Module : CONTROLLERS

Introduction to Process Control

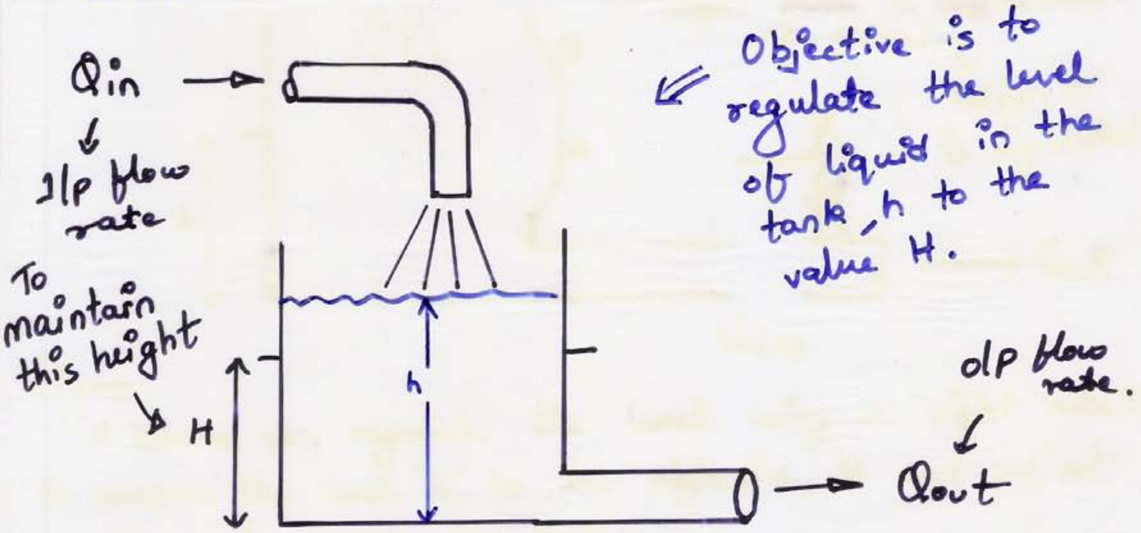
- Simply stated, the term 'control' means methods to force parameters in the environment to have specific values.
- This can be as simple as making the temperature in a room stay at 21°C, or as complex as manufacturing an integrated circuit or guiding a spacecraft to Moon.
- So, all the 'elements' necessary to accomplish the control objective are described by term 'control system'.
- Purpose of this module is to examine the elements and methods of control system operation used in industry to control industrial processes (hence the term 'process control').
- Natural process Control : Living organisms maintain temperature, biological functions.
- Technology of Artifical Control.
  When we learned how to use machines, electronics, and computers to replace human functions, term 'Automatic Control' came into use.

The Importance of Process Control

- Refining, combining, handling and otherwise manipulating fluids to profitably produce end products can be a precise, demanding and potentially hazardous process.
- Small changes in a process can have a large impact on the end result.
- Variations in proportions, temperature, flow, turbulence, and many other factors must be carefully and consistently controlled to produce the desired end product with a minimum raw materials and energy.
- Process control technology is the tool that enables manufacturers to keep their operations running within specified Limits and to set more precise limits to
  1) Maximize profitability.
  2) Ensure Quality of End Product.
  3) Ensure Safety.

Process - Control Principles:

- In process Control, basic Objective is to regulate the value of some quantity.
- To Regulate means to <u>maintain</u> that quantity at some <u>desired</u> <u>value</u> regardless of <u>external</u> <u>influences.</u>
- The Desired value is called 'Reference value or Setpoint'.



Objective is to regulate the level of liquid in the tank, h to the value H.

- $Q_{out} = K\sqrt{h}$ ie Higher the level (h), faster the liquid flow out.
- If o/p flow rate is not exactly equal to input flow rate, the level will drop, if $(Q_{out} > Q_{in})$ or rise, if $(Q_{out} < Q_{in})$.
- Here, liquid level will adopt some value for which input and output flow rates are the same, and there it will stay. (Self-regulation).

Human-Aided Control:

Suppose we want to maintain the level at some particular value, H in figure(1), regardless of input flow rate. Then something more than self-regulation is needed.

Modification of tank System to allow artificial regulation of the level by a human

[By Continuous monitoring of sight tube & adjustment of valve]

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heigh 'H' is regulated.

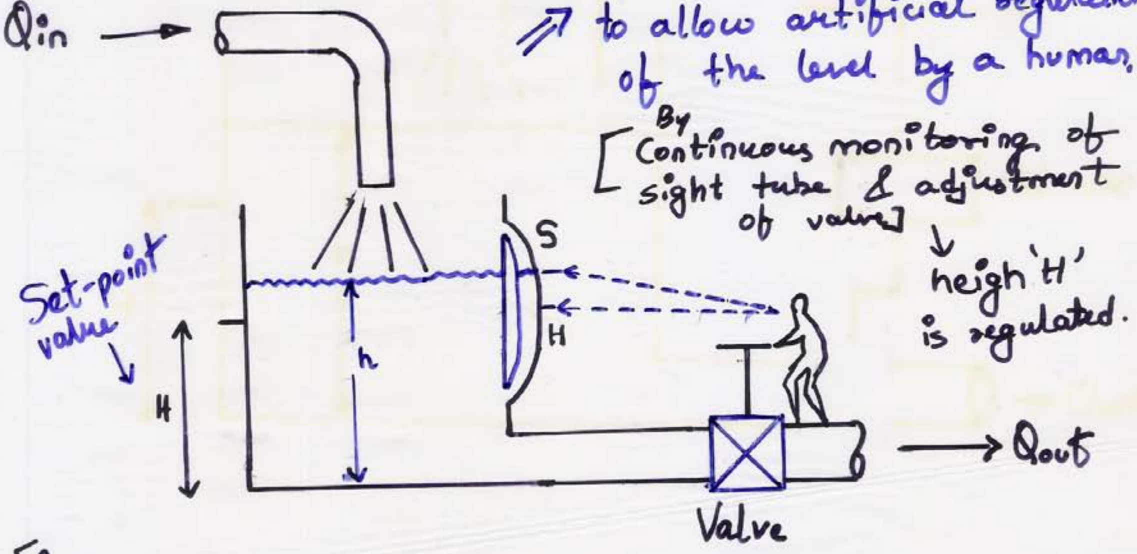
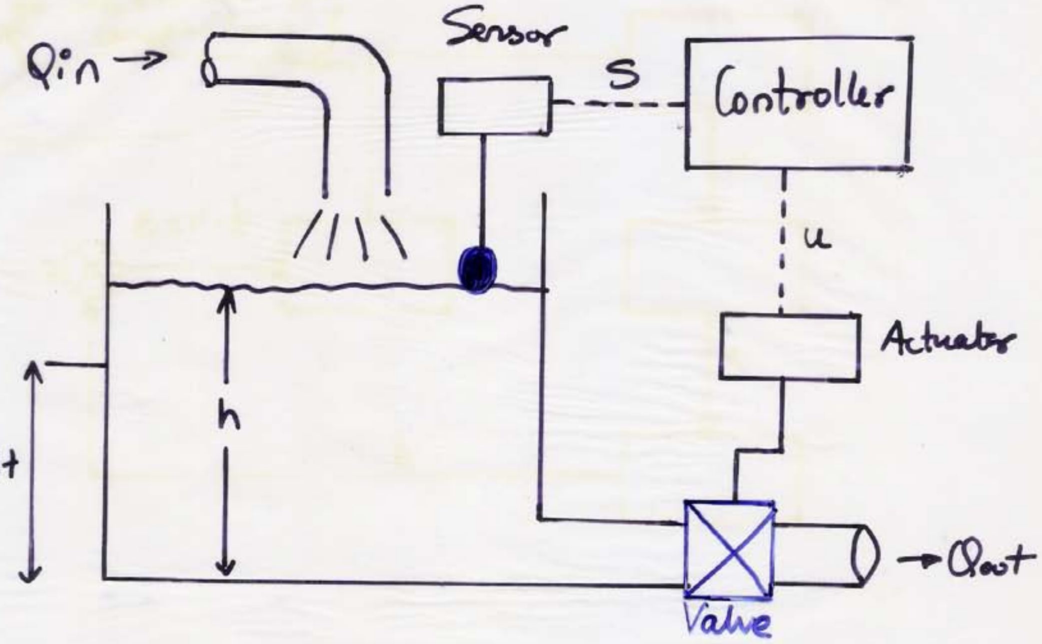


Figure:
A human can regulate the level using a sight tube S, to compare the level 'h' to the objective, H and adjust a valve to change the level.

- To regulate the level so that it maintains the value H, it will be necessary to employ a <u>sensor</u> to measure the level.
- The actual liquid level or height is called 'CONTROLLED VARIABLE'.
- The o/p flow rate is called 'MANIPULATED VARIABLE' or 'CONTROLLING VARIABLE'.

Role of 'Controller'

Automatic Control:



An Automatic level-control system replaces the human with a controller and uses a sensor to measure the level.

- To provide automatic control, an 'sensor' is added that is able to measure the value of the level and convert it into a proportional signal 's'.
- Controller performs the function of the human in evaluating the measurement and providing an o/p signal 'u', to change the valve setting via an 'actuator' connected to valve by a mechanical linkage.
- Job of Controller is to achieve the 'Set Point' and Maintain under any circumstances.

Block diagram of elements involved in Process-Control

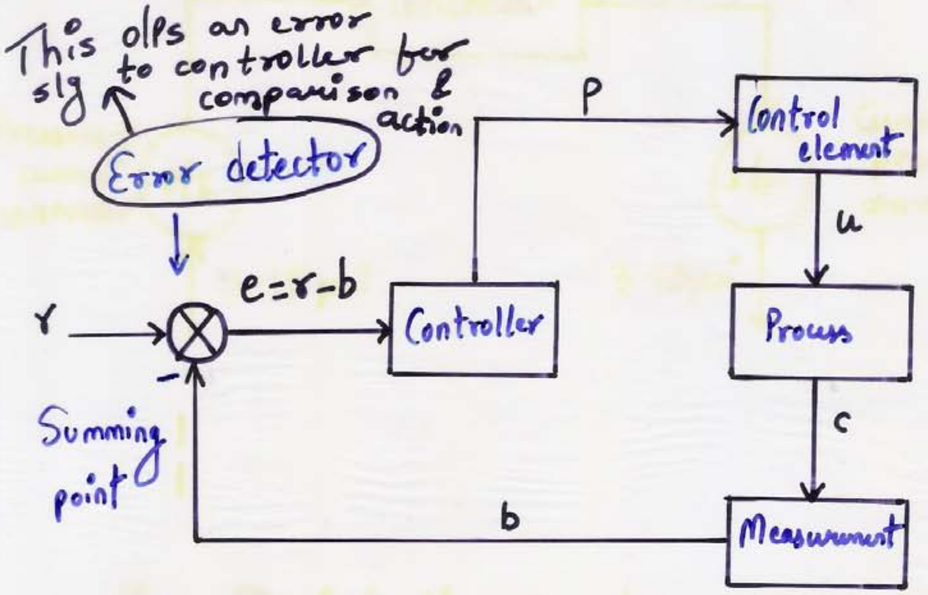


fig: This block diagram of a control-loop defines all the basic elements and signals involved

- The controlled variable in the process is denoted by 'c' and the measured representation of controlled variable is labeled 'b'.
- Controlled variable setpoint is labeled 'r' for reference.
- The controller uses the error input to determine an appropriate o/p slg., 'p' which is provided as i/p to control element.
- Control element operates on the process by changing the value of controlling process variable, 'u'.

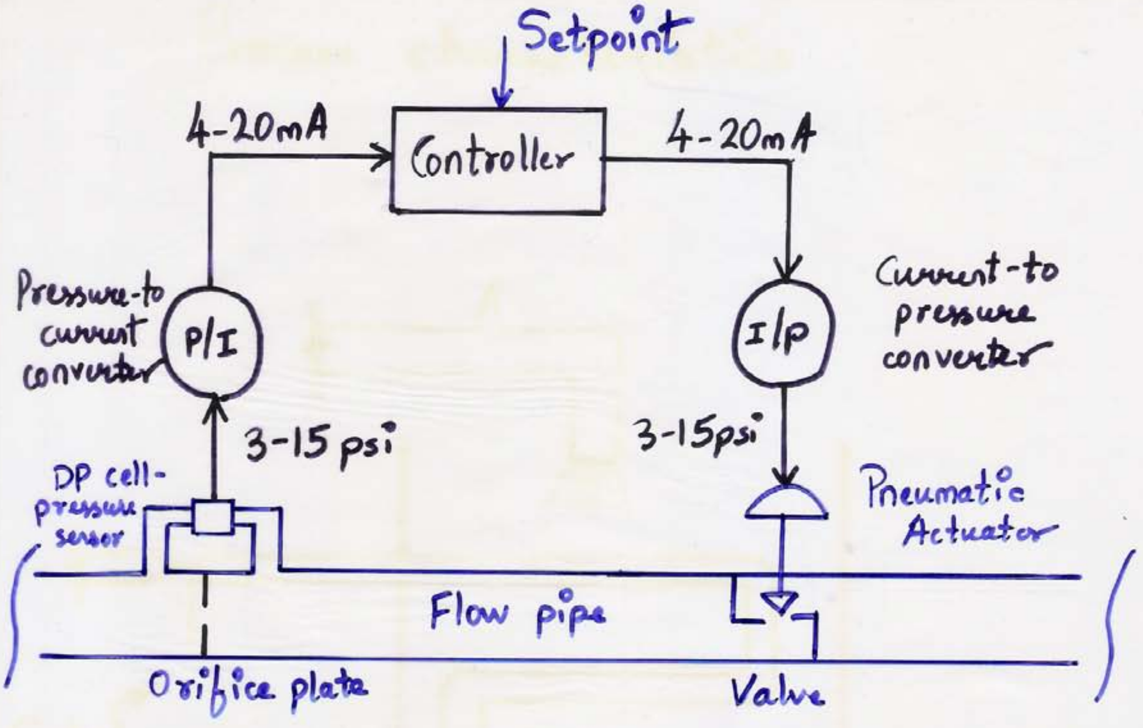


fig : Physical diagram of a process control loop

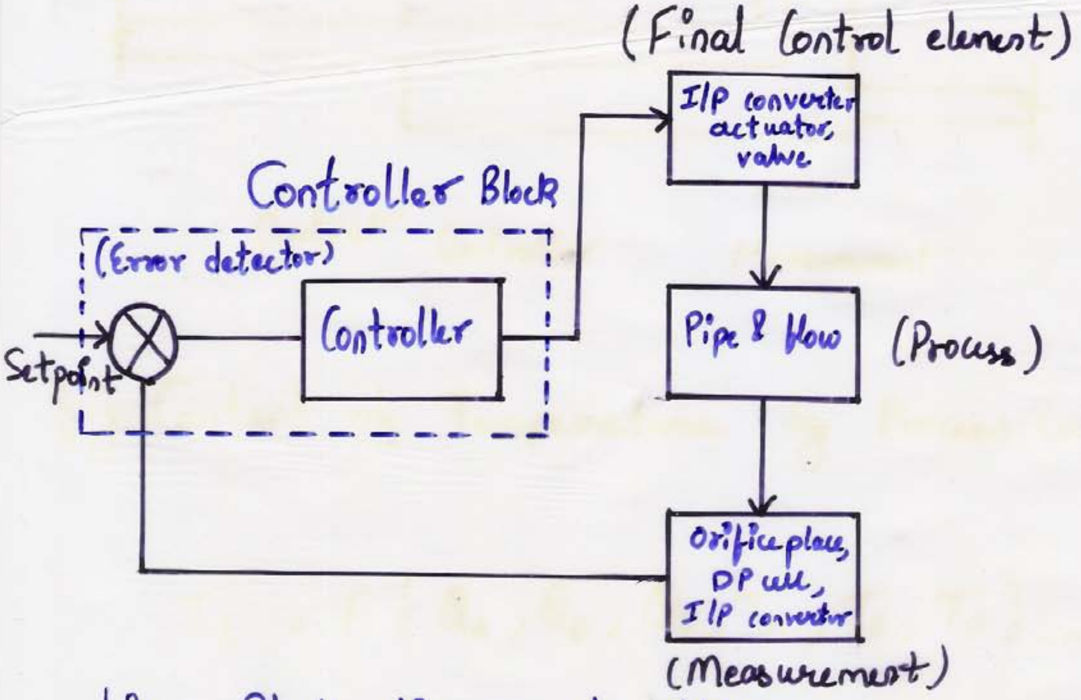
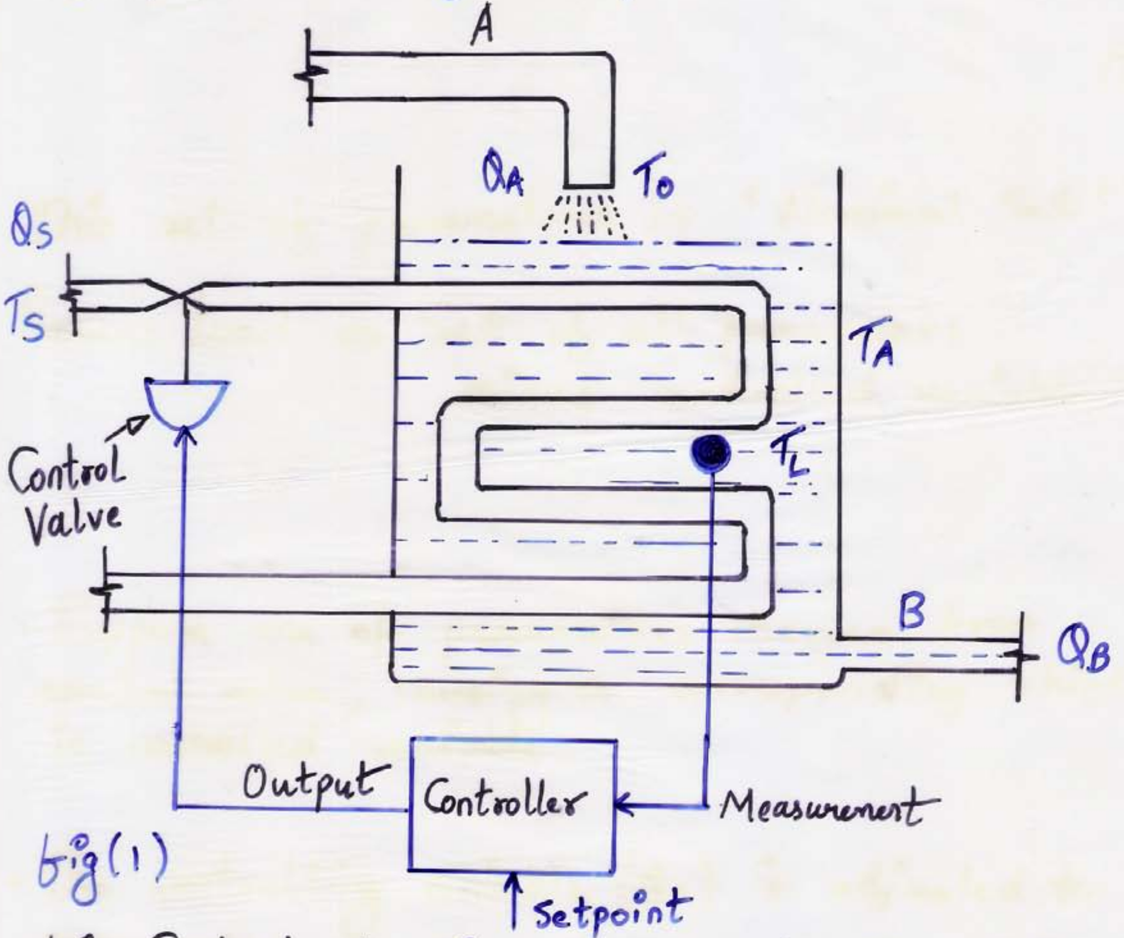


fig: Block diagram of the Process-control loop

Process characteristics

- The selection of what controller modes to use in a process is a function of characteristics of the process.



fig(1)

fig: Control of Temperature by Process Control

Process Equation

$$\underset{\substack{\downarrow \\ \text{Controlled variable}}}{T_L} = F\left(Q_A , Q_B , \underset{\substack{\downarrow \\ \text{controlling variable.}}}{Q_S} , T_A , T_S , T_o \right) \text{---} ①$$

Process Load

From process equation, or knowledge of and experience with the process, it is possible to identify a set of values for process parameters that results in controlled variable(T_L) having a Setpoint value.

This set of parameters is 'Nominal Set'.

Process Load => Set of all parameters minus controlled variable(T_L)

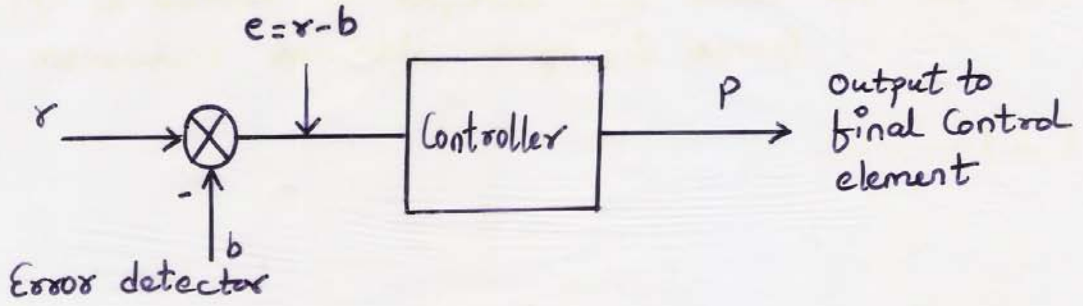
- When all parameters have their nominal value we speak of 'nominal load' on the system
- Suppose one of parameters changes from nominal value, causing a corresponding shift in controlled variable. We say that a 'process load change has occured.
- The controlling variable (Q_s) is adjusted to compensate for this load change.
- In previous example of temperature control, a process load change is caused by a change in any of five parameters affecting liquid temperature (T_L).

Transient: It is a temporary variation of one of load parameters.
The parameter returns to its nominal value here.

Process Lag:

- Process-control operations are time-varying
- At some point in time, a process-load change or transient cause a change in controlled variable (T_L).
- The process-control loop responds to ensure that some finite time later, variable returns to set-point value.
- Part of this time is consumed by 'process itself' and is called 'process lag'.
- For example, if suppose inlet flow is suddenly doubled. Such a large process-load change radically changes (reduces) liquid temperature.
- Controller responds by opening the steam inlet valve to allow more steam to bring T_L back to set-point.
- Control loop reacts faster than the process ie in fact, physical opening of control valve is the slowest part of Controller action.

Error Detector and Controller



- Measured indication of a variable is denoted by 'b', and the actual variable by 'c'.
- Thus, if a sensor measures temperature by conversion to resistance, the actual variable is temperature in °C, but the measured indication is resistance in ohms.

Error:

T_L

The deviation or error of controlled variable from the setpoint is given by,

$$\boxed{e = r - b}$$

where, e = error , b = measured indication of variable
r = setpoint of variable (reference)

Thus, if Setpoint in a 4 - 20mA range corresponds to 9.9 mA & measured value is 10.7 mA, we have an error of -0.8 mA. This current error has little direct meaning unless related to 'controlled variable'

If suppose, this error corresponds to a flow rate of 1.1 m^3/hr. Now this make sense !

To describe controller operation in a general way it is better to express the error as % of measured variable range (ie span).

$$\boxed{C_p = \frac{C - C_{min}}{C_{max} - C_{min}} \times 100} \quad \text{-----}(2)$$

where, C_p = measured value as % of measurement range

C = actual measured value.

C_{min}, C_{max} = minimum & maximum of measured value

Above equation (2) is in terms of Actual measured variable 'c'.

But same equation can be expressed in terms of measured indication, 'b'.

$$\boxed{e_p = \frac{r - b}{b_{max} - b_{min}} \times 100} \quad \text{-----}(3)$$

where, e_p = error expressed as % of span.

Using standard measured indication range like 4 to 20mA, span is always 16mA.

Suppose we have a setpoint of 10.5mA & a measurement of 13.7mA.

Then, without even knowing what is being measured we know the error is,

$$e_p = \frac{10.5mA - 13.7mA}{20mA - 4mA} \times 100 = -20\%$$

A +ve error indicates a measurement is below the Setpoint & -ve error indicates it is above the setpoint.

Control Parameter Range

- Final control element has some min and max effect on process.
- The controller o/p range is translation of o/p to range of possible values of final control element.
- Often, o/p is expressed as a % where 0% is minimum controller o/p and 100% the maximum.
- Thus, in example of fig(1), the valve in fully open position corresponds to a 100% contoller signal o/p.
- Often, however, minimum does not corresponds to zero effect.
- For example, a 0% minimum controller action may corresponds to flow rate with some % of open valve.

The controller o/p as a % of full scale when the o/p varies between specified limits is given by,

$$\boxed{p = \frac{u - u_{min}}{u_{max} - u_{min}} \times 100}$$

where, p = Controller o/p as % of Full scale

u = Value of o/p

u_{max} = maximum value of controlling parameter

u_{min} = minimum value of controlling parameter

Ex. A controller outputs a 4- to 20mA to control motor speed from 140 to 600 rpm with a linear dependence. Calculate (a) current corresponding to 310rpm and b) value of (a) expressed as % of control o/p.

Solution:

a) We find slope m and intersect S_o of linear relation between current I and speed S, where

$$S_P = mI + S_o$$

ie $\quad 140 = 4m + S_o \quad - (1)$

and $\quad 600 = 20m + S_o \quad - (2)$

Solving (1) & (2) simultaneously we get,

$$m = 28.75 \text{ rpm/mA} \quad \text{and} \quad S_o = 25 \text{rpm}$$

Thus, at 310 rpm, we have

$$310 = 28.75I + 25, \text{ which gives}$$

$$\boxed{I = 9.91 \text{mA}}$$

b) Expressed as a % of 4 to 20mA range, the controller o/p is

$$P = \frac{u - u_{min}}{u_{max} - u_{min}} \times 100$$

$$= \left[\frac{9.91 - 4}{20 - 4}\right] \times 100$$

$$= 36.9\%$$

Role of Final Control element

- Final element in process-control operation is device that exerts a direct influence on process; ie it provides those required changes in the controlled variable to bring it to the set-point

- This element accepts an input from the controller, which is then transformed into some proportional operation performed on the process.

- In our previous example, the control element is the valve that adjusts the outflow of fluid from tank.

- This element is also referred to as the 'final control element'.

× Often an intermediate operation between the controller o/p and the final control element.

- This operation is referred to as an 'actuator' because it uses the controller signal to actuate the final control element.

- The actuator translates the small energy signal of controller into a large energy action on the process.

Closed-Loop Control

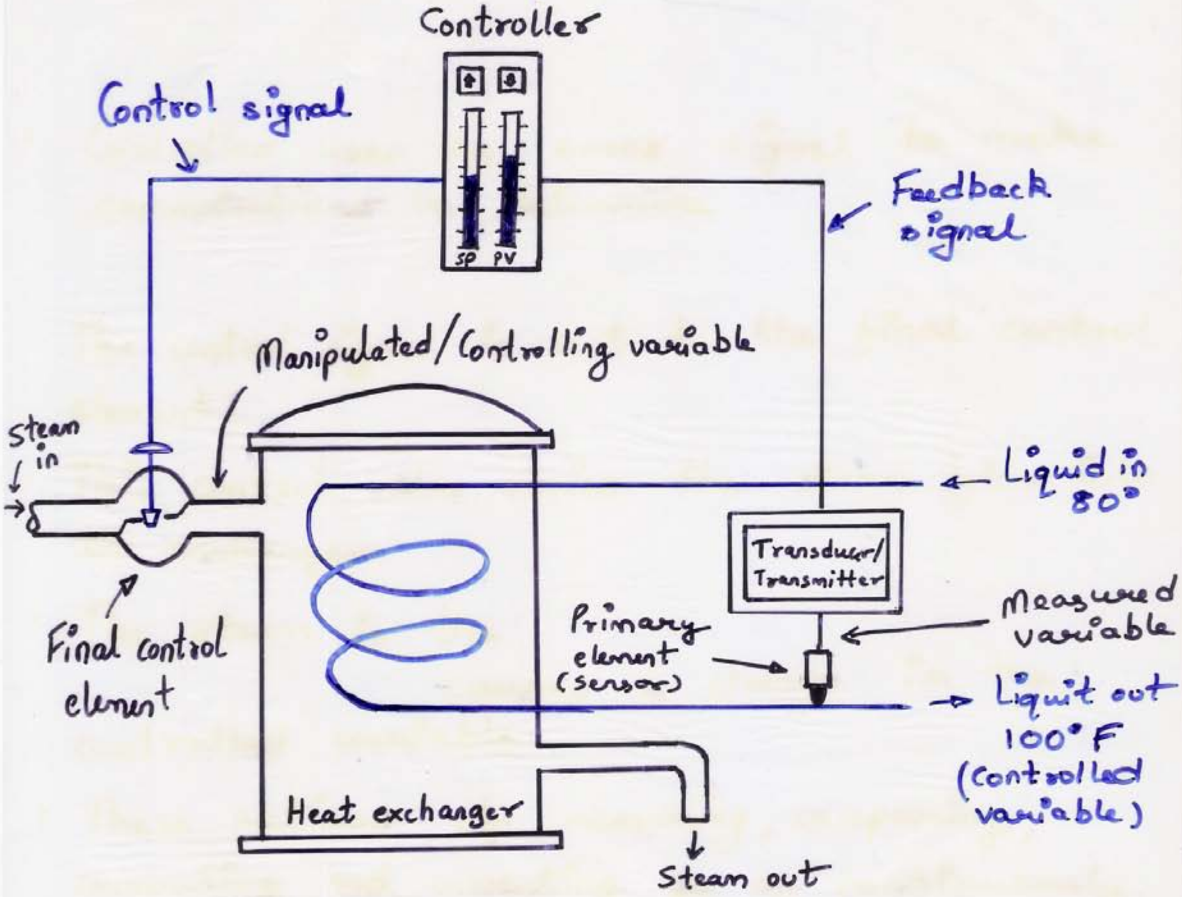


fig Closed-loop temperature Process Control System

- Heat Exchanger → used to heat a Liquid at temp of 100°F
- Amount of steam through control valve determines the temperature at which liquid is heated
- Primary element (sensor) → Detects condition of controlled variable
- Sensor's o/p, which is called 'measured variable' is conditioned by transmitted into a standard signal before it is sent to controller.

- Controller -> compares the feedback signal to the setpoint, and an error signal is developed if there is a difference.
- Controller uses the error signal to make computations to determine which type of control signal to produce at its output.
- The control signal is sent to the final control element (which is the control valve)
- This control valve varies the steam flow into the exchanger.
- The steam is the manipulated / controlling variable that causes a change in the controlled variable.
- These actions of measuring, comparing, computing and correcting go on continuously.

PROCESS BEHAVIOR

Primary objective of Process control is to cause a controlled variable to remain at a constant value at or near some desired setpoint irrespective of changes in value of other parameters involved in process control.

Process Behaviour

- A change can happen when only one of the following conditions occurs:
  - A disturbance appears.
  - Load demands vary.
  - Setpoint's are adjusted.

When a change does occur, objective of process control system is to return the controlled variable to the Setpoint as quickly as possible.

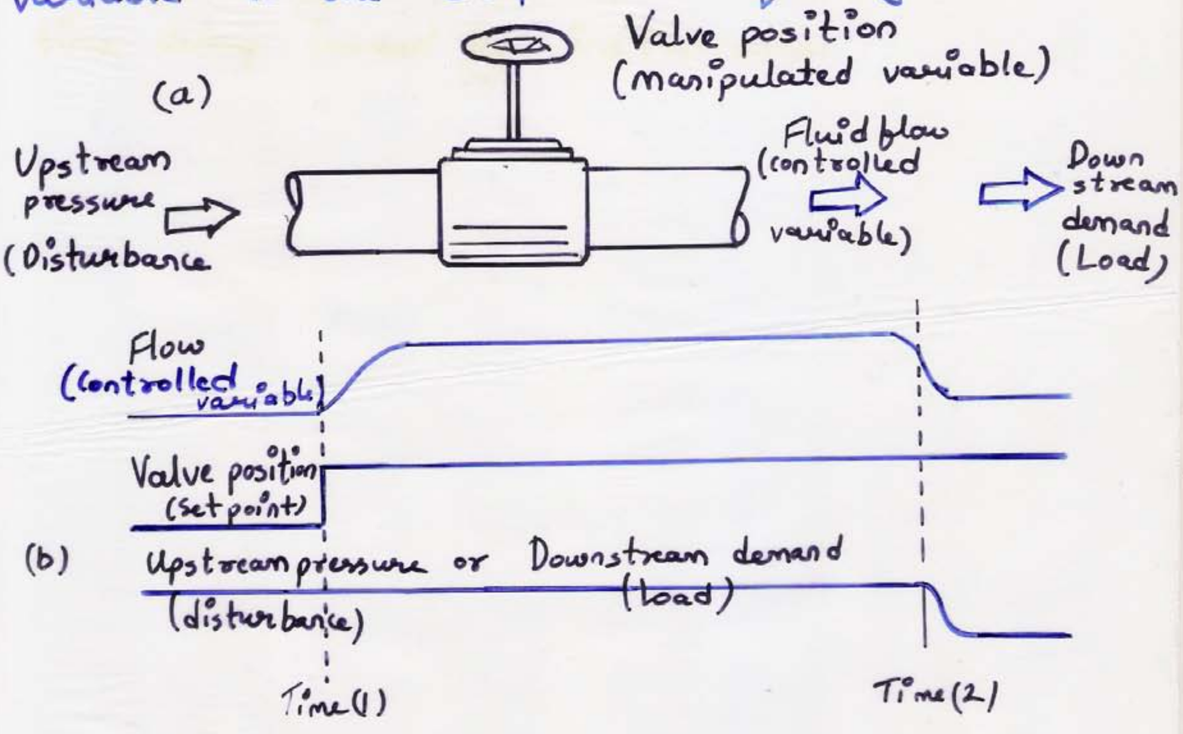


fig (a) A Pipe system
(b) Graphic illustration of process behavior

- Flow of fluid through a pipe system is a the Process.

Response Time of Instruments

- All instruments have a time lag. This is the time duration from when a change is received at its input until the instrument produces an o/p response.
- Time lag also includes the time duration as a signal passes from one instrument to the next.
- The following six factors contribute to the time delay caused by instruments:

  1. Response time of a sensor.
  2. Time lag of the transducer.
  3. The distance the feedback signal must travel from the transducer to the controller.
  4. The time required for the controller to process information.
  5. The distance the control signal travels from the controller to the final contol element.
  6. The time lag of final control element.

Pure Lag of Controlled Variable

- The controlled variable itself may contribute to the reaction time delay of the loop. where is termed as ‘Pure lag’.
- Factors affecting Pure lag time are
  1. Capacity (Physical size) of controlled variable.
  2. Physical properties of controlled variable.
  3. Chemical properties of controlled variable.

One common method used to analyze the pure lag of a controlled variable is to introduce a step change and observe the results.

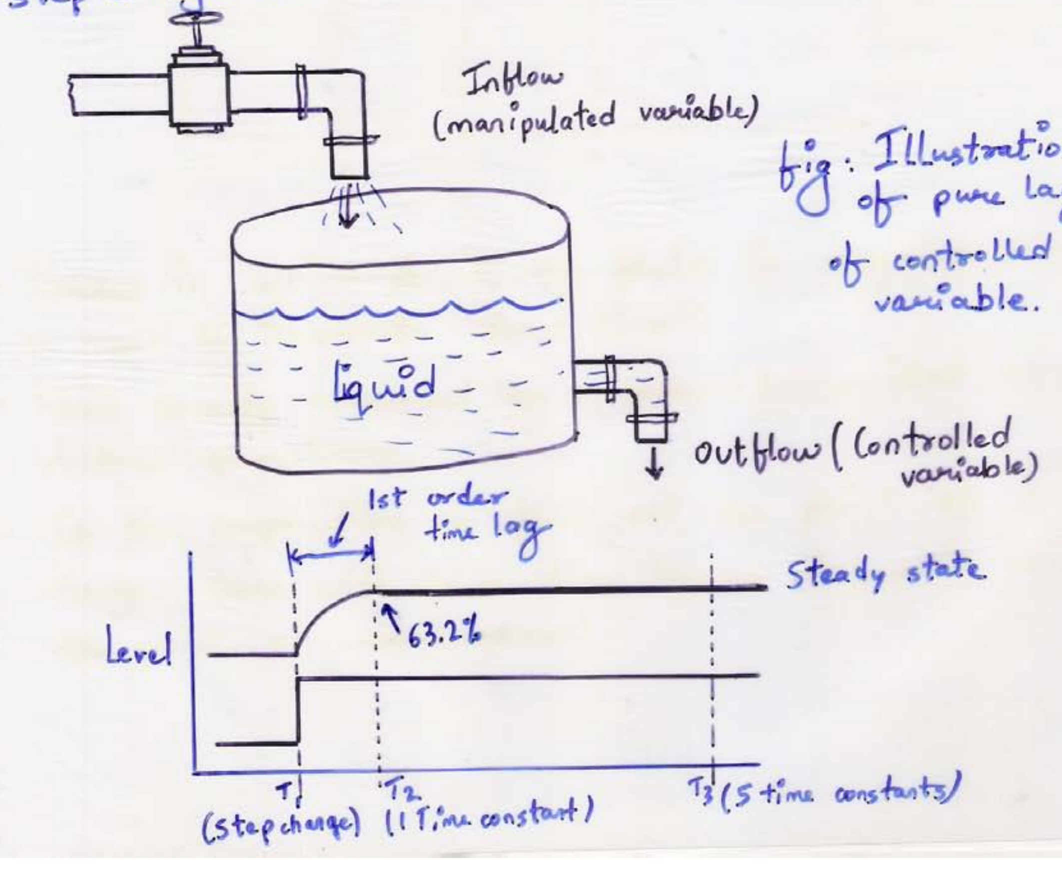


fig: Illustration of pure lag of controlled variable.