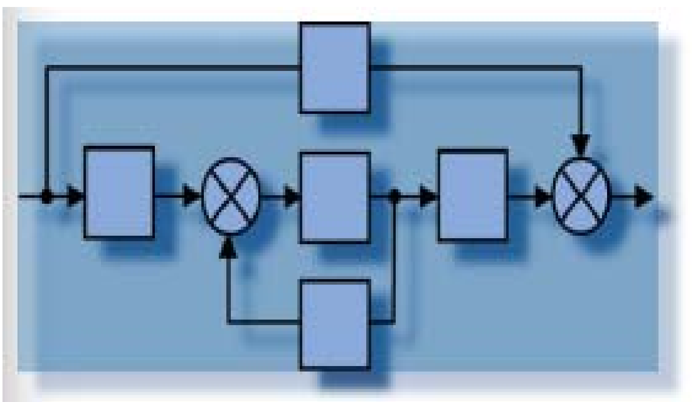
Pakistan Engineering Council
Islamabad

Fundamentals of Process Control Systems



Lecture -1

Prof. Dr. Shahid Naveed

Sequence of Presentation

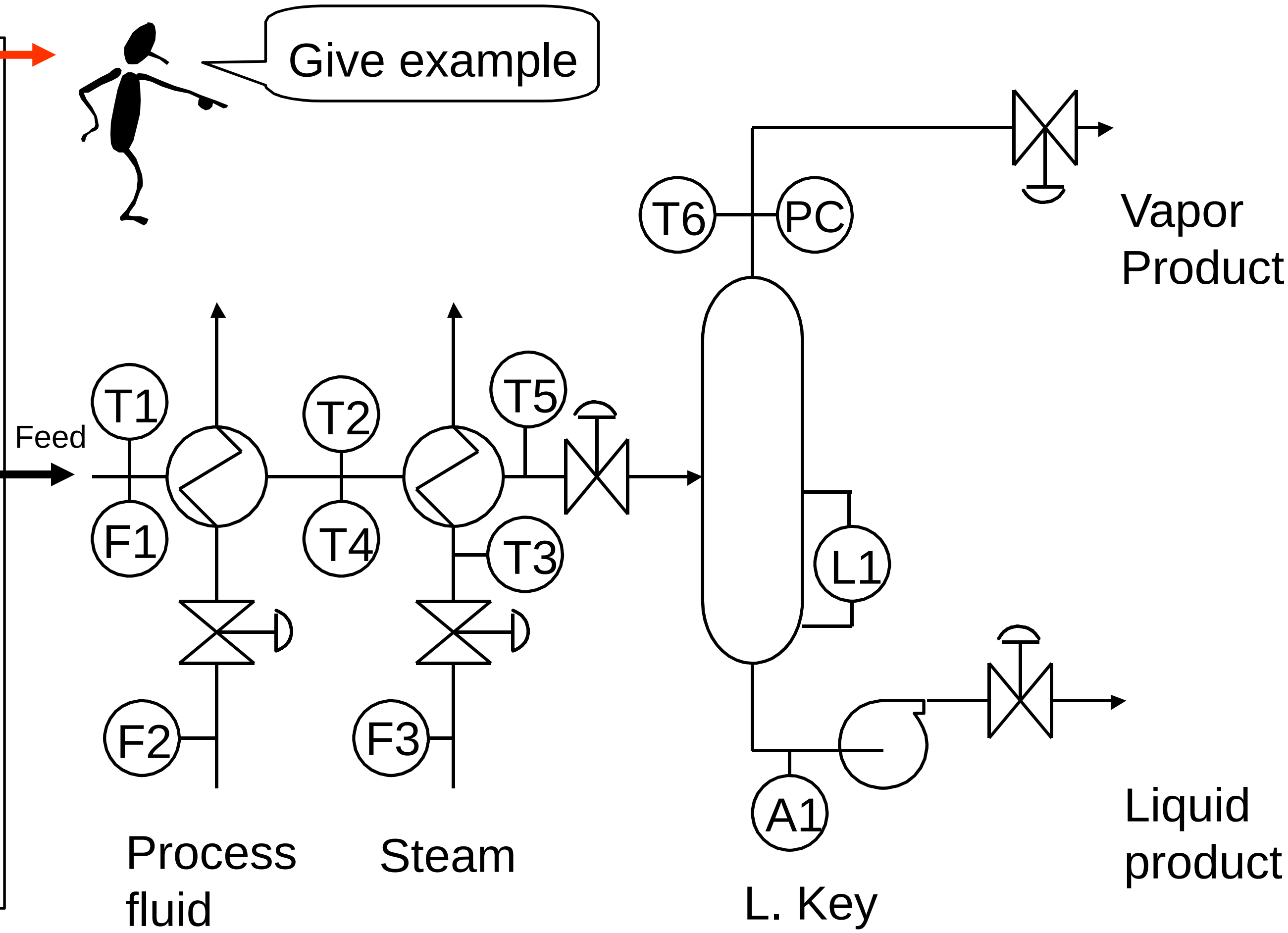
1. Why Process Control?
2. What to Control?
3. Role of Sensors and Instruments
4. Modes Of Control Systems
5. Basics of Feedback Control Systems
6. Examples of Servo Control Systems
7. Conclusions

1. Why Process Control ?

1. Safety of Equipment and Personnel
2. Productions Specification of quality & quantity
3. Operational Constraints
4. Observe Environmental and Country Laws
5. Economics

Control Objectives

1. Safety of Equipment & personnel
2. Production Specification of quality & quantity
3. Operational Constraints
4. Environmental Regulations
5. Economics



Safety of Equipment & Personnel

1. Safety of Equipment & personnel
2. Production Specification of quality & quantity
3. Operational Constraints
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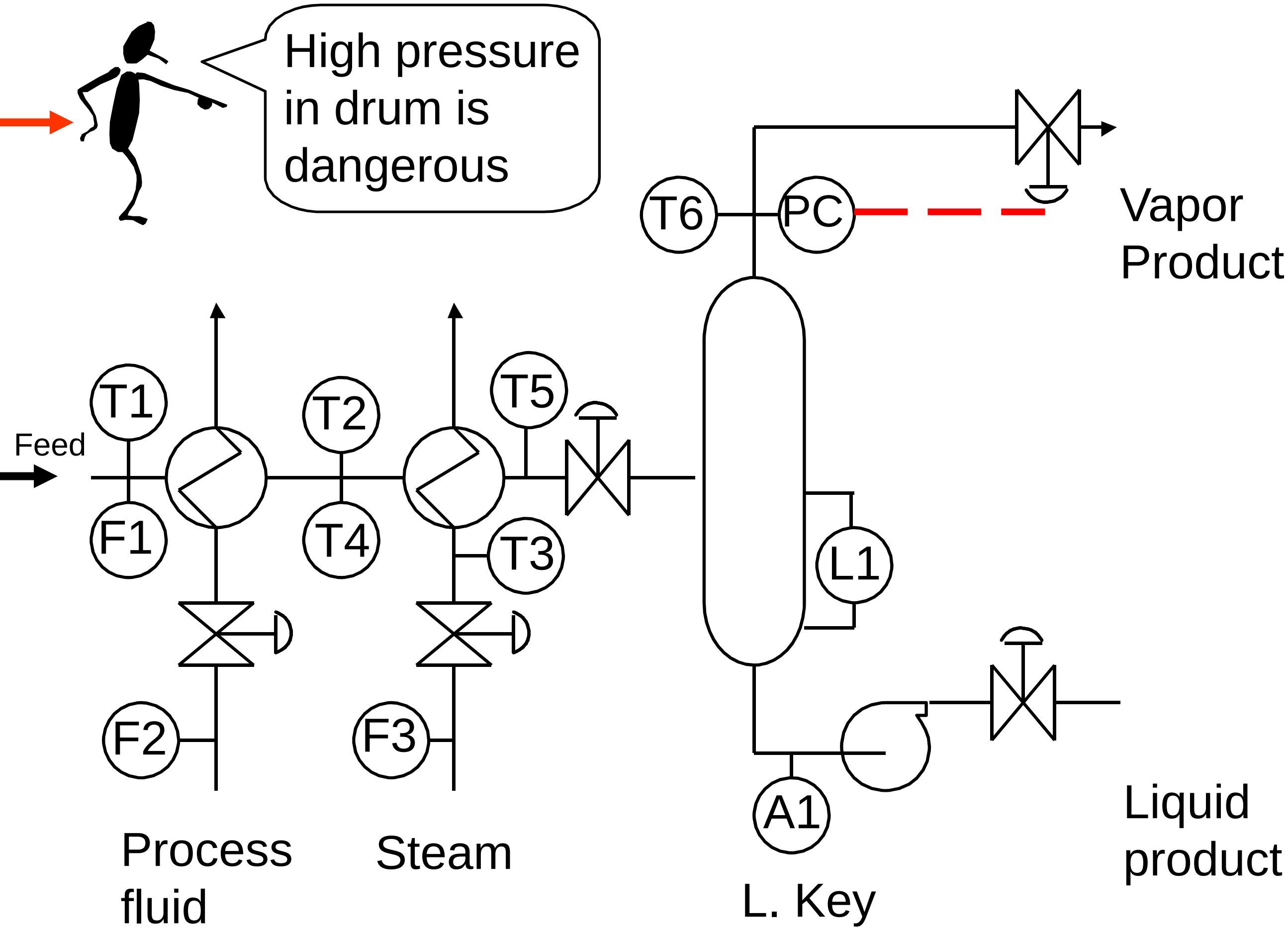
5. Economics



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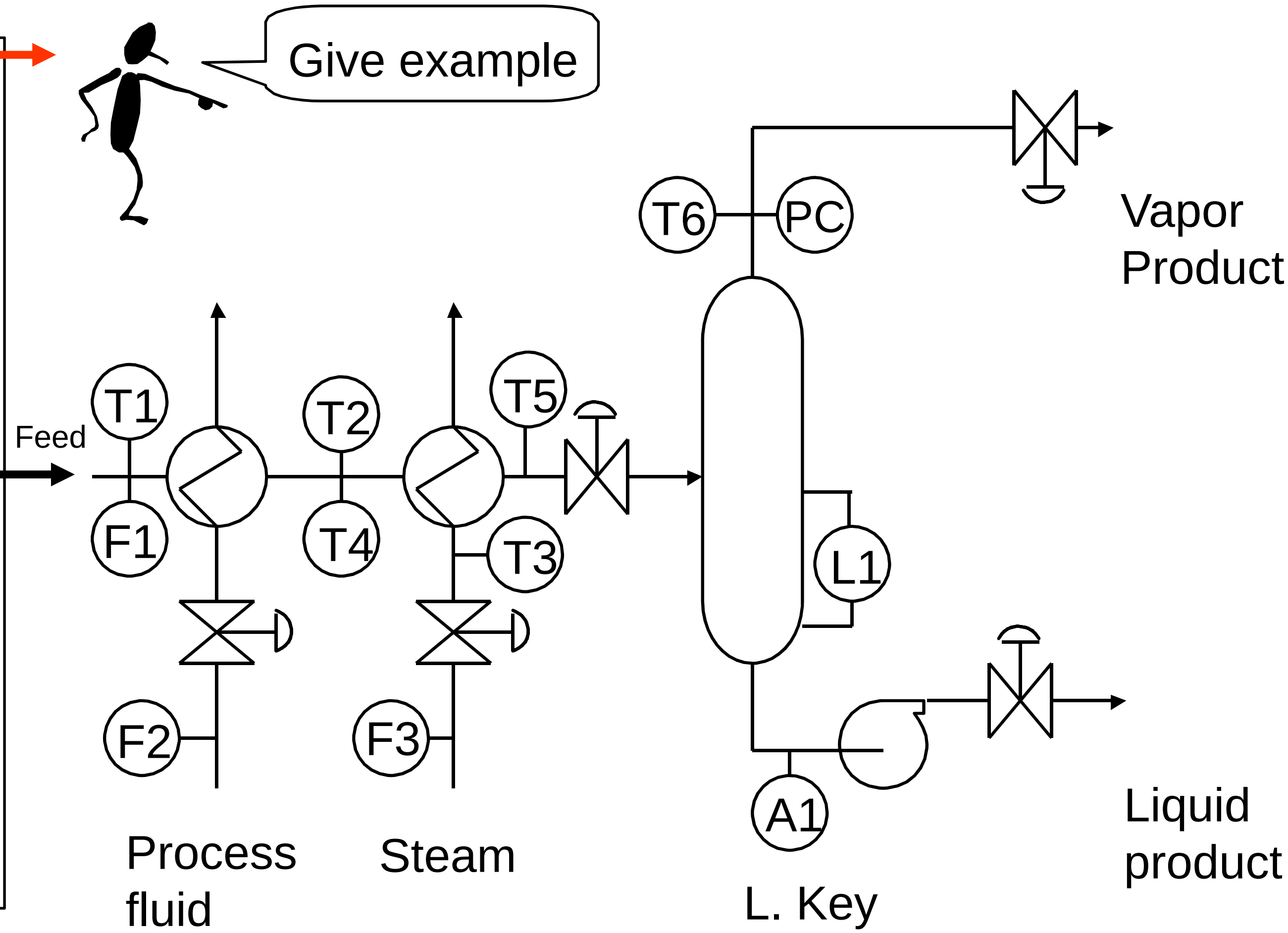
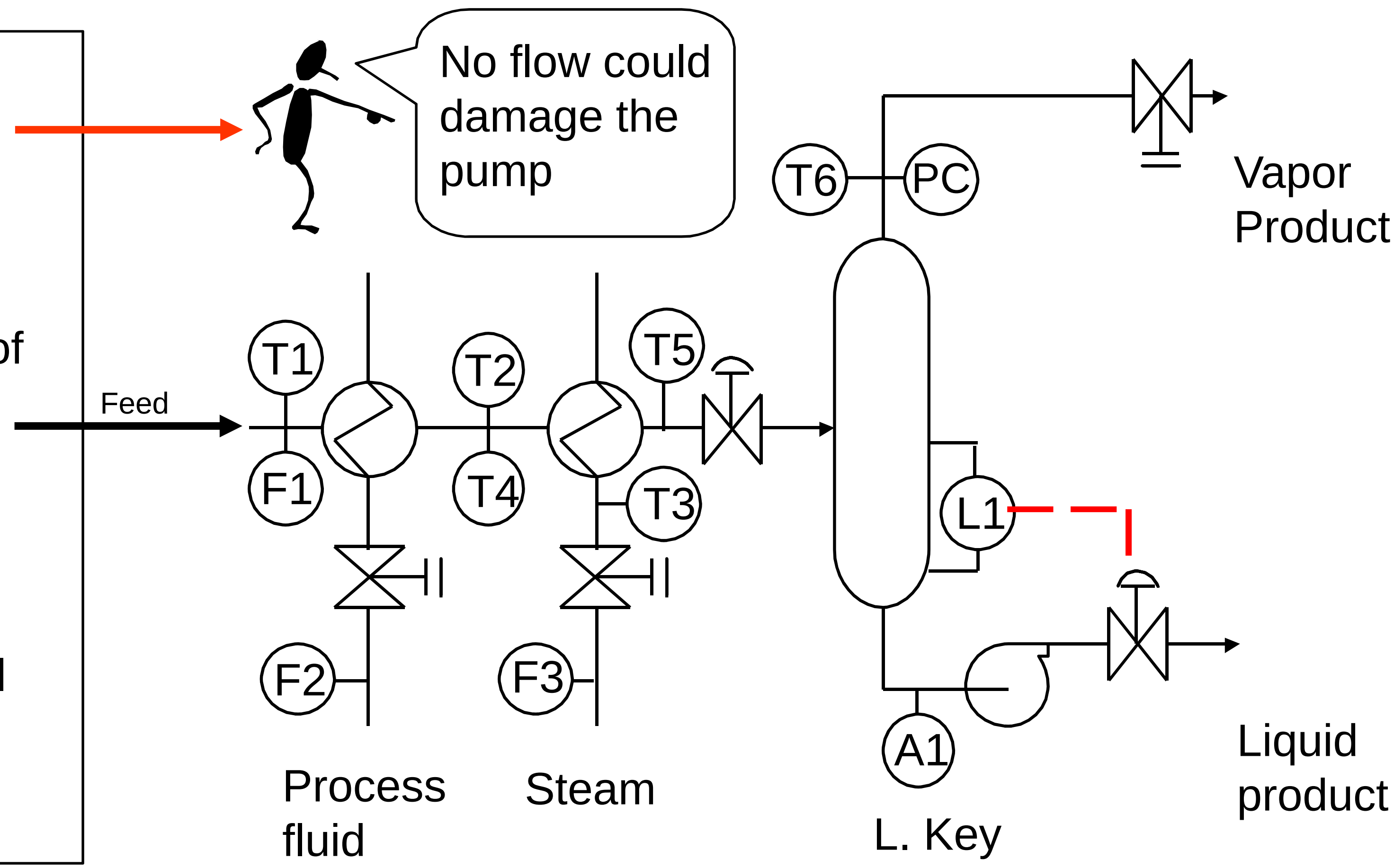


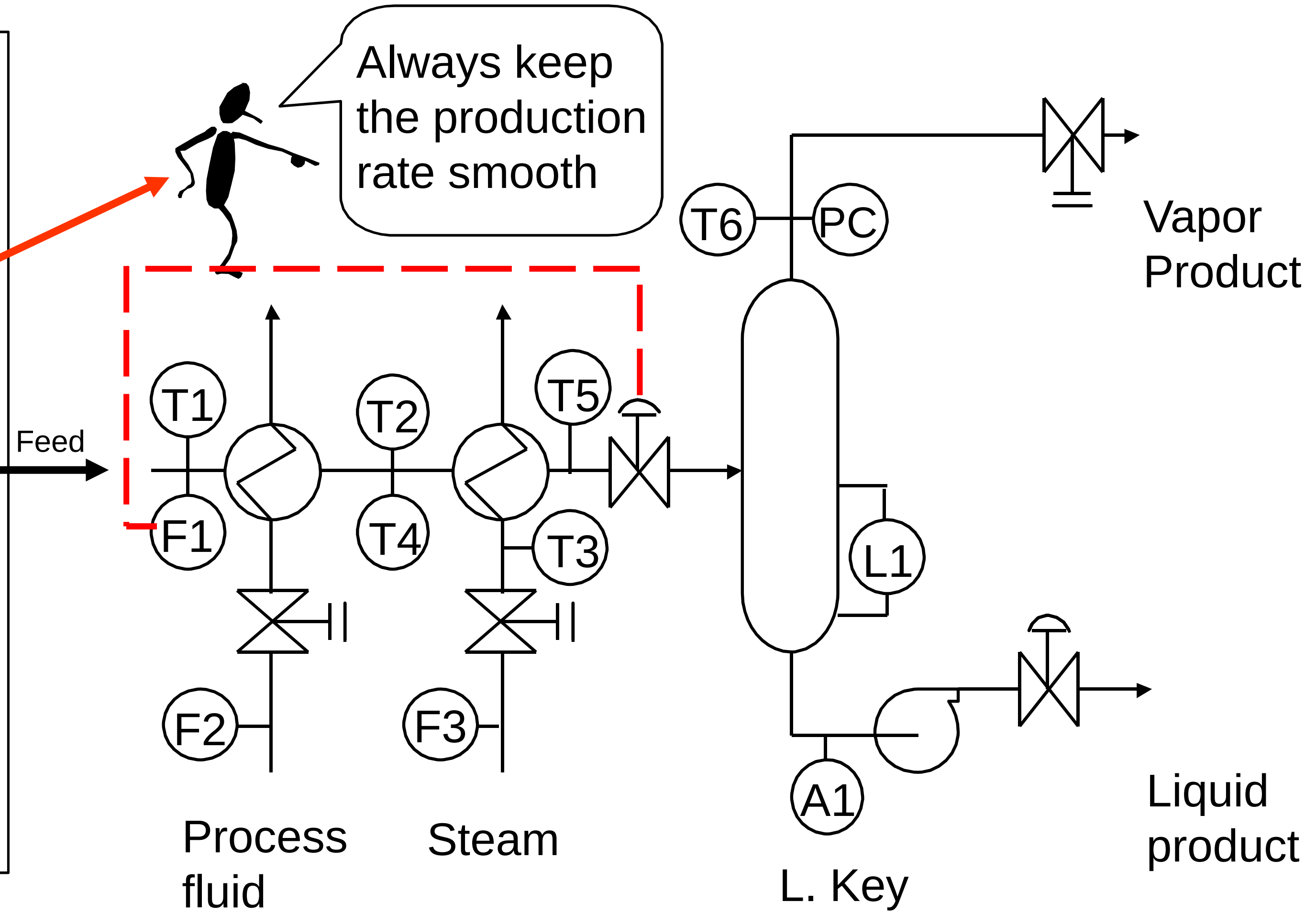
Safety of Equipment

1. Safety of Equipment & personnel
2. Production Specification of quality & quantity
3. Operational Constraints
4. Environmental Regulations
5. Economics



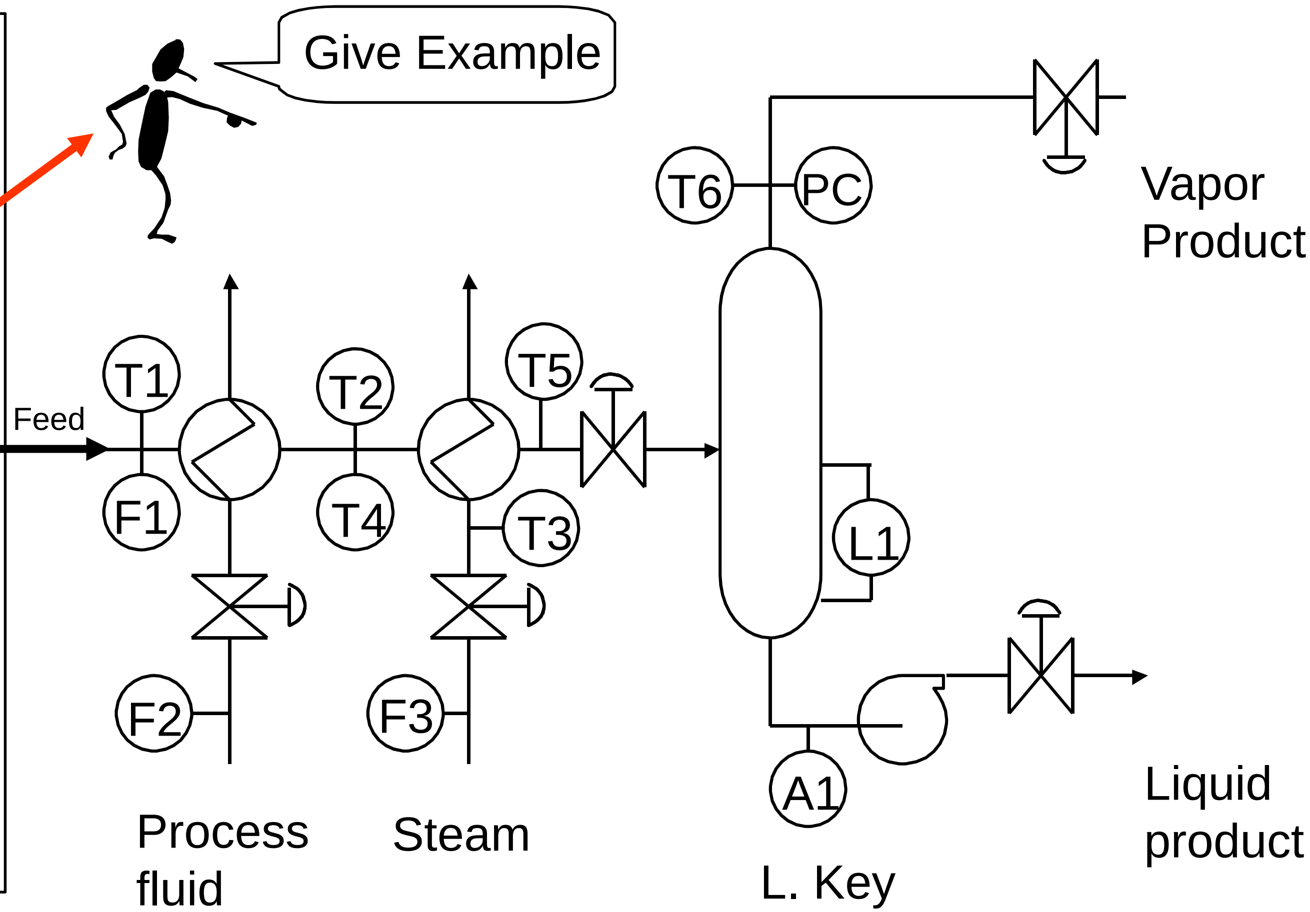
Smooth Production Rate

1. Safety of Equipment & personnel
2. Production Specification of quality & quantity
3. Operational Constraints
4. Environmental Regulations
5. Economics



Quality Assurance

1. Safety of Equipment & personnel
2. Production Specification of quality & quantity
3. Operational Constraints
4. Environmental Regulations
5. Economics



Quality Assurance

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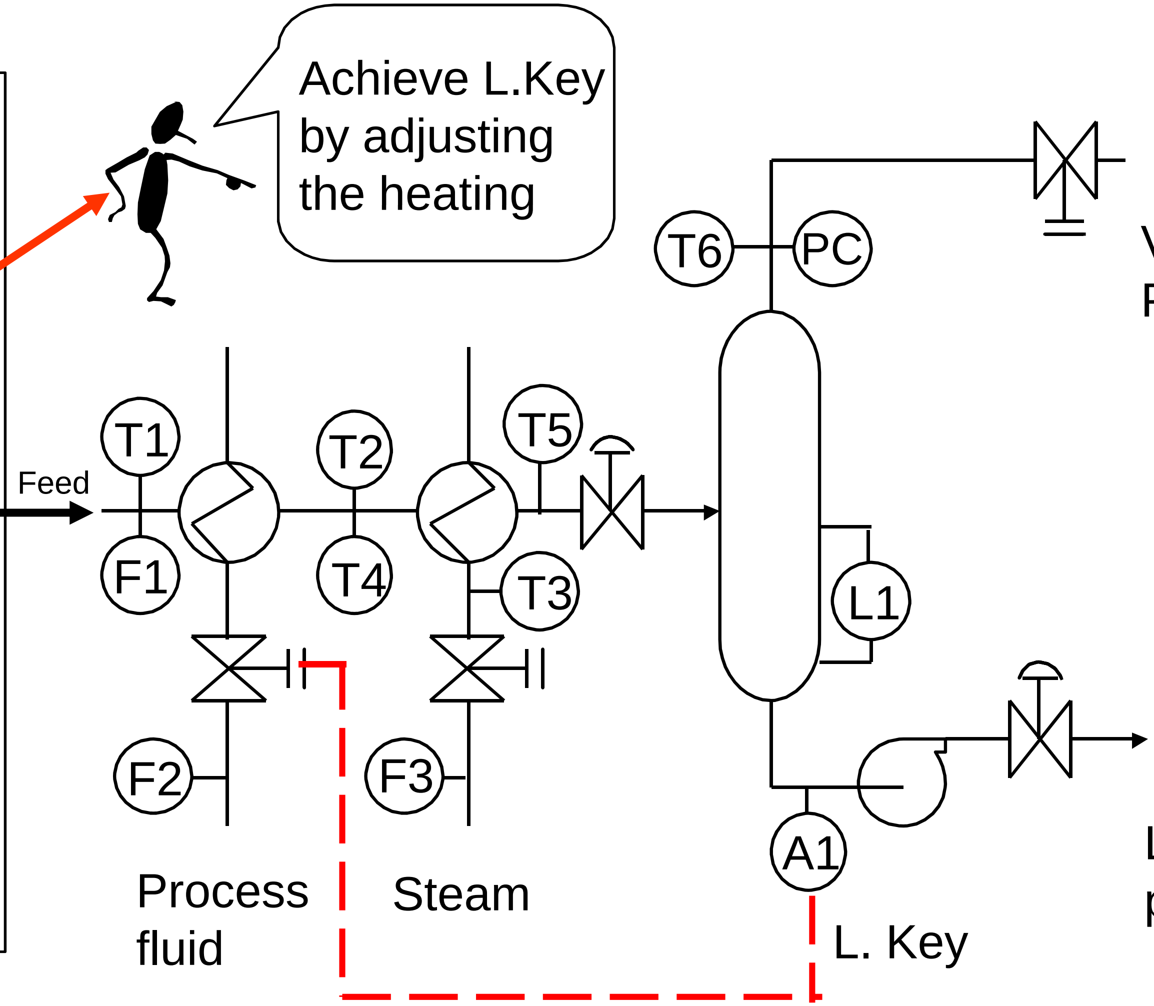
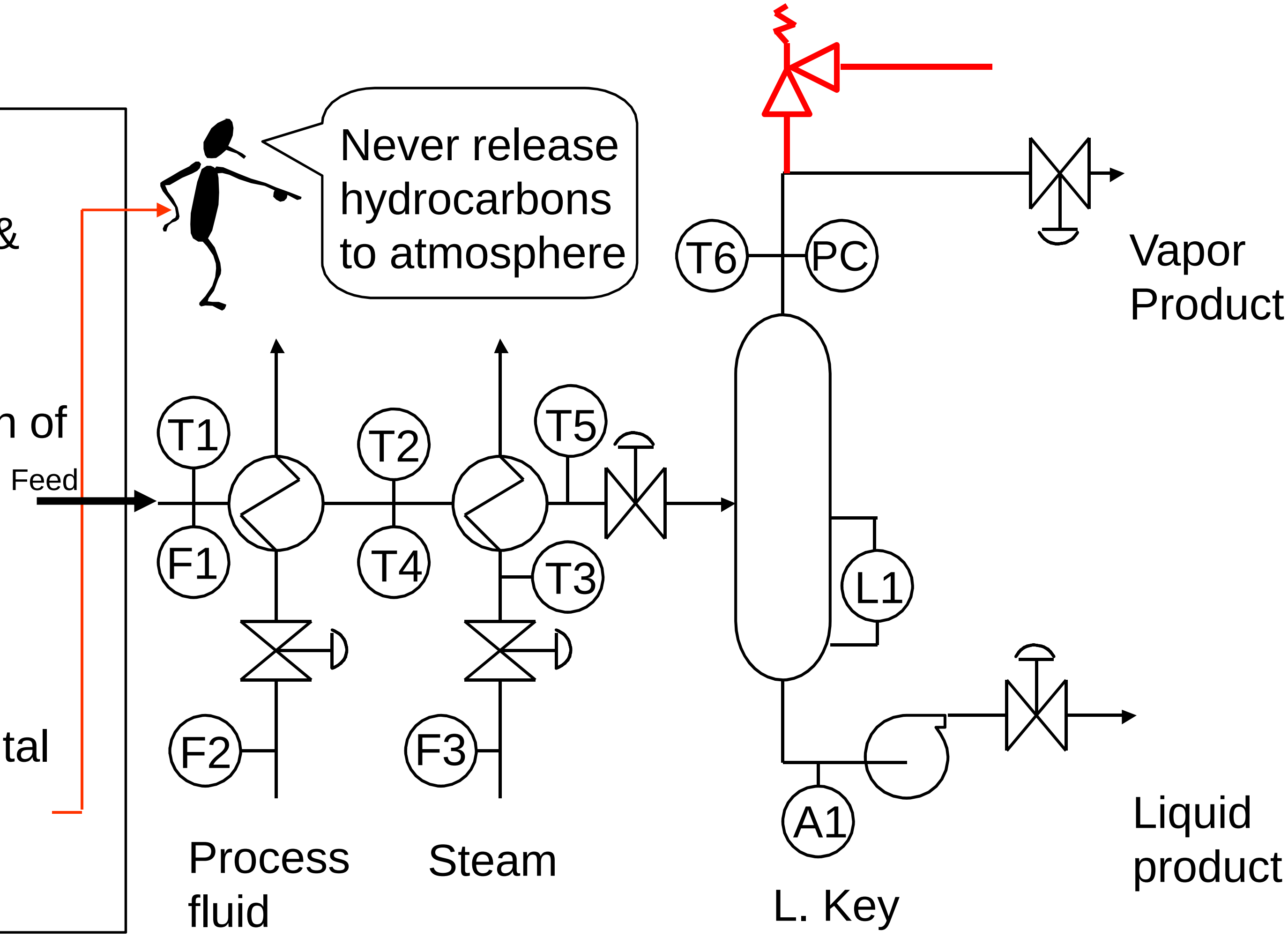


Observe Environmental and Other Regulations

1. Safety of Equipment & personnel
2. Production Specification of quality & quantity
3. Operational Constraints
4. Environmental Regulations
5. Economics



Economics

1. Safety of Equipment & personnel
2. Production Specification of quality & quantity
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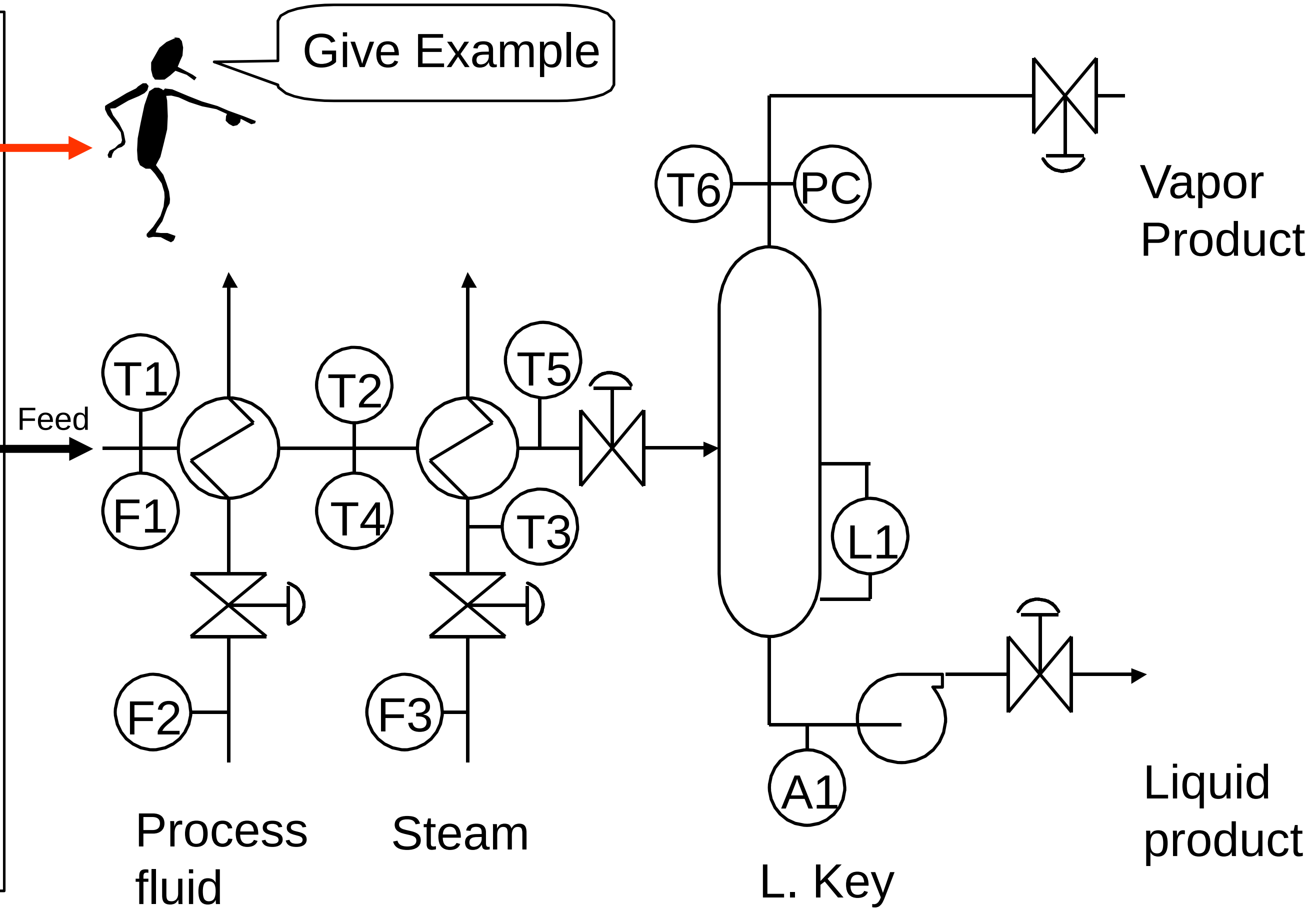

Economics

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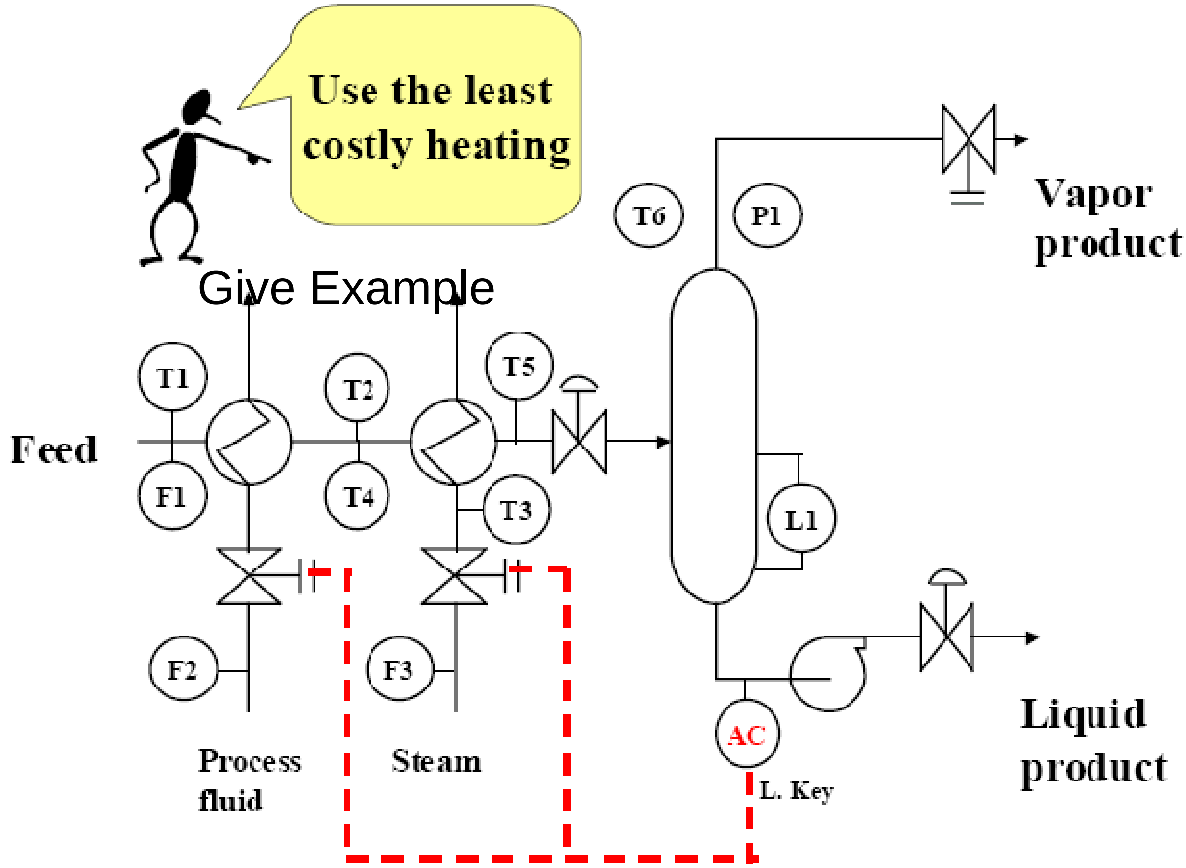


2. What to Control ?

1. The Influence of External Disturbances *(Suppress Them)*

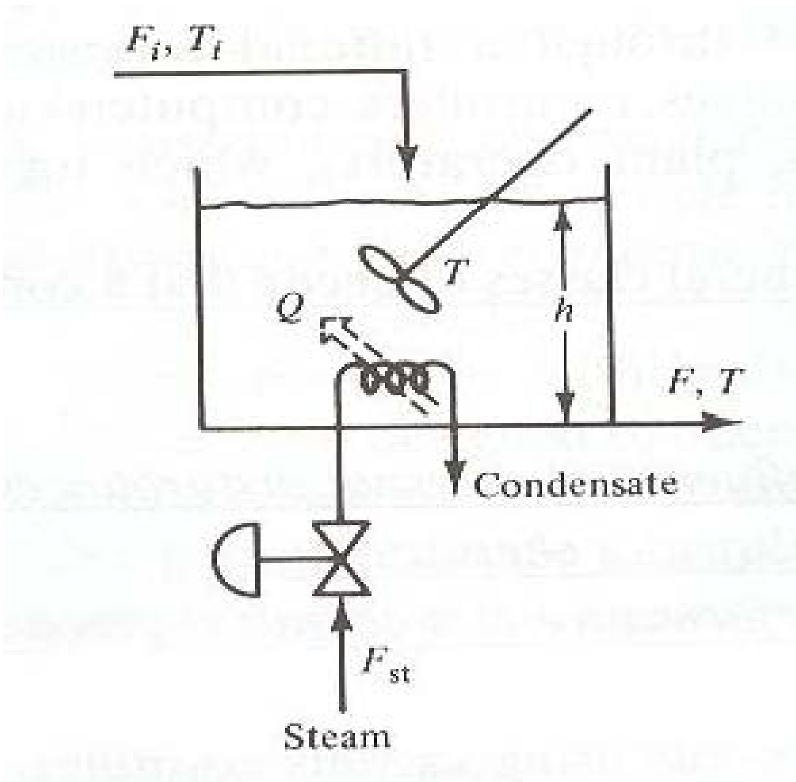
2. Ensure Stable Operation

   (Avoid Unsteady State)

3. Optimized Operation

   (Control Operating Costs)

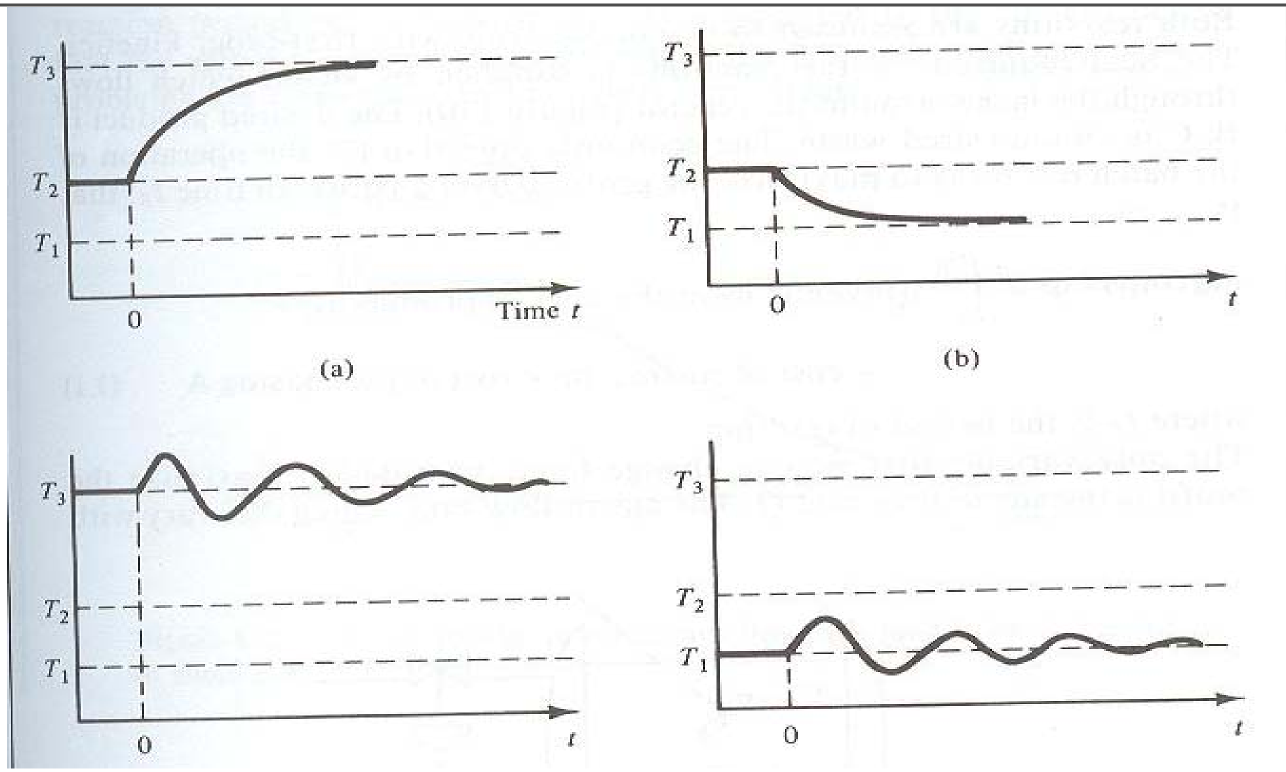
Suppress the Influence of External Disturbances

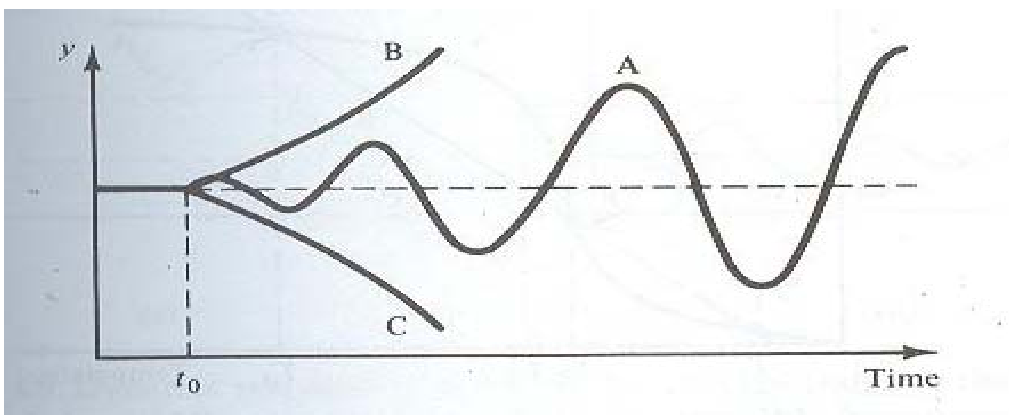


Disturbances?

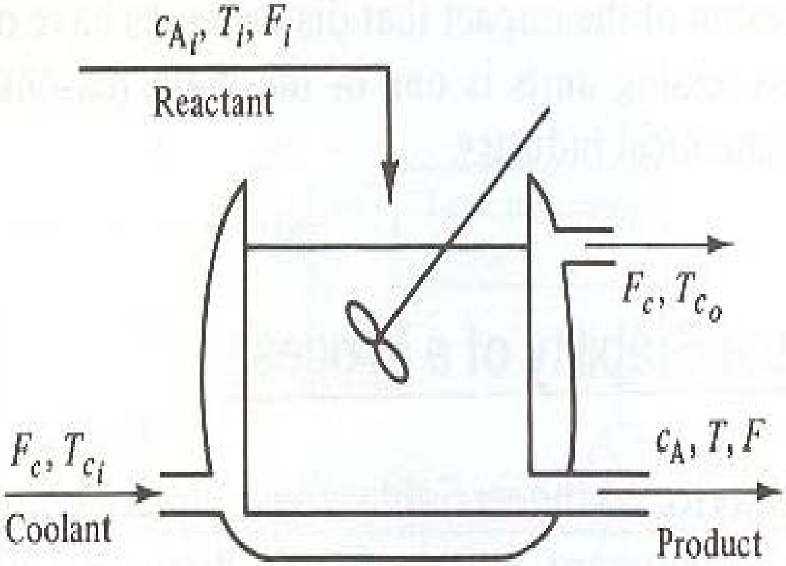
1. To keep the effluent temperature T at a desired value T_s
2. To keep the volume of the liquid in the tank at a desired value V_s

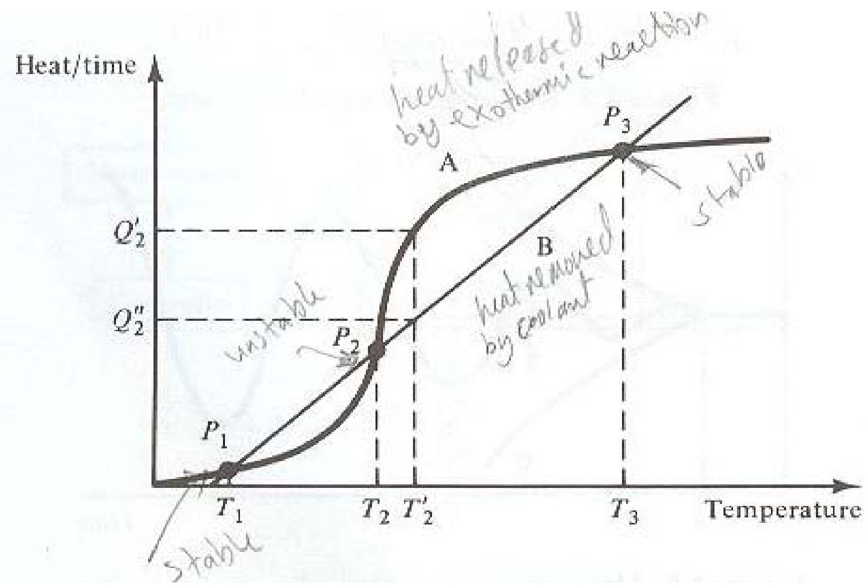
Ensure Stable Operation



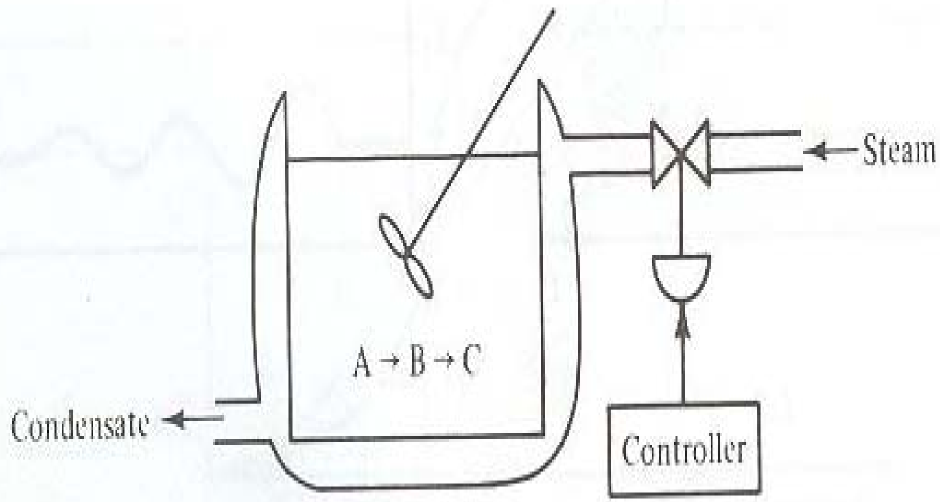


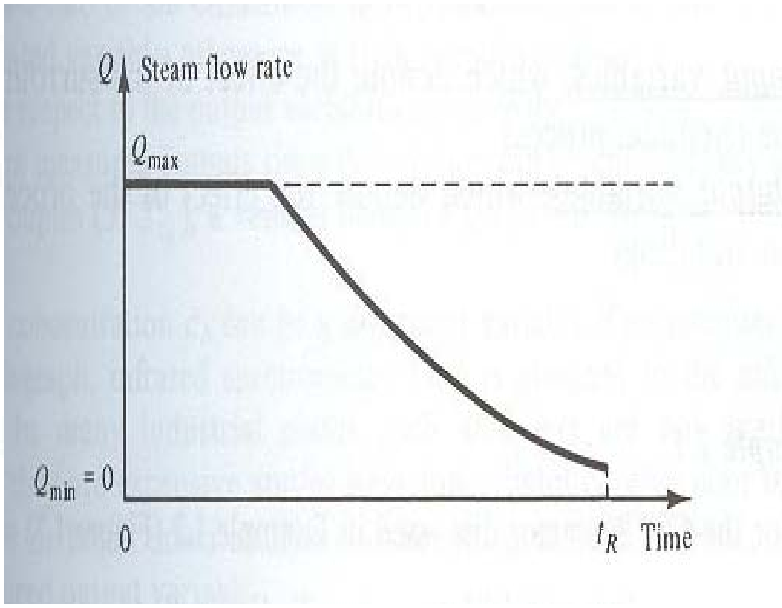
Ensure Stable Operation (cont'd)





Optimized Operation (online)

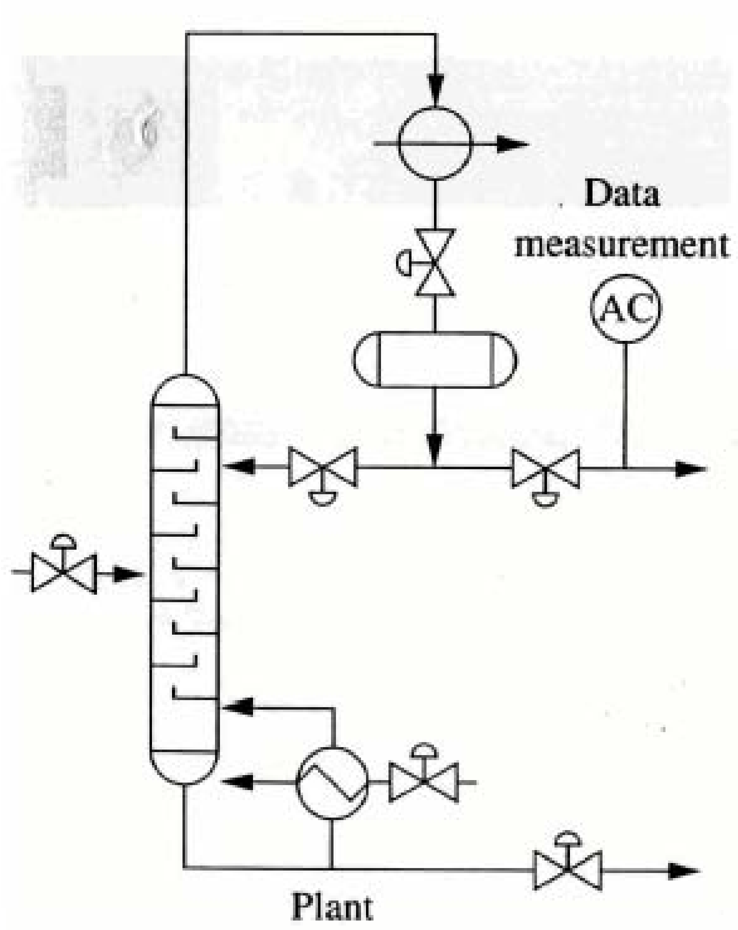


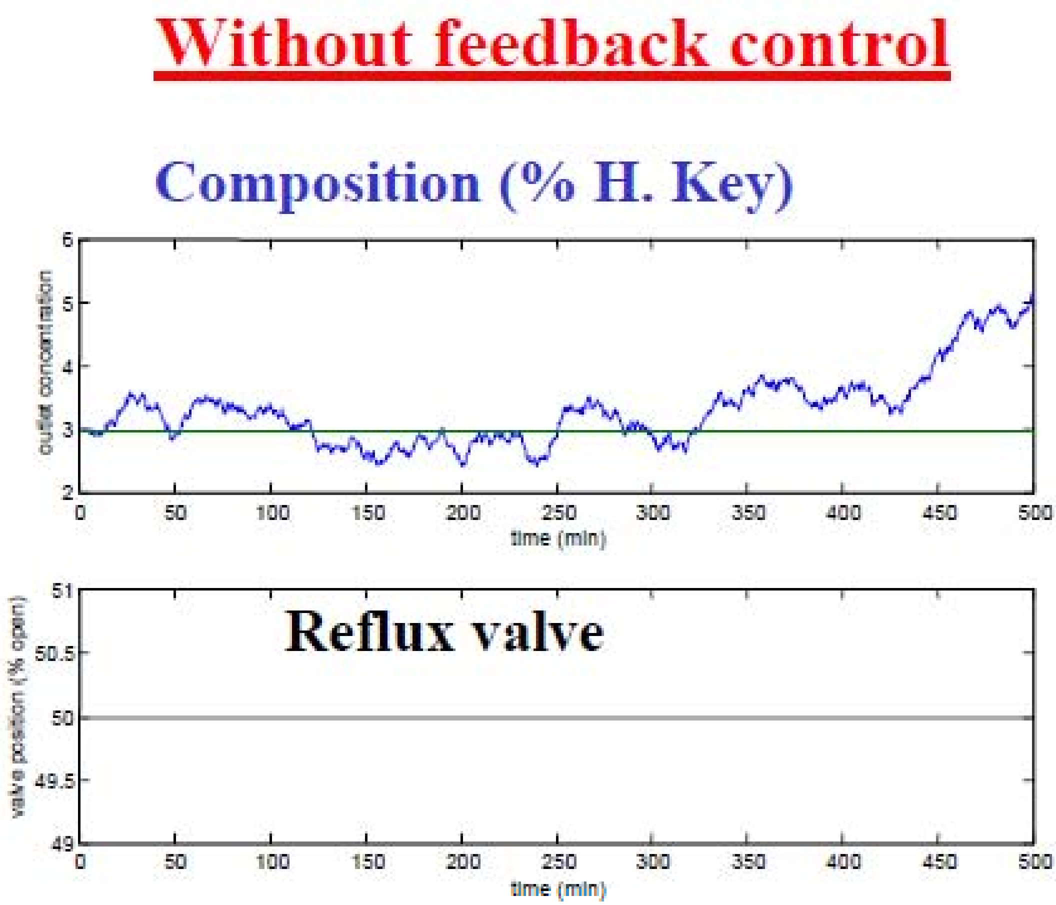


$$\text{maximize } \Phi = \int_0^{t_R} \{[\text{revenue from the sales of product B}] - $$
$$+ \text{cost of steam}\}\ dt + \text{cost of purchasing A}$$

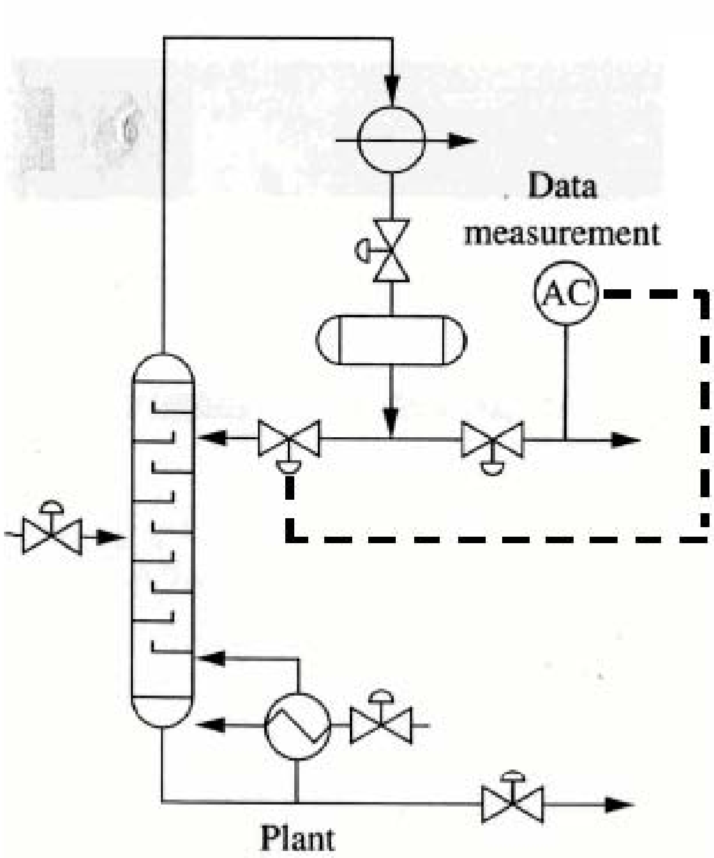
Potential Stochastic Gains through effective Process Control

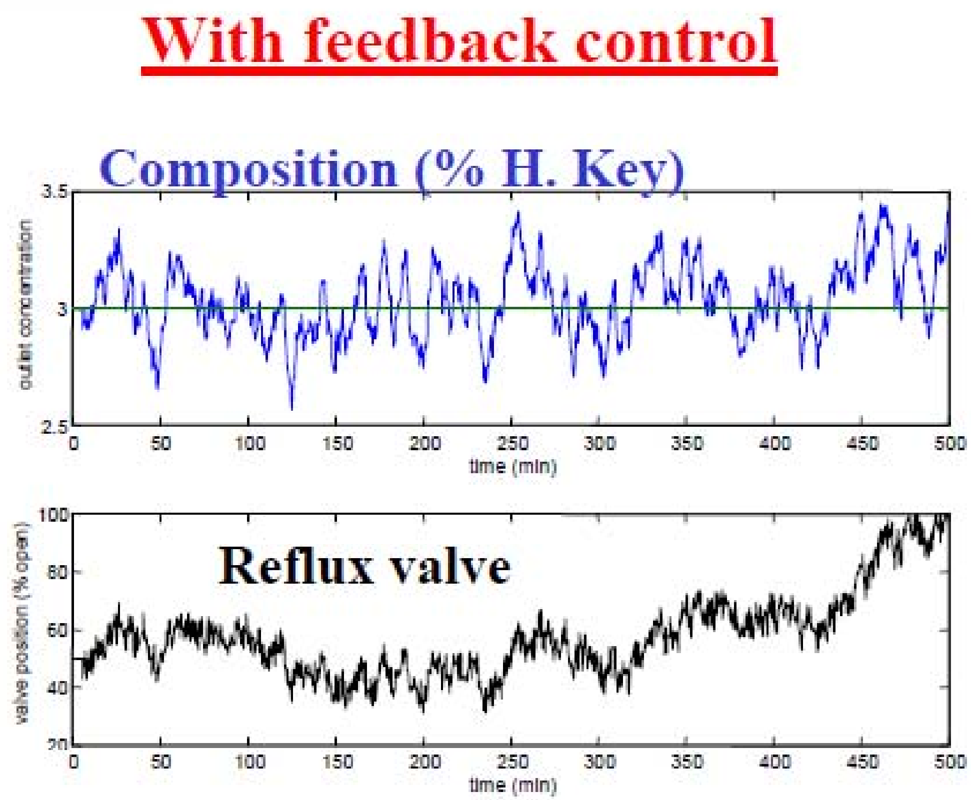
When we control a process, we reduce the variability.





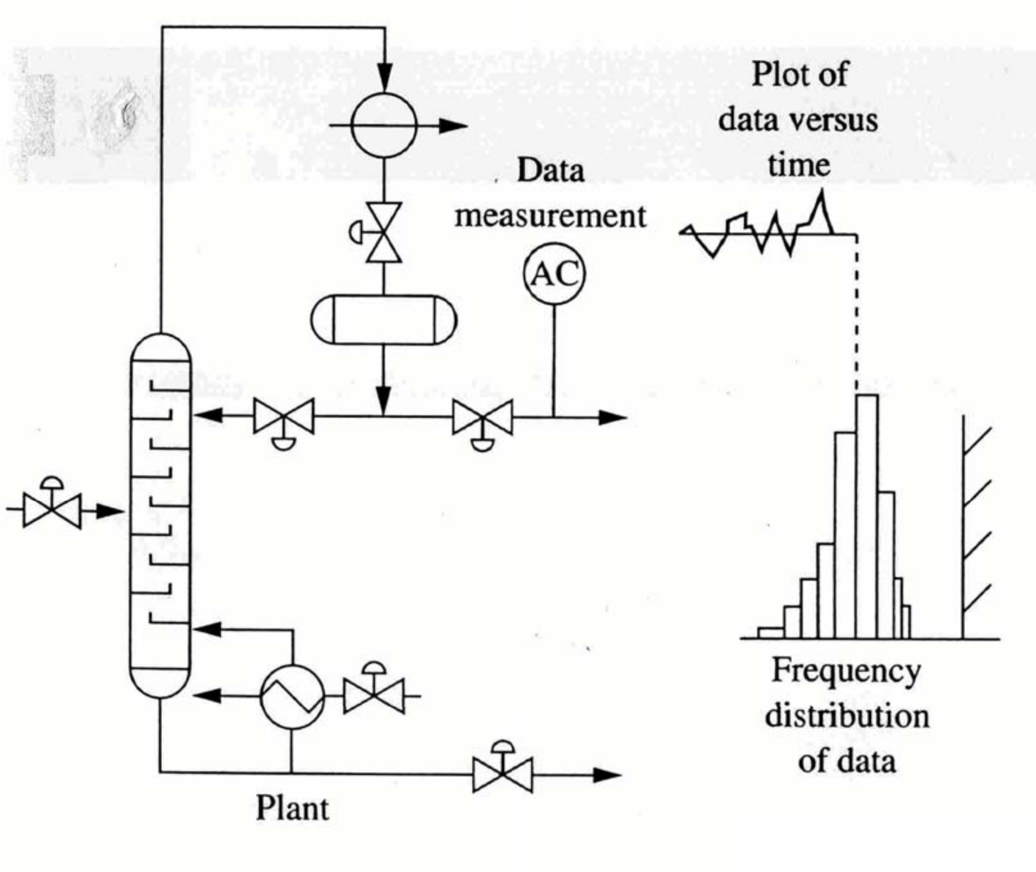
Potential Stochastic Gains through effective Process Control (Cont'd)



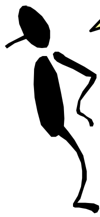


Variability is moved from controlled to manipulated variable!

Potential Stochastic Gains through effective Process Control (Cont'd)

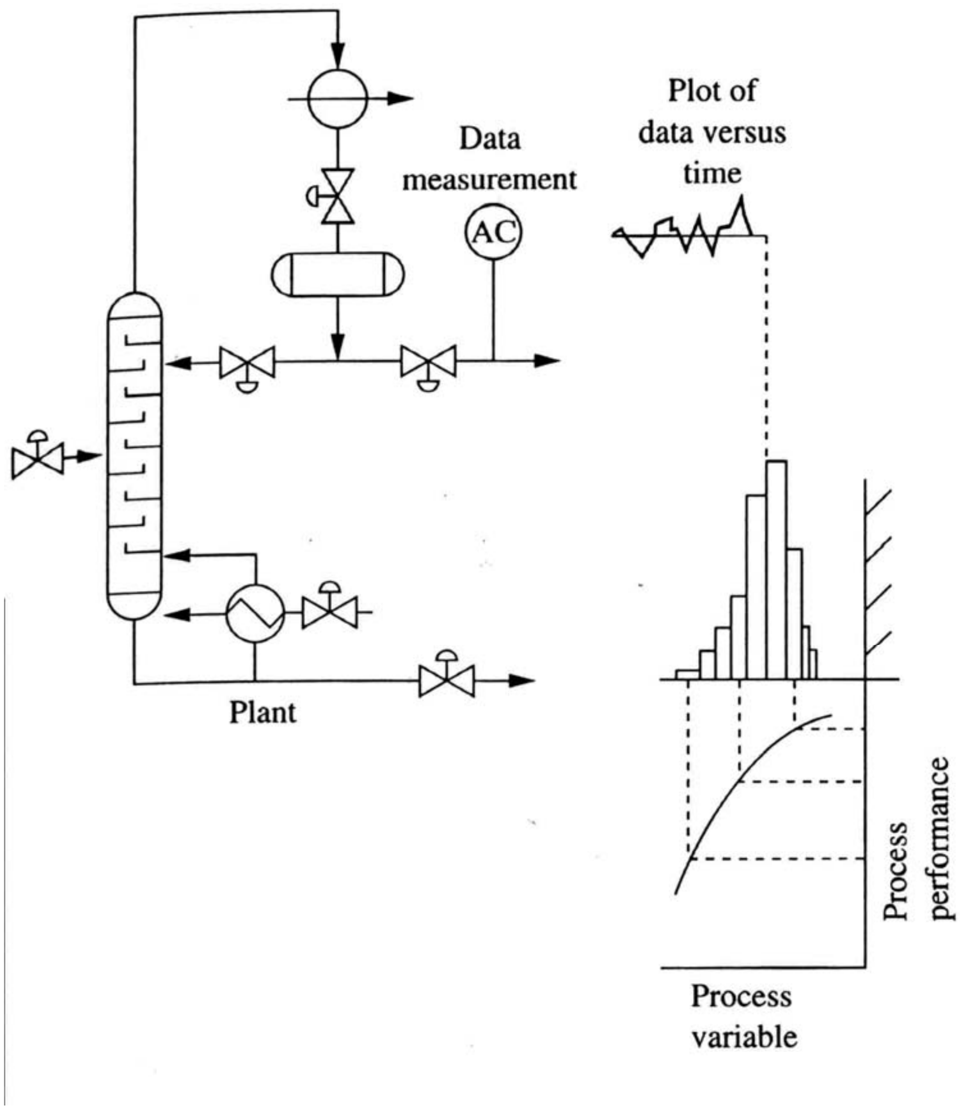


What statistics can we calculate from this data?



How do we relate variability to process performance?

Potential Stochastic Gains through effective Process Control (Cont'd)



Process performance efficiency, yield, production rate, etc. It measures performance for a control objective.

Calculate the process performance using the distribution, not the average value of the key variable!

3. Role of Sensors and Instruments

A typical instrument has three components:

- A Sensor
- A Modifier
- A Display (Or transmitting arrangement)

Sensors *feel* the condition and originate the signal followed by modification and amplification for effective display or transmission.

Comment on Sensors and Instruments

- Instruments are the eyes of engineer/ operator that can see & feel the intense process variable inside the vessels

- Accordingly the measurements should be reliable and as close to actual condition as possible with reasonable costs.

- Process control go hand in hand

  "If you cannot measure you cannot control!"

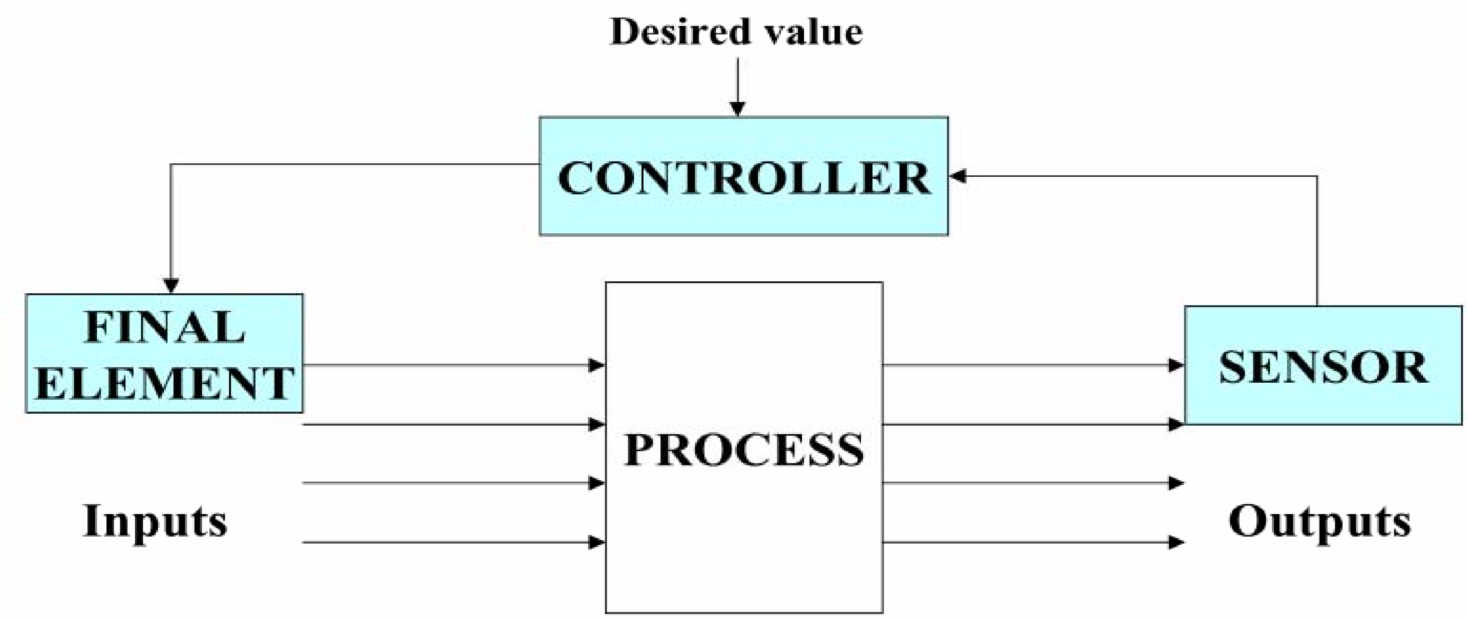
4. Modes of Control Systems

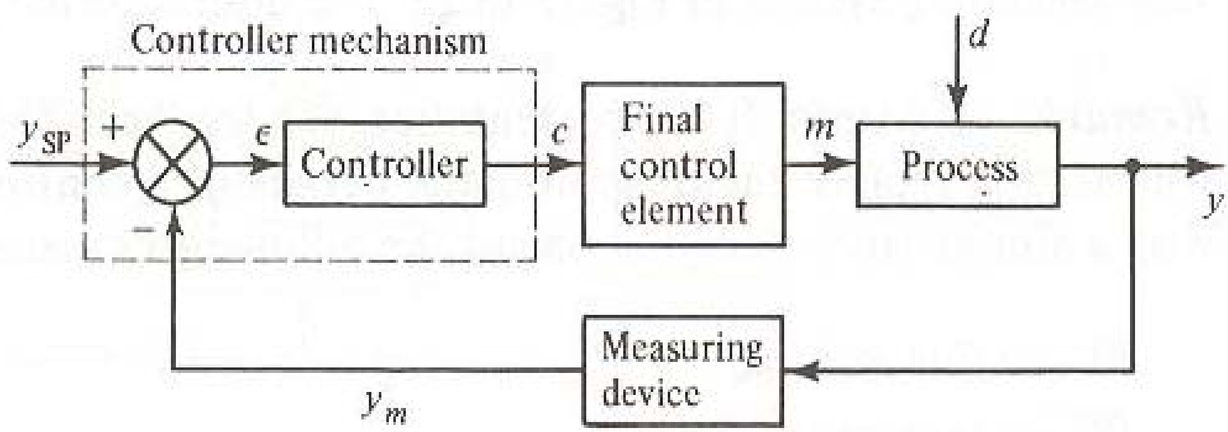
- Feedback Control Systems (Regulatory)
- Feedforward Control Systems(Servo, Tracking)
- Sequential Control System
- Distributed
- Integrated

Modes of Implementation

- Pneumatic
- Electronic
- Digital

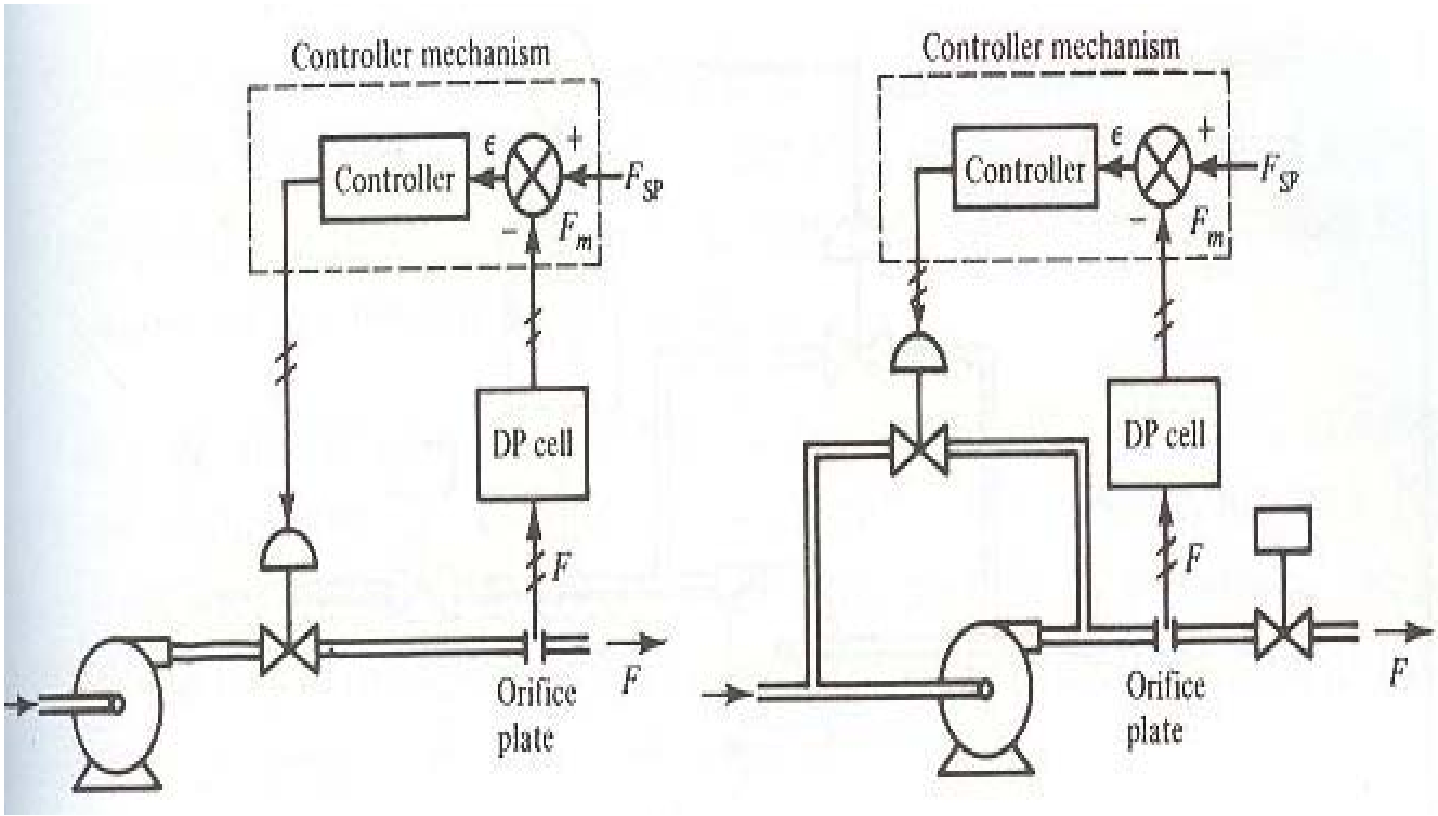
Basics of feedback control system





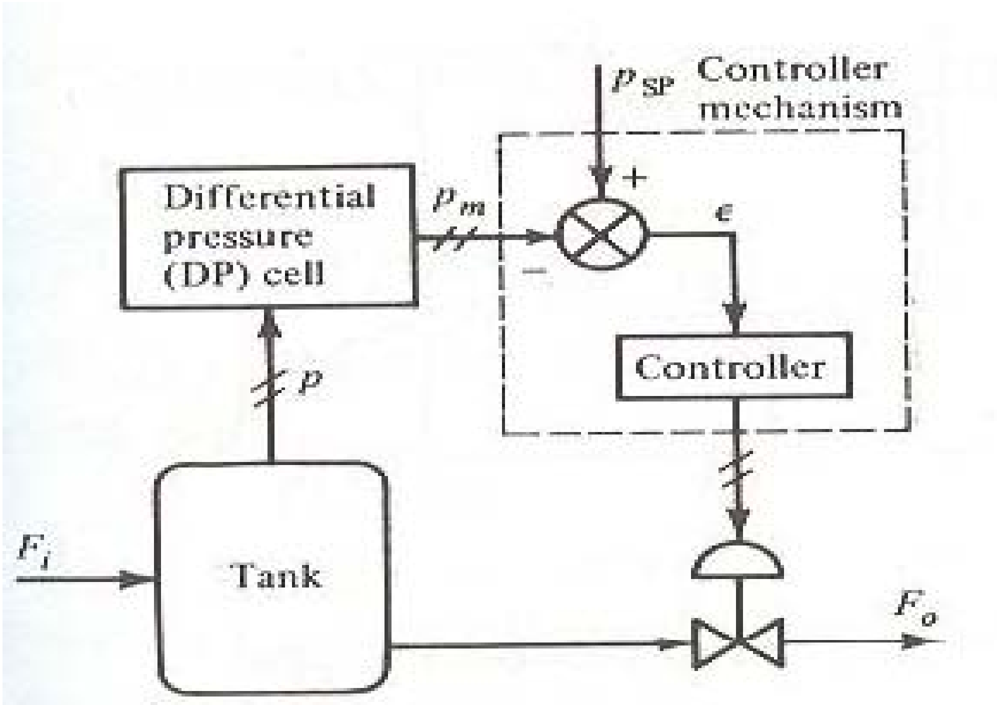
Examples of feedback system

FC for flow control



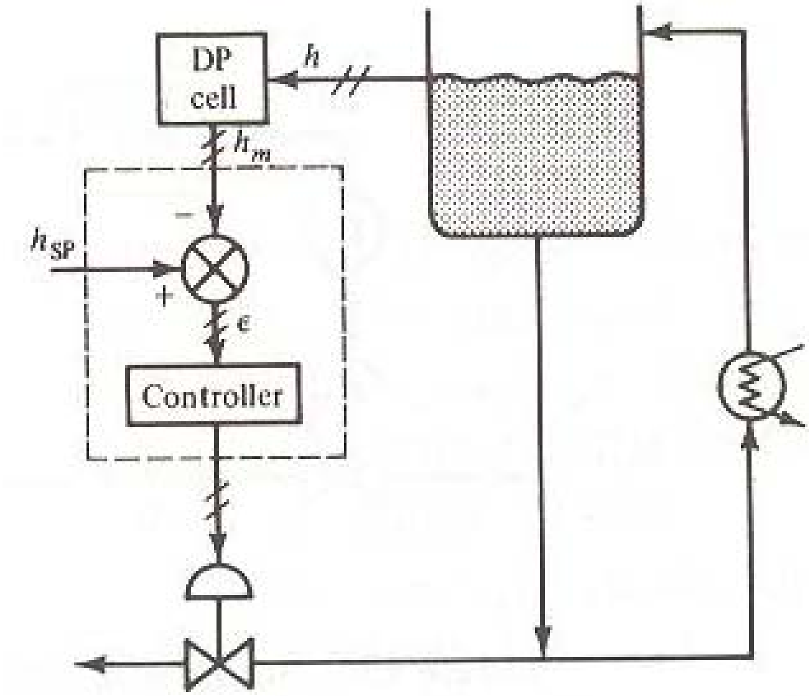
Examples of feedback system

PC for pressure control



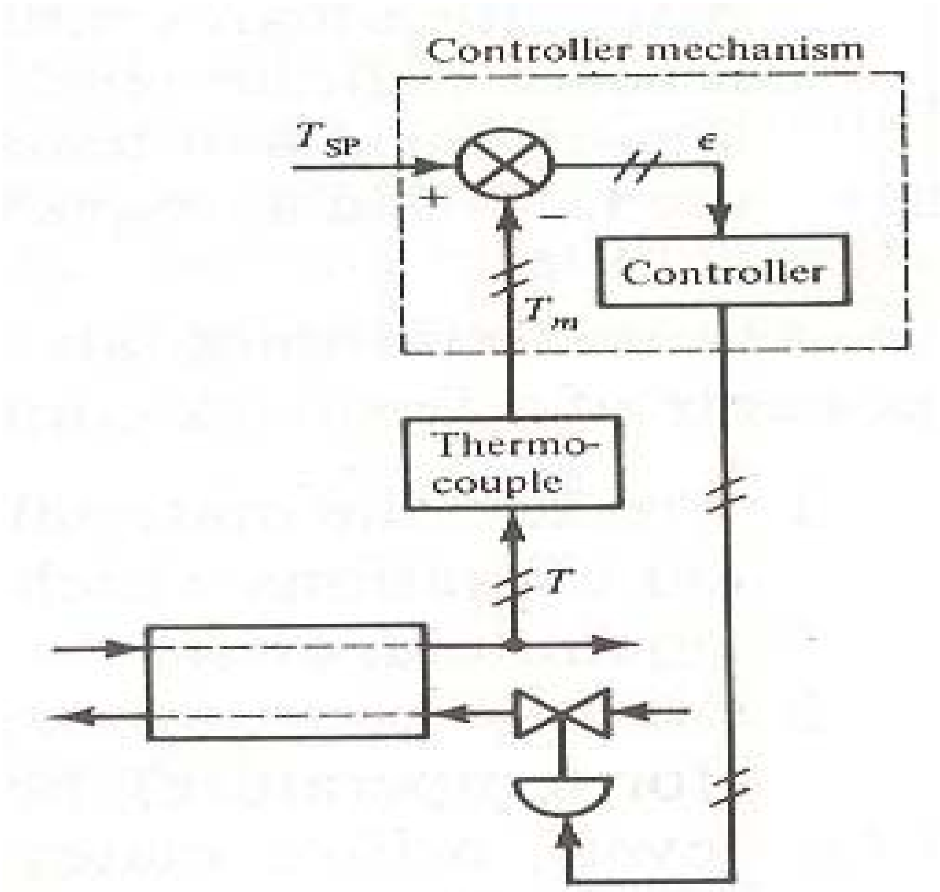
Examples of feedback system

LC for liquid-level control



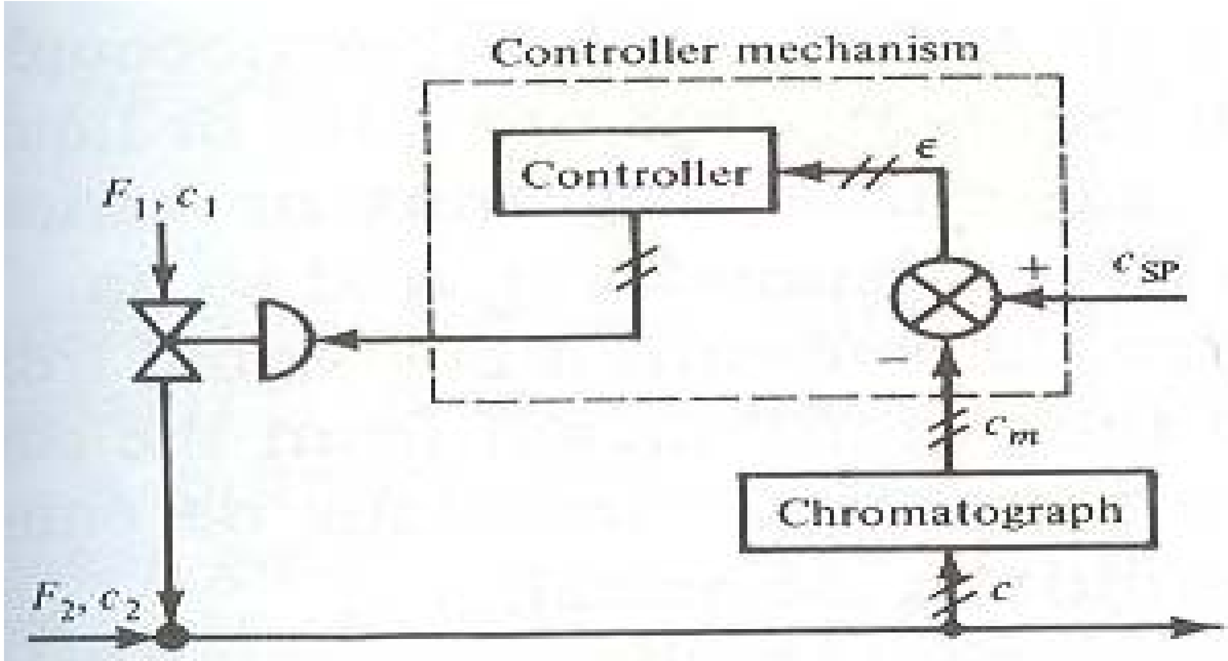
Examples of feedback system

TC for temperature control

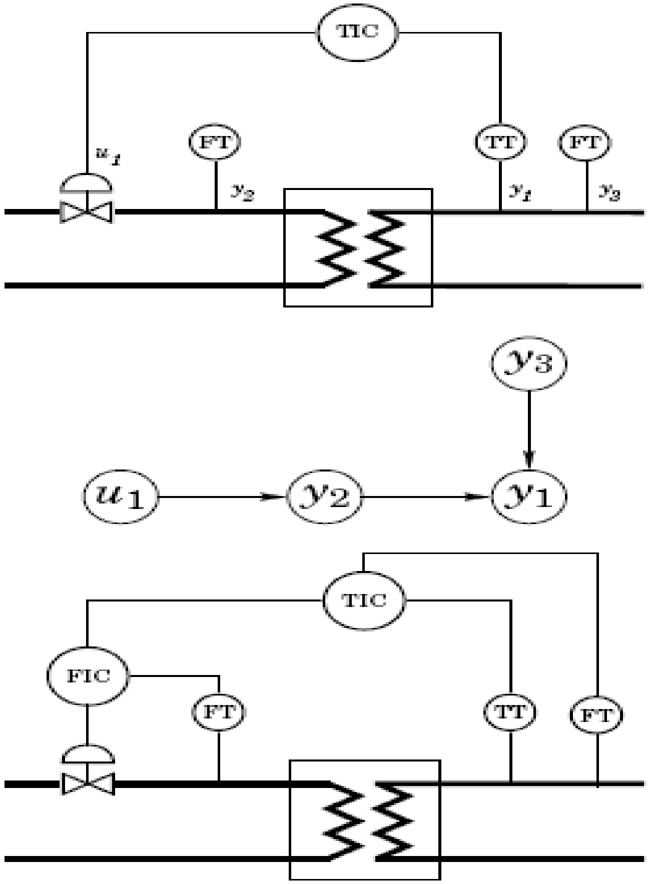


Examples of feedback system

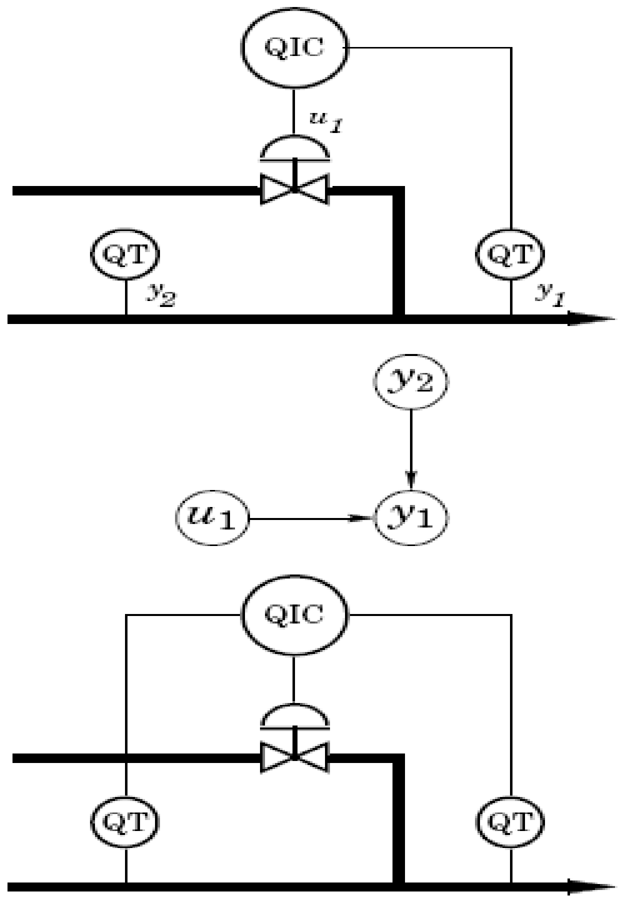
CC for composition control



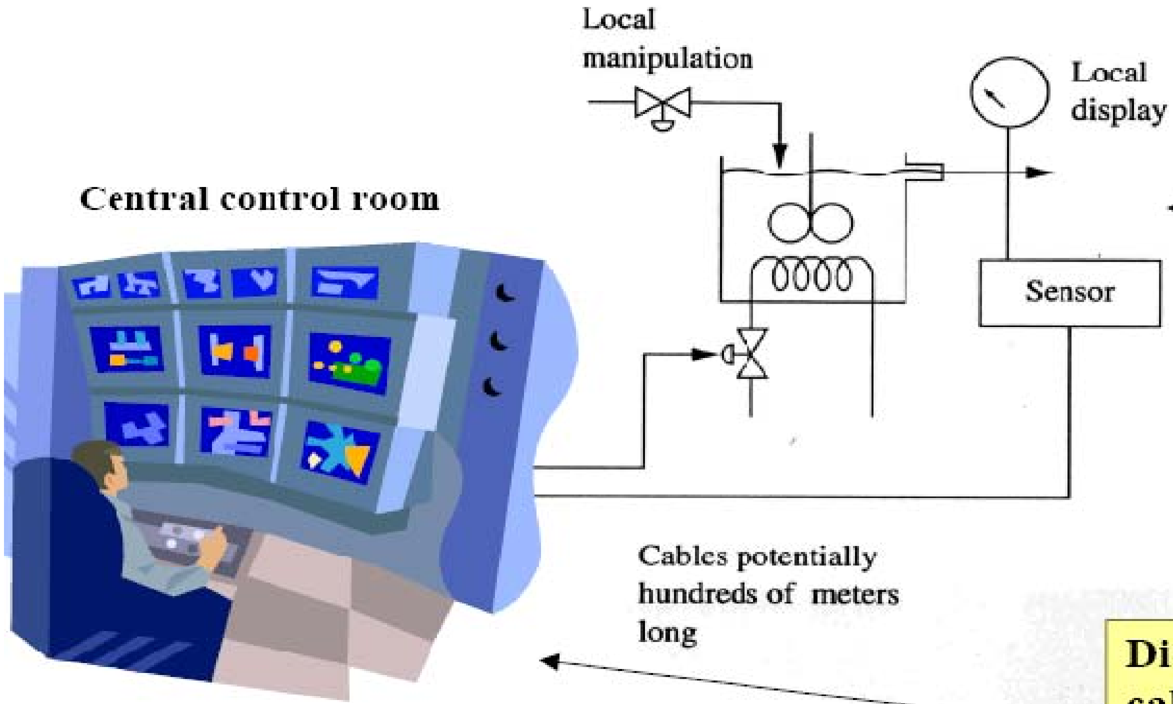
Example of Temperature Control (Heat exchanger)



Example of Composition Control



Where is Control Done?



Sensors, local indicators, and valves in the process

Displays of variables, calculations, and commands to valves are in the centralized control center.

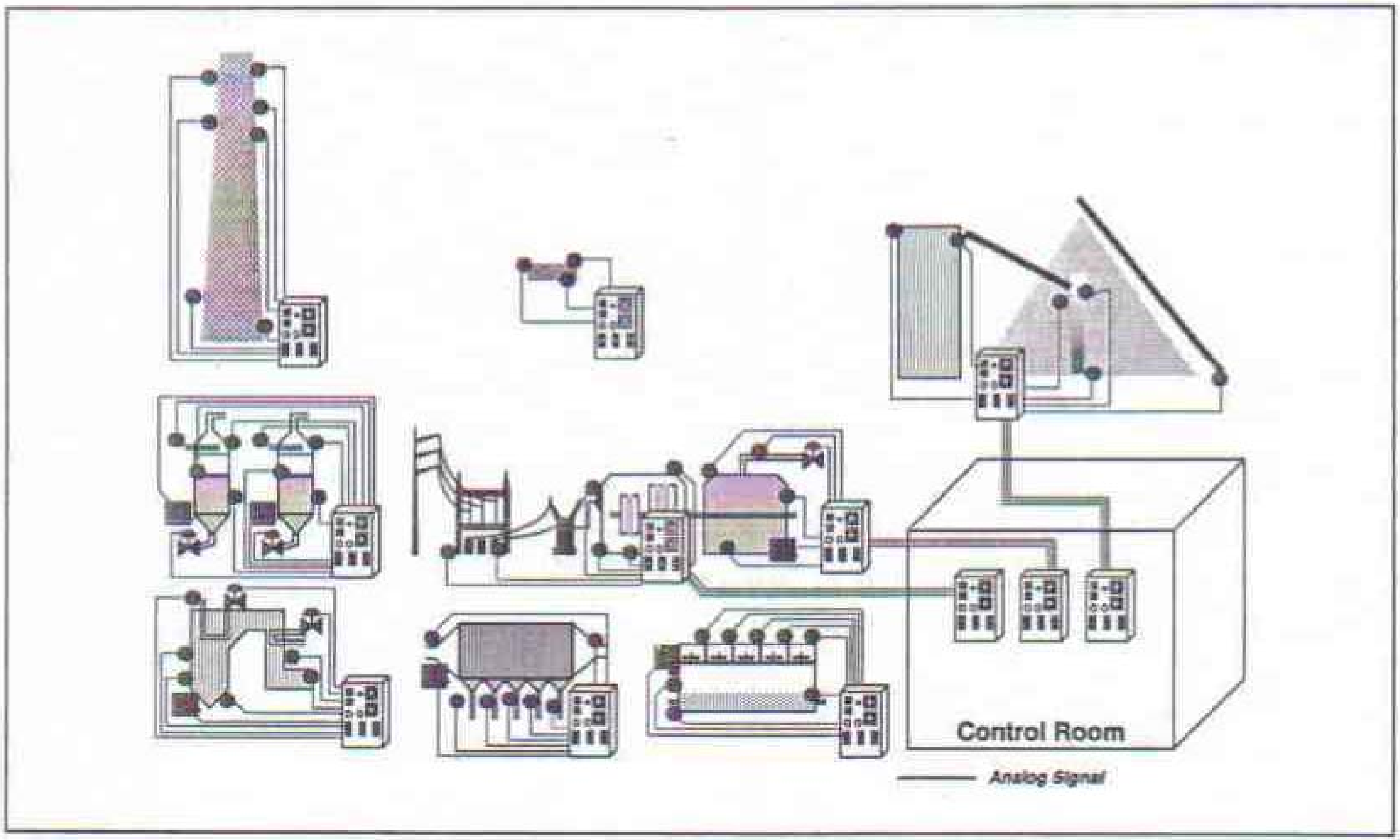
Shows a modern, computer-based control panel

Control System Implementation

- Analog and local Control
- Microprocessor based Distributed Control
- Field Bus based Distributed Control System

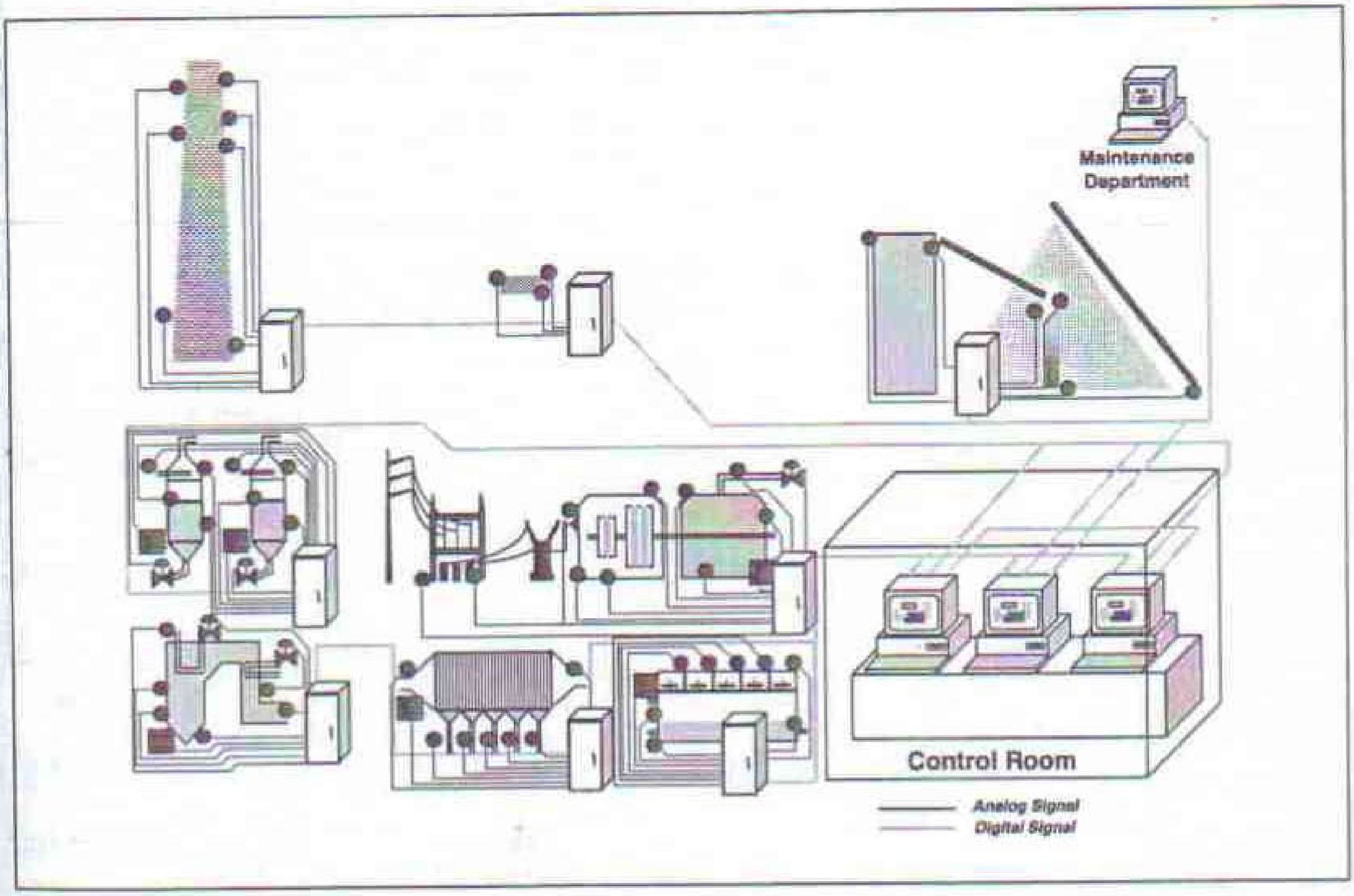
  (State of art with ever growing capabilities and features!)

Control Systems Implementations In Industry



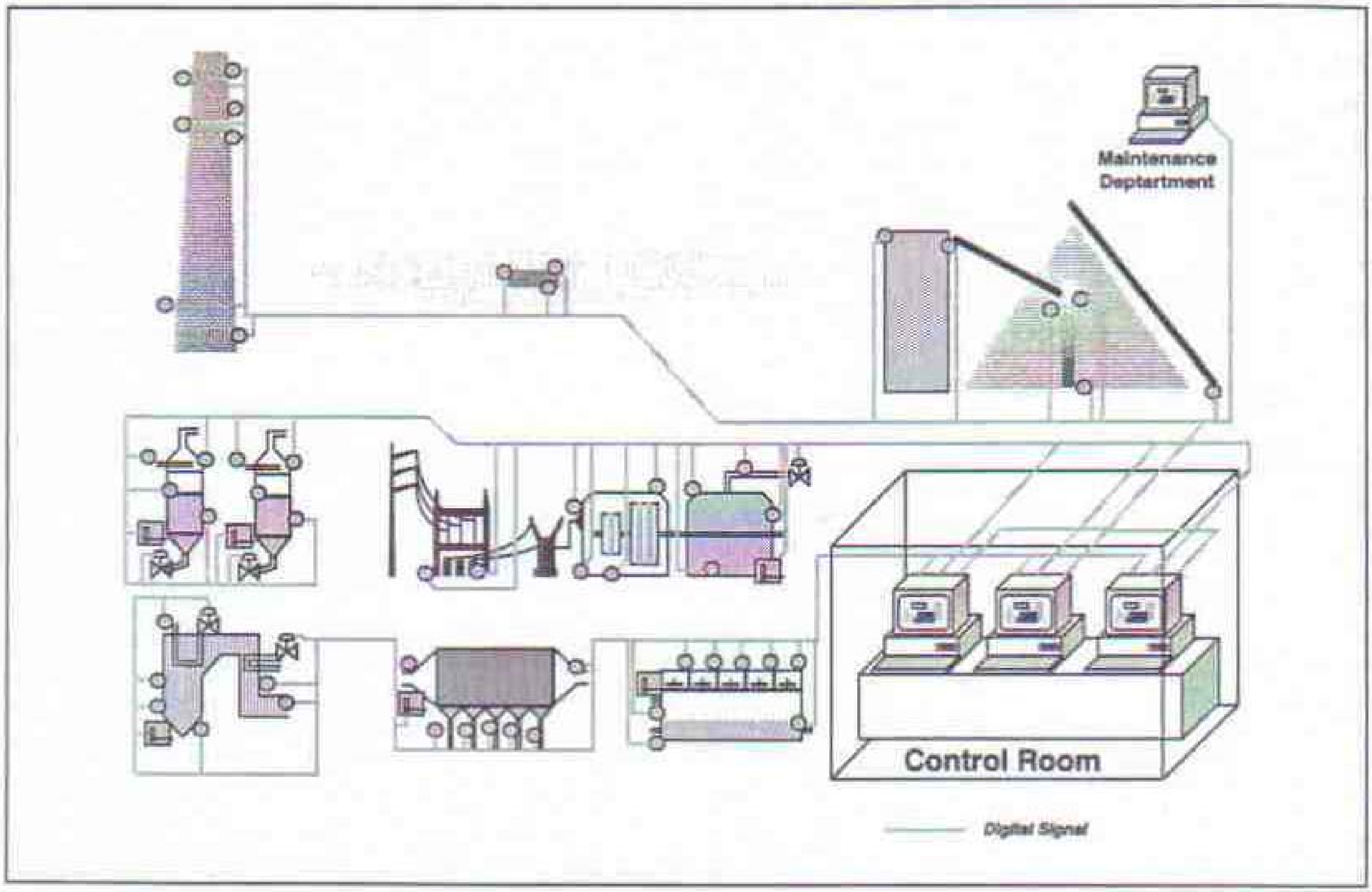
When Control and Monitoring Were Local and Analog; Not All Control Panels Were in the Control Room

Control Systems Implementations In Industry



. **Microprocessor Allowed the Design of Distributed Control and Monitoring to Happen**

Control Systems Implementations In Industry



Fieldbus Control and Monitoring Significantly Reduces Field Wiring

Open for discussions

Pakistan Engineering Council
Islamabad

Sensors & Instrumentation

Lecture -2

Dr. –Ing. Naveed Ramzan

Instruments are our eyes

- Performance characteristics of Instruments
- Principle measurements desired in industry

(a) Temperature
(b) Pressure
(c) Level
(d) Flow
(e) Others (Composition, pH etc.)

Sensors

- Human natural observation capabilities are generally not designed for process conditions.

- Instruments must have desired capabilities to match process conditions.

- Process Control has the role of a decision makers (Like brain)

Sensors feel the condition and originate the signal followed by modification and amplification for effective display /transmission or control objectives.

Importance of effective measurement in process industry

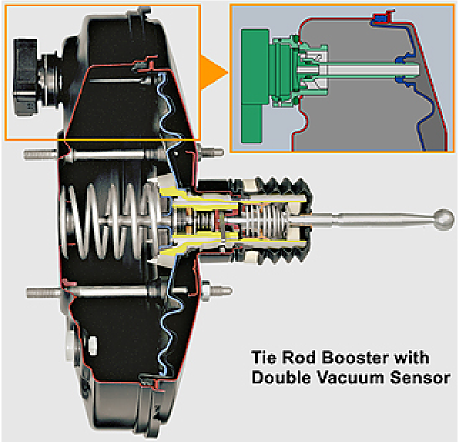
Failure to measure effectively the level of liquid in bottom of the tower lead to

--- Fire

--- Explosion

Typical components of instrument

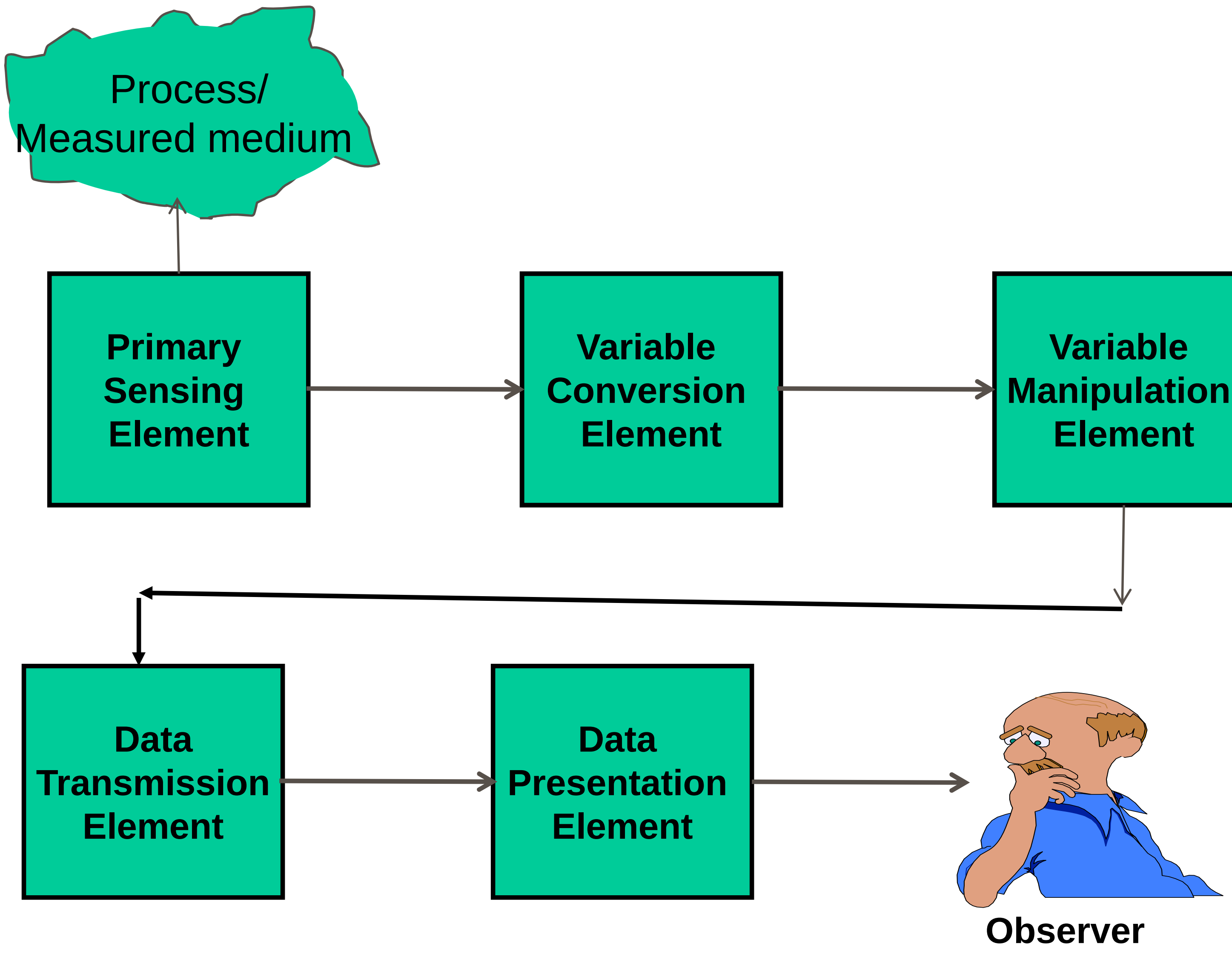
- ***A Sensor**:*
  (measures a physical quantity and converts it into a signal)



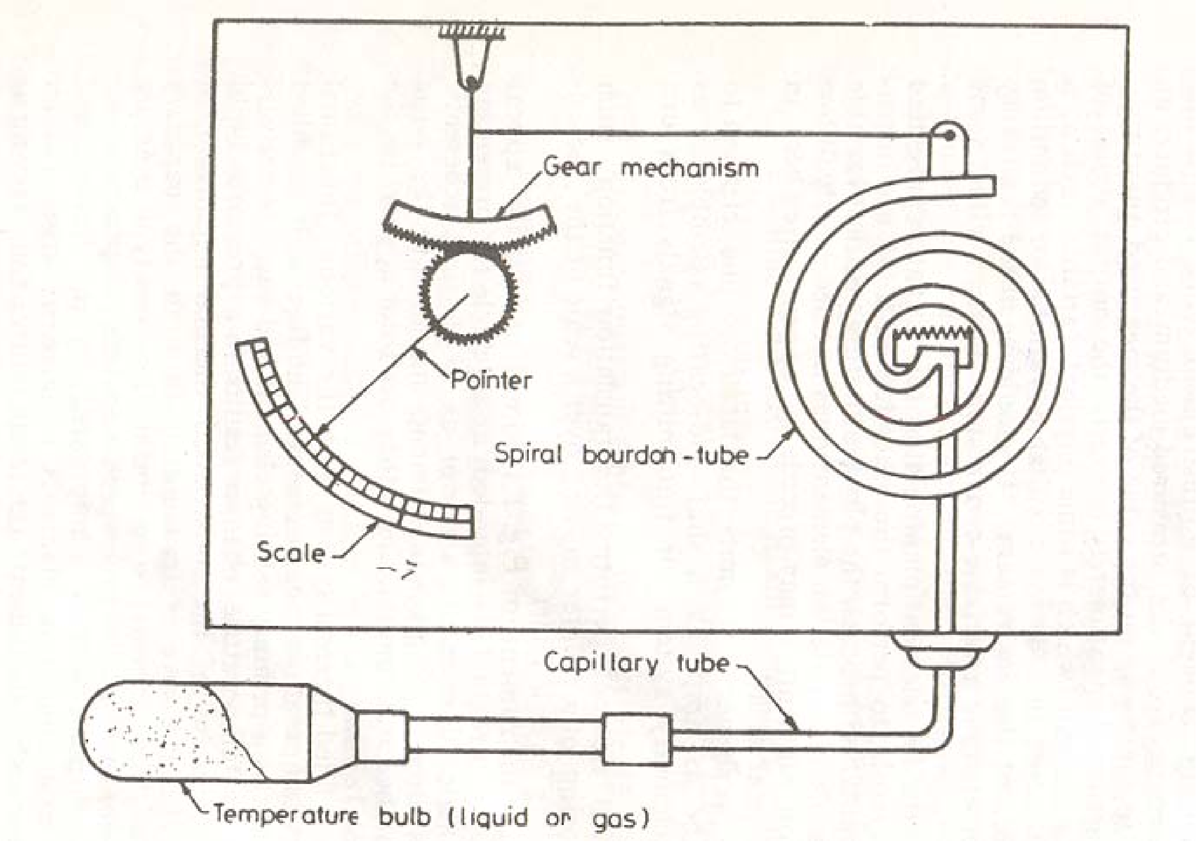
- ***A Modifier***
  (Change the type of signal)

- ***A Display unit***
  (transmitting arrangement)

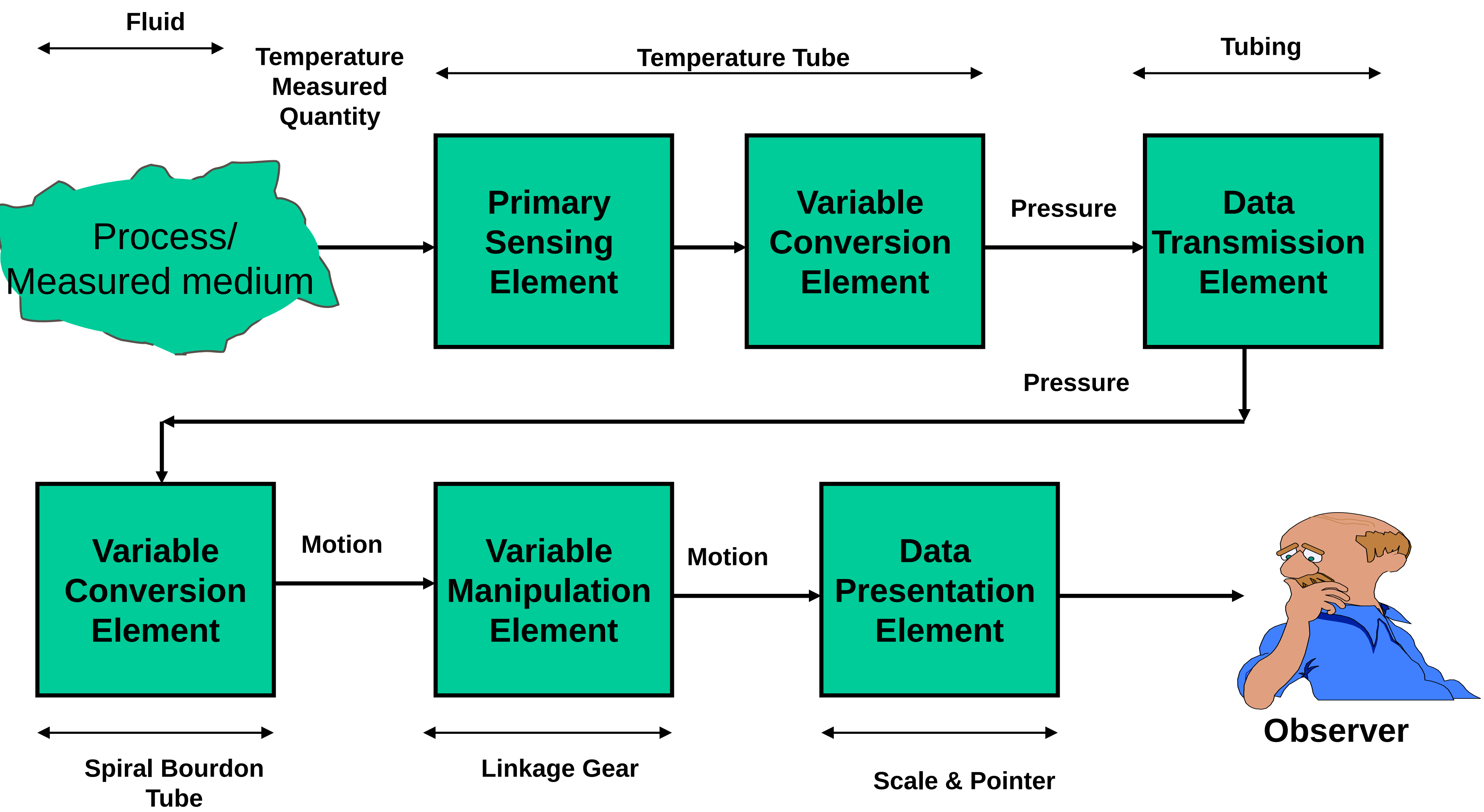
Functional Elements of an Instrument



Typical Example:



Functional Elements of an Instrument (Cont‘d)



Performance Characteristics of Instruments

- Static characteristics
- Dynamic characteristics

Static characteristics

Static characteristics of an instrument includes;

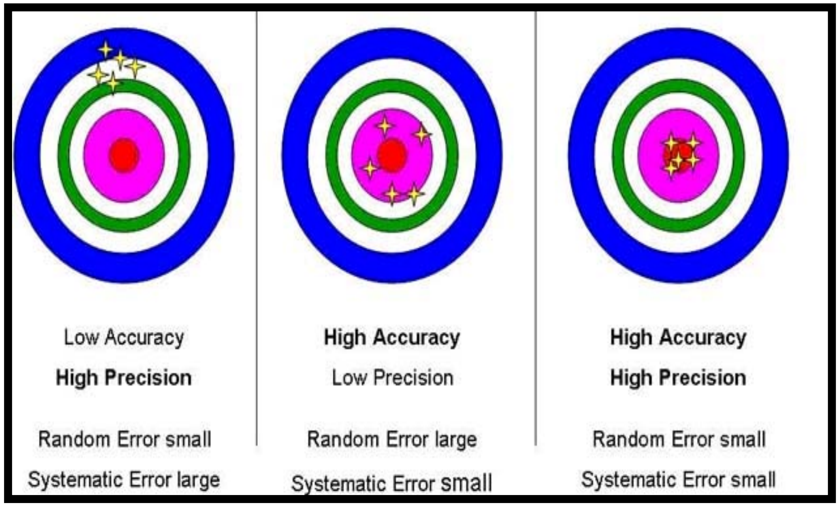
- **Accuracy**
- **Precision**
- **Repeatability**
- **Range**
- **Resolution**
- **Others (Sensitivity , Dead zone etc.)**

Static characteristics of an instrument includes;

1. Accuracy

❖The ability of a device or a system to respond to a true value of a measured variable under reference conditions.

❖In general accuracy expressed as "Limit of Error"

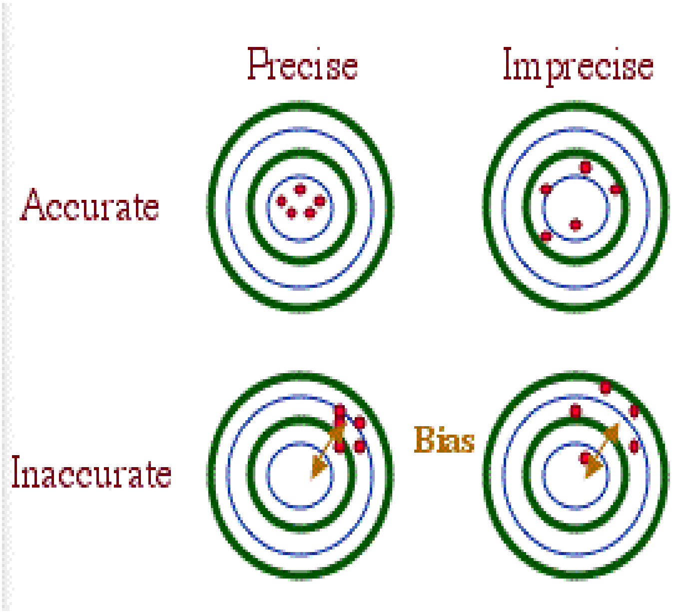


Static characteristics of an instrument includes;

2. Precision

- Precision is the degree of exactness for which an instrument is designed or intended to perform.

- It is composed of two characteristics;
  1. Conformity
  2. Number of significant figures



Static characteristics of an instrument includes;

3. Repeatability

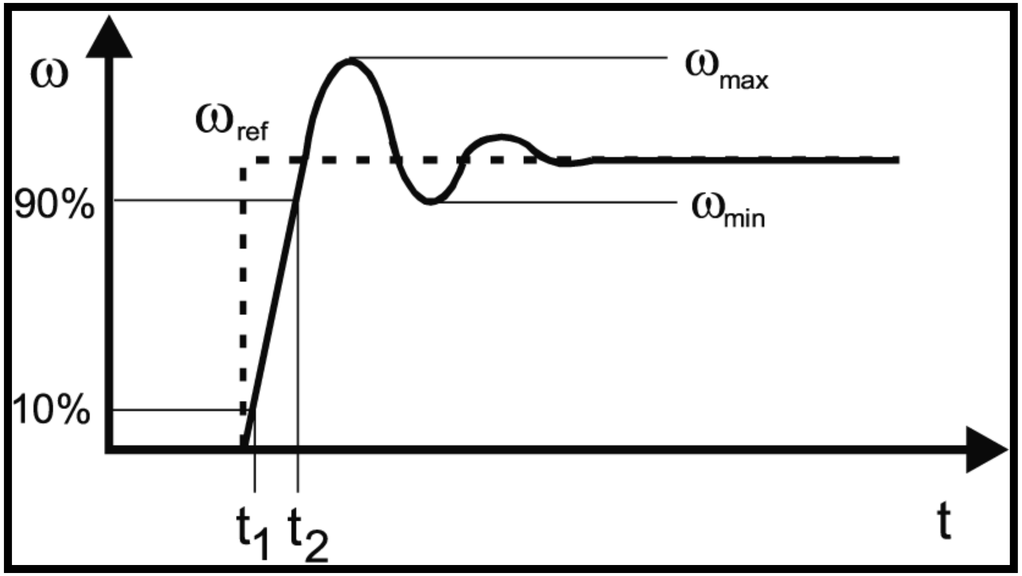
Repeatability is the variation in measurements taken by a single person or instruments on the same item and under the same conditions.

Assigning standard values to an equipment is calibration.

❖ Dynamic characteristics

Dynamic Characteristics of an instrument includes;

1. Speed of response
2. Fidelity
3. Lag
4. Drift



Principle measurements desired in Industry

Principle measurements desired in industry

(a) Temperature

(b) Pressure

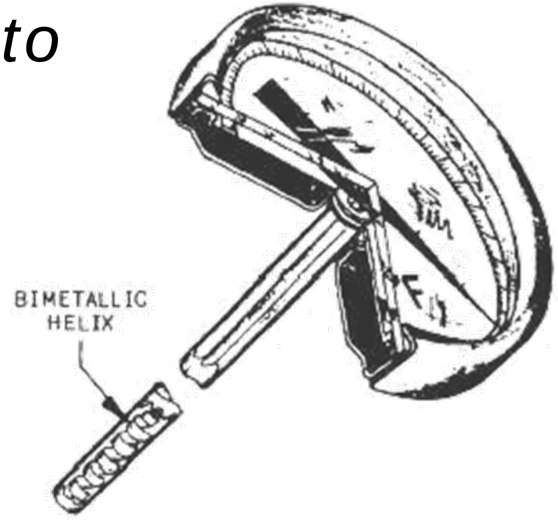
(c) Level

(d) Flow

(e) Others (Composition, pH etc.)

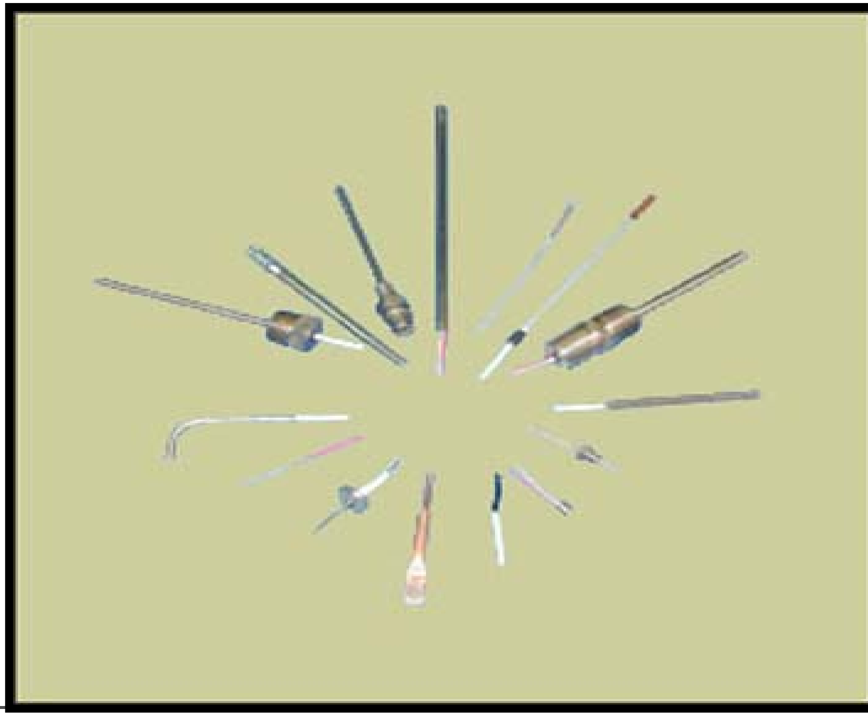
Temperature Sensor

"It is time to turn up the heat but first you must learn how to measure it"



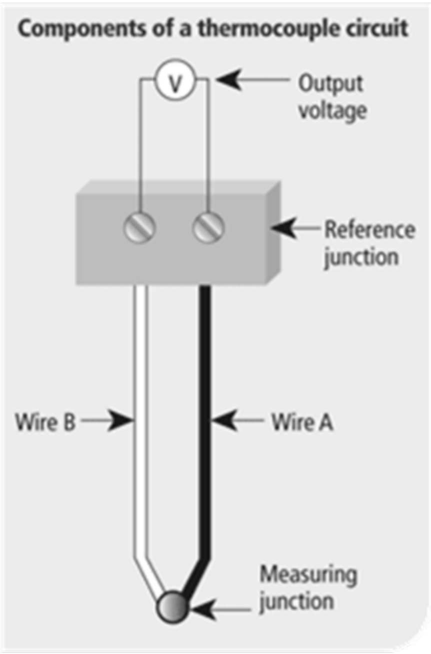
Methods of Temperature Measurement

1. Thermocouples
2. Thermistors
3. Electrical resistance change (RTD)
4. Expansion of materials
5. Pyrometers

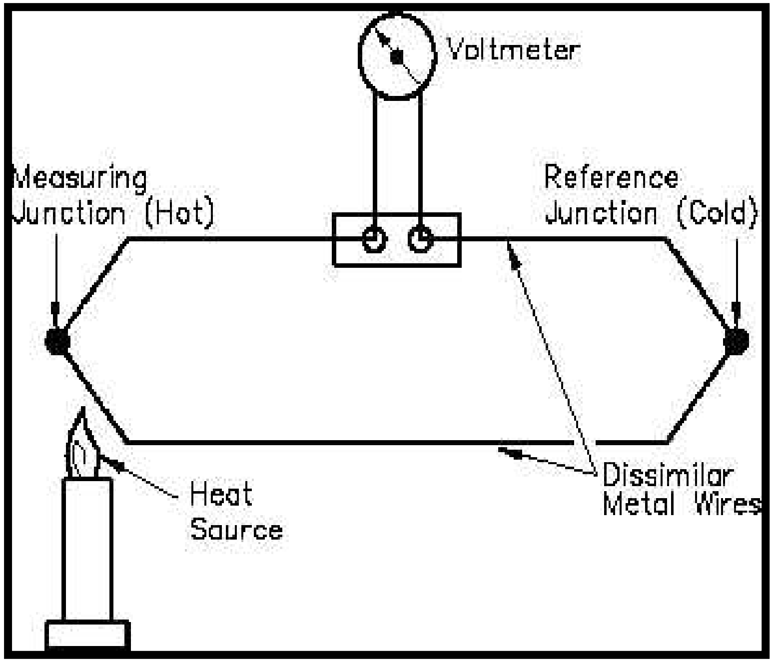


When 2 dissimilar metals are joined together to form a junction, an emf is produced which is proportional to the temperature being sensed.

Seebeck Effect:

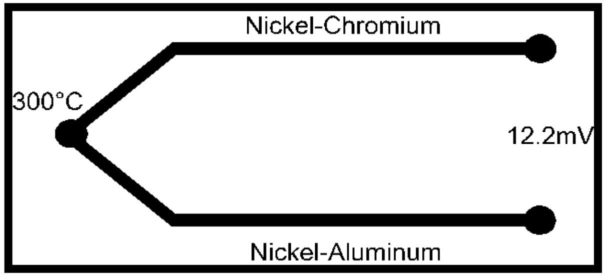


The generation of current in a circuit comprising of two wires of dissimilar metals in the presence of temperature difference



TCs are identified by a single letter type and grouped according to their temperature range

- Base Metals – up to 1000 °C
  - **Type J, Type E, Type T, Type K**
- Noble Metals – up to 2000 °C
  - **Type R, Type S, Type B**
- Refractory Metals – up to 2600 °C
  - **Type C, Type D, Type G**



Metal Combinations

TC Type	Colours	Range °C	Positive Lead (Coloured)	Negative Lead (all Red)
J	White/Red	-210 to 1200	Iron	Constantan
E	Purple/Red	-270 to1000	Chromel	Constantan
T	Blue/Red	0 to 400	Copper	Constantan
K	Yellow/Red	-270 to1372	Chromel	Alumel
R	Black/Red	-50 to 1768	Platinum-13% rhodium	Platinum
S	Black/Red	-50 to 1768	Platinum-10% rhodium	Platinum
B	Grey/Red	0 to 1700	Platinum-30% rhodium	Platinum-6% rhodium
C	White-Red/Red	0 to 2320	Tungsten/5% rhenium	Tungsten 26% rhenium

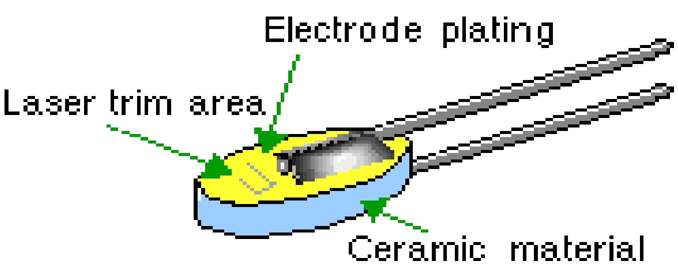
Chromel = Nickel-chromium
Alumel = Nickel-aluminum
Constantan = Copper-nickel

Thermocouple Tables

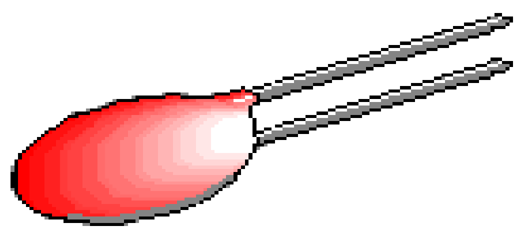
Type T Thermocouple (Blue & Red) Reference Junction 0 °C										
°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.352
10	0.391	0.431	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749
20	0.790	0.830	0.870	0.911	0.951	0.992	1.033	1.074	1.114	1.155
30	1.196	1.238	1.279	1.320	1.362	1.403	**1.445**	1.486	1.528	1.570
40	1.612	1.654	1.696	1.738	1.780	1.823	1.865	1.908	1.950	1.993

Thermistors

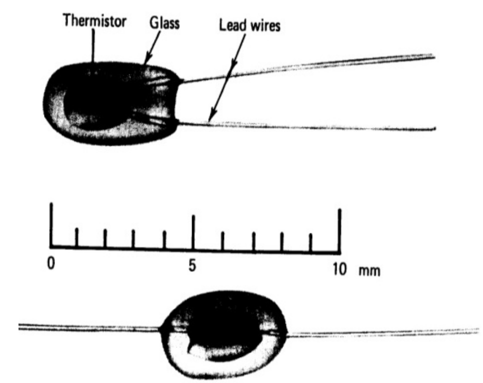
- Thermistor, a word formed by combining thermal with resistor, is a temperature-sensitive resistor fabricated from semiconducting materials.
- The resistance of thermistors decreases proportionally with increases in temperature.
- The operating range can be -200°C to + 1000°C



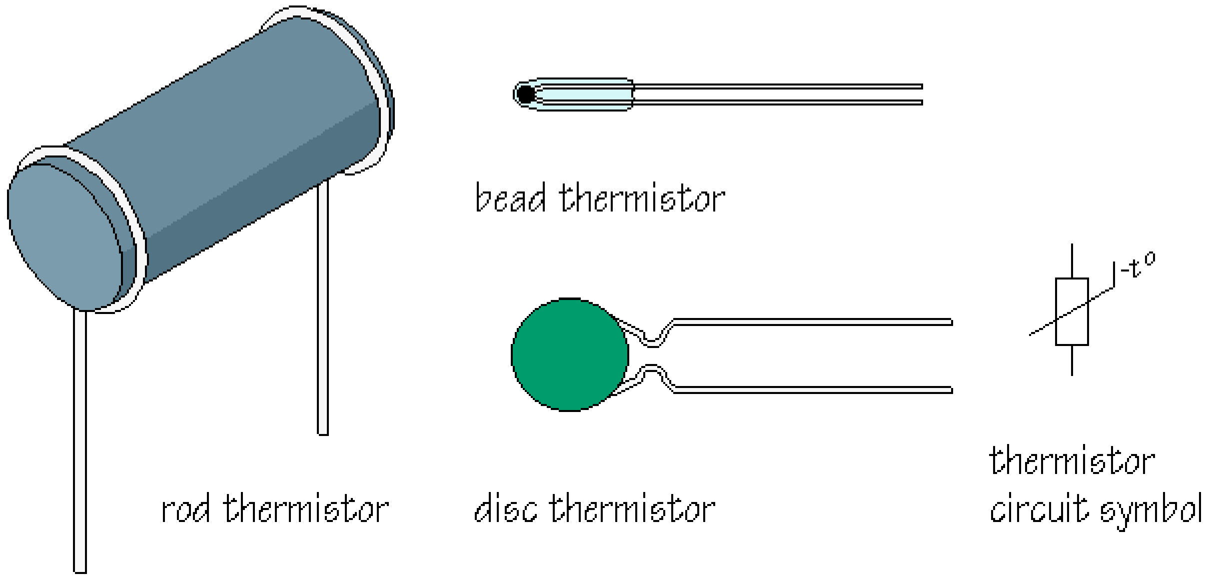
Thermistor without Encapsulation



Thermistor with Encapsulation



- The thermistors can be in the shape of a rod, bead or disc.



- Manufactured from oxides of nickel, manganese, iron, cobalt, magnesium, titanium and other metals.

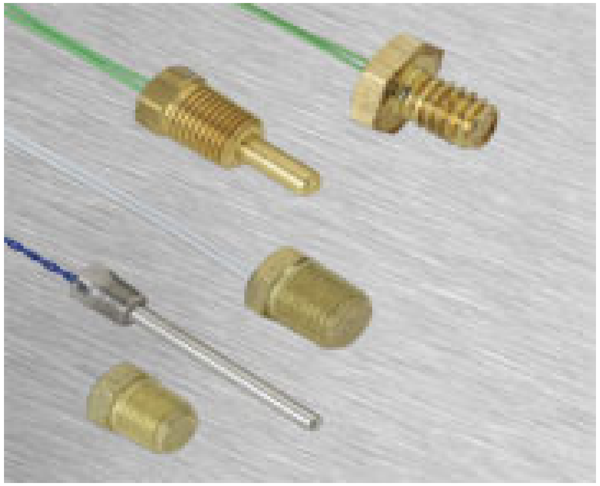
Advantages:

- Small sizes and fast response
- Low cost
- Suitability for narrow spans

Disadvantages:

- More susceptible to permanent decalibration at high temperatures.
- Use is limited to a few hundred degrees Celsius.
- Respond quickly to temperature changes, thus, especially susceptible to self-heating errors.
- Very fragile

Resistance Temperature Detector- RTD



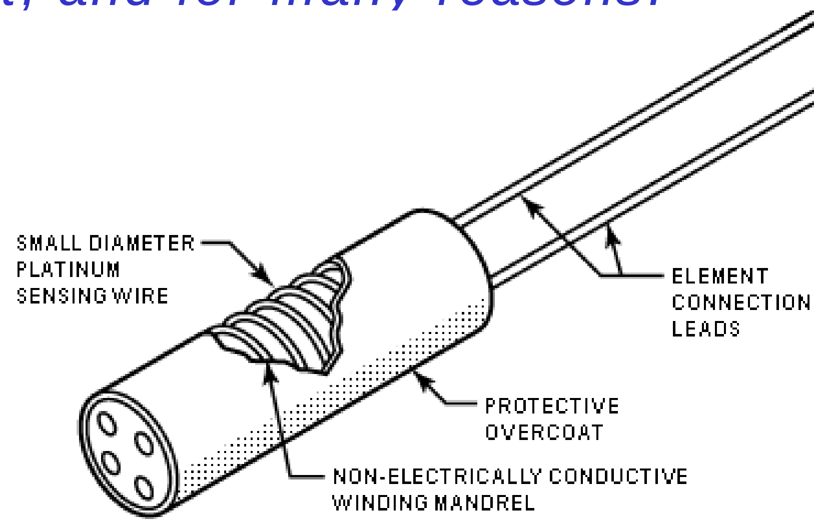
- RTD (Resistance Temperature Detector) is a temperature sensitive resistor.
- It is a positive temperature coefficient device, which means that the resistance increases with temperature.
- The resistive property of the metal is called its resistivity.

The industry standard is the platinum wire RTD (Pt100) whose *base resistance* is exactly 100.00 ohms at 0.0 °C.

Platinum Wire RTDs (PRTs)

PRTs have established themselves as the de-facto industry standard for temperature measurement, and for many reasons:

- linear temperature sensors
- Resistance vs temperature characteristics are stable and reproducible
- linear positive temperature coefficient (-200 to 800 °C)
- very accurate and suitable for use as a secondary standard



Electrical Resistance Change (RTD)

Other RTDs

- 10 ohms **Copper** RTD - .00427 coefficients
- 100 ohms Platinum RTD - .00385 coefficients (new IEC)
- 100 ohms Platinum RTD - .00392 coefficients (old)
- 120 ohms **Nickel** RTD - .00672 coefficient
- 604 ohms **Nickel-Iron** RTD - .00518 coefficients

All base resistances are specified at a temperature of 0 degrees C

A Pt1000 will have a base resistance of 1000 ohms at 0 deg. C

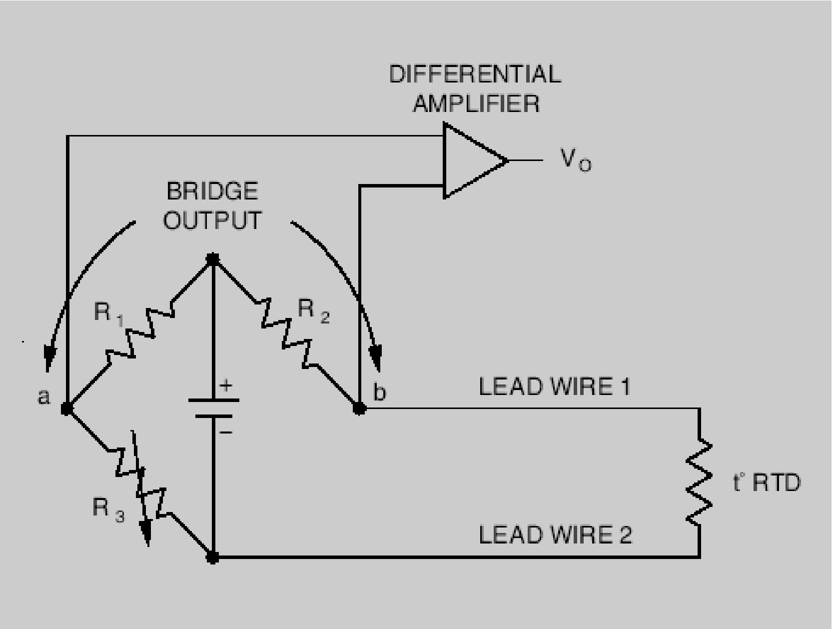
RTDs with a bridge circuit

Only practical if the RTD lead wires are short.

In many applications the RTD is located far from the conditioning circuit adding extra resistance because the length of the copper lead wire.

$$Cu = 0.0302\ \Omega \text{ per ft.}$$

How much error will 100 ft length of Cu lead wire introduce?

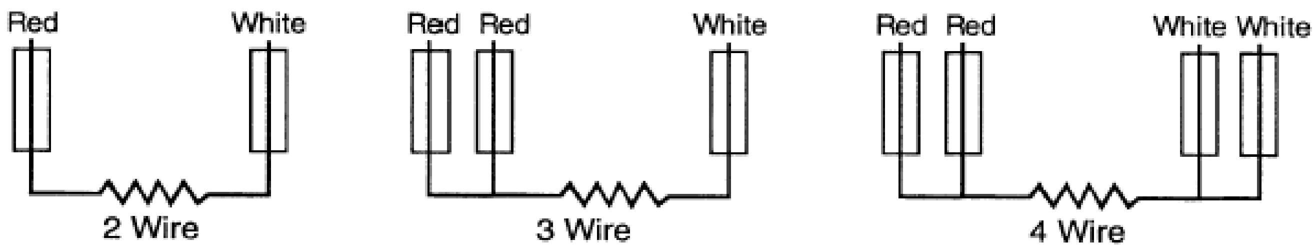


Most RTD’s have an extra wire to compensate for the length of lead wire.

RTD Colour Code

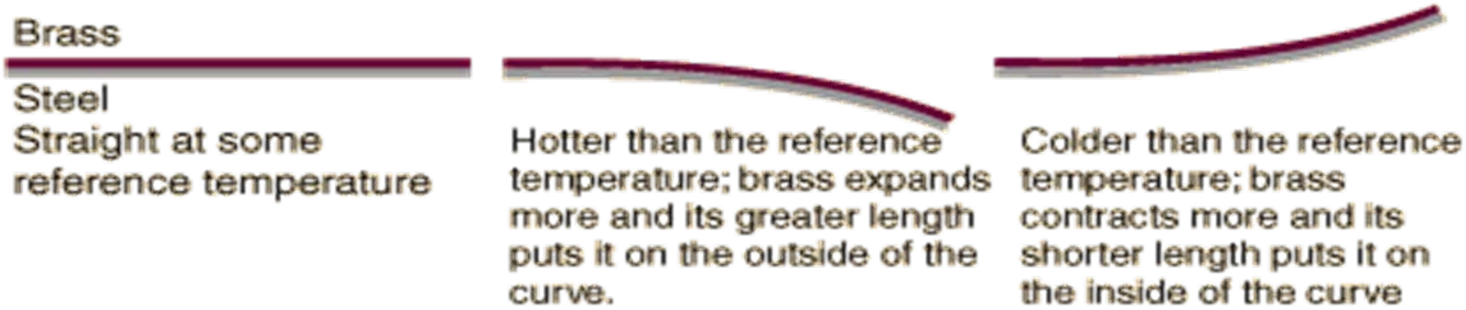
Not standardized but this is common colour arrangement. Some (like in the lab) will use BLK-BLK-RED

Recommended Colour Codes BS EN 60751:1996

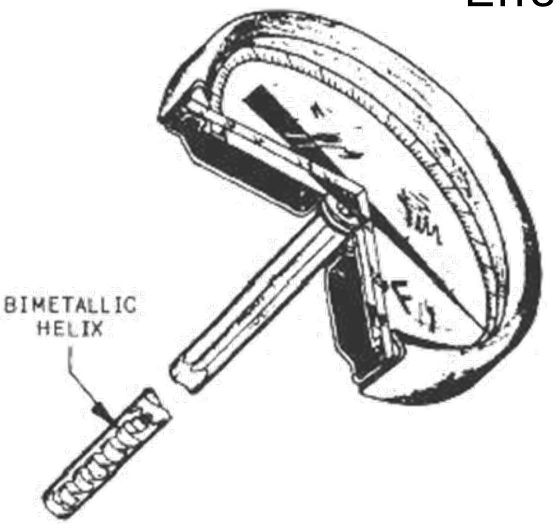


Bimetallic Thermometer

(Expansion of solids)



Effect of unequal expansion of a bimetallic strip



Bimetallic thermometer

-Different metals have difference coefficient.

-Configured as spiral or helix for compactness

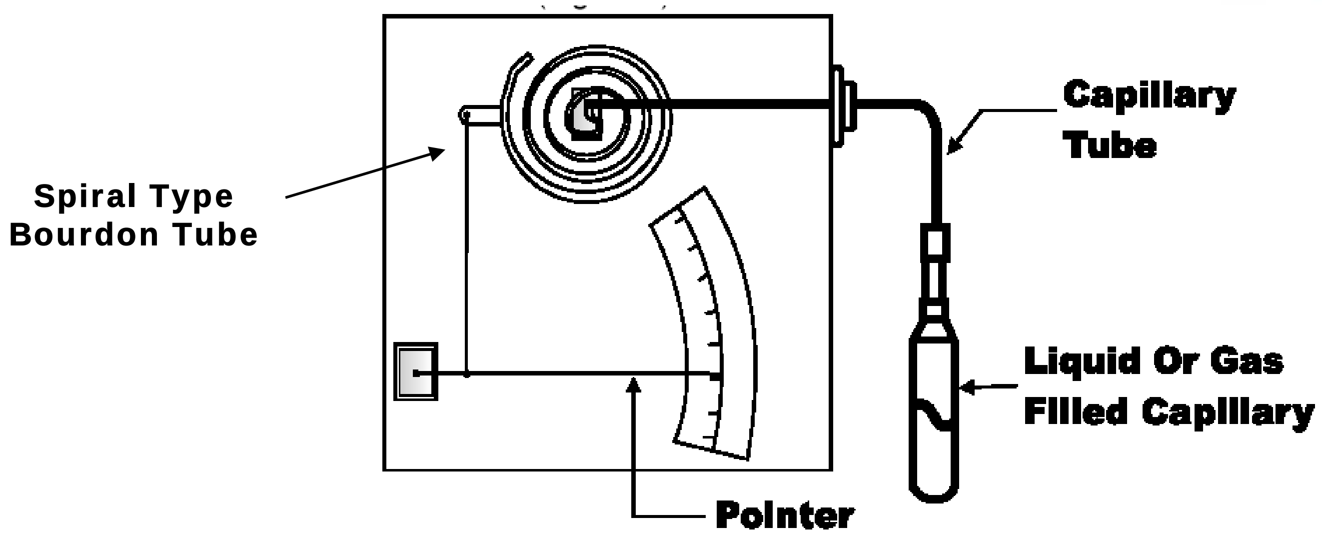
- Can be used with a pointer to make an inexpensive compact rugged thermometer.

- Filled Thermal Systems

(Filled System Thermometer, Filled Bulb Thermometer)

Similar operation as the liquid in glass

- Bulb
- Capillary tube
- Pressure element
- Scale



Expansion Thermometers

- Filled Thermal System Classes

  (Filled System Thermometer, Filled Bulb Thermometer)

  - Class I A,B – Liquid filled
  - Class II A,B,C,D –Vapour filled
  - Class III A,B – Gas filled
  - Class V A,B – Mercury Filled

	Temperature Range	Response
Class I:	-125 F to + 600 F	Slowest
Class II:	-40 to 32 or 32 to 600 F	Fastest
Class III:	-450 F to +1400 F	Fast
Class V:	-40 F to +1200 F	Fast

Pyrometer

Pyrometry is a technique for measuring temperature without physical contact

An apparatus for measuring high temperatures that uses the radiation emitted by a hot body as a basis for measurement.

- Radiation pyrometers (measurement of radiant energy)
- Optical Pyrometers (comparison of the intensities)

Summary of Temperature Sensor Characteristics

Type	Linearity	Advantages	Disadvantages
Bimetallic	Good	Low cost, rugged, wide range	Local measurement, or for On/Off switching only
Resistance	Very good	Stable, wide range, accurate	Slow response, low sensitivity, expensive, self-heating, range
Thermistor	Poor	Low cost, small, high sensitivity, fast response	Nonlinear, range, self-heating
Thermocouple	Good	Low cost, rugged, very wide range	Low sensitivity, reference needed
Semiconductor	Excellent	Low cost, sensitive, easy to interface	Low sensitivity, reference needed, slow response, range, power source

Pressure Sensors

"In any given plant, the number of pressure gauges used is probably larger than all other instruments put together"

1. Elastic pressure transducers

2. Electric pressure transducers

3. Pressure measurement by measuring vacuum

4. Pressure measurement by balancing forces produced on a known area by a measured force

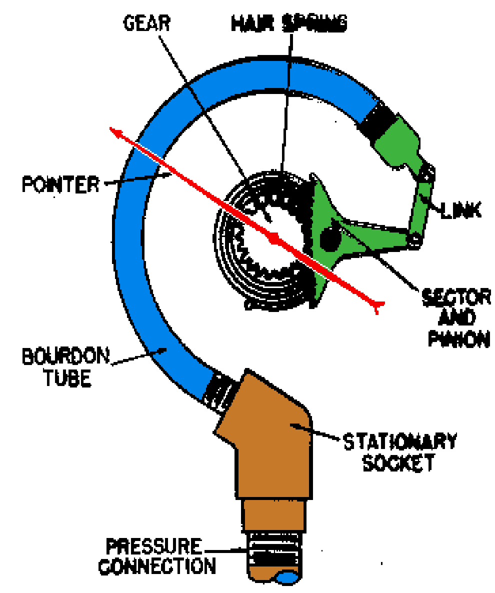
5. Manometer method

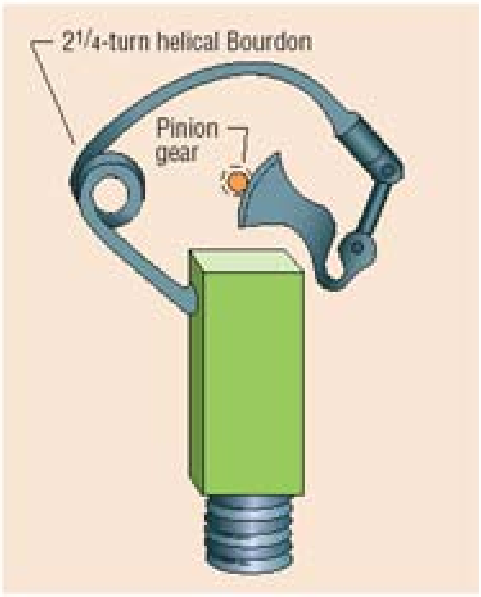
1. Bourdon tube pressure gauge
2. Diaphragm pressure transducers
3. Bellows

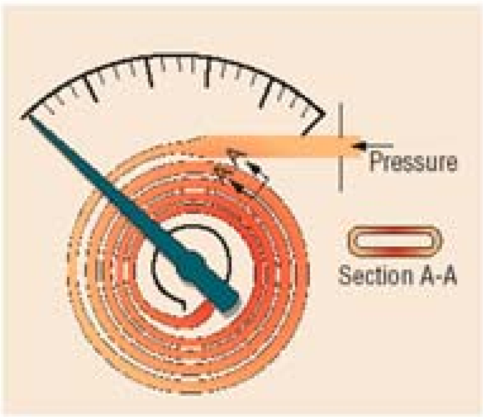
Bourdon Tube Pressure Gauge

Bourdon tubes are generally are of three types;

1. **C-type**
2. Helical type
3. Spiral type



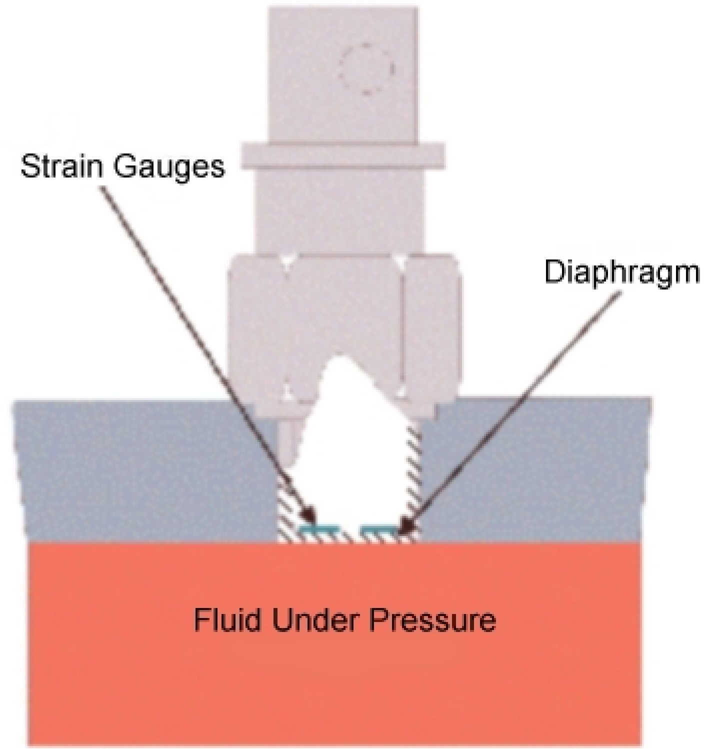




They are used to measure gauge pressures over very low ranges.

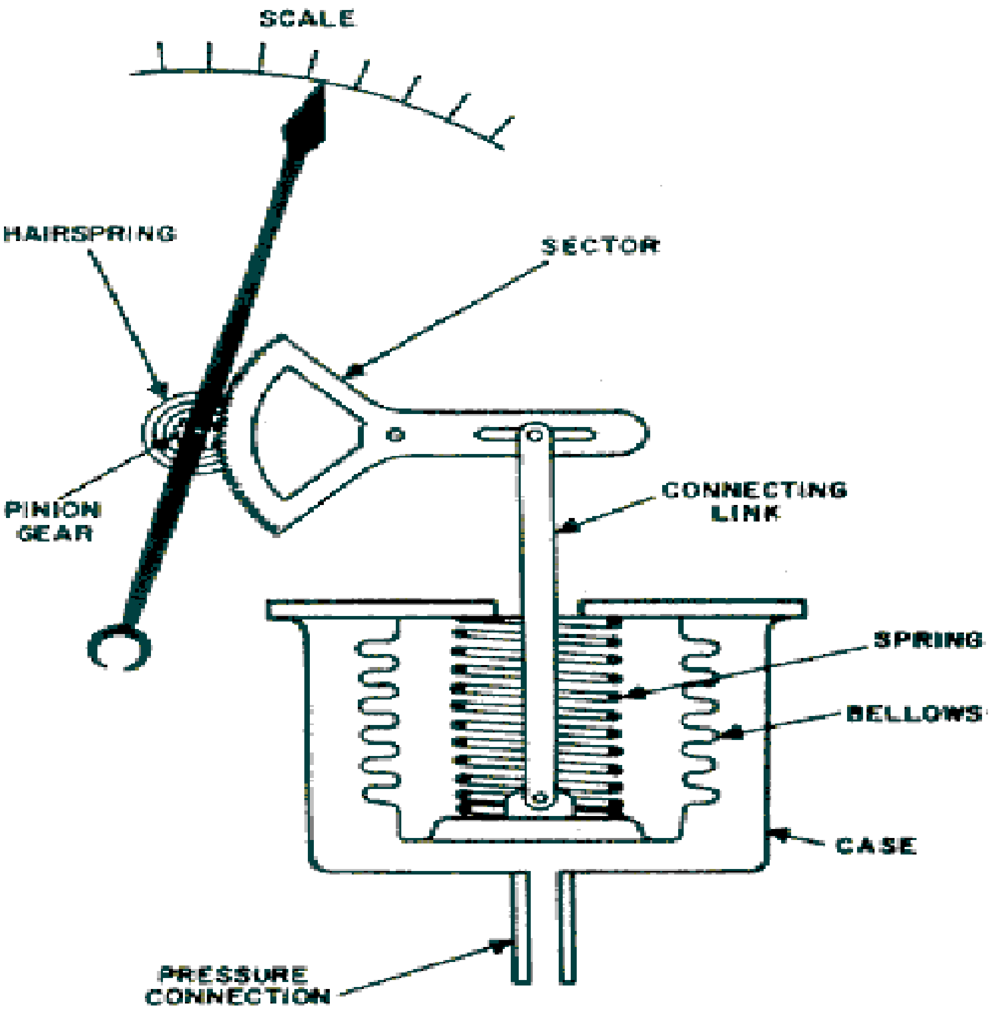
- Two types of diaphragm pressure guages are:

1. Metallic diaphragms gauge
2. Slack diaphragms gauge



Bellows

- More sensitive than bourdon type gauge.
- Used to measure low pressures



Electric Pressure Transducers

Electrical pressure transducers consists of three elements

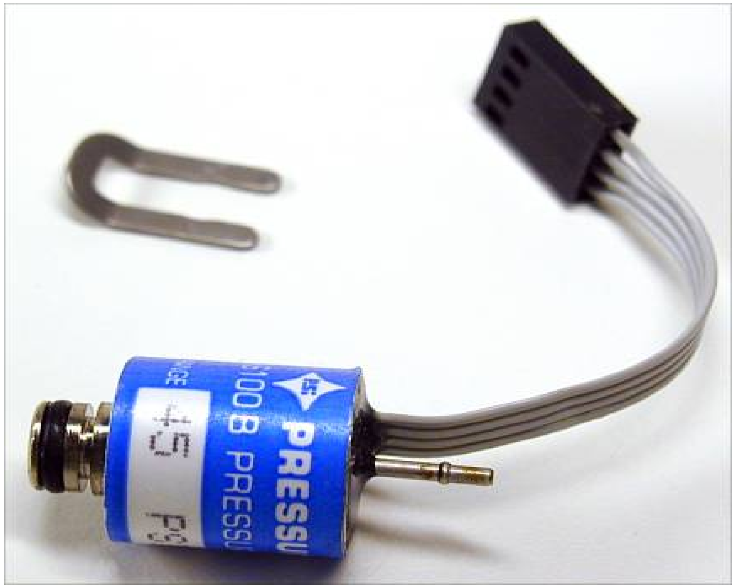
1. Pressure sensing element such as a bellow , a diaphragm or a bourdon tube

2. Primary conversion element e.g. resistance or voltage

3. Secondary conversion element

Types of Electric Pressure Transducers

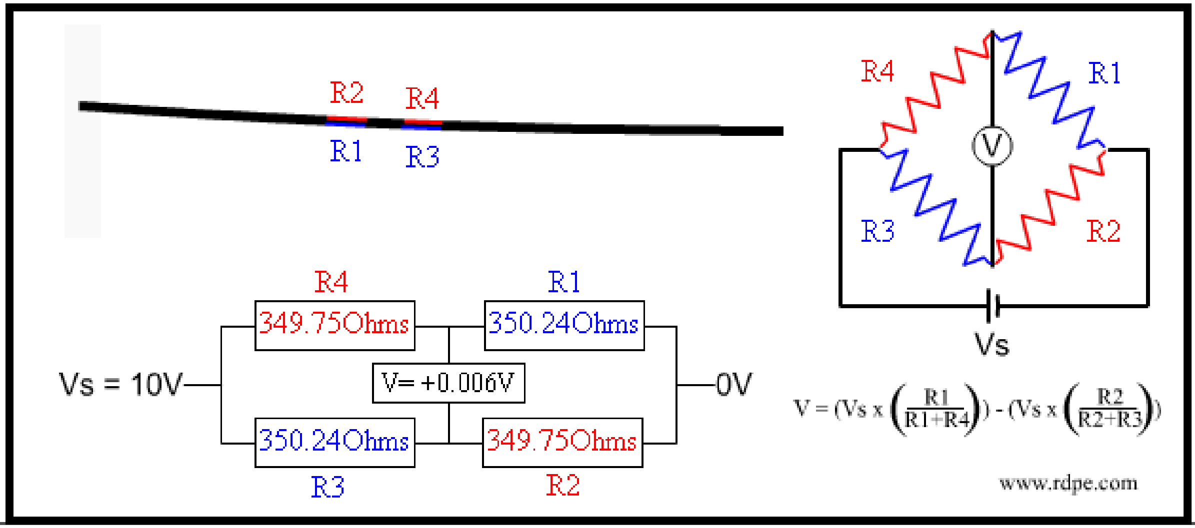
- Strain gauge pressure transducers
- Potentiometer pressure transducers
- Capacitive pressure transducers



Strain Gauge Pressure Transducer

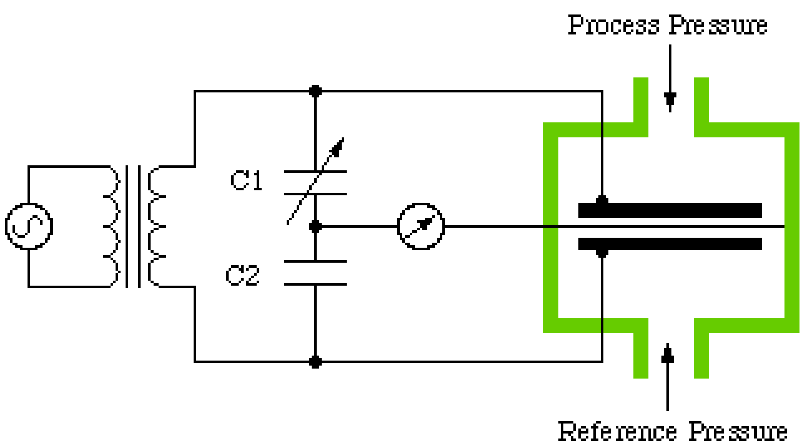
A strain gauge is a passive type resistance pressure transducer whose electrical resistance changes when it is stretched or compressed

A pressure transducer contains a diaphragm which is deformed by the pressure which can cause a strain gauge to stretch or compress. This deformation of the strain gauge causes the variation in length and cross sectional area due to which its resistance changes.

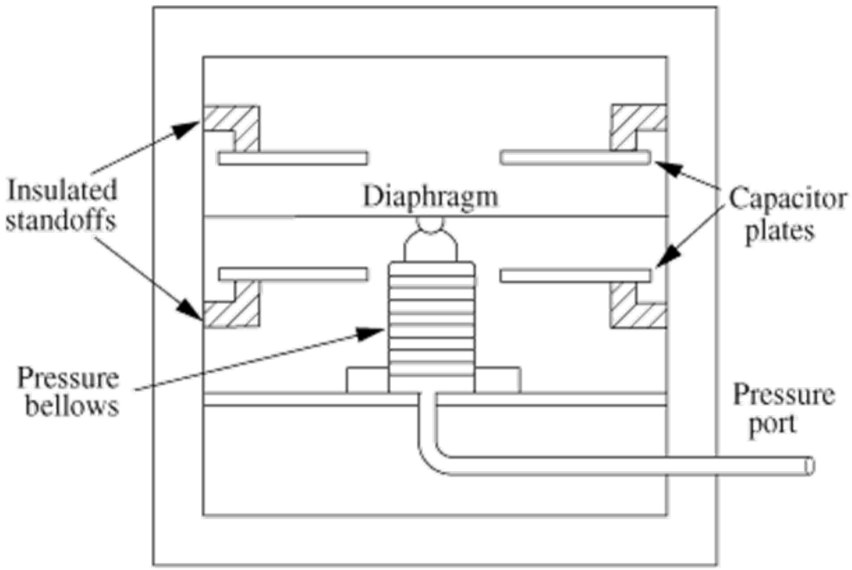


Capacitive Pressure Transducer

The sensing diaphragm and capacitor form a differential variable separation capacitor. When the two input pressures are equal the diaphragm is positioned centrally and the capacitance are equal. A difference in the two input pressure causes displacement of the sensing diaphragm and is sensed as a difference between the two capacitances

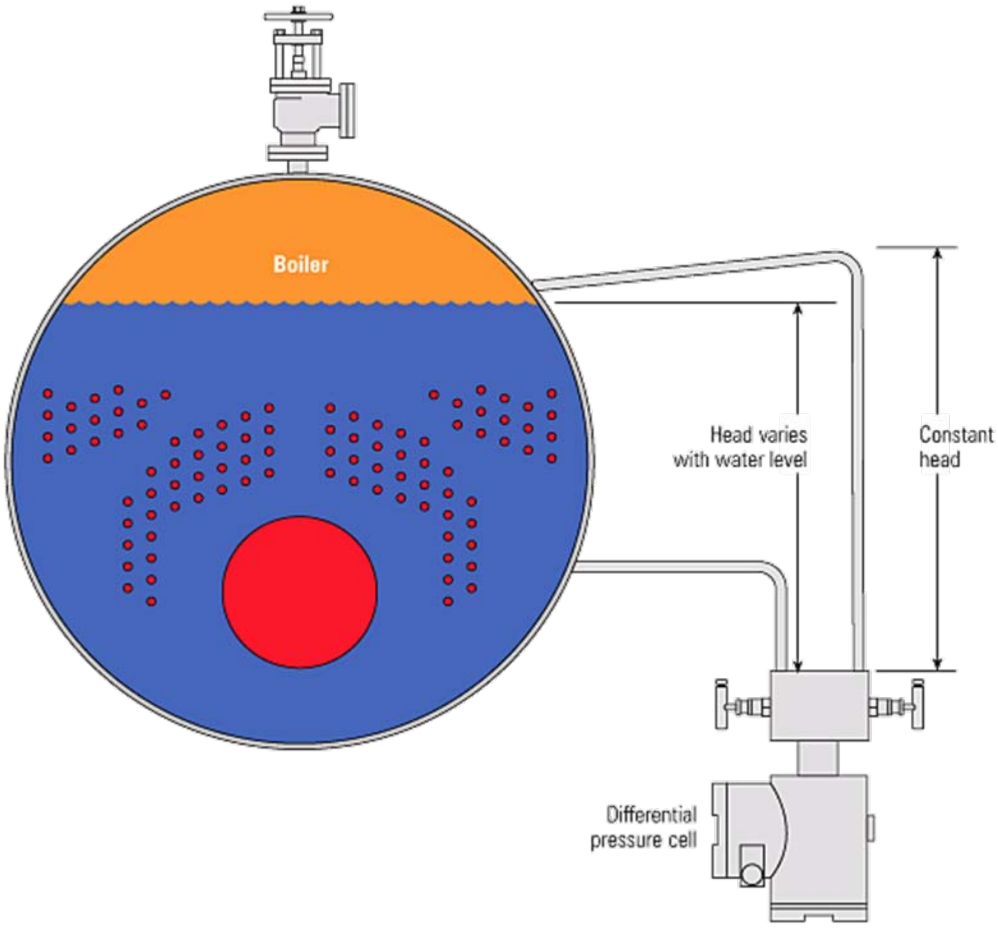


Circuit 6. Schematic capacitive pressure sensor



Differential Pressure Cell (DP Cell)

It is a device that measures the differential pressure between two inputs.

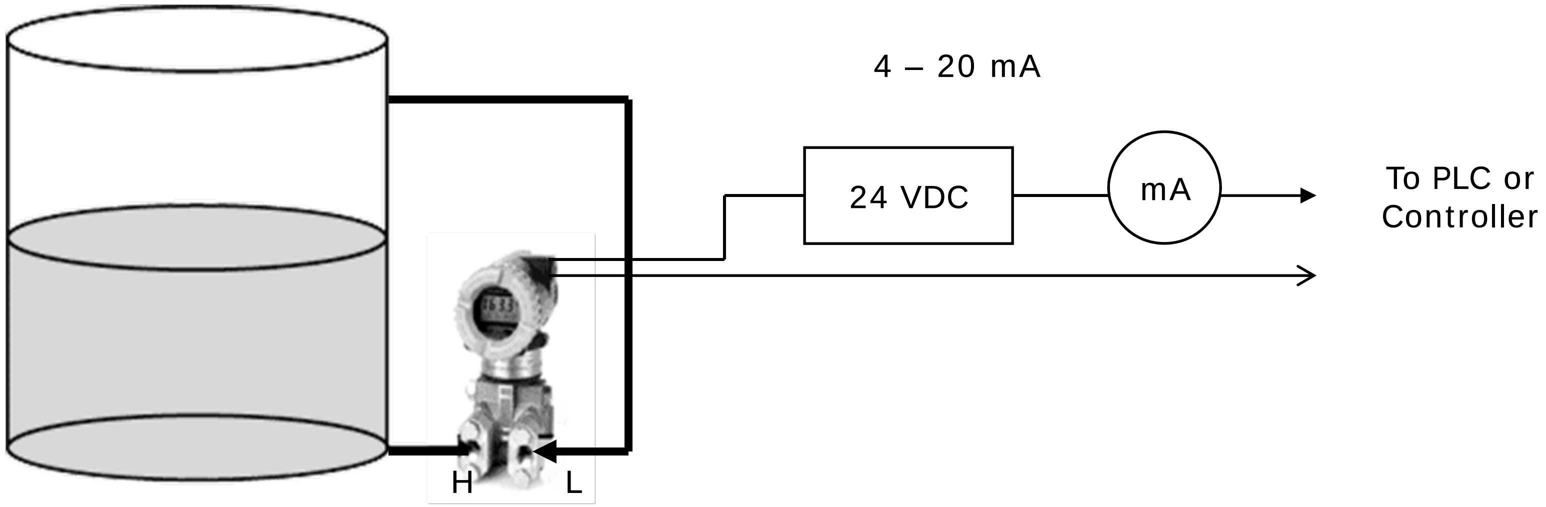


- Depending on what class the DP-cell is, it will give you feedback with a current signal.

- Normal in Europe is 4-20 mA, where 4 is lowest and 20 is highest.

Using a d/P Cell Transmitter

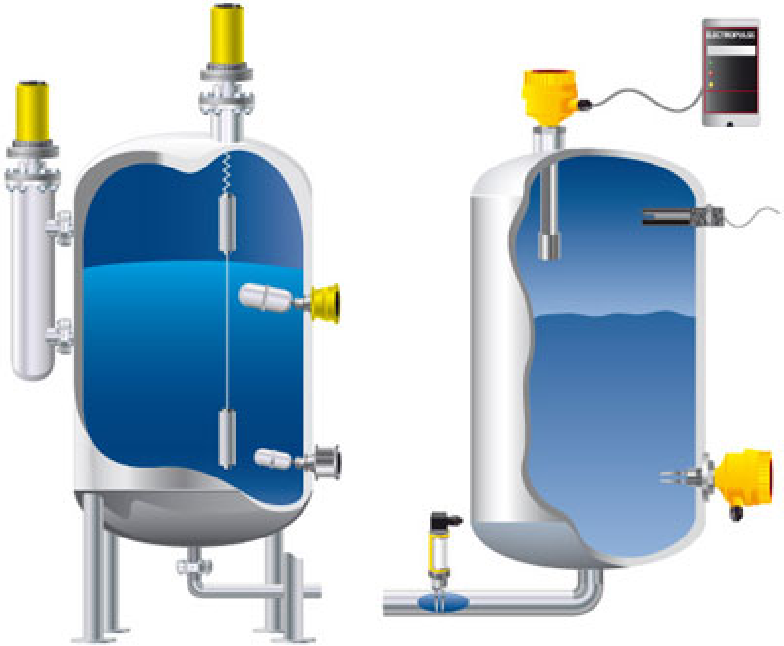
In a closed tank, the Low side of the d/P cell is connected to the top of the tank and will cancel the effects of the vapour pressure above the surface.



Closed Tank Measurement

- **Lo side of the d/P cell measures the vapour pressure above the surface.**
- **Hi side measures the hydrostatic head pressure which is proportional to the height of the liquid and its density + vapour pressure**

Level Sensors



Level Measurement

Level is another common process variable that is measured in many industries. The method used will vary widely depending on the nature of the industry, the process, and the application.

Inventory:

-- a constant supply or storage of material

Control:

-- continuous, batch, blending, and mixing control

-- stabilize flow to the next process

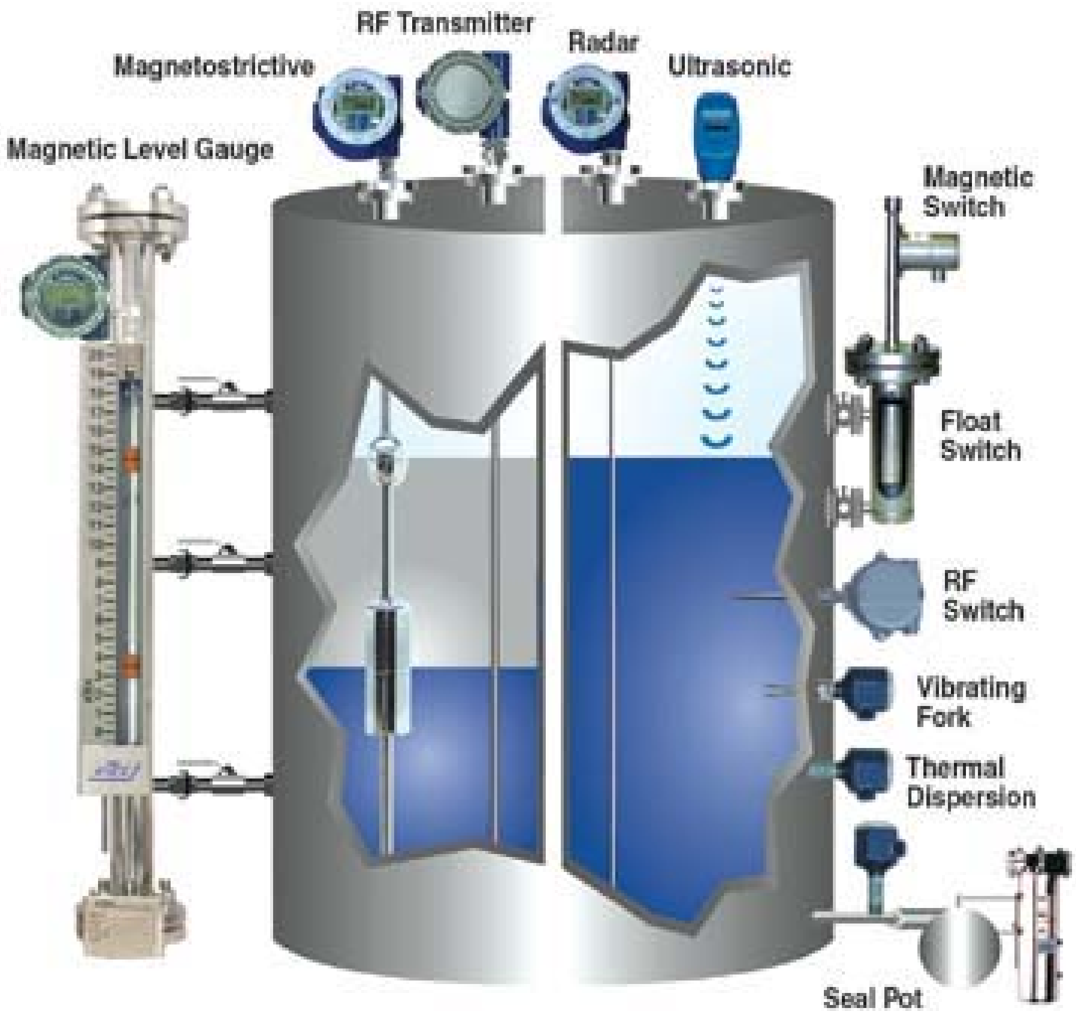
Alarming:

-- hi/lo limits, safety shut down

Data Logging:

-- material quantities for inventory and billing purposes and where regulatory requirements are necessary

Methods ---- Direct or Indirect (inferential)



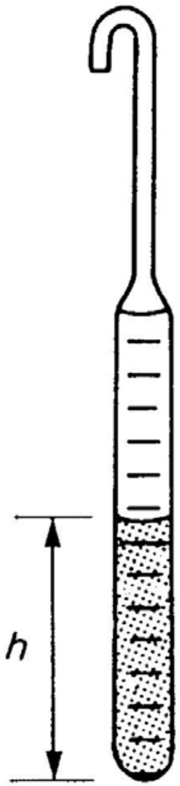
- Hydrostatic Head
- Float
- Load Cells
- Magnetic Level Gauge
- Capacitance Transmitters
- Magnetostrictive
- Ultrasonic
- Microwave
- Laser
- Radar
- Guided Wave Radar
- Dip Stick
- Vibration

Selection Criteria

When determining the type of level sensor that should be used for a given application, there are a series of questions that must be answered:

- Open tank or closed tank?
- Can the level sensor be inserted into the tank or should it be completely external? Contact or non-contact?
- Continuous measurement or point measurement?
- Direct or Indirect measurement?
- What type of material is being measured? Liquid or Solid? Clean or Slurry?

Dip Stick

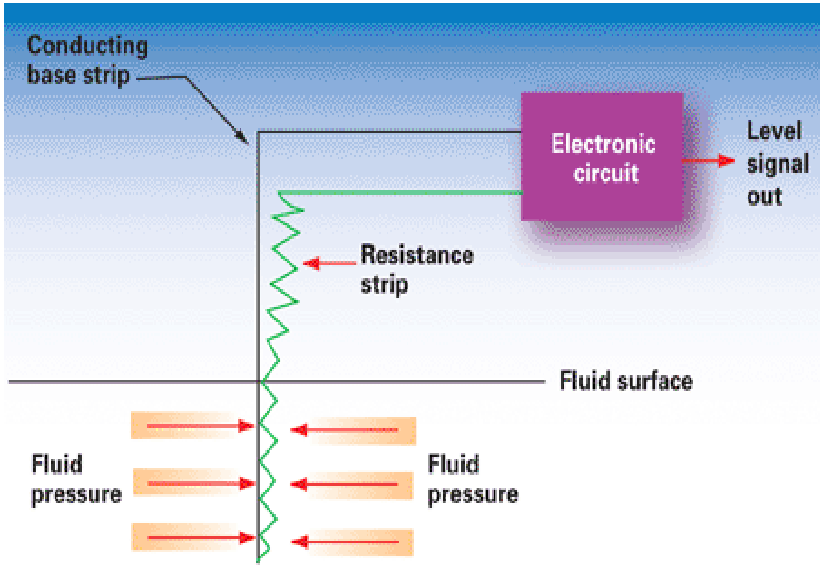


- *Simple and cheap*
- *Can be used with any wet material and not affected by density.*
- *Can not be used with pressurized tanks*
- *Visual indication only (electronic versions are available)*

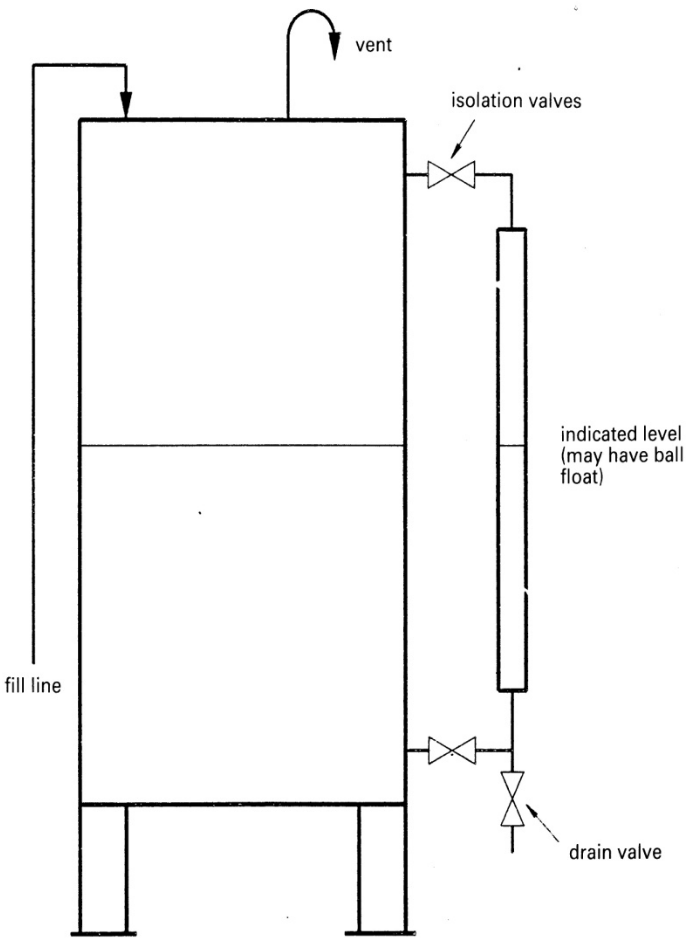
RodGauge - similar to a dipstick found in a car, it has weighted line markings to indicate depth or volume

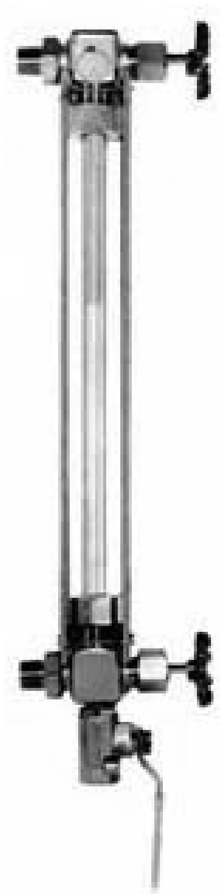
Resistance Tape

The pressure of the fluid in the tank causes the tape to short-circuit, thus changing the total resistance of the measuring tape. An electronic circuit measures the resistance; it's directly related to the liquid level in the tank.



Sight Glass

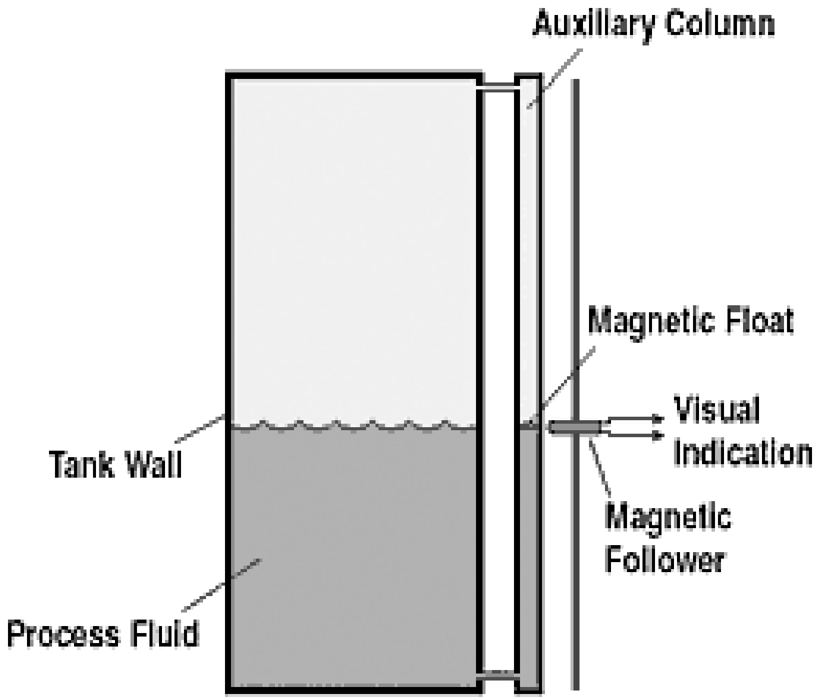




- *Another simple direct method of measuring liquids.*
- *Can be used in pressurized tanks (as long as the glass or plastic tube can handle the pressure)*

Good for applications where non-contact measurement is needed (like beverages)

Magnetic Level Sensor



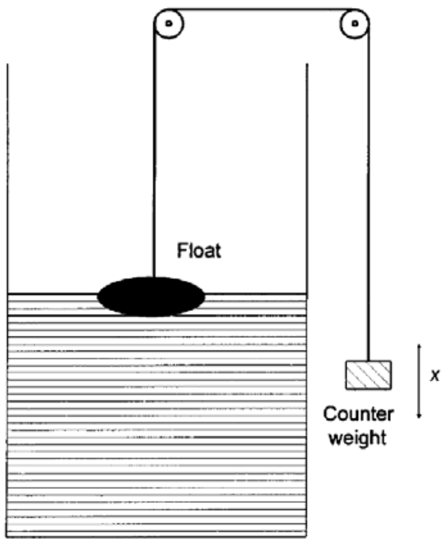
Used where the sight glass level gauge can not be used.

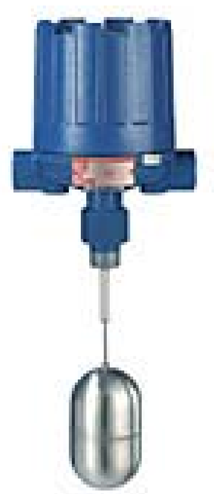
Magneto-resistive types can provide an electrical output.

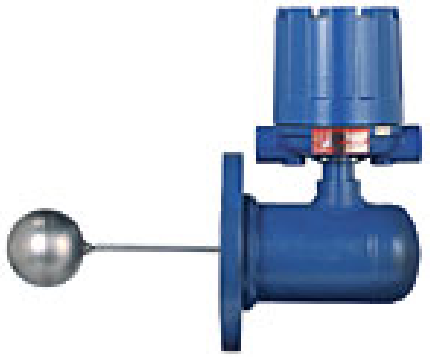
Liquid/liquid interface (such as water and oil) can be measured by changing the buoyancy of the magnetic float

Floats

Float rides the surface level to provide the measurement. Many different styles are available.





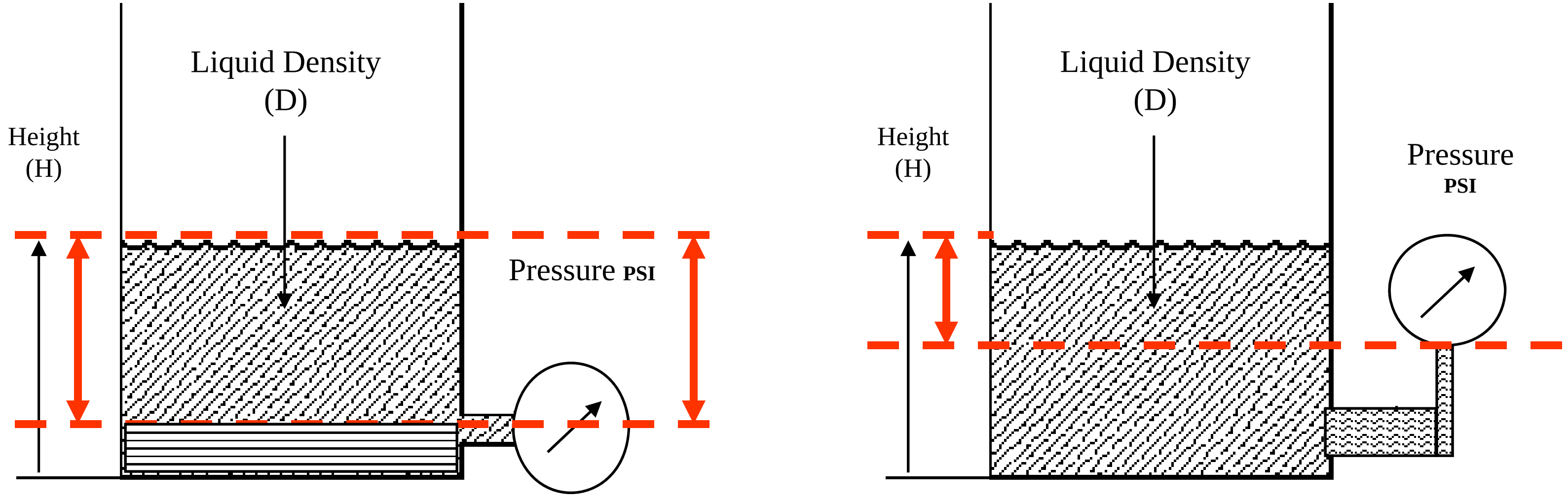


Liquid density does not affect measurement

- *These methods infer level by measuring the hydrostatic head produced by the liquid column.*
- *A pressure sensing element is installed at the bottom of the tank and pressure is converted to level.*
- *Different liquid densities or closed tank applications must be accounted for.*

Practical Considerations when using head type instruments

The reference point of the tank vs instrument input must be considered.

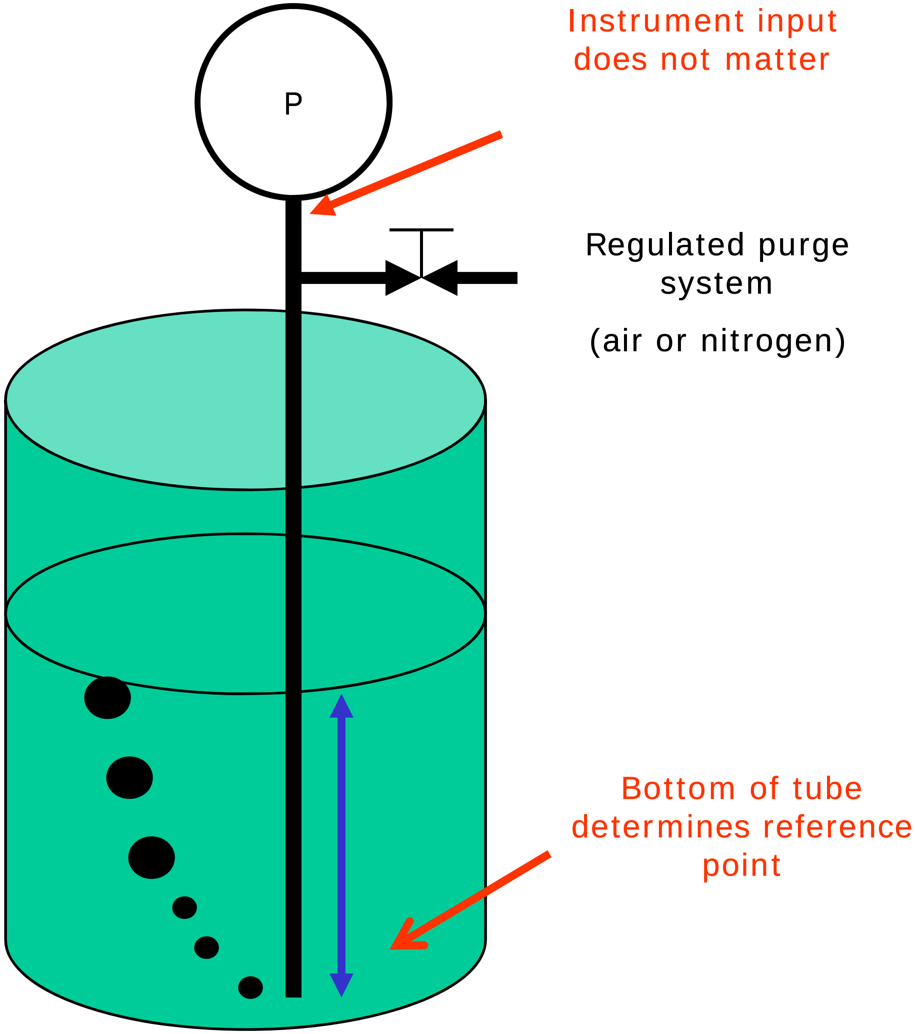


This may not be practical in some applications where the tank elevation is below grade or where a remote visual reading is required.

Bubblers

Bubblers allow the indicator to be located anywhere.

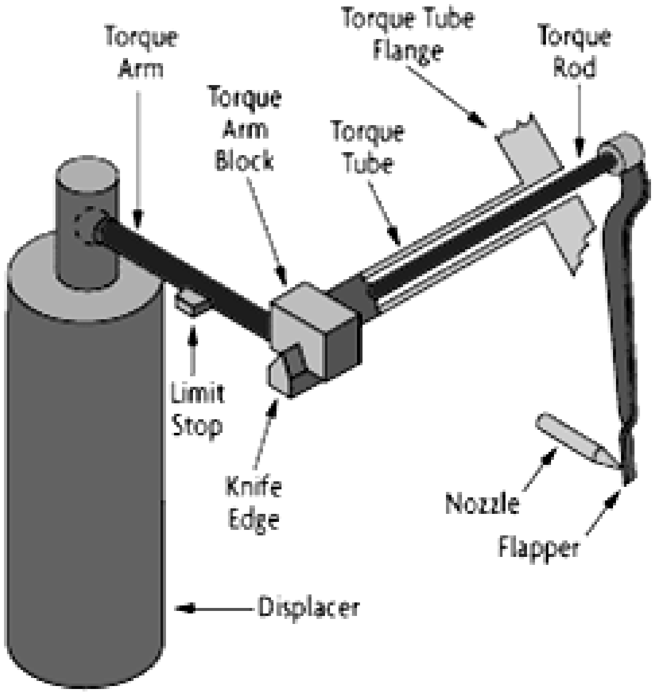
The air pressure in the tube varies with the head pressure of the height of the liquid.



Can't be used in closed tanks or where purging a liquid is not allowed (soap). Very popular in the paper industry because the air purge keeps the tube from plugging.

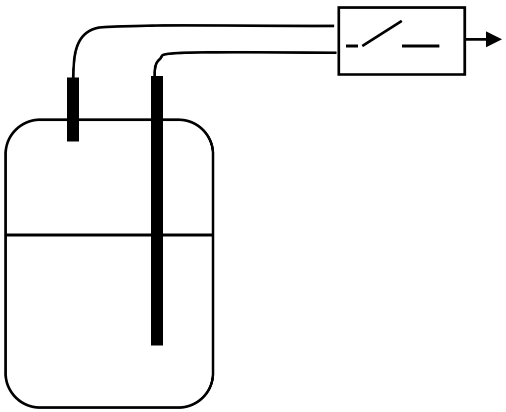
Displacers

- *Not the same as a float.*
- *The displacer is immersed in the tank and the buoyant force of the liquid produces a torque which is proportional the amount of liquid level.*

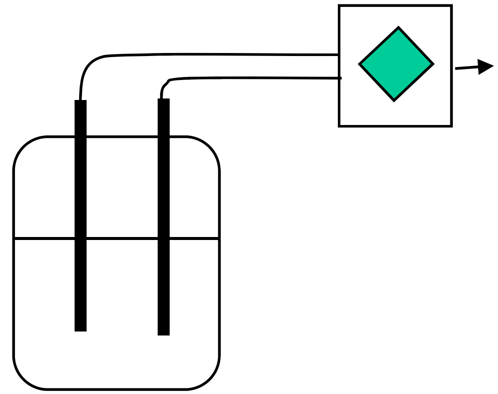


The output force can be converted to provide a proportional pneumatic or electrical continuous output of tank level.

Conductivity Level Measurement



Point Level Measurement

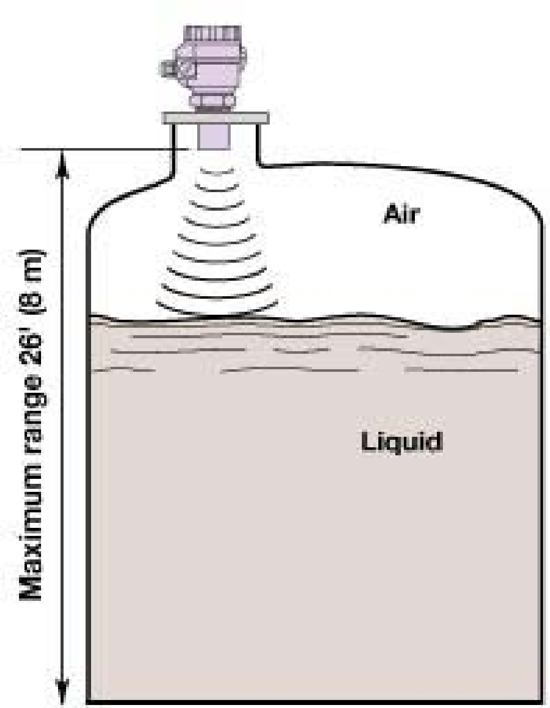


Continuous Level Measurement

Advantages and disadvantages

Low Cost
Conductive, non-coating liquids only
Insulating coatings can cause problems

UltraSonic Level Measurement



- *Non-Contact direct level sensor*
- *Level is a function of the time it takes an ultrasonic pulse to hit the surface and return*

Limitations include:

- Surface foam absorbs signal, agitation create reflections
- High Pressure & High Temperatures affect the signal speed
- Vapour and condensate create false echo's

Radar Level Sensors (Microwave)

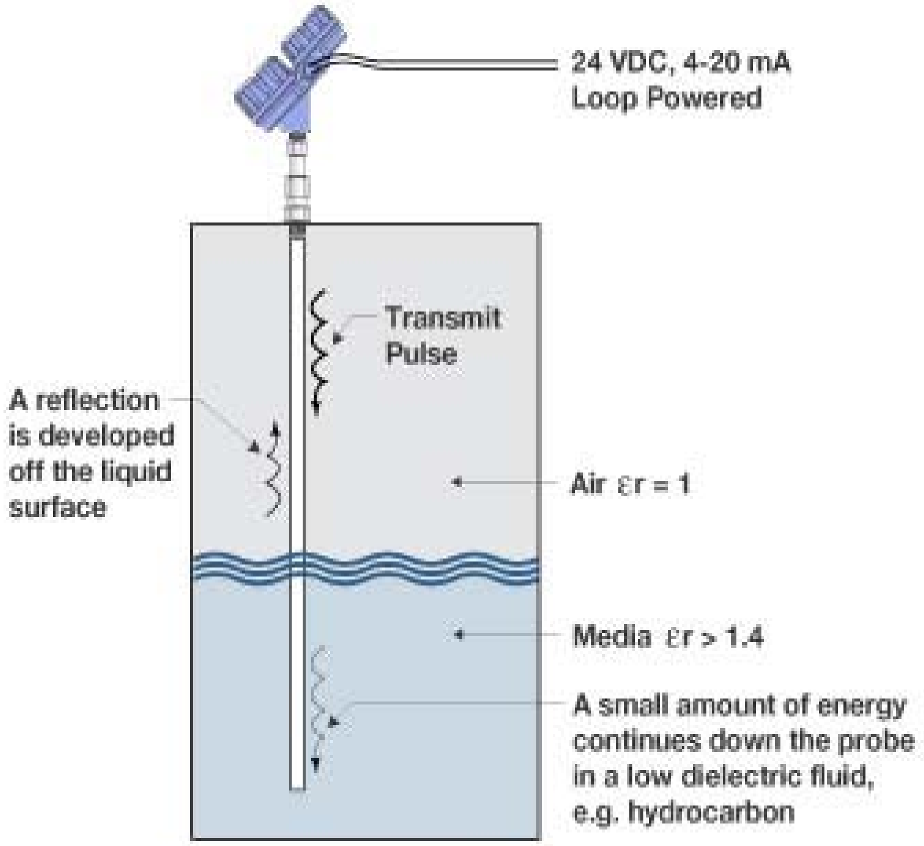
Similar to ultrasonic but at a much higher frequency (6.3 GHz)

Various designs

-- Frequency Modulated Continuous Wave

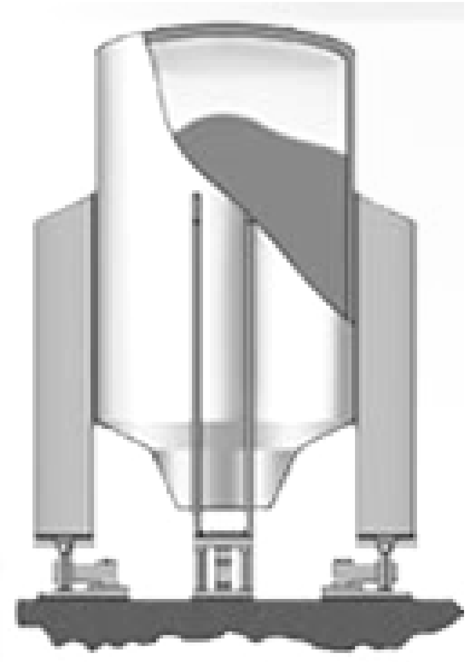
-- Pulsed Wave

-- Guided Wave



These sensors have better performance in applications where vapour, dust or uneven surfaces exist.

Load Cells

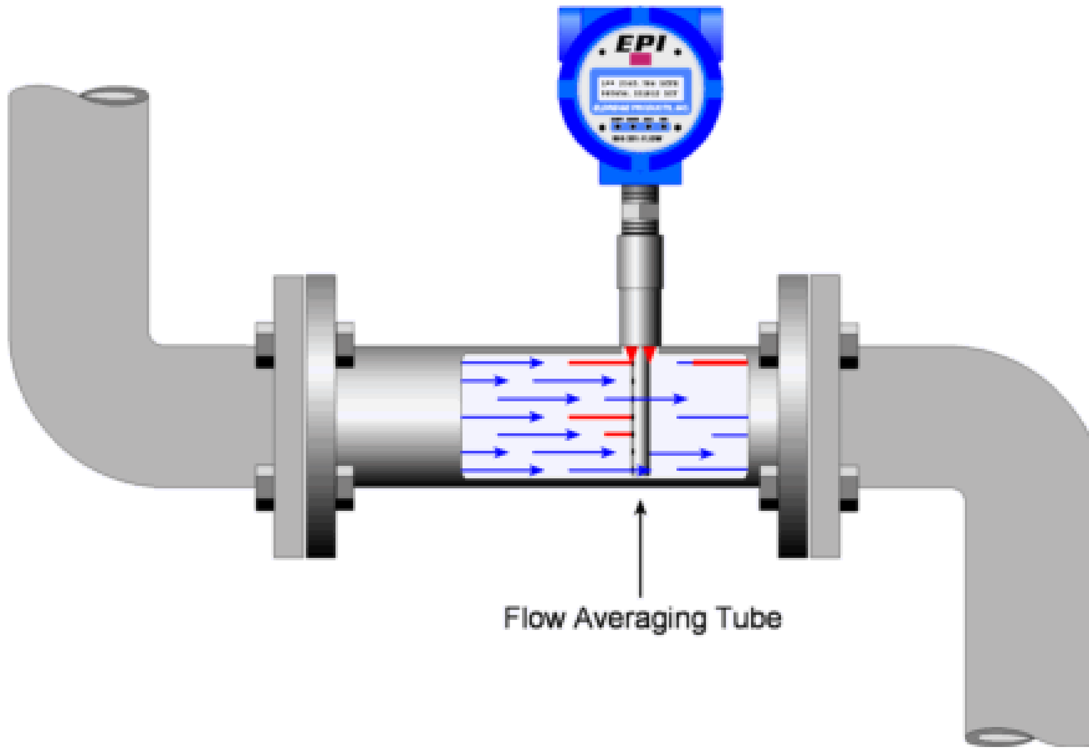


Button-Style Compression Load Cells

Tank level is determined by the weight of the quantity of material

Load Cells (strain gauge transducers) placed at the bottom of the tank measure the weight and then convert it to an electrical signal.

Flow Sensors



Reasons for Flow Metering

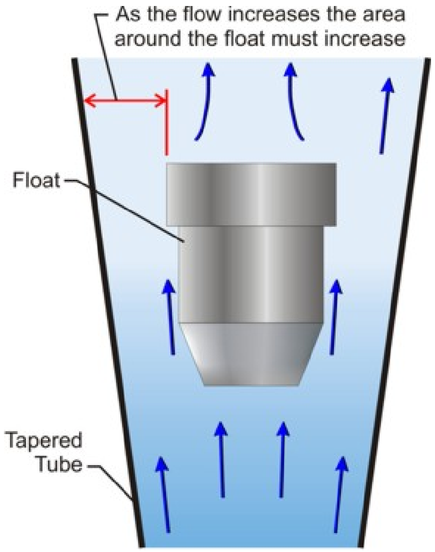
- Plant control, for product quality and safety reasons.
- Custody transfer, both interplant and selling to outside customers.
- Filling of containers, stock tanks and transporters.
- Energy, mass balancing for costing purpose and health monitoring of heat exchangers.
- Health monitoring of pipelines and on-line analysis equipment, Government and company legislation may dictate the use here of such equipment.

Types of Flow Meters

- Differential Pressure Meters.

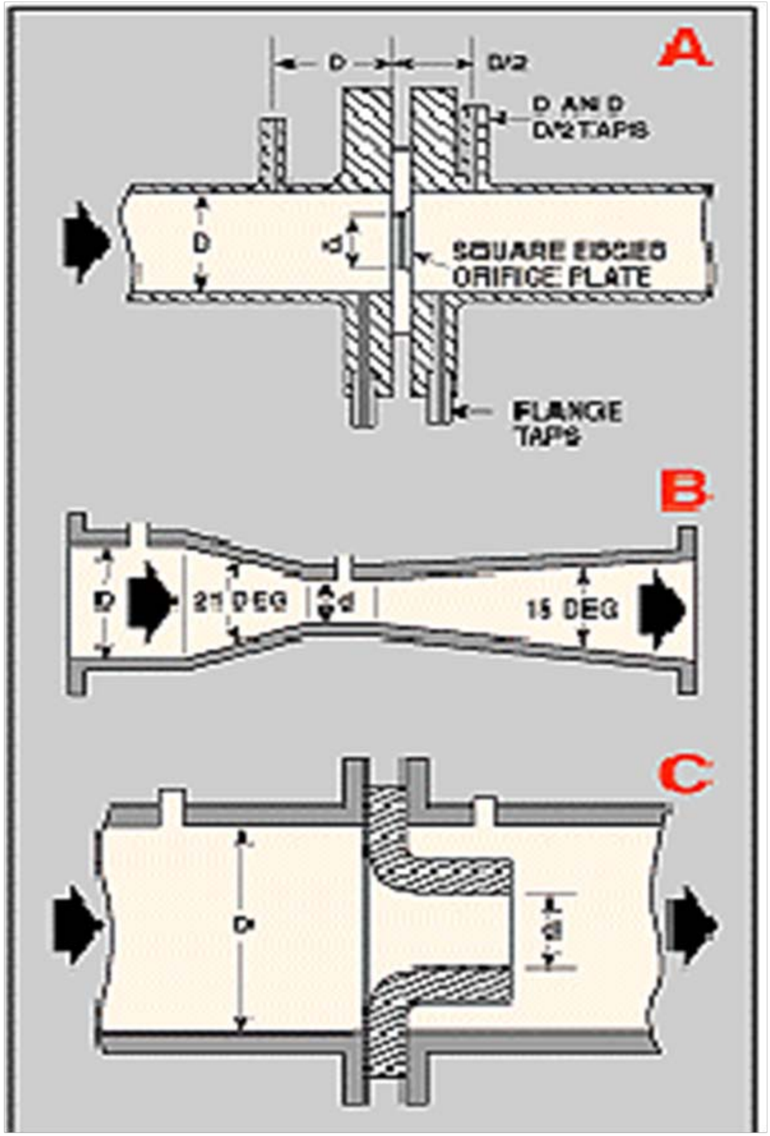
- Rotary Meters.
1. *Displacement*
2. *Inferential*

- New Flow Meters.
1. *Electromagnetic*
2. *Vortex Shedding*
3. *Ultrasonic*
4. *Cross Correlation*
5. *Tracer*
6. *Swirl*
7. *Fluidic*

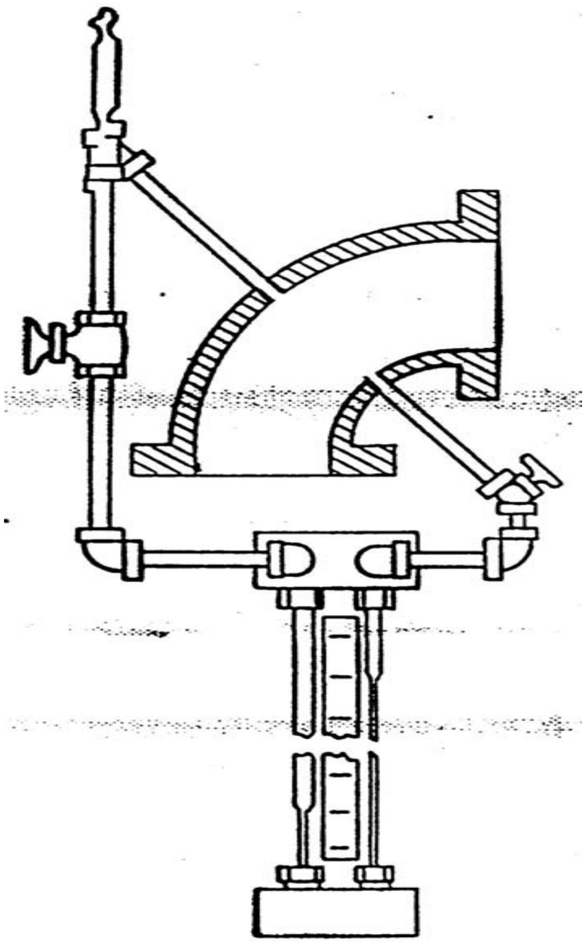


- Point Velocity Meters.
- Mass Flow Maters.

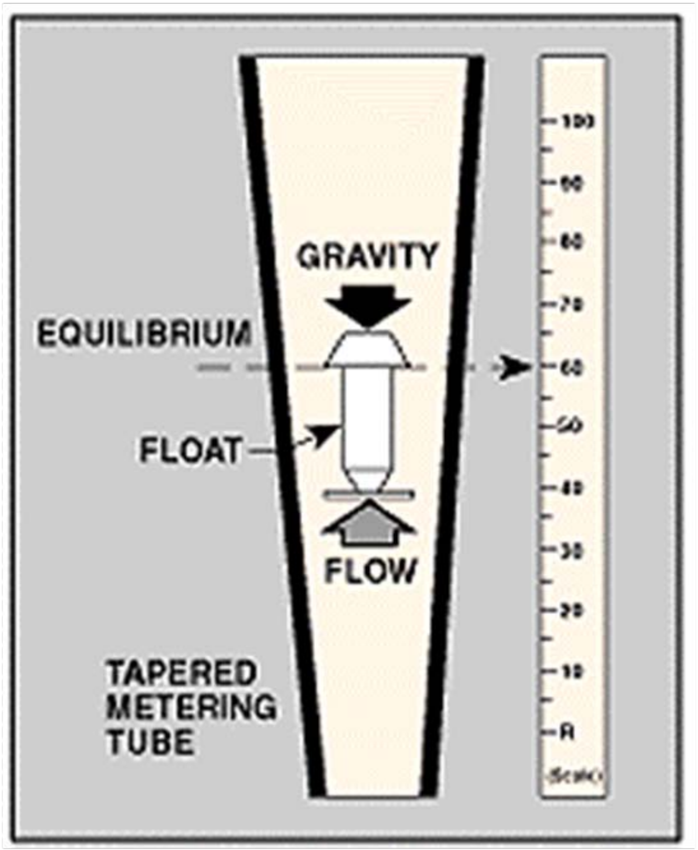
- Orifice Plate
- Dall Tube
- Venturi Tube
- Pitot Tube
- Rota meter
- Target mater
- Averaging Pitot
- Nozzle
- Spring Loaded
- Intake Meter
- Elbow Meter
- Bypass Meter



Differential Pressure Meters (Cont‘d)



Elbow Flow meter



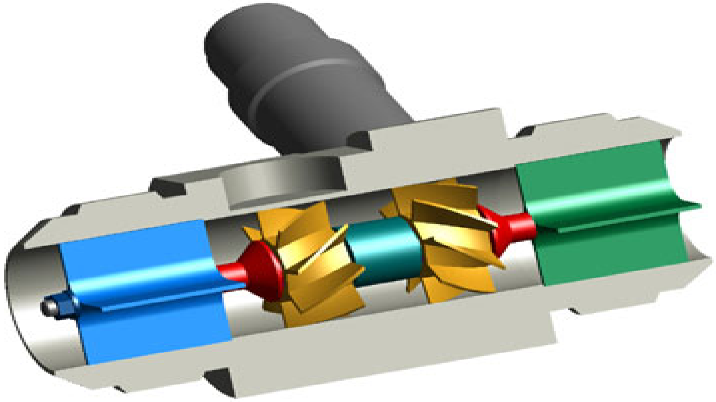
Rota meter

Displacement Meters

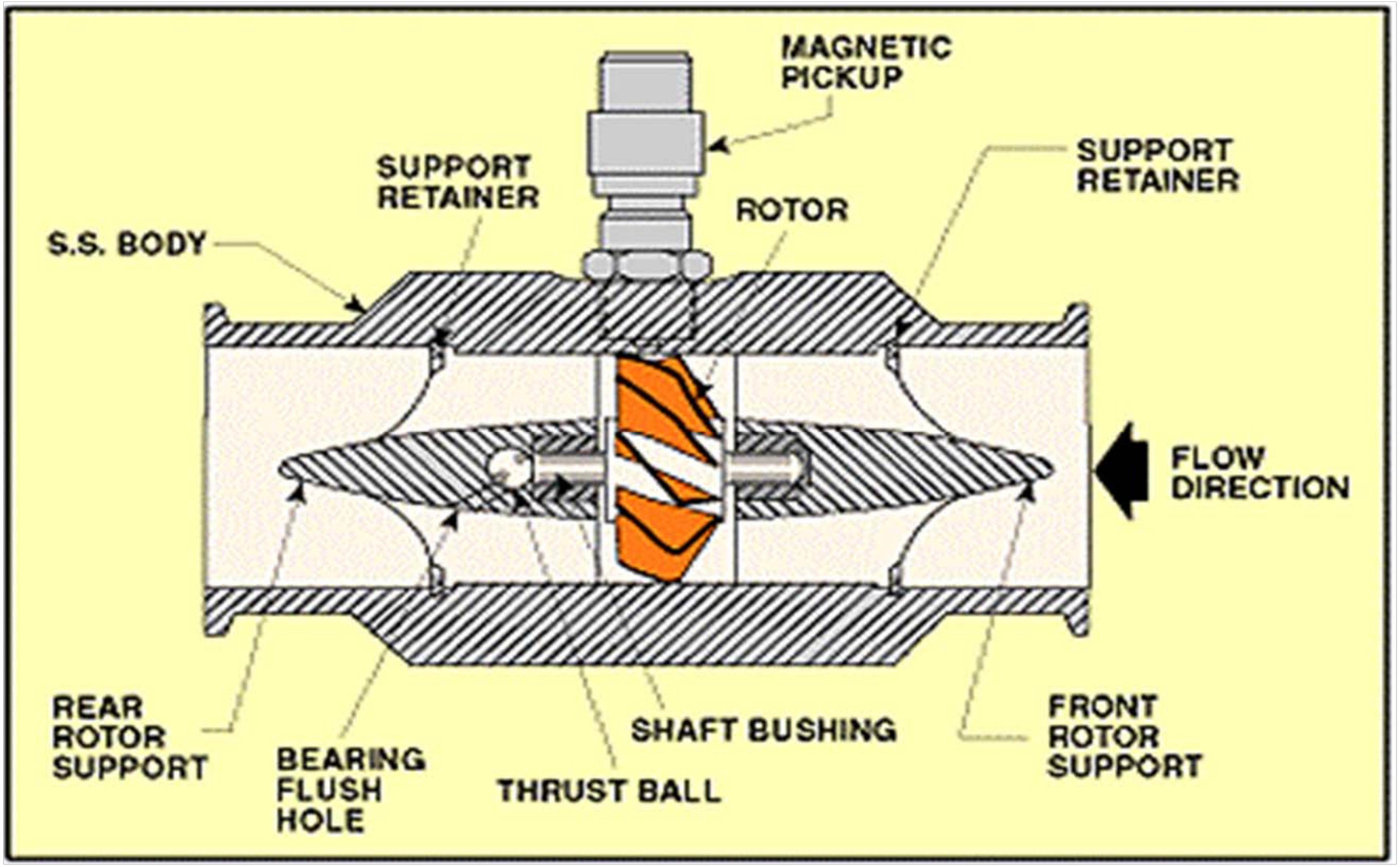
- Gear
- Oval wheel
- Vane Meter
- Gear (Roots)
- Diaphragm Meter
- Liquid Sealed Meter

Inferential Meters

- Turbine Meter
- Hoverflo Meter



Turbine Flow Meters



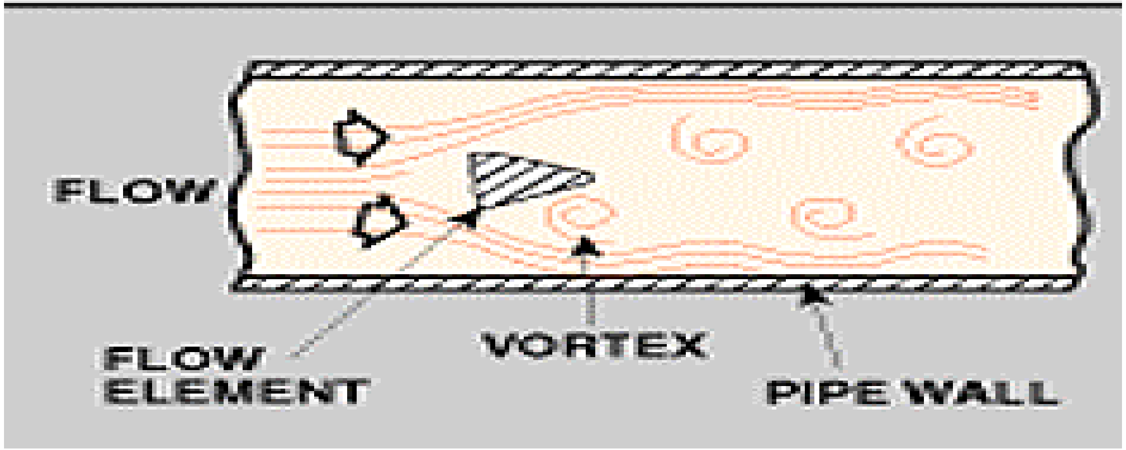
- Electromagnetic

EM Meter

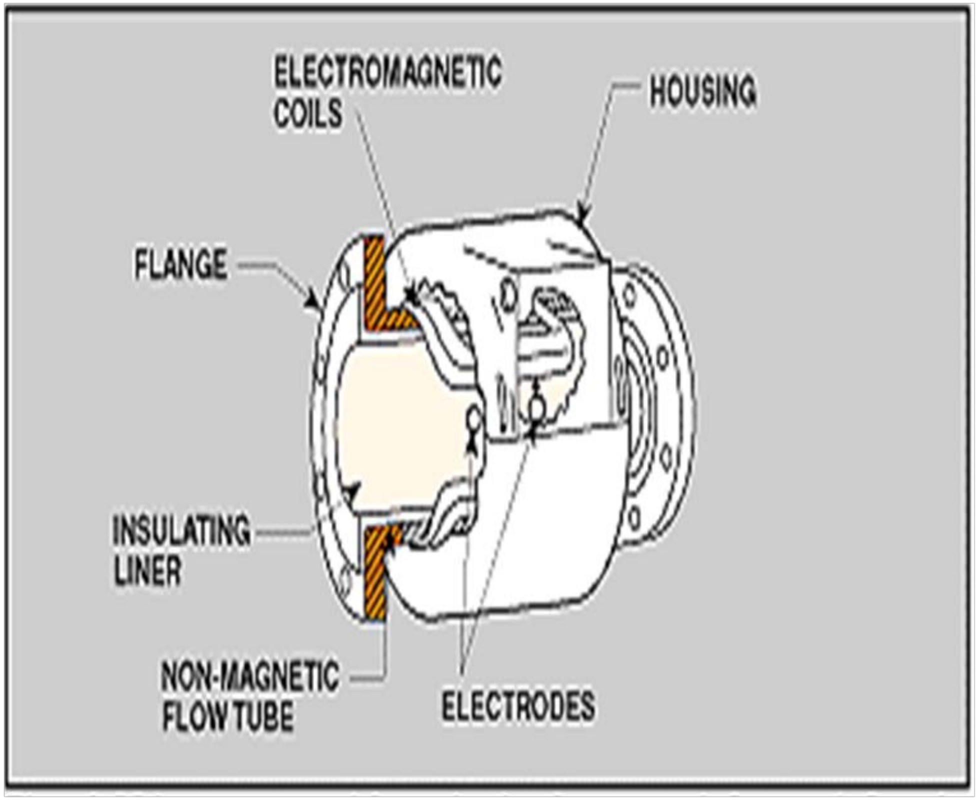
- Vortex Shedding Meter

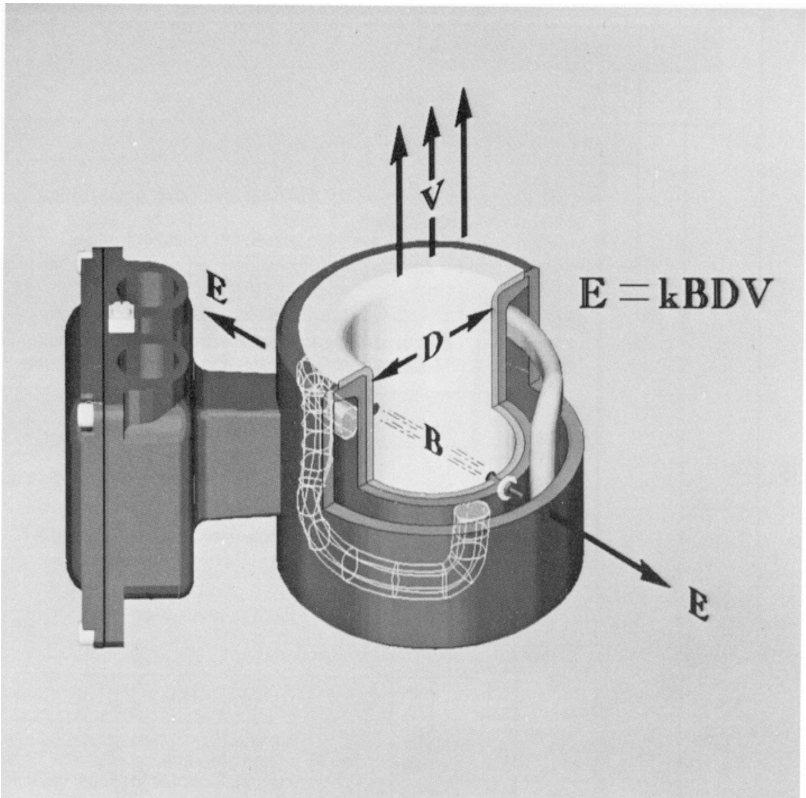
Vortex Generation Meter

- Ultrasonic Flow Meters

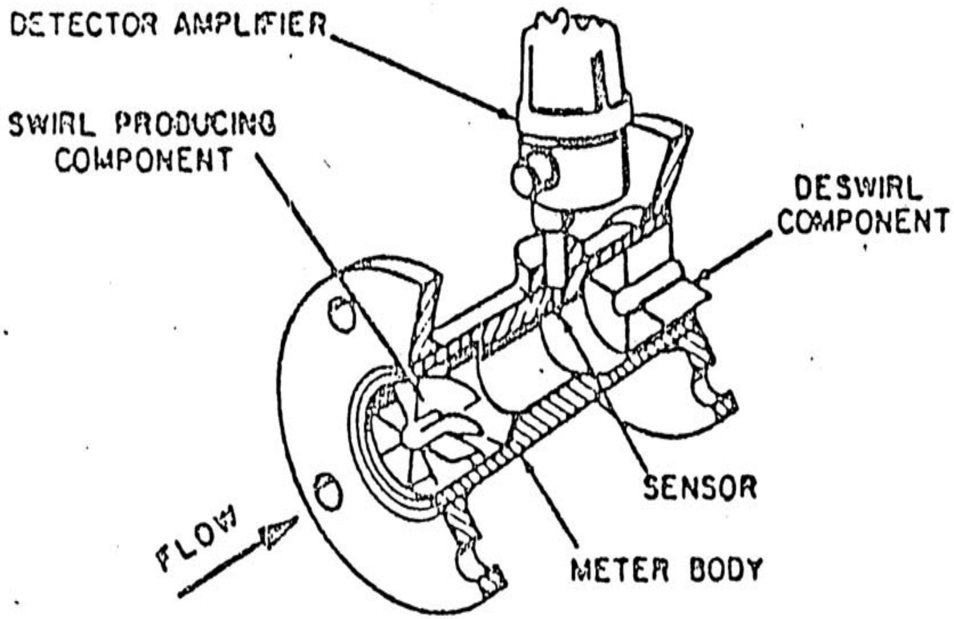


Magnetic Flowmeter



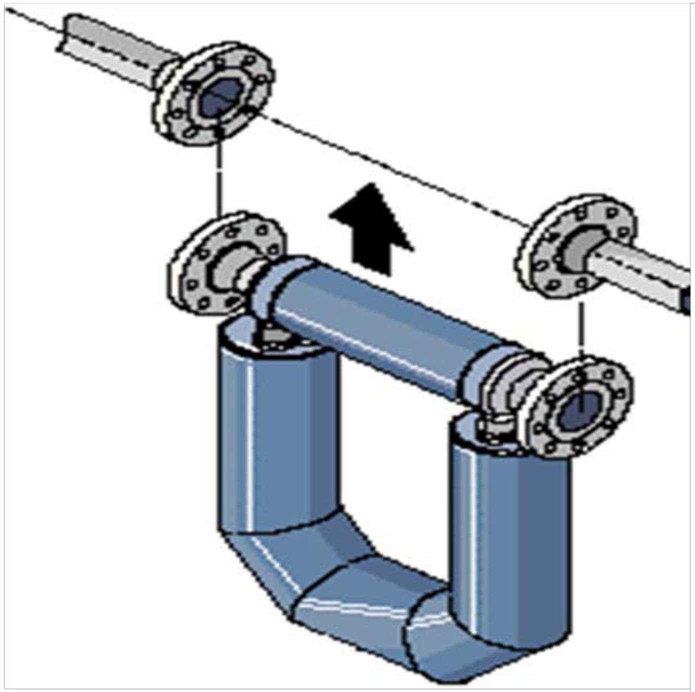


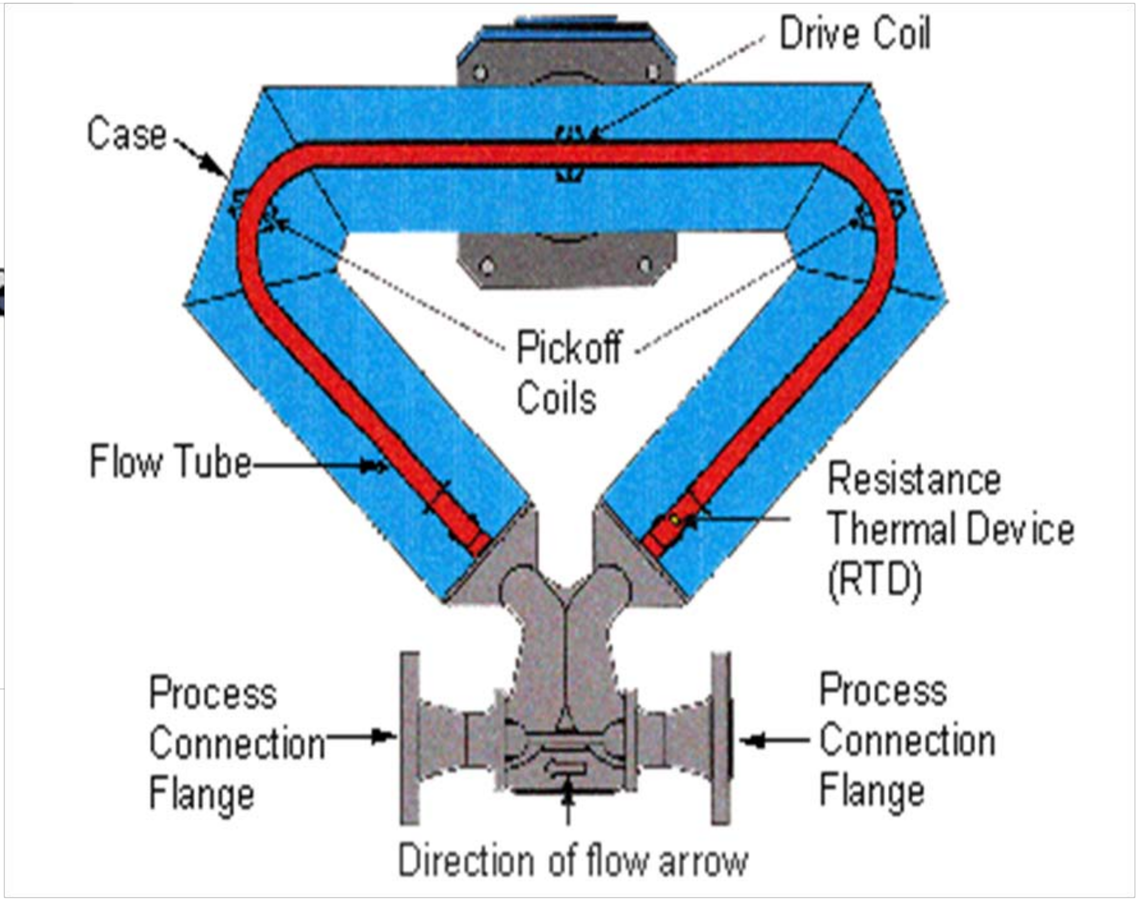
New Flow Meters (Cont‘d)



Swirl Meter

Coriolis Mass Flowmeter





Others

- pH meter
- Turbidity Meter
- Dissolved oxygen meter
- Atomic absorption spectrophotometer
- Gass Chromatograph etc.

Discussion & Questions?

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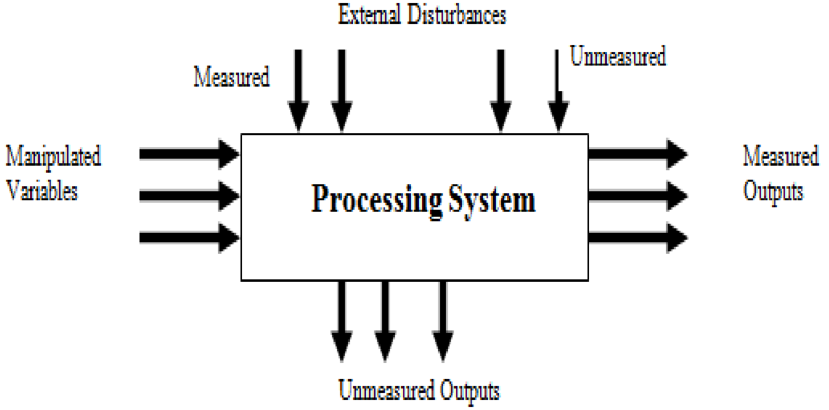
Design of Control Systems & Standard Practices



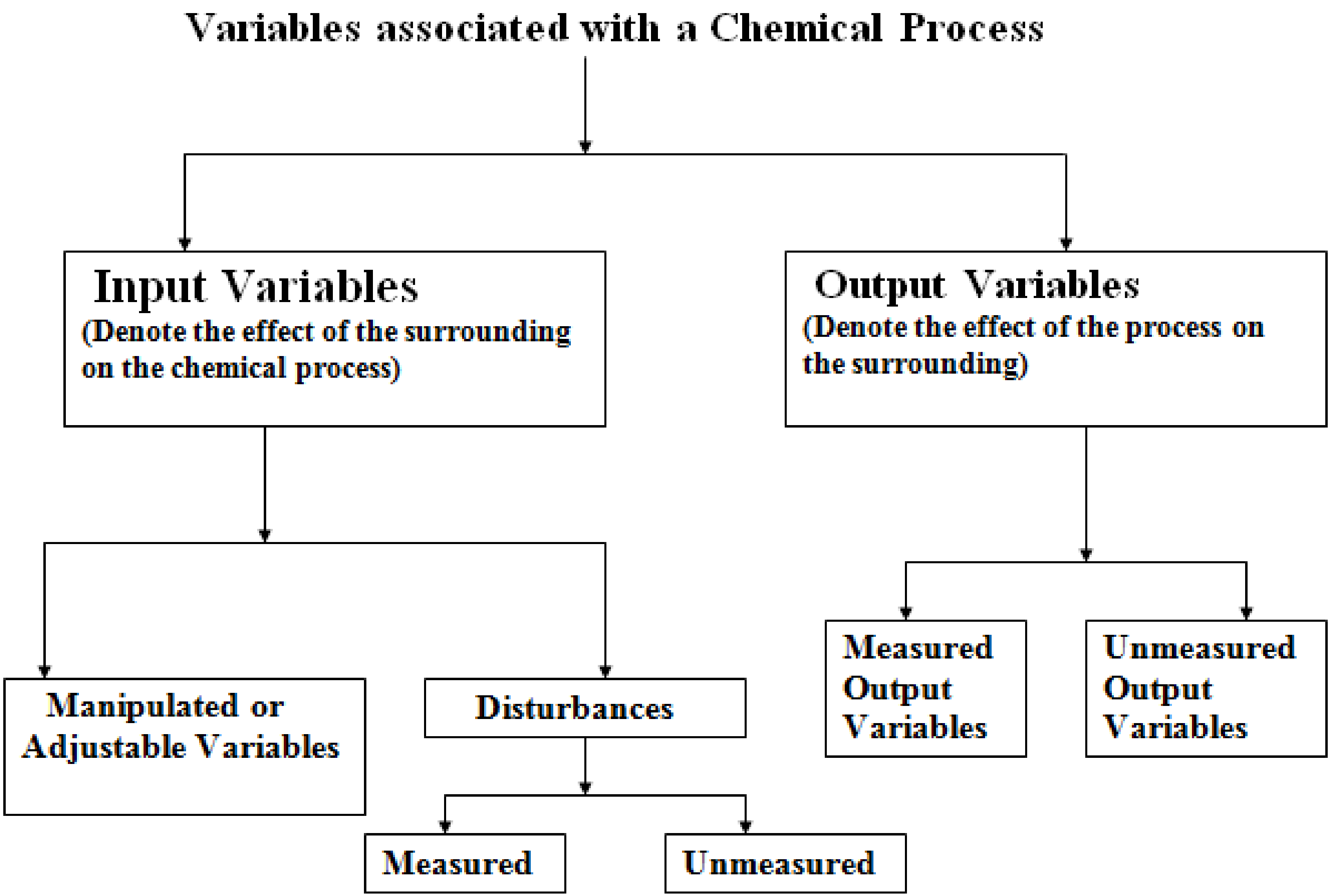
Lecture -3

Prof. Dr. Shahid Naveed

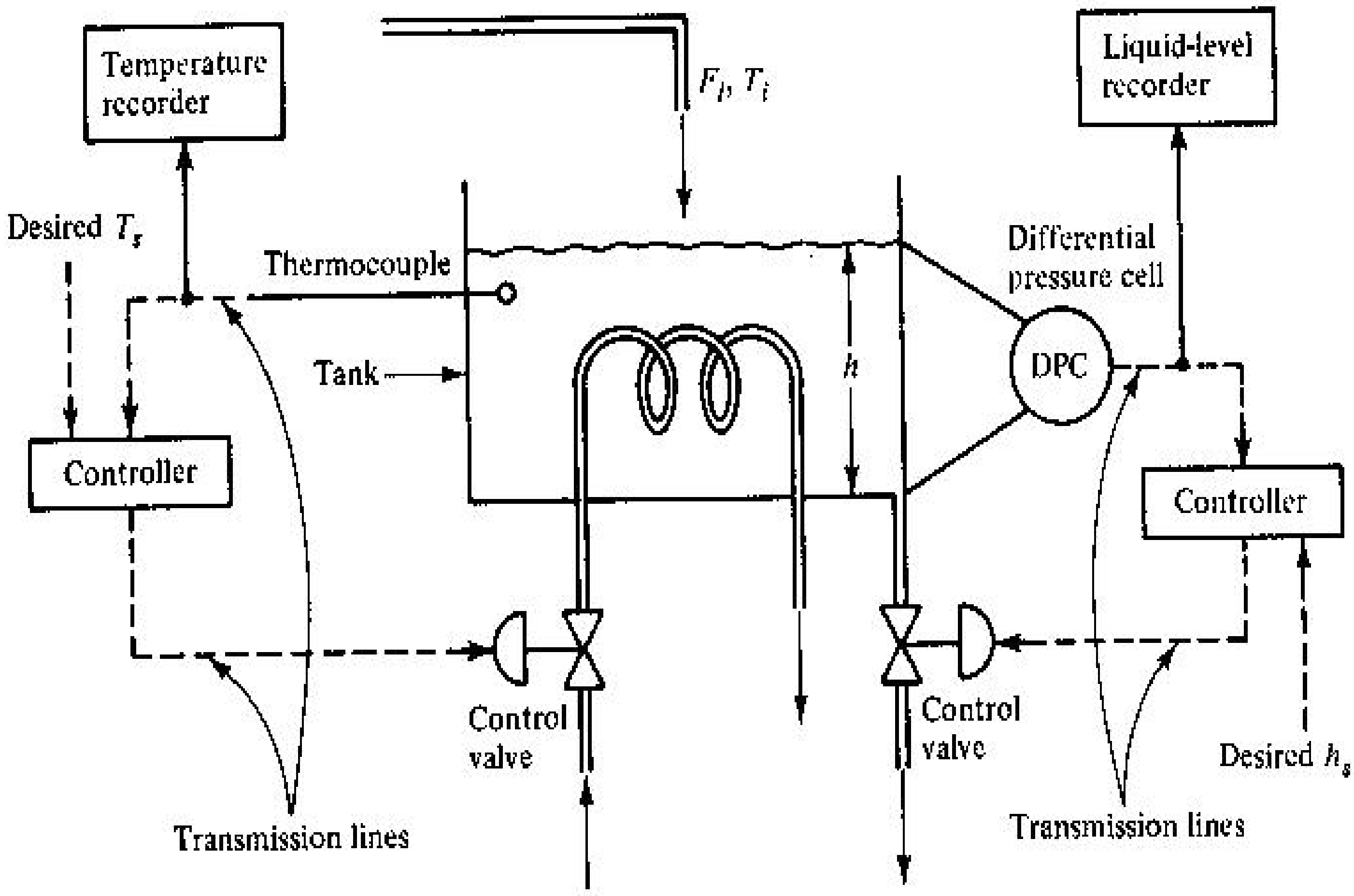
Sequence of Presentation

1. Design Objectives and Variables
2. Steps in Design of a Control System
3. Standard Practices
4. Controller Selection & Tuning
5. Conclusion

Variables in a Chemical Process



Hardware for a process Control System



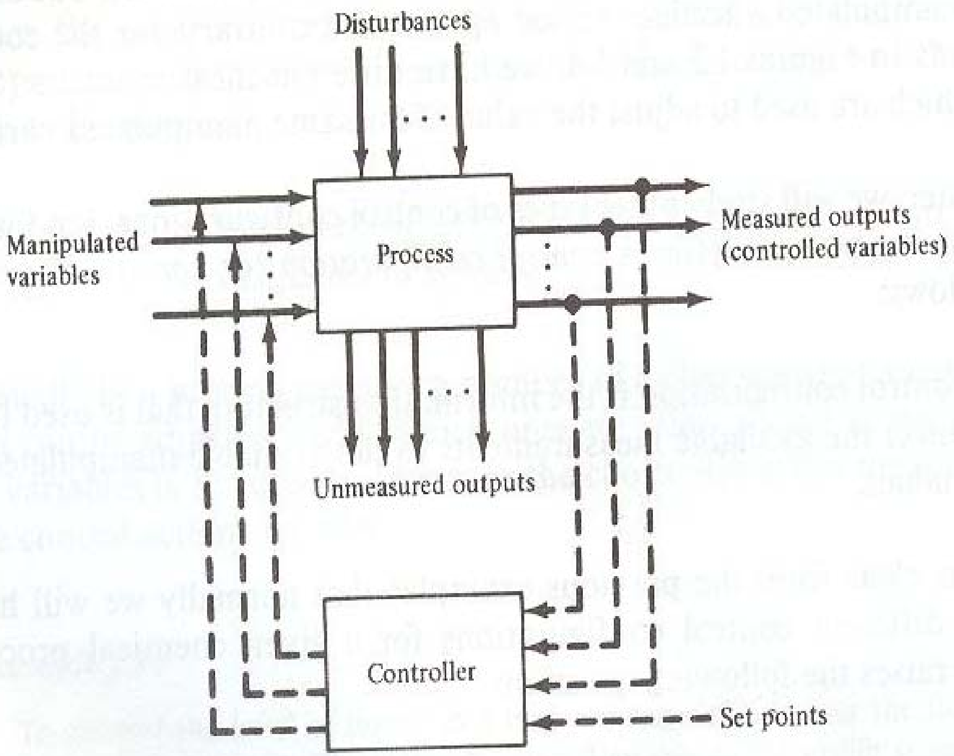
Steps in Design of a Control System

1. Define the control objective (Purpose)
2. Select the measurement variable/s

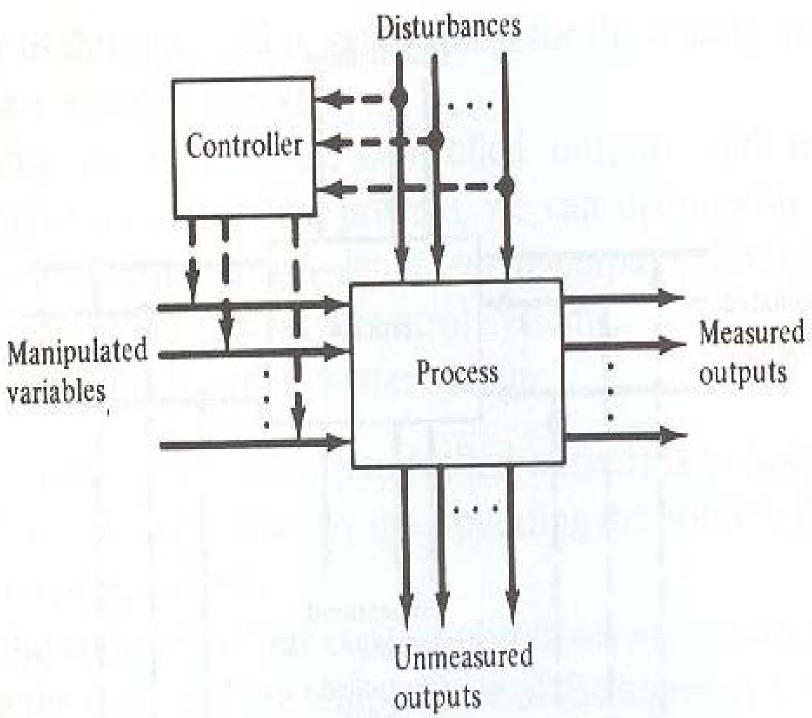
   (Primary / Secondary measurements, Easily, Rapidly, Reliably)
3. Select the manipulated variable/s (Utility/process)
4. Choose the control configuration (Configuration Standard/New)
5. Design/choose the controller

   (Degree of controllability desired)
6. Design of multiple input multiple output systems (MIMO)

Feedback control

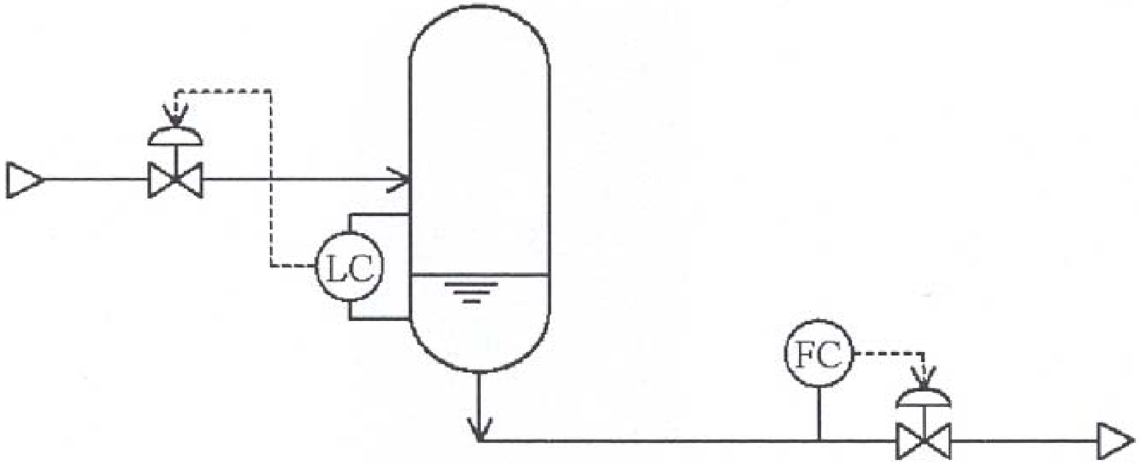


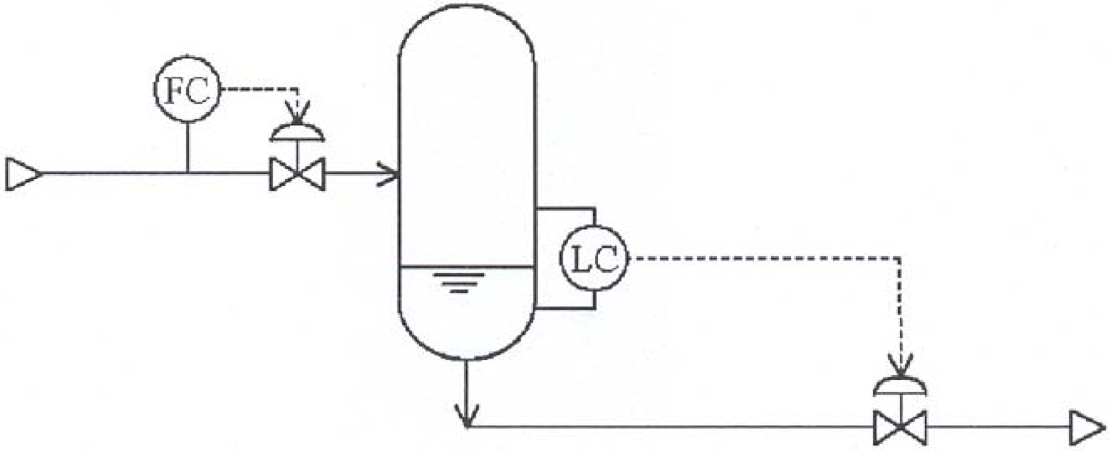
Feed-forward control



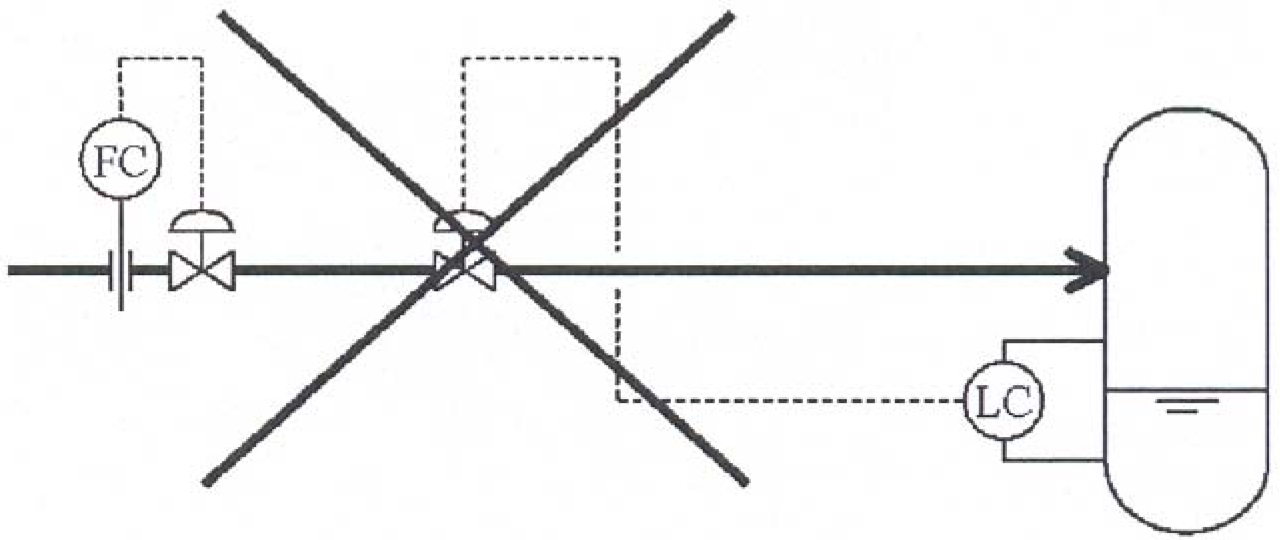
Recommended Control Schemes and Standard Practices

Level Control



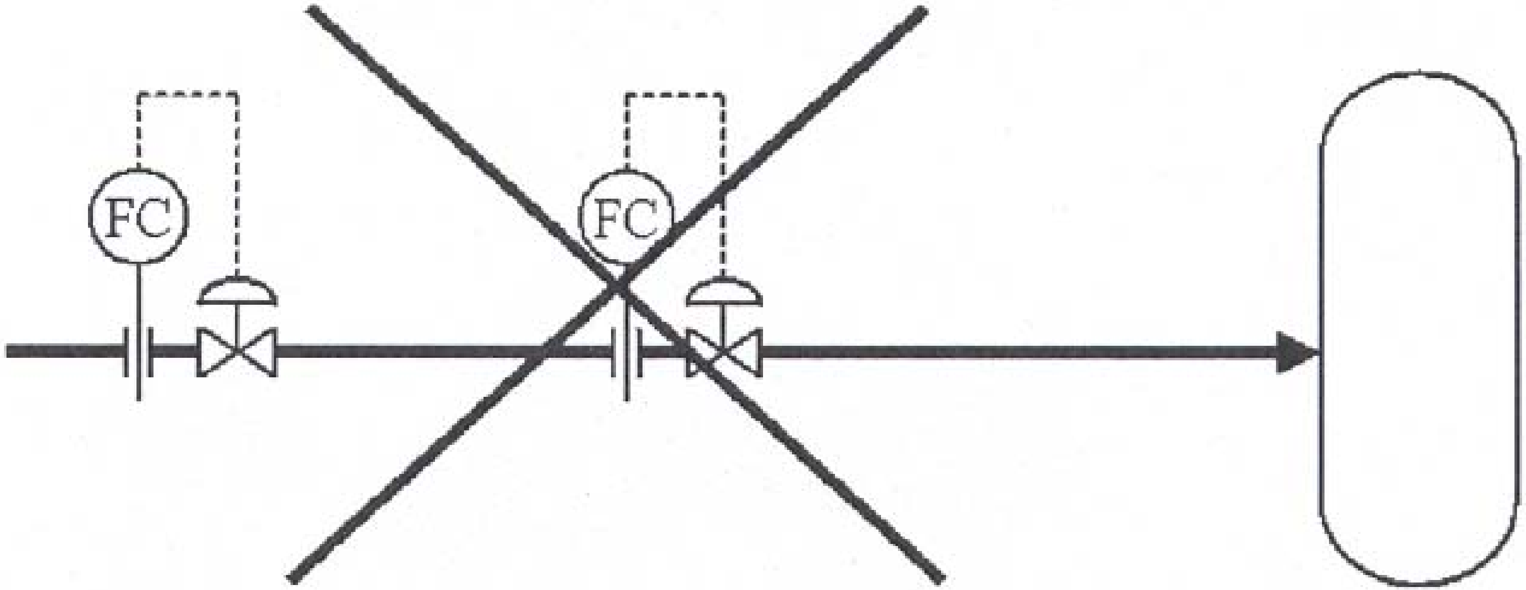


Level Control (cont'd)

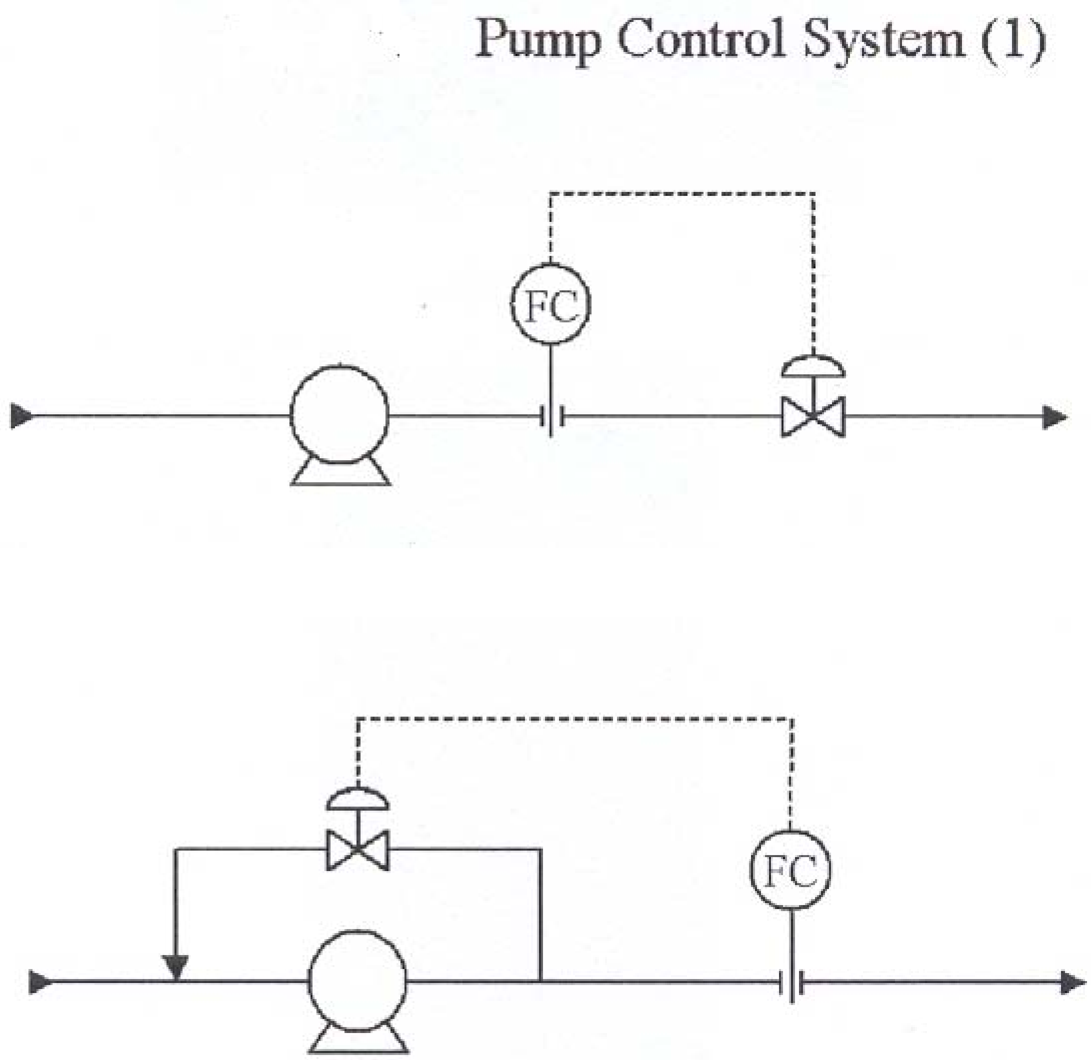


Flow Control

Two FC's on Onstream (Wrong Configuration)

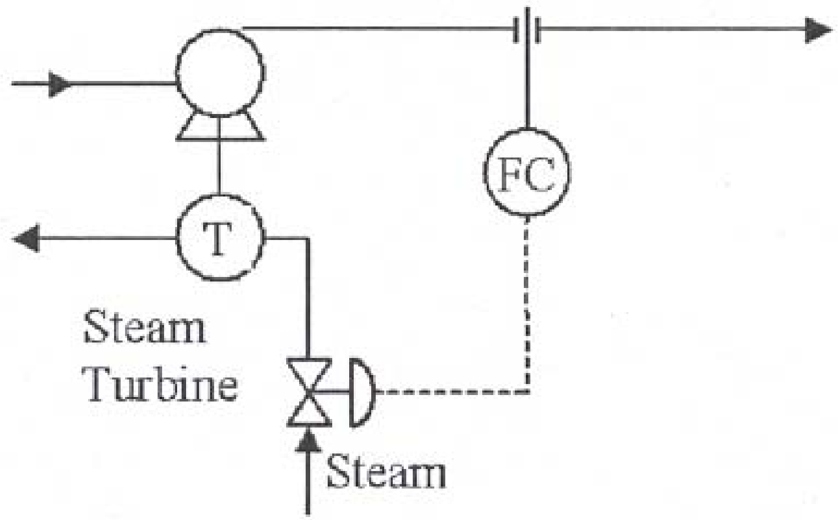


Pump Control



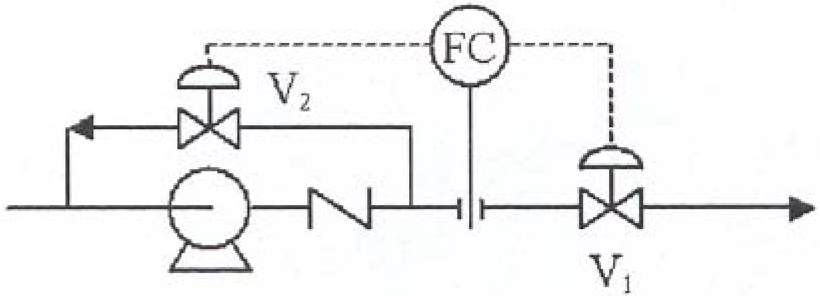
Steam Turbine Driven Pump Control

Flow Control at a Centrifugal Pump Driven by a Steam Turbine

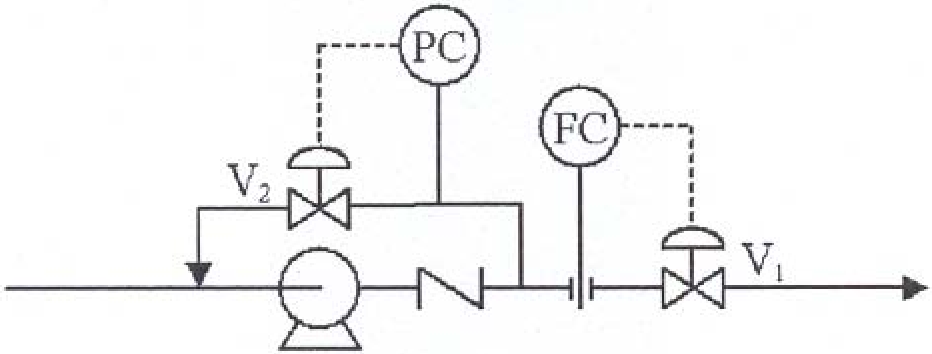


Rotary Pump Control

Flow Control at a Rotary Pump by a Discharge Valve and Spillback Valve

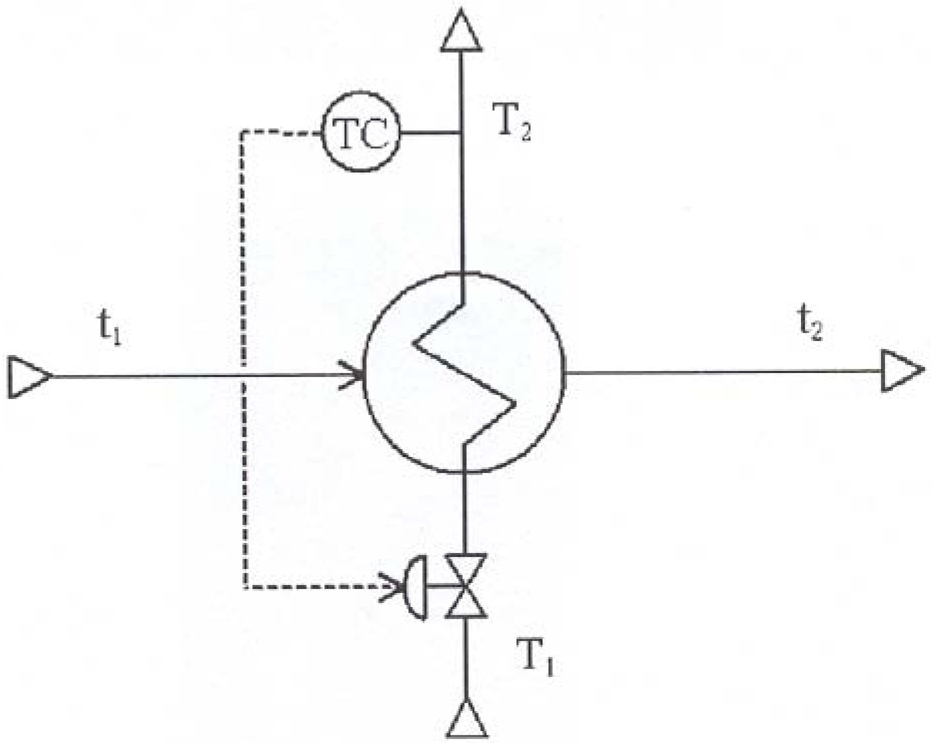


Flow Control at a Rotary Pump by FC and PC



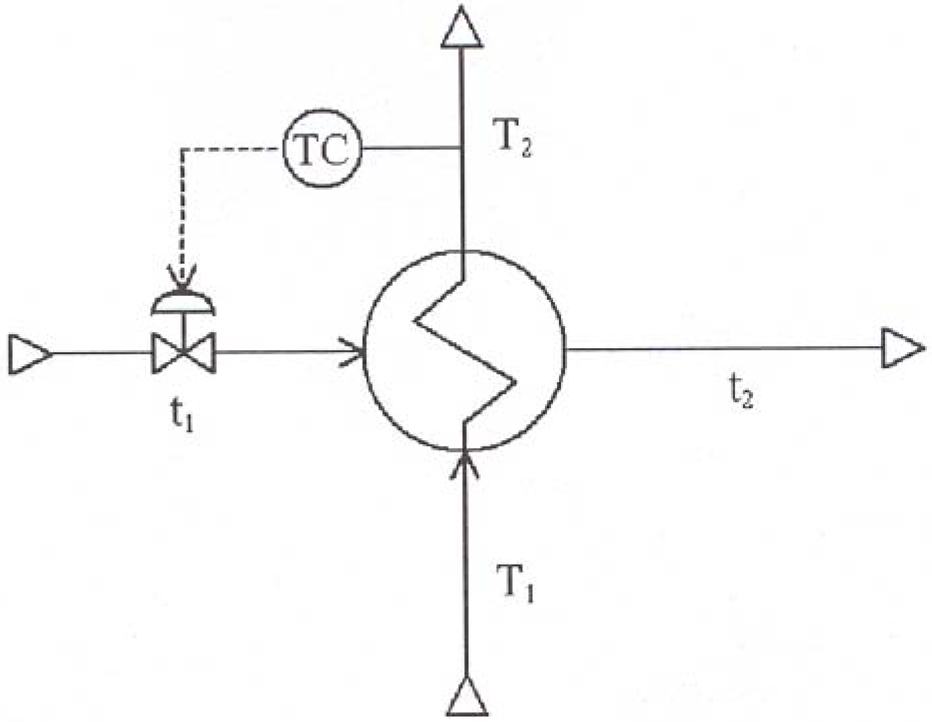
Temperature Control of HE

Temperature Control of a Heat Exchanger (1)

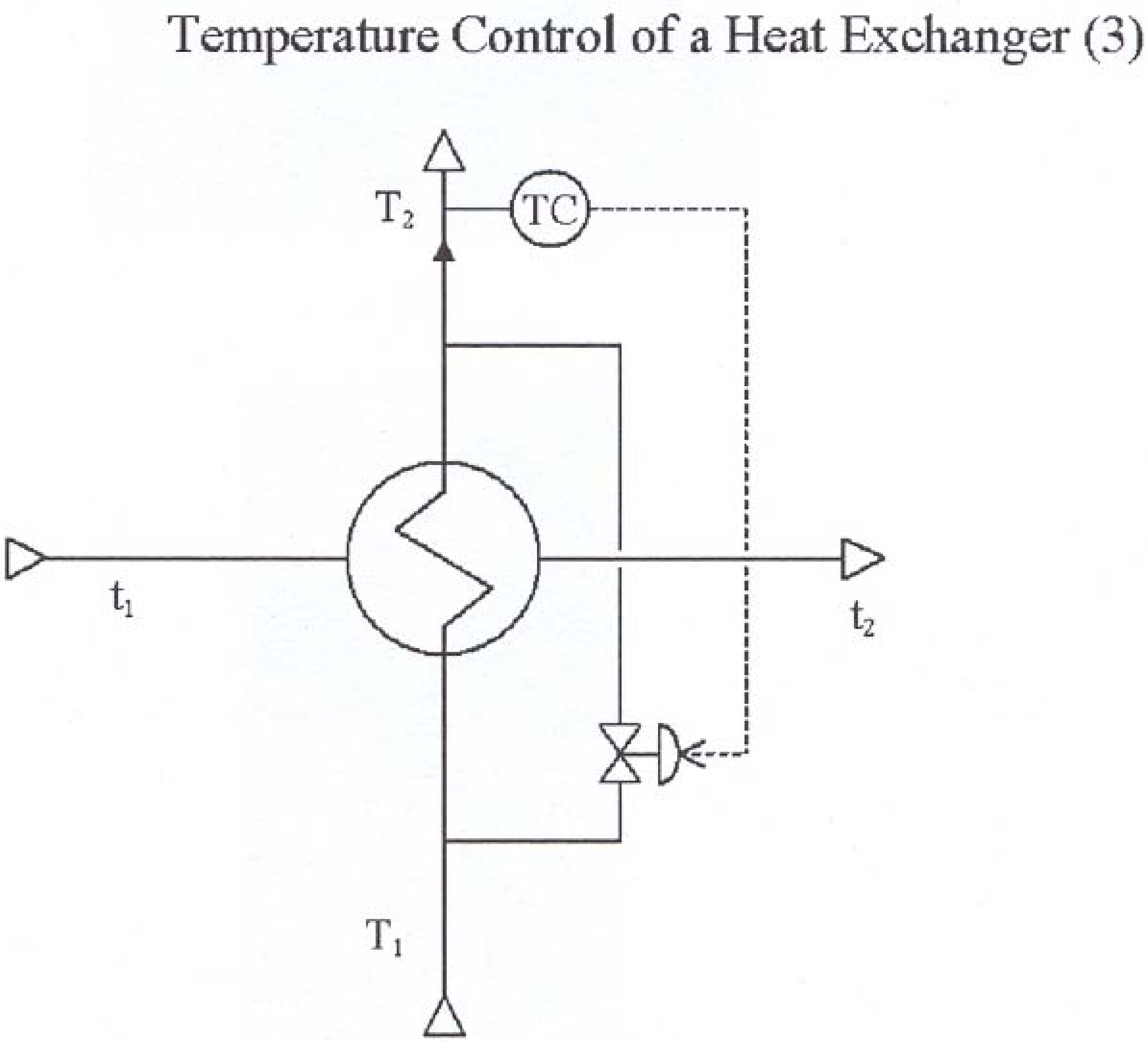


Temperature Control of HE (cont'd)

Temperature Control of a Heat Exchanger (2)

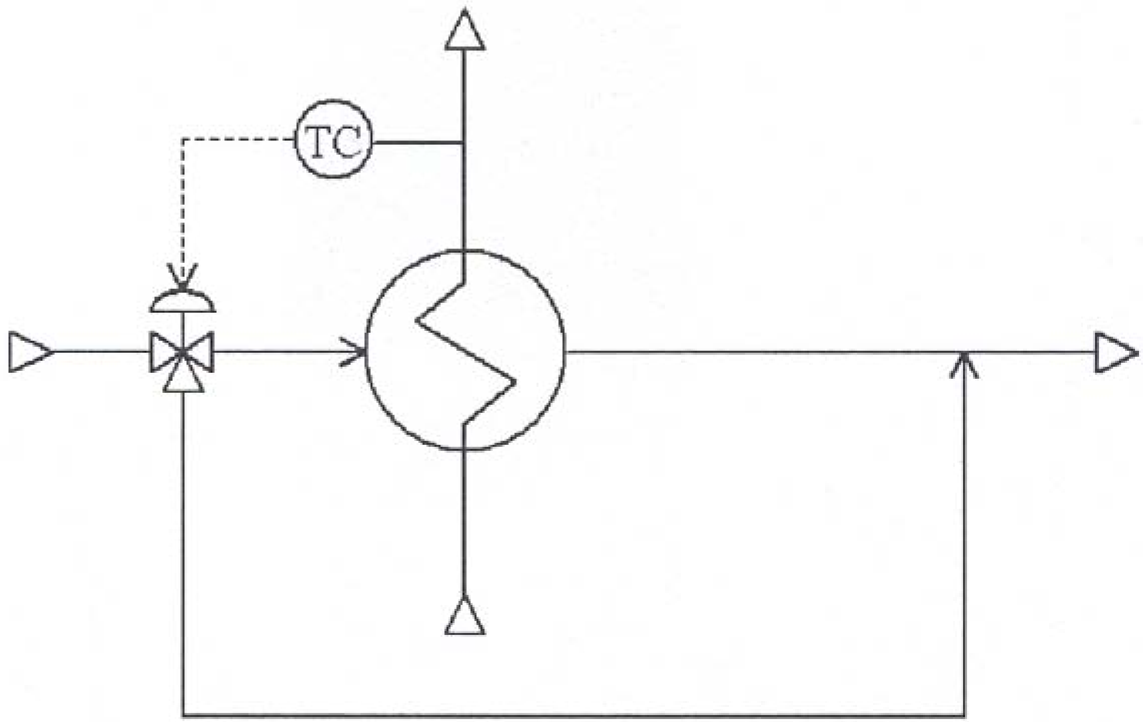


Temperature Control of HE (cont'd)



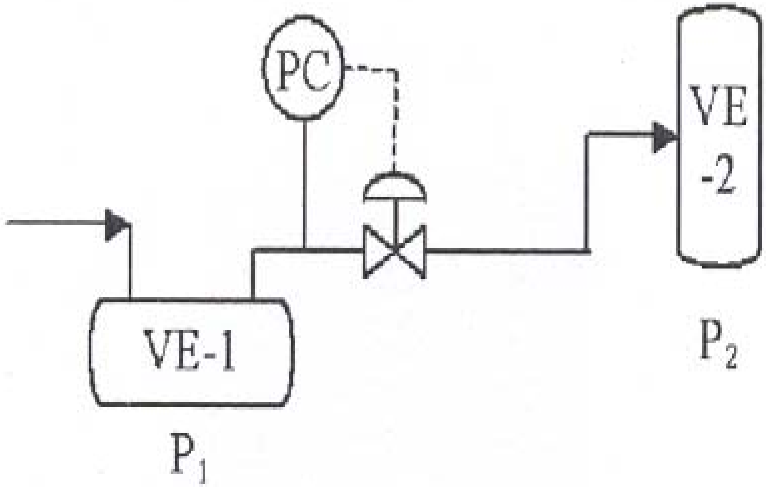
Temperature Control of HE (cont'd)

Temperature Control of a Heat Exchanger (5)

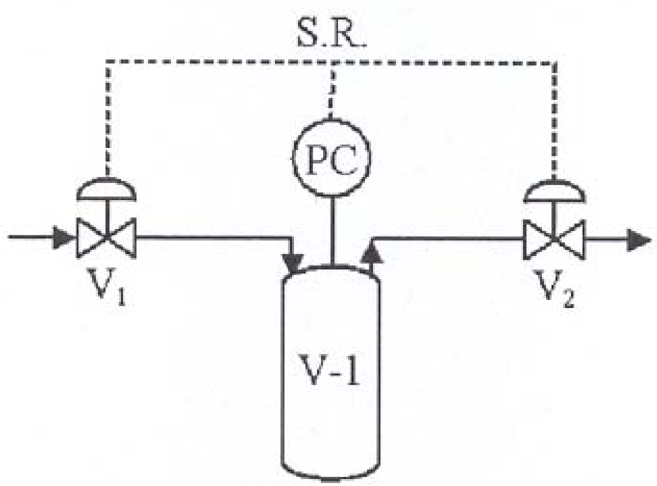


Pressure Control of Pressure Vessel

Pressure Control of Pressurized Vessel by the Vessel Outlet PCV

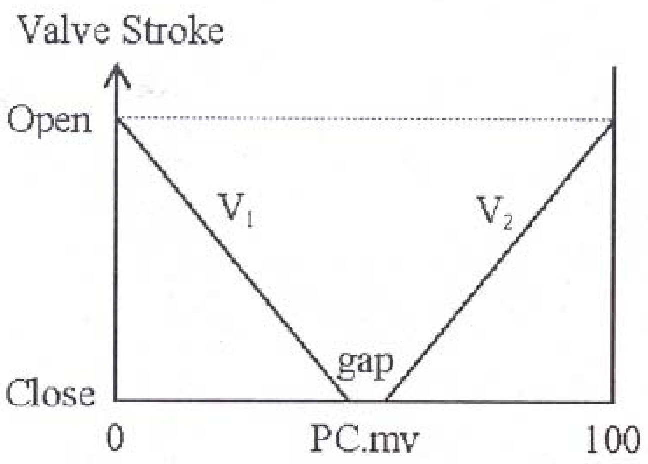


Pressure Control of Pressurized Vessel by SR of Inert Injection and Vapor Discharge

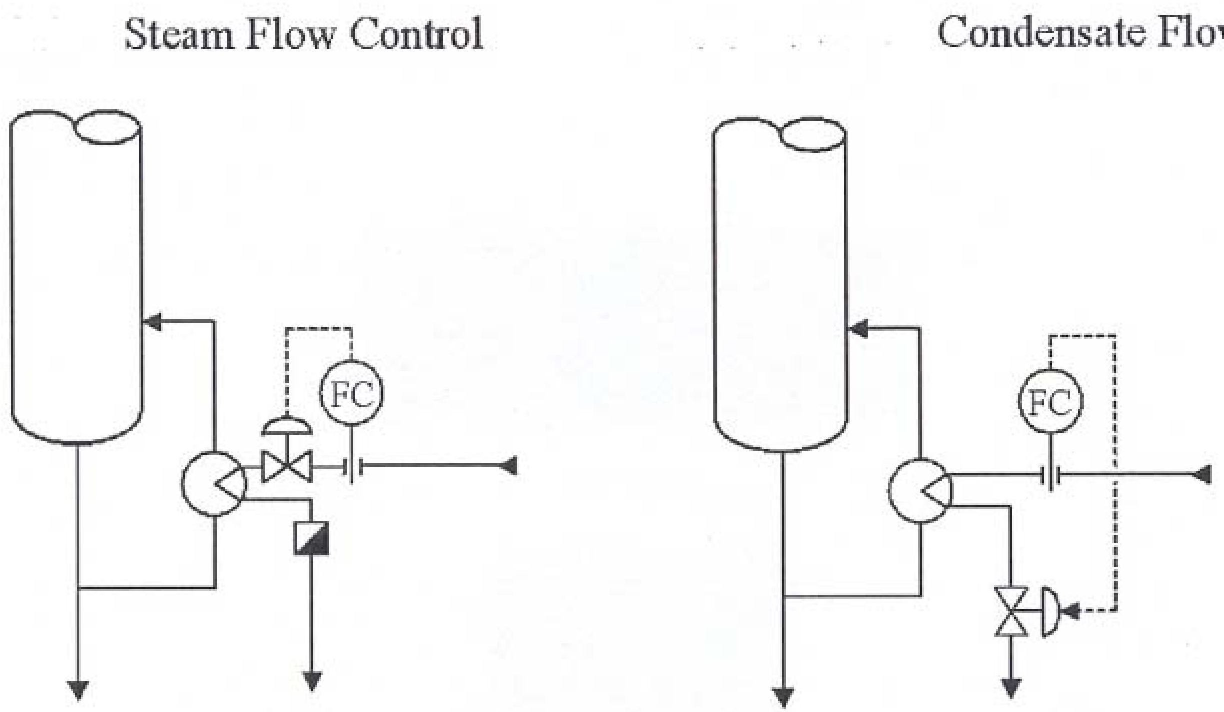


Common for net zero vapor application.

SR may be configured with some gap.

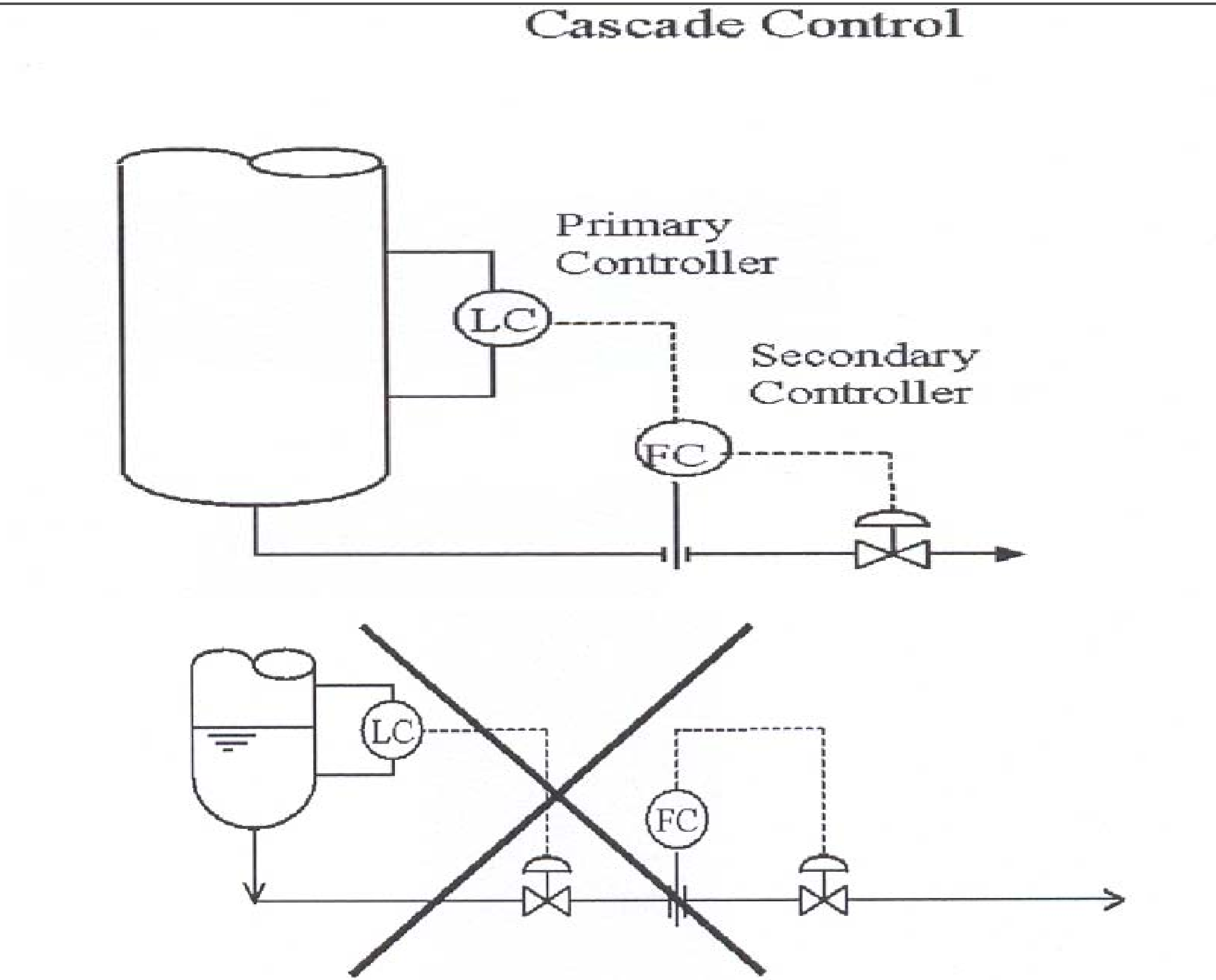


Steam Flow Control (Reboiler)

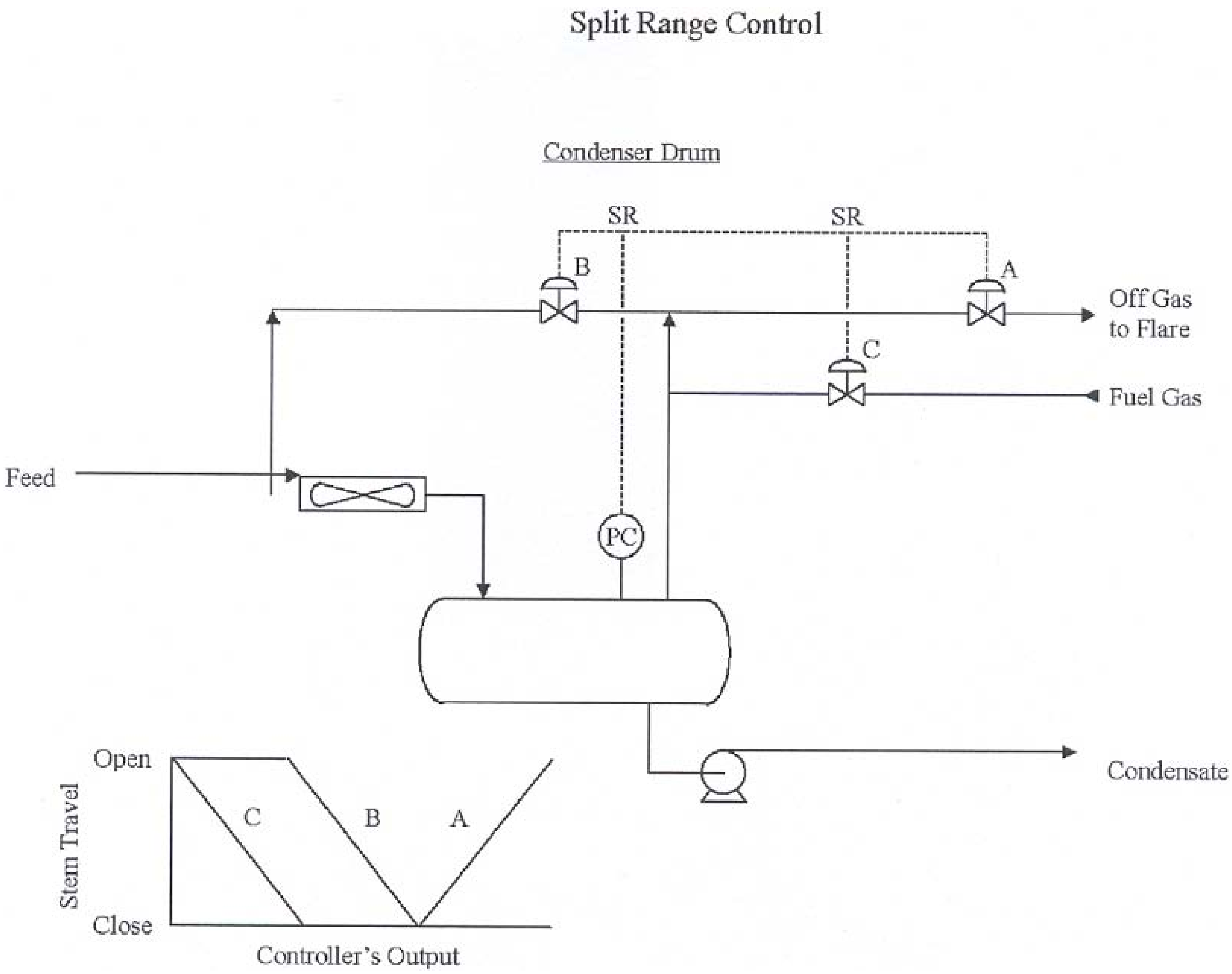


NOTE:
FI should be better located at the upstream of the reboiler from the layout's viewpoint.

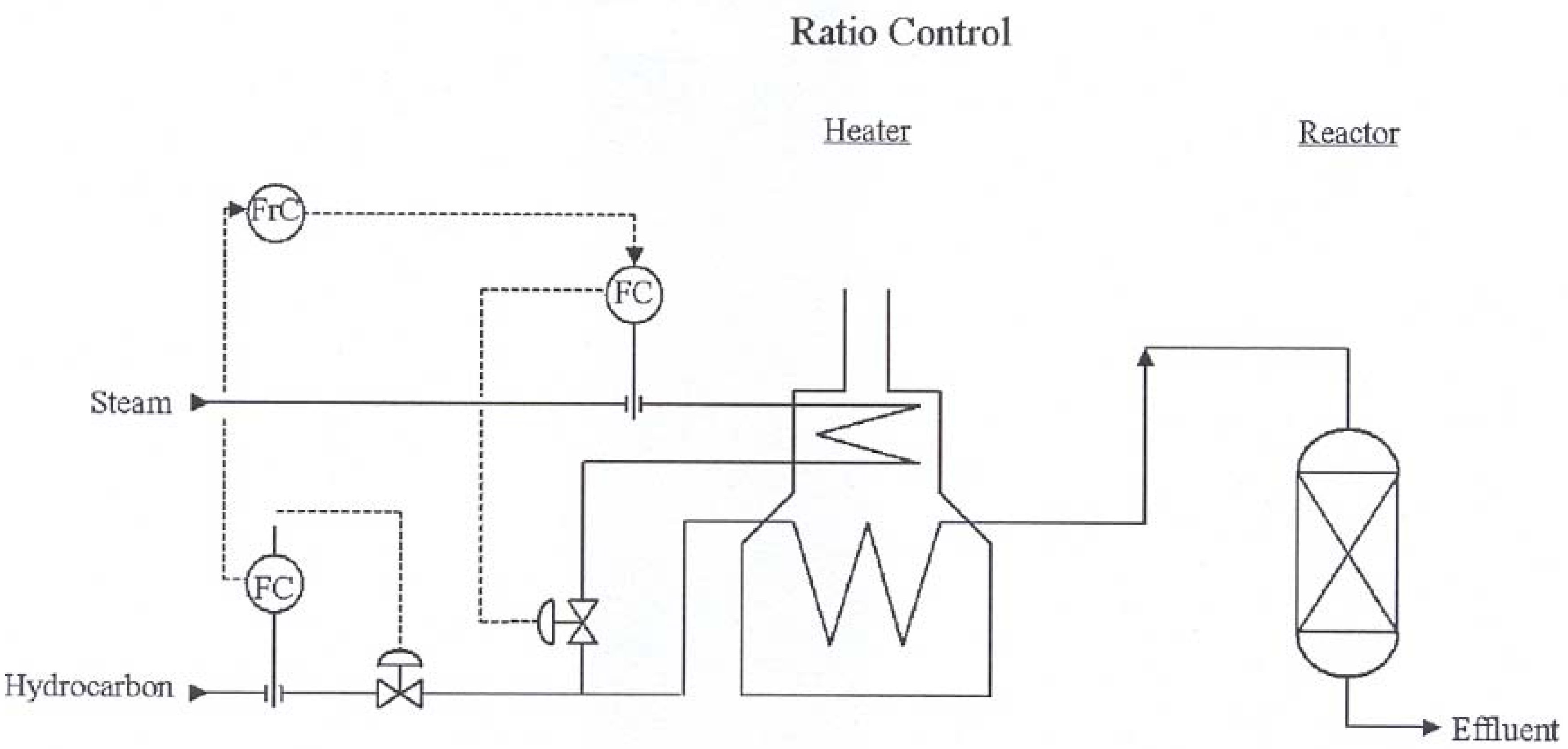
Cascade Control



Split Range Control

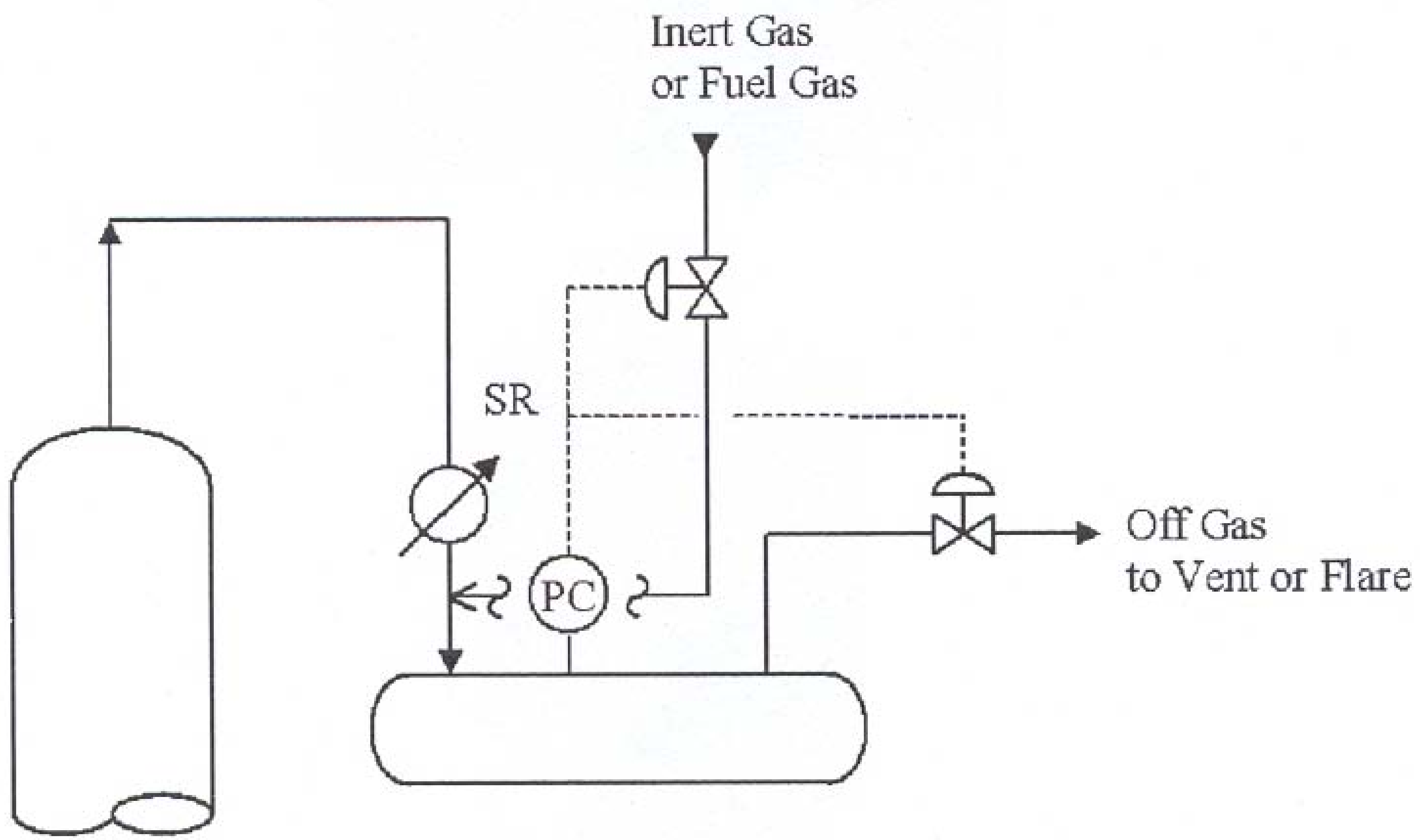


Ratio Control



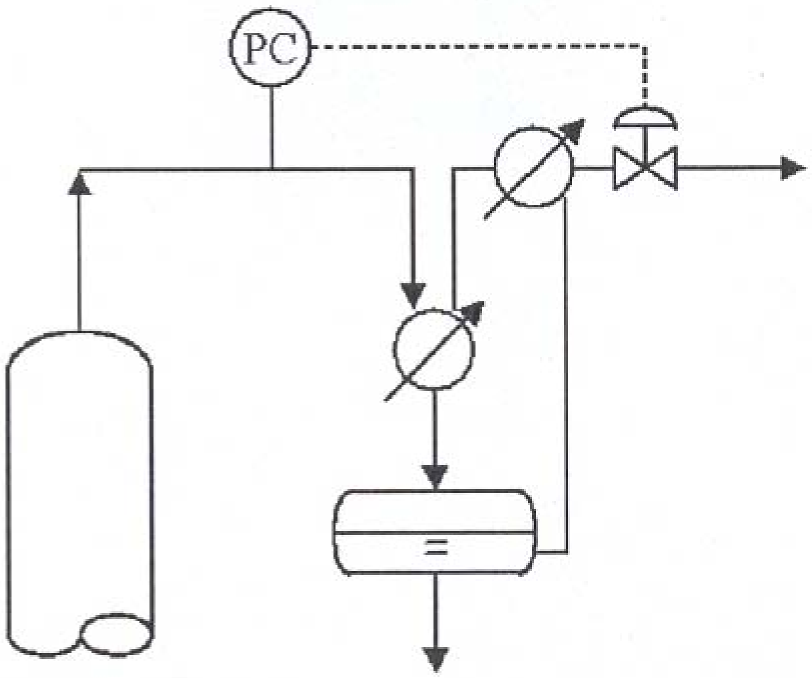
Pressure Control

Pressure Control of Distillation Tower (2)



Pressure Control (Cont'd)

Pressure control of Distillation Tower (3)



Controller Selection & Tuning Methods

Available Methods

- Ziegler-Nichols Tuning Technique
- Cohen-Coon Setting
- Quartering Technique
- Minimum Offset
- Minimum Integral Square Error ISE
- Minimum Integral Time Average Error ITAE
- Minimum Integral Average Error IAE

Ziegler-Nichols tuning technique

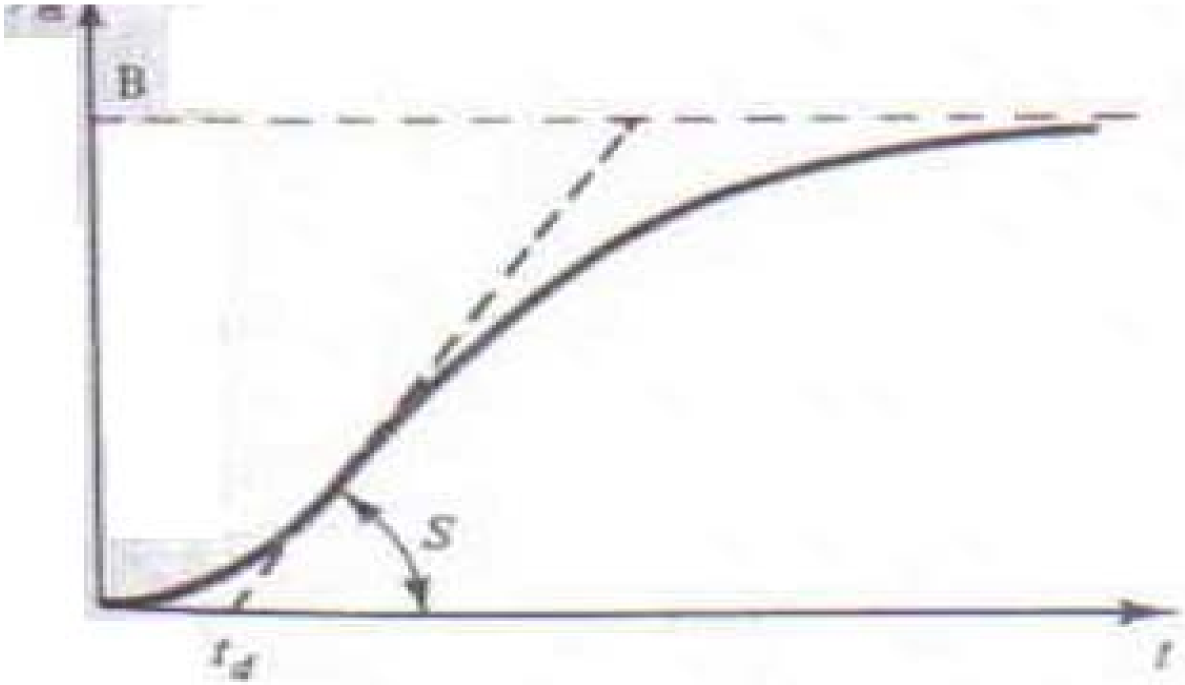
It is for closed response system.

	Kc	Ti (min)	Td (min)
▪ **Proportional**	$Ku/2$	-	-
▪ **Proportional integral**	$Ku/2.2$	$Pu/1.2$	-
▪ **Proportional integral derivative**	$Ku/1.7$	$Pu/2$	$Pu/8$

Where;
Ultimate gain = Ku = $\frac{1}{M}$ (M is the amplitude ratio for sustained oscillations)

Ultimate period = Pu = $\frac{2\pi}{Wc\circ}$ $\min/cycle$

Cohen Coon's Method



(a)

$$K = \frac{B}{A} = \frac{Output}{Input}$$ (at steady state)

$$T = \frac{B}{S}$$

B= ultimate response, t_d=time elapsed until system started to response

S=slope of curve

Other Methods of Tuning Controllers

- Quartering
- Minimum Offset
- Minimum Integral-Square Error

$$ISE = \int_{o}^{\alpha} \varepsilon^2(t)\,dt$$

- $$ITAE = \int_{o}^{\alpha} t\left|\varepsilon(t)\right|dt$$

- $$IAE = \int_{o}^{\alpha} \left|\varepsilon(t)\right|dt$$

Selecting the Best controller and the values of P, I, D

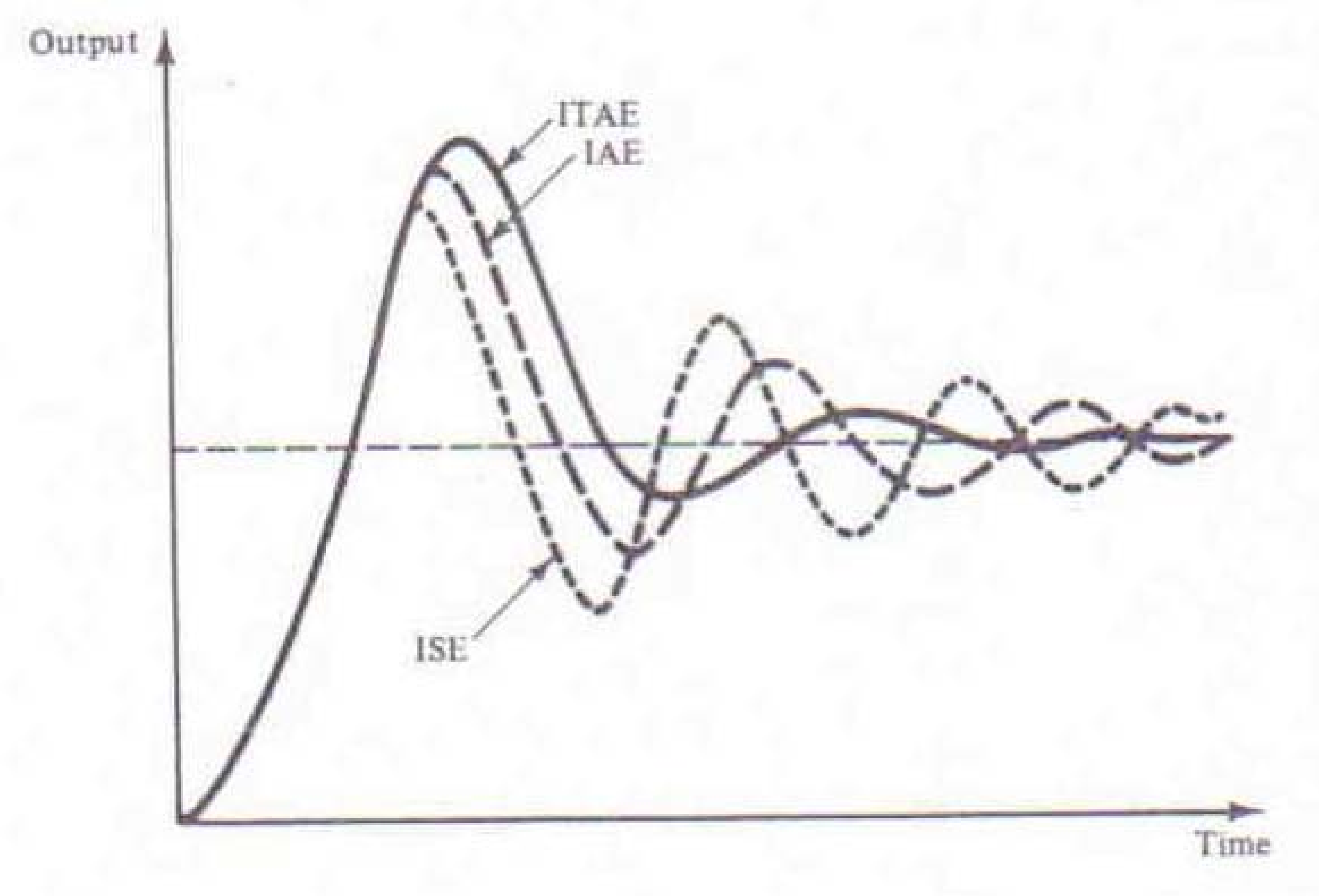
The general guidelines for tuning are as follows:

- If you want to strongly suppress the *Large Errors , ISE is better than IEA* because the errors are squared and that contribute more to the value of the integral.

- If you want to suppress the Small Errors, IAE is better than ISE because when square small numbers (smaller than one) they become even smaller.

- To suppress errors that persist for Long Times, the ITAE criteria will tune the controllers better because the presence of large "t" amplifies the effect of even small errors in the value integral.

Selecting the Best controller and the values of P, I, D



General Criteria to Select Feed Back Controller

- Define approximate performance criteria ISE, IAE or ITAE.

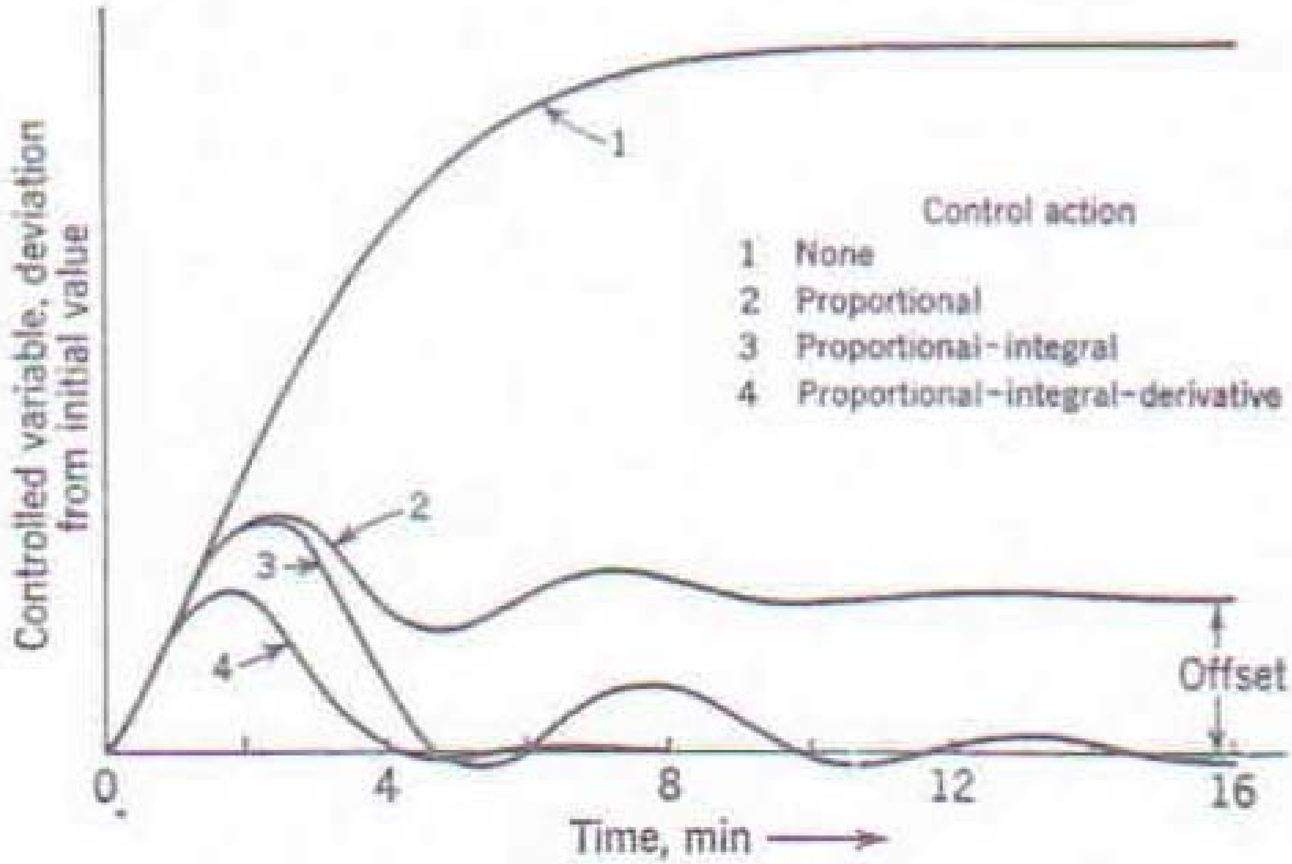
- Compute the value of the performance criteria using P or PI or PID controller with the best adjusted Kc, Ti, and Td.

- Select the Controller that gives the "BEST" value for the performance criteria.

Rules of Thumb

- If possible use simple proportional (P) controllers.
- If simple Proportional action is unacceptable use a Proportional Integral (PI) controller.
- Use a Proportional Integral Derivative (PID) control to increase the speed of response and retain robustness.

Critical Features of P, PI & PID Controllers.



Summary & Conclusion

Design of Control System is a science and an art.

Recommended control practices play an important role in it.

The role of engineer stretches far beyond its design in application through understanding

Open for discussions

Pakistan Engineering Council
Islamabad

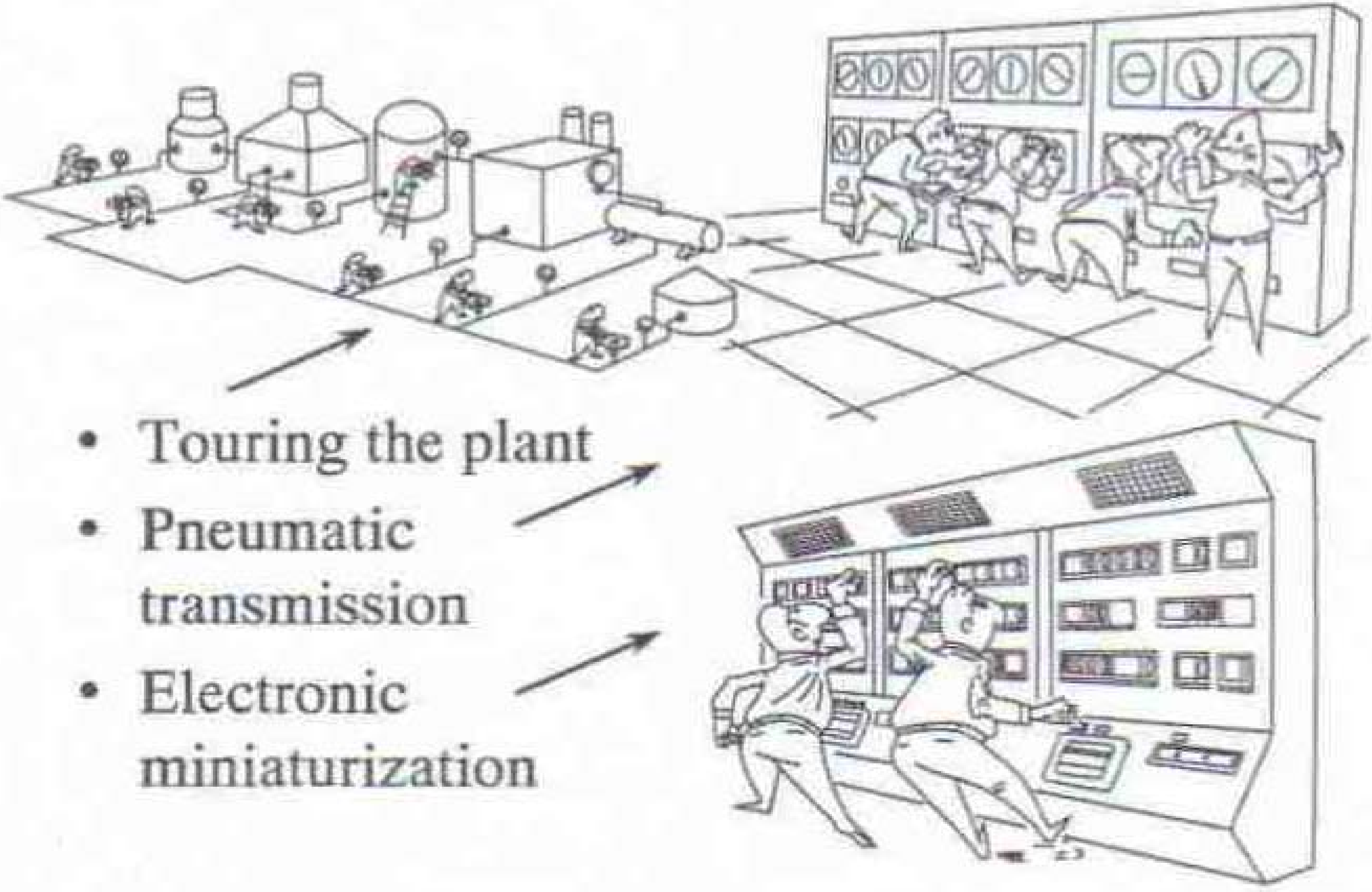
Computer Control Systems

Lecture -4

Dr. –Ing. Naveed Ramzan

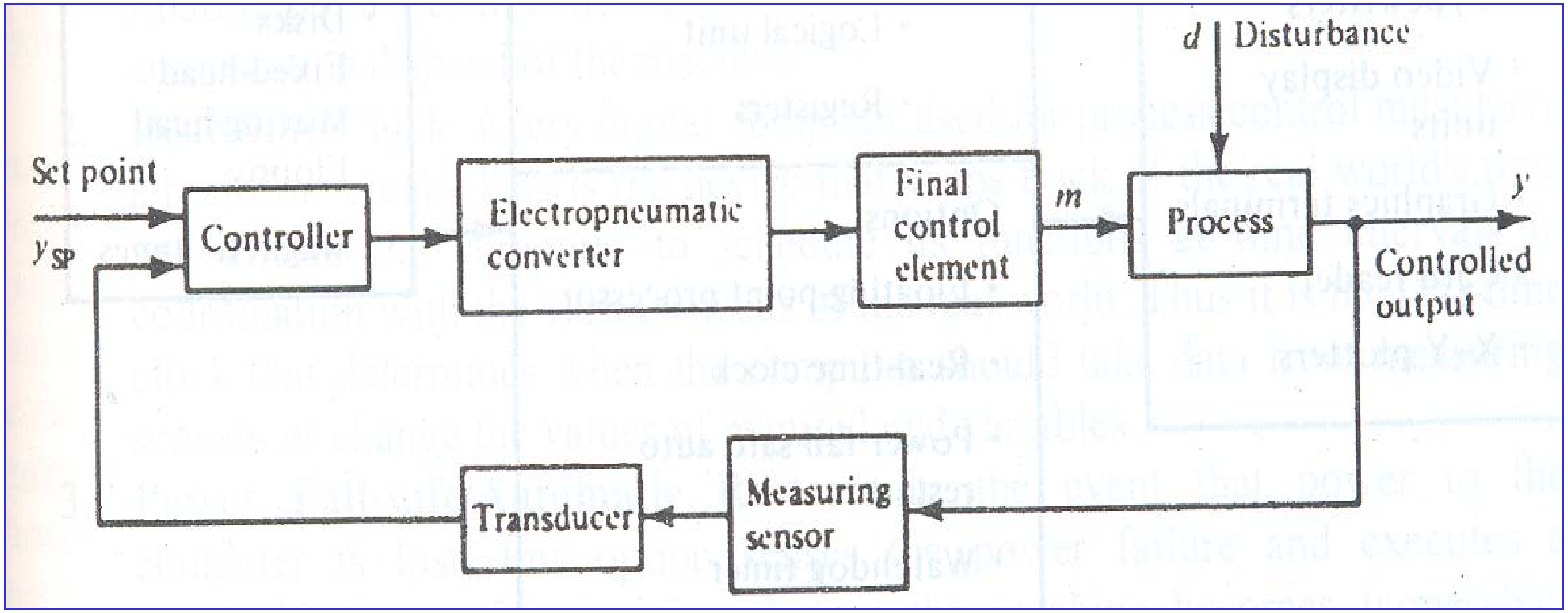
Sequence of Presentation

- **Basics of Computerized Control**
- **Essential components of computer control system**
- **Advantages of Computer Control**
- **Types of computer control implementation**



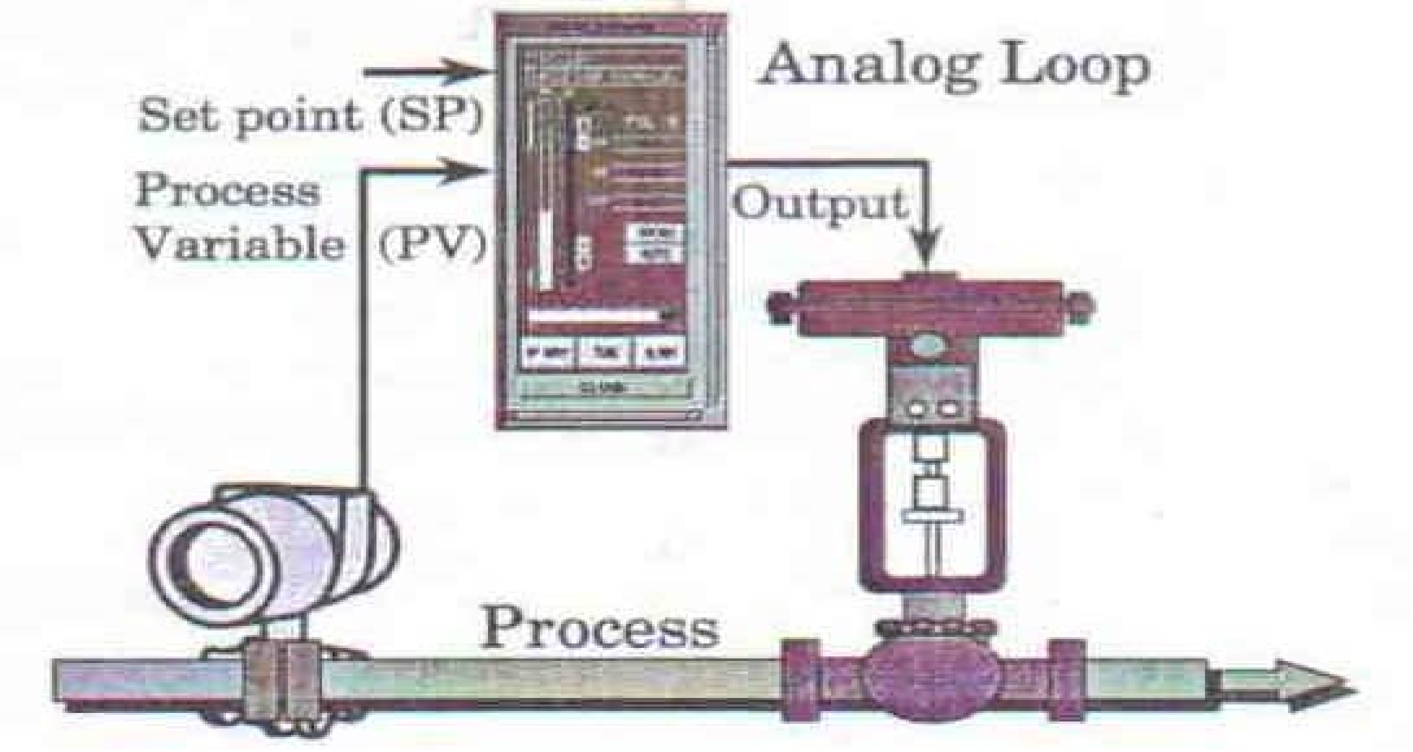
- Touring the plant
- Pneumatic transmission
- Electronic miniaturization

Feedback Control Loop

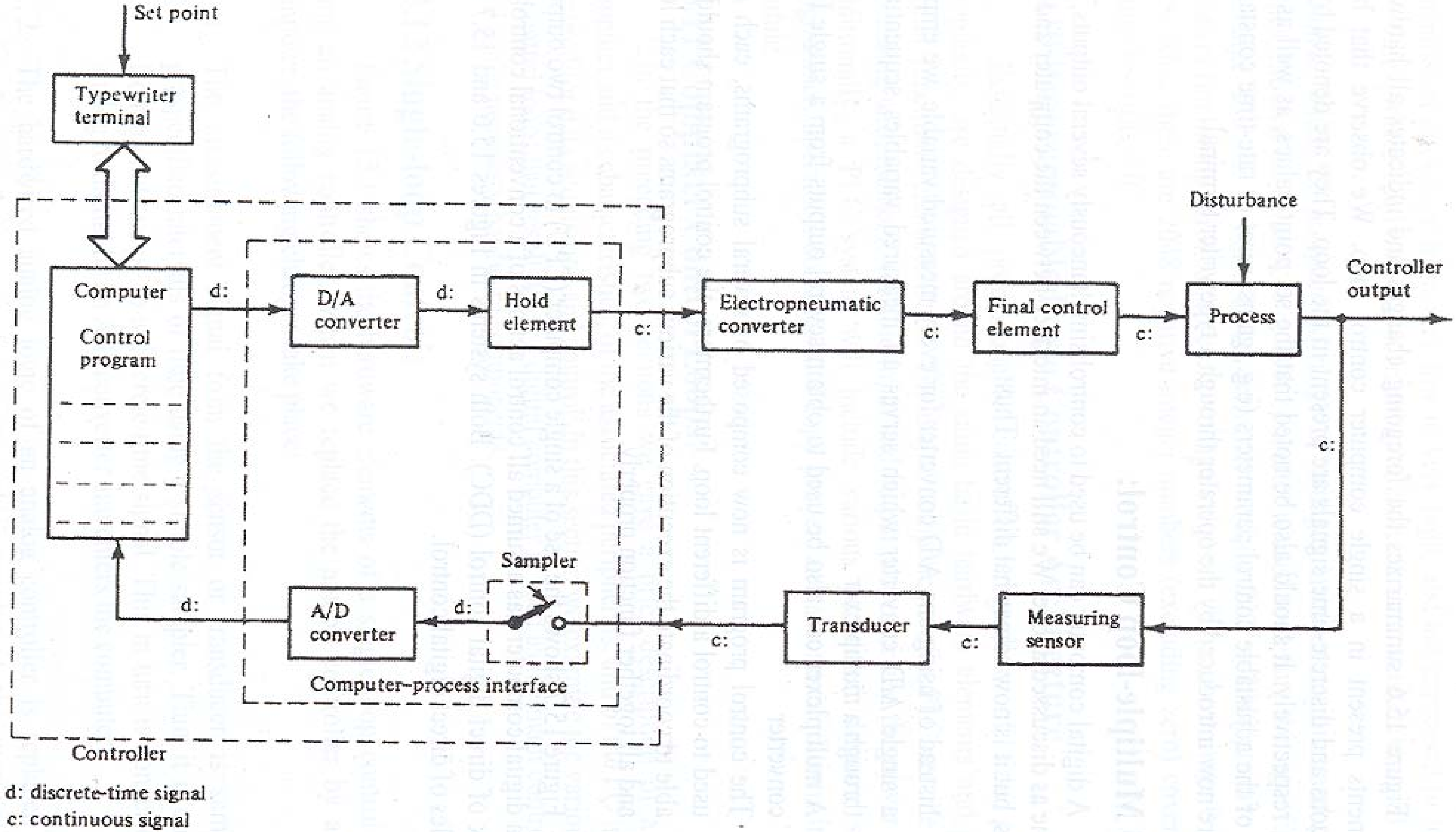


Single Loop Control (SLC) (Cont'd)

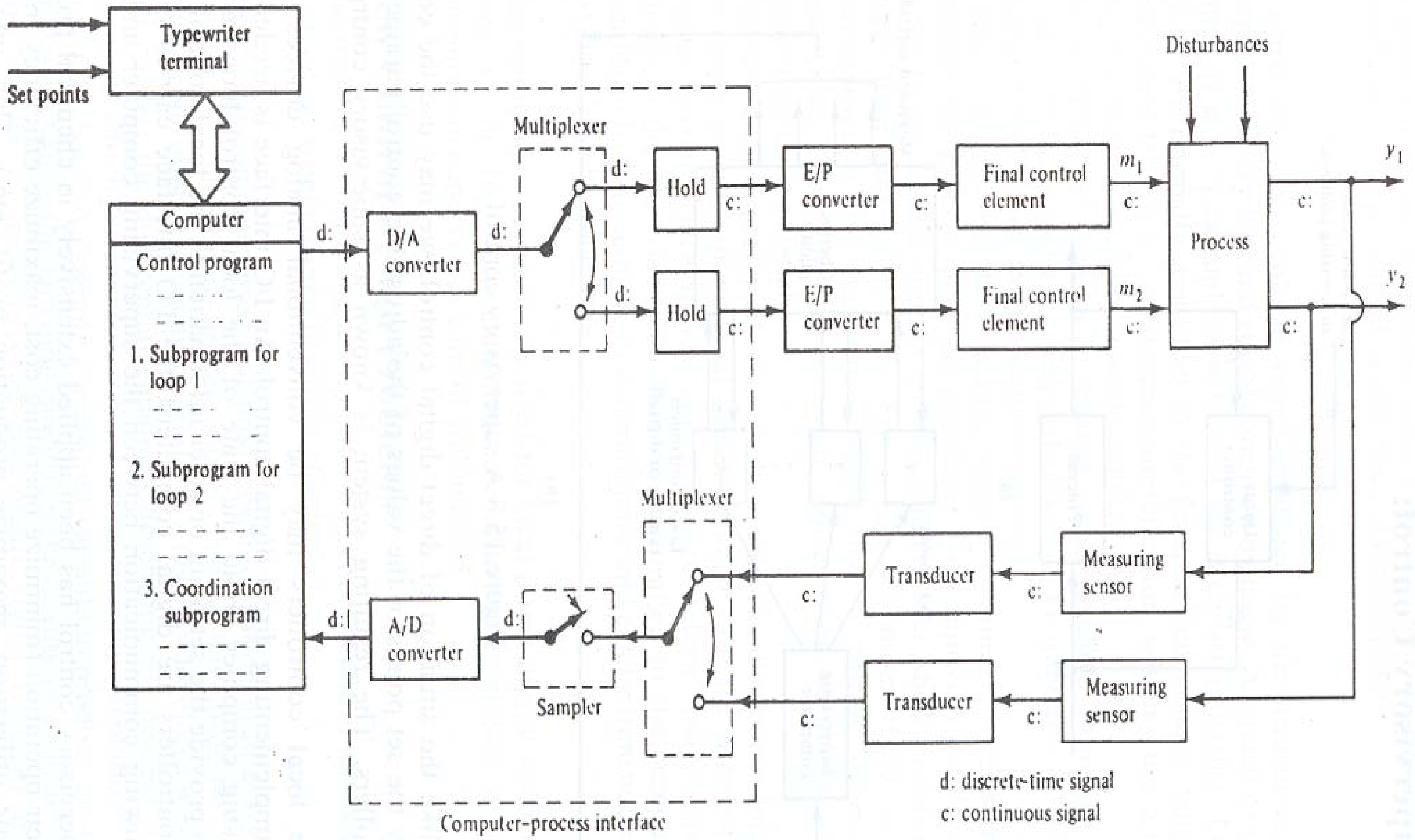
Traditional Single Loop Controller



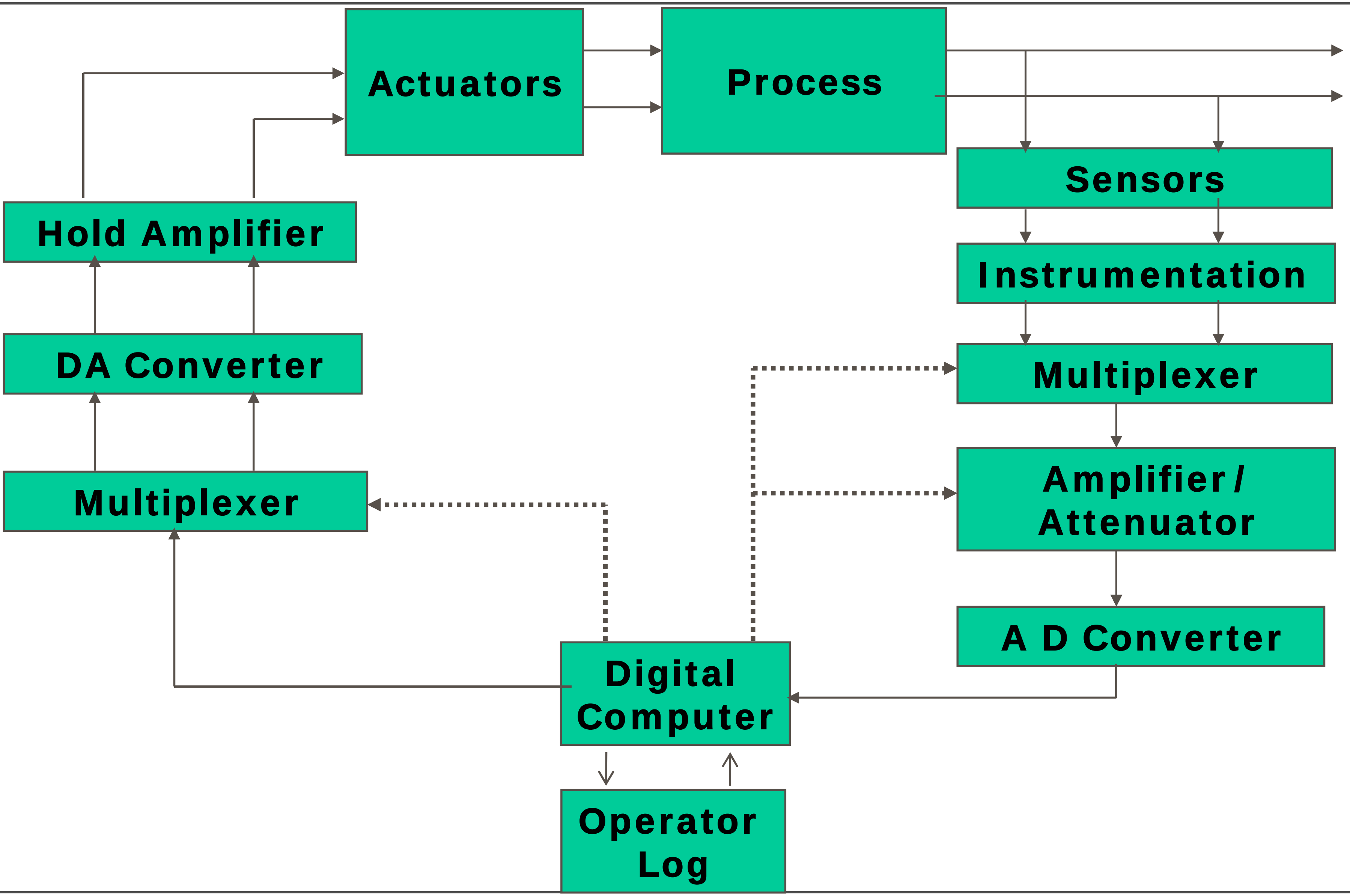
From Traditional Analog Controller to Computer Control

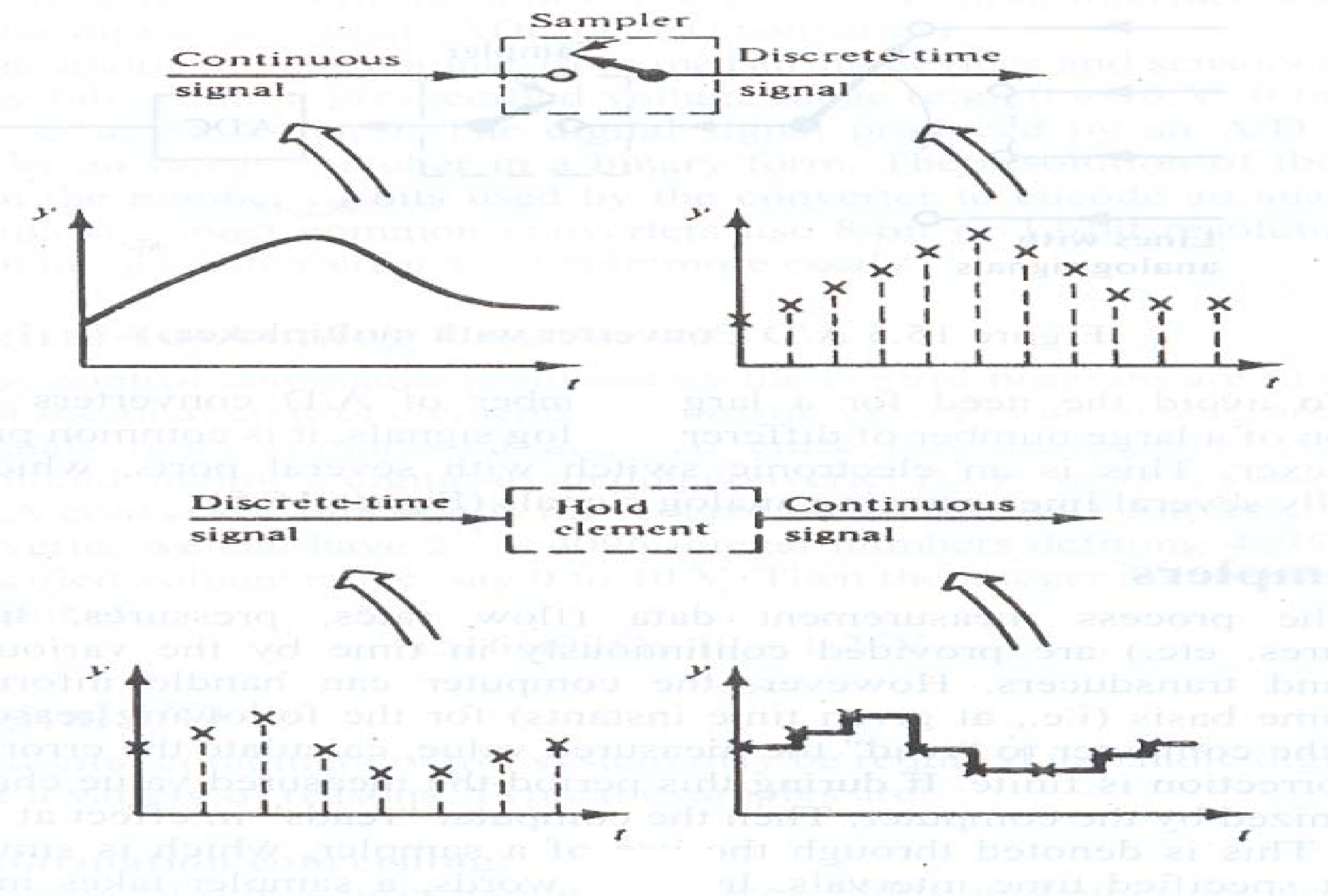


Multiple loop Control

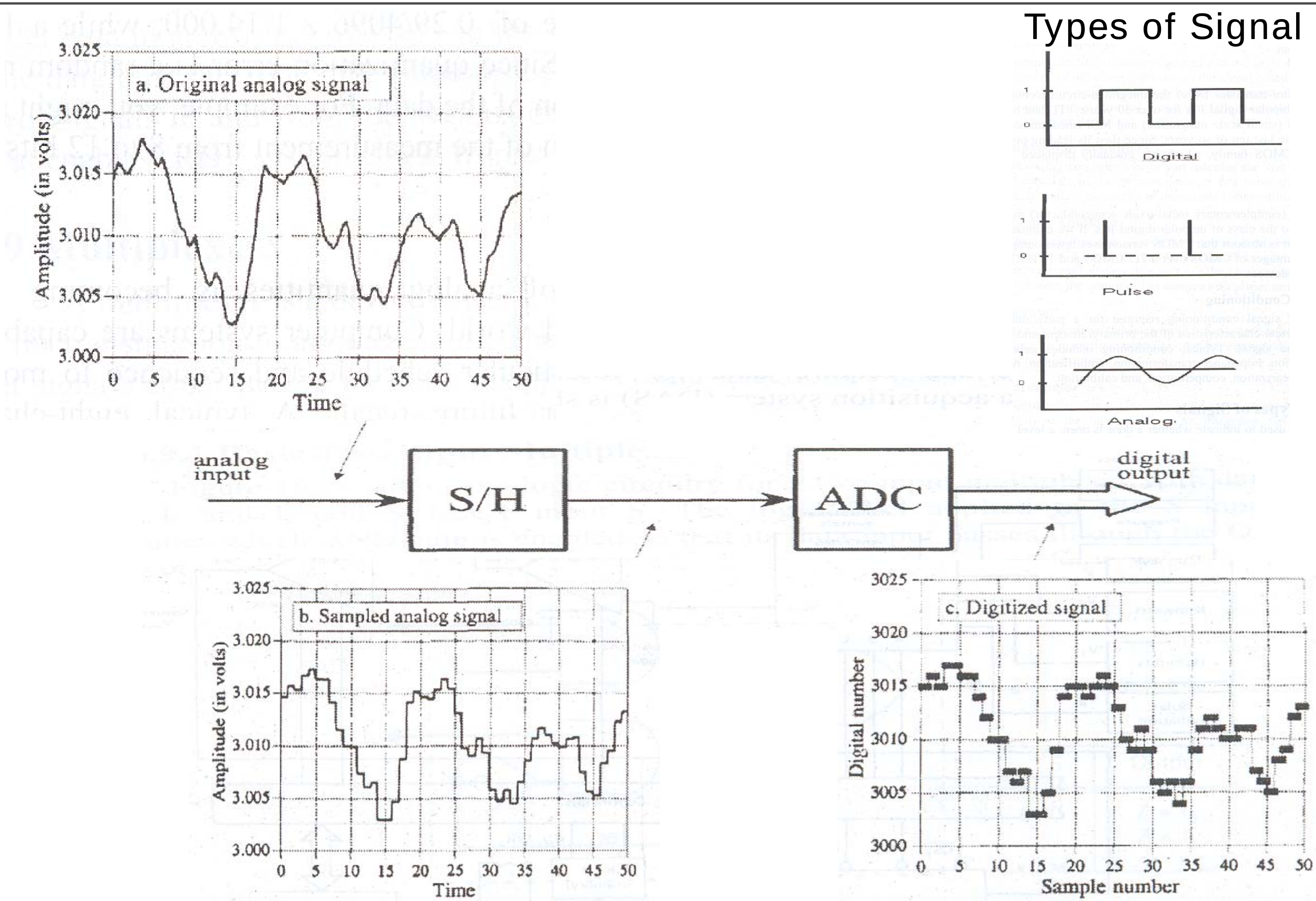


Essential Components of Computer Control

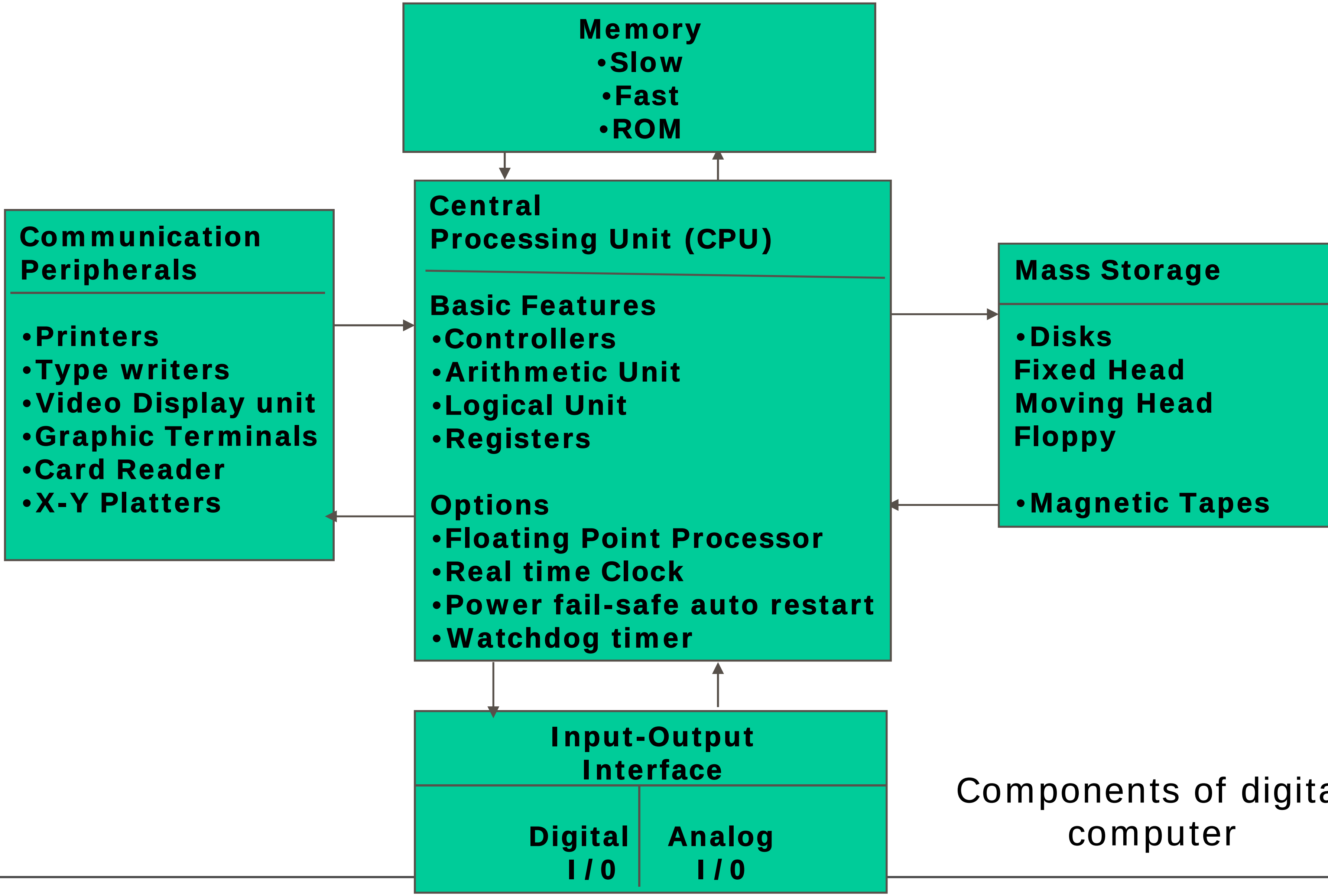



Sampler
Continuous signal
Discrete-time signal
Discrete-time signal
Hold element
Continuous signal
y
t

Types of Signal

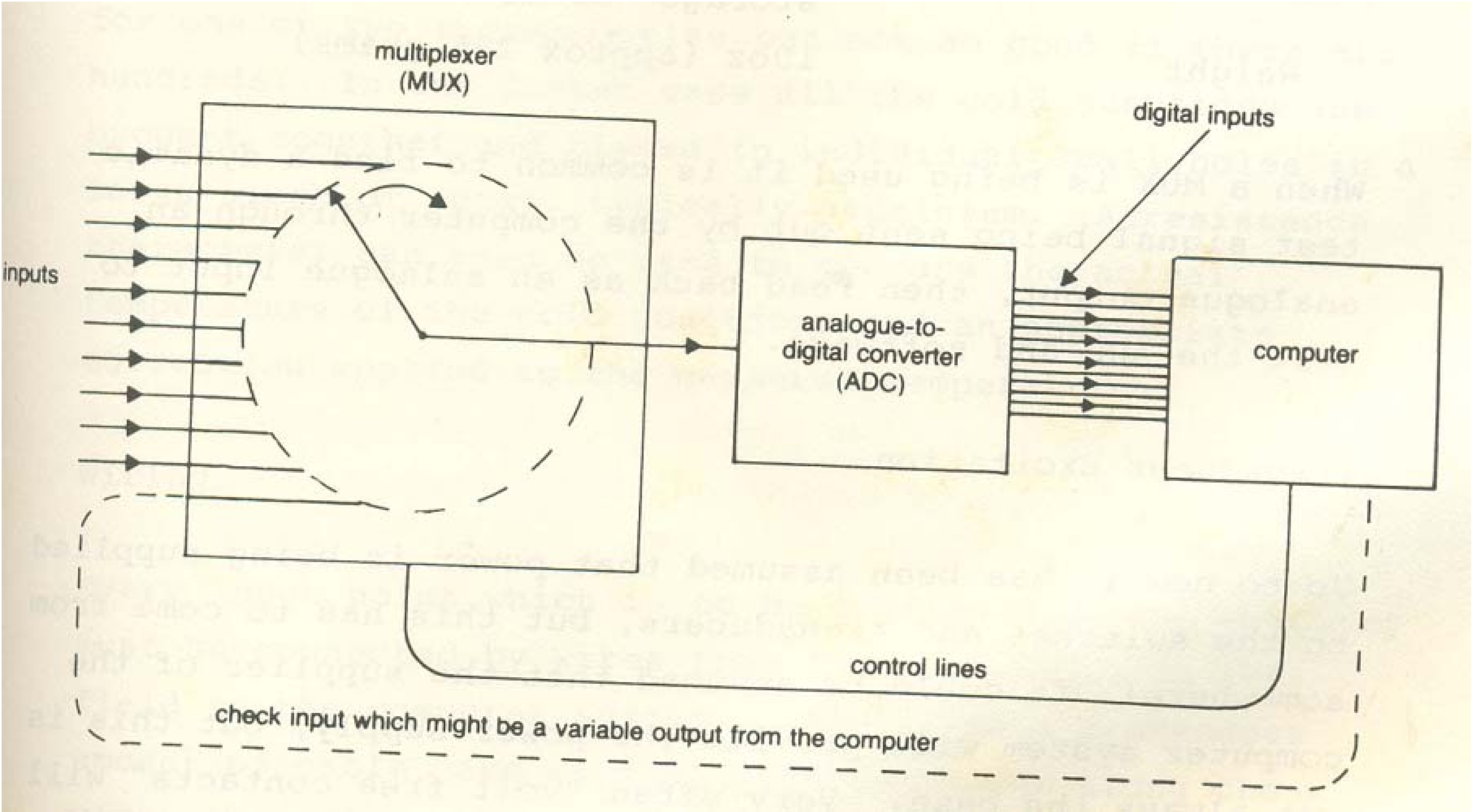


Essential Components of Computer Control (Cont‘d)

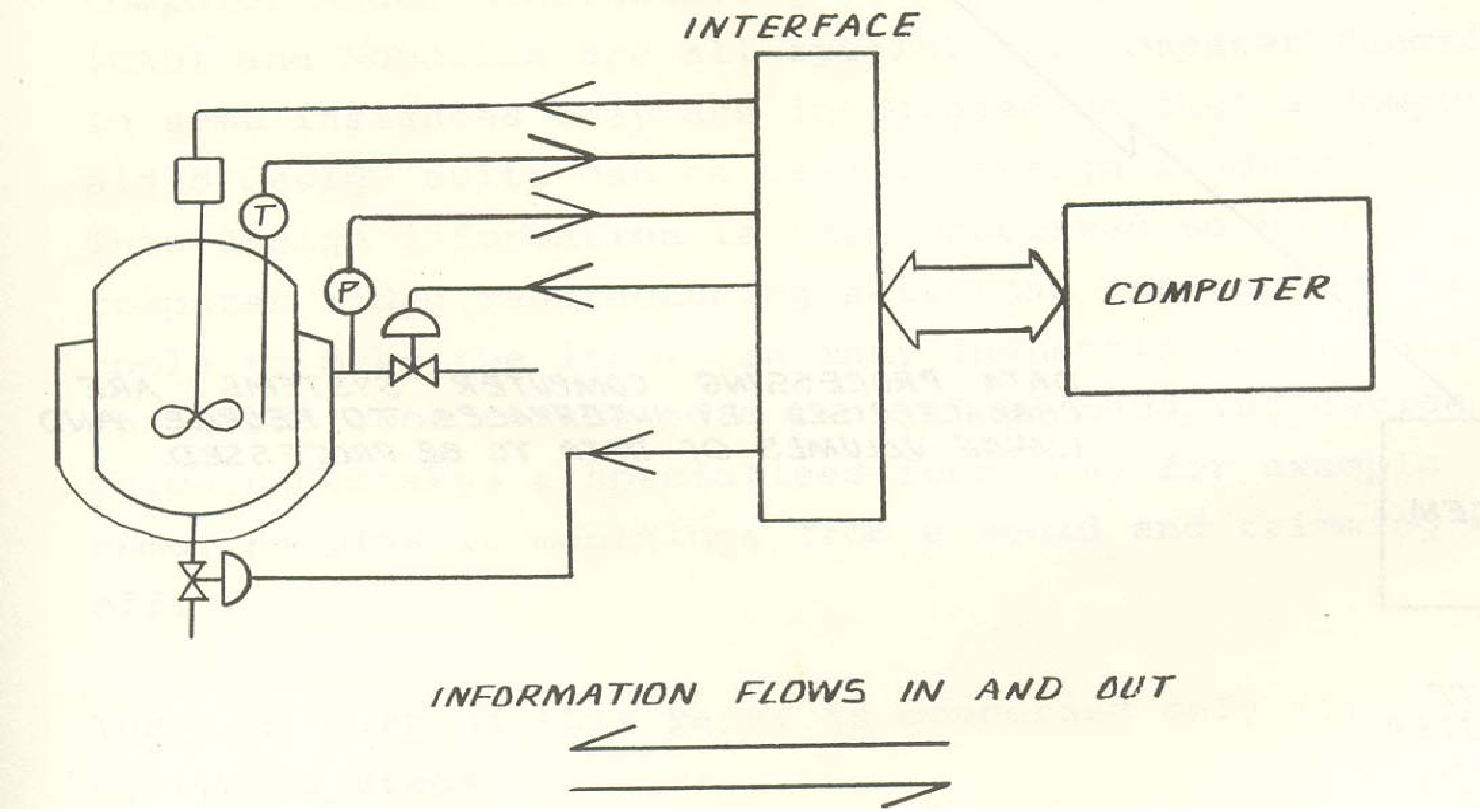


Components of digital computer

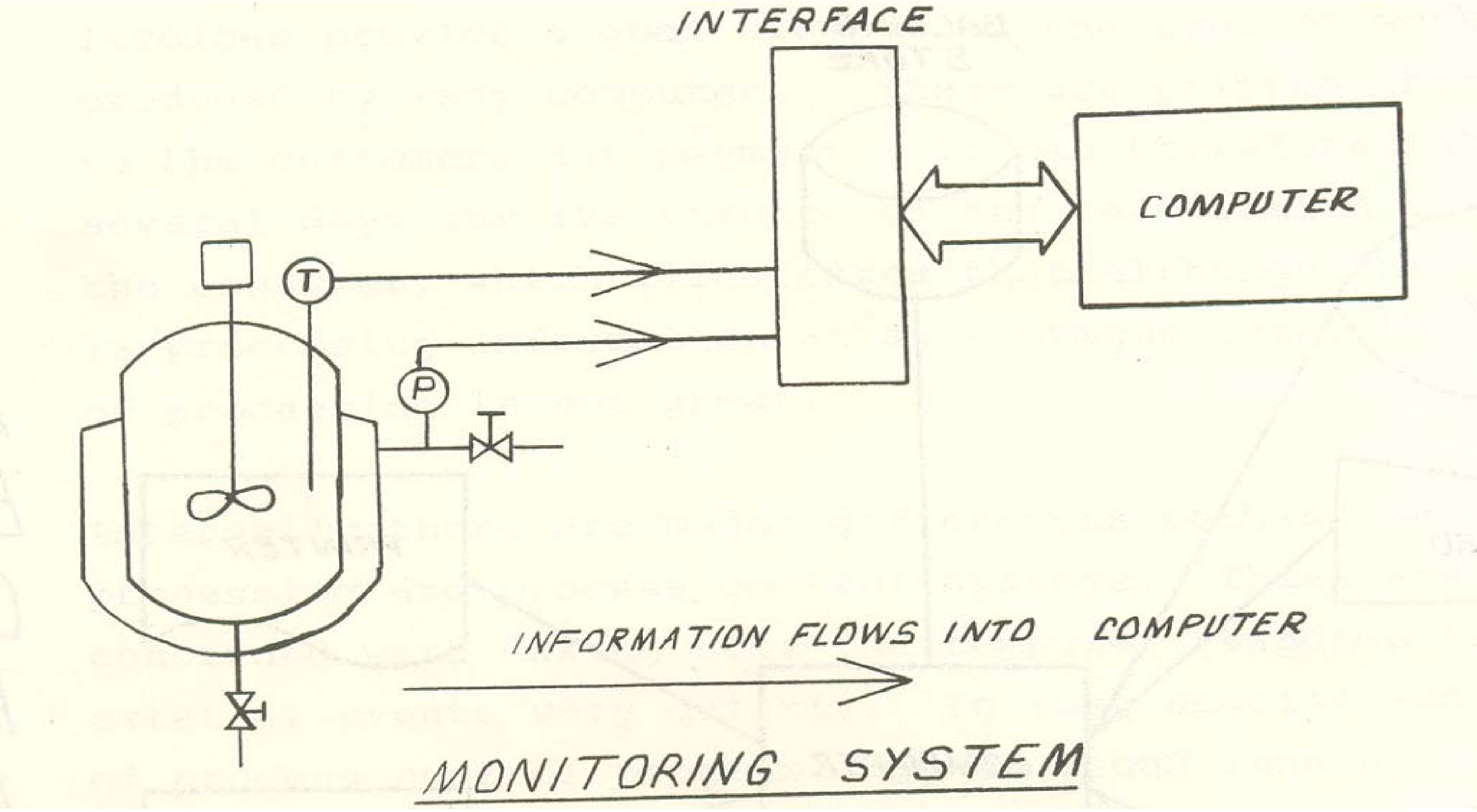
Plant Inputs : Multiplexing



- **Control System**



- **Monitoring System**



Advantages of Computer Control

-- all plant data is available at a central point and/or distributed points around the plant or works

-- alarm conditions are detected and reported quickly

-- plant is run according to the plan set by management, which may not be the case where there is a lot of manual intervention

-- displays and printouts of information are available readily

-- changes to the operating conditions or recipes are made in smooth, repeatable and closely controlled manner

Advantages of Computer Control

-- written records of all alarms and operator actions are available for post-incident or routine analysis

-- alarm conditions are detected and reported quickly

-- control room and control panel size is reduced

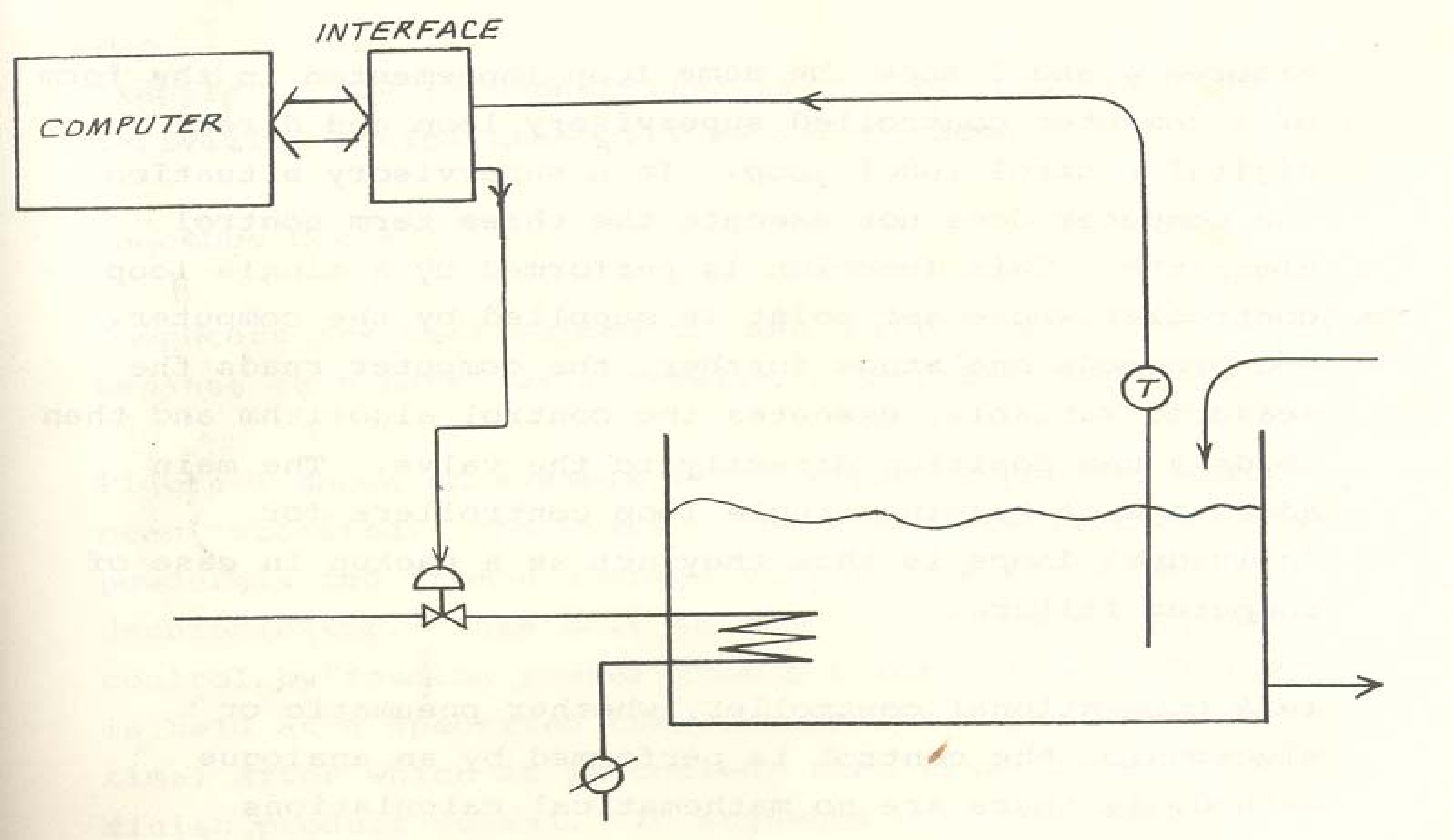
-- all batches of material are treated identically

-- batch logs are recorded automatically

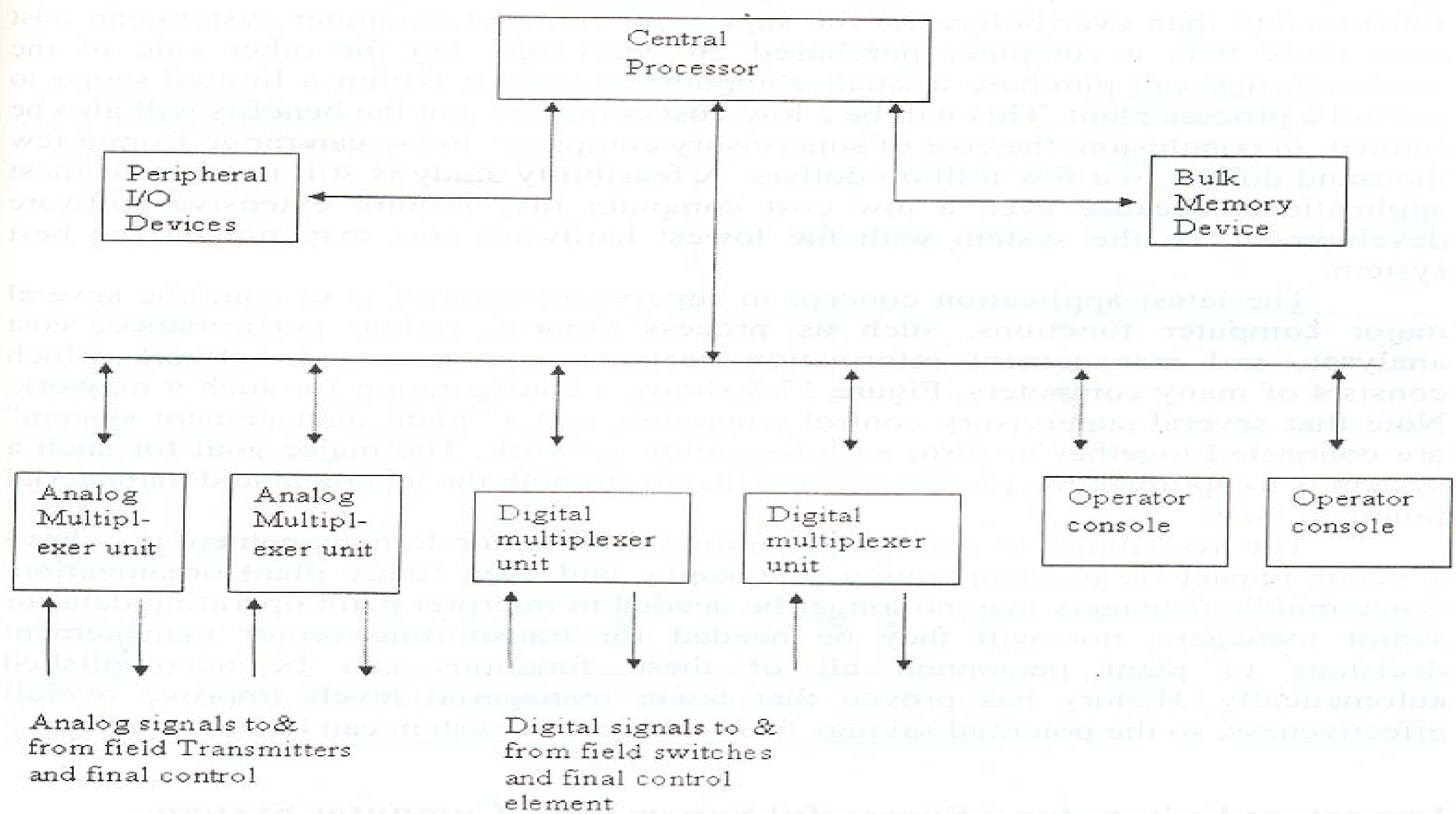
-- complex start-up and shut-down procedure can be automated

-- safety interlocks can be programmed into the system

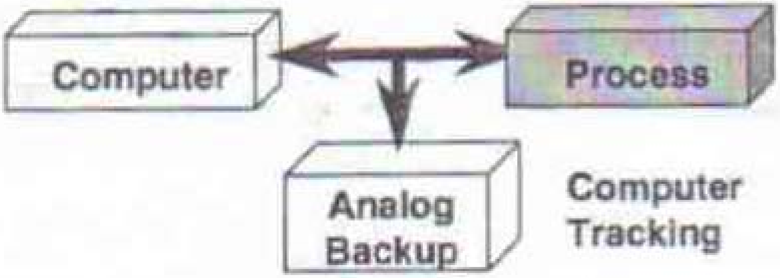
Direct Digital Control loop



Direct Digital Control loop



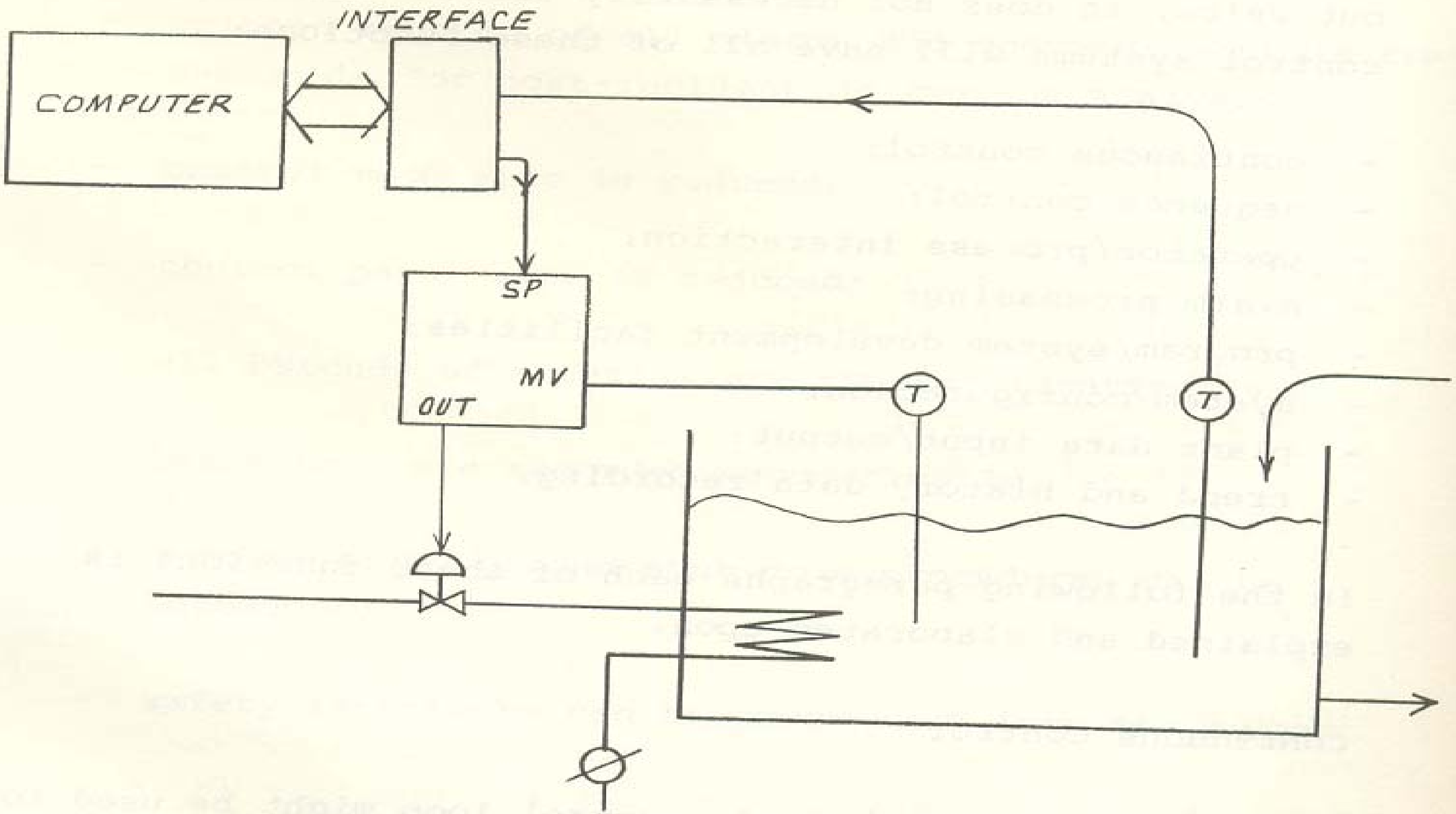
Direct Digital Control loop



- **Advantages:**
  - Sophisticated control
  - Flexible control
  - Data acquisition and alarm
- **Disadvantages:**
  - Computer reliability
  - Redundant computer or controllers
  - Wiring complex and extensive
  - HMI required high-level operators
  - Expensive

Digitally Directed Analog Control (DDAC)

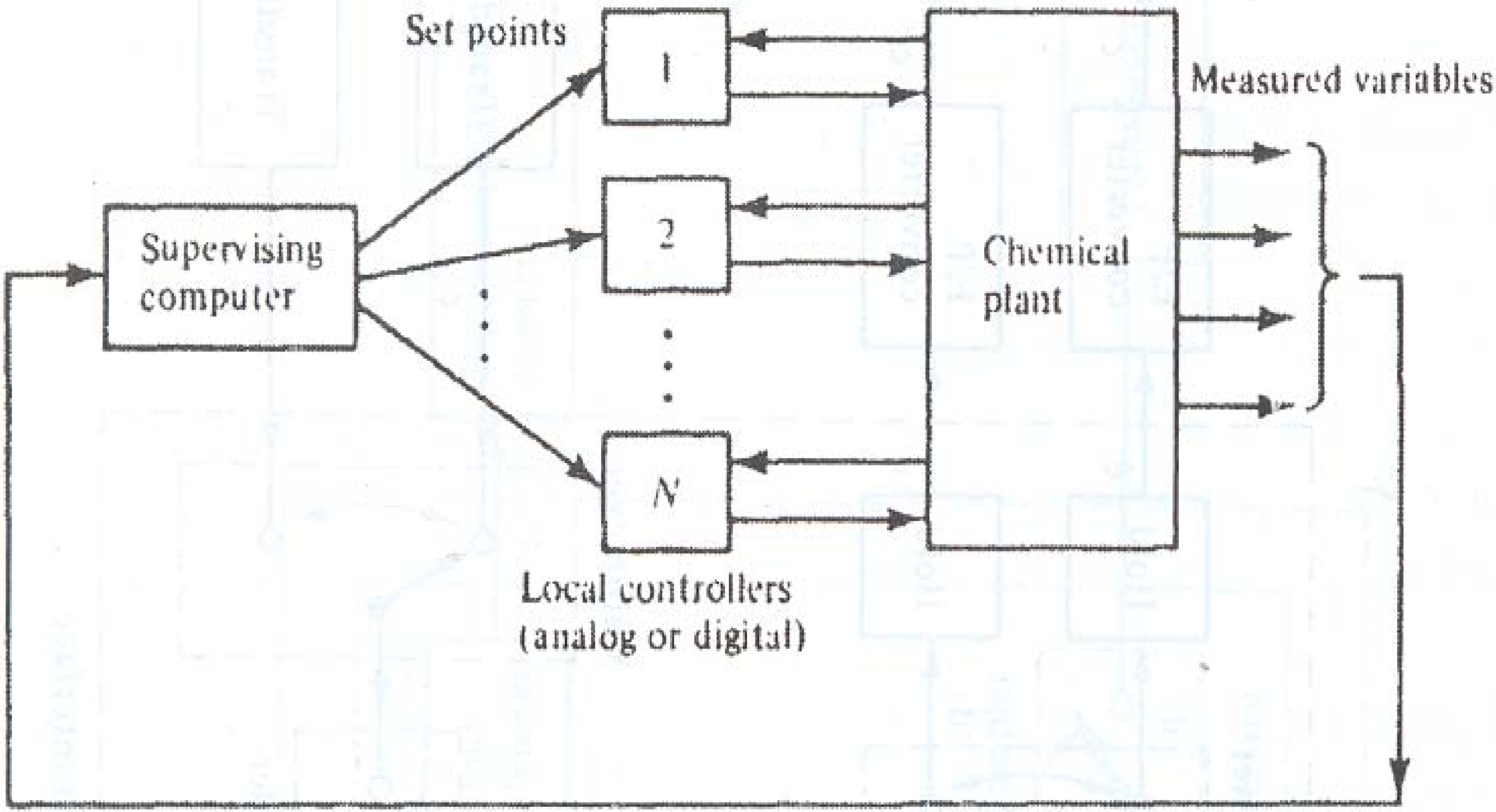
- Supervisory computer control



SUPERVISORY CONTROL OF LOCAL CONTROLLER.

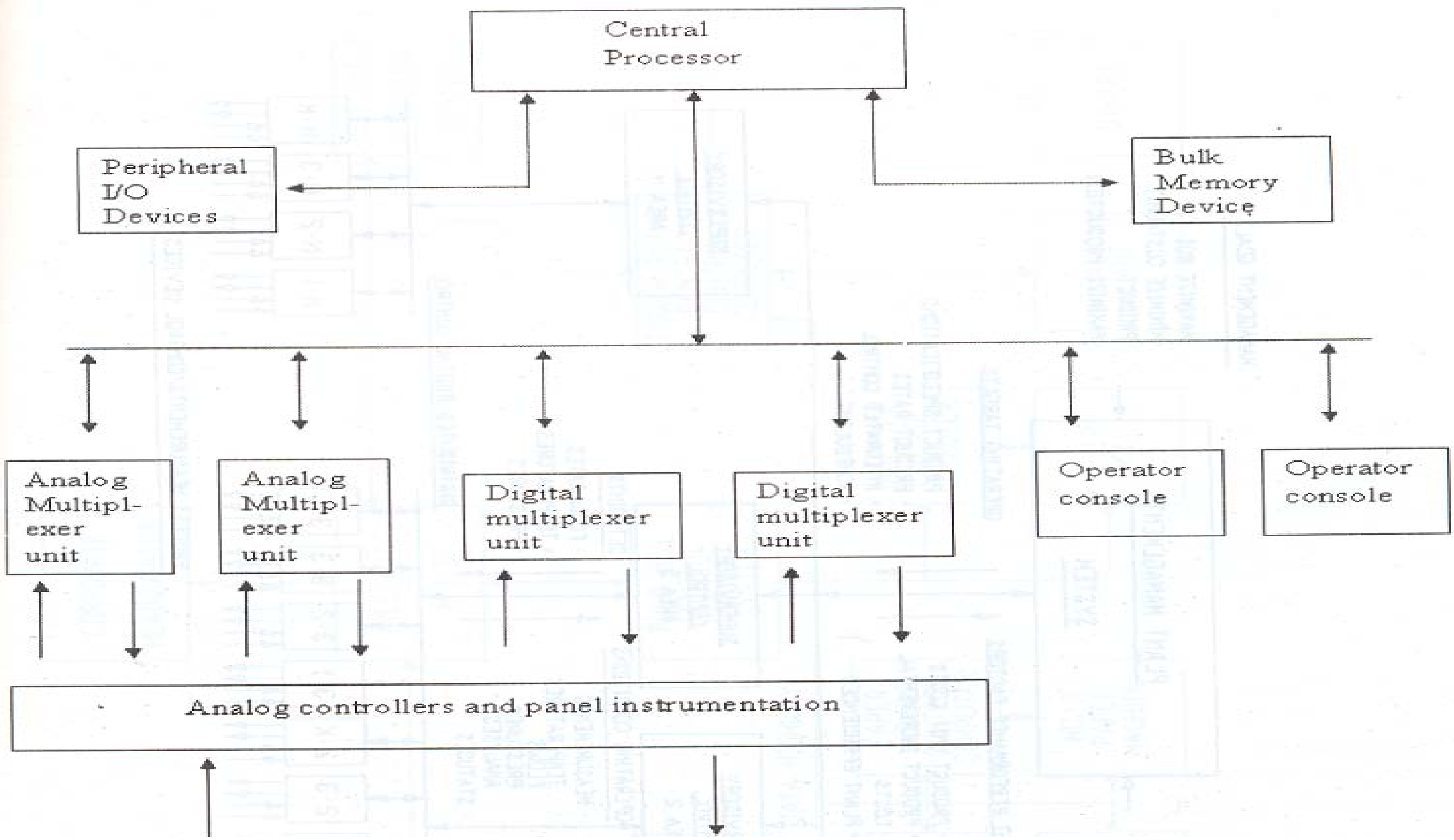
Digitally Directed Analog Control (DDAC)

- Supervisory computer control



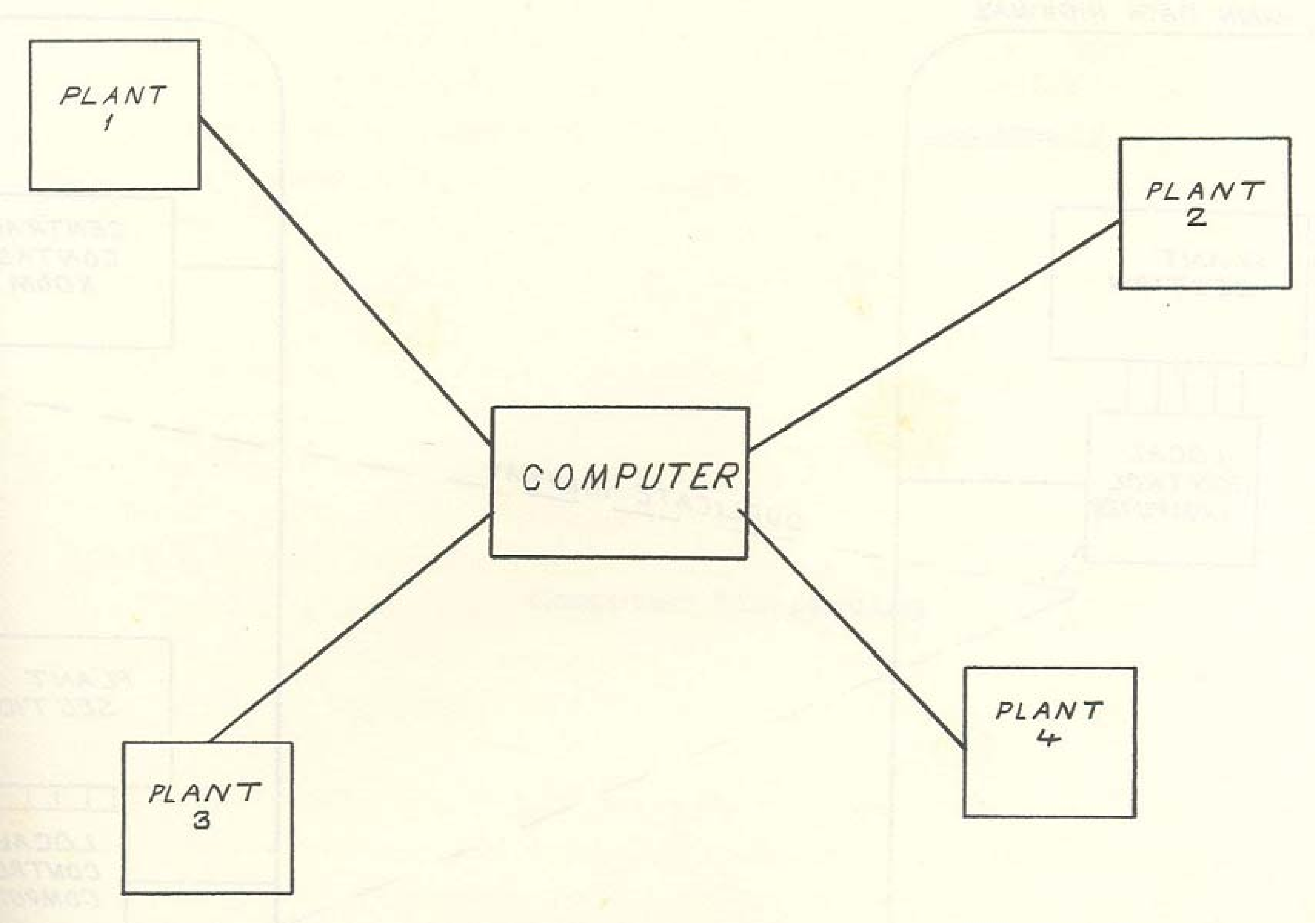
Types of Computer Control Implementation

Simplified Diagram of supervisory control



Types of Computer Control Implementation

Centralized Computer System

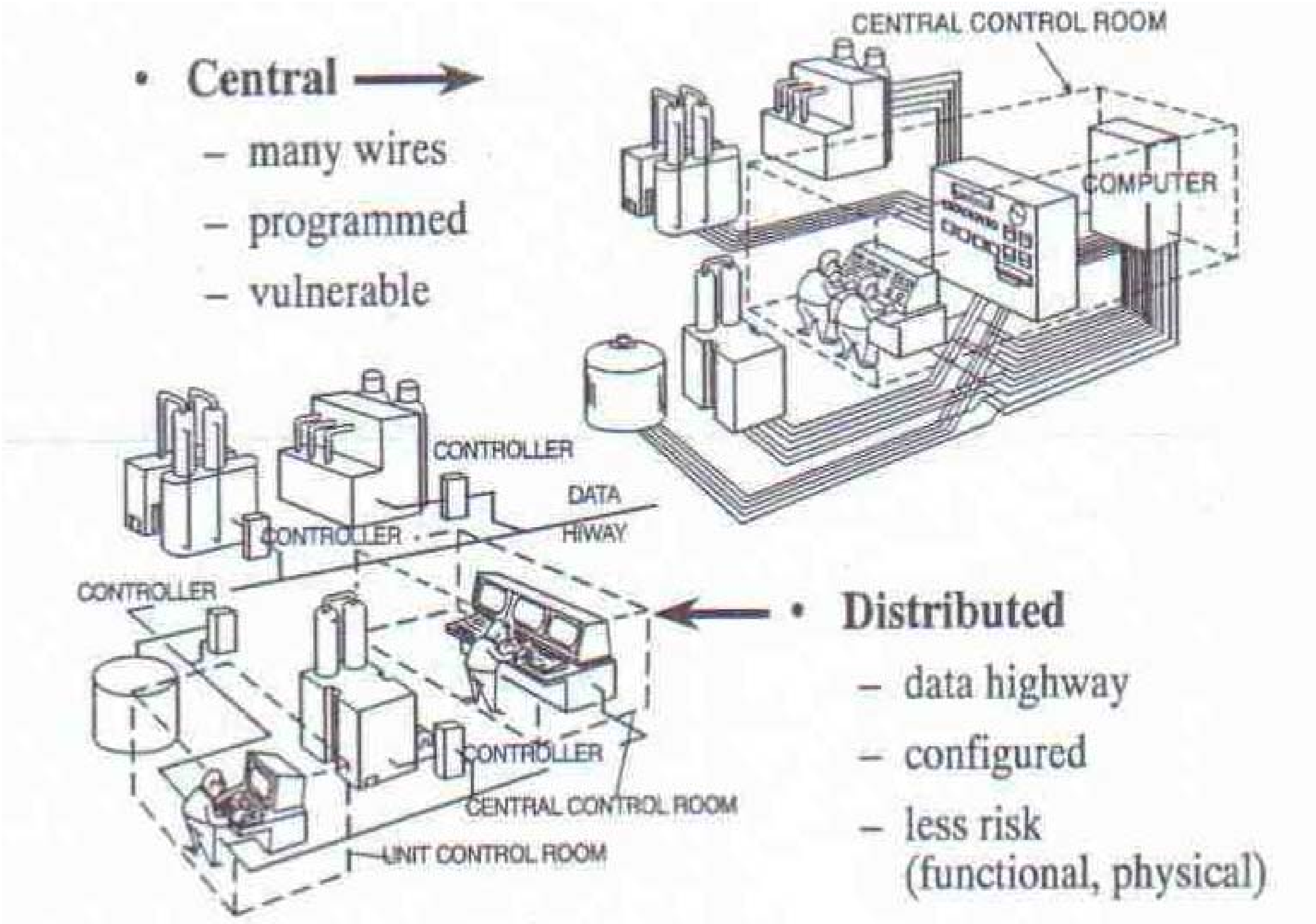


Types of Computer Control Implementation

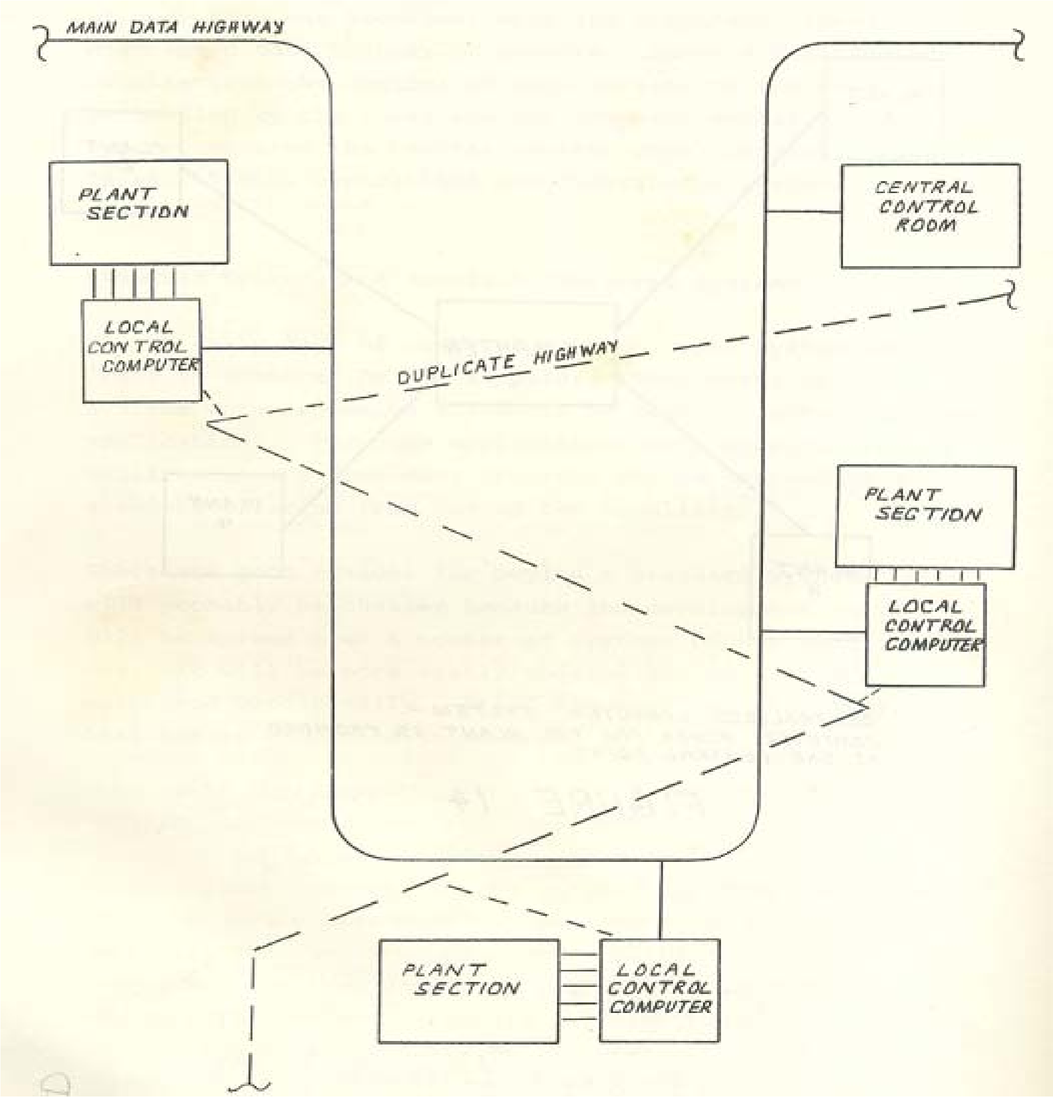
Supervisory computer control

- **Advantages:**
  - High reliability
  - Human-machine interface adequate
  - Data acquisition and alarms
  - Sophisticated control
  - Complete redundancy
- **Disadvantages:**
  - Complex wiring and installation
  - Difficult to make strategy changes
  - Expensive

Distributed Control System



Distributed Control System



Programmable Logic Controller

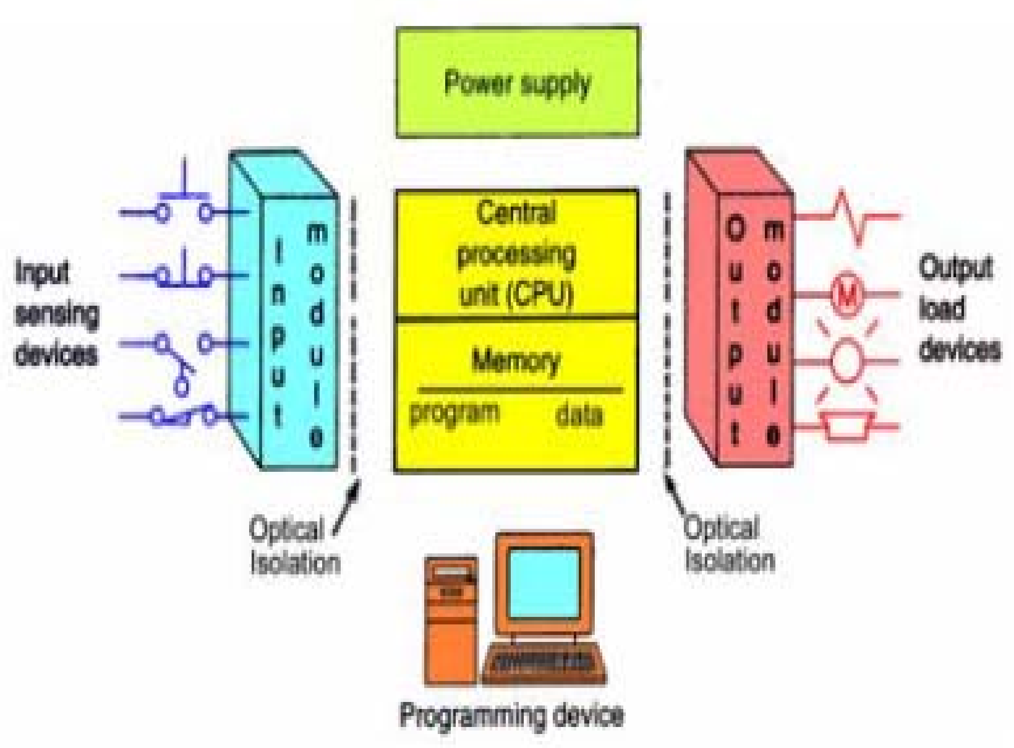
Programmable Logic Controller (PLC)

- A programmable logic controller (PLC) is a specialized computer used to control machines and process.
- It uses a programmable memory to store instructions and execute specific functions that include On/Off control, timing, counting, sequencing, arithmetic, and data handling.

Types of Computer Control Implementation

- Used to monitor process parameters and adjust process operations accordingly.
- A computer designed for use in machine control.
- Eliminates much of the hard wiring that was associated with conventional relay control circuits.

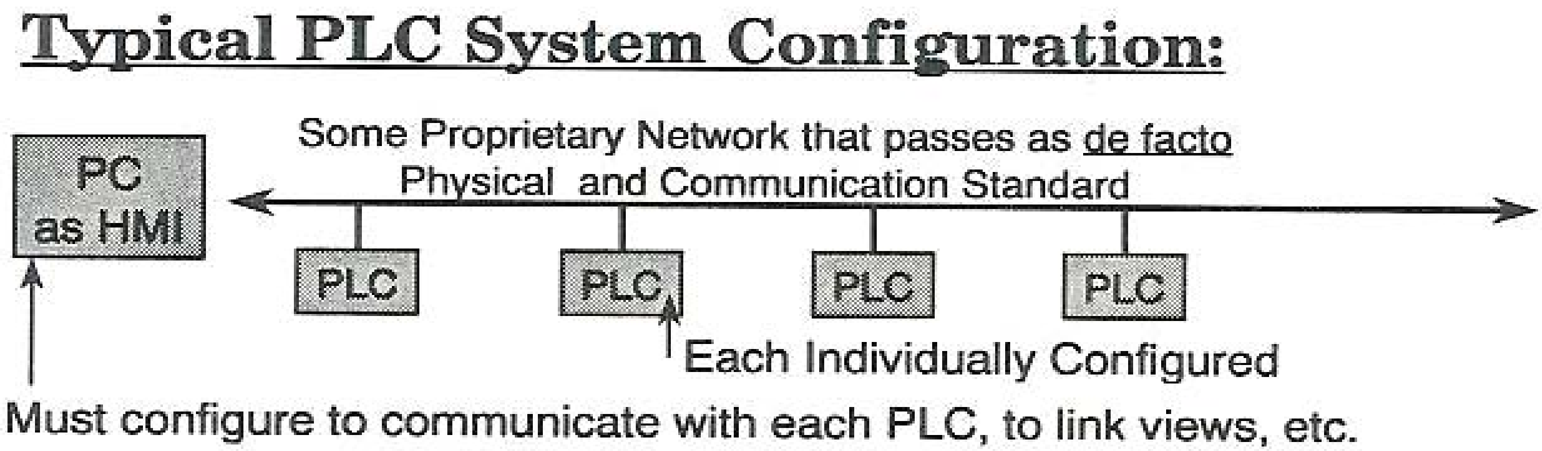
Programmable Logic Controller



Parts of a PLC

- Central Processing Unit (brain)
- Memory
- Input / Output System
- Power Supply
- Programming Device
- Network Interface (optional)

Programmable Logic Controller



Programmable Logic Controller

Programmable Logic Controller compared to older Technologies

- *Increased Reliability:*
- Once a program has been written and tested it can be downloaded to other PLCs.
- Since all the logic is contained in the PLC's memory, there is no chance of making a logic wiring error.

Programmable Logic Controller

Programmable Logic Controller compared to older Technologies

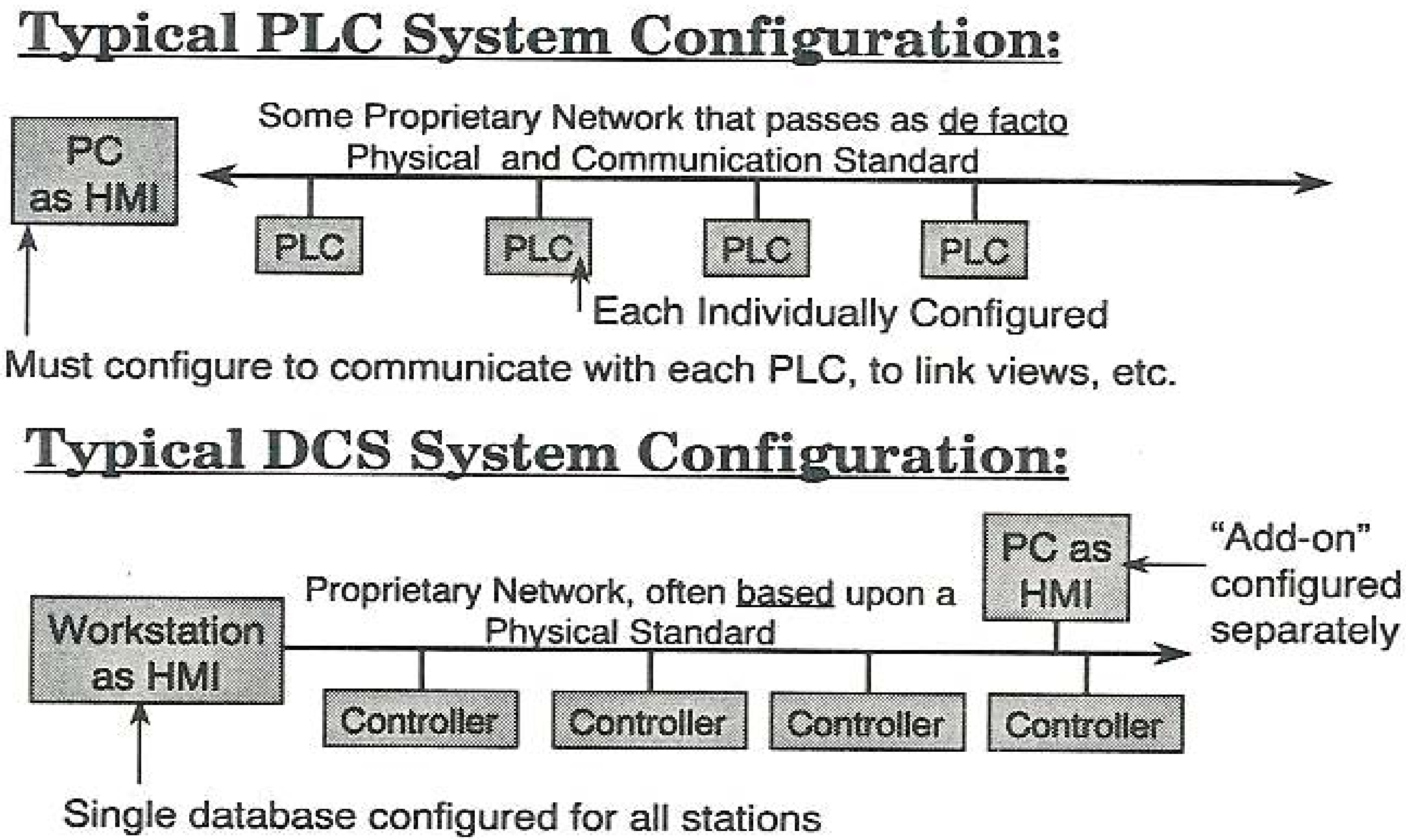
- *More Flexibility:*
- Original equipment manufacturers (OEMs) can provide system updates for a process by simply sending out a new program.
- It is easier to create and change a program in a PLC than to wire and rewire a circuit.
- End-users can modify the program in the field.

Programmable Logic Controller

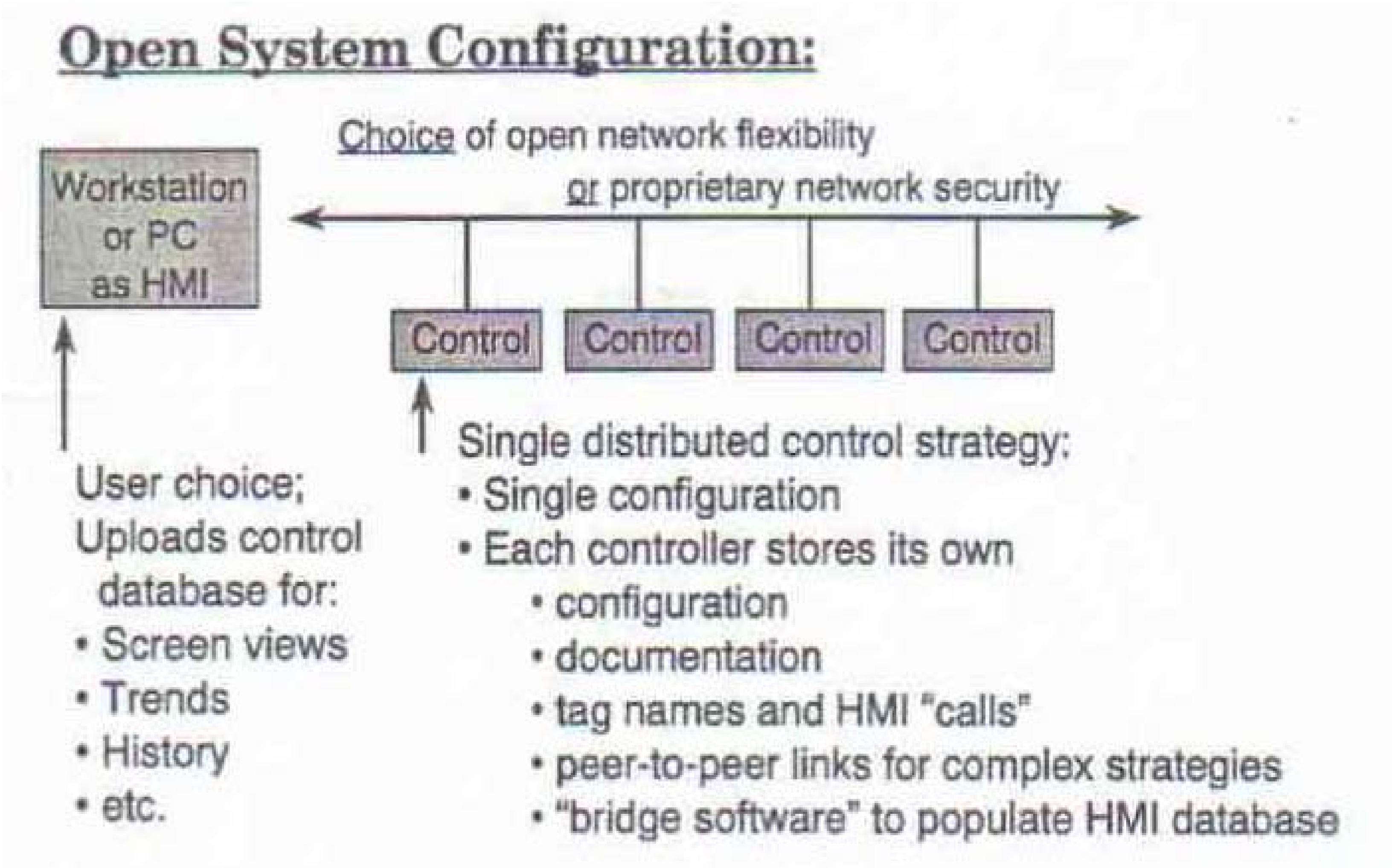
Programmable Logic Controller compared to older Technologies

- *Communications Capability:*
- A PLC can communicate with other controllers or computer equipment.
- They can be networked to perform such functions as: supervisory control, data
- gathering, monitoring devices and process parameters, and downloading and uploading of programs.

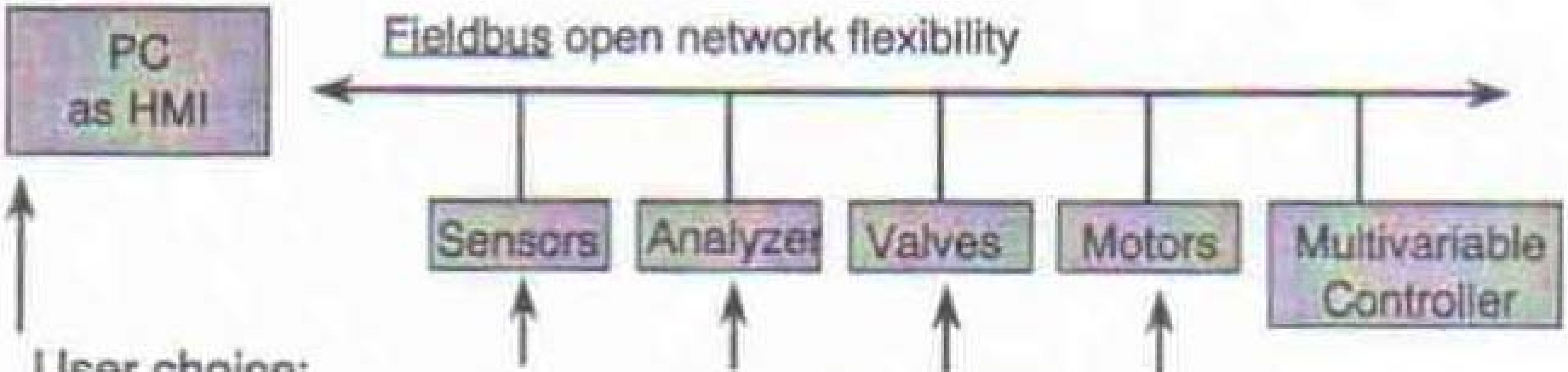
Comparing DCS with PLC for ease of configuration



Open System Configuration



Emerging (Ideal) Configuration:



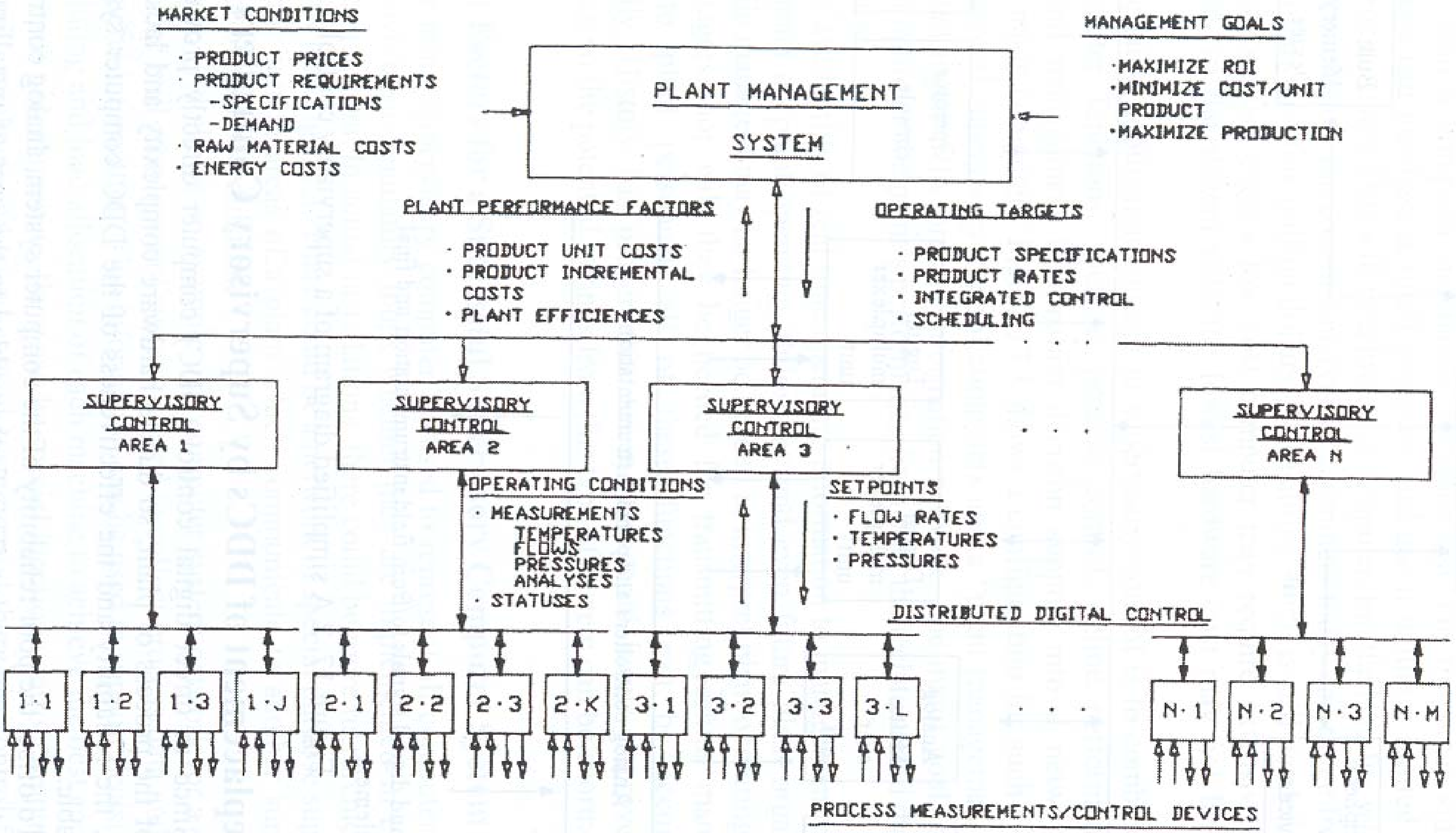
User choice;
Configures control database and:

- Screen Views
- Trends
- History
- etc.

Smart transmitters, sensors, end elements:

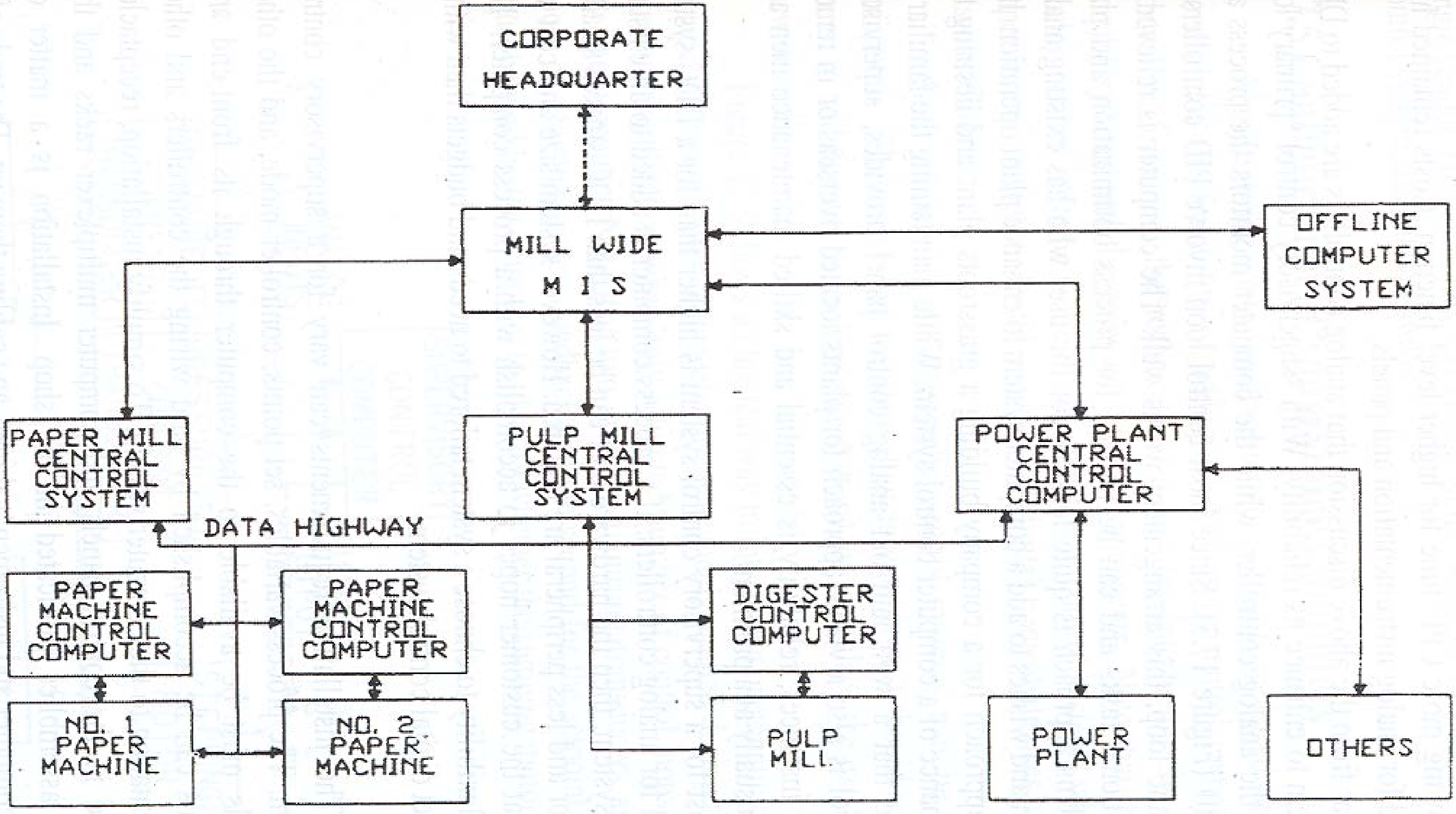
- Multivendor within same system
- Common function blocks
  - configuration
  - documentation
  - tag names and HMI "calls"
  - peer-to-peer links for complex strategies

Integrated Computer Control System

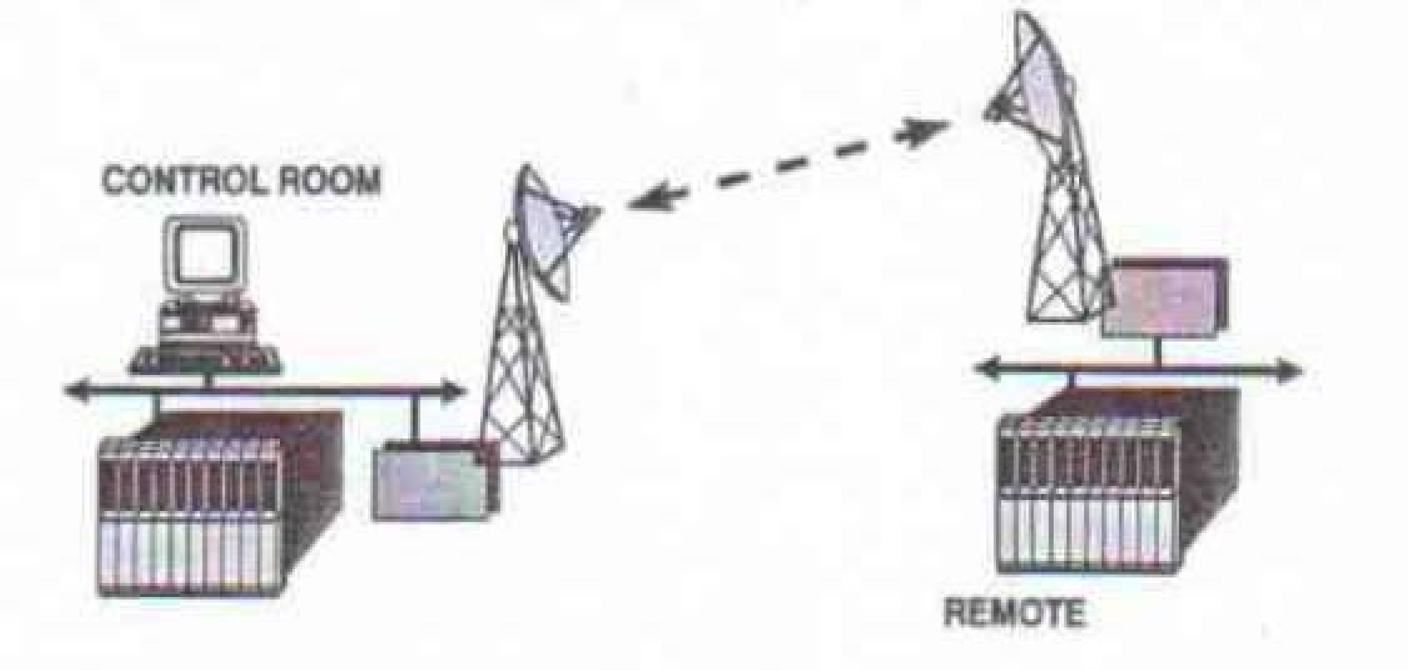


Types of Computer Control Implementation

Integrated Computer Control System for a paper and pulp mill

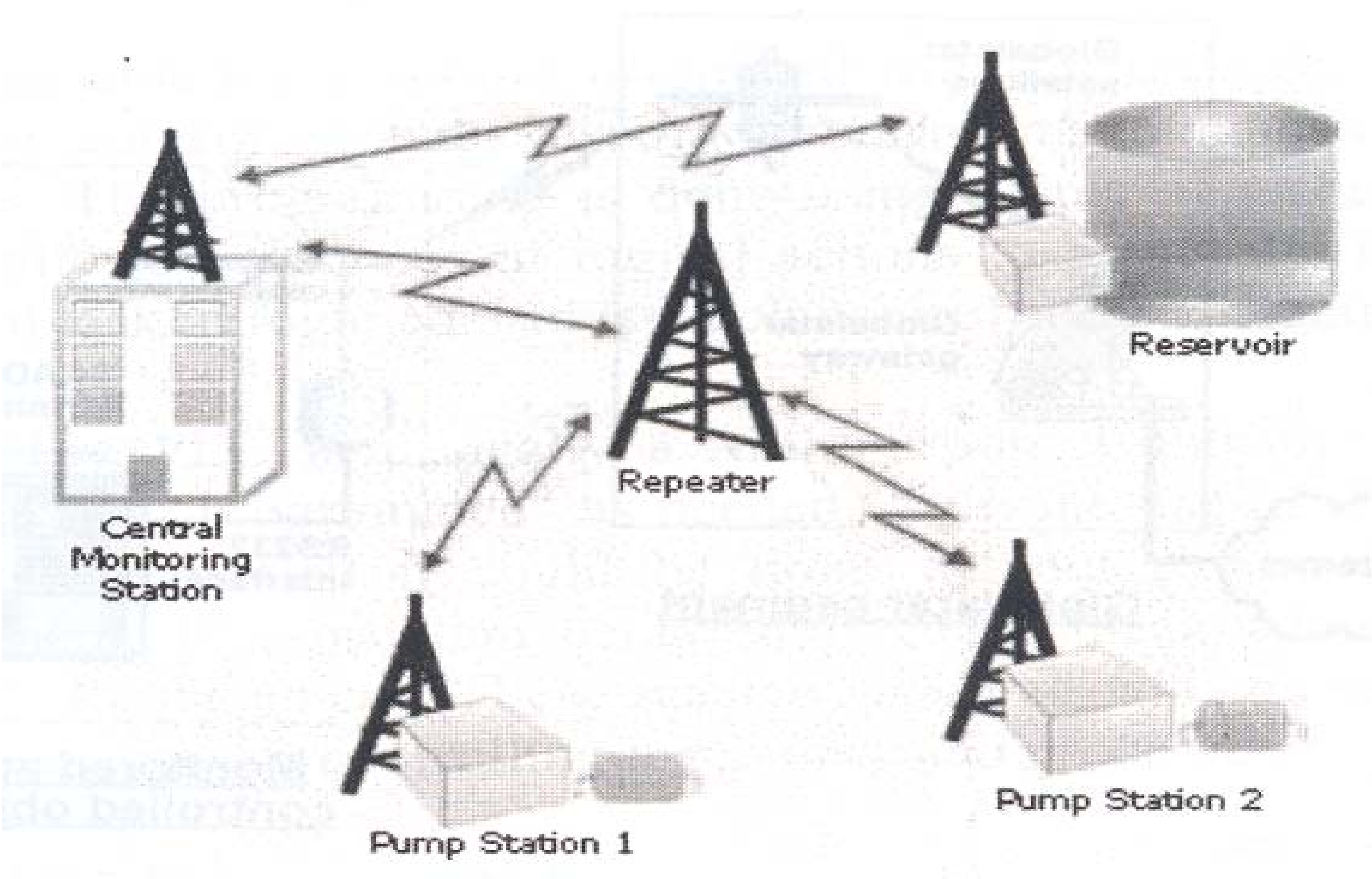


Traditional SCADA



- Field Instrumentation
- Remote Stations
- Communications Network
- Central Monitoring Station

Water distribution system using SCADA



Discussion

Pakistan Engineering Council
Islamabad

Fundamentals of Distributed Control Systems

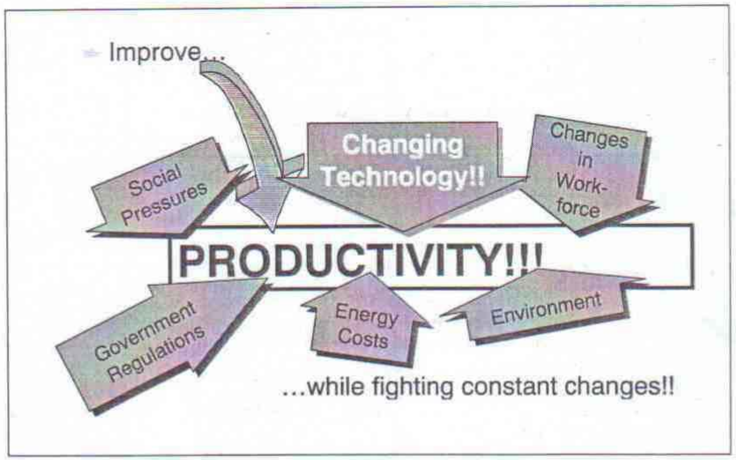
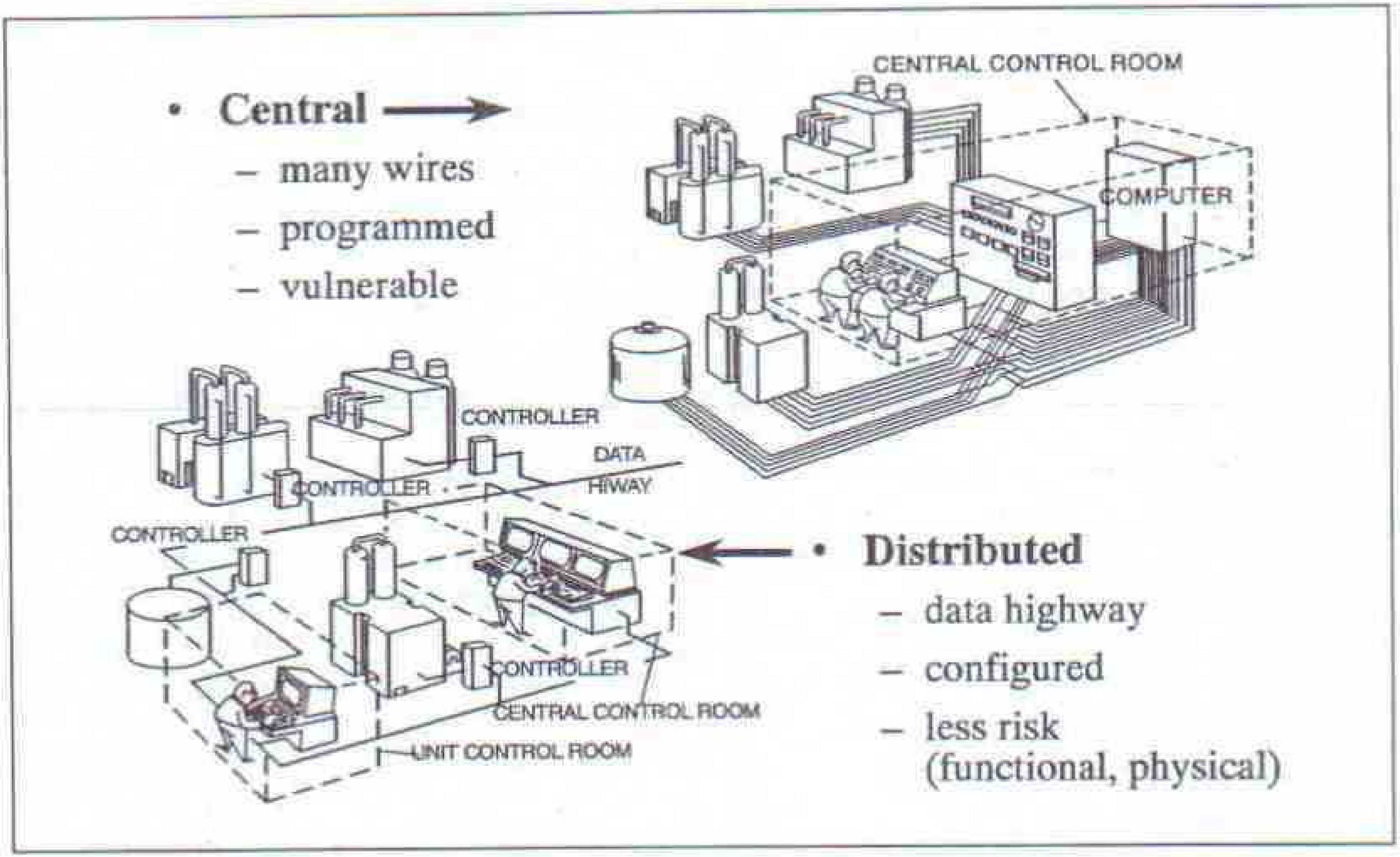


Figure 1-2. Many Factors Work Against Productivity

Lecture -5

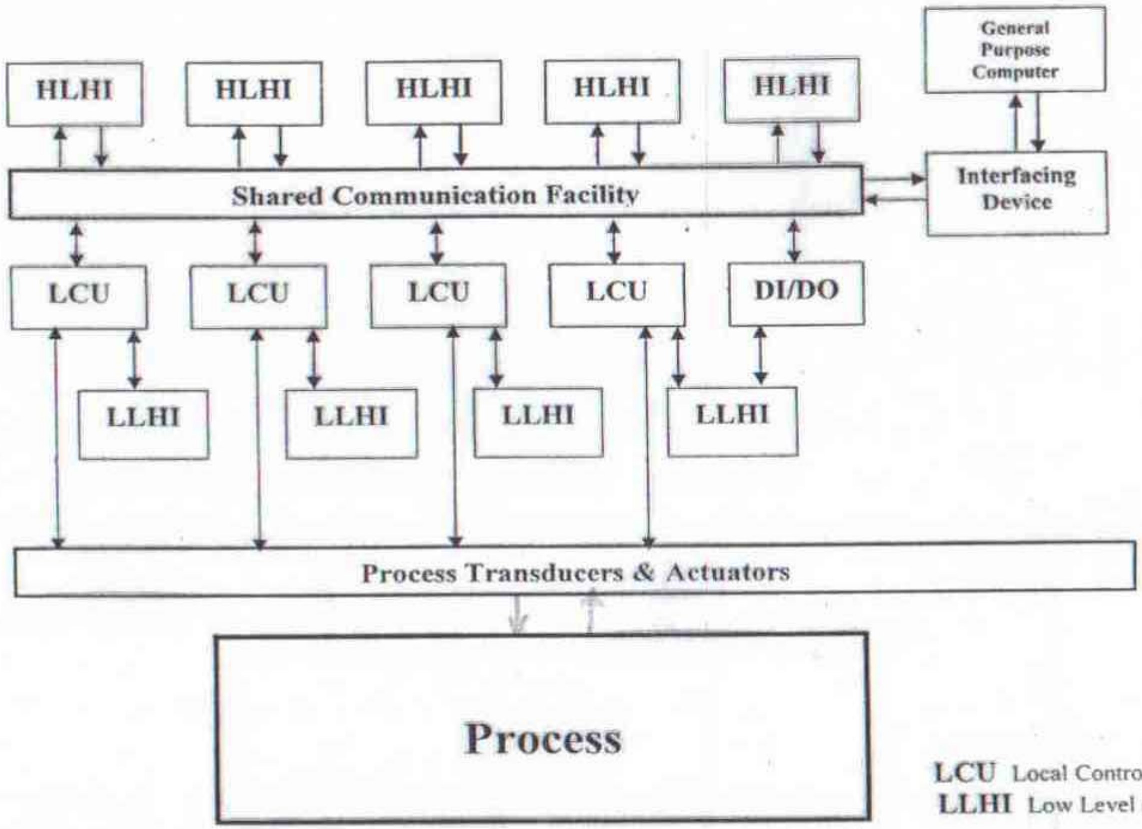
Prof. Dr. Shahid Naveed

Mainframe To Distributed Control



Central Mainframe Computer Grew to Distributed Computer

How does a DCS look like?



LCU Local Control Unit
LLHI Low Level Human Interface

DCS is a Computer Network with Control Objectives

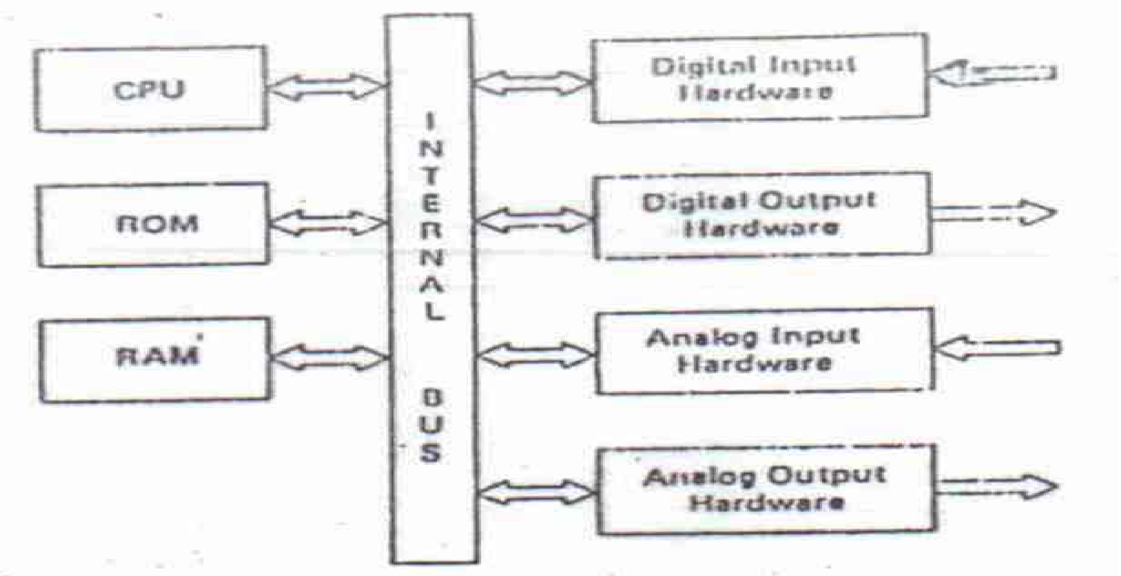
1. The usual benefits of computer network on Ethernet (or like) are availed e.g. resource sharing (hard/soft), backup/archive, database updating, control algorithm computation, data logging etc
2. Each Local Control Unit (LCU) is used to control the process variables. The information in shared through communication interfaces for multiple usage and Low/High Level Interfaces.
3. The High Level Human Interface (HLHI) is provided in the control room and for managerial applications throughout the plant

Typical Benefits of DCS

- Scalability & Expandability of System
- Improved Control Potential
- Improved Operator Interface Capability
- Integration of System Function
- Single Point Failure
- Lower Installation costs
- Easy to Maintain

Local Control Unit Architecture

1. It is the smallest collection of hardware in a distributed control system that performs closed loop control.
2. LCU malfunctioning can cause a condition that is hazardous to both people and equipment its proper design is critical



Basic Elements of a Local Control Unit.

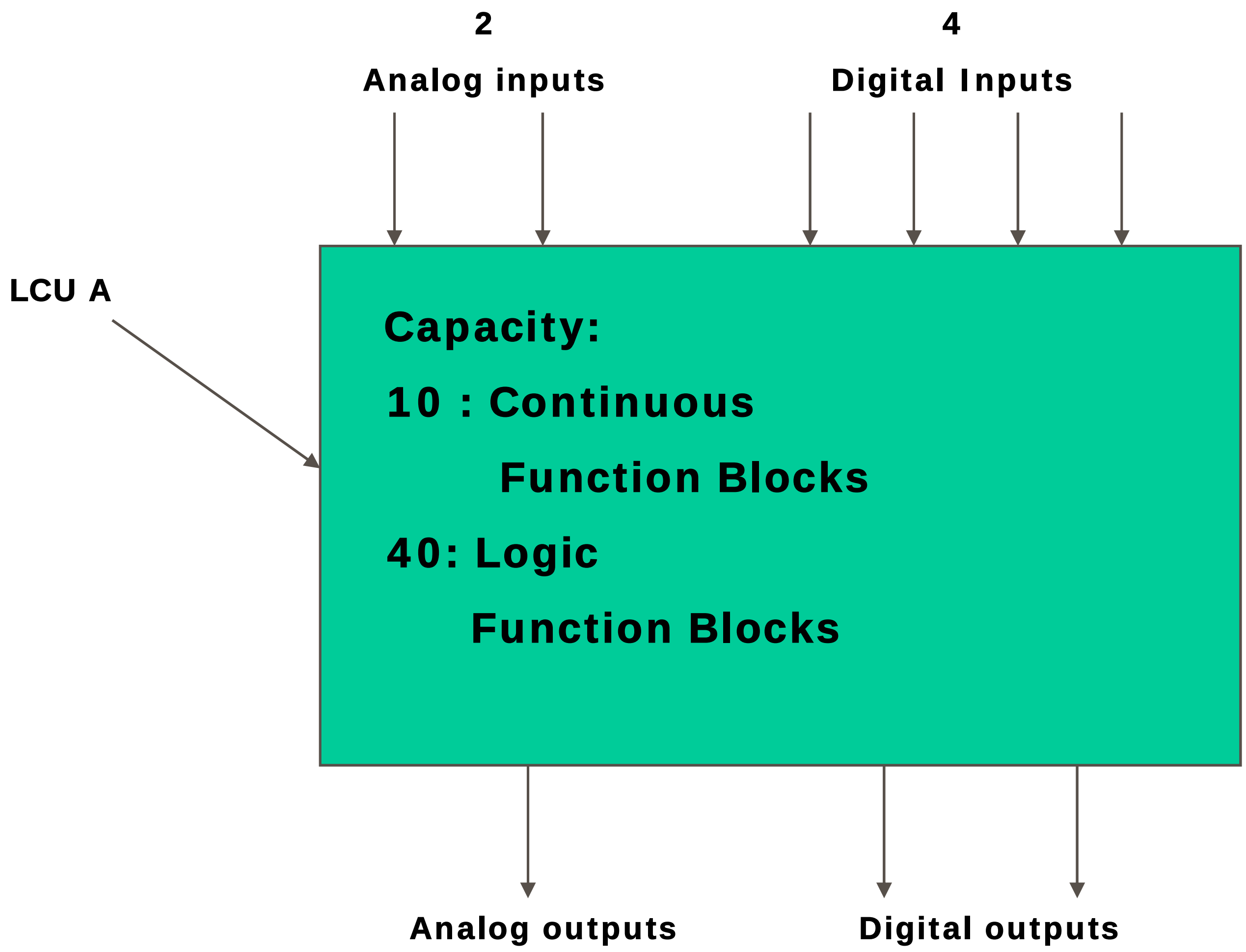
Typical Requirements of LCU

- Flexibility of changing control configuration
- Ability to use the controller without being expert
- Ability to bypass the controller in case it fails so that the process can be controlled manually
- Ability of LCU to communicate with other LCUs and other elements of the system

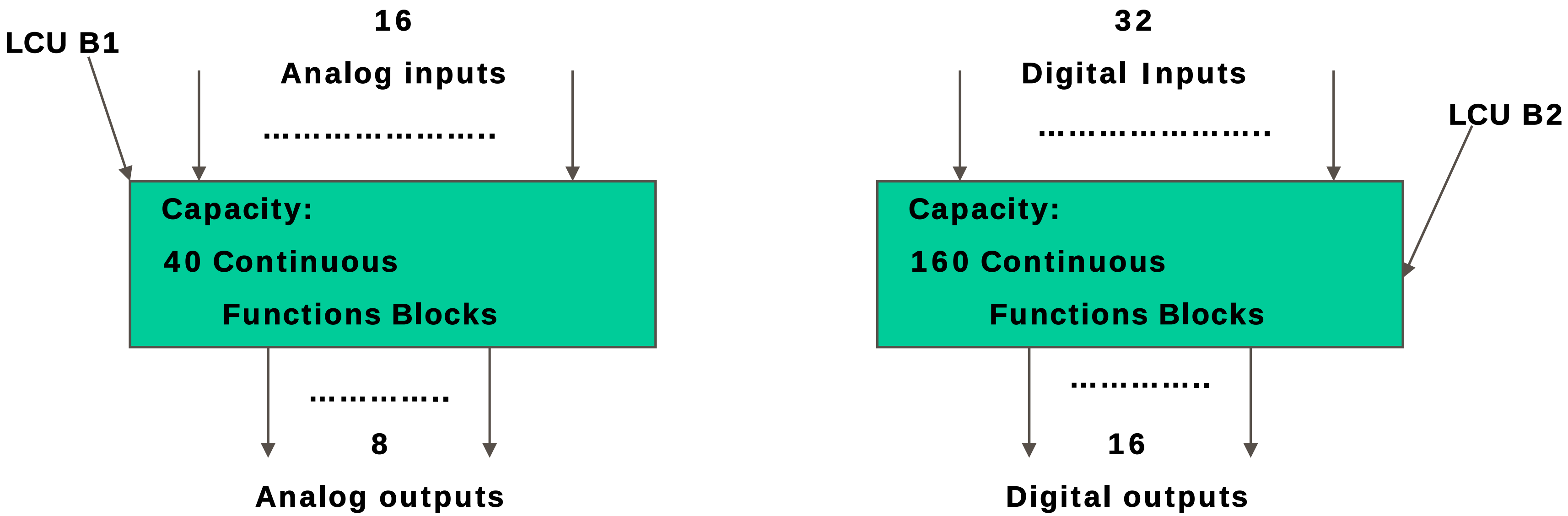
Architectural Parameters of LCU

- Size of Controller
- Functionality of Controller
- Performance of Controller
- Communication channels out of Controller
- Controller Output Security

A LCU

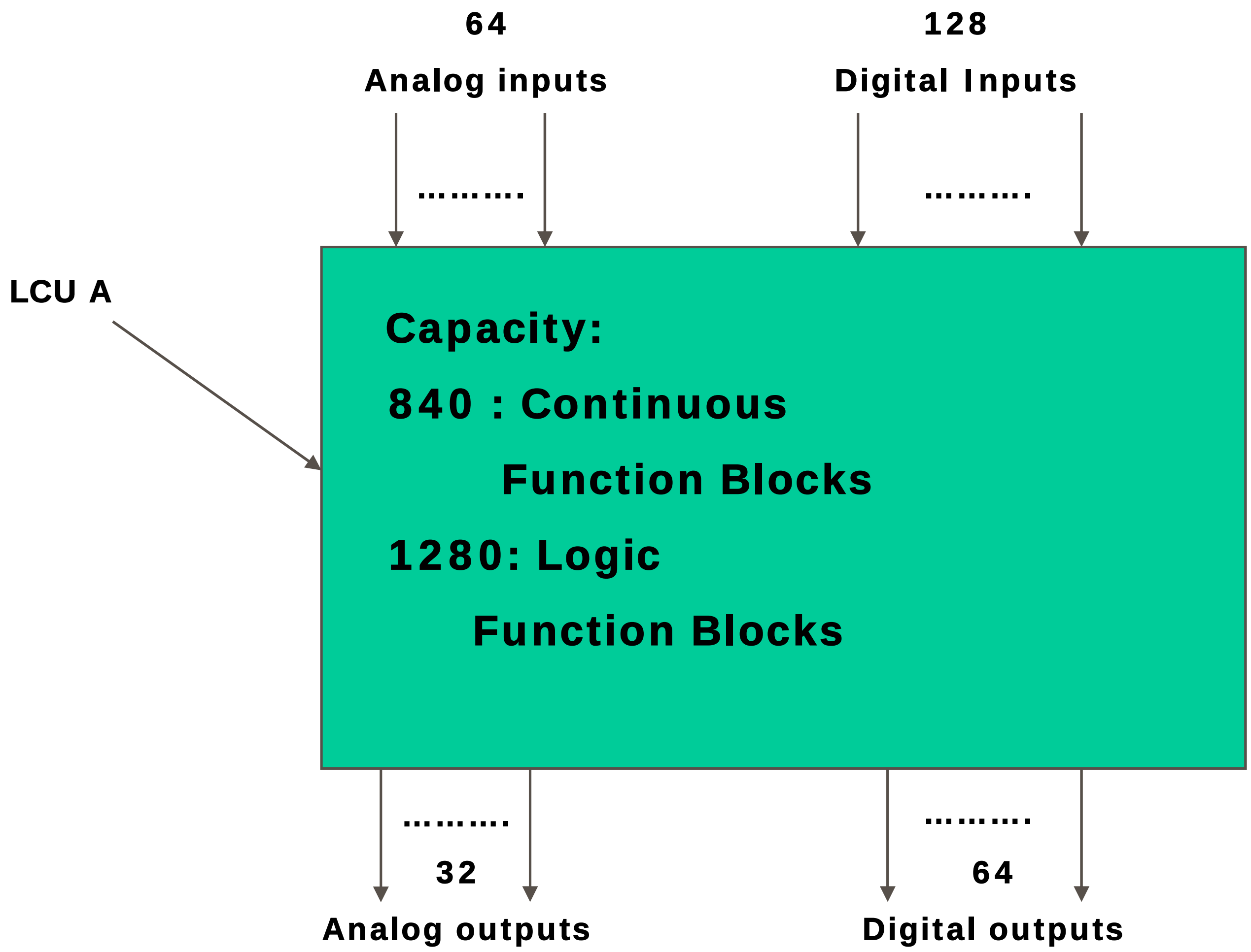

2
Analog inputs
4
Digital Inputs
LCU A
Capacity:
10 : Continuous
Function Blocks
40: Logic
Function Blocks
Analog outputs
Digital outputs

A LCU (Cont'd)



LCU B1
16
Analog inputs
……………………
Capacity:
40 Continuous
Functions Blocks
…………..
8
Analog outputs
32
Digital Inputs
……………………
LCU B2
Capacity:
160 Continuous
Functions Blocks
…………..
16
Digital outputs

A LCU (Cont'd)


64
Analog inputs
128
Digital Inputs
……….
……….
LCU A
Capacity:
840 : Continuous
Function Blocks
1280: Logic
Function Blocks
……….
……….
32
Analog outputs
64
Digital outputs

Architectural parameters of LCU

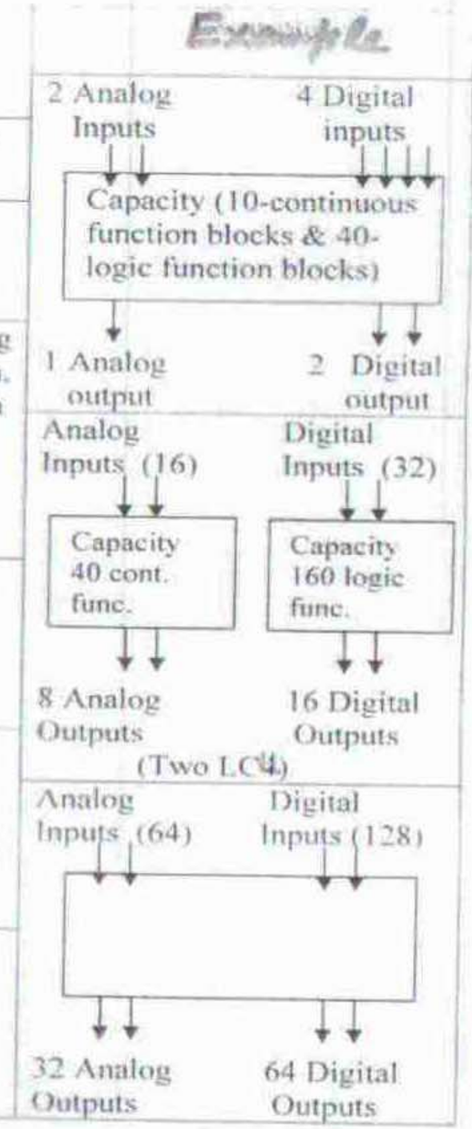
- Size of Controller
- Functionality of Controller
- Performance of Controller
- Communication channels out of Controller
- Controller Output Security

A large number of configuration are possible

- *Single loop*
- *Two LCU types*
- *Multiple Loops*

Comparison of Local Control Unit

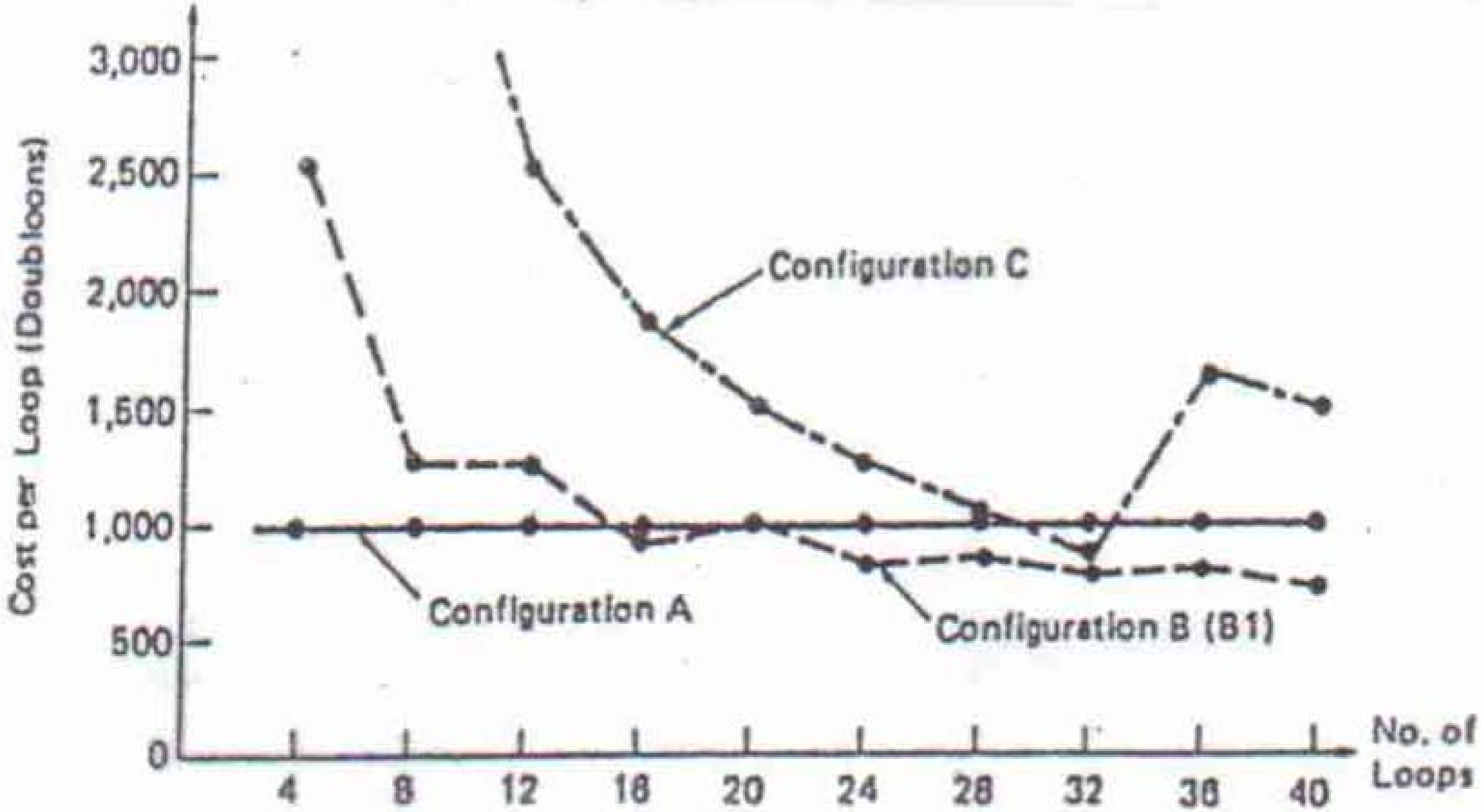
Sr. No.	Parameter of Controller	Configuration LCU Single Loop	Two Types	Multiple Loop
1	**Size of controller**	Nos of functions needed for single PID loop	I/O needed for 8 control loops & a logic controller	System size is small
2	**Functionality**	Uses both analog & logic function blocks	Continuous & logic functions are split into two controllers	Uses both analog & logic function. can support high level language
3	**Performance**	Requirements can be met with inexpensive hardware	Because functional split, excessive performance is not possible	Hardware must be high performance to execute large data functions
4	**Communication channels**	Needed b/w various modules. Minimum human interface	Functional separation requires close interface b/w controller types	Large communication requirement to human interface
5	**Security**	Controller has single loop integrity	Lack of single loop integrity requires redundancy in critical application	Size of controller requires redundancy in all applications



Comment

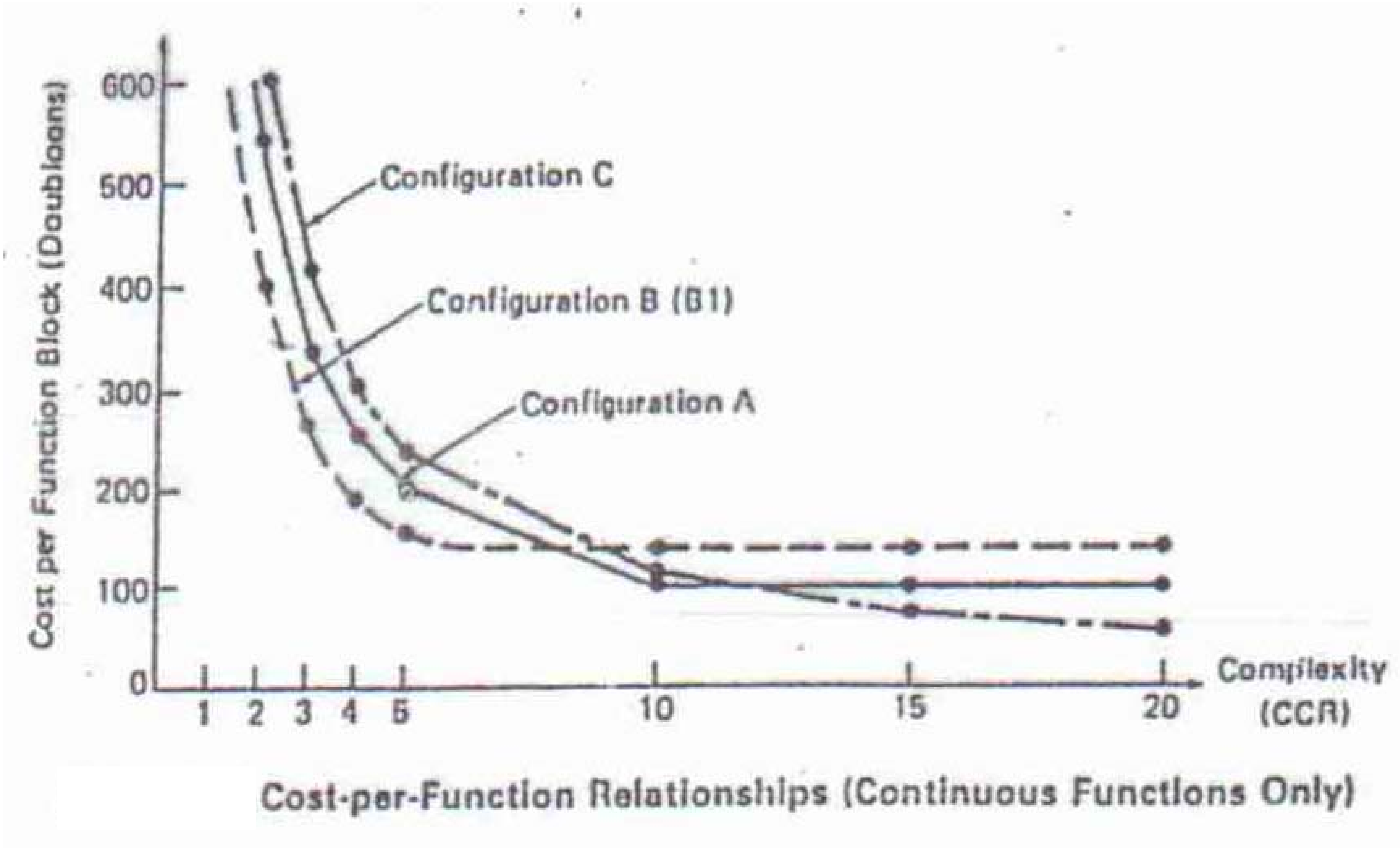
- Typical cost effectiveness of architectures is estimated with each of the configuration
- Configuration-A 12 controllers are required
- Configuration-B 3 controllers + 1 backup required
- Configuration-C 2 controllers + 1 backup required

Typical cost effectiveness



Cost-per-Loop Relationships (Continuous Functions Only)

Typical cost effectiveness



Control Complexity Ratio

- $$CCR = \frac{\text{Nos. of function blocks in control sys}}{\text{Nos. of control system output}}$$

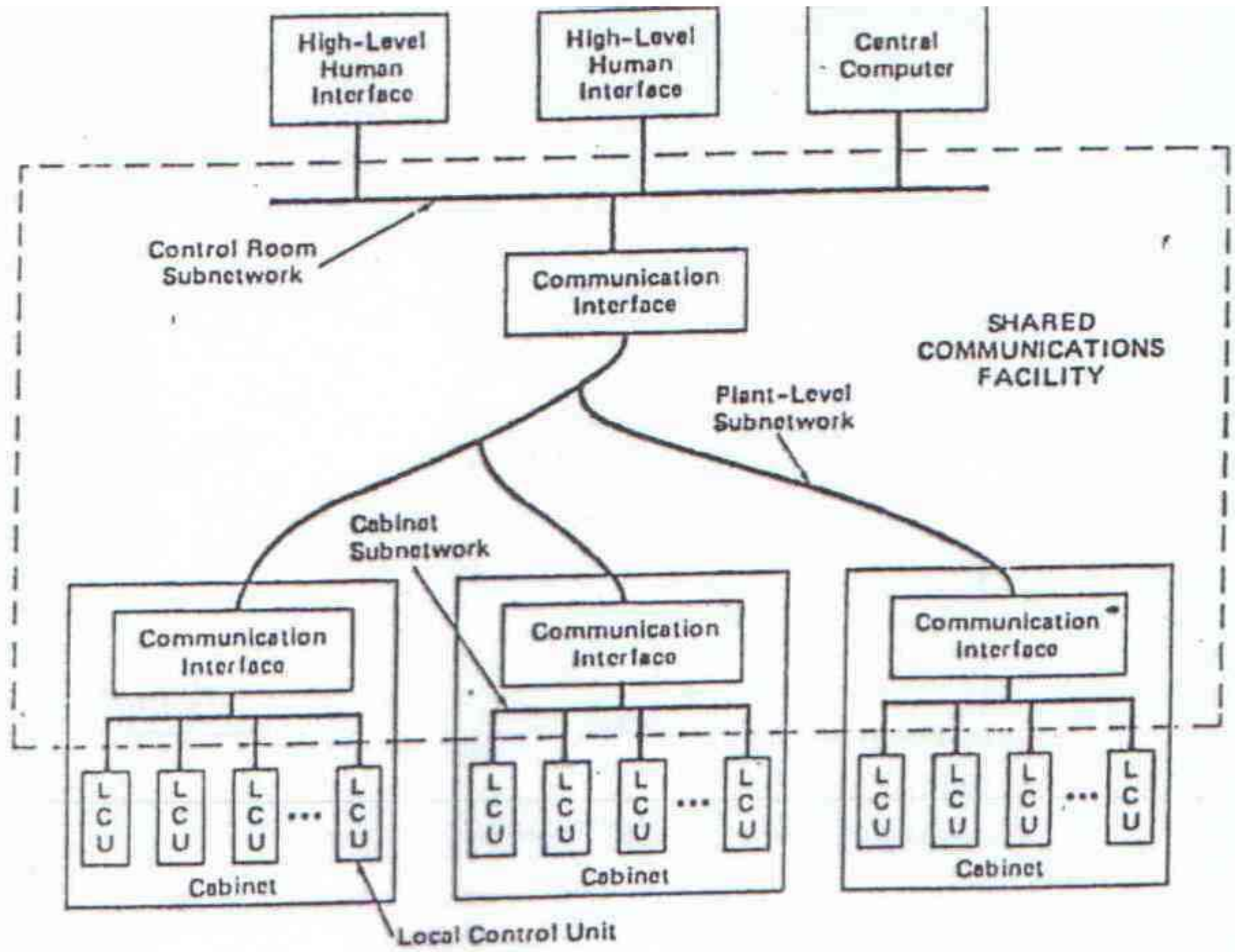
- $$CCR = \frac{\text{Nos. of continuous function blocks}}{\text{Nos. of control analog output}}$$

For complex system the CCR is 30-40

Other Architectural Issues

- How long each cable can be extended?
- How many communication channels the system can support?
- What kind of delay is expected?
- What is the internal communication system?

Distributed Communication



Communication System Partitioning—Example 1

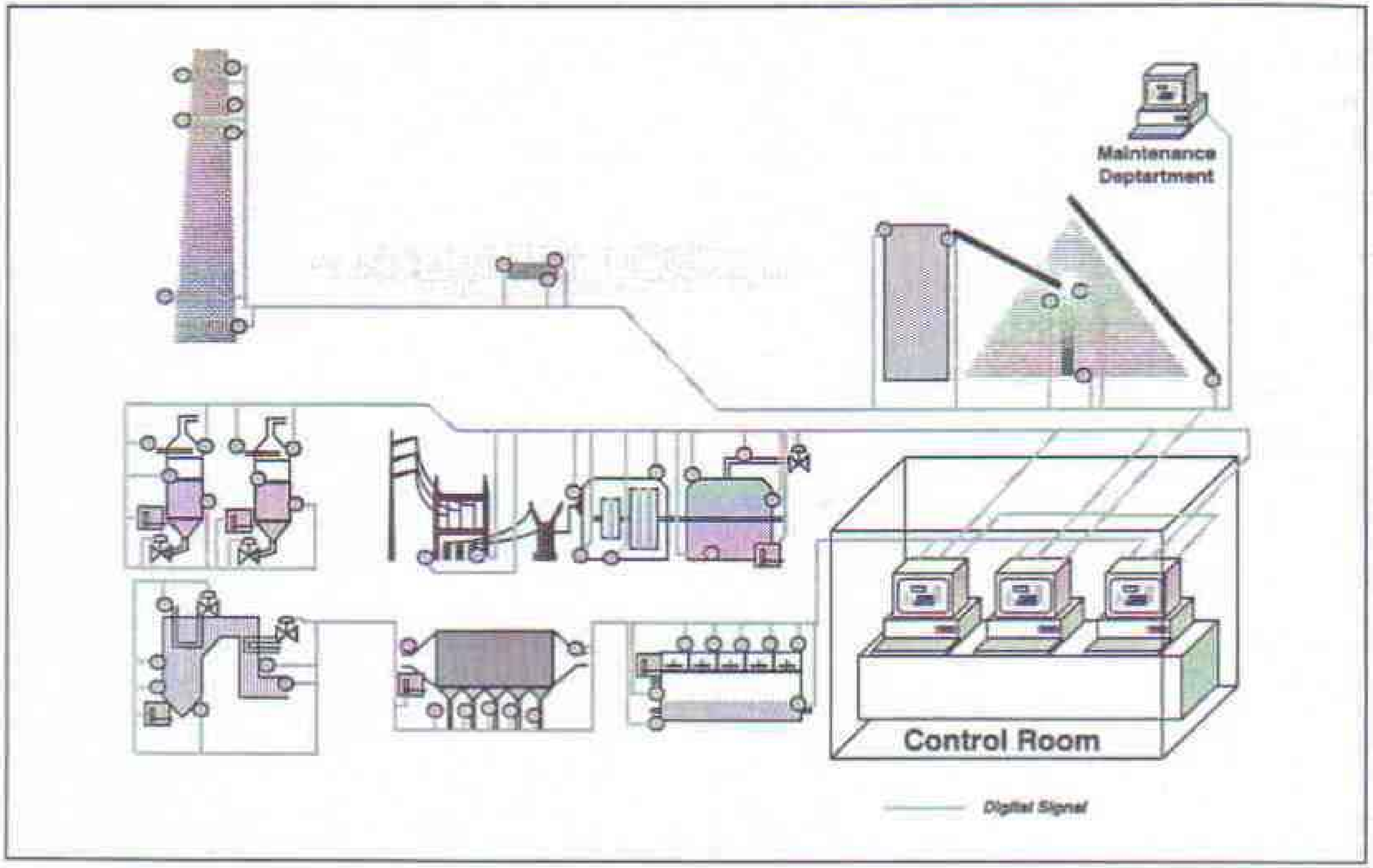
Level of Sub networks

Several high level operation interfaces and communication elements located in the central control room area must communicate with each other at moderate load of message traffic.

The message communication has generally three levels.

1. A load bus or subnet
2. A local network in the central control room
3. A plant wide communication

Field-bus Reduces Wirings



Fieldbus Control and Monitoring Significantly Reduces Field Wiring

Benefits of Distributed Communication

A comparison between non-distributed and distributed Communication facility reveals the following benefits:

- Cost of wiring is reduced significantly
- Flexibility of making changes in software & firmware increases
- Less time to implement a large control system
- The control system becomes more reliable due to significant reduction of physical connection

Typical worries for Distributed Communication

Existing one-is-to one configuration had no time delay. Sharing the data buses may have some delay! *The answer is NO*

Overloading of channels!

The answer is Overloading may take place.

Requirements of Communication System

1. Minimize time delays and maximized security of transmission.
2. Communication between various modules and HLHI/ LLHI should be effective.
3. Communicate set points, operating modes and control variable from HLHI devices.

Additional Requirements

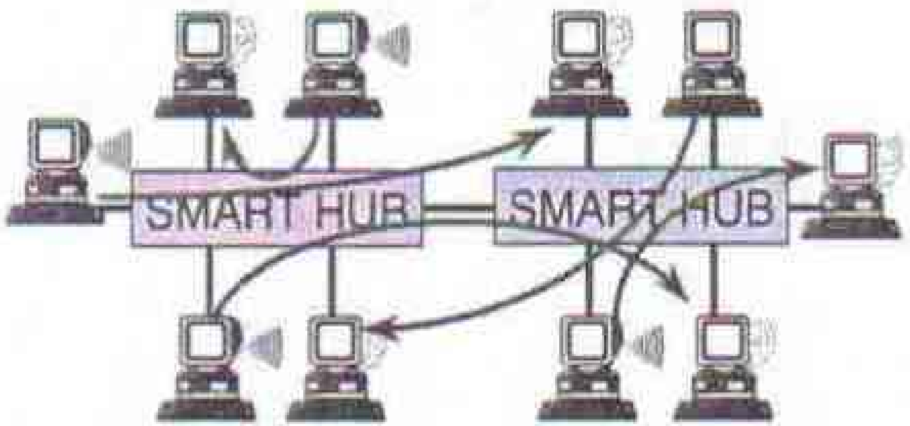
- Download control configurations, tuning parameters and user programs for HLHI.
- Transmission of information from data input/ output units to high level computing devices.
- Synchronization of real- time and elements of machines.
- Transfer large data for high level processing take trends and searching applications.

Communication Issues

1. Maximum permitted size of the system
2. Maximum acceptable time
3. Maximum allowed delay in systems
4. Communication rate
5. Rate of undeleted errors occurring in the system (due to noise)
6. Sensitivity to traffic loading (traffic of signal load)
7. System scalability (expandable/ large/ small)
8. Fault Tolerance (failure of one channel should not effect other)
9. Interacting requirement (protocol issues RS 232c, RS 422, IEEE 488, smart)
10. Ease of application/ maintenance

Smart Hubs In Networks

- Full duplex communications between switched hubs
- Multiple simultaneous conversations w/o interference
- Little chance for collisions to delay signals



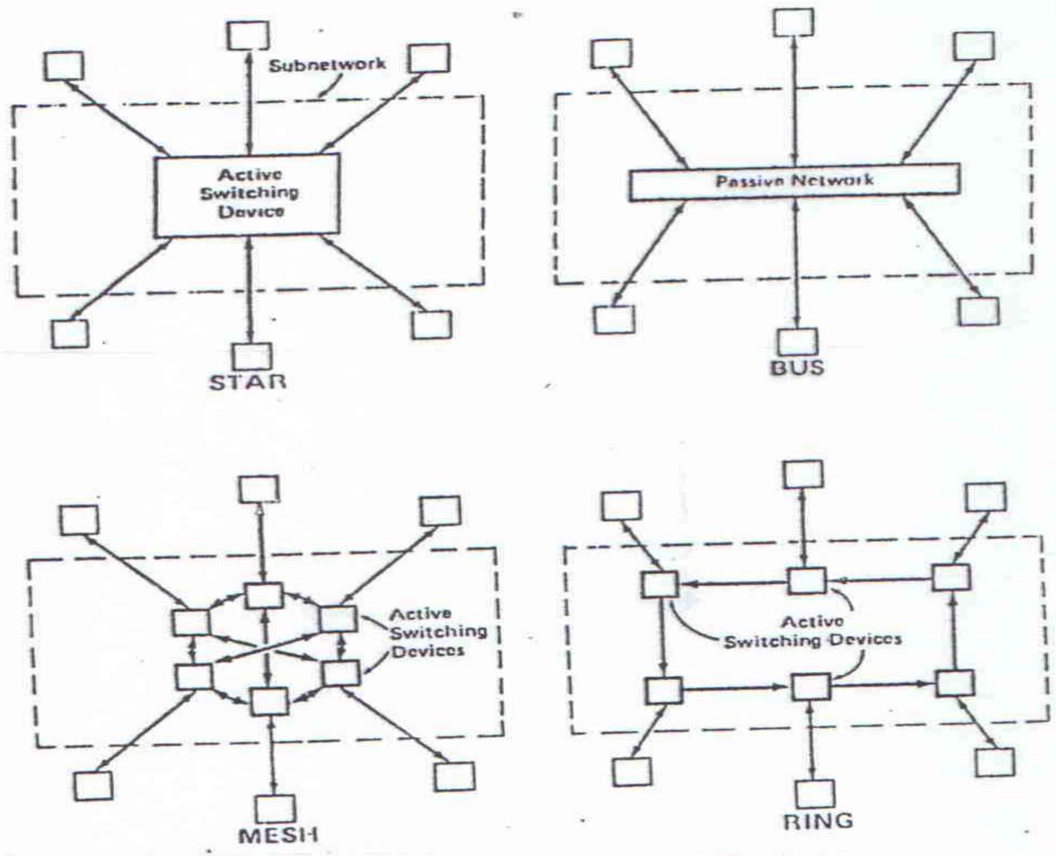
Smart Hubs in Networks Allow Any Two Stations to Talk Without Interference

Topology refers to the structure of physical connections among the elements in a network.

Some of the popular topologies are:

- Star
- Bus
- Mesh
- Ring

Network Topologies (Cont'd)



Network Topologies (Cont'd)

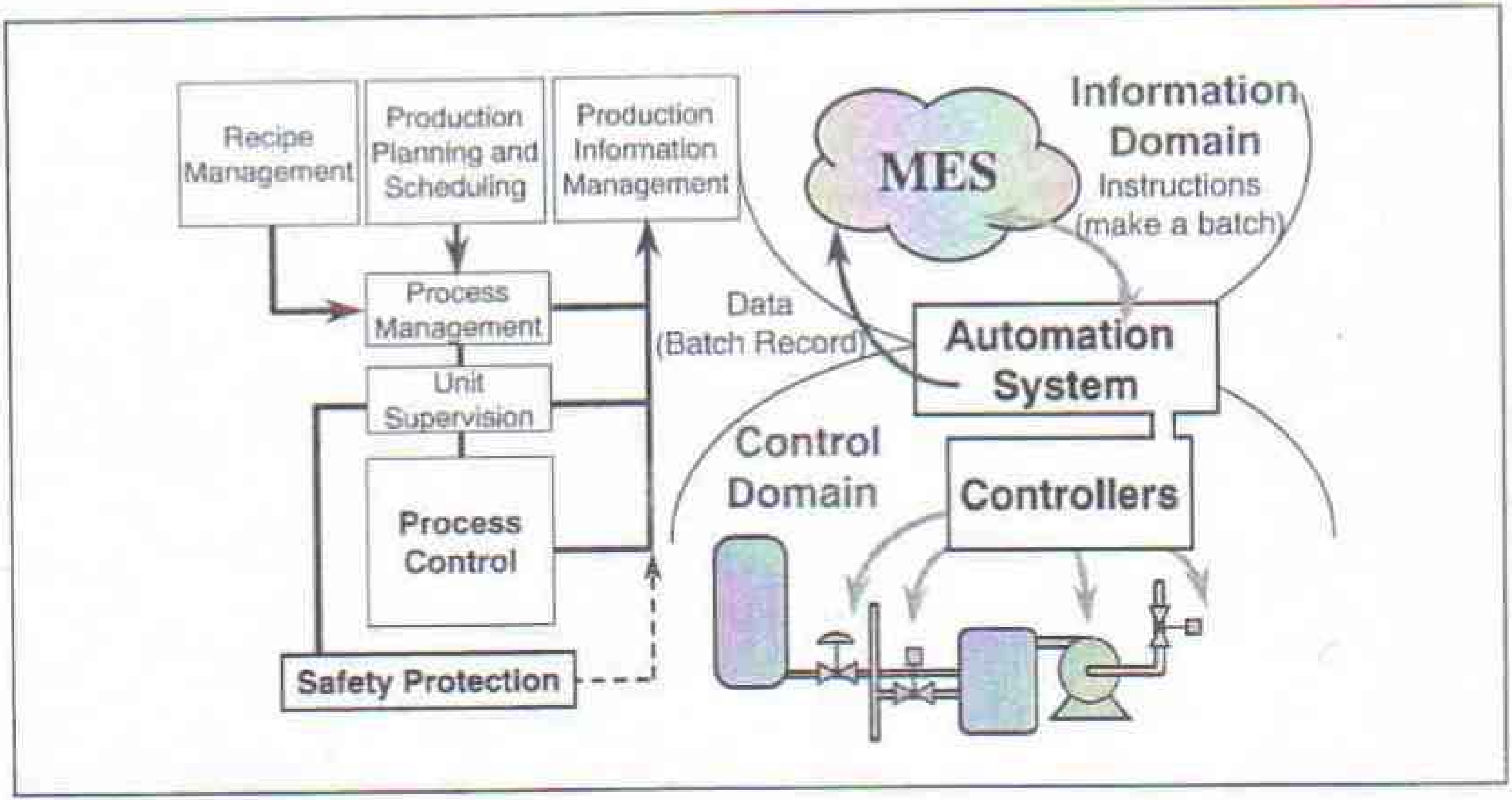
"Star" is simplest but its failure shall cause the entire sub network to stop functioning

"Bus" topology is similar to star but the same problem exist i. e. sharing one bus

"Mesh" topology tries to overcome the limitation of star topology and is generally adopted in industry

"Ring" or "loop" topology is a special case of Mash topology that provides connections between active switching devices in a loop sequence

The Way Ahead-- Management Executive Systems

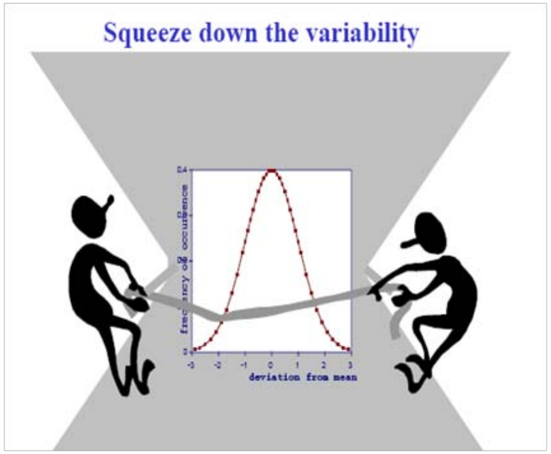


Boundary between Information and Control is *Not* Smooth!

Laboratory Session

Pakistan Engineering Council
Islamabad

The Opportunity in Stochastic Process Control



Prof. Dr. Shahid Naveed

Lecture -6

Sequence of Presentation

1. Objective of SPC
2. Basic Concepts of SPC
3. Techniques & Analysis
4. Common & Special Causes of Process Deviations
5. Stable Process
6. Trend Analysis
7. Process Capability

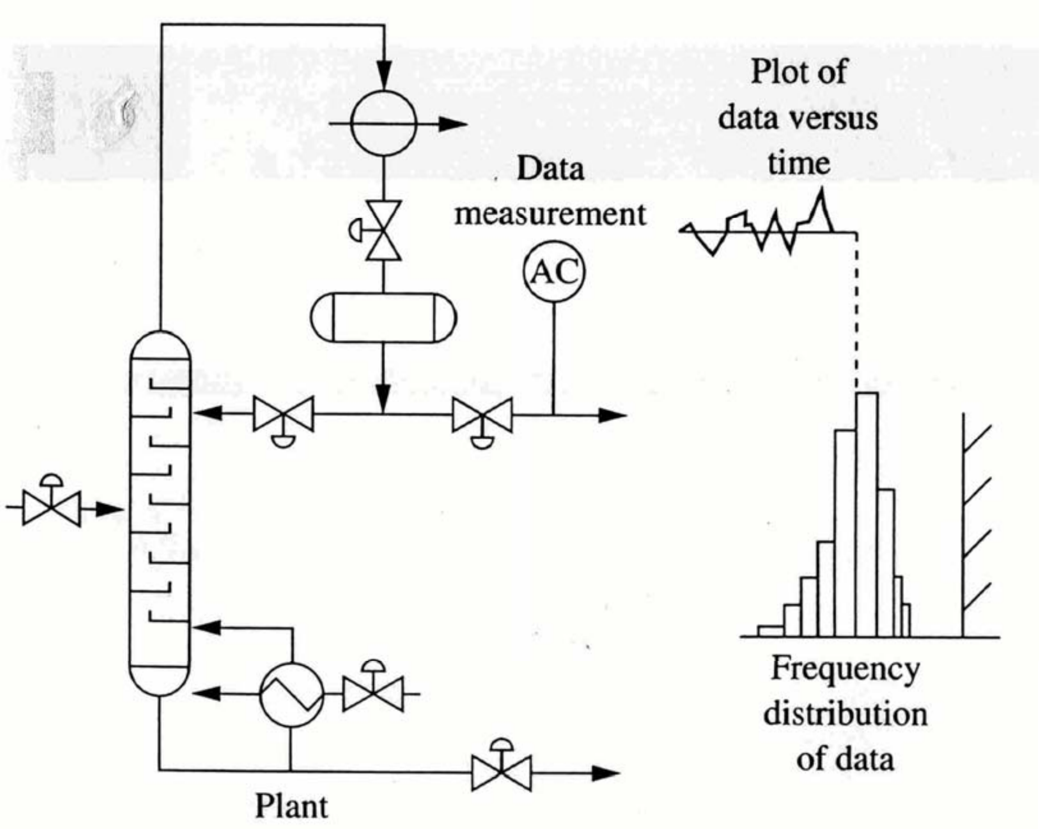
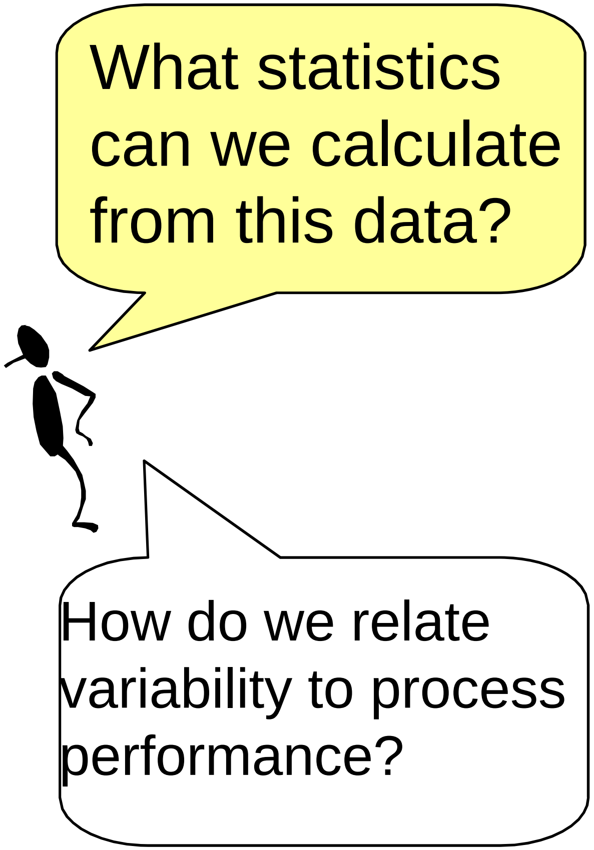
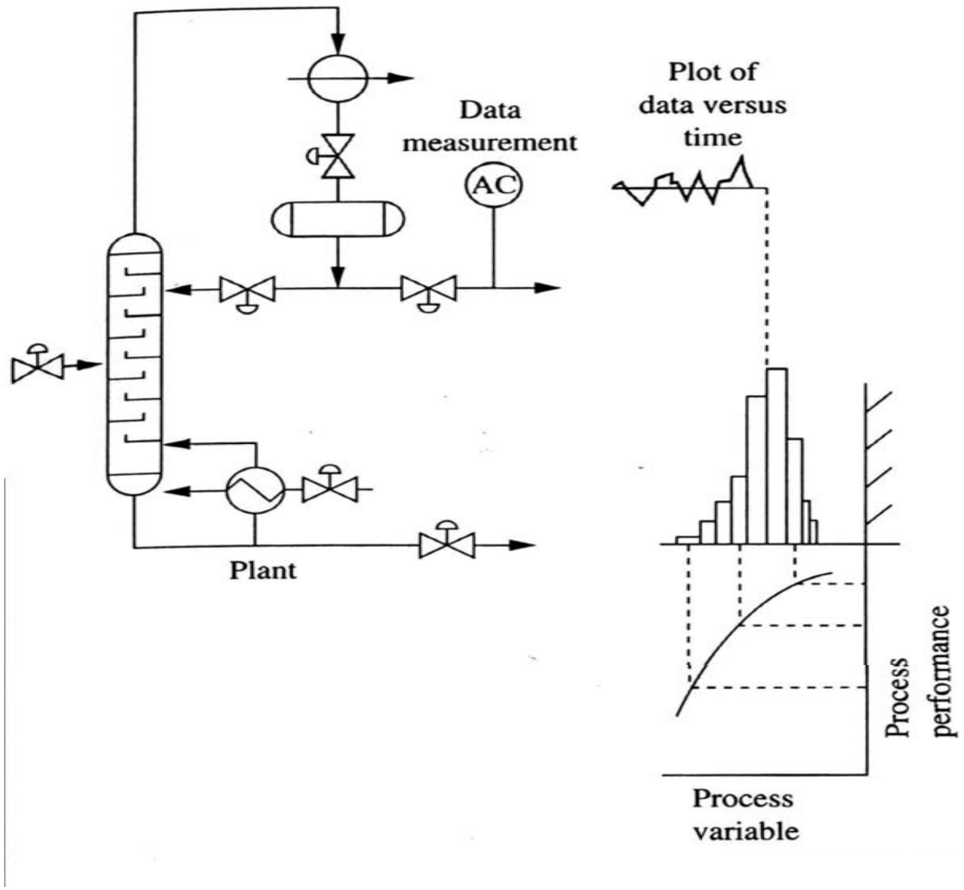

Plot of
data versus
time
Data
measurement
AC
Frequency
distribution
of data
Plant

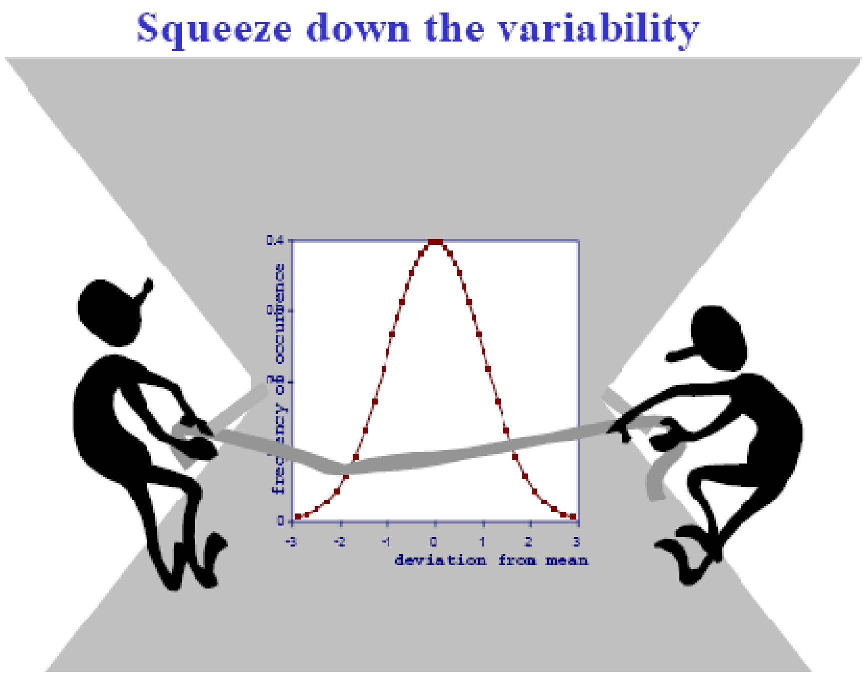
FIGURE 2.8


What statistics can we calculate from this data?
How do we relate variability to process performance?

Calculate the process performance using the distribution, not the average value of the key variable!



In Nutshell Squeeze the Variability is the 1st Objective

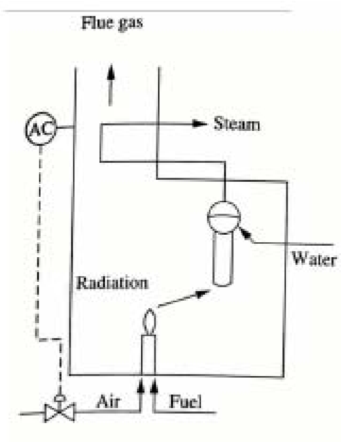


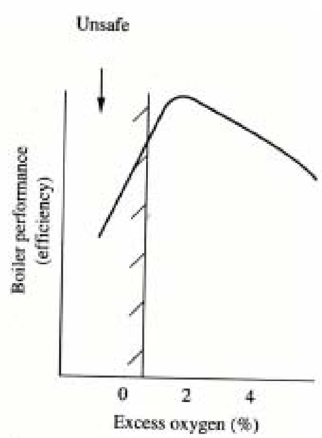
Another Example

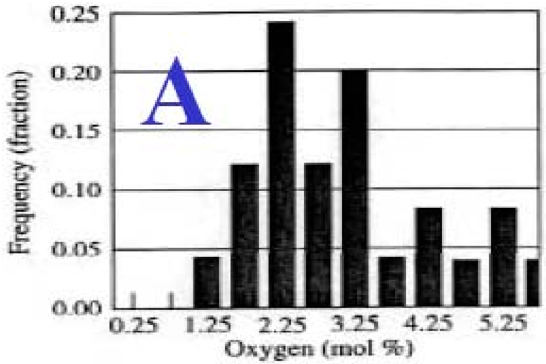
Example of Benefits of reduced variability for chemical reactor

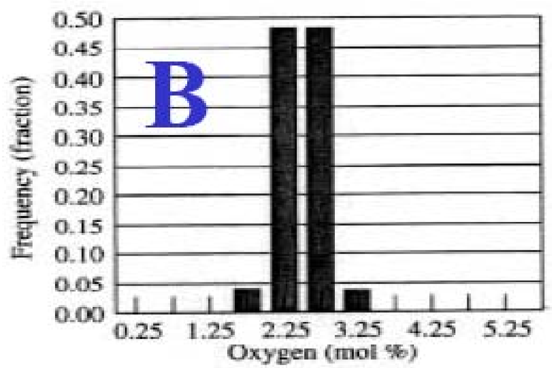
Goal: Maximize efficiency and prevent fuel-rich flue gas

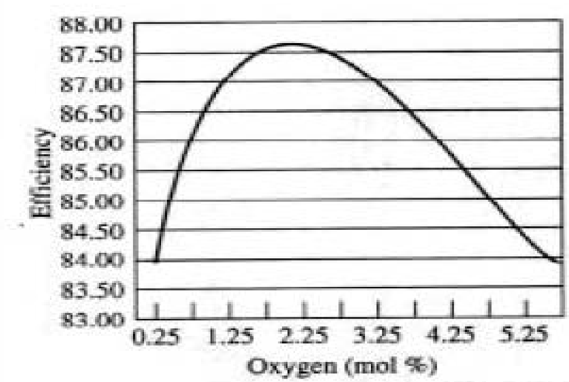
Which operation, A or B, is better and explain why.











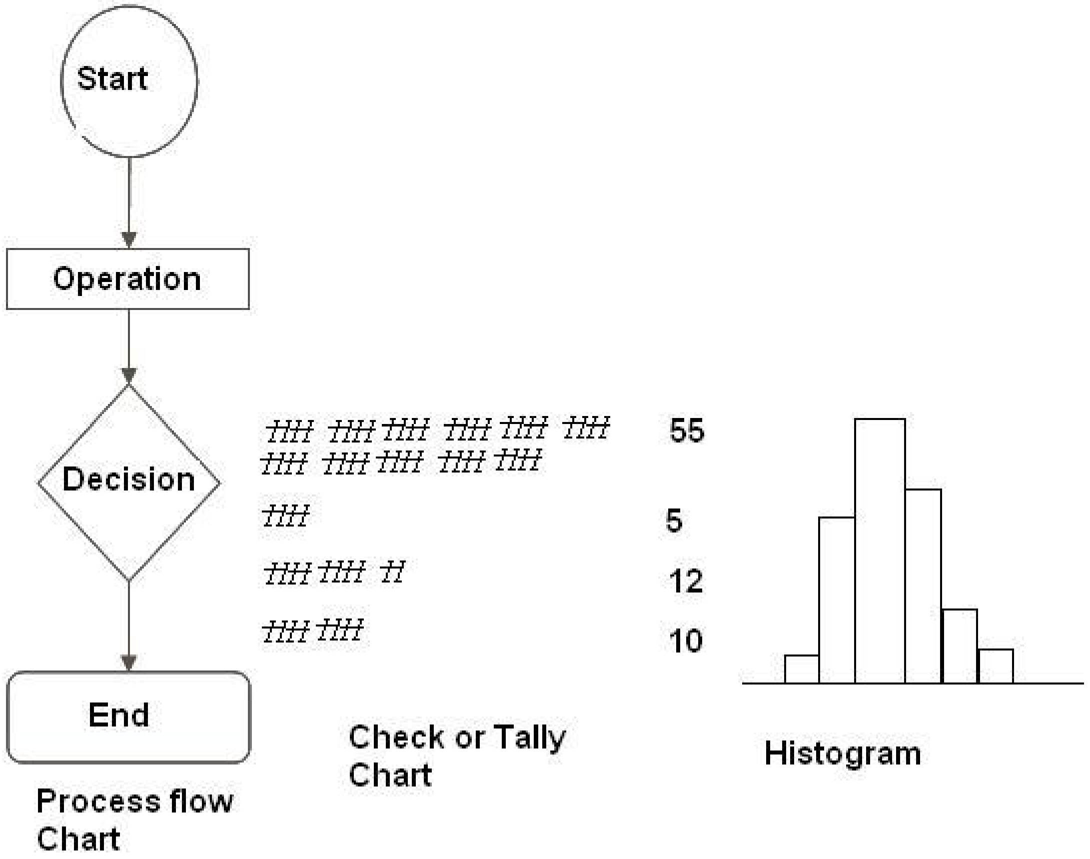
2. Basic Concepts for SPC

- What is a process?
  - Converting raw materials into products
- What is control?
  - Achieving the objectives in the desired manner
- Have we done the job correctly?
  - Only Historic Data can reveal
- Can we do the job more consistently?
  - Through online statistical monitoring/trend analysis

SPC Related Queries

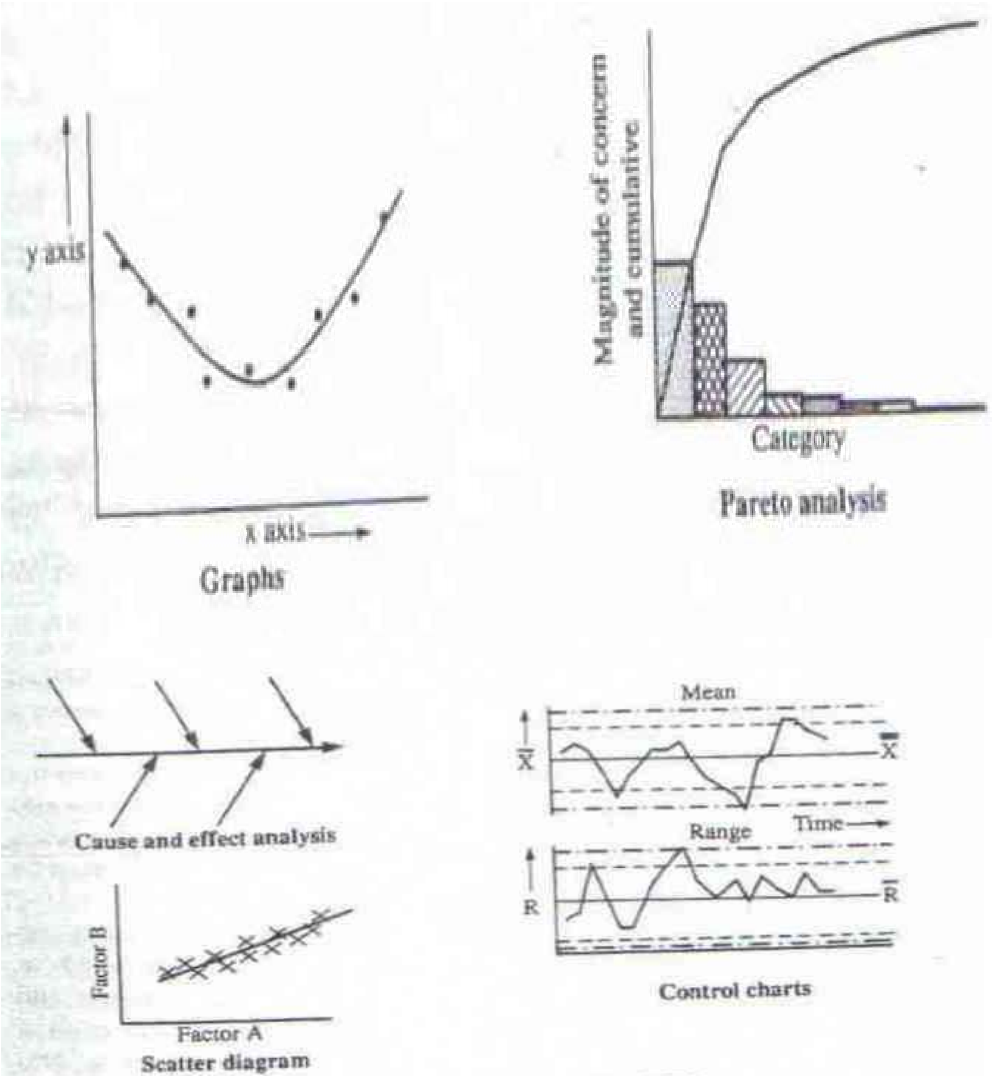
- Are we doing the job correctly?
    - *Detection, prevention, confirmatory to design aspects*
- Can we do the job better?
    - *The process and human capability is under question*
- Can capability/ quality be enhanced?
    - *Through process improvement and training*

- What statistical tools are available?
  - Process flow Charts
  - Check or tally charts
  - Histograms

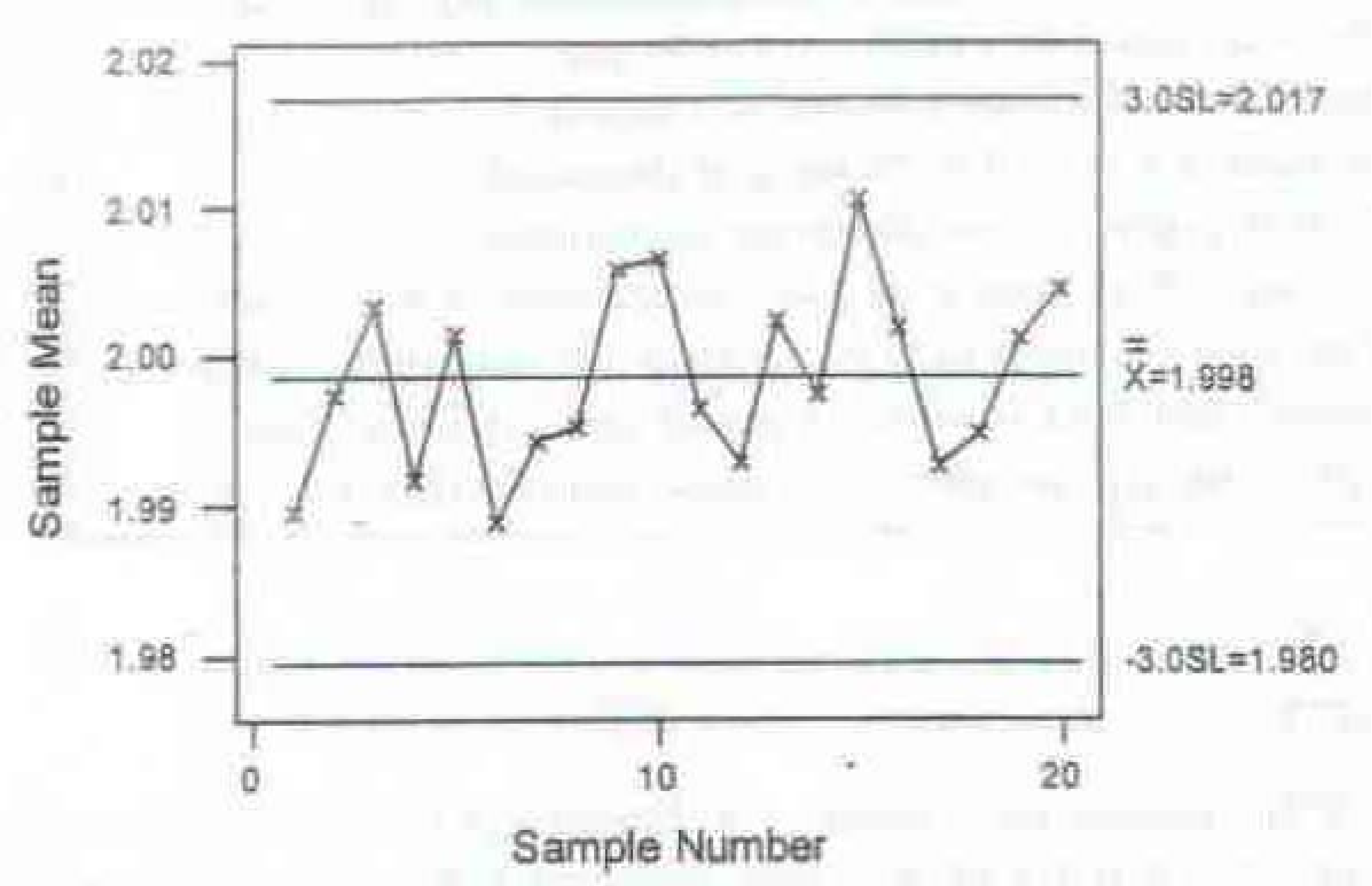


3. Techniques & Analysis (cont'd)

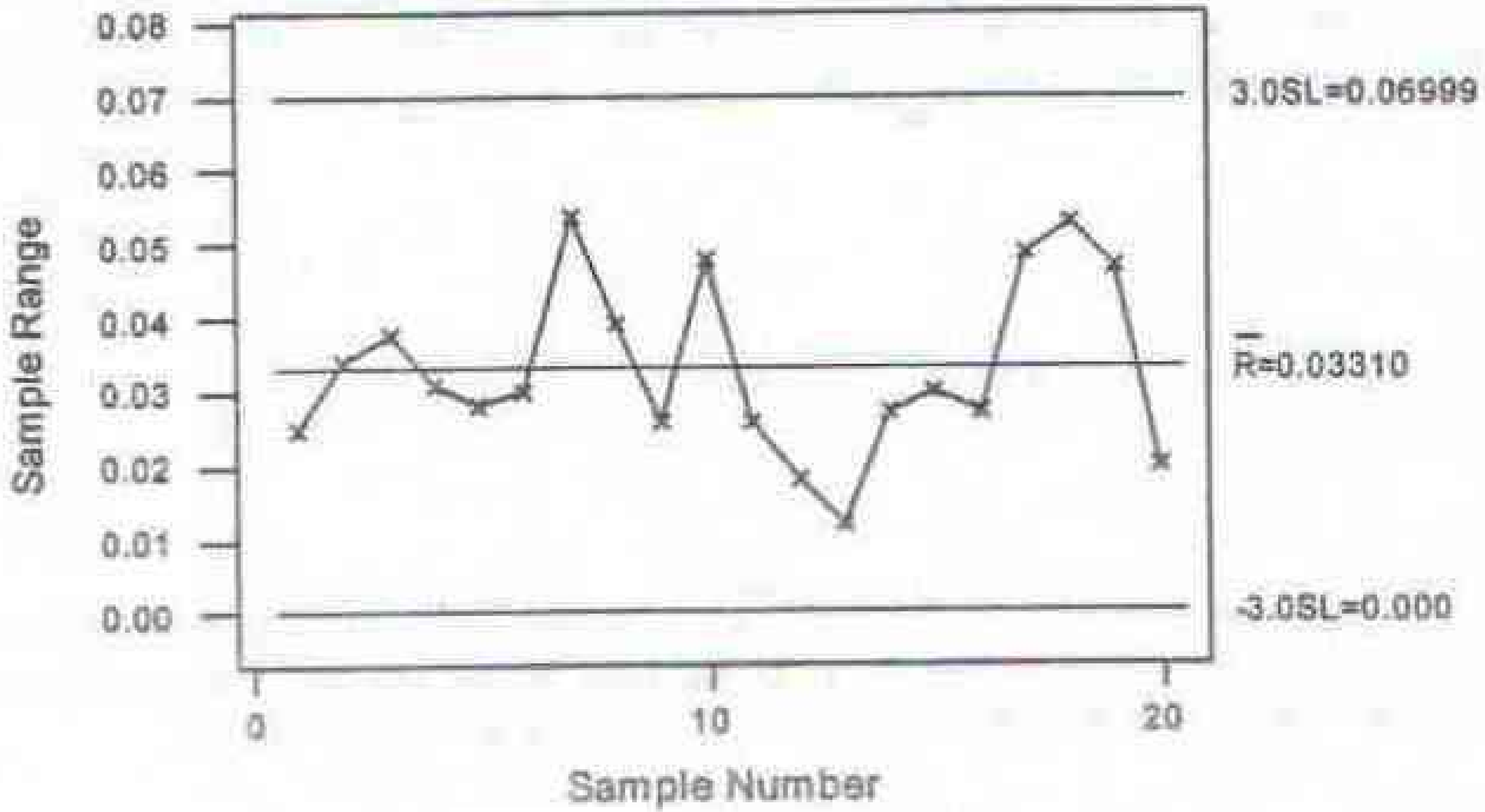
- Graphs
- Pareto Analysis
- Cause & effect diagrams
- Scatter diagram
- Control Charts



What is a Control Chart?



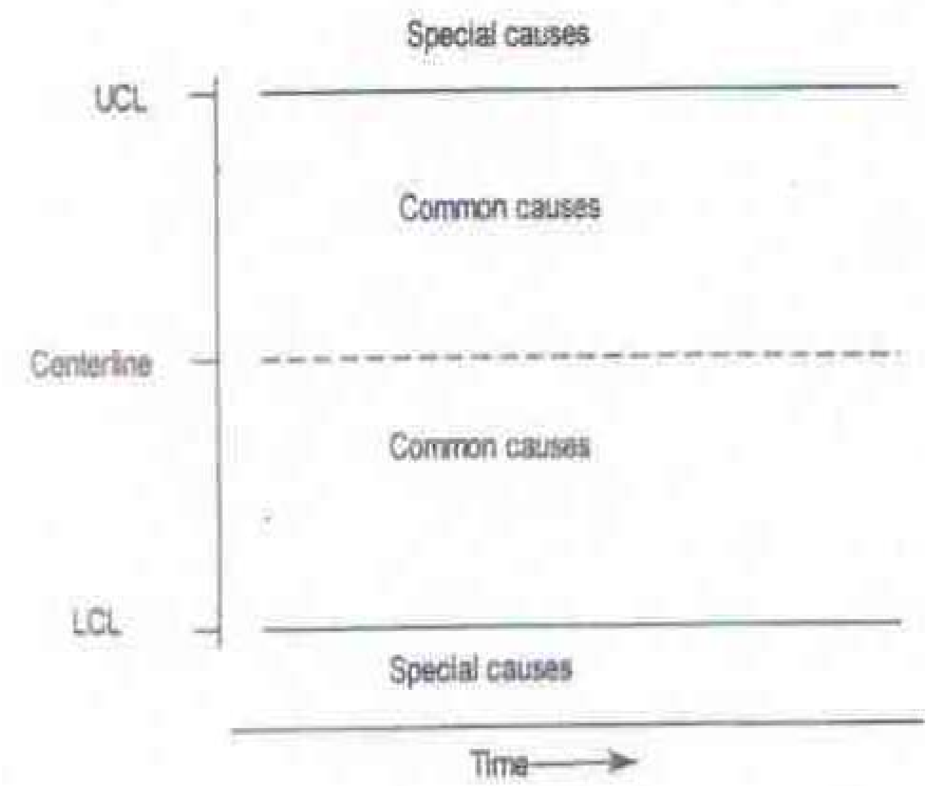
What is a Control Chart?



R chart for width.

4. Objective of Control Charts

- Process monitoring for extended periods
- To identify common causes of process variation / deviation
- To identify special causes of process variation/ deviation



Fault Diagnostics

Common Causes of Process Variations

- Inherent or natural variation in the inputs and transformation activities.

How to identify them?

- Repeatable, predictable, non- symmetric or random.
- Global to the system and originate from many sources.
- Lie within the process band within which a process is expected to vary.

Special Causes of Process Variations

- These are variations due to process inputs and transformation activities that occur irregularly. They are not part of the system but originate from outside.

How to identify them?

- They are localized to an operator, shift or piece of equipment.

- The general policy to improve process monitoring is to *minimize common causes and eliminate special causes* of disturbances.

Common Causes can be minimized by:

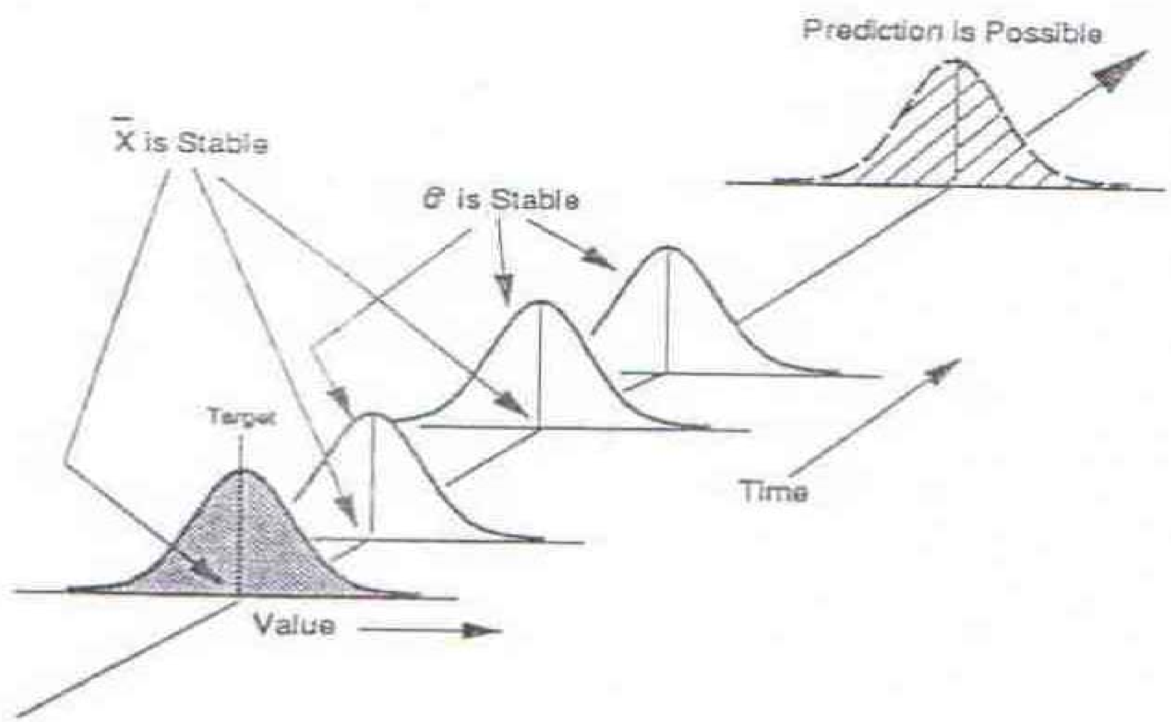
- Reduction in variability in inputs and transformation activities
- Improve the process
- Improve work practices
- Improve operating guidelines

__Special Causes__ need to be attended specifically

- Whenever a control chart signals a special cause, search immediately for what was done differently on that instance.
- The discovery of special cause of variation is usually the responsibility of someone who is directly connected with the process.
- Do not make a fundamental change in process, identify and permanently remove the special cause to prevent the recurrence.
- If a special cause can not be pin-pointed make process adjustment.

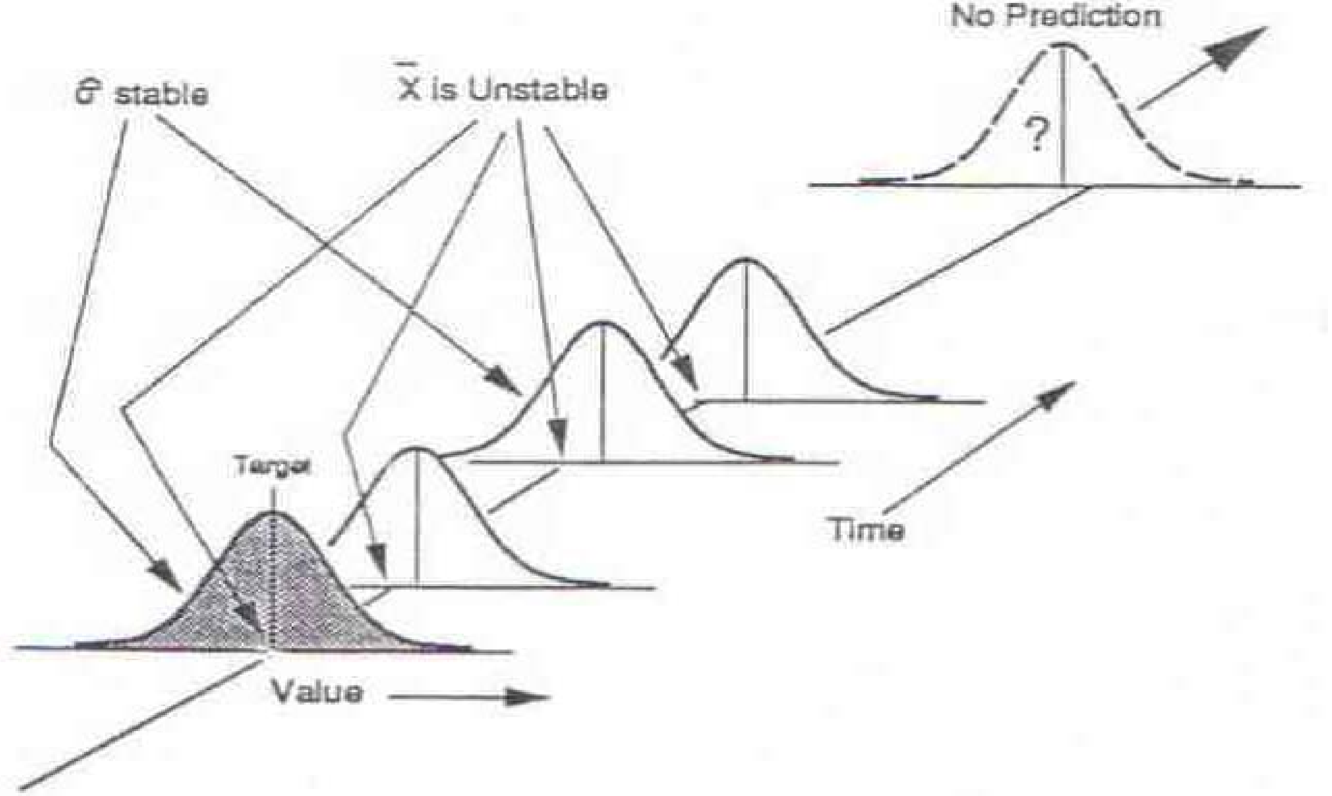
5. What is a Stochastic Stable Process ?

- A Process is said to be in a *state of Stochastic Stable Control* if the distribution of measurement data has the same shape location and spread over time.
- In other words, a process is stable when the effects of *all special causes have been removed* from a process, so that the remaining variability is only due to common causes.



What is a Stochastic Un-stable Process ?

A process is said to be *unstable or NOT in a state of statistical control* if it changes from time to time because of a shifting average , or shifting variability, or a combination of shifting averages and variation.



Trend Analysis

Trend Analysis leads to answer the queries like

1. Are we in control ?

2. Do we continue to be in control ?

and is instrumental to

1. Fault diagnostics

2. Capability enhancement

Trend Analysis (cont'd)

After a process is recognized to be out of control trend analysis is employed to search for the sources of problems.

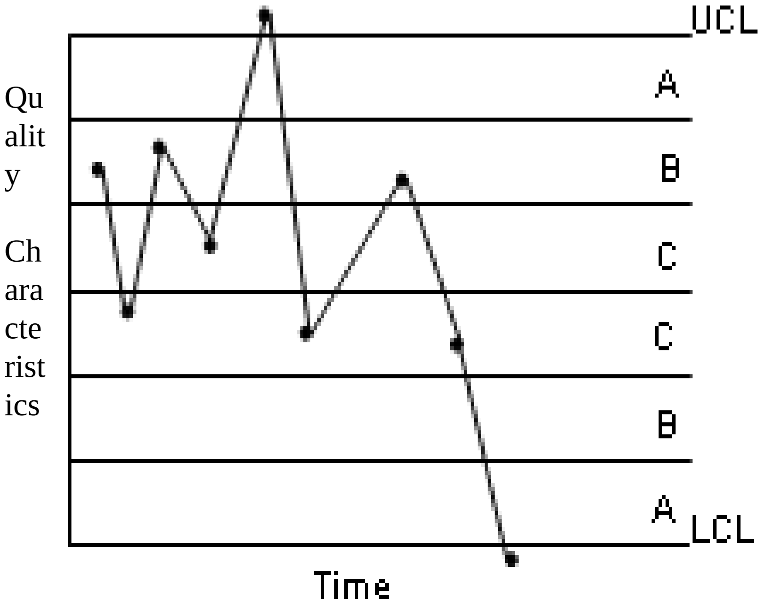
The chart is divided into three zones. Zone A is between +/- 3σ. zone B is between +/- 2σ and zone C is between +/- 1σ

The following eight tests can be performed.

Trend Analysis (cont'd)

Test 1

Pattern: One or more points falling outside the control limits on either side of the average.



Problem source:

- Equipment breakdown
- New Operator
- Drastic change in raw material quality
- Change in method, machine, or process setting

Action:

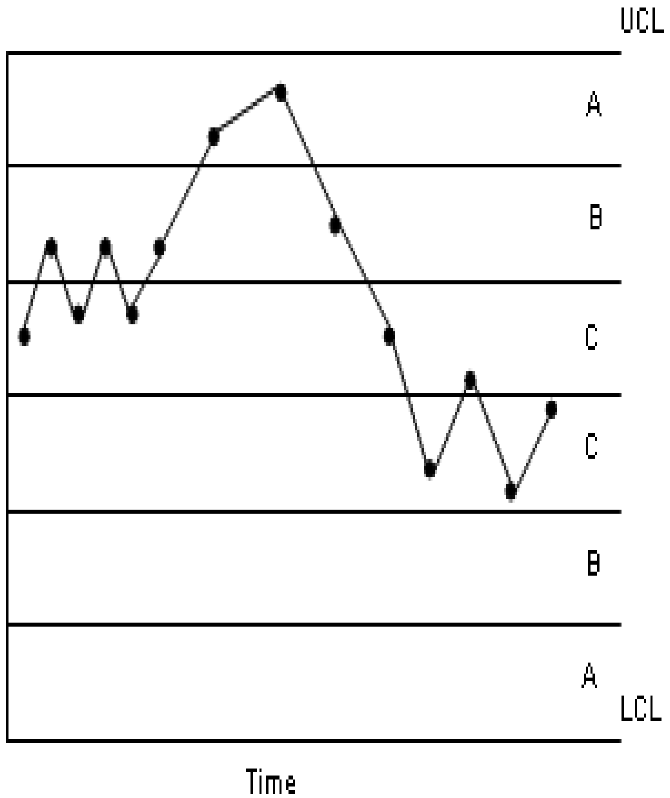
Go back and look at what might have been done differently before the out of control point signals.

Trend Analysis (cont'd)

Test 2

Pattern: A run of nine points on one side of the average.

Quality Characteristics

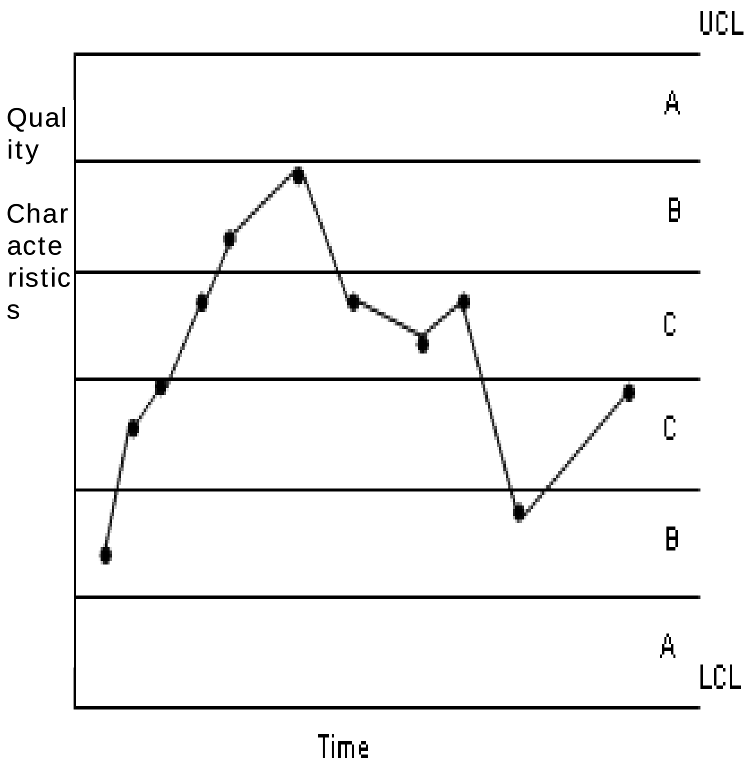


Problem source:
This may be due to a small change in the level of process average. This change may be permanent at the new level.

Action:
Go back to the beginning of the run and determine what was done differently at that time or prior to that time

Test **3**

Pattern: A trend of six points in a row either increasing or decreasing



Problem Source:

- Gradual tool wear
- Change in characteristics such as gradual deterioration in mixing or concentration of a chemical.
- Deterioration of plating or etching solution in electronics or chemical industries

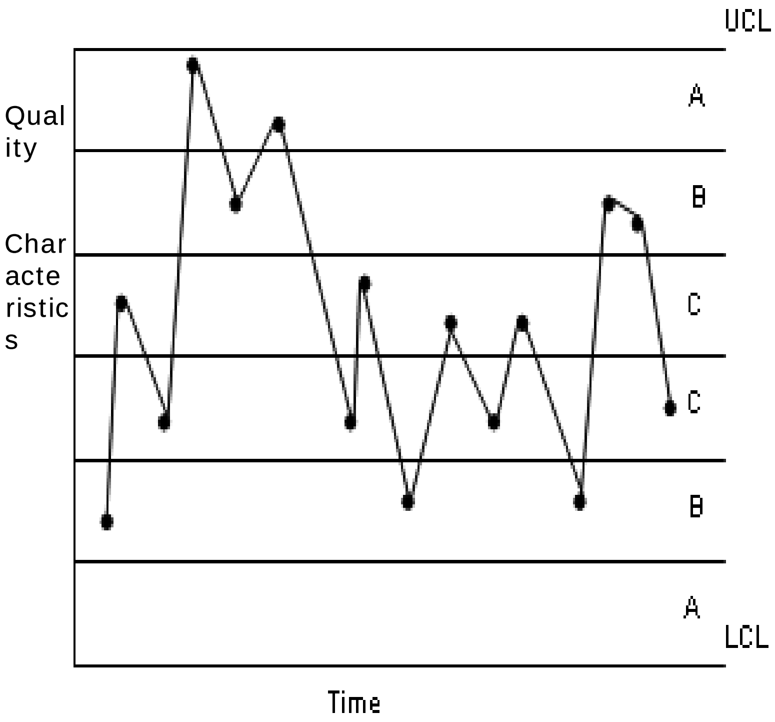
Action:

Go back to the beginning of the run and search for the source in procedure

Trend Analysis (cont'd)

Test **4**:

Pattern: Fourteen points in a row alternating up and down within or outside the control limits.



Problem source:

•Sampling variation from two different sources such as sampling systematically from high and low condition with two different averages.

or

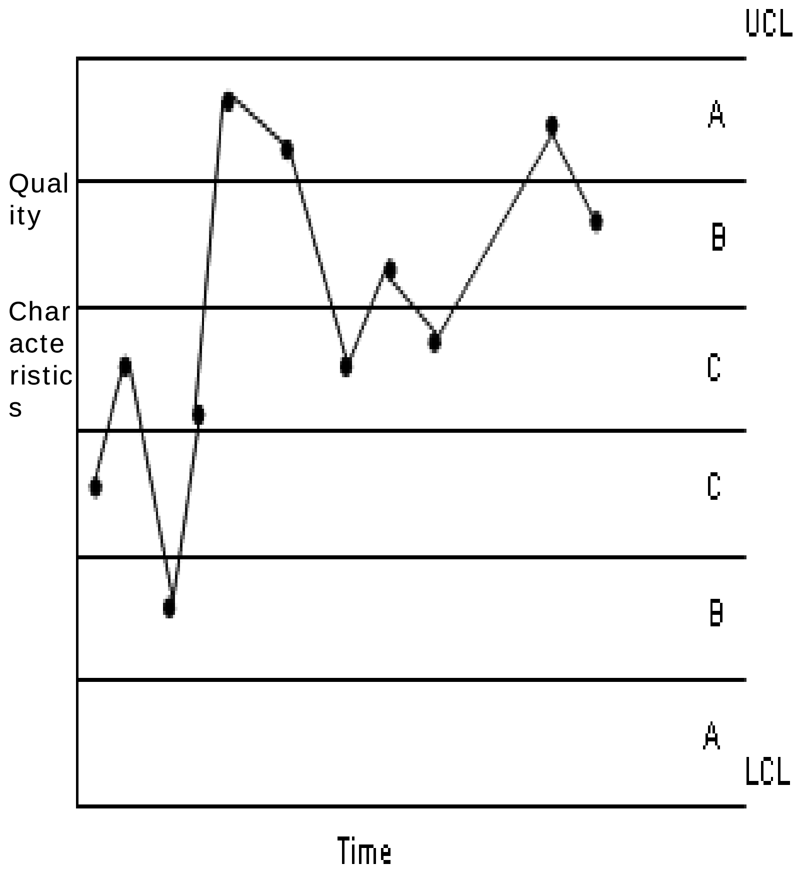
•Adjustment is being made all the time (over control).

Action: Look for cycles in the process, such as humidity or temperature cycles or operator over control of process

Trend Analysis (cont'd)

<u>Test **5**</u>

<u>Pattern:</u> Two out of three points in a row on one side of the average in zone A or beyond.



<u>Problem source:</u>

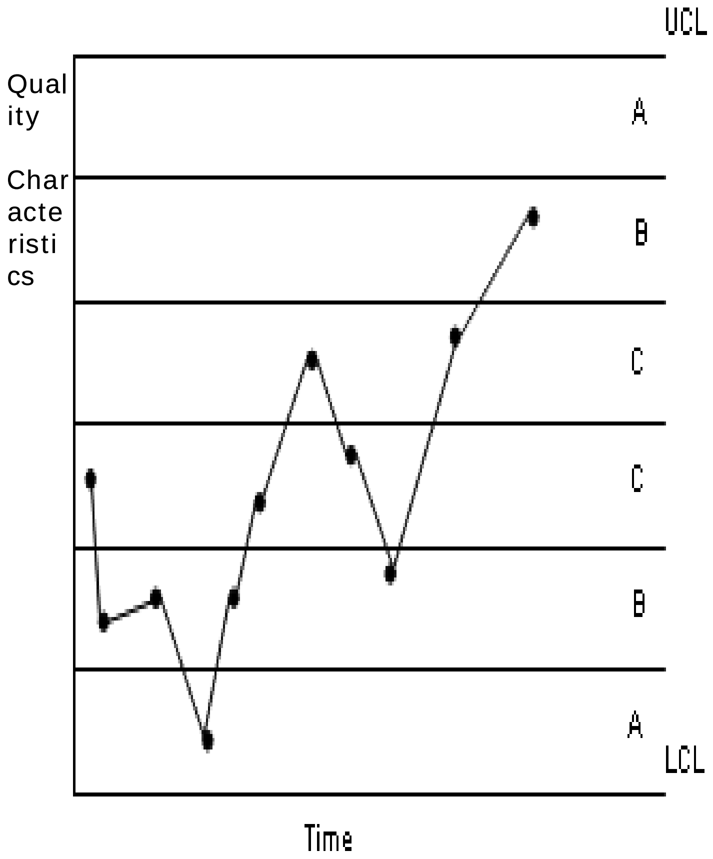
- This can be due to a large, dramatic shift in the process level.
- Provides early warning, particularly if the special cause is not as obvious as in the case of Test 1

<u>Action:</u>

Go back in time and determine what might have caused the large shift in the level of the process

Test 6

Pattern: Four out of five points in a row on one side of the average in zone B or beyond



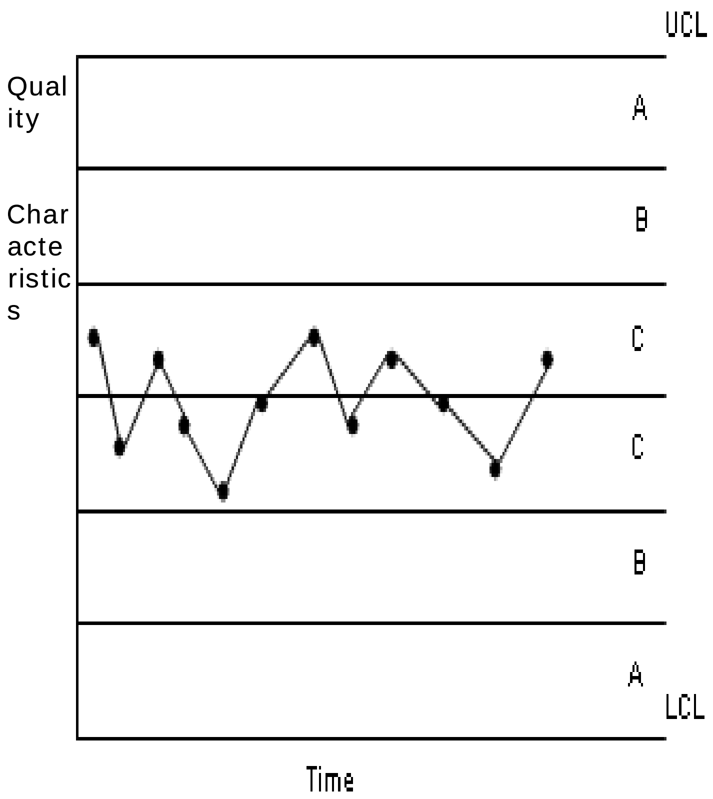
Problem source:
This may be due to a moderate shift in the process

Action: Go back three or four points in time to find the root cause.

Trend Analysis (cont'd)

Test 7

Pattern: Fifteen points in a row on either side of the average in zone C



Problem Source:

Unnatural small fluctuations or absence of points near the control limits

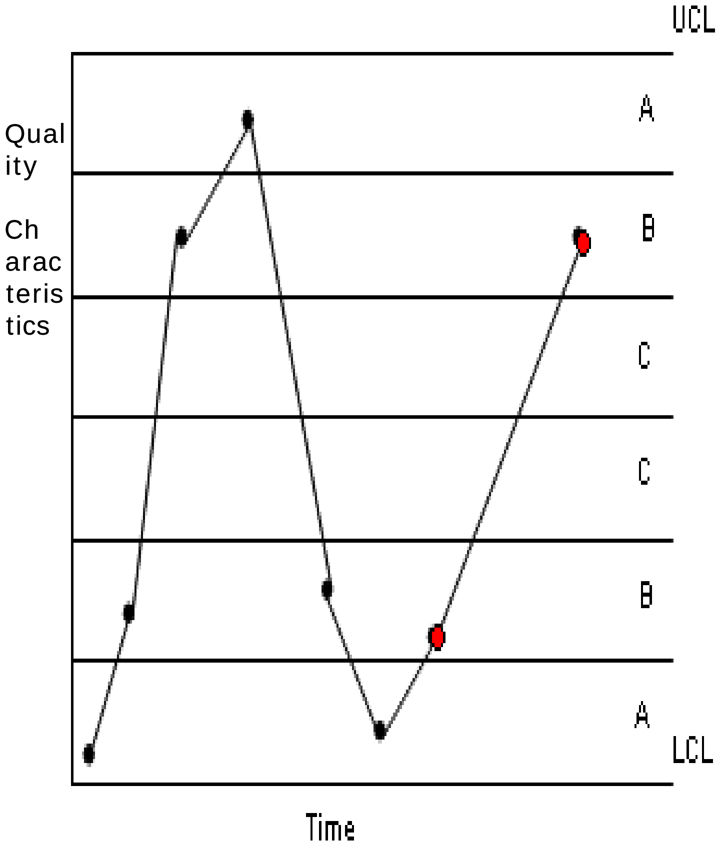
- It may appear to be good control but this is not.
- Incorrect selection of subgroups.
- Sampling from various sub-population and combining them into a single subgroup for charting
- In **correct** calculation of control limits

Action: Look very close to the beginning of the pattern

Trend Analysis (cont'd)

Test 8

Pattern: Eight points in a row on both sides of the center line with none in zone C.



Problem source: No sufficient resolution on the measurement system

Action: Look at the range chart and see if it is in control

Understanding Capability!

- Whether the process is capable of meeting the requirements ?
- Whether the process is meeting the requirement at any point in time ?
- Can the parameter be corrected or adjusted when it is not meeting the requirements ?

Process Capability

The capability of a stable process is defined in terms of a distribution. It is the spread of all values of the process distribution.

Capable Process (Cp)

Cp measures the effect of the inherent variability

Cp is defined mathematically as

$$Cp = \frac{USL - LSL}{6\sigma}$$

$$Cp = \frac{\text{Allowable process spread}}{\text{Actual process spread}}$$

Where:

USL = upper specification limit

LSS: lower specification limit

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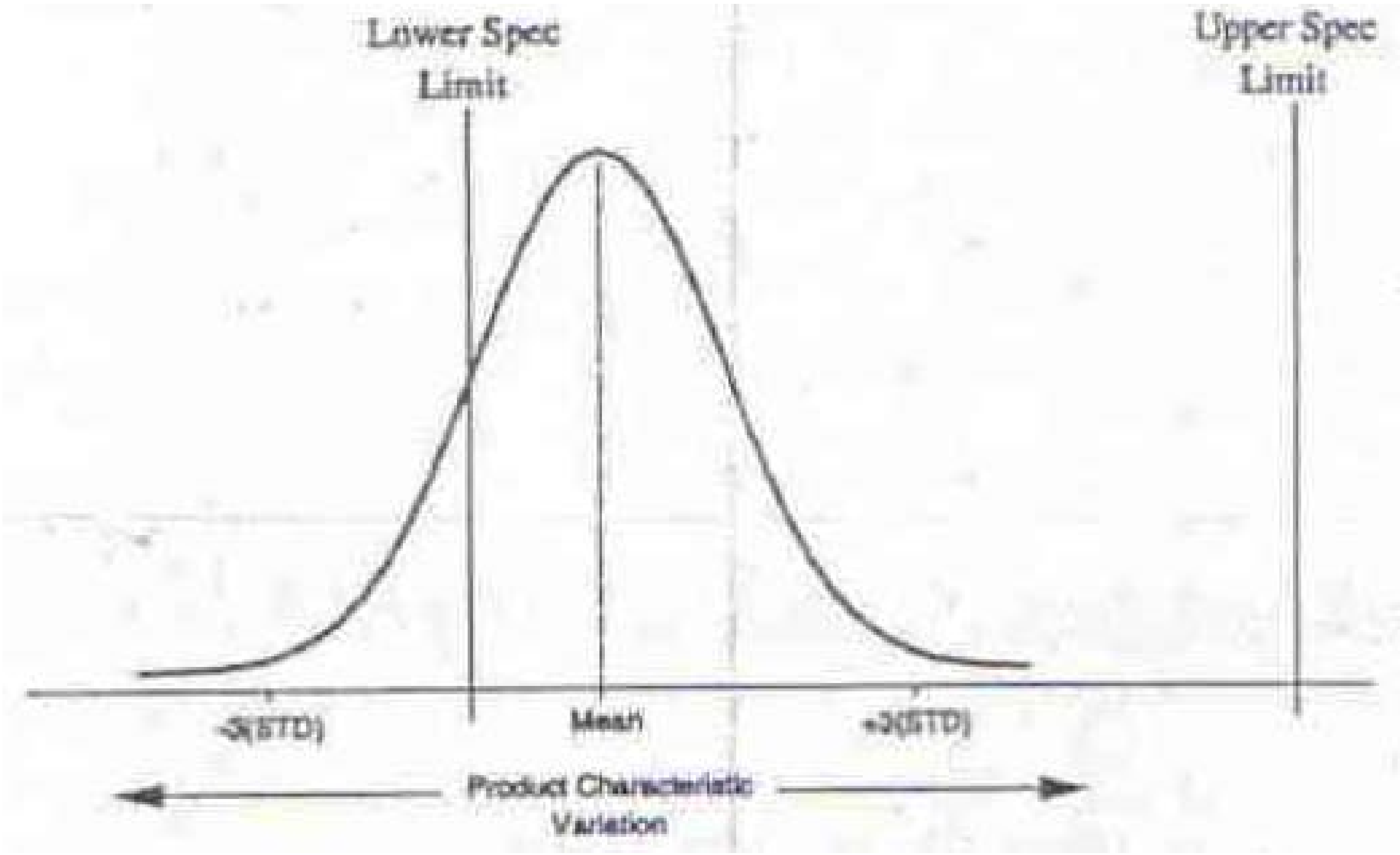
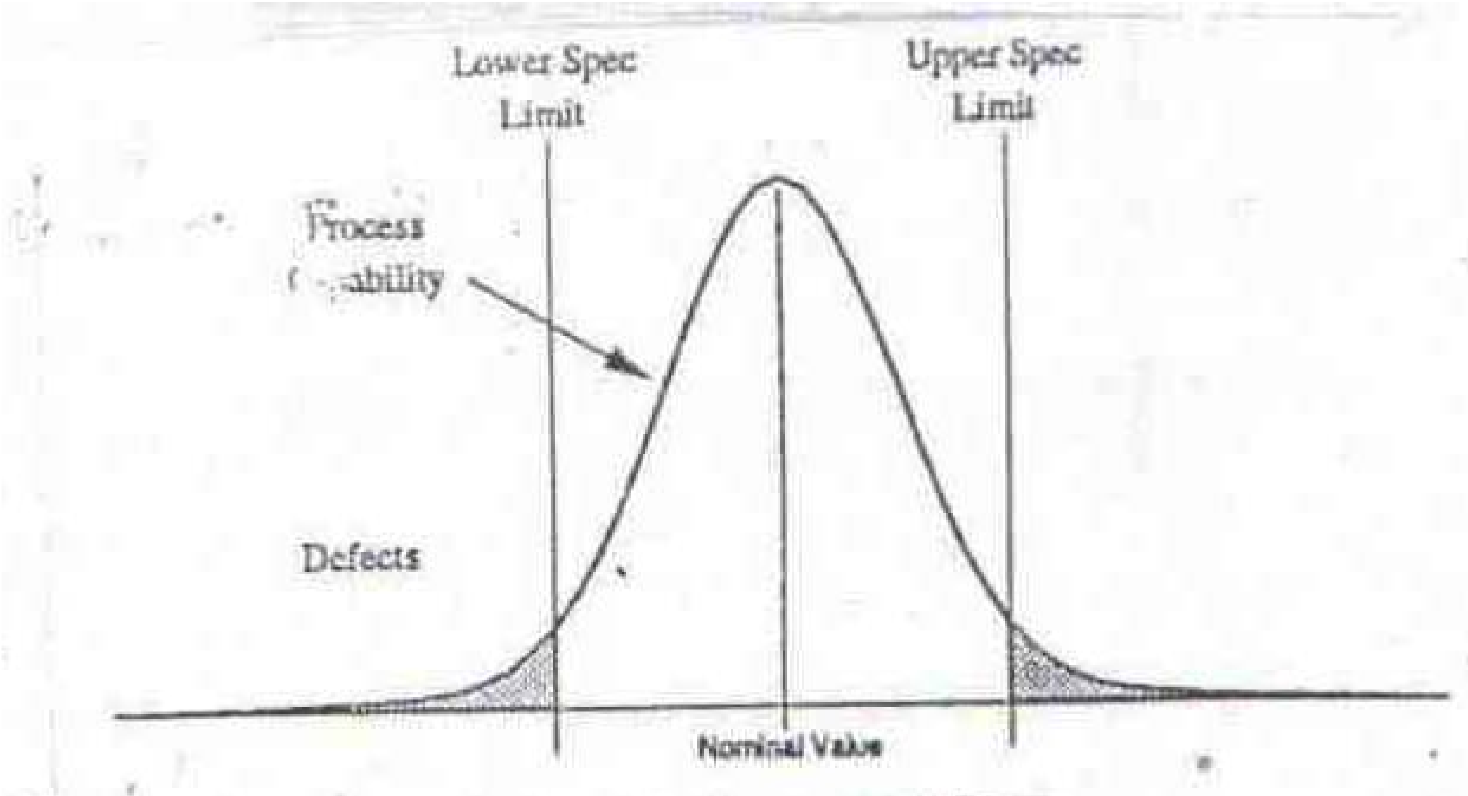
Process Capable but not Centered



The Control implementation is erring towards on lower side. (Or underutilized)

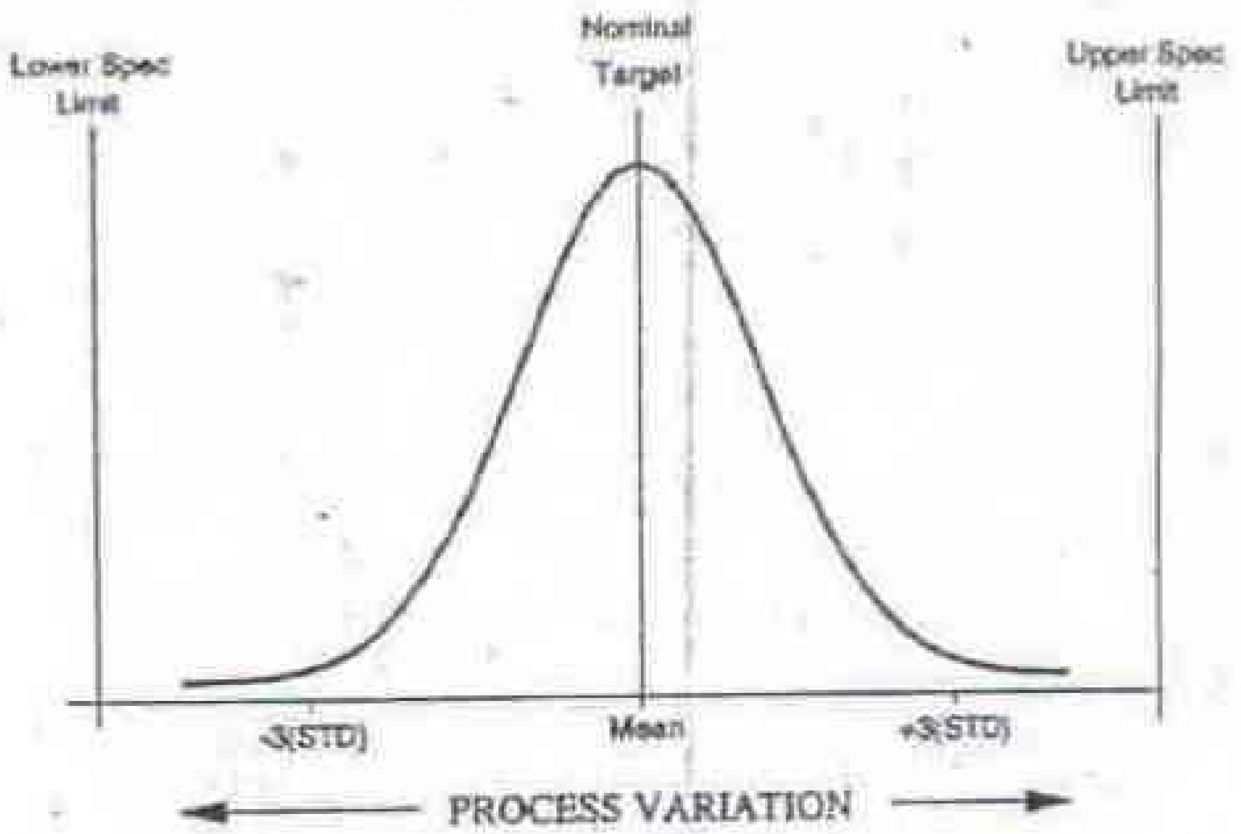
Process Centered but not Capable



A process that is centered but not capable.

One of actions may be to integrate designed experiment to gain additional knowledge on the process and designing control strategies. Alternatively the production specifications maybe altered.

Centred & Capable Process



A process that is centered and capable.

Capability index (C_{pk})

The long term objectives of C_{pk} is to continuously improve process and reduce variability

Mathematically defined as:

$$C_{pk} = \text{Minimum } \{USL- X / 3\sigma, X-LSL/3\sigma\}$$

Where X= overall process average
C_{pk} is applicable for process centering.

If for a two sided specification the capability index (C_{pk}) is equal to or greater than 1.33, then the process may be adequately centered.

C_{pk} may be employed even when there is only one sided specification. This is used to determine the percentage of observations out of specification.

Capability index (C_{pk}) (cont'd)

- A process is capable ($Cp \geq 1$) if its natural tolerance lies within the engineering tolerance or specifications. The measure of process capability of a stable process is 6 σ where σ is the inherent process variability estimated from the process.
- A minimum value of Cp = 1.33 is generally used for an on –going process. This ensures a very low reject rate of 0.007% and therefore is an effective strategy for prevention of nonconforming items.

Conclusion

Stochastic Process Control has great Opportunities leading to Production, Quality Assurance, Fault Diagnostics, Capability Enhancement etc.

Make Use Of the Opportunity before it is lost

Open for discussions