



PROCESS CONTROL-I

VIRENDRA KUMAR
Senior Instrument Engineer
NATIONAL SUGAR INSTITUTE, KANPUR



Session Topics

- History
- Basic Terminology
- Open loop & closed loop system
- ON-Off Controller
- PID controller
- Final Control Element



History

- The application of Control techniques, historically speaking started in the area of process control only .This is typical of 1900 – 1940 era.
- During the second world war the need of automatic air plane pilot, The gun positioning system, Radar antenna control systems etc.
- To solve these problems theory of servomechanisms was developed. The Word servomechanism originated from the word SERVO means the slave or the servant and the mechanisms this means servomechanisms is a system which is slave to the command. And this was the requirement of the weaponry system during the world war -2.
- The theory of Servomechanisms and the process control are converging now and a unified feedback control theory has emerged.



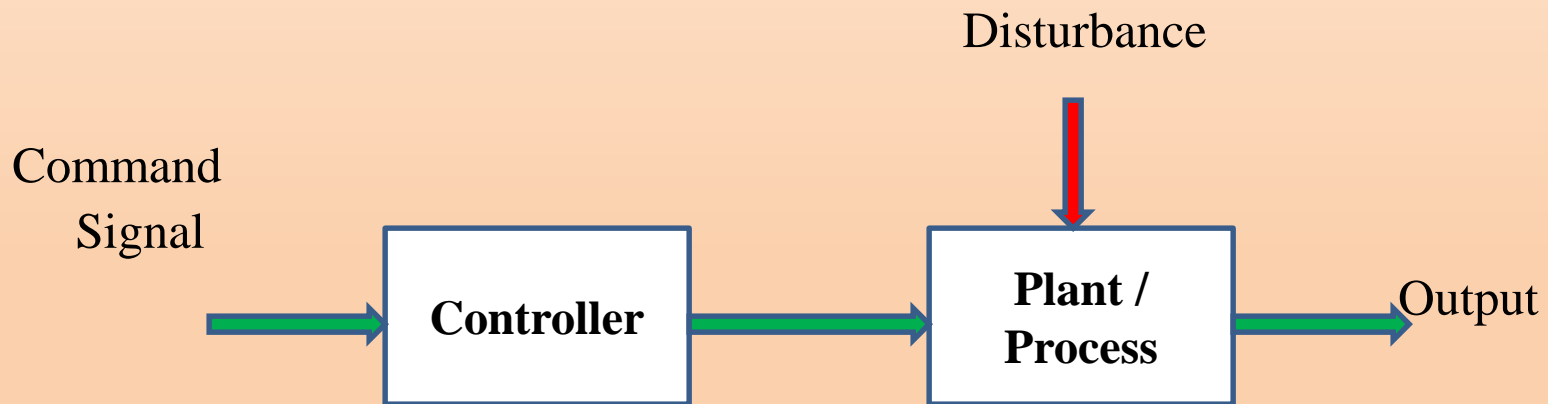
Basic Terminology

- **System** – An interconnection of elements and devices for a desired purpose
- **Control System** – An interconnection of components forming a system configuration that will provide a desired response
- **Process** – The device, plant, or system under control. The input and output relationship represents the cause-and-effect relationship of the process.
- **Controlled Variable:** The attribute of the process you want to control
- **Manipulated Variable:** MV is the variable to which process is going to react.
- **Disturbance variable:** The variable which is uncalled for and beyond our control.



Open Loop System

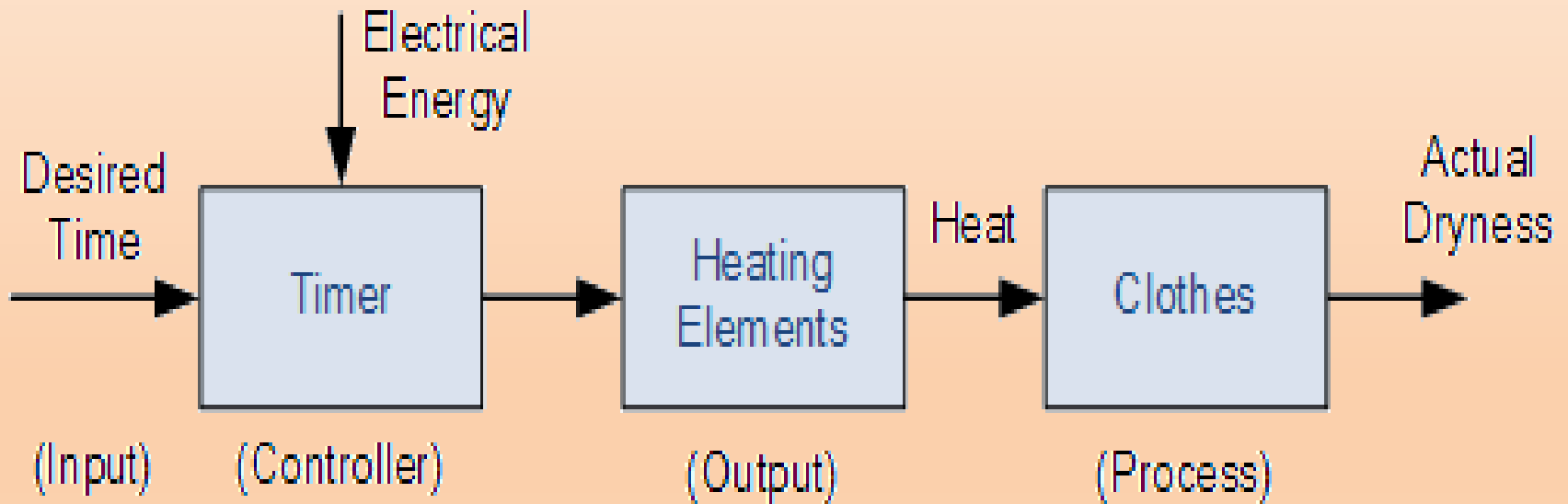
- An **Open-loop system**, also referred to as non-feedback system, is a type of continuous control system in which the output has no influence or effect on the control action of the input signal. In other words, in an open-loop control system the output is neither measured nor “fed back” for comparison with the input. Therefore, an open-loop system is expected to faithfully follow its input command or set point regardless of the final result





Example: Open loop system

- Open-loop Drying System





Advantages Of Open Loop Control System

- Simple in construction and design.
- Economical.
- Easy to maintain.
- Generally stable.
- Convenient to use as output is difficult to measure

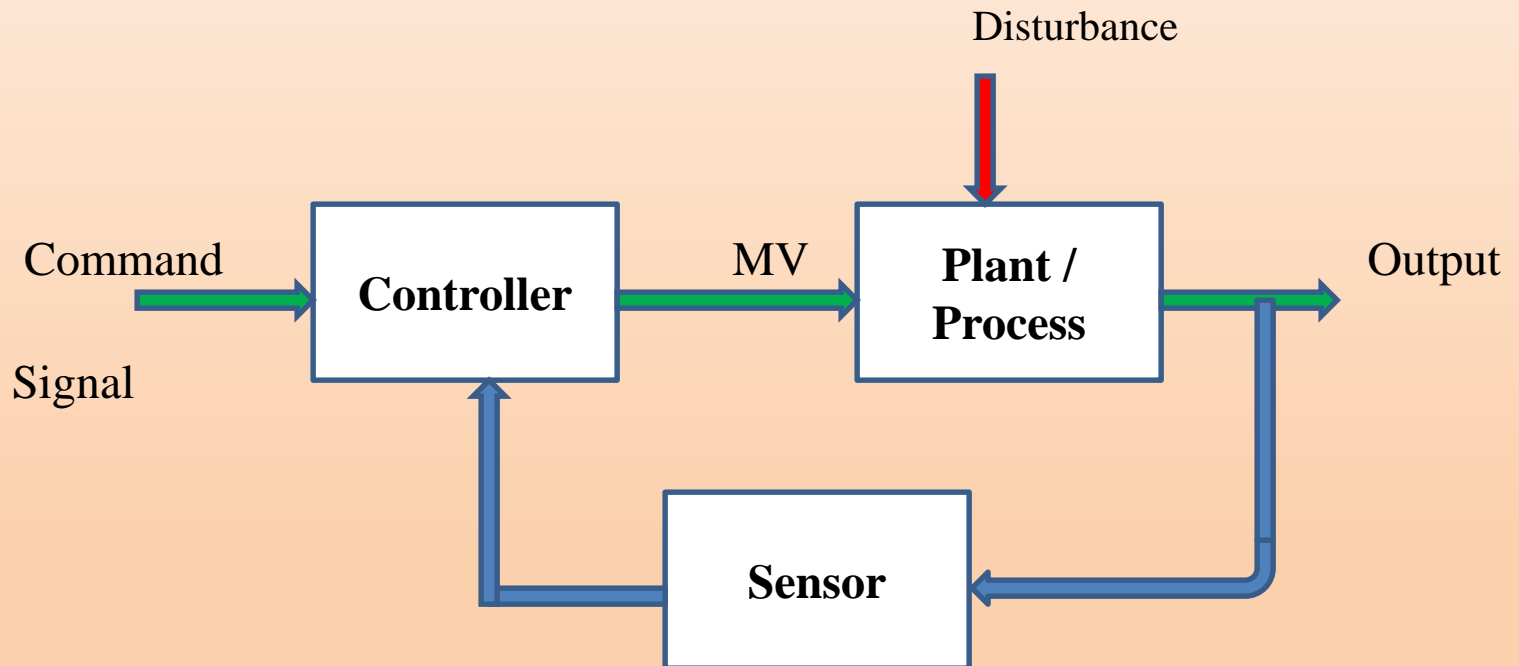
Disadvantages Of Open Loop Control System

- They are inaccurate.
- They are unreliable.
- Any change in output cannot be corrected automatically.



Closed Loop System

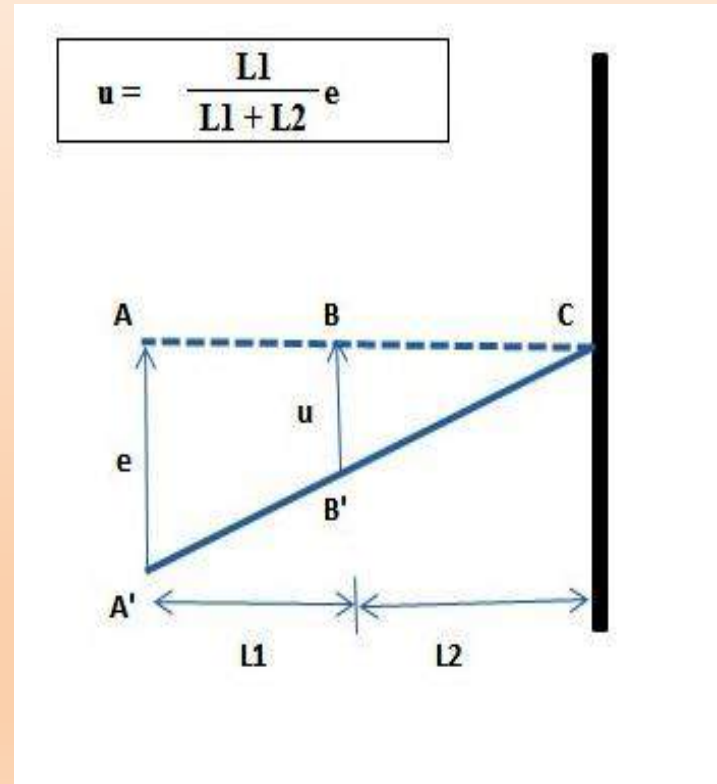
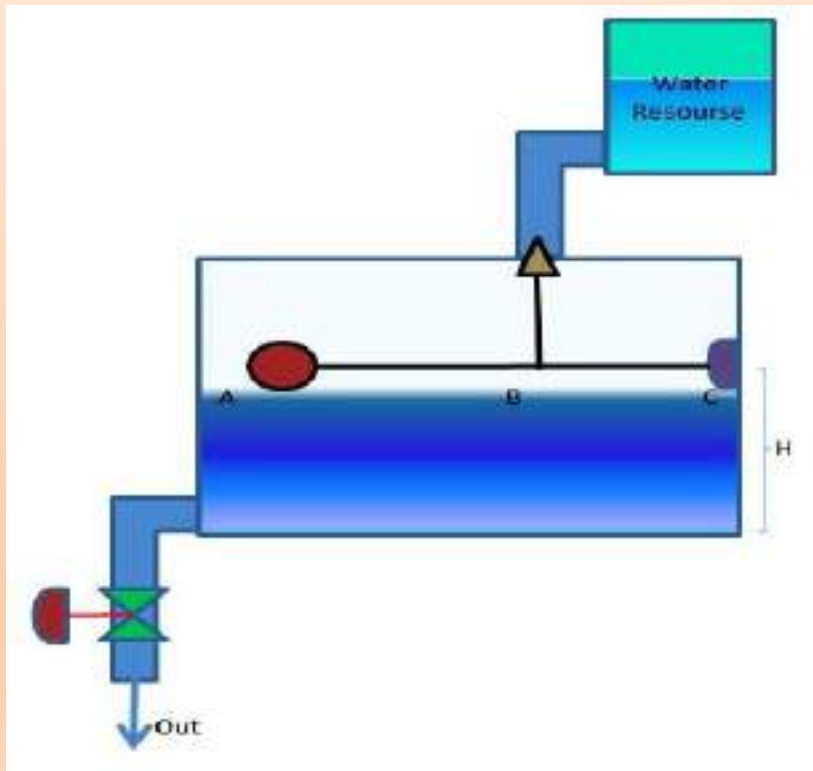
- A **Closed-loop Control System**, also known as a *feedback control system* is a control system which uses the concept of an open loop system as its forward path but has one or more feedback loops (hence its name) or paths between its output and its input. The reference to “feedback”, simply means that some portion of the output is returned “back” to the input to form part of the systems excitation.





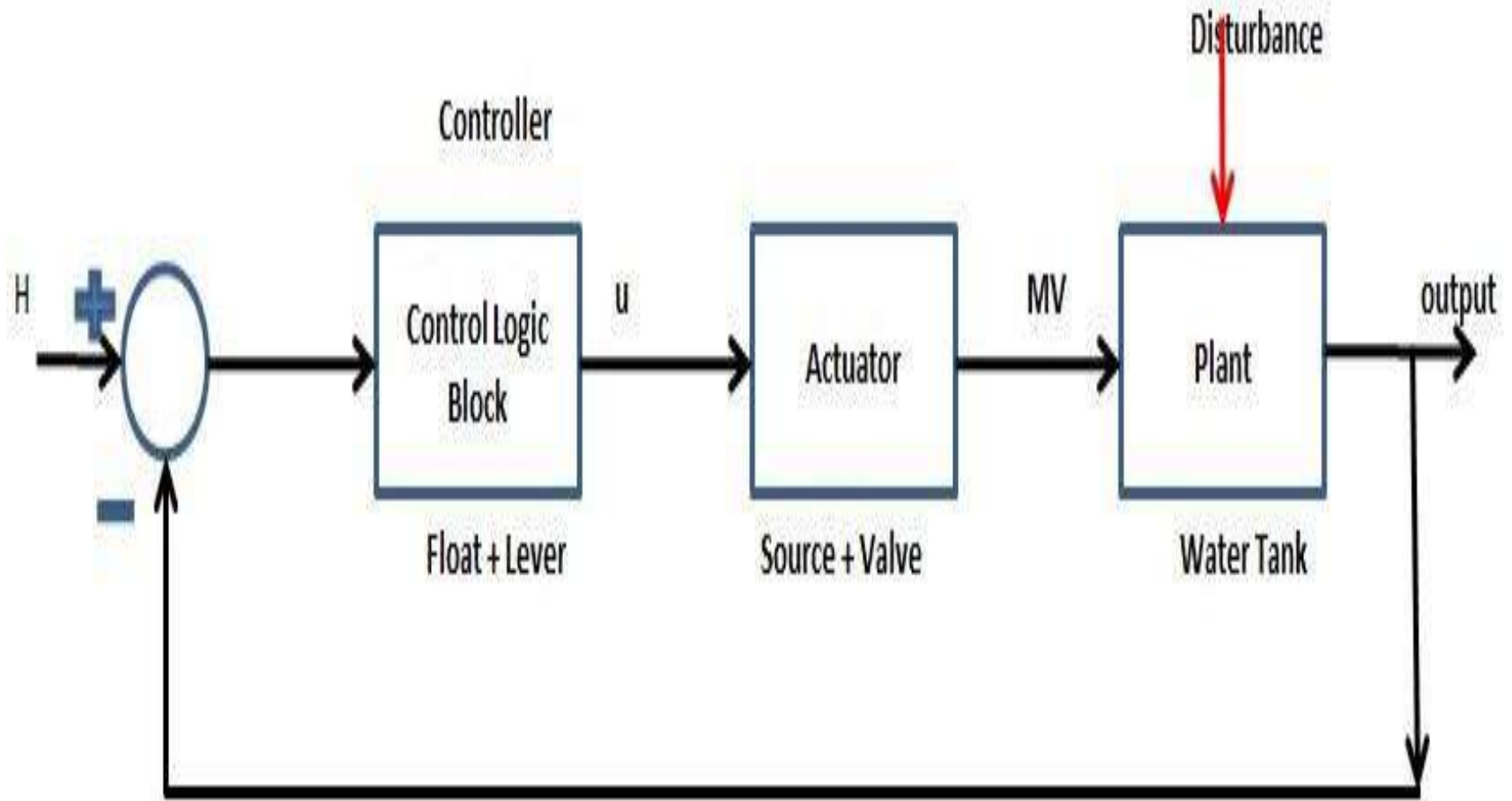
Example: closed loop system

- Bathroom Toilet Tank (SISO System)



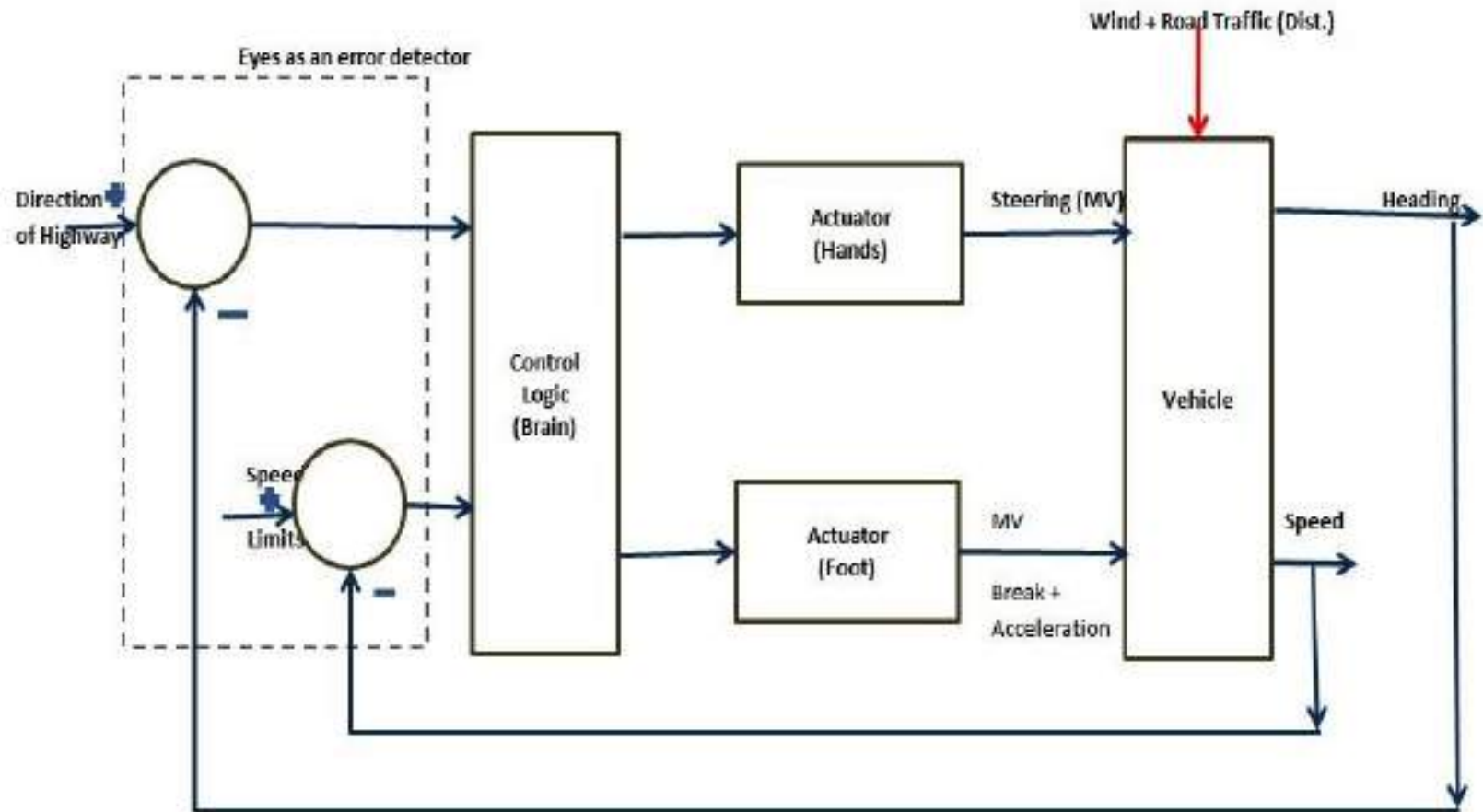


Closed Loop System- Block Diagram





Automobile Driving system (MIMO)





Advantages OF Closed Loop Control System

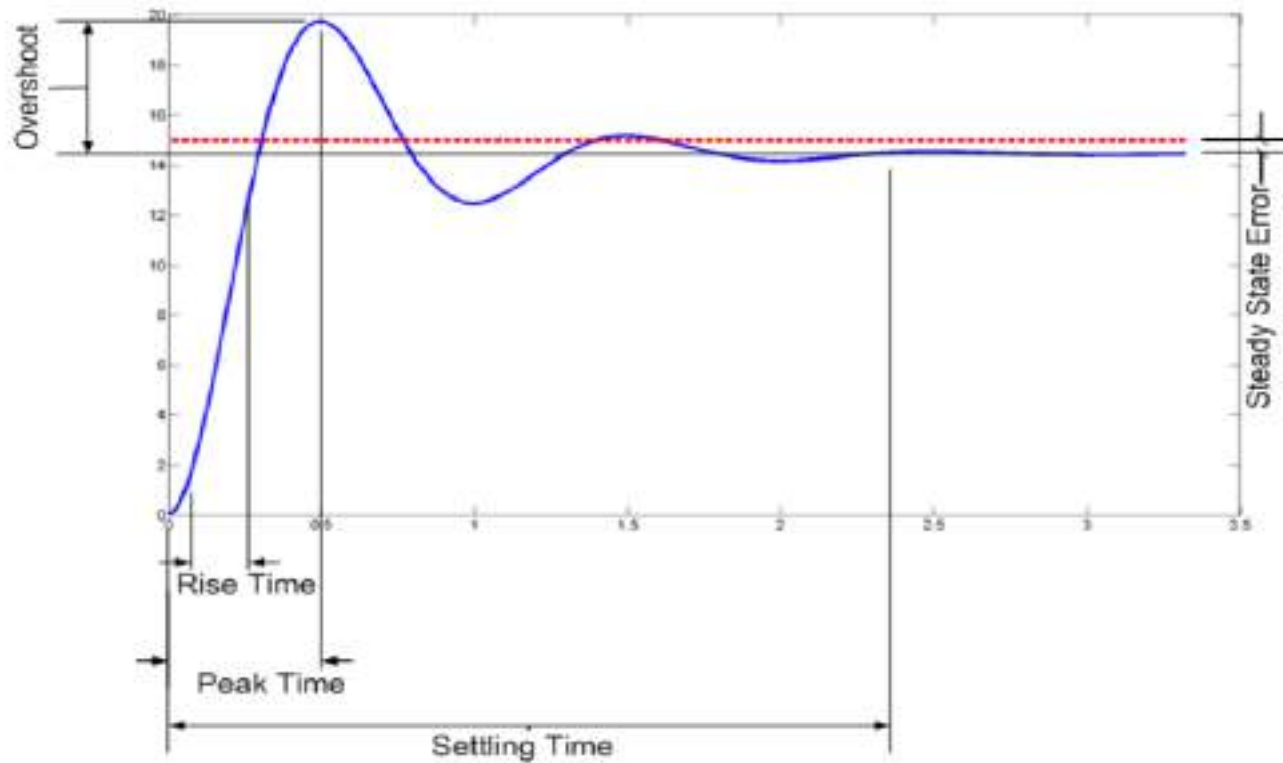
- Closed loop control systems are more accurate even in the presence of non-linearity.
- Highly accurate as any error arising is corrected due to presence of feedback signal.
- Bandwidth range is large.
- Facilitates automation.
- The sensitivity of system may be made small to make system more stable.
- This system is less affected by noise.

• Disadvantages Of Closed Loop Control System

- They are costlier.
- They are complicated to design.
- Required more maintenance.
- Feedback leads to oscillatory response.
- Overall gain is reduced due to presence of feedback.
- Stability is the major problem and more care is needed to design a stable closed loop system.



Second order step response

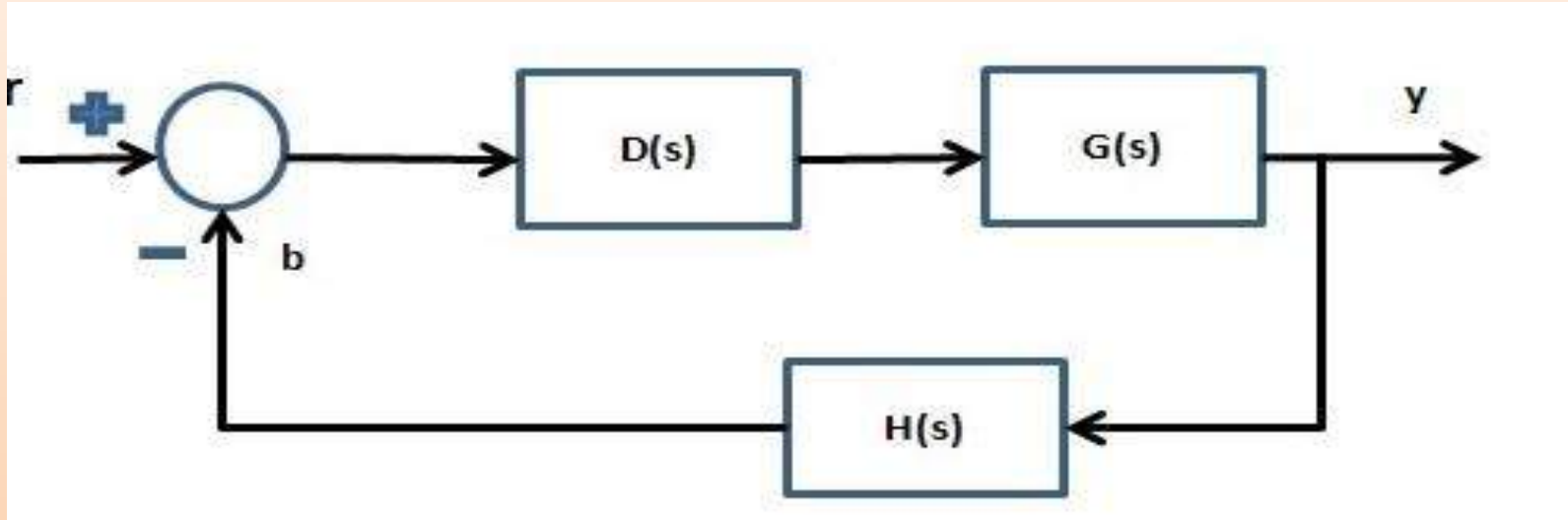




- **Rise time (t_r)** : The time taken for the output to go from 10 % to 90 % of the final value.
- **Peak Time (t_p)**: The time taken for the output to reach its maximum value.
- **Overshoot (M_p)**: $(\text{Max value} - \text{final value}) / \text{Final value} * 100$
- **Settling time (t_s)**: The time taken for the signal to be bounded to within a tolerance of x% of the steady state value.
- **Steady state error (e_{ss})**: The difference between the input step value and the final value



Transfer function of a closed loop system

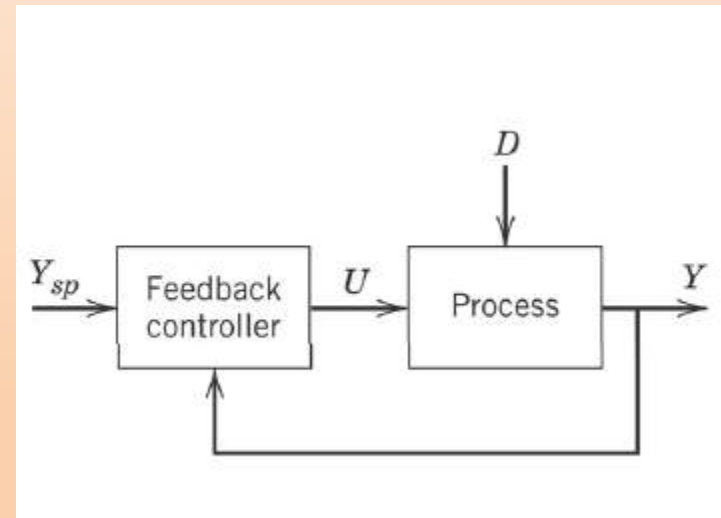
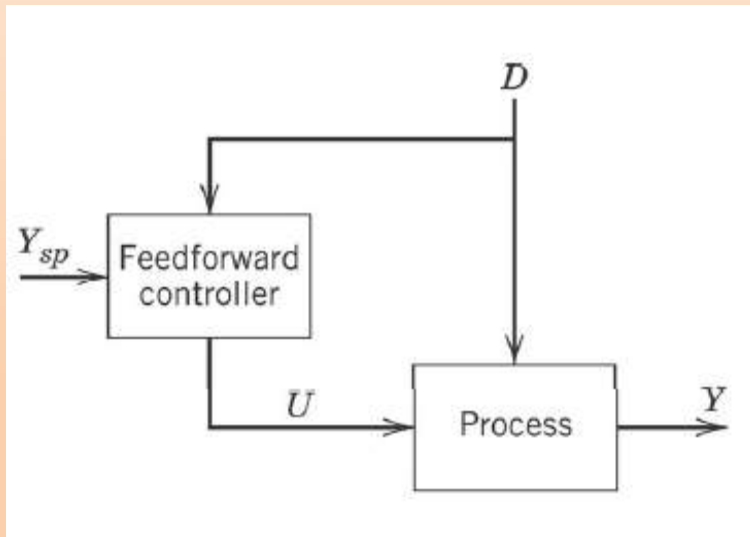


- $T(s) = \frac{D(s)G(s)}{1+D(s)G(s)H(s)}$



Feedforward Control

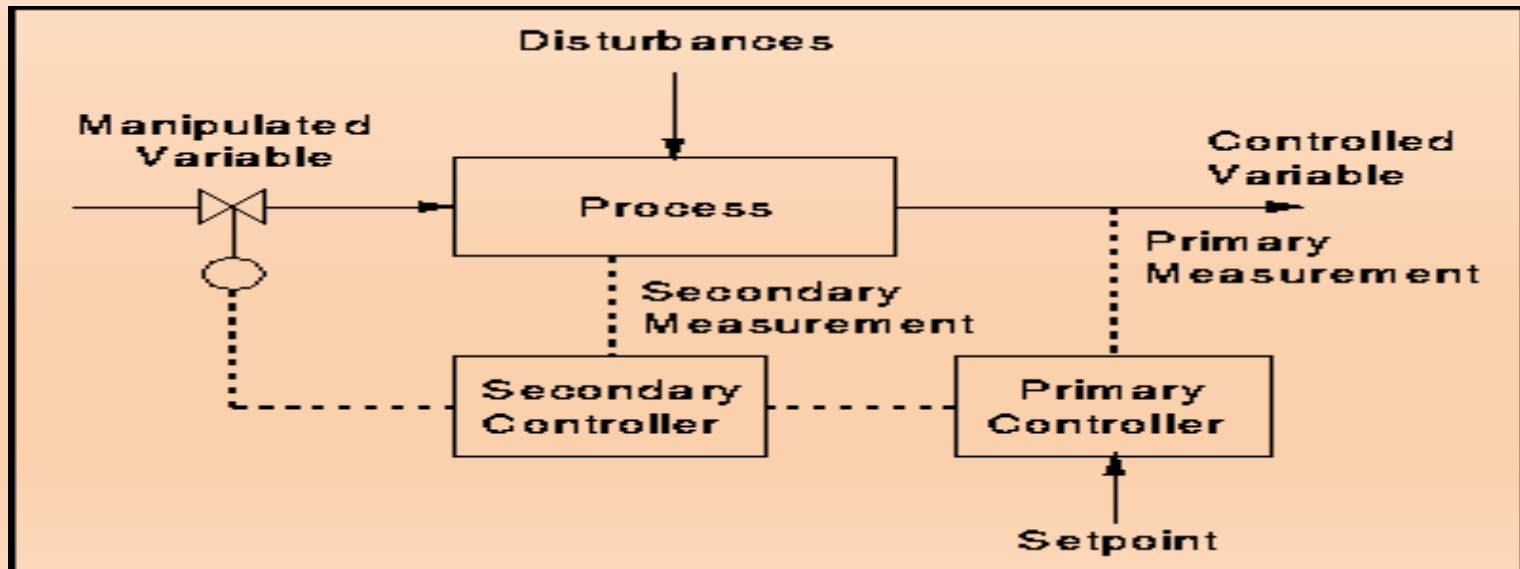
- The basic concept of feedforward control is to measure important disturbance variables and take corrective action before they upset the process.





Cascade Control

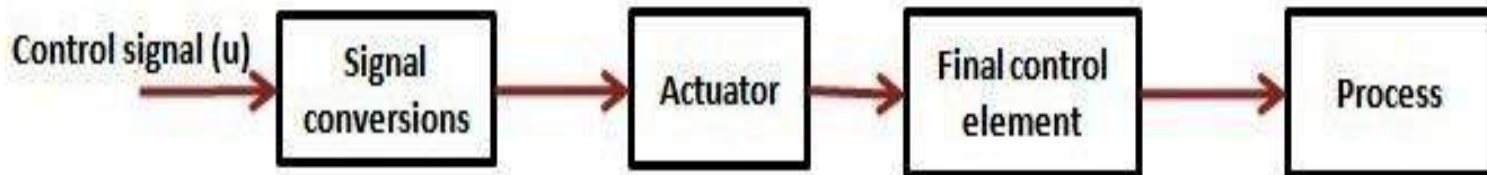
- The inherent interaction that occurs between two control systems in many applications is sometimes used to provide better overall control.
- In this scheme two measurements are taken from the system and each is used in its own control loop. In its outer loop, however, the controller output is the setpoint of the inner loop. Thus if outer loop controlled variable changes, the error signal that is input to the controller effects a change in the setpoint of the inner loop





Final Control Operation

- Final control element operations involve the steps necessary to convert the control signal (generated by a process controller) into proportional action on the process itself. Thus to use a typical 4 -20 mA control signal to vary a large flow rate from, say, 10 m³/min to 50 m³/min certainly requires some intermediate operations.
- For a typical process control application, the conversion of process controller signal to a control function can be represented by the steps shown in fig.





Signal conversions

- This step refers to the modifications that must be made to the control signal to properly interface with the next stage of control i.e. Actuator.
- For ex. If a valve control element is to be operated by an electric motor actuator, then a 4 -20 mA dc control signal must be modified to operate the motor. If a DC motor is used , modification might be current to voltage conversion and amplification.
- The devices that performs such signal conversions are often called transducers.
- Controller output signal are typically in one of the three forms
 1. Electrical current , usually 4 -20 mA
 2. Pneumatic Pressure, usually 3 to 15 psi
 3. Digital signals

There are amny different schemes for the conversion of these signals to other forms depending on the desired final form.



Examples of signal conditioning devices:

1. Amplifiers
2. Divider circuits
3. Bridge circuits
4. Pneumatic circuits

Amplifiers

- High power ac or dc amplifiers often can provide the necessary conversion of the low energy control signal to a high energy form.

Divider circuits

- These circuits are used to convert a resistance value to voltage signal

Bridge circuits

- These circuits are used for converting resistance value to mV signals.



Pneumatics

- The general field of pneumatics covers a broad spectrum of applications of gas pressure to industrial needs.
- Pneumatics as a means of propagating information i.e. A signal carrier.

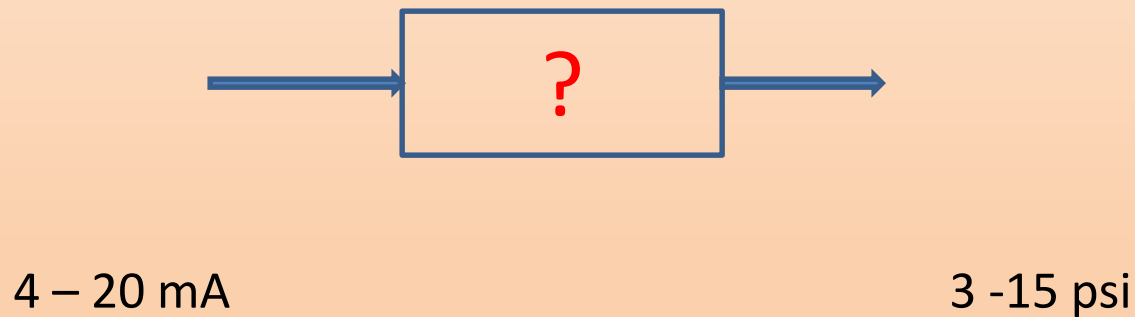
Principle: In a pneumatic system, information is carried by the pressure of gas in a pipe. If we have a pipe of any length and raise the pressure of gas at one end, this increase in pressure will propagate down the pipe until the pressure throughout is raised to the new value.

- The pressure signal travels down the pipe at a speed in the range of the speed of sound in the gas (say air) which is about 330 m/s.
- Advantages of using Pneumatics:
 1. Air can be exhausted to atmosphere, you don't need the reservoirs.
 2. Non inflammable
 3. Viscosity of air is negligible compared to that of hydraulic fluid.



Pneumatics

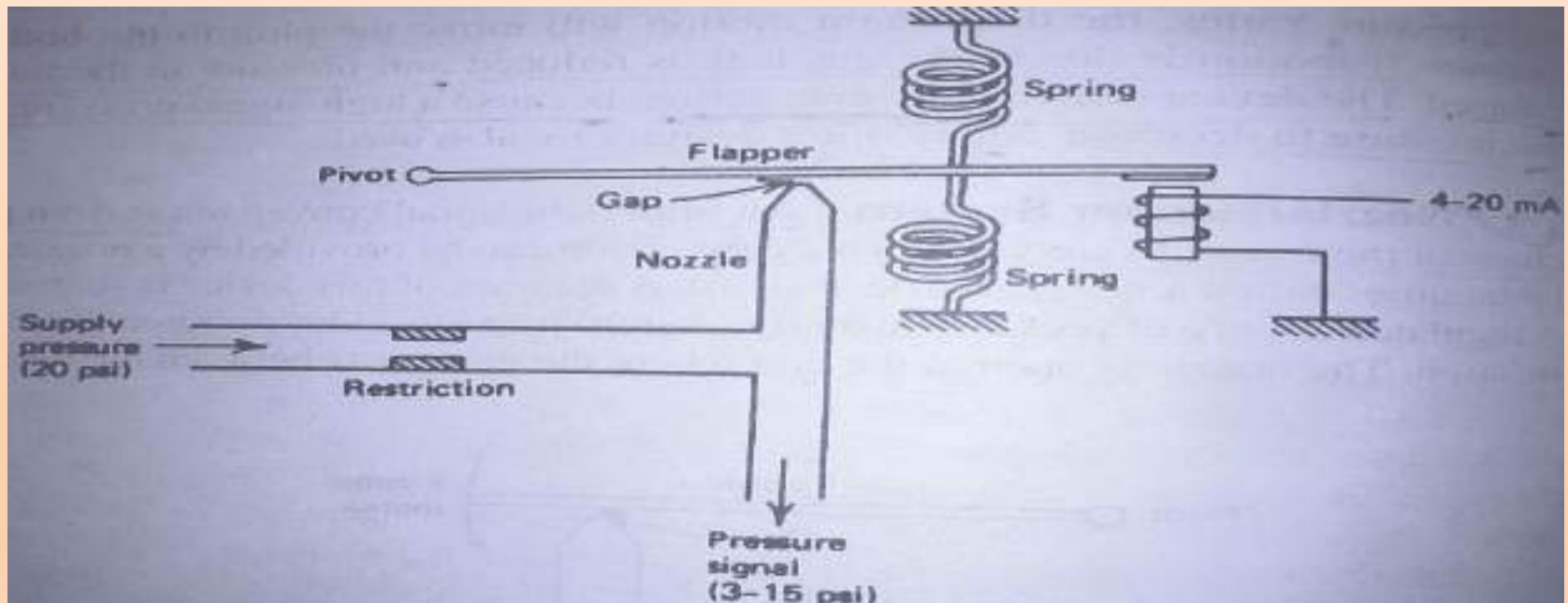
- The standard signal conversion is 4 -20 mA current to 3 -15 psi pressure signal
- How to do this conversion?





I/P Converter

- This can be done by *Electropneumatic transducer (I/P converter)*



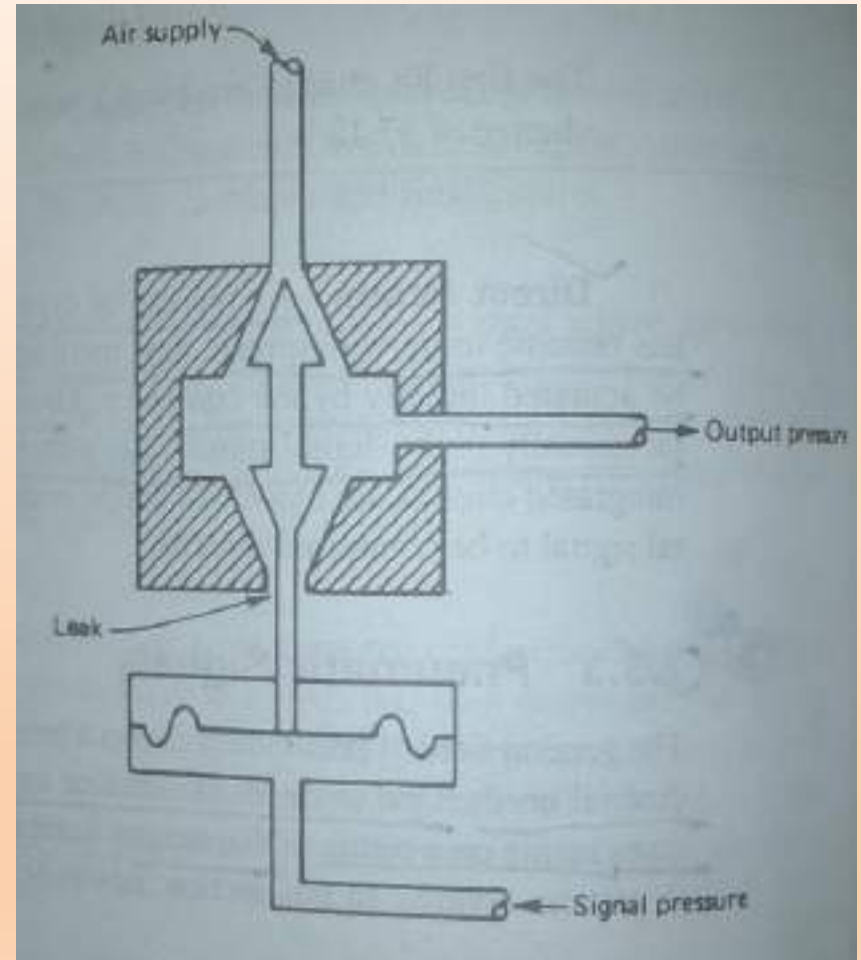


- I/P converter translate the 4 -20 mA current signal to 3 -15 psi pressure signal .
- There are many designs for these converters, but the basic principle almost involves the use of a nozzle flapper system.
- The current through the coil produces a force that will tend to pull the flapper down and close off the gap.
- A high current produce a high pressure so that the device is direct acting.
- Adjustment of the springs and the position relative to the pivot to which they are attached allows the unit to be calibrated so that 4 mA corresponds to 3 psig and 20 mA corresponds to 15 psig.



Pneumatic Amplifier

- A pneumatic amplifier, also called booster, raises the pressure and / or air flow volume by some linearly proportional amount from the input signal.
- If the booster has a pressure gain of 10, the output would be 30 to 150 psi for an input of 3 -15 psi.
- This is achieved via a regulator that is activated by the control signal.
- This is reverse acting because a high signal pressure will cause output pressure to decrease.





Actuators

- The actuator is a translation of the converted control signal into action on the control element. Thus if a valve is to be operated, then actuator is a device that converts control signal into the physical action of opening or closing the valve.

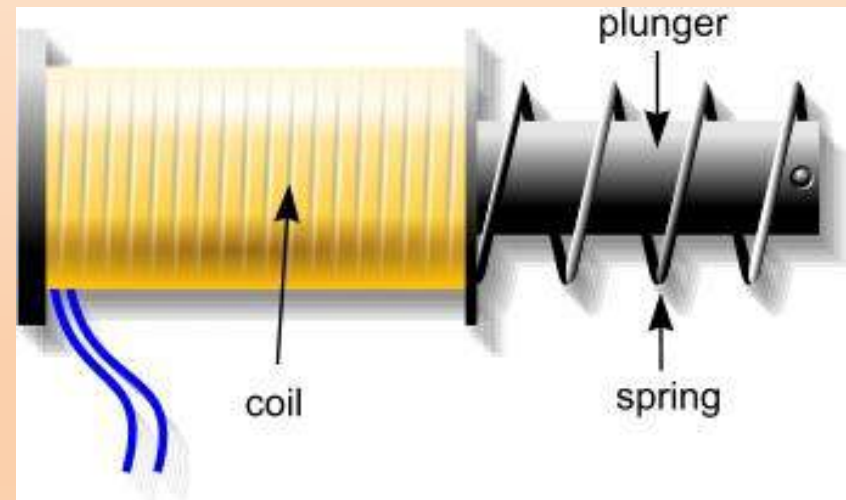
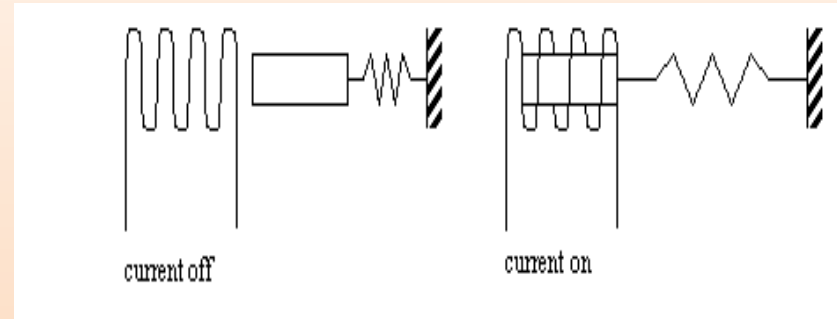
Types of Actuators

- There are several types of actuators we are using in the industry
- Electrical Actuator
- Pneumatic actuator
- Hydraulic Actuator



Electrical Actuators

- **Solenoid:** The basic principle of operation involves a moving ferrous core (a piston) that will move inside a wire coil as shown. Normally the piston is held outside of the coil by a spring. When a voltage is applied to the coil and current flows, the coil builds up a magnetic field that attracts the piston and pulls it into the centre of the coil. The piston can be used to supply a linear force. There are many and varied applications of solenoid actuators. All requiring a similar type of movement and force.





Electrical motor

- In any electric **motor**, operation is based on simple electromagnetism. A current-carrying conductor generates a magnetic field; when this is then placed in an external magnetic field, it will experience a force proportional to the current in the conductor, and to the strength of the external magnetic field.



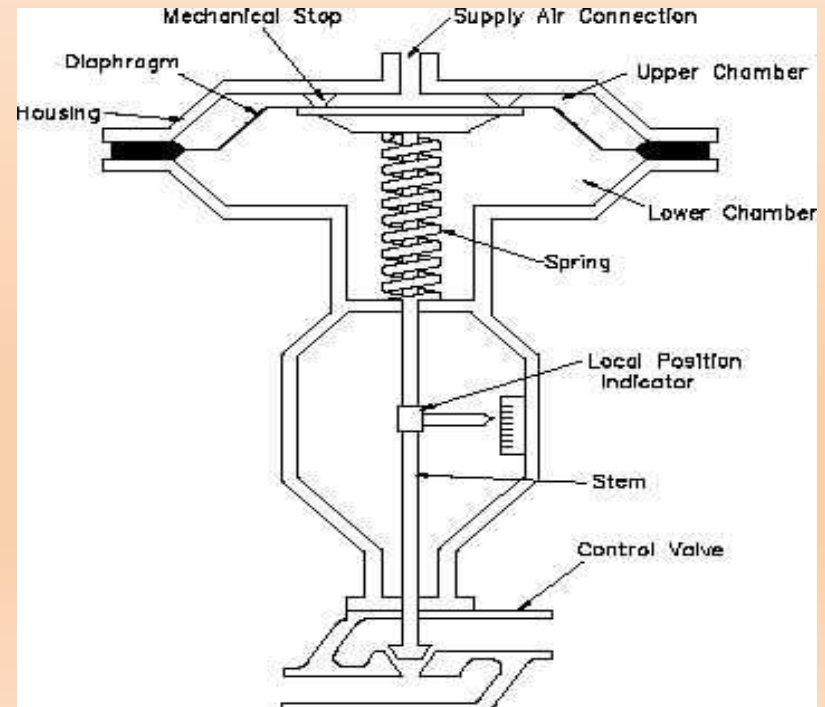


Pneumatic Actuators

- The actuator often translates a control signal into a large force or torque as required to manipulate some control element. The pneumatic actuator is the most useful for such translation.
- The principle is based on the concept of pressure as force per unit area. If we imagine that a net pressure difference is applied across a diaphragm of surface area A , then a net force acts on the diaphragm given by

$$F = (p_1 - p_2) A$$

Where $p_1 - p_2$ = Pressure difference
 A = Diaphragm area
 F = Force





- The pressure and force are linearly related, as shown in previous equation and the compression of spring is linearly related to forces (as $F = k \cdot \Delta X$).
- Then we see that the shaft position is linearly related to the applied control pressure.

$$\Delta X = (A / k) * \Delta P$$

Where

ΔX = Shaft travel (m)

ΔP = Applied gauge pressure (Pa)

A = Diaphragm area (m²)

k = Spring constant (N/m)

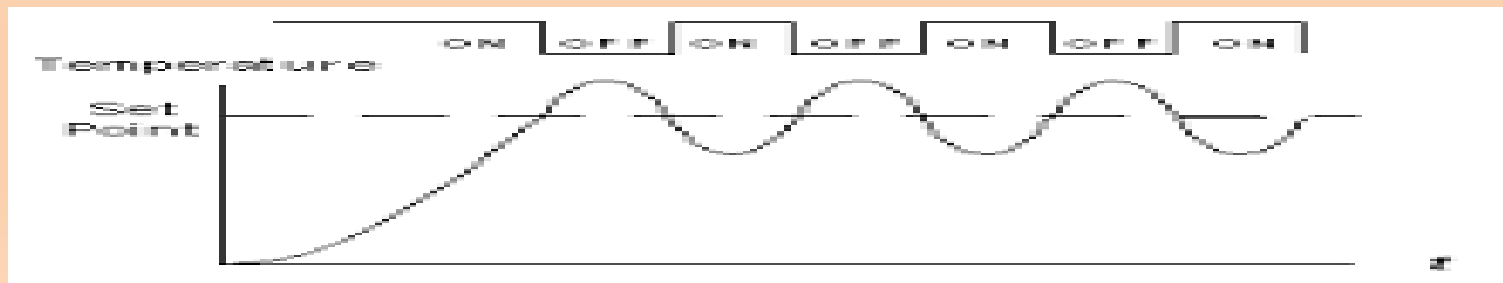


- Hydraulic Actuators are very fast acting devices. In the industry we are using CPC as the final control element of governing mechanism of turbine.



On – Off Controller

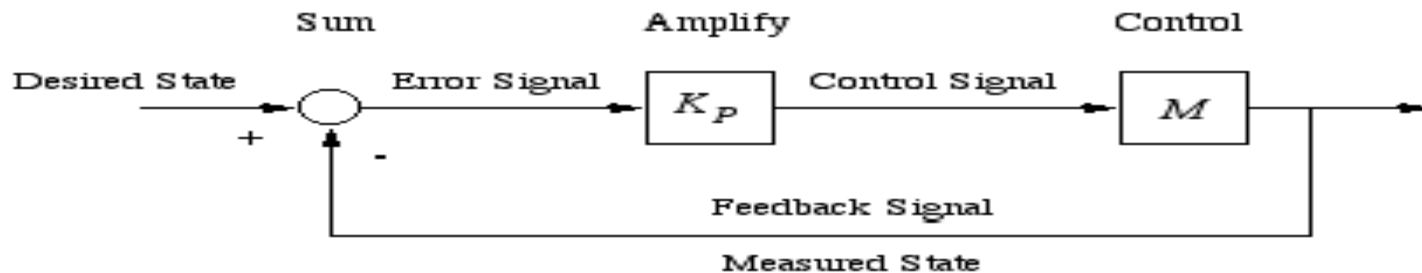
- On-Off control is the simplest form of feedback control. An on-off controller simply drives the manipulated variable from fully closed to fully open depending on the position of the controlled variable relative to the setpoint. A common example of on-off control is the temperature control in a domestic heating system. When the temperature is below the thermostat setpoint the heating system is switched on and when the temperature is above the setpoint the heating switches off.
- Although on-off is a very cheap form of control it is rarely used in process control applications because of the oscillation it causes in the controlled and manipulated variables. In a connected process these oscillations would be propagated right through the system.





P- Controller

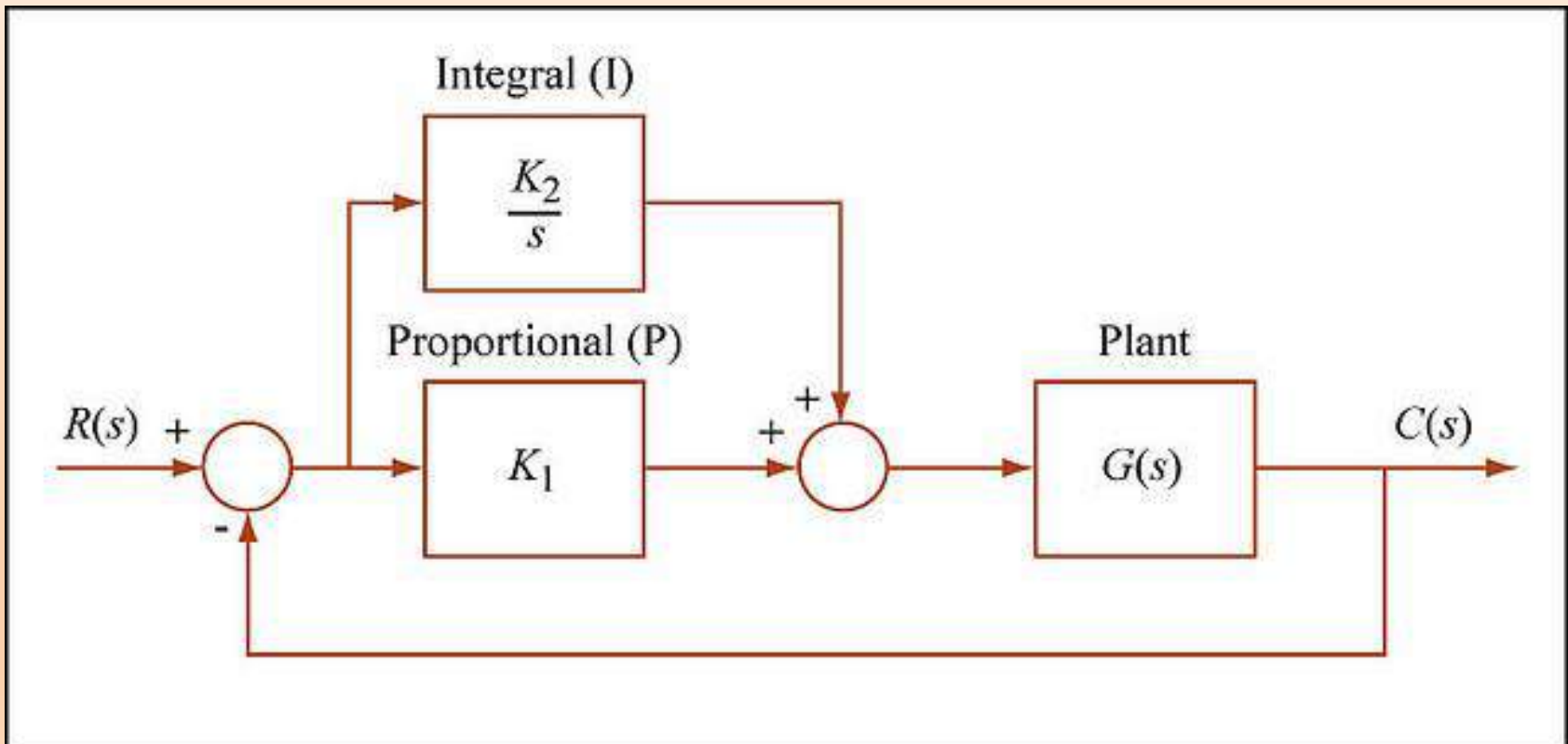
- **Proportional Control**
- A proportional controller attempts to perform better than the On-off type by applying power in proportion to the difference in temperature between the measured and the set-point. As the gain is increased the system responds faster to changes in set-point but becomes progressively underdamped and eventually unstable. The final temperature lies below the set-point for this system because some difference is required to keep the heater supplying power.





PI

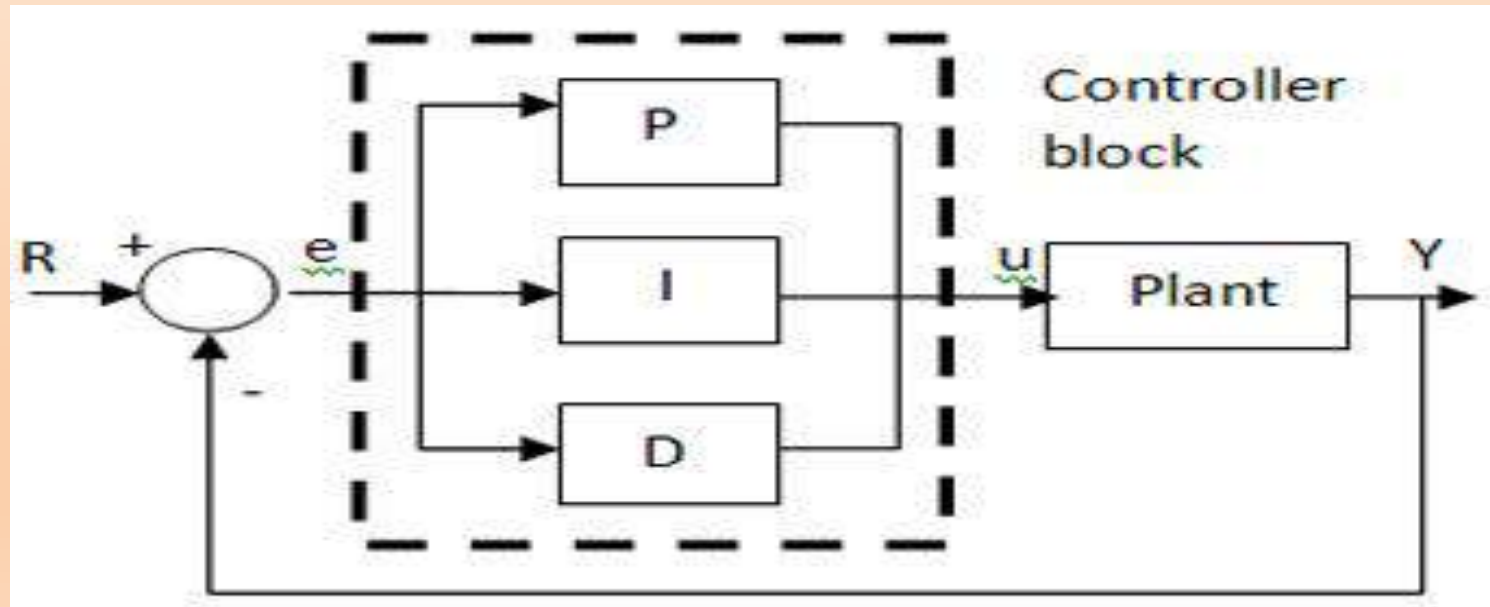
- The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error.





PID

- Although PD control deals neatly with the overshoot and ringing problems associated with proportional control it does not cure the problem with the steady-state error. Fortunately it is possible to eliminate this while using relatively low gain by adding an integral term to the control function which becomes





Equations related to controllers

- **P- Controller:**

$$u = K_p * e$$

- **PI- Controller:**

$$u = K_p(e + 1/T_i \int e \, dt)$$

- **PD – Controller:**

$$u = K_p(e + T_d \, de/dt)$$

- **PID – Controller:**

$$u = K_p(e + 1/T_i \int e \, dt + T_d \, de/dt)$$

Where

u	=	Control Signal
e	=	Error Signal (SP – PV)
K _p	=	Proportional gain
T _i	=	Integral time
T _d	=	Derivative time



The Characteristics of P, I, and D controllers

CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
K_p ↑	Decrease	Increase	Small Change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small Change	Decrease	Decrease	Small Change



Pneumatic Control Valves

- Why Control Valves used
- Process plants consist of hundreds, or even thousands, of control loops all networked together to produce a product to be offered for sale. Each of these control loops is designed to keep some important process variable such as pressure, flow, level, temperature, etc. within a required operating range to ensure the quality of the end product. Each of these loops receives and internally creates disturbances that detrimentally affect the process variable, and interaction from other loops in the network provides disturbances that influence the process variable.
- To reduce the effect of these load disturbances, sensors and transmitters collect information about the process variable and its relationship to some desired set point. A controller then processes this information and decides what must be done to get the process variable back to where it should be after a load disturbance occurs. When all the measuring, comparing, and calculating are done, some type of final control element must implement the strategy selected by the controller



Principles of Operation

- The most common final control element in the process control industries is the control valve. The control valve manipulates a flowing fluid, such as gas, steam, water, or chemical compounds, to compensate for the load disturbance and keep the regulated process variable as close as possible to the desired set point.
- Control valves may be the most important, but sometimes the most neglected, part of a control loop. The reason is usually the instrument engineer's unfamiliarity with the many facets, terminologies, and areas of engineering disciplines such as fluid mechanics, metallurgy, noise control, and piping and vessel design that can be involved depending on the severity of service condition.

Valve flow = f (Valve Pressure drop, stem position)



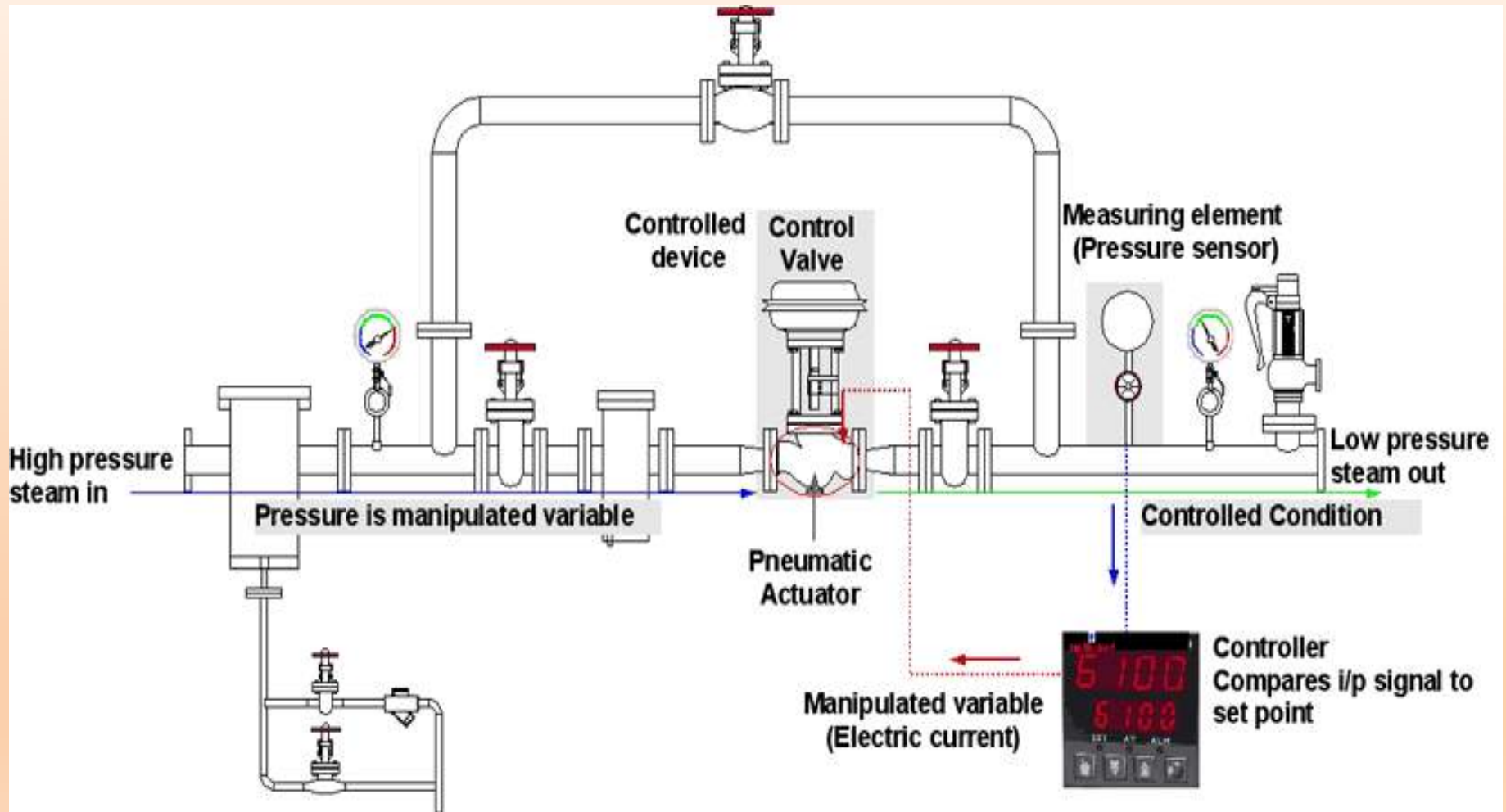
What is a Control Valve?

- Control valves automatically regulate pressure and/or flow rate, and are available for any pressure. If different plant systems operate up to, and at pressure/temperature combinations that require Class 300 valves, sometimes (where the design permits), all control valves chosen will be Class 300 for interchange-ability. However, if none of the systems exceeds the ratings for Class 150 valves, this is not necessary.
- Globe valves are normally used for control, and their ends are usually flanged for ease of maintenance. Depending on their type of supply, the disk is moved by a hydraulic, pneumatic, electrical or mechanical actuator. The valve modulates flow through movement of a valve plug in relation to the port(s) located within the valve body. The valve plug is attached to a valve stem, which, in turn, is connected to the actuator.





Control Valve Arrangement





Control Valve flow characteristics

- There are two types of characteristics of the control valves
 1. Inherent flow characteristics
 2. Installed flow characteristics

Inherent Flow characteristics

- The percent of flow through the valve is plotted against valve stem position. The curves shown are typical of those available from valve manufacturers. These curves are based on constant pressure drop across the valve and are called **inherent flow characteristics**.

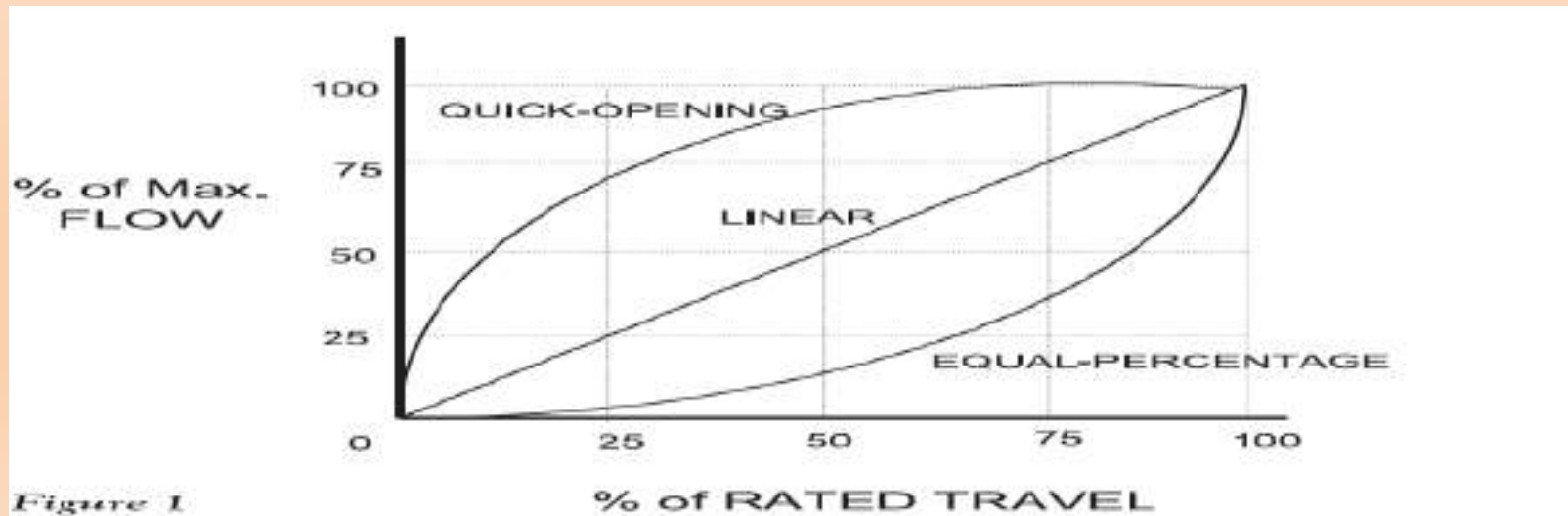


Figure 1



Control Valve flow characteristics-Contd

- **Linear** - flow capacity increases linearly with valve travel.
- **Equal percentage** - flow capacity increases exponentially with valve trim travel. Equal increments of valve travel produce equal percentage changes in the existing C_v
- **Quick opening** provides large changes in flow for very small changes in lift. It usually has too high a valve gain for use in modulating control. So it is limited to on-off service, such as sequential operation in either batch or semi-continuous processes.

Installed Control Valve Flow Characteristics

- When valves are installed with pumps, piping and fittings, and other process equipment, the pressure drop across the valve will vary as the plug moves through its travel.
- When the actual flow in a system is plotted against valve opening, the curve is called the **Installed Flow Characteristic**.



PROCESS CONTROL-II

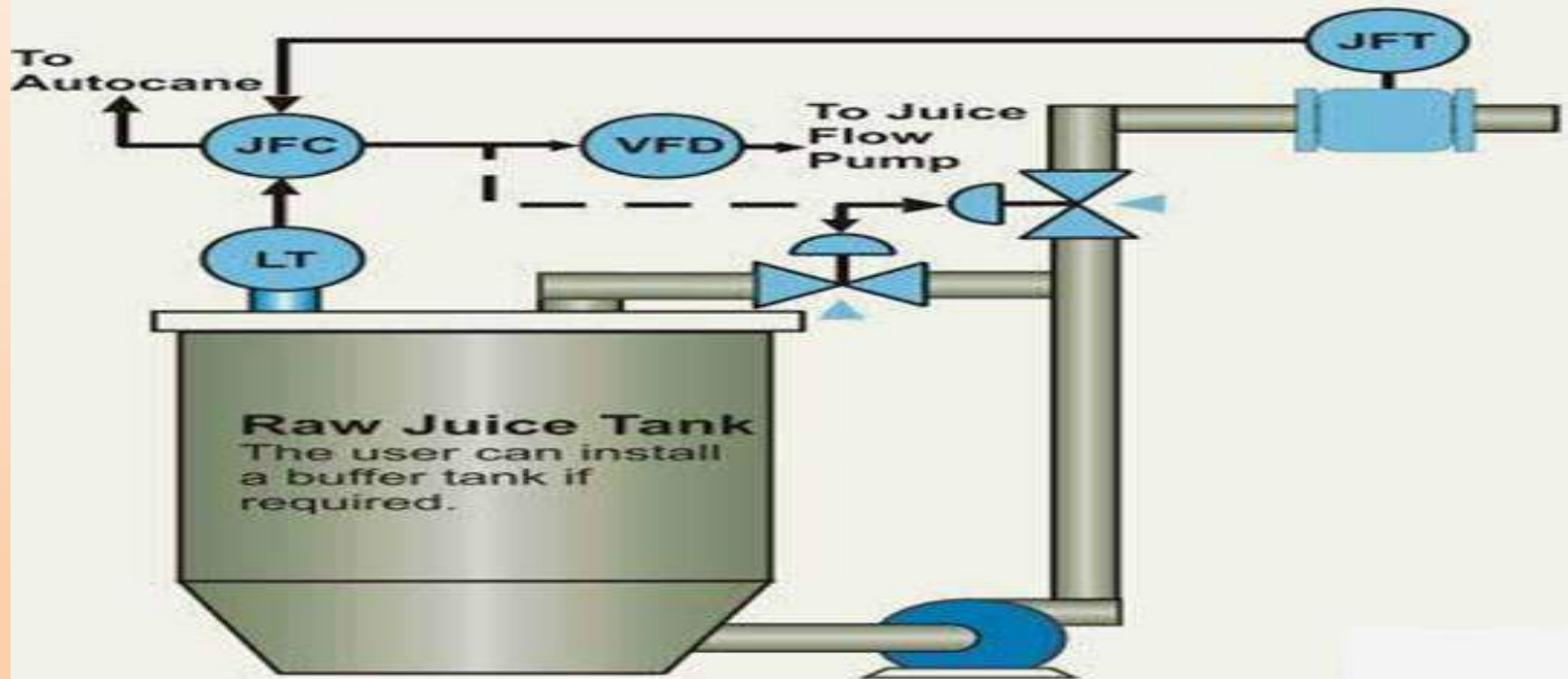
VIRENDRA KUMAR
Senior Instrument Engineer
NATIONAL SUGAR INSTITUTE, KANPUR



Some important Process Control loops of Mill,
Boiler and Process sections.



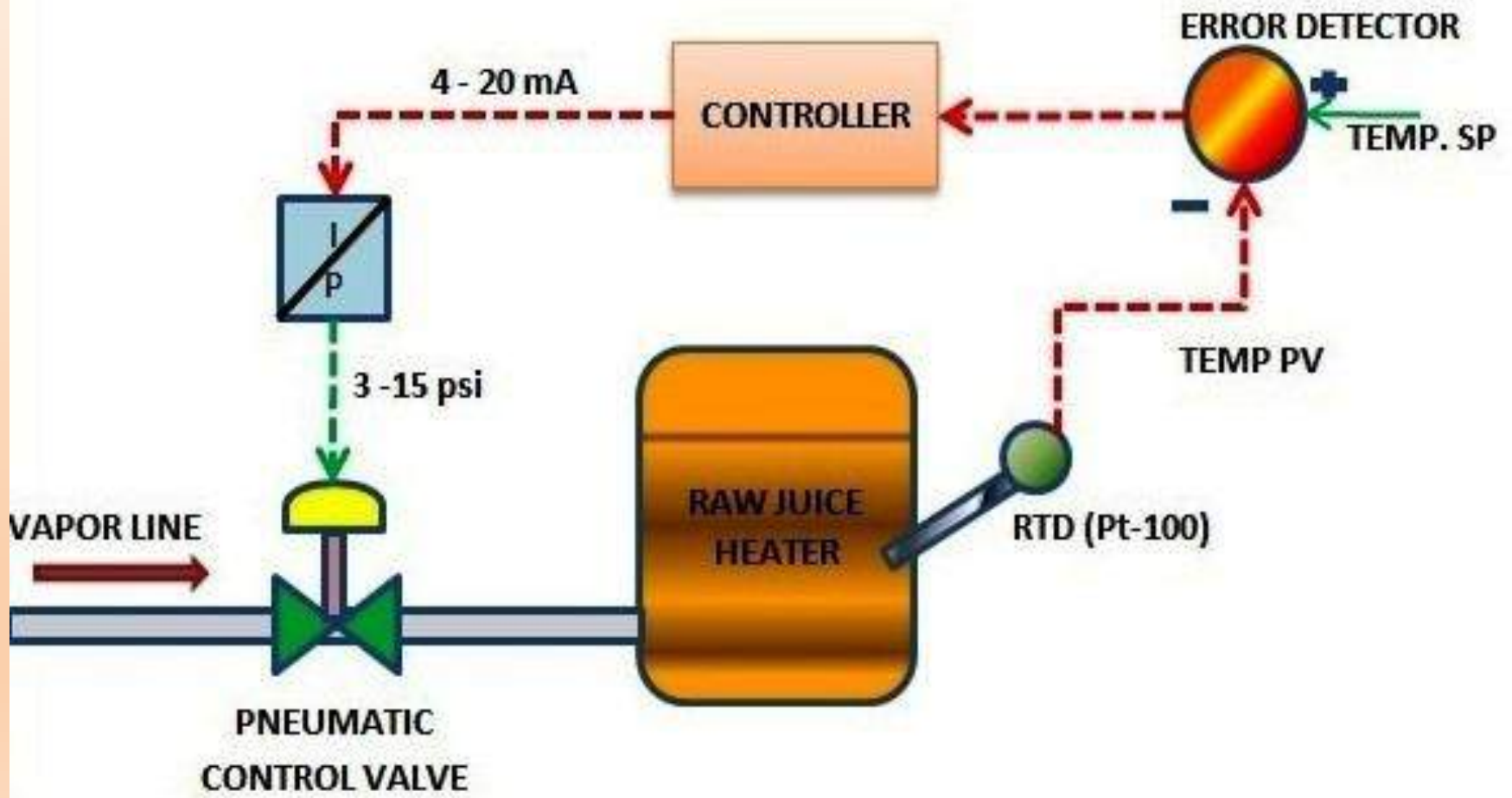
Juice flow stabilization



Automatic Juice Flow Control System

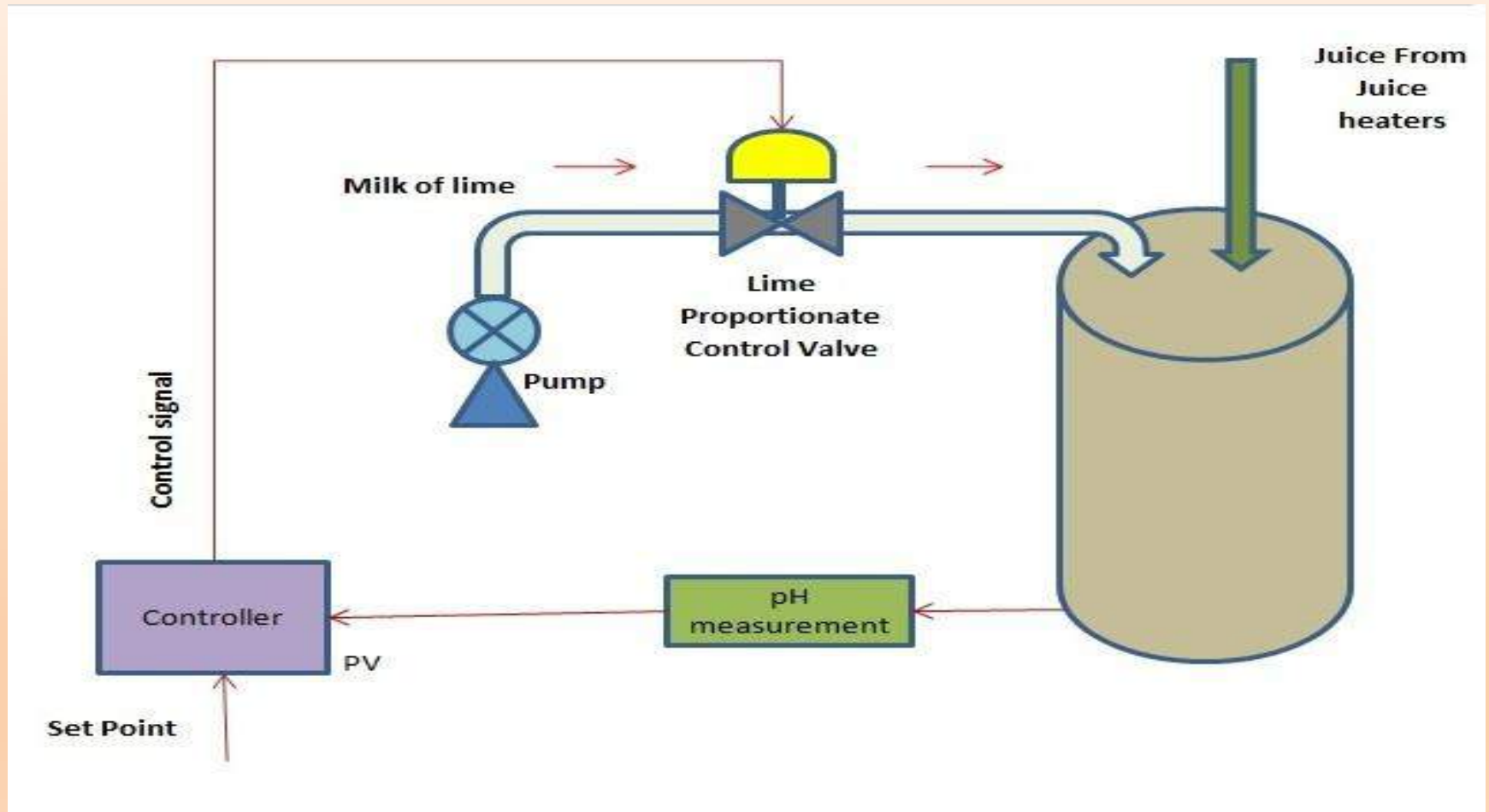


JUICE HEATER TEMPERATURE CONTROL LOOP



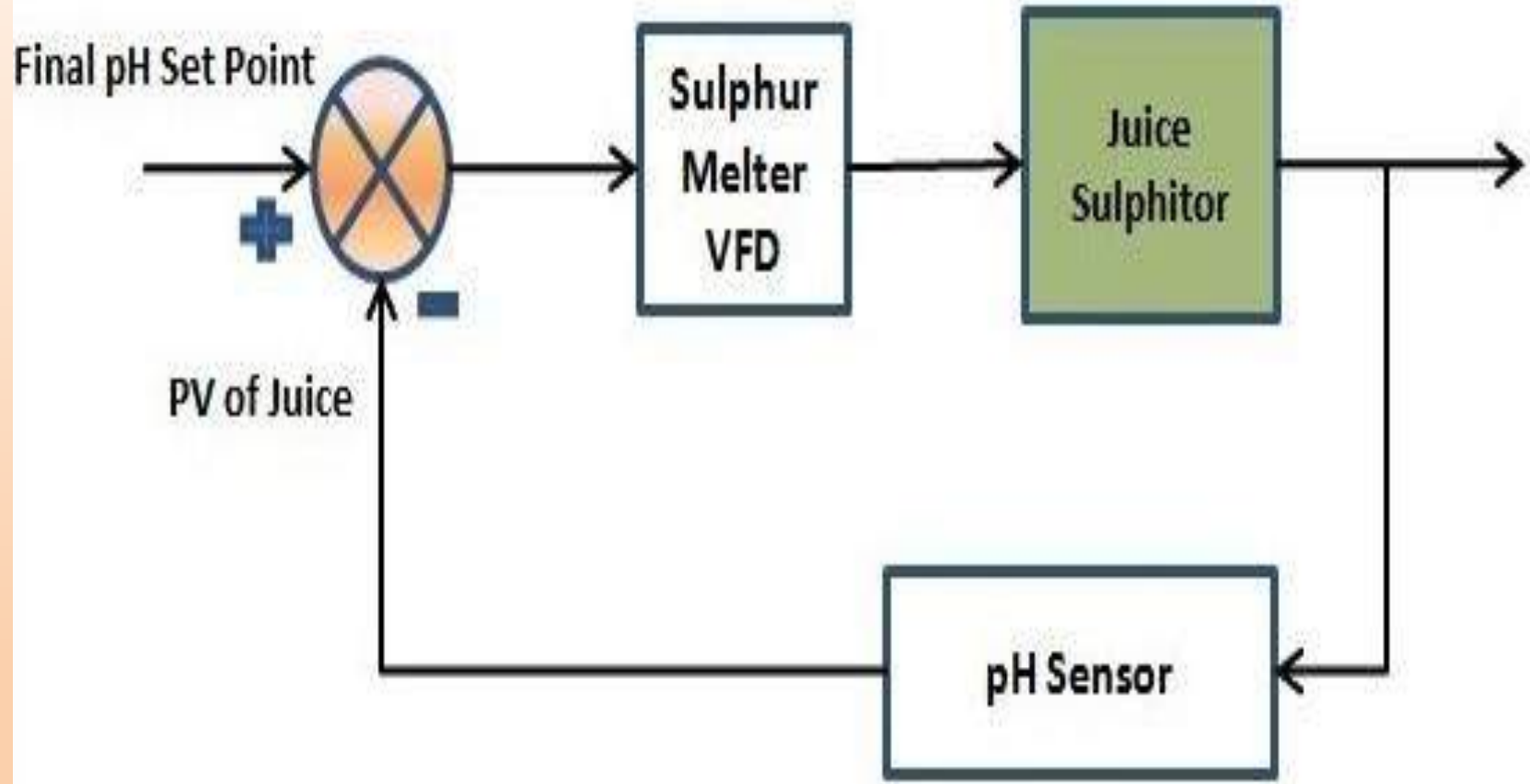


Shock pH Control



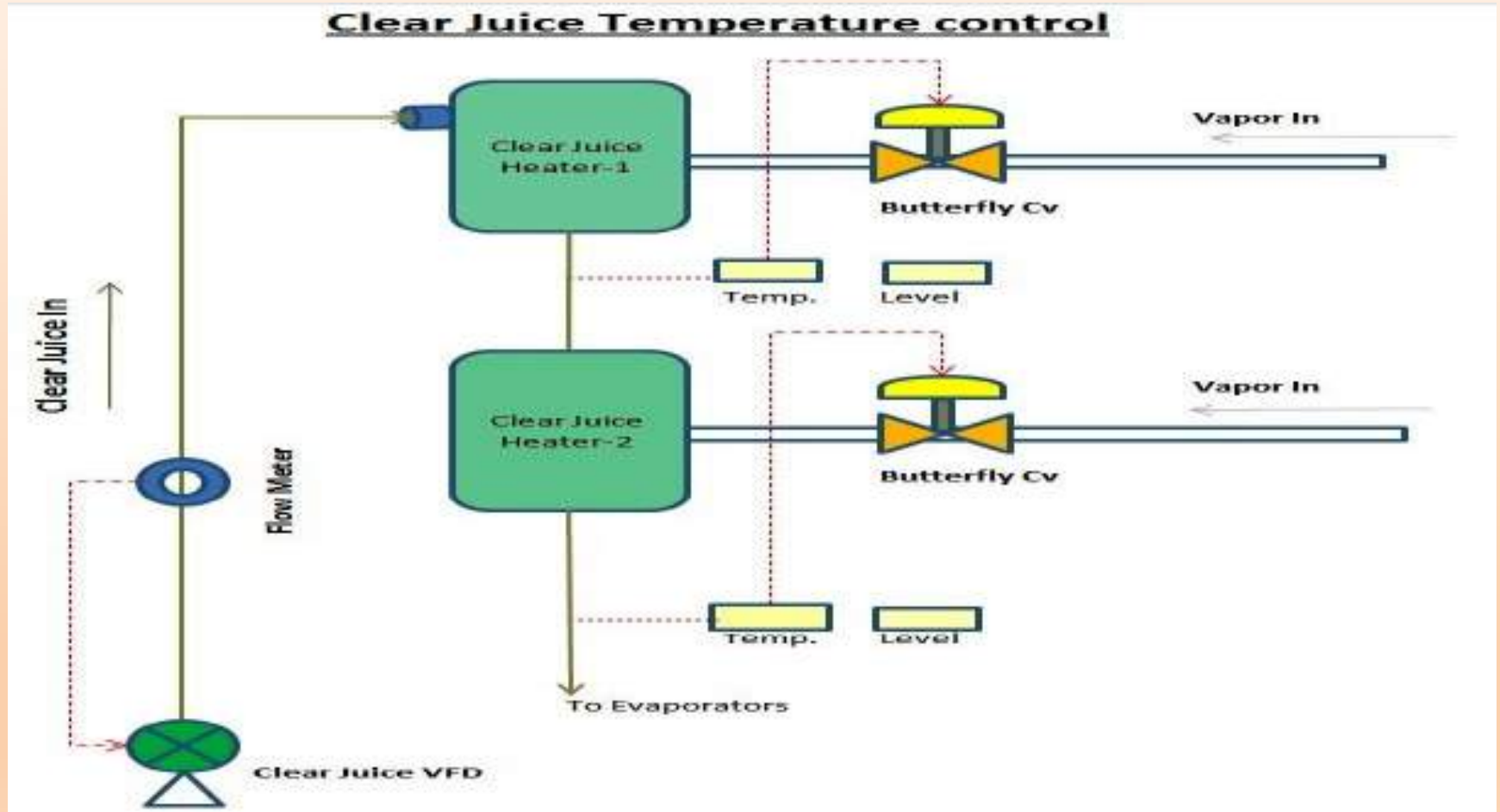


Final pH Control Loop



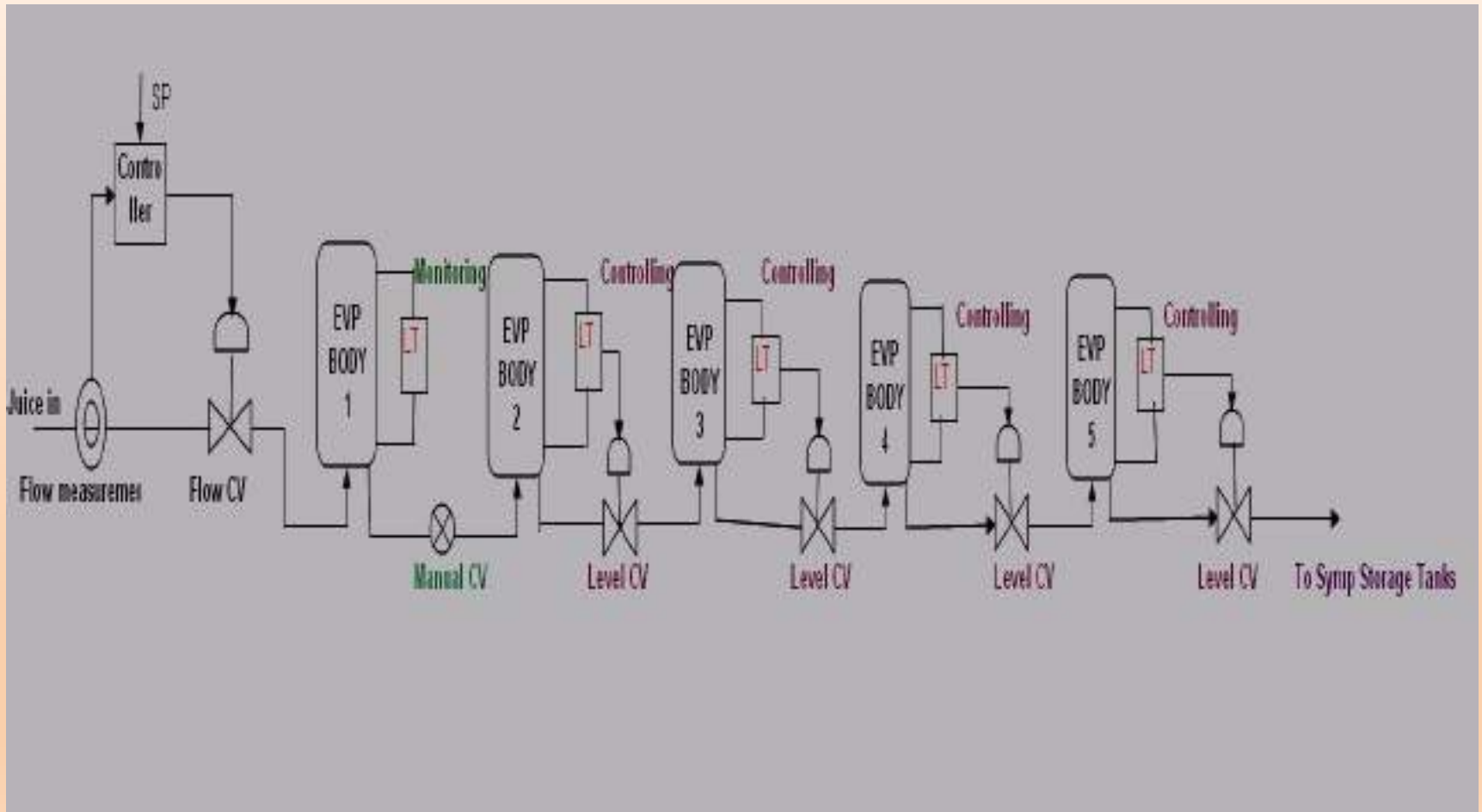


Clear Juice (DC type heater) control



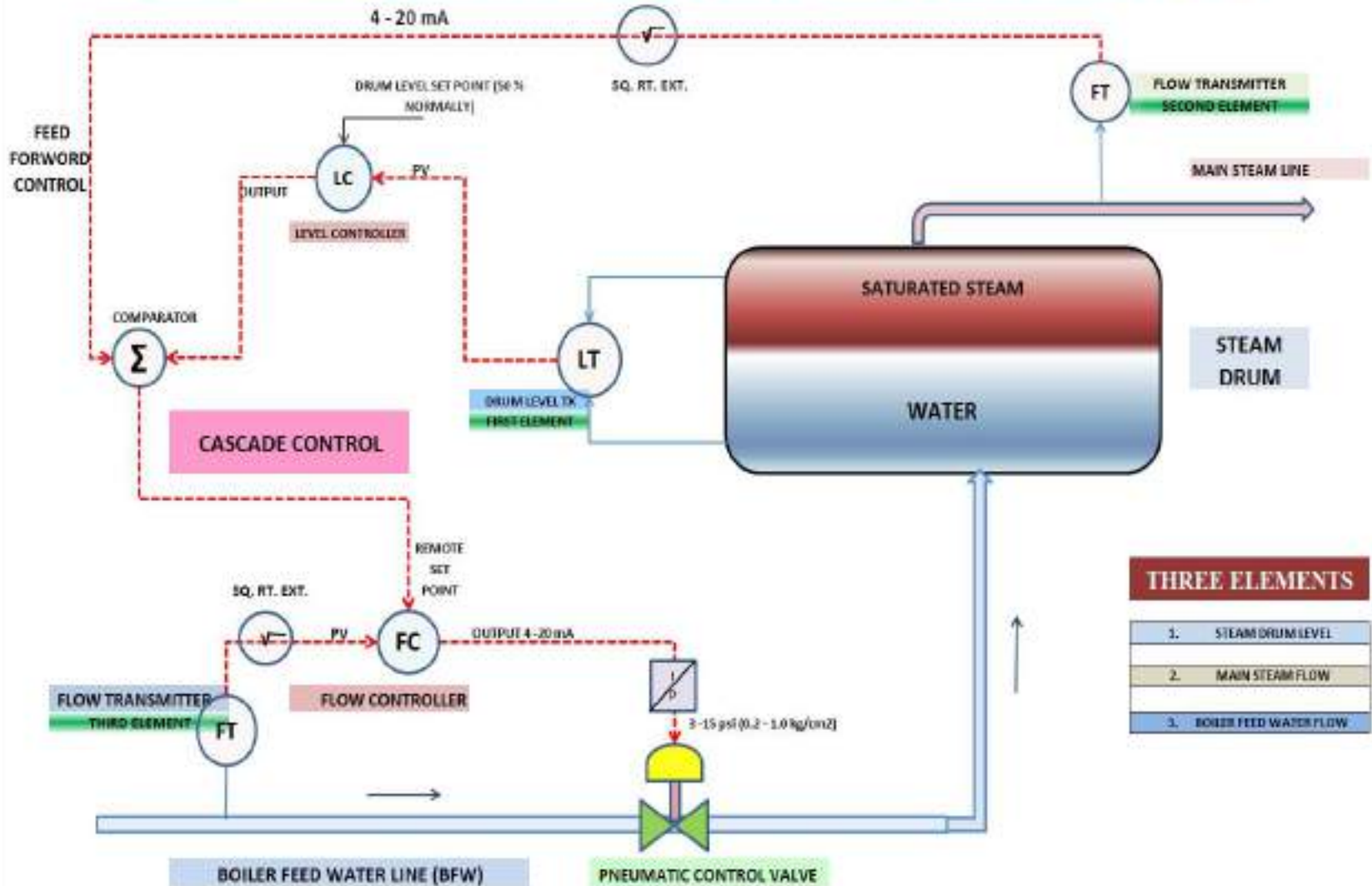


Evaporator Automation



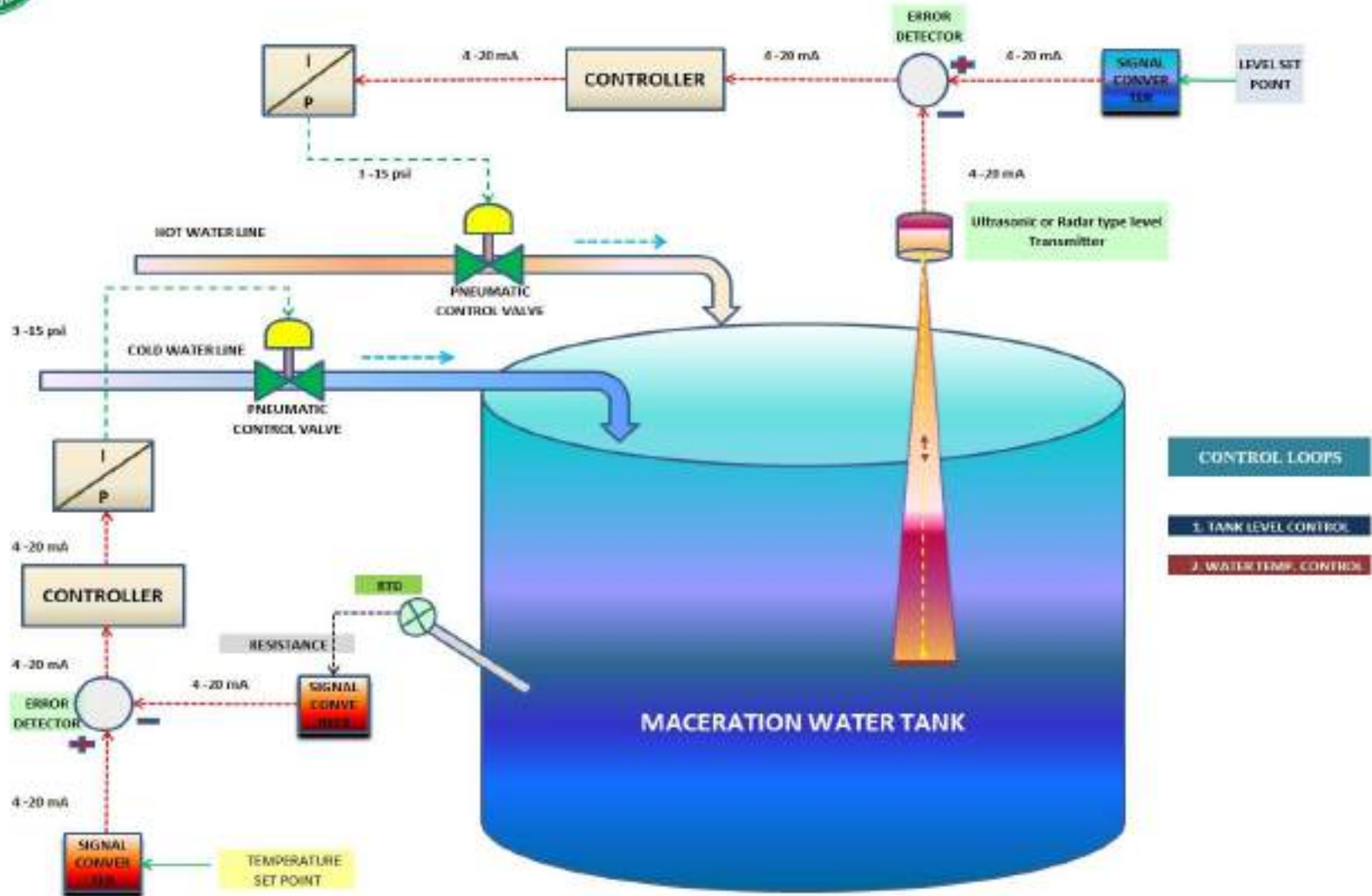


3 - ELEMENT BOILER DRUM LEVEL CONTROL



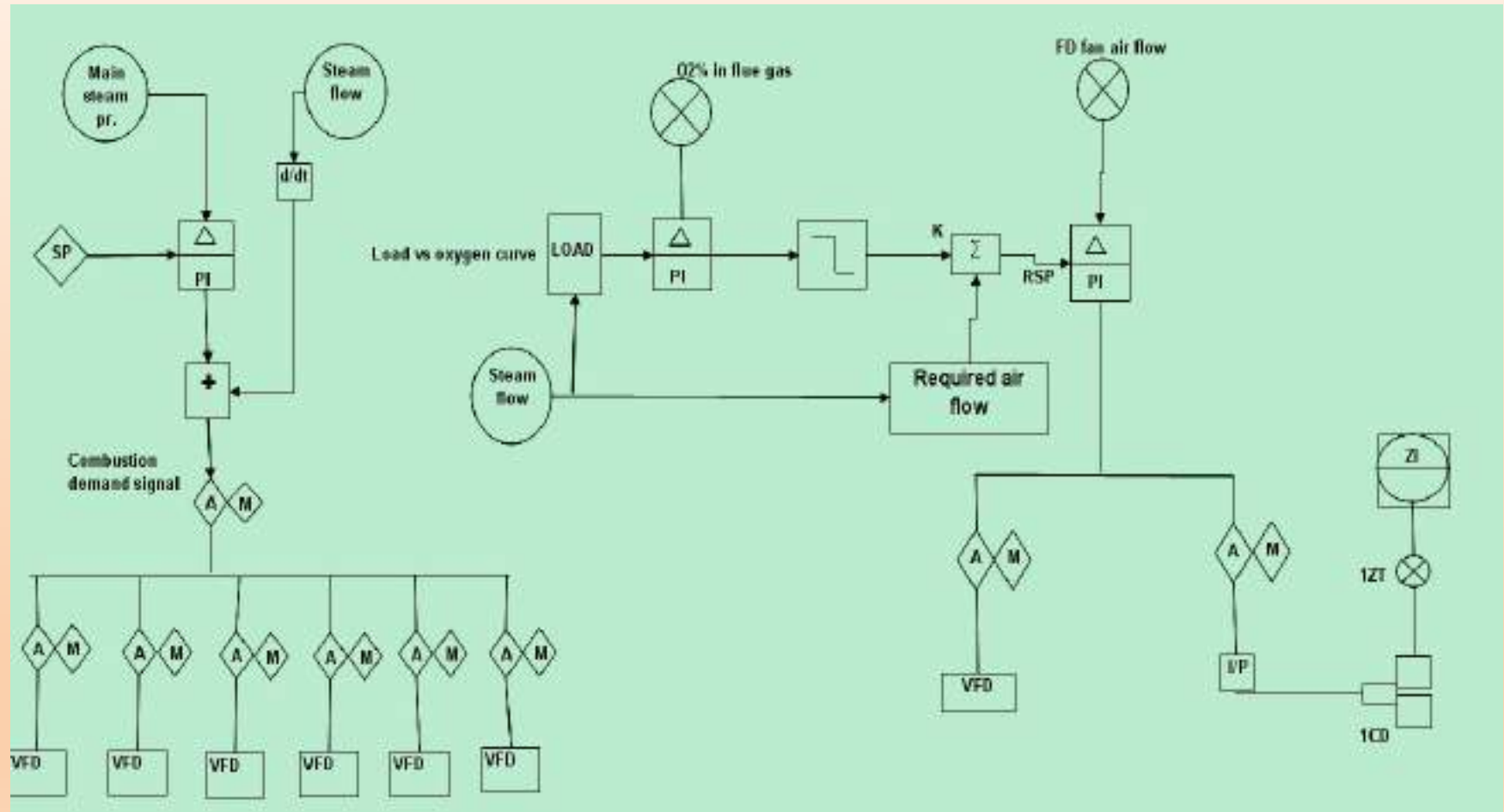


MACERATION WATER TANK LEVEL AND TEMPERATURE CONTROL



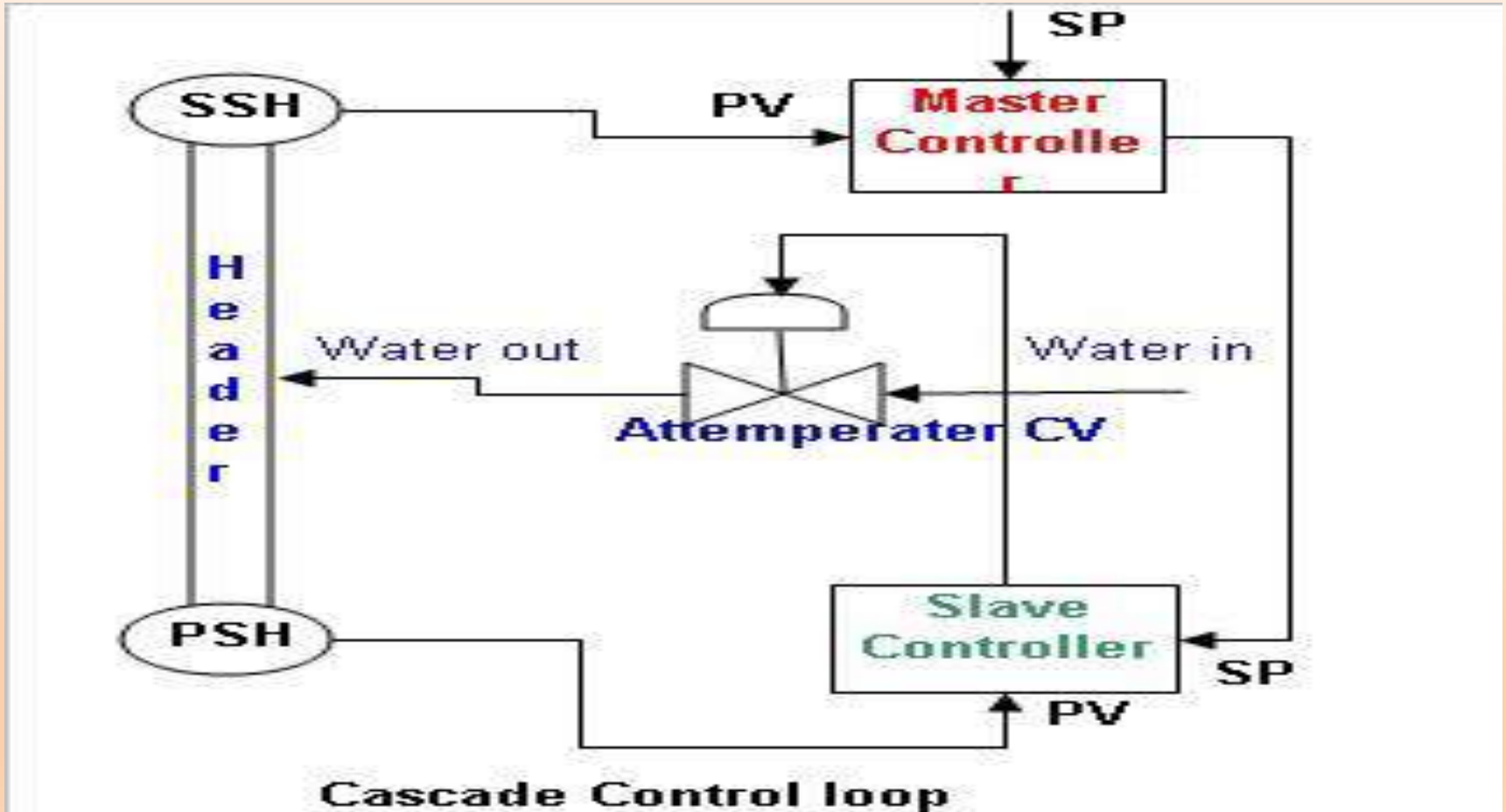


Combustion control



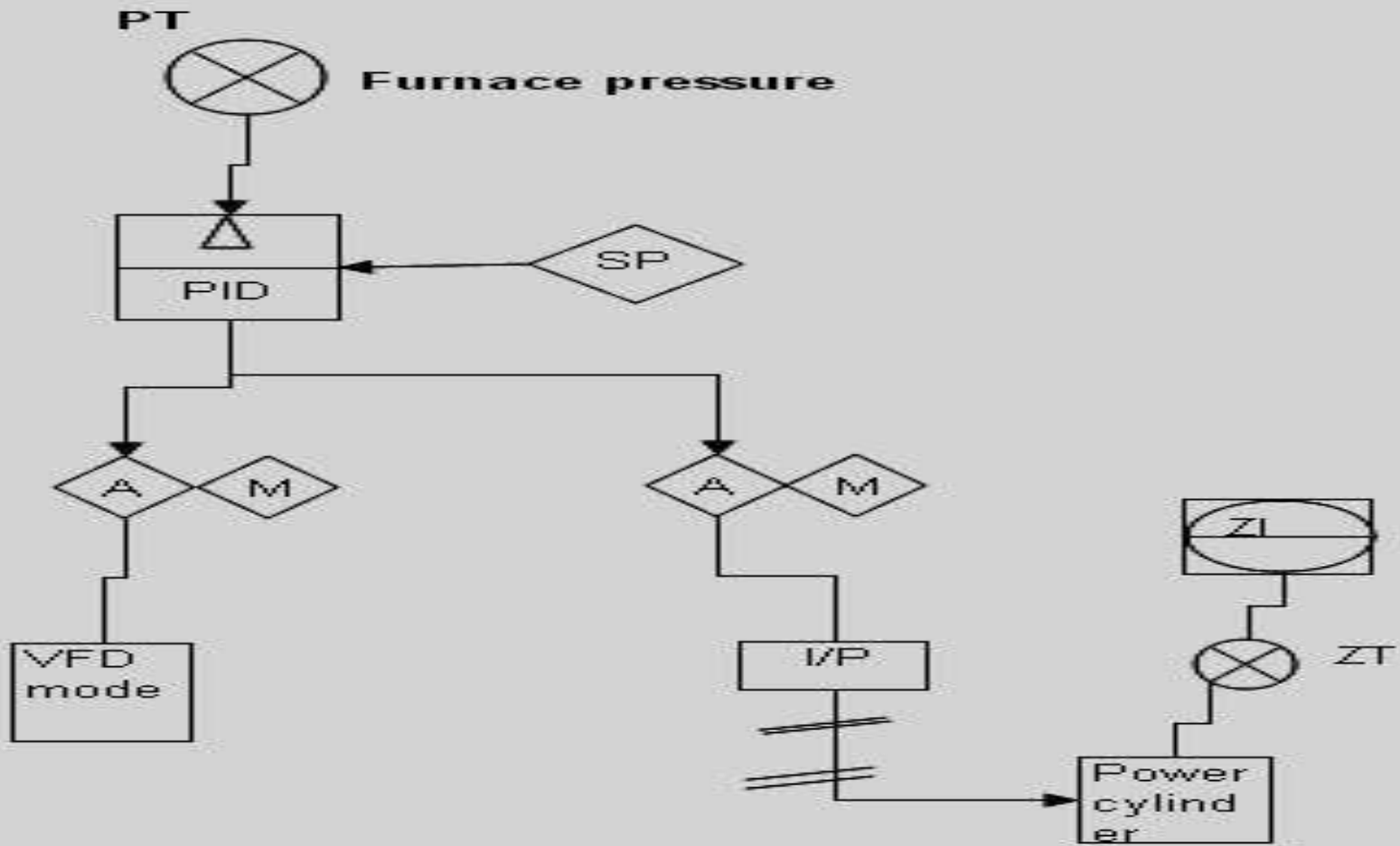


Superheated steam temp. Control



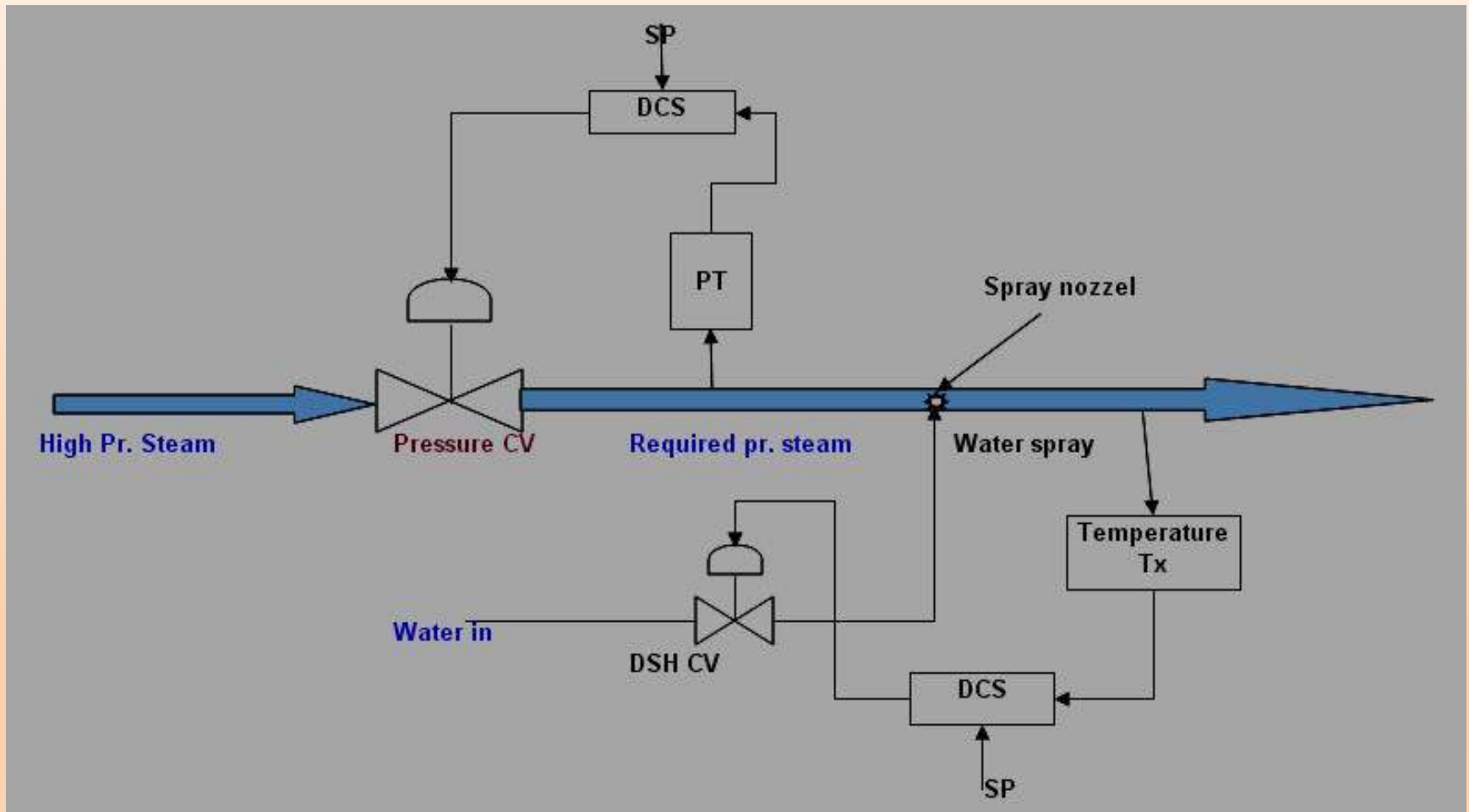


Furnace draft Control



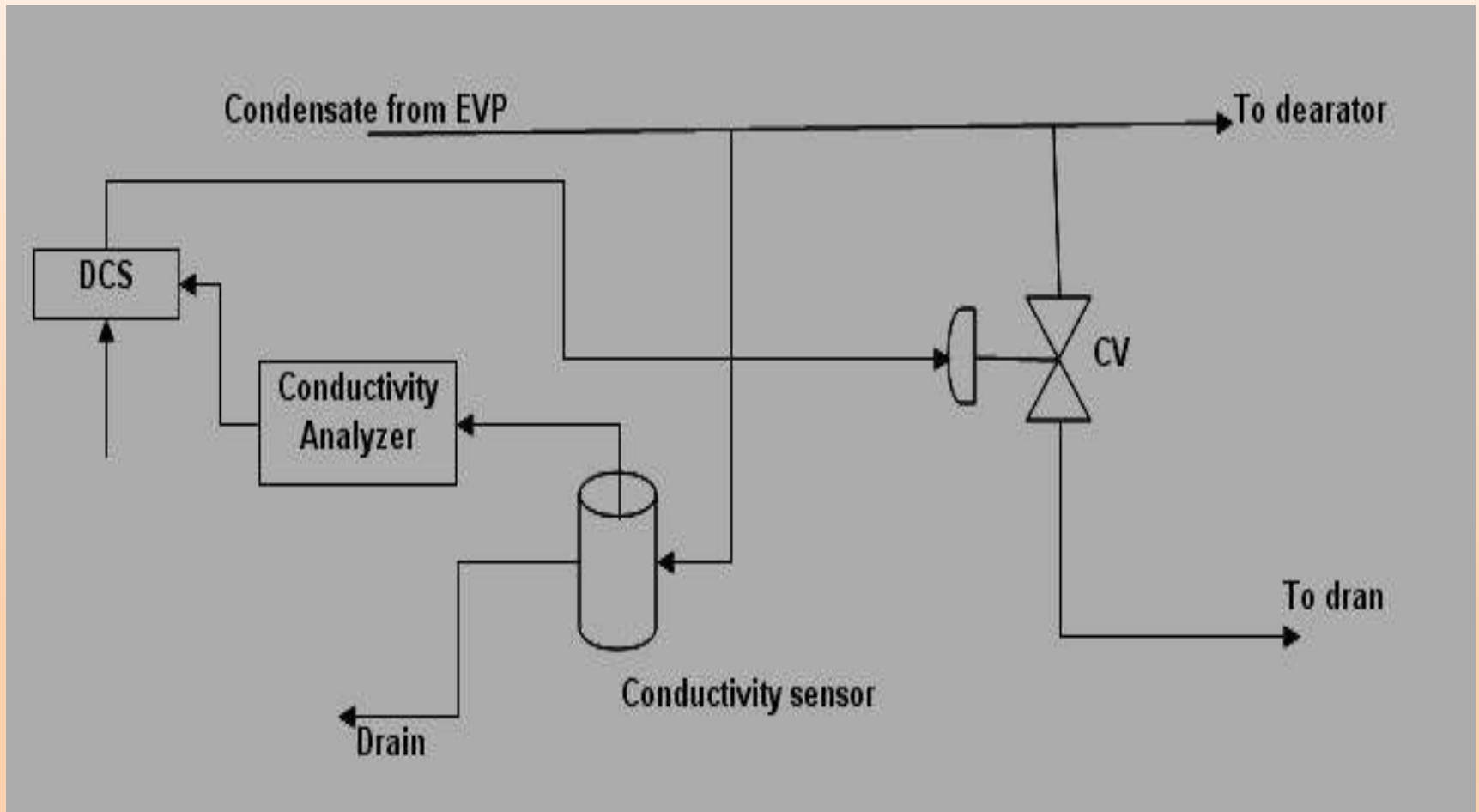


PRDS control system





Condensate conductivity control





Thanks