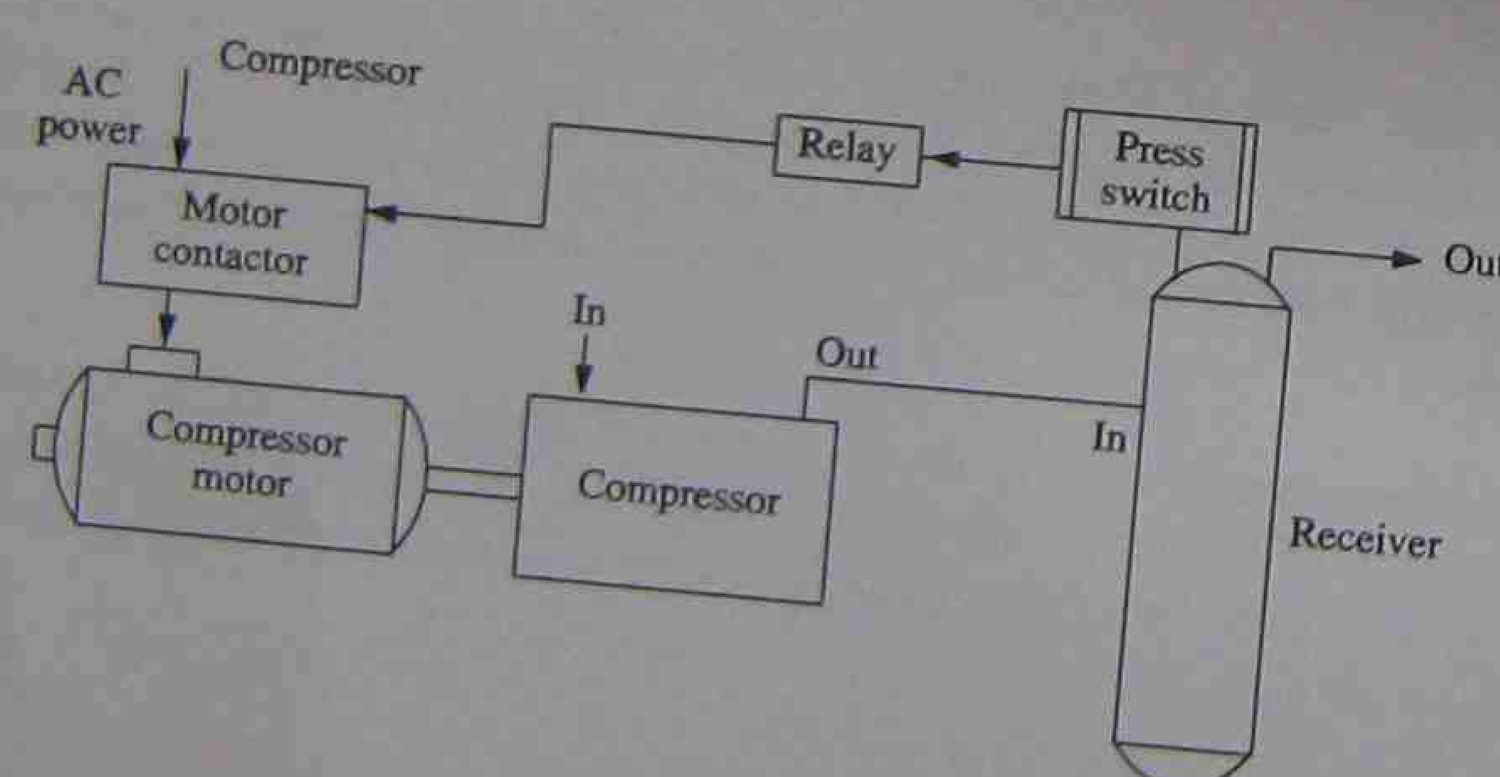
(b) Ideally, a process under on-off control should cycle with a low amplitude and a long period. Therefore processes with a very long time constant, and a suitable long period are most suited. These characteristics will result in a shallow cycle (small overshoot) and infrequent operation of the control valve or solenoid etc.

7.



The operating pressure of the unit (the set point) is usually set by adjusting a spring opposing the force of the bellows. Some pressure switches also allow adjustment of the differential gap.

8.



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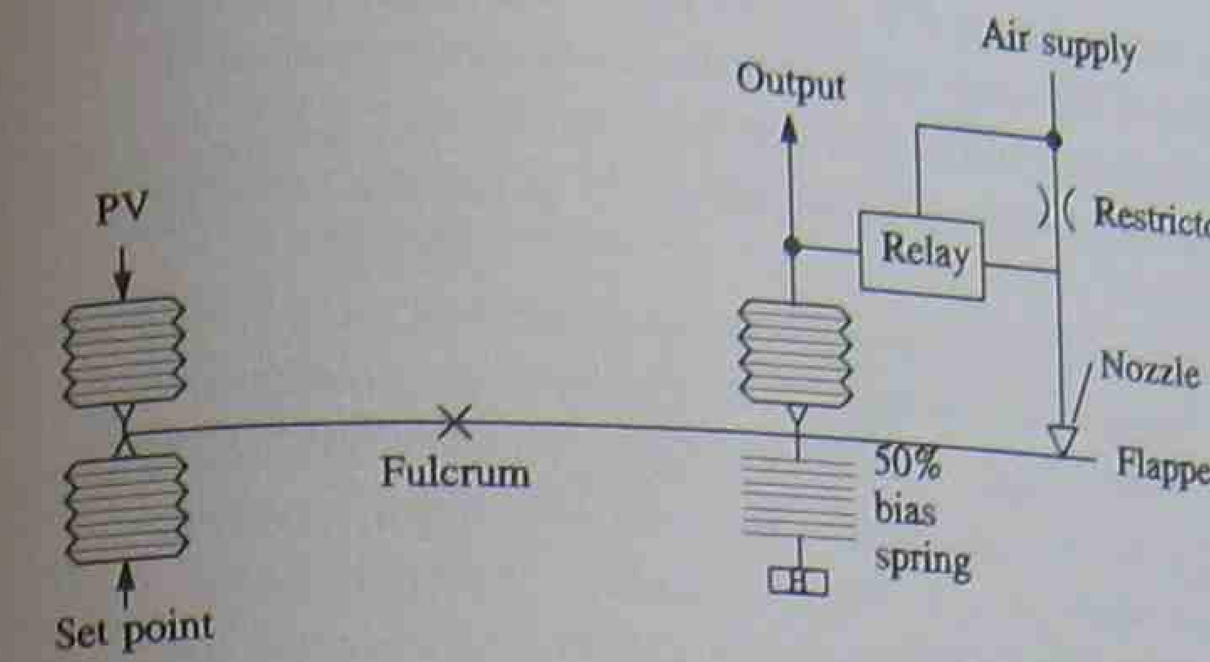

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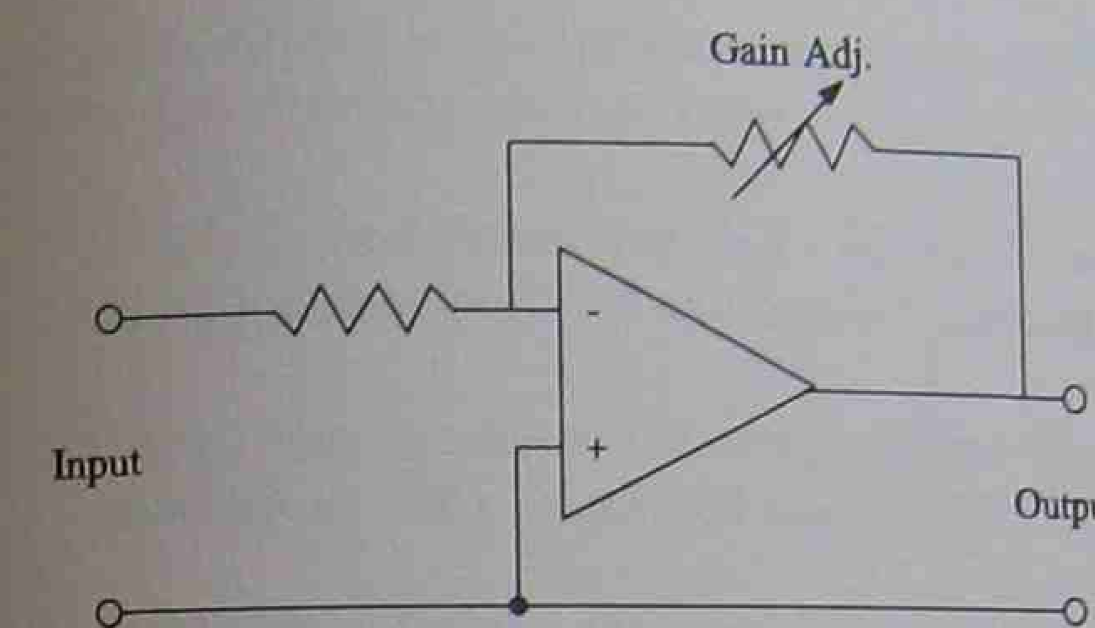
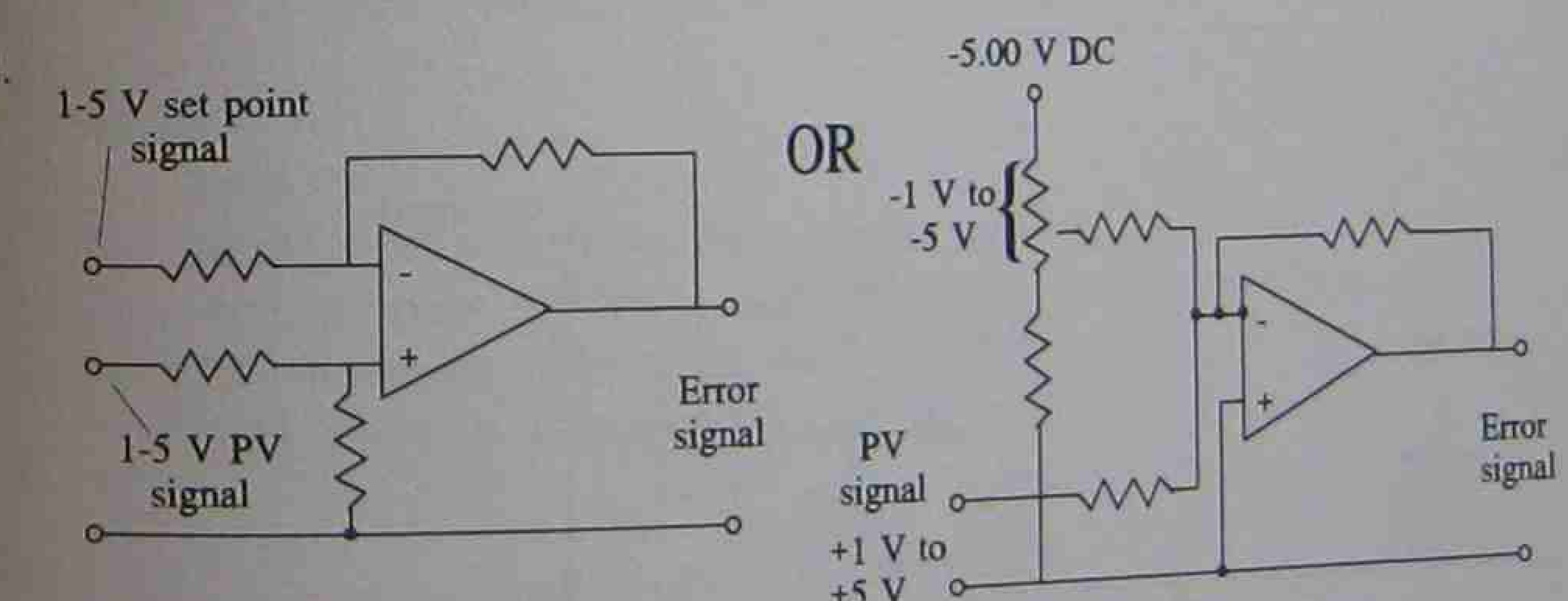


11. The error signal is the difference between the process variable and the set point. (i.e. error signal = PV - set point). This subtraction may be done pneumatically, electronically, or by software.

12.

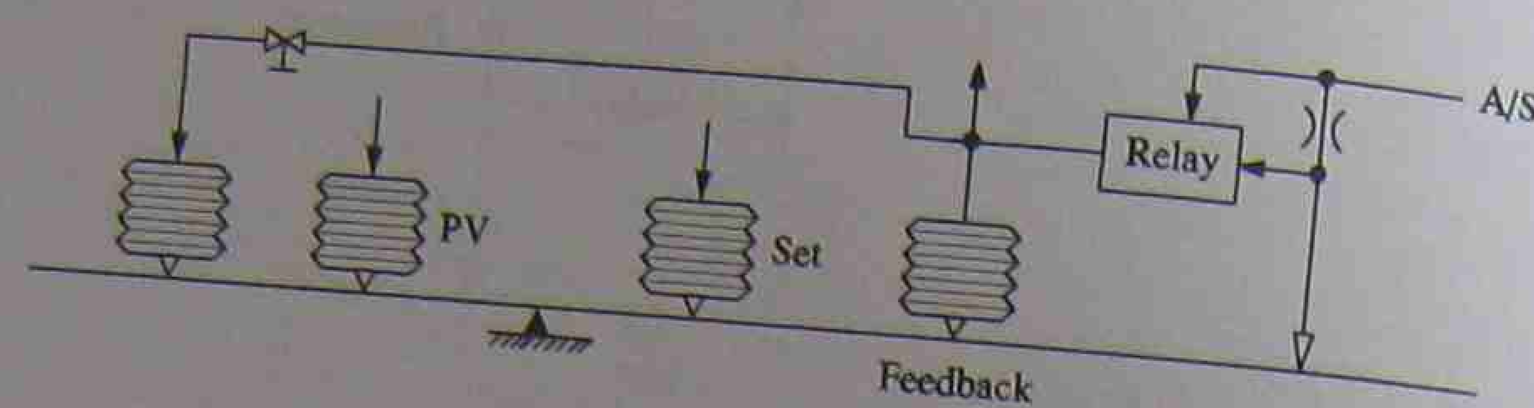


13. (a) P and I controller (force balance)

A - Process variable bellows
B - Set point bellows
C - Feedback (proportional) bellows
D - Integral (reset) bellows
E - Relay
F - Controller output signal
G - Integral adjustment
H - Restrictor
I - Force bar
J - Fulcrum

inputs to the PV and set point bellows.

(c)



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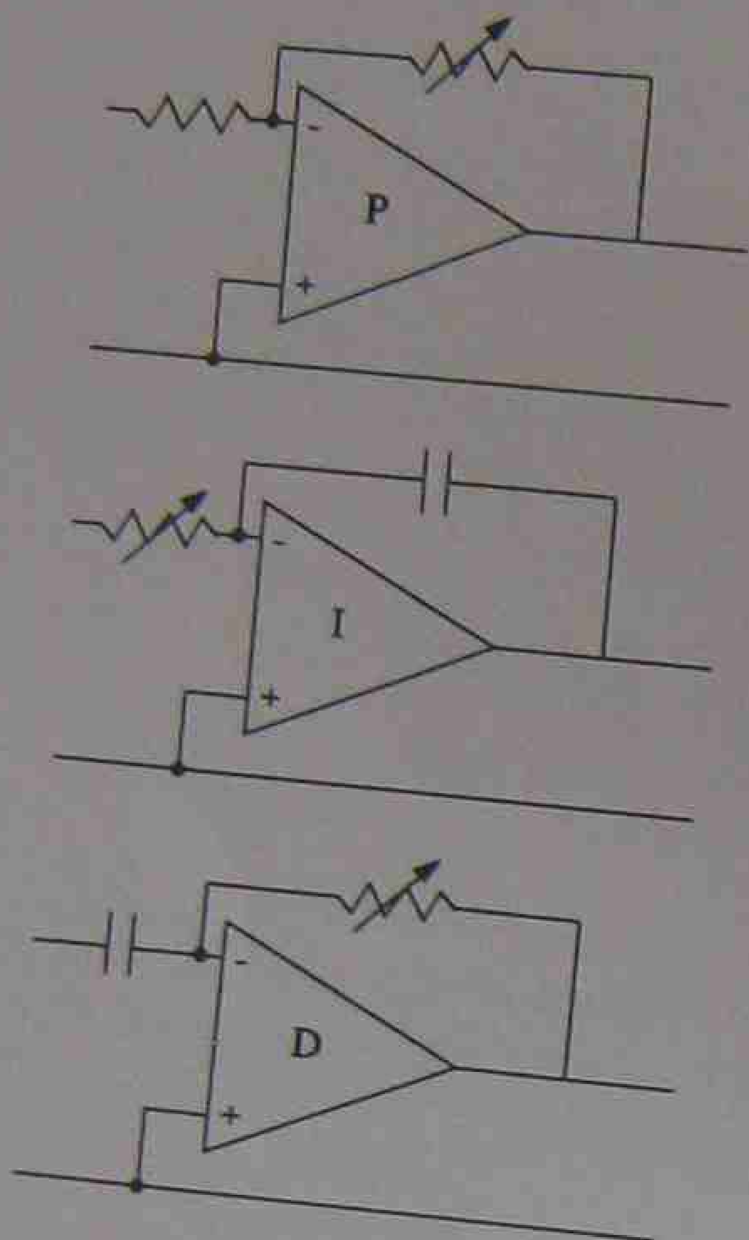

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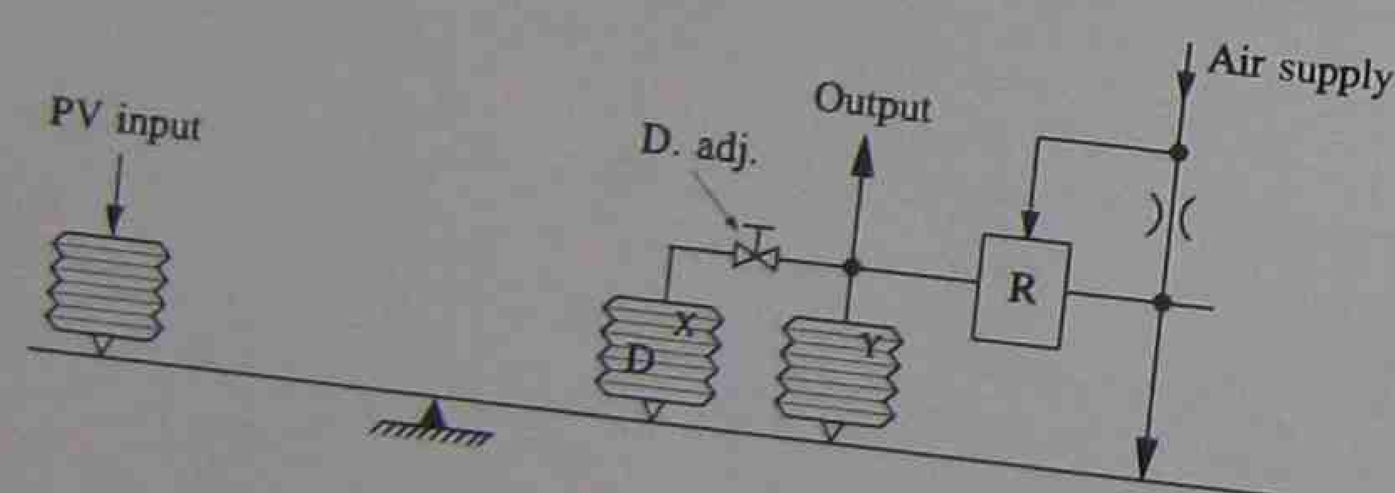


Derivative action

The derivative bellows and derivative adjustment has been labelled on the diagram above. The two feedback bellows have been labelled X and Y. The device shown applied derivative action to the input signal (usually the PV signal).

Operation:

(a) With the derivative adjustment fully open (Off) the two feedback bellows, X and Y operate as one, and the device has a gain of one (X1). For any input signal or changing input signal, the output will equal the input.

(b) When the derivative adjustment is restricted, derivative action will occur. For a changing input signal, the feedback pressure in X will lag behind that in Y, thus negative feedback is reduced and so the gain will increase. a fast changing input will result in a large increase in gain, a slow changing input a small increase. When the input signal stops changing, bellows X and Y will equalise and the gain will return to one (X1).

16. A/D - Analogue to Digital converter, converts input to binary code for processing by the microprocessor and digital circuitry.

CPM - Central Processing Unit - the microprocessor performs calculation of the PID functions (etc), and any required logic operations.

RAM - Random Access Memory contains user adjustable parameters such as set point values, PID values and alarm limits etc.

ROM - Read Only Memory contains the program required to perform PID calculations, square root extraction, etc.

D/A - Digital Analogue Converter converts the binary coded output signal back to an analogue output signal.

17. *Note:* Proportional output = error signal x gain + bias

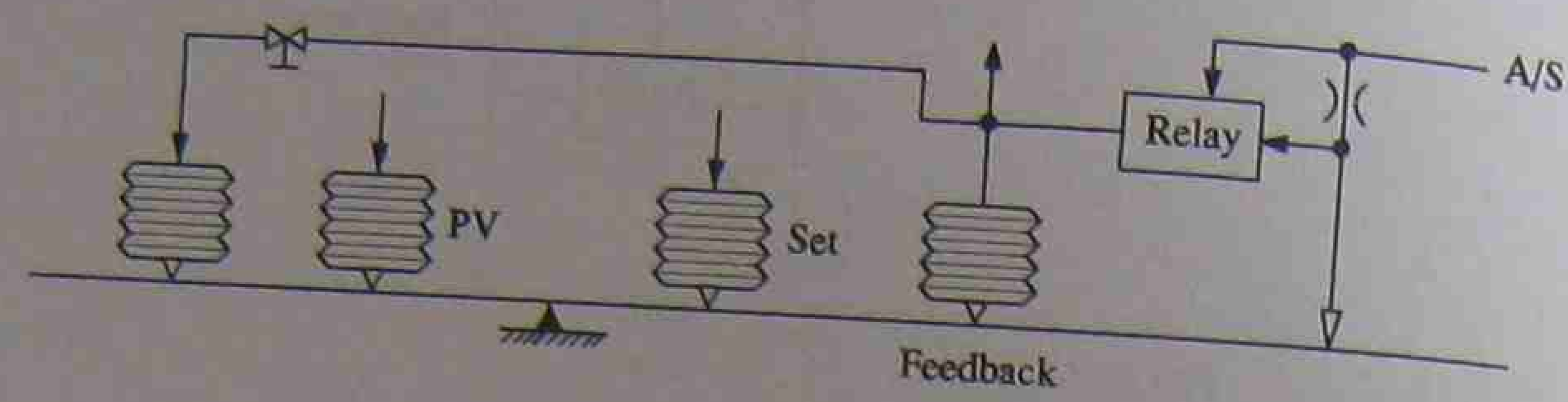
Steps:
1. Read PV.
2. Subtract set point from PV to obtain the error signal.
3. Multiply error signal by controller gain.
4. Add bias typically 50% to 3%.
5. Send answer 4. to output (D to A).

18.

Performance	*Controller (a, b, c or d)*
Basic performance	b
2	c
3	d
4	a

(b) Reversing the inputs to the PV and set point bellows.

(c)



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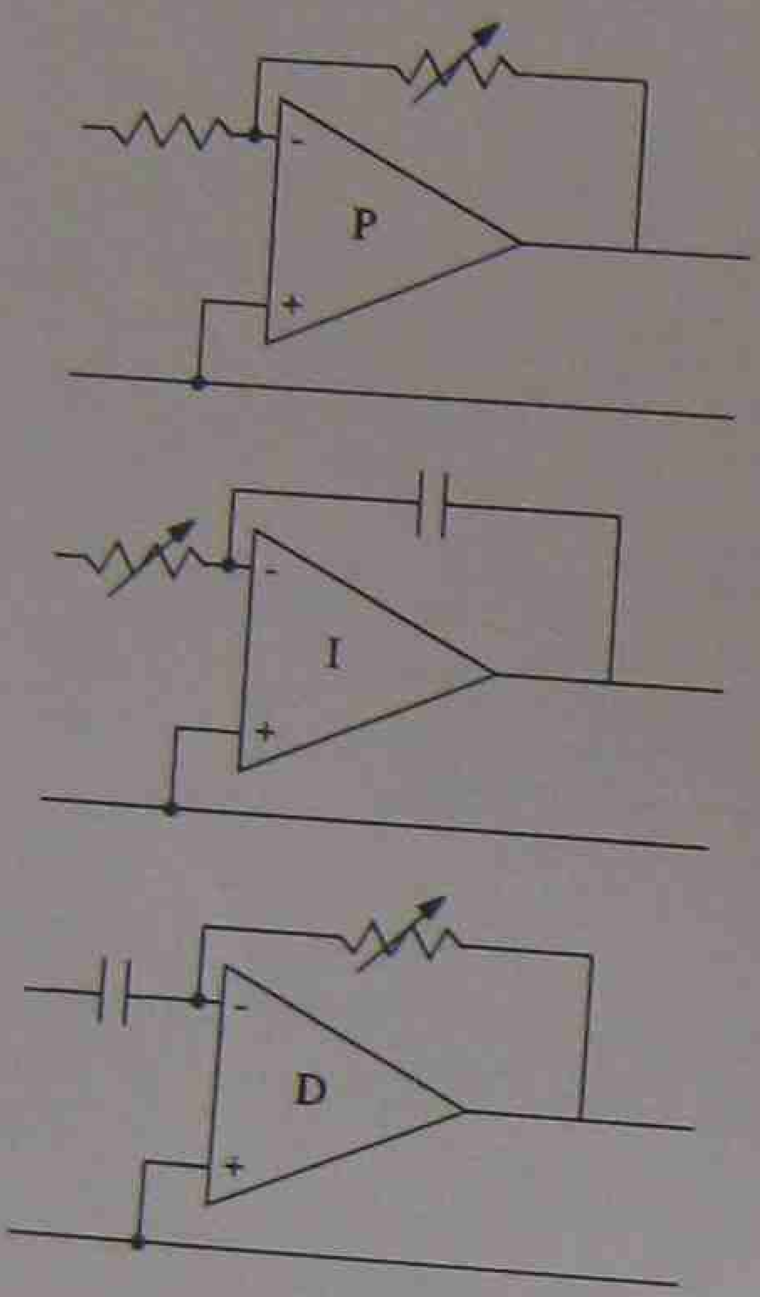

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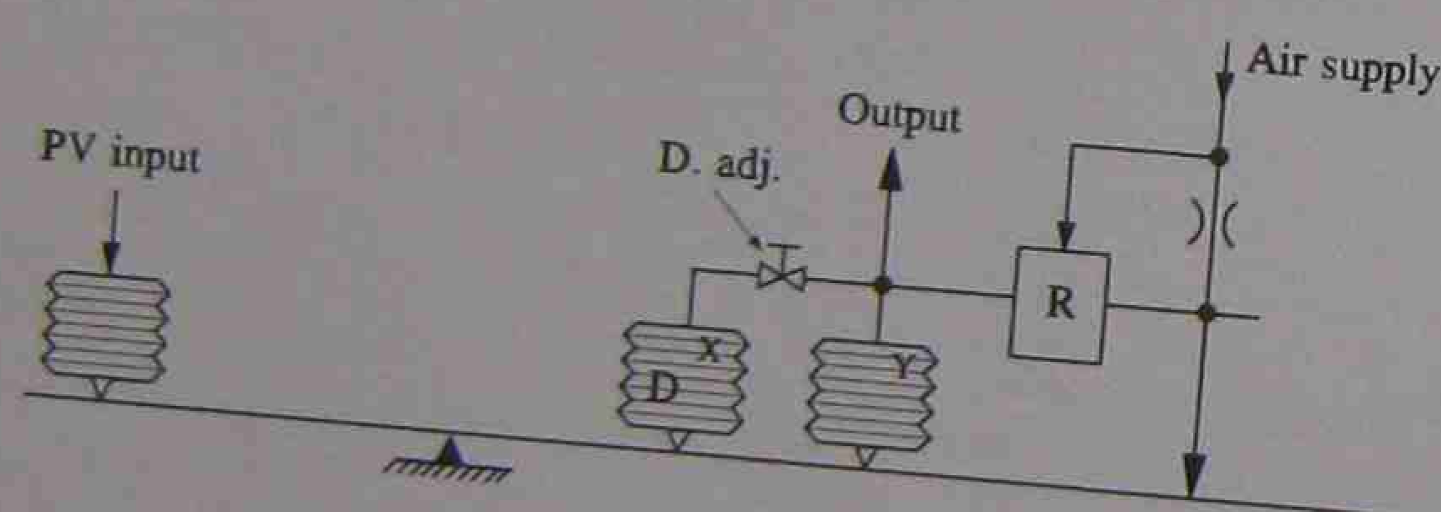

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Steps:
1. Read PV.
2. Subtract set point from PV to obtain the error signal.
3. Multiply error signal by controller gain.
4. Add bias typically 50% to 3%.
5. Send answer 4. to output (D to A).

18.

Performance	*Controller (a, b, c or d)*
Basic performakce	b
2	c
3	d
4	a

19. Temperature control.

20. Long time constant processes may be suited to On-Off control.

21. (a) To avoid 'chattering' of the final control element when the PV signal is noisy.

(b) To set high-low operating limits to the Process Variable. e.g. a pressure receiver may be set to a nominal value of 1000 kPa, with pressure switch settings of 1050 kPa (Off) and 950 kPa (On).

22. Proportional action provides a correction that is proportional to the *size (magnitude)* of the error.

Integral action provides a correction that is proportional to the *time duration* of the error.

P and I action provides a correction that is proportional to the *magnitude* and *time duration* of the error.

Derivative action provides a correction that is proportional to the *rate of change* of the error.

23. (a) Proportional mode is used to *stabilise* the process, by attempting to match the process input (supply) with the process load (demand). Proportional control can stabilise a process, but with control will an *offset* if load changes occur.

(b) Integral mode is used to *return (reset)* the PV to the set point. It is used in conjunction with proportional action to eliminate offset is load changes occur.

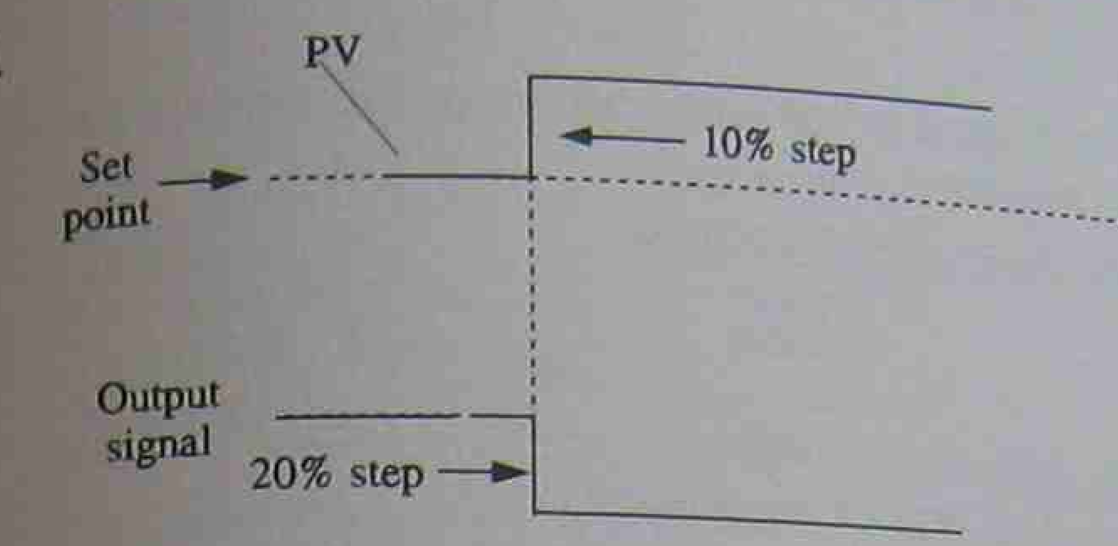
(c) Derivative mode is used to try to compensate for time lags in the control loop. Time lags (deadtime) influence the amount of overshoot or undershoot (of the set point) that will occur before control action takes place. (i.e. there is a delayed control response). The derivative mode 'boasts the effect of proportional action, to try to compensate for the delayed control response.

24.
- Minimal deadtime
- Infrequent disturbances
- Small and minimal load changes. (Preferably *no* load changes)

25. Integral action is used to eliminate offset that occurs due to load changes when using proportional control by itself. Thus a process that requires P and I to provide satisfactory control would be subject to load changes, as well as having characteristics suited to proportional control.
Note: Load changes should not be too long, or reset windup can occur.

26.
- A process with time lags (deadtime) in the loop. But note that derivative cannot compensate for excessive time lags, these will cause instability if derivative is applied. In general time lags should not be greater than 10% of this process time constant.
- A process that is not 'noisy' as this will cause excessive derivative action.

27.



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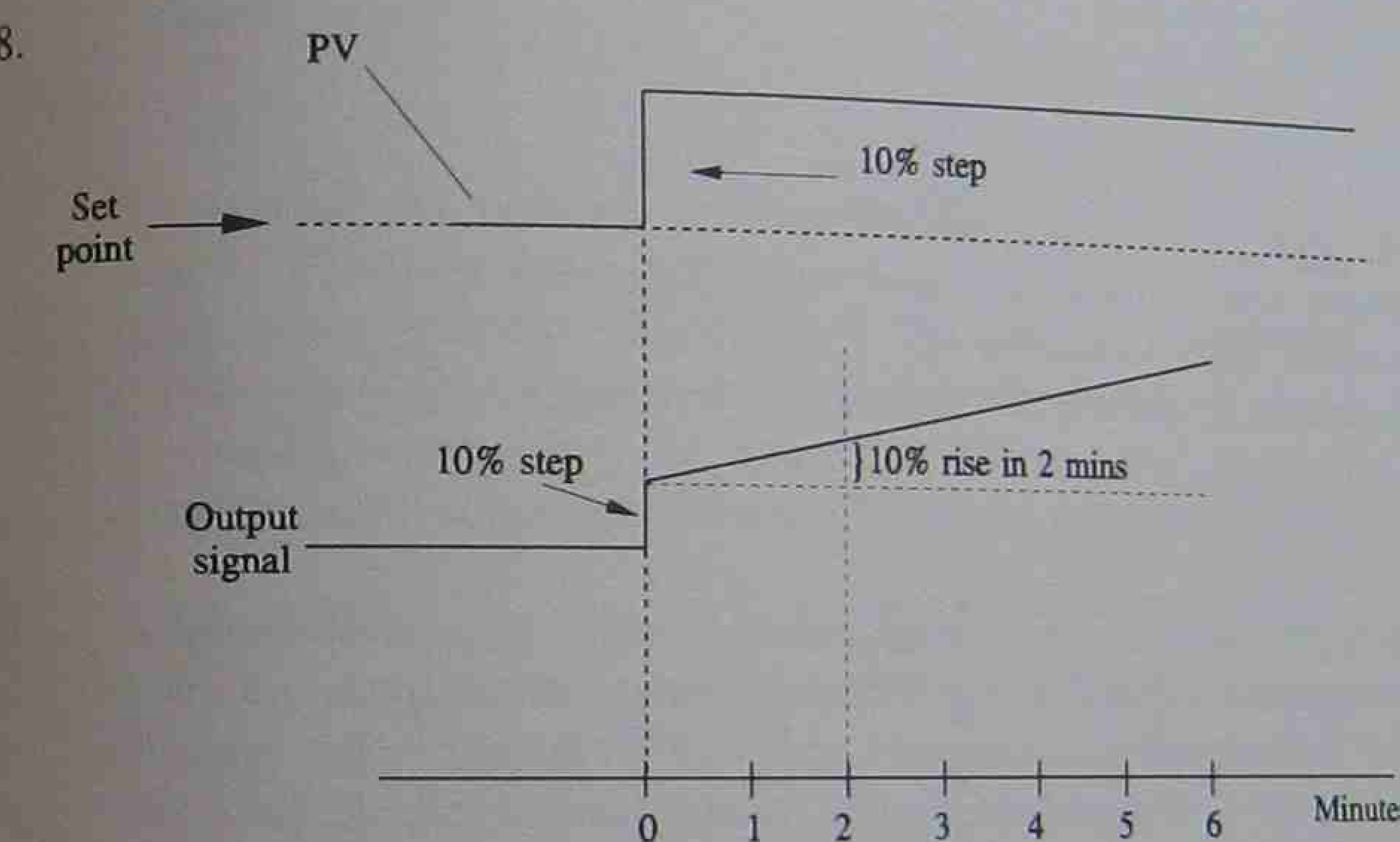
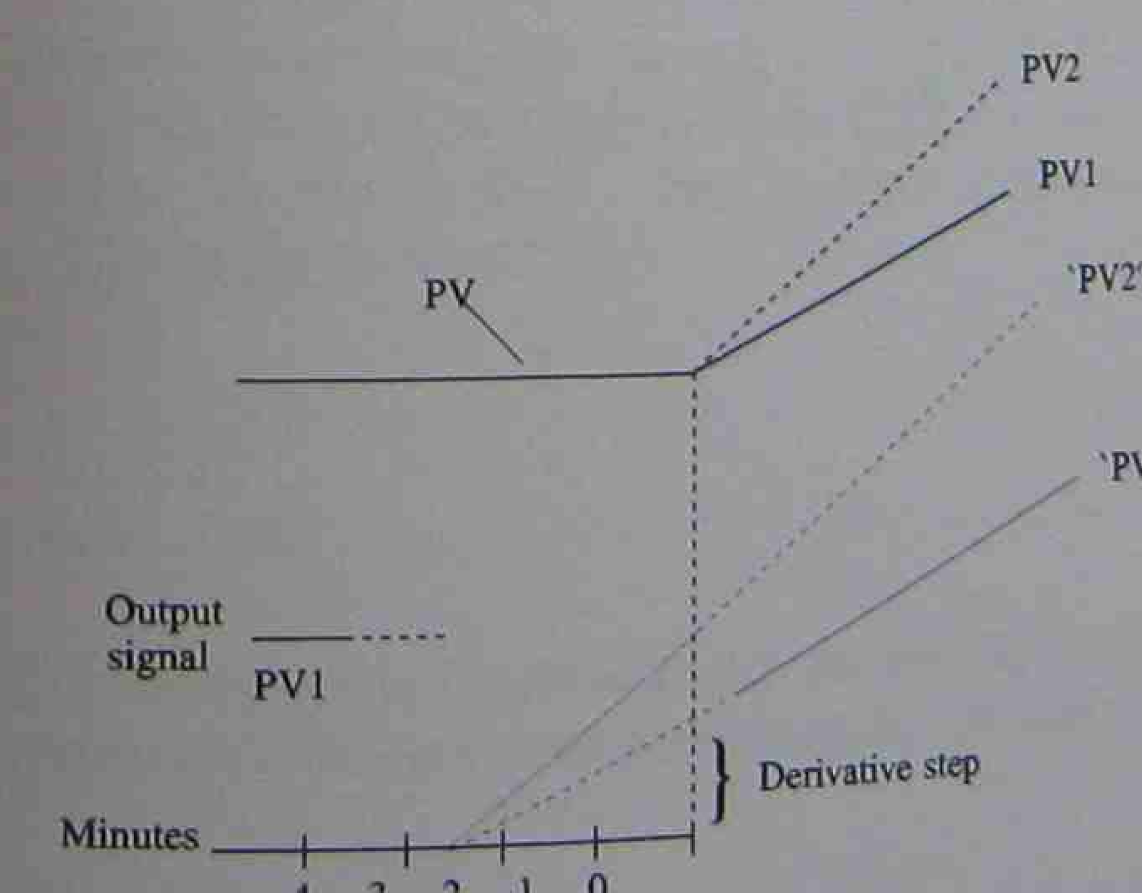


29. (a)



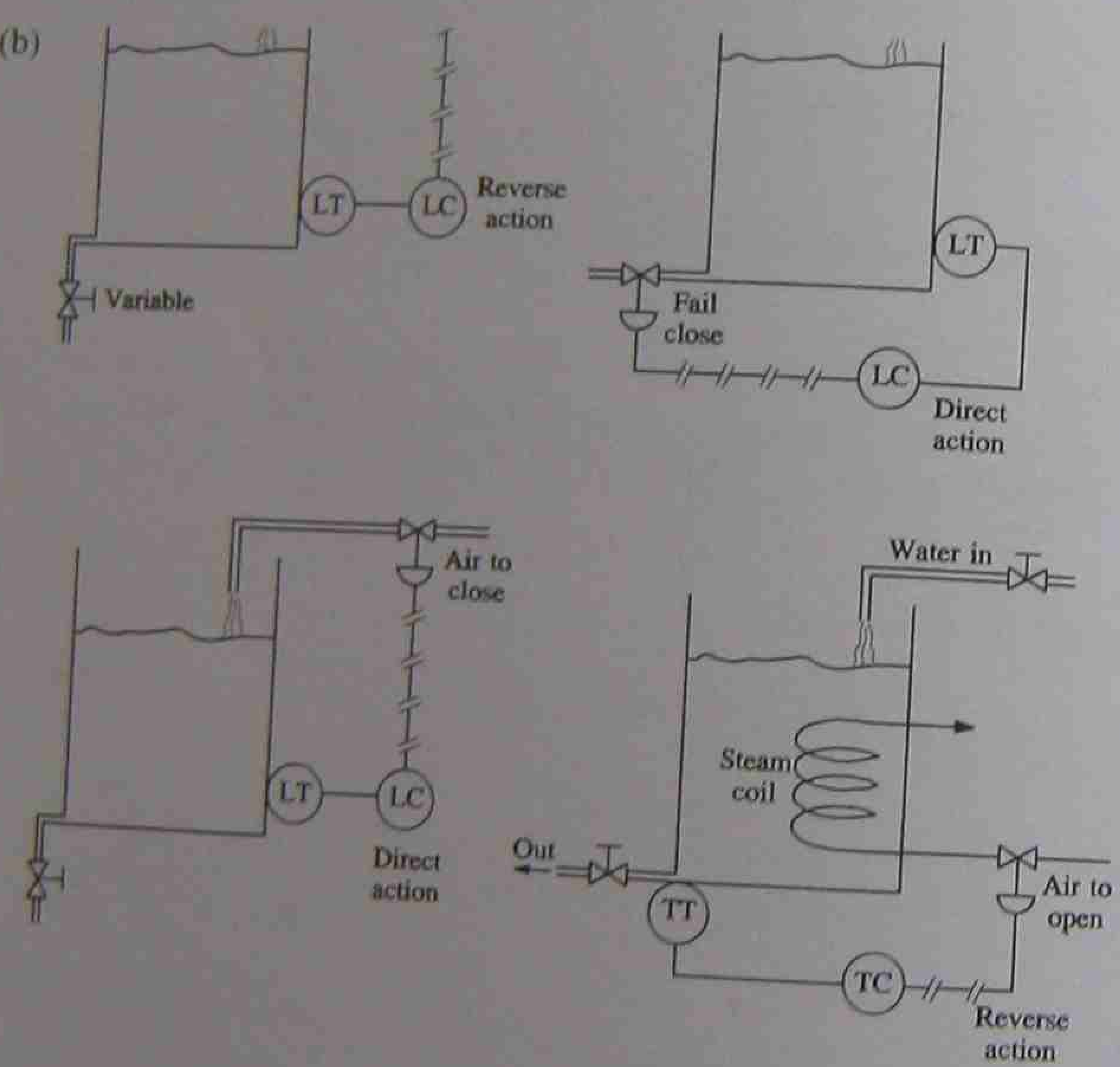
(b) As shown in the diagram proportional action appear to have occurred two minutes prior to the change in the recorded process variable. Due to control loop lags, the recorded change will lag the actual process (PV) change. Thus derivative action as shown, attempts to compensate for time lags in the control loop.

(c) (iii) The derivative step would increase.

30. (a) Direct action - Output change is in the same 'direction' as input change.
i.e. If input increase, then output increases
If input decreases, then output decreases

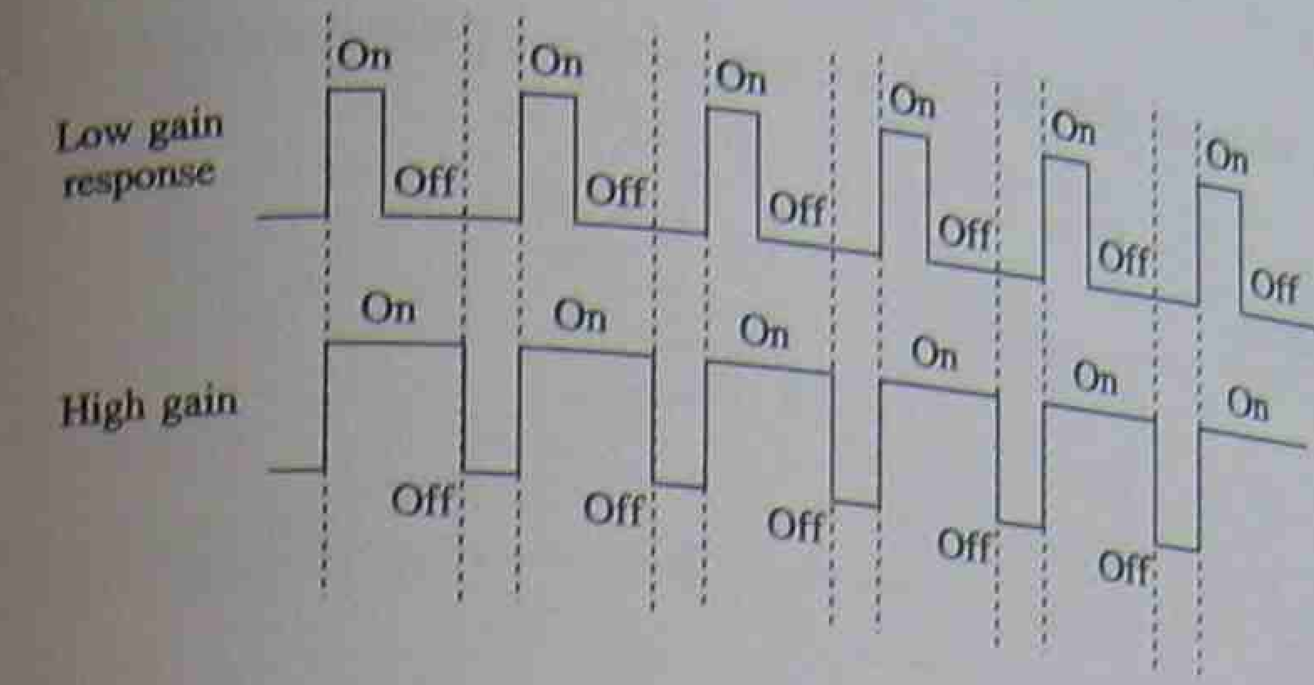
Reverse action
If input increases, then output decreases
If input decreases, then output increases

(b)

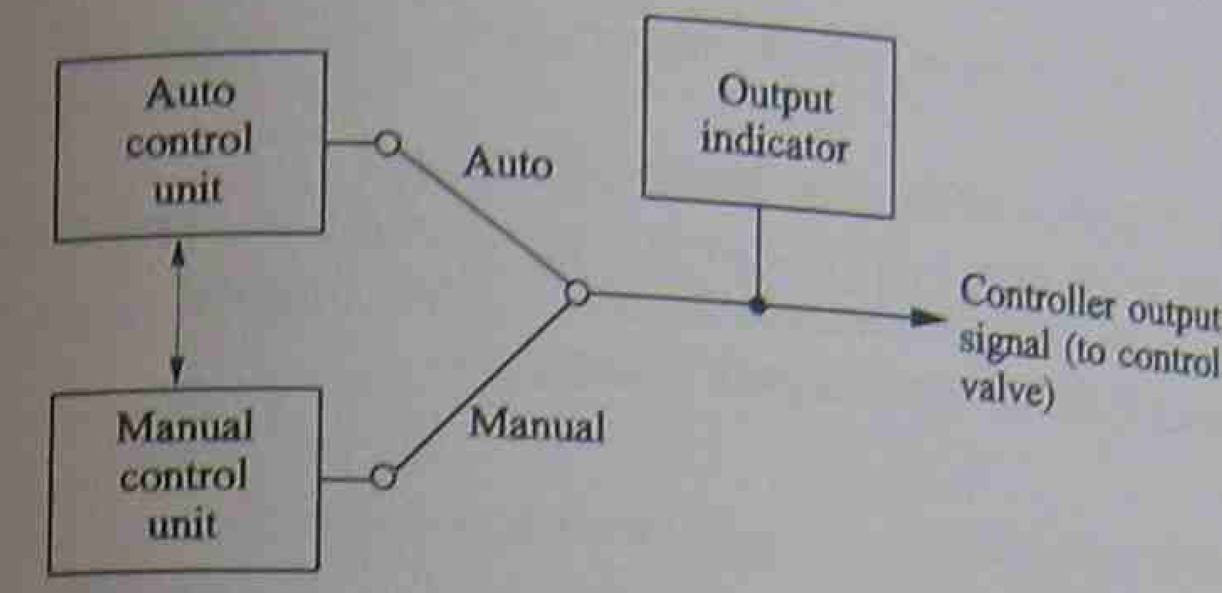


(c) Yes
The valve shown is 'air-to-open' (i.e. 'fail closed'). Thus if air failure occurs the valve will close and shutoff the steam flow, so overheating will not occur.

31.



32.



When switching between auto and manual, the controller output should *not* change, otherwise there will be a change in control valve position and a disturbance to the process, (A 'bump'). The 'bumpless transfer' function operates to make the auto output follow the manual output when on manual, and makes the manual output follow the auto output when on auto. Thus when switching between auto and manual, the controller output will not change.

33. 'Set point tracking' is a function that operates when the controller is on manual. When the controller is on manual, the set point will follow and equal the PV (the set point will 'track' the PV). Thus when switching back to auto, the set point will equal the PV and the process will not be disturbed. If the set point is not the desired/required value, it dan be adjusted at the users discretion.

34. A local set point is adjusted directly on the controller by the user. A remote set point is adjusted by an external signal from a remote device e.g. a transmitter, controller, or hand station. Two common applications are ratio control and cascade control systems.

35. (a) (i) 1%
(ii) 2%
(iii) 10%

(b) The output signal will change by 1% when the gain is one (1), and progressively change up to 10%, as the gain is increased to ten.

(c) It does not change. (Note: Error x gain = zero x gain = zero)

(d) Zero

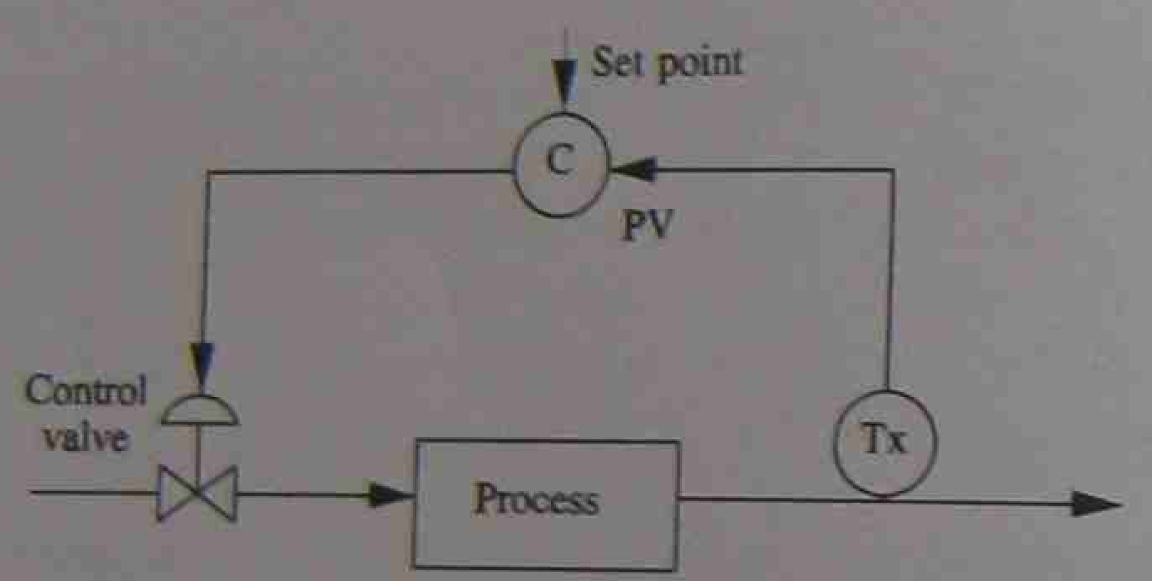
(e) Alignment

36. (a) True
(b) True
(c) False
(d) False
(e) False

37. • The PV and set point indicators must be in calibration.
• The error detector must give a zero error signal when the PV and set point signals are equal. (This may be checked by altering the controller gain, if the output signal varies then the error signal is not zero).

Section 2

1.

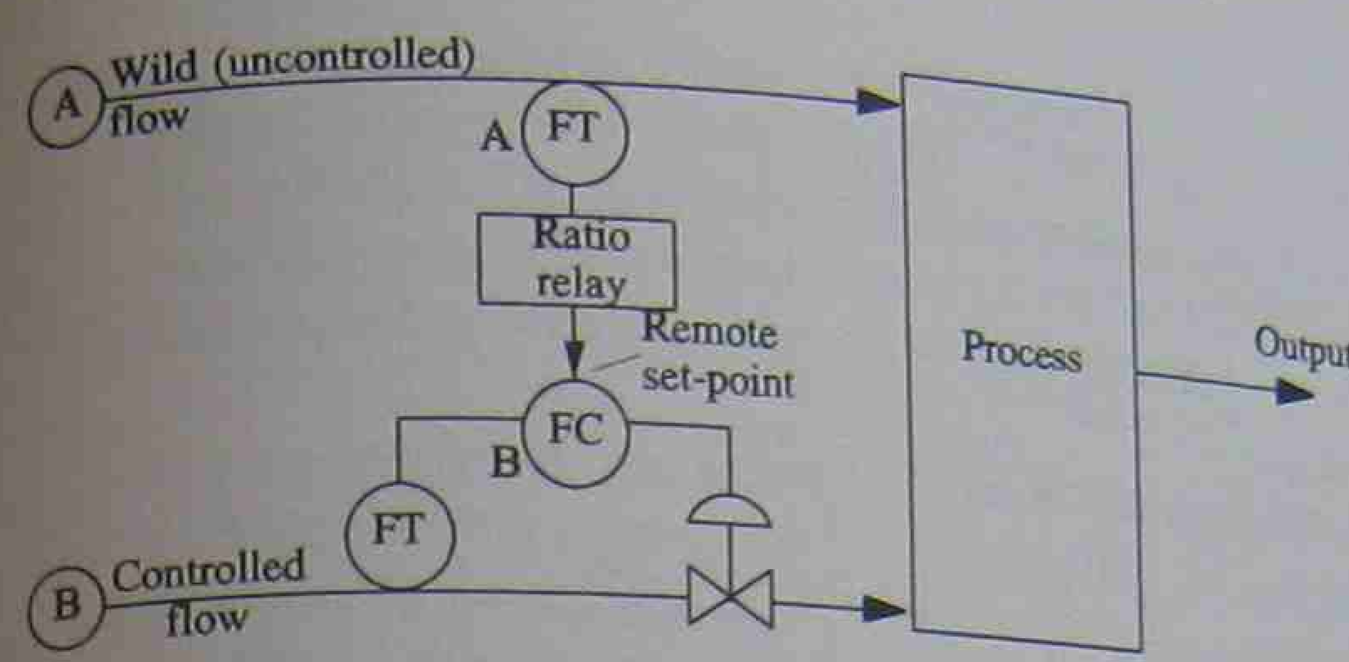


(a) The transmitter measures the PV and sends the PV signal to the controller (C).
(b) The controller subtracts the set point value with the PV value to determine any error and provide the appropriate correction.
(c) The correction signal is sent to the control valve, which will alter the PV.
(d) The sequence 1, 2 and 3 operates continuously to try to maintain the PV at the set point.

2. Operation - flow B is controlled to maintain a fixed ratio to flow A (e.g. 2:1). Flow A is uncontrolled, it is used to set the set point of controlled flow B. When flow A varies, flow B will ????????.

Applications - Blending of two (or more) liquids. Mixing two fluids in an appropriate ratio to obtain a product - air-fuel ratio control (combustion control).

3.



Purpose - (a) Assume the desired ratio of flow B to flow A is 2:1.

(b) If both flow transmitters and the flow controller have the same range (e.g. 0-100 ℓ/min), then if flow A increases by 10% flow B must increase by 20%.

(c) It follows that if the signal from flow transmitter A increases by 10%, then the set point of the flow controller must increase by 20% (to give the 2:1 ratio).

(d) So therefore the ratio relay must be set to x2. (i.e. 10% input change gives 20% output change).

(e) Thus the purpose of the ratio relay is to provide the correct alteration of the remote set point signal in order to obtain the desired ratio of B to A.

4. (a) (i) 10%
(ii) 10%, 50 ℓ/hr
(iii) $\frac{50 \ l/hr}{20 \ l/hr} = 2.5:1$

(b) $\frac{Range\ B}{Range\ A} \times R = 2$

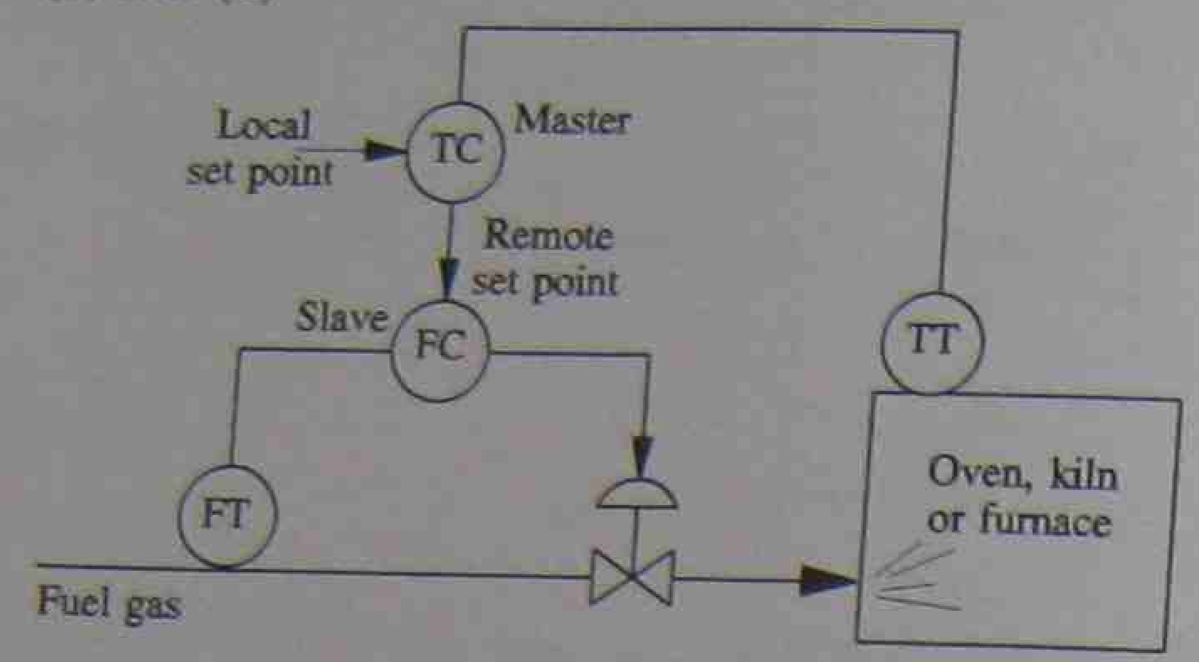
$\therefore \frac{500}{200} \times R = 2$

$\therefore 2.5 \times R = 2$

$\therefore R = \frac{2}{2.5} = \frac{4}{5} = 0.8$

A 10% change in flow A will change set point by 10 x 0.8 = 8%, 40 ℓ/hr (2:1).

5. (a) and (b)



(c) Flow transmitter
Flow controller
Control valve

(d)
- Assume the temperature increases (thus less fuel gas is required).
- When the temperature increases, the output signal of the master controller must decrease in order to lower the set point of the fuel gas flow controller.
- The fuel gas flow controller will control at this new set point value (as long as the temperature is maintained at the set point of the temperature controller).

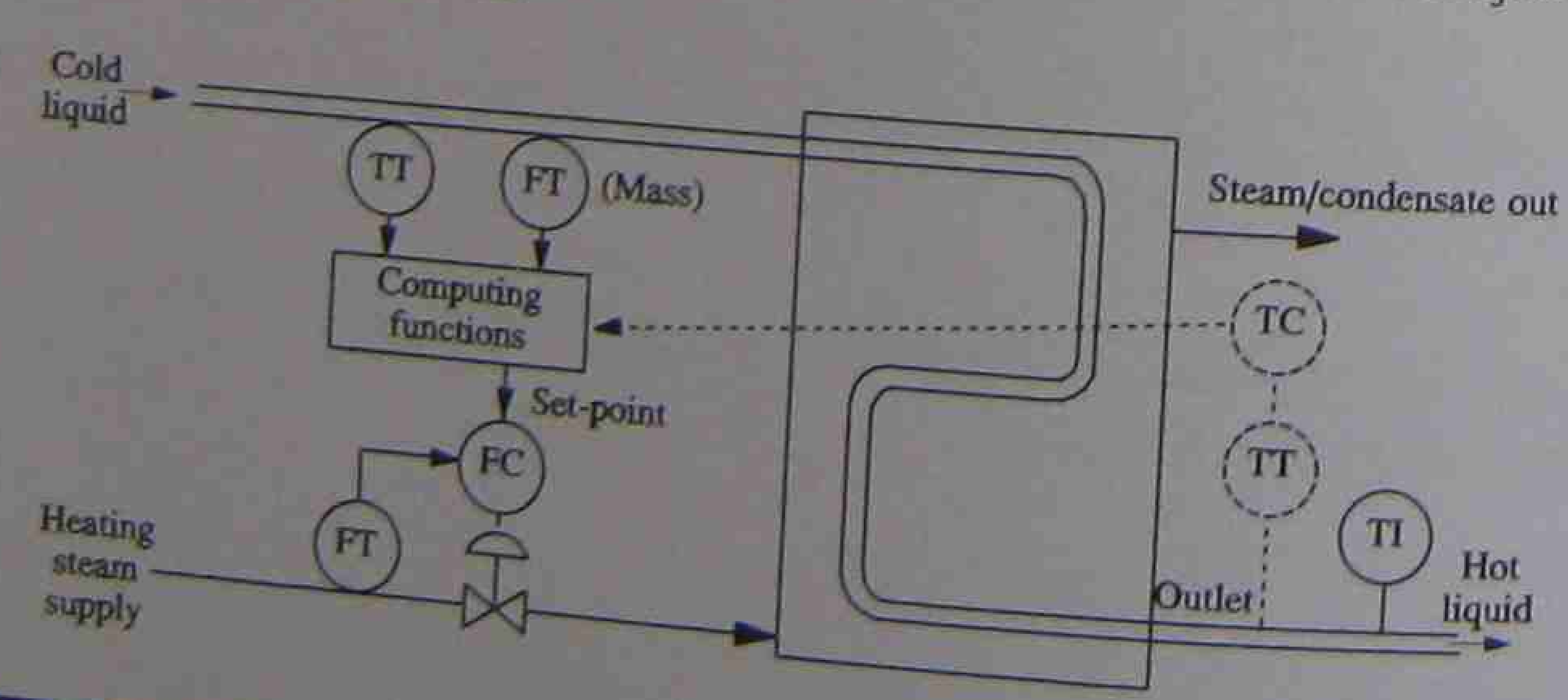
Note: The additional flow control loop in this system, provides greater stability than can be achieved with just a basic feedback loop.

(e) The slave loop must have a much shorter time constant than the master (the slave process must be faster than the master process). This is necessary, so that the slave controller and process can keep up with set point change sent from the master controller.

(f) If supply pressure changes occur, the slave flow controller will maintain a far more stable flow compared to a basic feedback loop, and thus a much smaller supply disturbance deviation of the master process variable. Also, if both supply and demand changes occur at the same time, a basic feedback loop will give poor control.

(g) If supply side variations are large and/or frequency and occur in conjunction with demand variations.

6. (a)

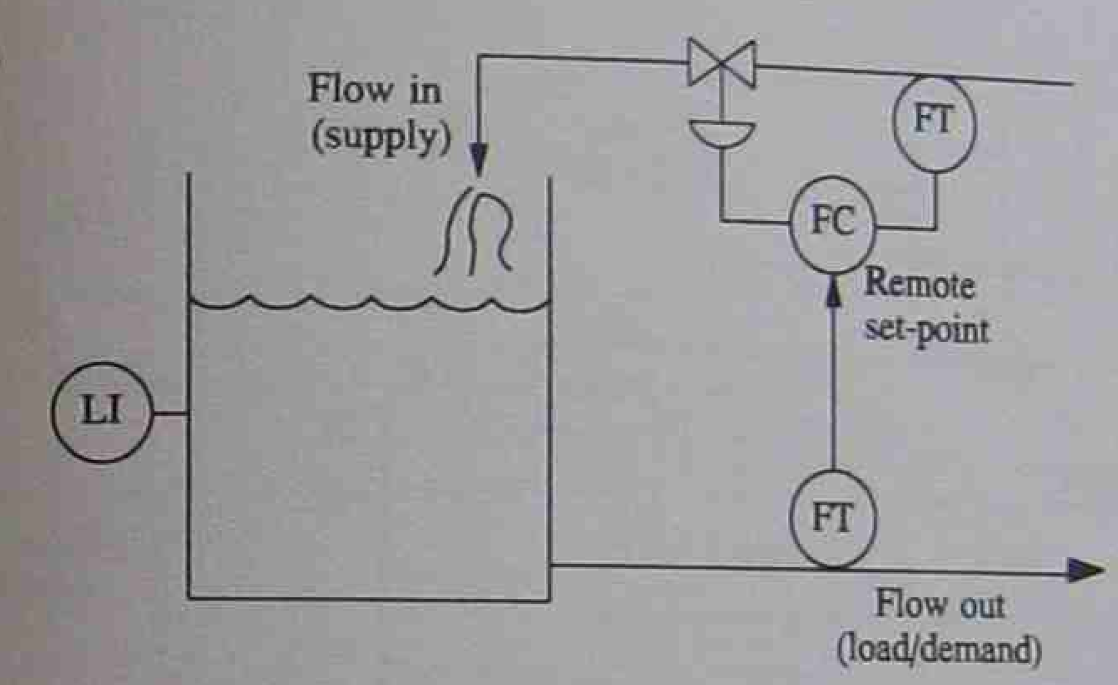


(b) The heating process shown above, uses steam to heat a liquid to a desired (outlet) temperature, shown by TI, (temperature is the process variable). The quantity of heat required depends on the load. The load depends on the mass flow rate and the temperature of the liquid, (and of course its specific heat capacity, which is assumed to be constant).

The operation of the system above is therefore as follows, the load is determined from measurements of the liquid inlet temperature and mass flow rate, and the corresponding heat requirement is computed. The calculate heat demand is used to set the set point of the steam flow controller.

(c) Feedback trim is shown with dotted lines.
Operation - If all measurements, calculations an control valve responses were perfect, the basic feedforward system would provide perfect control. In practice small errors occur and the PV will drift over time from its desired value. To overcome this problem, a feedback loop is included in the feedforward system to provide 'feedback trim'.

(d)



Note: The system shown above, achieves a stable level by measuring demand, and matching supply (flow in) with demand (flow out). i.e. when flow in = flow out, the level must be stable.

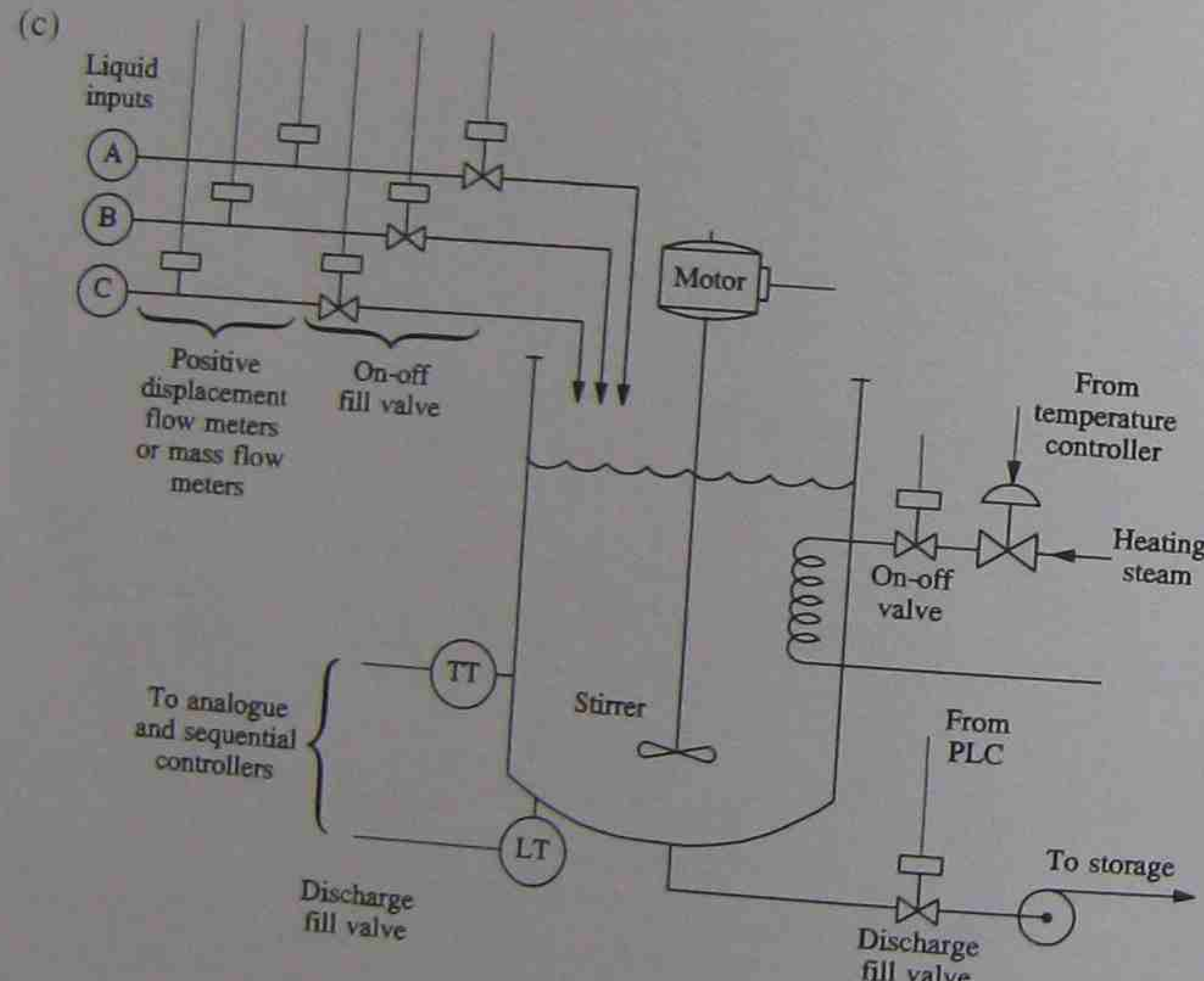
(e) There are two reasons:
- While the level may be stable, it could be stable at any level, and would require initial setting up on manual.
- For perfect operation, both flow measurements must be totally accurate, otherwise the level will drift over time (even though the measured flow in equals the set point). Thus, the level must be measured (as well as the demand) and used to provide feedback trim to the operation of the feedforward system.

7. (a) A batch process manufactures a product in discrete amounts (batches) rather than continuously. The required 'ingredients' are fed into the process vessel in the required amounts and in the right sequence. The vessel is then stirred/heated/pressurised etc. as may be required, in an appropriate sequence and time, in order to produce the desired product.

(b) Any two of the following:

- *Beer* is brewed in large 'batches' (similar to home brewing on a very large scale, with all the various operations and procedures being automated).
- *Margarine* is manufactured from oils, in large 'batches', by a process of hydrogenisation.
- *Sugar* is manufactured by boiling crystallising sugar in vessels called 'pans'.
- *Vinyl chloride monomer (VCM)* is produced in batches in autoclaves.
- Various *pharmaceuticals* (tablets, capsules, cough mixtures) are manufactured by batch processes.

(c)



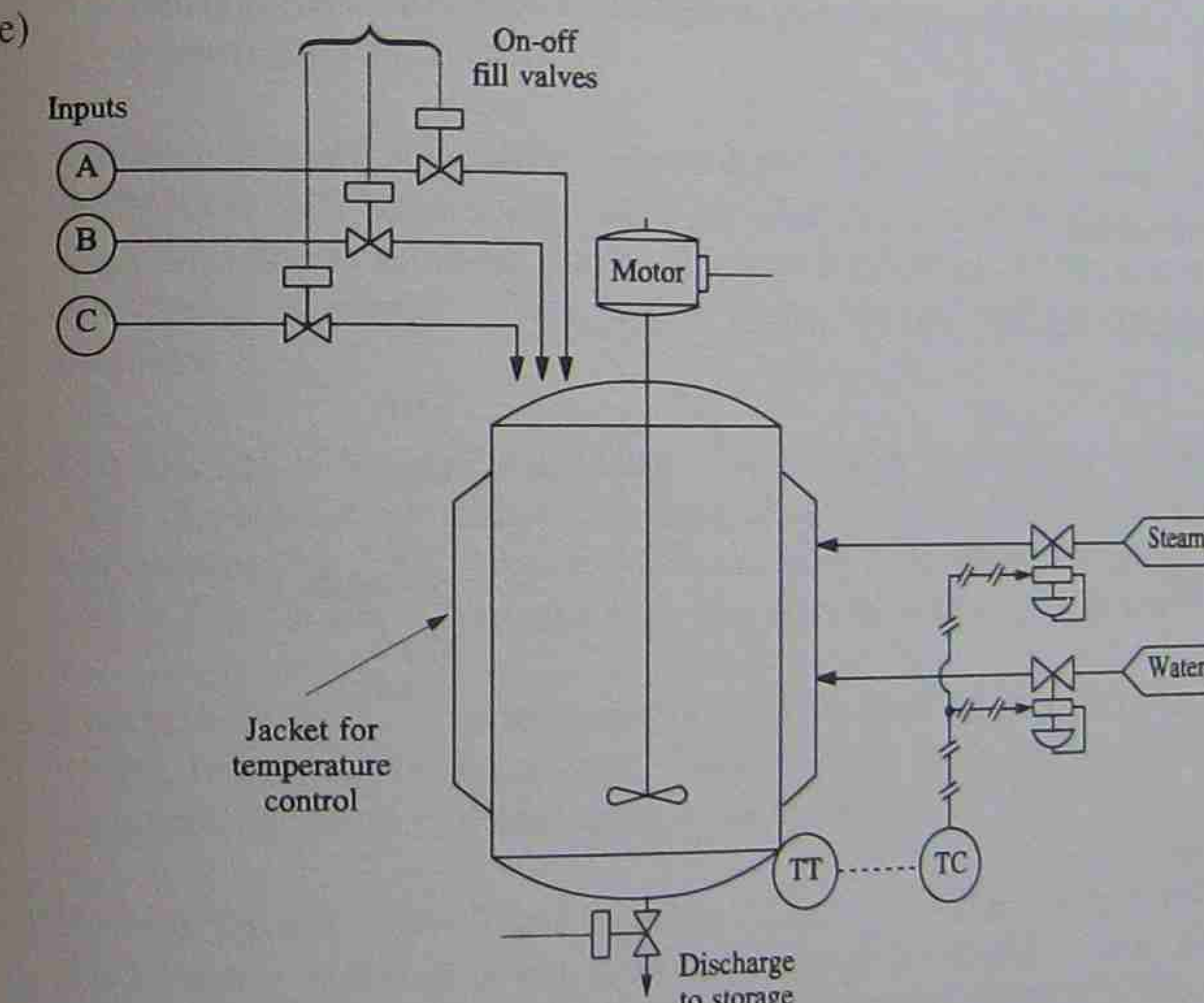
Operation - The required quantities of liquids A, B and C are measured by the flowmeters and the PLC then shuts the on-off fill valves, in the required sequence (and stops the fill pumps, not shown).

The level transmitter measures the liquid level as a double check to ensure that each liquid has been added to the vessel. When the vessel has been correctly filled (charged), the process sequence is initiated. e.g.

Time Zero:	Stirrer on
3 mins:	Heating steam is introduced (steam on-off valve is opened), and the temperature controller raises the temperature to the desired value in a controlled ramp-up in 12 minutes.
15 mins:	Temperature is maintained at the desired value for 20 minutes.
35 mins:	Steam flow is shut off.
40 mins:	Stirrer off. When stirrer is off, the discharge valve is opened. When the discharge valve is open the discharge pump starts and empties the product from the vessel. Pump stops and valve closes when vessel is empty.

(d) PLCs are used to monitor and control sequenced operations, as illustrated in the previous question.

(e)



(f) The feedback temperature control loop provides continuous temperature control during the processing phase of the batch cycle.

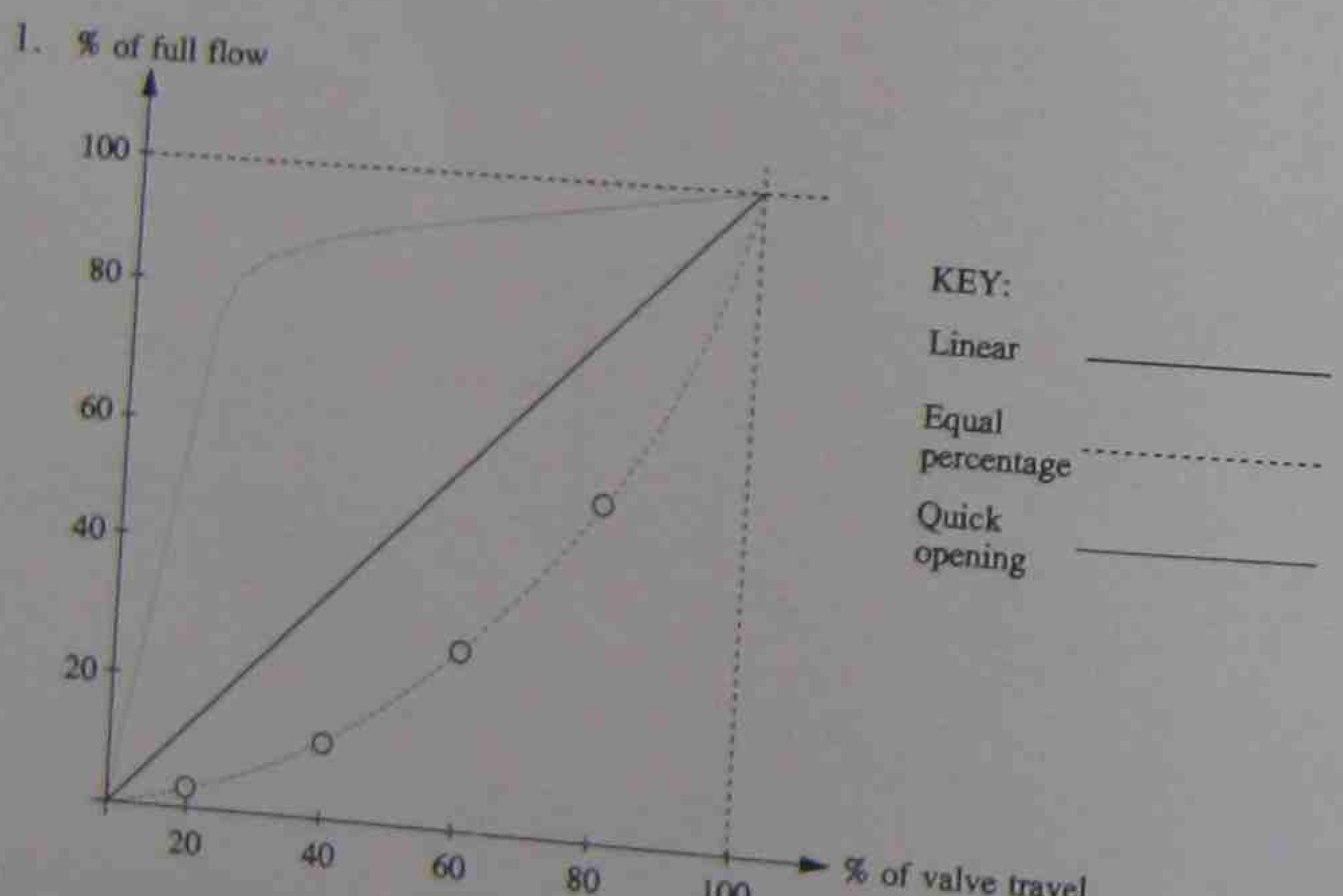
8. (a) +(A4) and -(A5)
(b) +(A7) and -(A8)
(c) FB13
(d) FB14
(e) These point are connected to the display 'P' is the process variable, and 'V' is the output signal to the value.
(f) FB17
(g) Loop 1 has a tracking set point. When the controller is on manual, the set point function block makes the set point signal equal to the PV.

9. (a) Basic PID controller with non-tracking set point and auto-manual facility.
(b) Loop 2 has provision for an external (remote) set point signal.
(c) FB11 allows selection of the local (FB17) or the remote (FB02) set point.

10. (a) Basic PID controller with remote set point facility.
(b) The ratio function provided by function block FB07 has been added.
(c) This allows the controller to be used as a ratio controller in a ratio control loop.
(d) When used in a ratio control loop, the external set point signal comes from the flow transmitter measuring the uncontrolled (wild) flow.

Section 3

1.



2. Inherent characteristic - This is determined under condition of a constant pressure drop across the valve for all values of flow and valve travel from 0 to 100%.

Installed characteristic - This varies from the inherent characteristic, because in the installed (real life) situation the pressure drop across the value decreases. Thus the actual flow at larger valve openings is *less* than that shown by the *inherent* characteristics.

3. Rangeability - is the ratio of maximum controllable flow to minimum controllable flow. *Note:* the minimum controllable flow is not the leakage flow when the valve is shut off. For typical industrial globe the control valves, the minimum controllable flow is about 2%, thus the typical rangeability is about $\frac{100\%}{2\%}$ i.e. 50:1.

Turndown - is the ratio of the maximum controlled flow in the installed situation to minimum controllable flow. e.g. $\frac{80\%}{2\%}$ i.e. 40:1.

4. (a) Undersized valve - A valve that is too small for the application, cannot provide the maximum demand required by the process, (and thus will not be able to control at maximum demand).

(b) Oversized value - A valve that is too large for the application, will:
- normally operate near its closed position, causing possible damage to the valve trim due to the high velocity of flow through the small valve opening
- operate (stroke) over a restricted part of the available valve travel, leading to poor control.

5. (a) Process (i) is self regulating. For example, if the flow is increased, the level in the tank will rise until the head pressure increases to the point where the flow out (due to the head pressure) equals the flow in. At this occurs if the load valve is altered. Thus, within limits, the tank will not empty out or overflow.

(b) Process (ii) is not self regulating. The variable speed pump, draws liquid from the tank at a constant rate, regardless of the head pressure in the tank, so therefore the head pressure does not have a stabilising/regulating effects and if flow in does not equal flow out, the tank will empty, or overflow.

(c) Process (ii) has a linear response, because the flow out depends on the pump speed, not on the head pressure. Thus when the pump speed (or flow in) is changed, the level will change in a linear fashion.

(d) Process (i) has a non-linear response. The level will not change linearly if the flow in, or the flow out is altered, because the change in head pressure (when the level rises or falls) will change the outlet (load) flow rate.

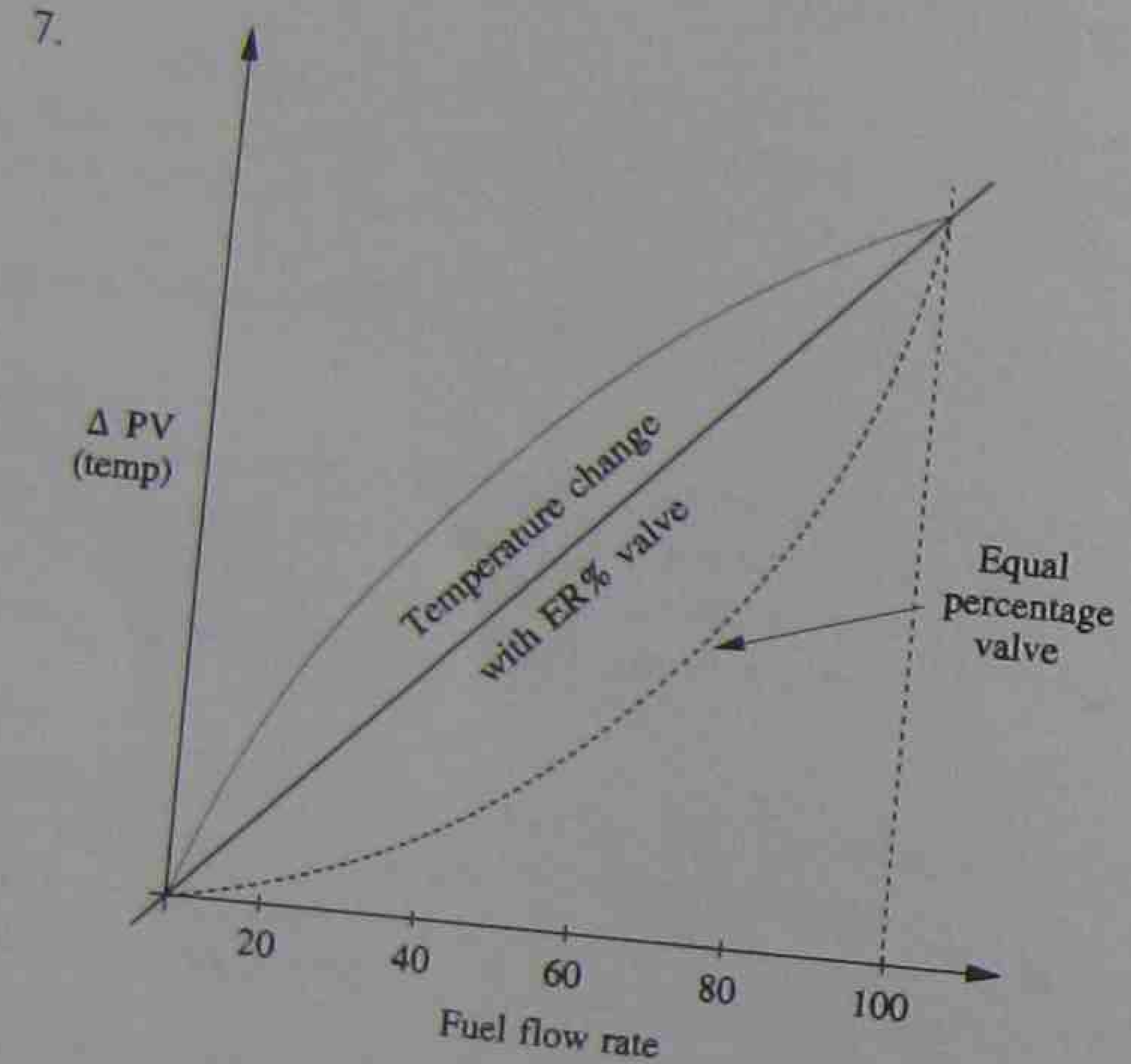
(e) • Process (i) is self-regulating. A linear valve would thus give a similar response, assuming the installed characteristic was basically unchanged from the inherent characteristic. The installed characteristic would also vary, depending on whether the valve was installed on the inlet or outlet.

• An equal percentage value may have the effect of linearising the level response (again depending on the installed characteristic).

6\. (a) The simplest way of achieving the rangeability of 200:1 would be to select a different type of valve, e.g. a ball valve or an eccentric disc valve ('camflex'). Alternatively, two valves (a small valve and a large valve) can be used in a split range configuration. Note, two valves (each with a 50:1 rangeability) may be split ranged to provide a combined rangeability of 50 x 50 = 2500:1.

(b) Cavitation on flashing can occur in flowing liquids. *Flashing* causes a vapour phase to occur, which therefore degrades control valve performance. (i.e. if the valve has been sized for liquids). *Note:* Flashing also damages the valve trim. Cavitation, occurs when the vapour bubbles implode. This causes severe valve trim damage, again affecting the correct performance of the control valve.

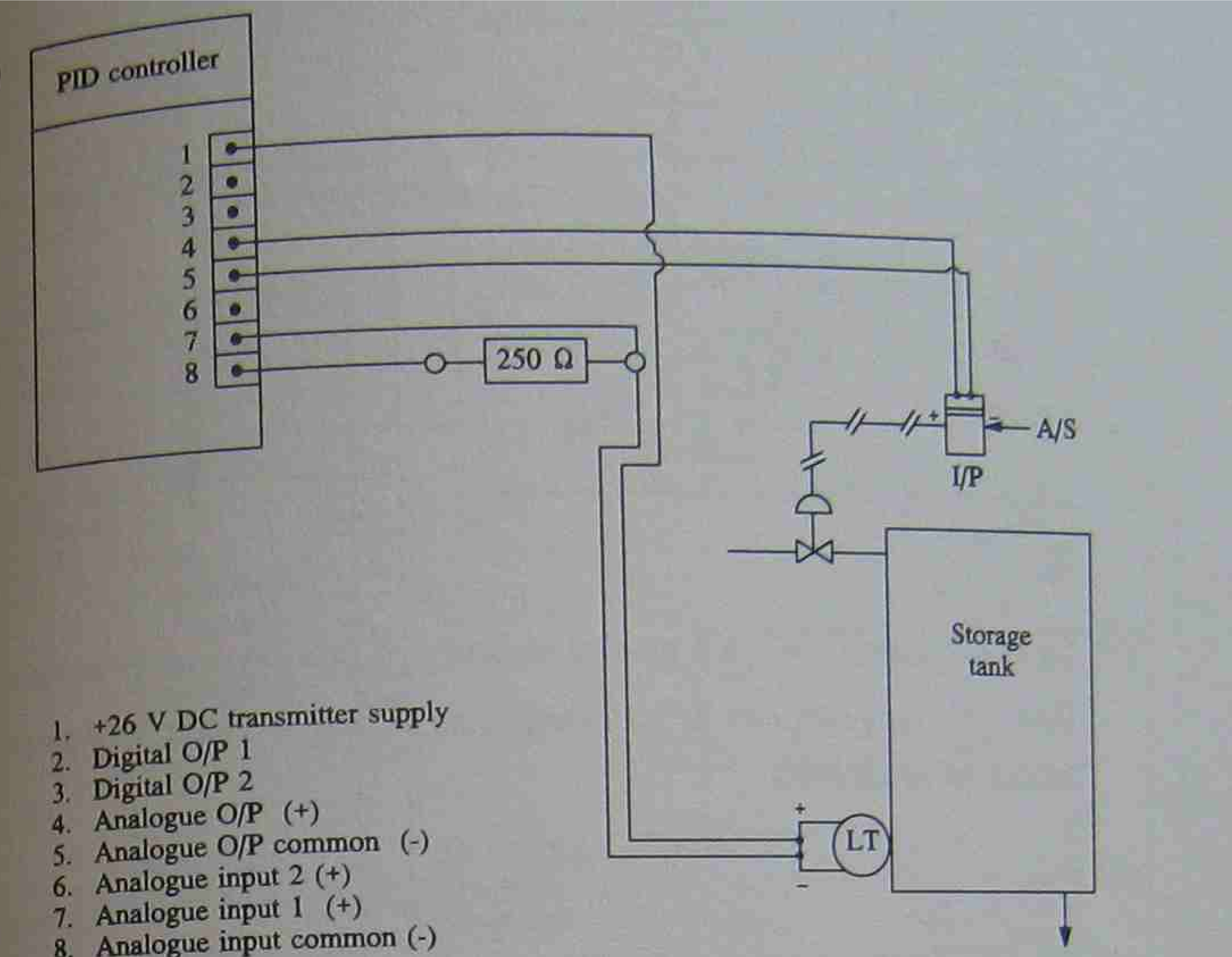
7\.



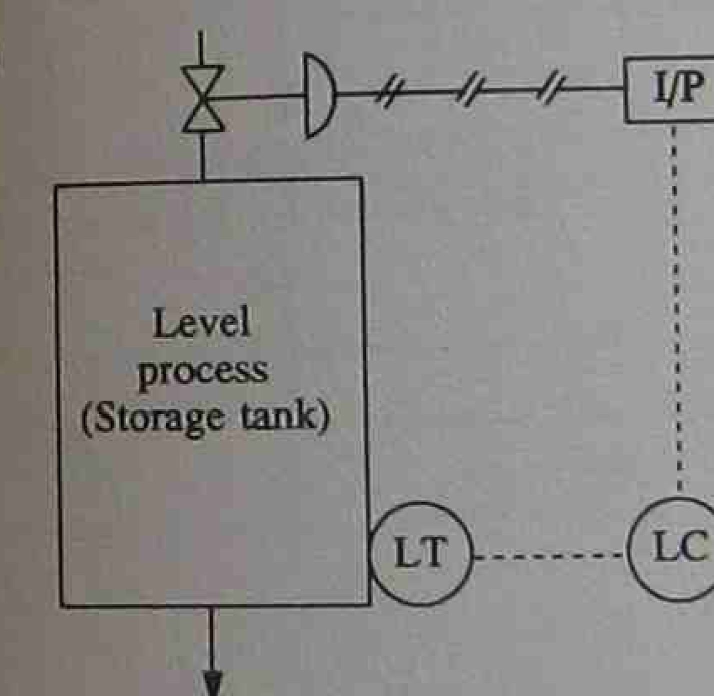
(a) A linear value, that retains its inherent characteristic will, will give a temperature response a shown above.

(b) An equal percentage value has a low gain at low flows, and a high gain at high flows. If the inherent characteristics is retained, this will have the effect of providing a linear temperature response to control value change. (See diagram).

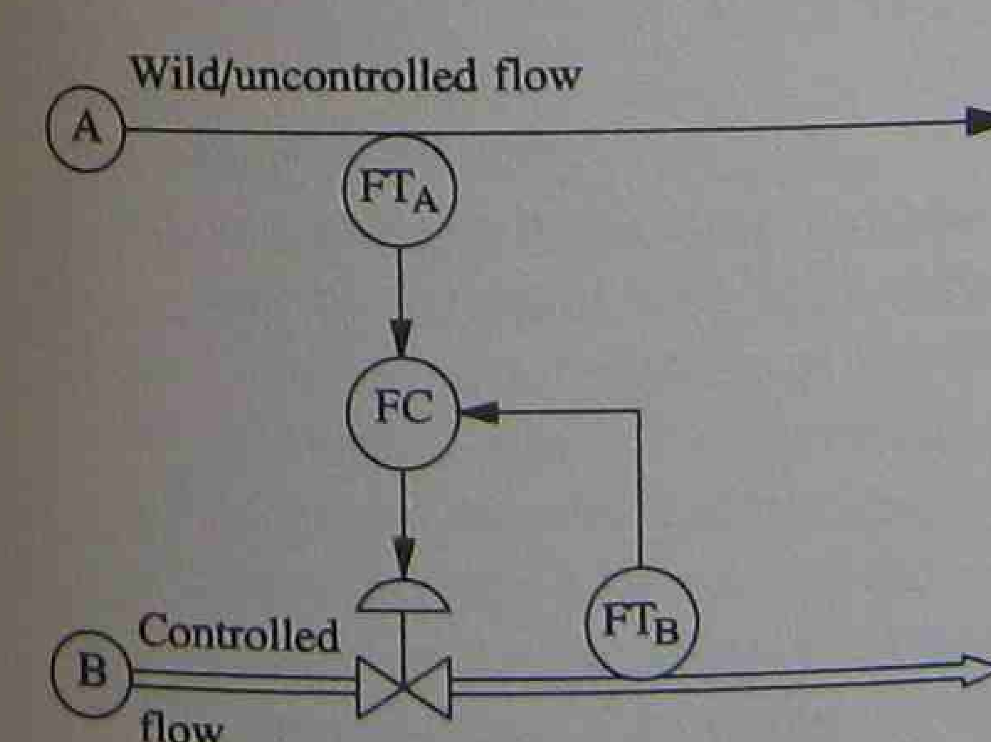
(a)



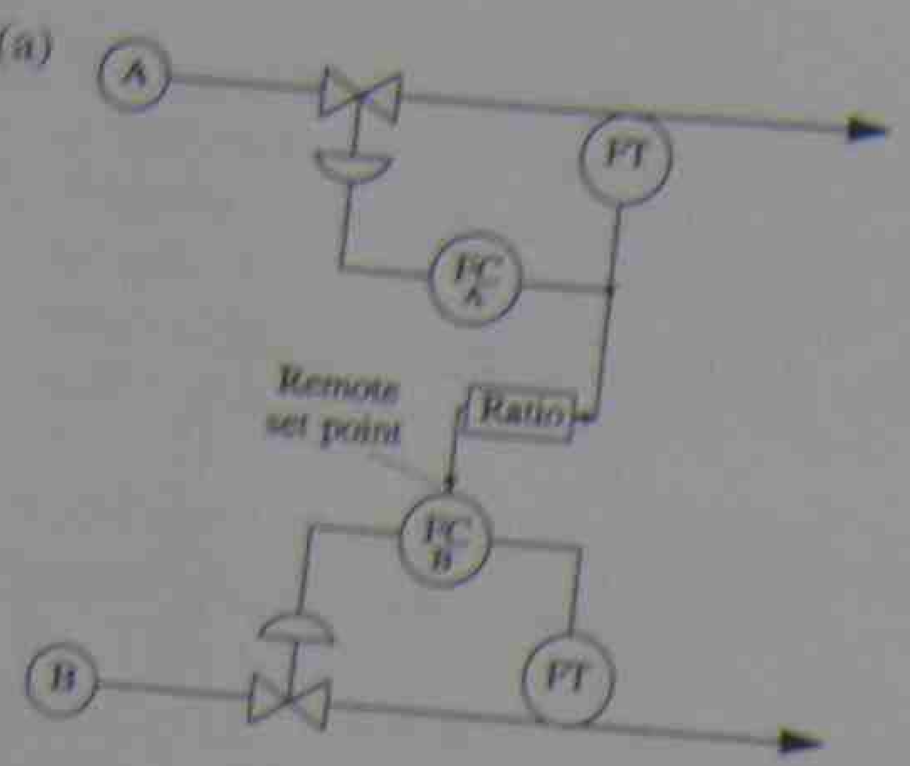
(b)



9\. (a) and (b)



10. (a)

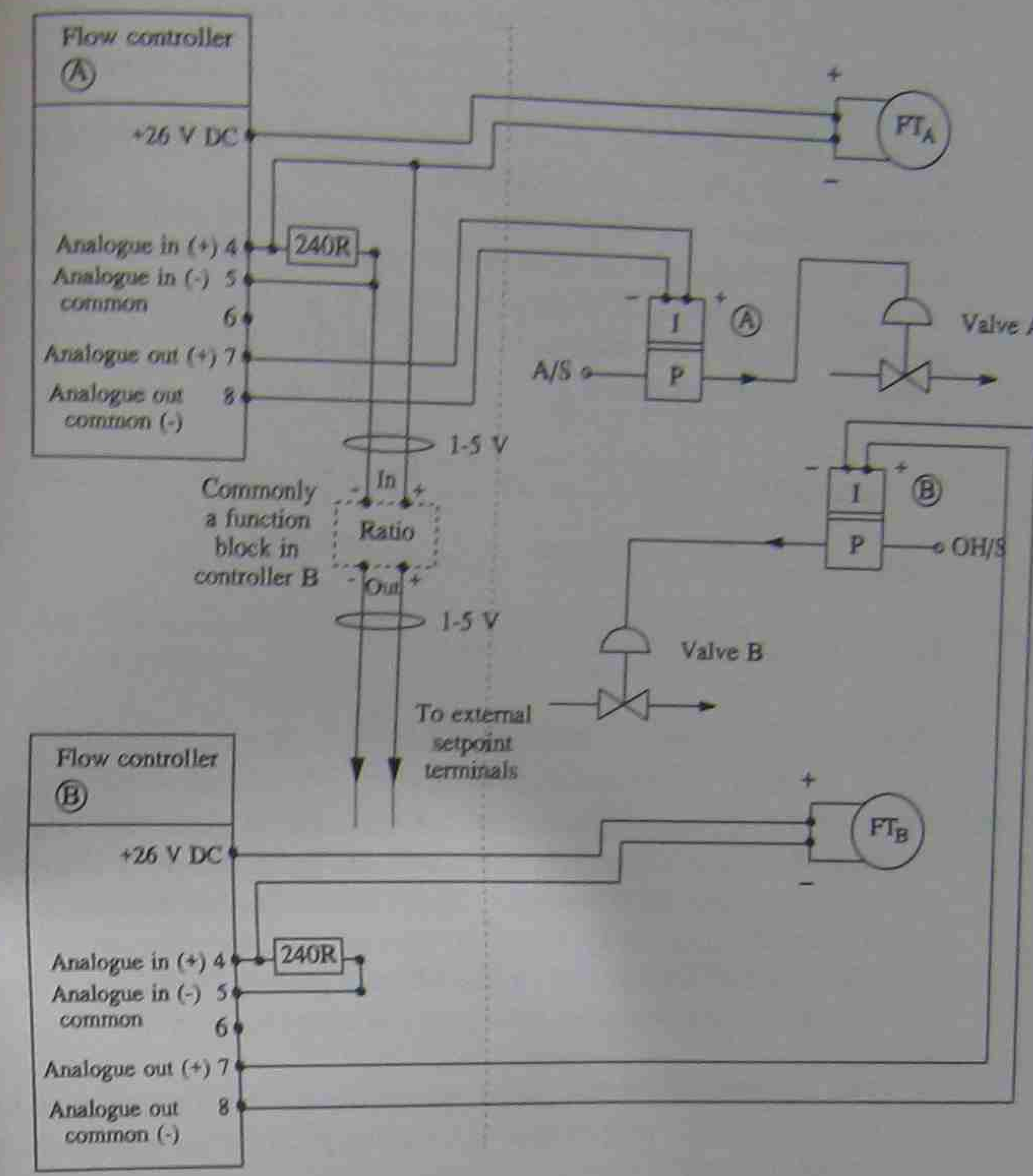


(b) By controlling flow (A), greater stability of ratio system is achieved. Also, flow (A) set point can be adjusted to any desired value, and flow (B) will follow in proportion.

(c) FC_B

(d) FC_A has a local set point (the diagram does not show a remote set point). FC_B has a remote set point, obtained from flow (A) flow transmitter.

11.



12. (a) Preliminary:
- Derivative off (td = zero)
- Gain low e.g. 0.3
- Controller on auto

Tuning procedure:
- Progressively increase the controller gain and make a small step change to the set point with each increase in gain.
- Observe the response of the PV to each set point change.
- Continue the above procedure until response is obtained.
- Increase the derivative time so that the QAD cycle is damped.
- Increase the gain so that the cycle amplitude increases again.
- Increase derivative time to dampen the cycle.
- Repeat 5 and 6 to obtain an overdamped QAD response.

(b) Preliminary: As for (a) above, but
integral is turned off as well (ti = max).

Tuning procedure:
As for (a) above first adjust the controller gain and derivative time.
Then adjust the integral time as follows:
Gradually decrease the integral time. Make a small set point change with decrease in integral time and observe the response of the PV achieved when the desired response is ????? the PV returns to the set point as quickly as possible but without any increase in cycling. If cycling begins to show, then double the integral time.

13. (a) Controller gain $\approx \frac{Ku}{2} = \frac{1.8}{2} = 0.9$

Integral time $\approx \frac{Pu}{3} = \frac{4 \text{ minutes}}{3} \approx 1.3$ mins

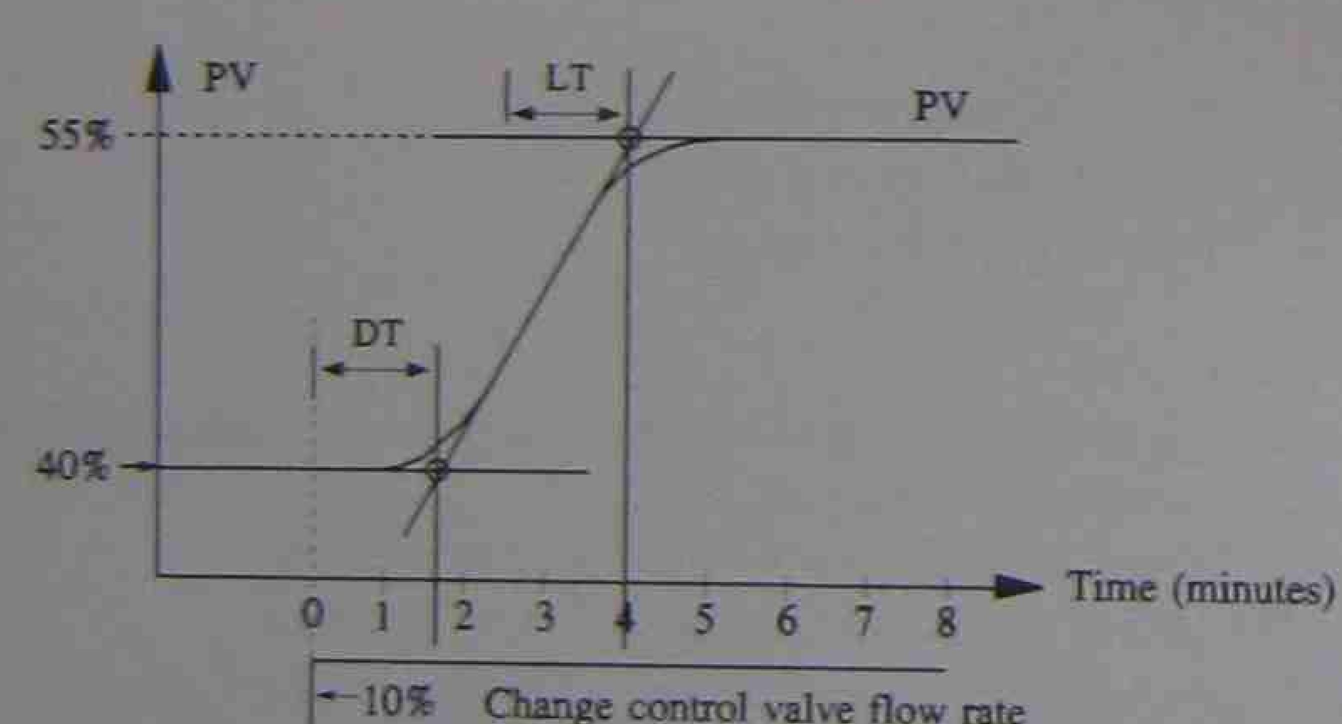
Derivative time $\approx \frac{Pu}{6} \approx \frac{4}{6} \approx 0.7$ mins

Note: Some authorities recommend Ti = Td = $\frac{Pu}{6}$

(b) • With integral and derivative off, the controller is placed on auto. The controller gain is gradually increased, and small set point changes are made, until the PV just starts to cycle with a constant amplitude. This is called the ultimate cycle, and the gain is called the ultimate gain (Ku). The period of the cycle is Pu (the ultimate period). From the values of Ku and Pu, the controller setting are calculated as above.

• The calculated controller setting are usually not perfect and need to be fine tuned. This may be used as a starting point for the systematic trial tuning method.

14.



DT = 1.6 mins LT = 2.4 mins (obtained from graph).

Lag ratio (R) = $\frac{LT}{LD} = \frac{2.4 \text{ mins}}{1.6 \text{ mins}} = 1.5$

Plant gain (C) = $\frac{\% \text{ change of PV}}{\% \text{ change of valve stroke}} = \frac{15\%}{10\%} = 1.5$

Calculated PID settings:

% proportional band = $85 \times \frac{C}{R} = 85 \times \frac{1.5}{1.5} = 85\%$

Integral time = $1.5 \frac{DT \times C}{R} = \frac{1.5 \times 1.6 \text{ mins} \times 1.5}{1.5} = 2.4$ mins

Derivative time = $0.5 \times \frac{DT \times R}{C} = \frac{0.5 \times 1.6 \text{ mins} \times 1.5}{1.5}$

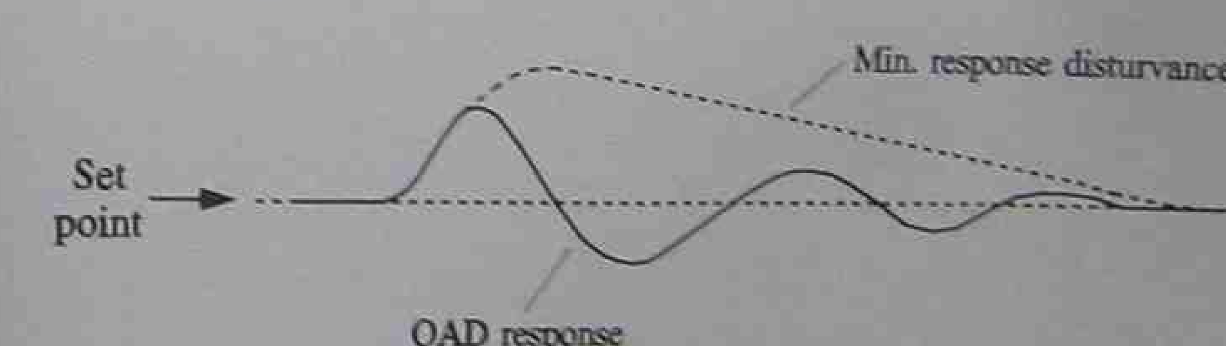
= 0.8 mins

15. (a) The controller is placed on manual. A recorder is required to record the PV response.

(b) A step change is applied to the control valve (typically between 5% and 10%), and the PV response is recorded by the recorder. The PV graph is read from the time the step change to the control valve was made. From the PV graph, the delay time (DT) the lag time (LT) and the plant gain is obtained as shown in the previous question.

(c) Using the appropriate equations (see question 10), the PID settings may then be calculated.

16.



17. QAD - The QAD (or minimum area) response is commonly used on most control loops. The QAD response returns the PV back to the set point in the minimum possible time, with the least waste of energy. However the QAD (Quarter Amplitude Damped) response cycles for three to four cycles before the PV stabilises again.

Minimum disturbance - If cycling is undesirable, the minimum disturbance response may be used. For example, boiler drum level, and distillation column process variables should *not* cycle, as this can cause damage and/or bad product. Note that the minimum disturbance response results in a greater deviation and takes longer to stabilise than the QAD response. The minimum disturbance response is achieve by using less gain than required for QAD.

18. ‘Self-tuning’ (microprocessor-based) controllers commonly use the process reaction curve (step response) method to calculate the required PID settings. (This is the same method as covered in question 14 and question 15).

The controller does this by making a small step change to its output, and measuring the resulting process reaction curve parameters (DT, LT etc.). From these, the controller then calculates the appropriate PID settings.
Note: A controller may ‘self-tune’ on a routine basis (say every hour), or after any large change to load conditions.