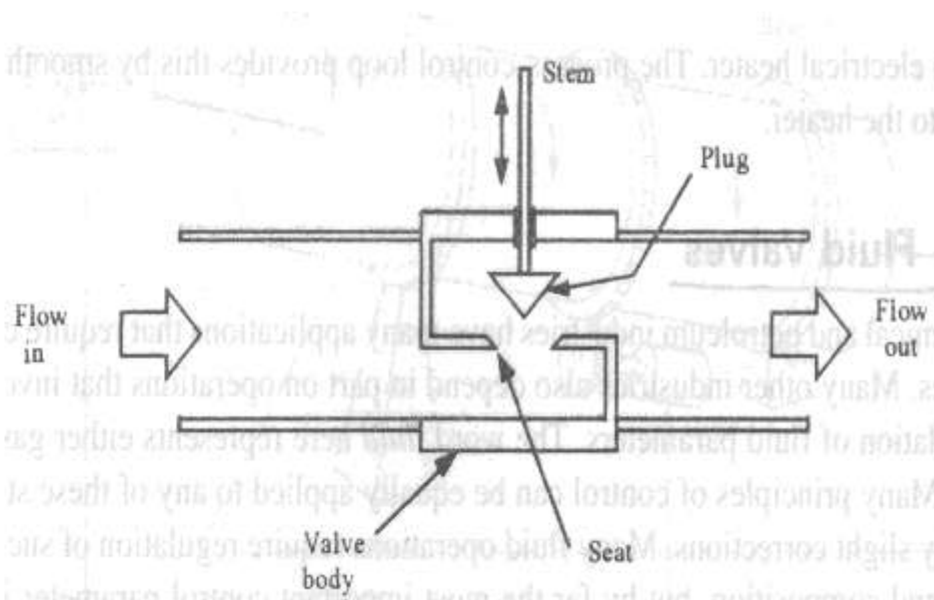
UNIT 2

- **Control Valves**

Control valves are valves used within industrial plants and elsewhere to control operating conditions such as temperature, pressure, flow, and liquid level by fully or partially opening or closing in response to signals received from controllers that compare a "set point" to a "process variable" whose value is provided by sensors that monitor changes in such conditions.

- The opening or closing of control valves is done by means of electrical, hydraulic or pneumatic systems.

Basic structure of a valve



- **Valve parts**

❑ Body

The majority of the valve consists of the valve **body**, including most of the exterior. The valve body is the vessel or casing that holds the fluid going through inside the valve. Valve bodies are most commonly made of various metals or plastics, although valve bodies fused with glass laboratory items in one piece are also made of glass.

❑ Ports :

The body consists of two or more openings, called **ports** from which movement occurs from one opening to the next. These ports are controlled by a valve. Valves with two or three ports are the most common, while valves consisting of four or more ports are not as frequently used. Extra ports that are not needed can be closed off by the valve.

Manufacturing of valves often occurs with the intent that they will be connected with another specific object. These objects can vary, but generally these include some type of piping, tubing, or pump head. In some cases, a valve port is immediately connected to a spray nozzle or container. To make a connection, valves are commonly measured by the outer diameter the ports they connect to.

Combined with a valve, ports have the ability to act as faucets, taps, or spigots, all while one or more of its remaining ports are left unconnected. Most valves are built with some means of connection at the ports. This includes threads, compression fittings, glue or cement application (especially for plastic), flanges, or welding (for metals).

❑ Discs and rotors :

Inside the valve body, flow through the valve may be partly or fully blocked by an object called a **disc**. Although valve discs of some kinds of valves are traditionally disc-shaped, discs can come in various shapes. Although the valve body remains stationary within the fluid system, the disc in the valve is movable so it can control flow. A round type of disc with fluid pathway(s) inside which can be rotated to direct flow between certain ports can be called a **rotor**.

Ball valves are valves which use spherical rotors, except for the interior fluid passageways. Plug valves use cylindrically-shaped or conically-tapered rotors called *plugs*. Other round shapes for rotors are possible too in *rotor valves*, as long as the rotor can be turned inside the valve body. However not all round or spherical discs are rotors; for example, a ball check valve uses the ball to block reverse flow, but is not a rotor because operating the valve does not involve rotation of the ball.

❑ Seat :

The valve **seat** is the interior surface in the body which contacts or could contact the disc to form a seal which should be leak-tight, particularly when the valve is shut (closed). If the disc moves linearly as the valve is controlled, the disc comes into contact with the seat when the valve is shut. When the valve has a rotor, the seat is always in contact with the rotor, but the surface area of contact on the rotor changes as the rotor is turned.

If the disc swings on a hinge, as in a swing check valve, it contacts the seat to shut the valve and stop flow. In all the above cases, the seat remains stationary while the disc or rotor moves. The body and the seat could both come in one piece of solid material, or the seat could be a separate piece attached or fixed to the inside of the valve body, depending on the valve design.

- **Stem** :

The **stem** is a rod or similar piece spanning the inside and the outside of the valve, transmitting motion to control the internal disc or rotor from outside the valve. Inside the valve, the rod is joined to or contacts the disc/rotor. Outside the valve the stem is attached to a handle or another controlling device. Between inside and outside, the stem typically goes through a valve bonnet if there is one. In some cases, the stem and the disc can be combined in one piece, or the stem and the handle are combined in one piece.

The motion transmitted by the stem can be a linear push or pull motion, a rotating motion, or some combination of these. A valve with a rotor would be controlled by turning the stem. The valve and stem can be threaded such that the stem can be screwed into or out of the valve by turning it in one direction or the other, thus moving the disc back or forth inside the body. Packing is often used between the stem and the bonnet to seal fluid inside the valve in spite of turning of the stem. Some valves have no external control and do not need a stem; for example, most check valves. Check valves are valves which allow flow in one direction, but block flow in the opposite direction. Some refer to them as one-way valves.

Valves whose disc is between the seat and the stem and where the stem moves in a direction into the valve to shut it are **normally-seated** (also called 'front seated'). Valves whose seat is between the disc and the stem and where the stem moves in a direction out of the valve to shut it are **reverse-seated** (also called 'back seated'). These terms do not apply to valves with no stem nor to valves using rotors.

- **Bonnet** :

A **bonnet** basically acts as a cover on the valve body. It is commonly semi-permanently screwed into the valve body. During manufacture of the valve, the internal parts were put into the body and then the bonnet was attached to hold everything together inside. To access internal parts of a valve, a user would take off the bonnet, usually for maintenance. Many valves do not have bonnets; for example, plug valves usually do not have bonnets.

- **Spring**

Many valves have a spring for spring-loading, to normally shift the disc into some position by default but allow control to reposition the disc. Relief valves commonly use a spring to keep the valve shut, but allow excessive pressure to force the valve open against the spring-loading,

- **Control valve working principle**:

  The purpose of control valve is to regulate the flow rate of fluids through pipes in the system. This is accomplished by placing a variable – size restriction in the flow path as seen above. We see that as the stem and plug move up and down, the size of the opening between the plug and seat changes, thus changing the flow rate.

- We have a pressure drop across the restrictor and the flow rate varies with the square root of this pressure drop, with an appropriate constant of proportionality, shown by,

- $Q = K \sqrt{(\Delta P)}$ Where, K = proportionality constant and, $\Delta P = P_2 - P_1$ = pressure difference across valve.

- The constant K, depends on the size of the valve, the geometrical structure of the delivery system and up to some extent on the material flowing through valve.

- **While discussing control valve, we should specially look for the followings**

❑ The valve body, its geometry, and materials of construction

- the valve plug, its geometry, and materials of construction.

- The combined geometry of the body and plug determines the flow properties of the valve.

- **Valve body** :

  Control valve bodies may be screwed, flanged or welded into the flow line. The most common body materials are cast iron and carbon steel. Low alloy steels are used for high temperatures. Stainless steel, bronze, monel, nickel etc are used in the case of corrosive environment or for very high or low temperature applications.

❑ **Valve plug**

The plug and seat geometry is the most significant factor in the determination of flow rate Vs. stem position characteristics of the valve.

- **<u>Different types of control valves</u>**:

  Classification based on movement

❑ **Linear spindle movement:**

Here we have the following types,

- **Globe valve**
- **Slide valve**

- **Rotary spindle movement**

OR

- **Quarter turn valve**

Here we have the following types,

- **Ball valve**

- Good for ON/OFF control
- Easily actuated
- Used to give predictable flow pattern
- Economic
- Gives tight shut-off for steam or other fluids up to 250 degree C.

- **Butterfly valve**

- Used for simple control activities, particularly in larger size systems, where limited turn-down is needed.
- Differential pressure limits are lower than those for globe valves.

- **Plug valve**

- **eccentric plug valve**

- To improve leverage/effectiveness and closing force
- Suitable for ON/OFF control
- Gives equal percentage characteristics

- **Actuators**

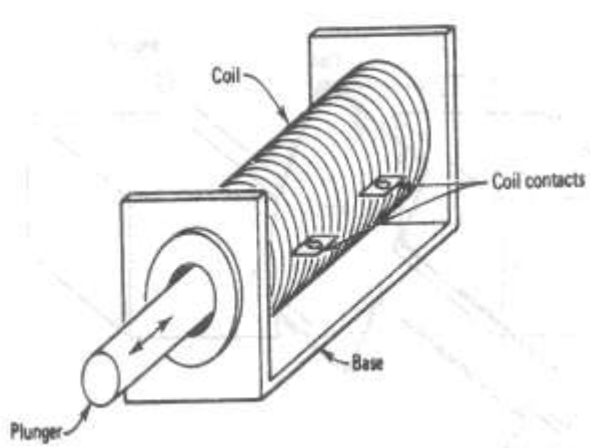
  Are used for the automation of industrial valves and can be found in all kinds of technical process plants.

Types:

- **Electrical actuators**
  - Solenoid
  - Motors
    - dc motor
    - ac motor
    - stepping motor
- **Pneumatic actuators**
- **Hydraulic actuators**

- **Electrical Actuators**

<u>Solenoid:</u>



Solenoid is the elementary device that converts the electrical signal into mechanical motion in straight line, it consists of coil and plunger (may be spring loaded). Whenever the coil is excited and plunger faces pull or push force. They are used when a large, sudden force must be applied to perform some job.

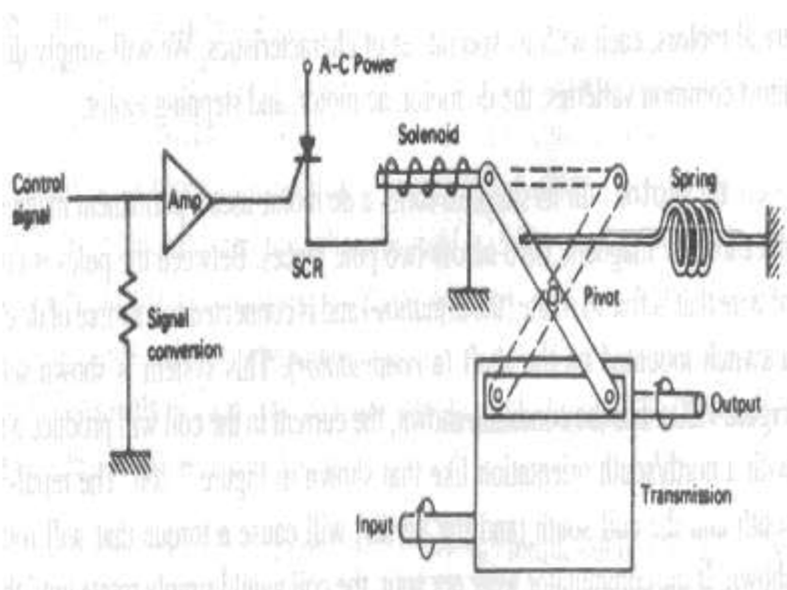
- **Pneumatic Actuators:**

Converts energy (in the form of compressed air) into motion. The motion can be rotary or linear, depending on the type of actuator. Some of the pneumatic actuators are as follows,

- Tie rod cylinder
- Rotary actuators
- Grippers
- Rodless actuator with magnetic linkage
- Rodless actuator with mechanical linkage
- Pneumatic artificial muscles
- Vacuum generators etc.

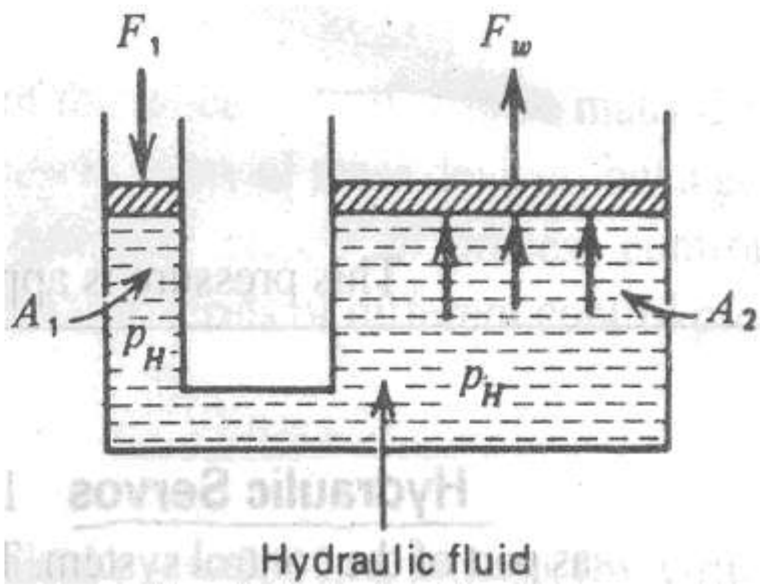
- **Electro-pneumatic Actuator:**

In the diagram shown below the solenoid is used to change the gears of a two position transmission, an SCR is used to activate the solenoid coil.



- **<u>Hydraulic Actuator:</u>**

With very large force, this actuator is employed. Here in the diagram below, this actuator converts a small force F1 into an amplified force Fw.



- **Why controllers need tuning?**

Definition of tuning :

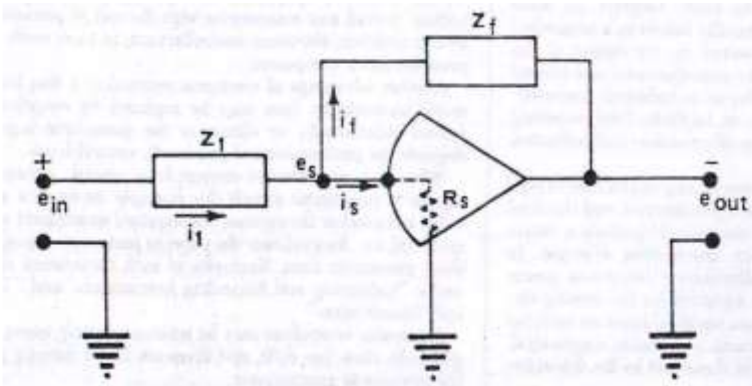
"Tuning" a control loop is the adjustment of its control parameters (gain/proportional band, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response.

- **Generation Of Control Action**

- Electronic Controllers
- Pneumatic Controllers

- **Electronic Controllers**

Use of Operational Amplifier:



Operational amplifier with input and feedback impedances.

The impedances Z1 and Z2 may be resistors/capacitors/inductors/combination depending upon the desired relationship between input and o/p voltages.

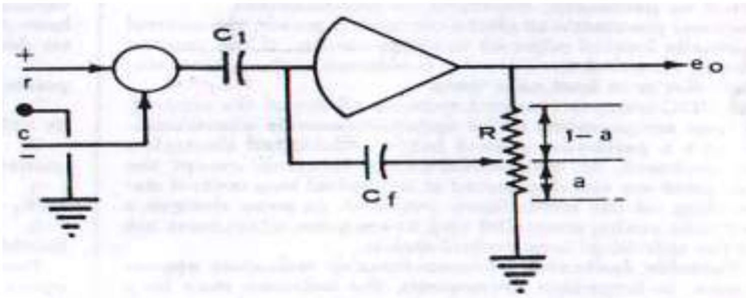
Electronic controller Inputs and Outputs:

For 0 to 100 percent of the input – signal range, typical outputs are 1 – 5 mA, 4 – 20mA, 10 – 50 mA, and 1 – 5 V. most controllers will accept a variety of input signals by properly sizing input resistors, but the output is usually limited to a single range.

- **Generation of Proportional control mode:**

- The controller o/p is $e_0 = -K(r\text{-}c)$.

- Look at the diagram shown below,



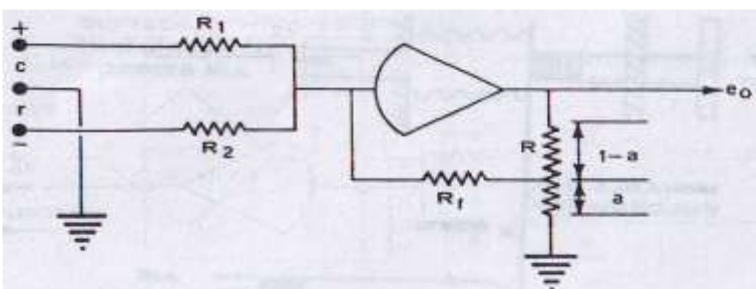
$Z_1 = \frac{1}{sC_1}$ $K_c = \frac{C_1}{aC_f}$, $0 < a < 1$

$Z_f = \frac{1}{asC_f}$ $e_o = +K_e (r - c)$

Proportional controller utilizing capacitances for the feedback and summing-junction input impedances. K_c is the proportional gain and R the proportional adjustment resistor.

- Here the input impedance component is a capacitor, and the feedback impedance is a resistor – capacitor network in which the resistance is adjustable.

- Now, look at the another diagram shown below, Here, all the impedance components are resistors.



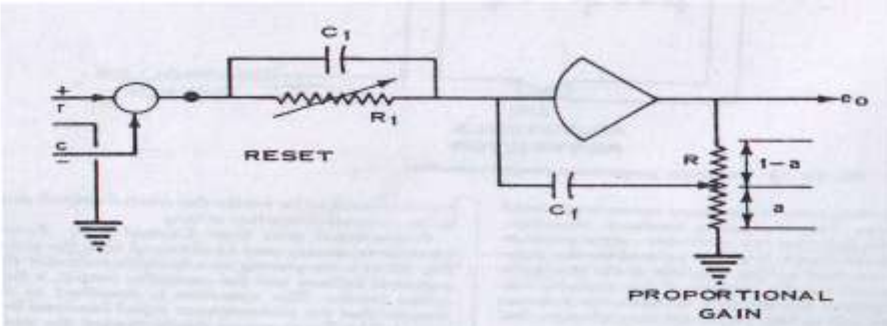
$Z_1 = R_1$ $K_c = \frac{R_f}{aR}$, $0 < a < 1$

$Z_f = \frac{R_f}{a}$ $e_o = +K (r - c)$

FIG. 22-107 Proportional controller utilizing resistors for feedback and summing-junction input impedances.

- **Generation of PI action:**

- Many schemes are possible, among them two schemes are shown below,



$$Z_1 = \frac{\frac{1}{s_1}}{1+\frac{1}{sC_1R_1}}$$

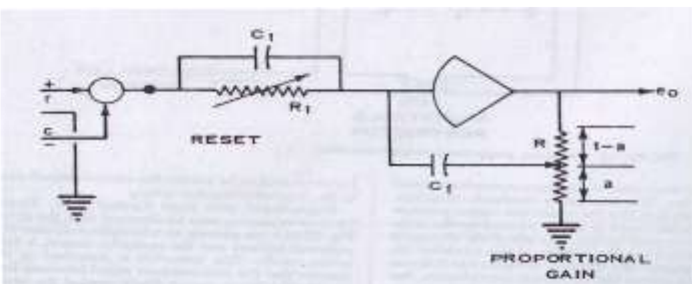
$$e_0 = \frac{Z_f}{Z_1}(r-c) = K_c\left[(r-c)+\frac{1}{T_i}\int(r-c)\,dt\right]$$

$$Z = \frac{1}{asC_f}$$

$$K_c = \frac{C_1}{aC_f}, \quad 0<a<1$$

$$T_i = R_1C_1$$

FIG. 22-108 Proportional-integral controller utilizing input capacitor-resistor networks for reset adjustment.



$$Z_1 = \frac{\frac{1}{s_1}}{1+\frac{1}{sC_1R_1}}$$

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$$Z = \frac{1}{asC_f}$$

$$K_c = \frac{C_1}{aC_f}, \quad 0<a<1$$

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FIG. 22-108 Proportional-integral controller utilizing input capacitor-resistor networks for reset adjustment.

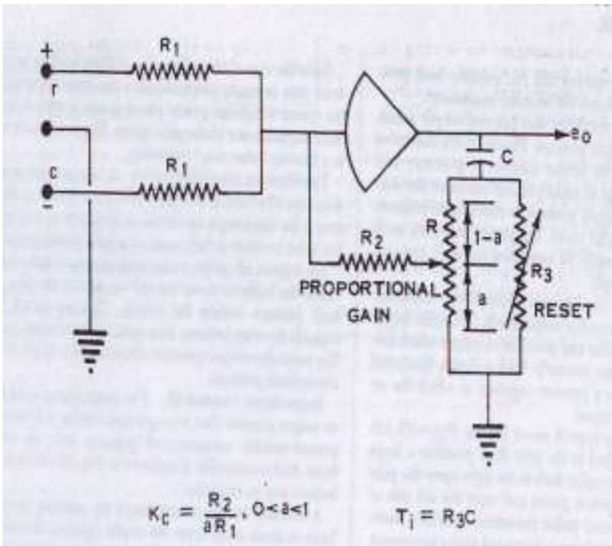


FIG. 22-109 Proportional-integral controller utilizing a feedback capacitive-resistive network for adjustments of proportional gain and reset.

Generation of PID action:

- Derivative action is added into PI generator circuit by adding a resistor- capacitor network in the feedback path.

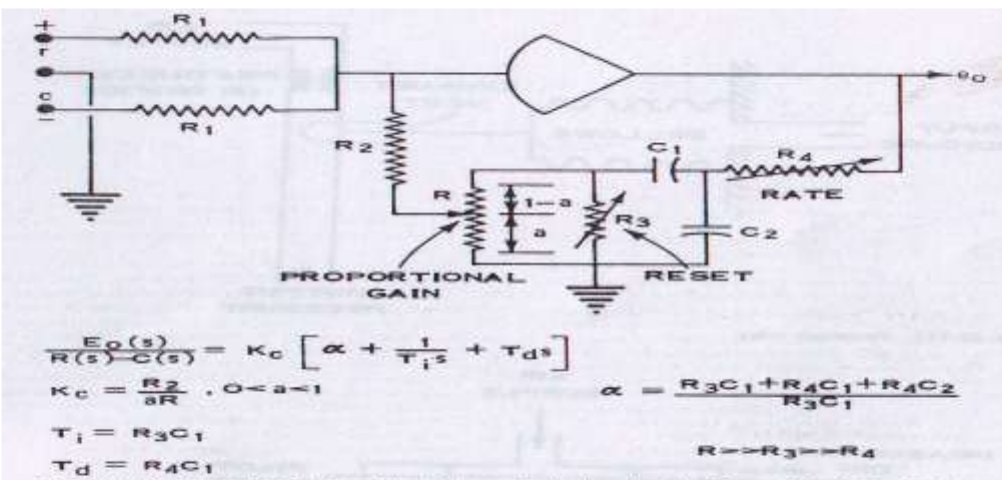


FIG. 22-110 Proportional-integral-derivative controller based on the PI controller of Fig. 22-109.

- **Controller Mode**

- Controller generates a control signal to the final element . Based on a measured deviation of the controlled from the set point.

- **Controller Classification** :

1. Continuous Controller
2. Discontinuous Controller

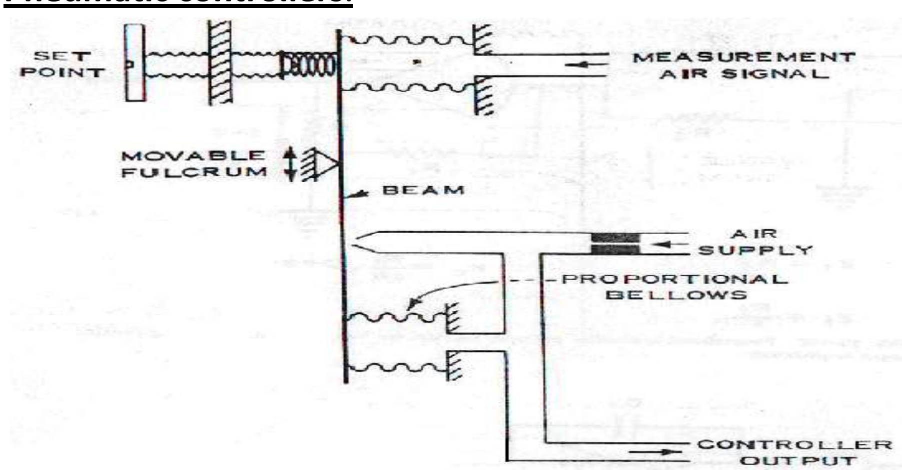
- **Continuous Controllers**

- Proportional Controller Mode
- Integral Controller Mode
- Derivative Controller Mode

Composite Controller Mode –

- PI controller mode
- PD controller mode
- PID controller mode

Pneumatic controllers:



- **Steps to explain:**

- Measurement bellows shrunk, left movement
- SP spring right movement

- Beam rotation clockwise, away from nozzle
- Proportional bellows in opposition of rotation
- Controller o/p pressure decreased
- Proportional bellows pressure decreased, off-setting some of the beam movement
- Controller o/p pressure passed to actuator
- o/p pressure is proportional to the difference between SP and I/P pressure.

- ## P Control mode

For the same diagram **not having reset bellows and its restrictor**, by a small movement of the flapper, the o/p pressure is obtained as directly proportional to the movement of the flapper. Such an arrangement can give a proportional band of the range of 0-600 percent. Usually the less is the PB without affecting stability and providing the desired recovery for disturbances, the more is the advantage.

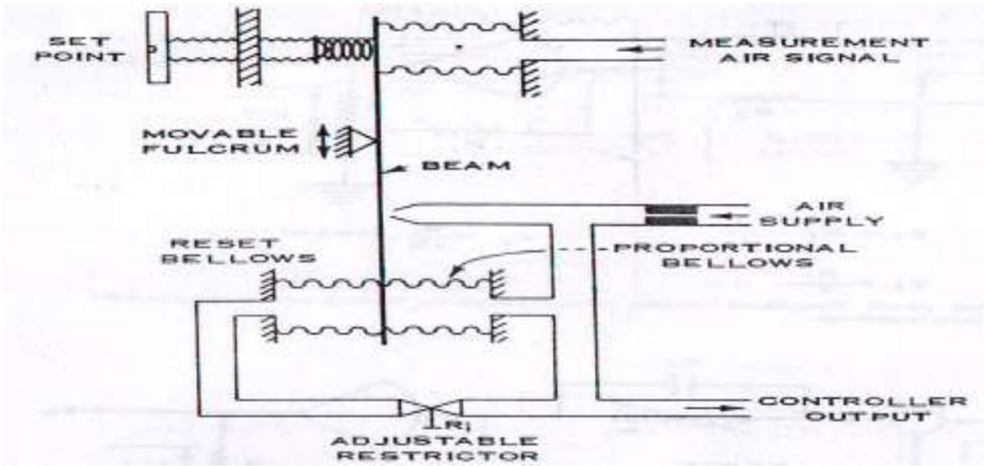
- ## I Control mode:

Provided by attaching Resetting bellow and a restrictor (air does not pass immediately, but step by step, its valve opens only after certain predefined/pre-adjusted pressure level)

- ## PI Control mode:

The addition of reset or integral action to a proportional controller involves the addition of a reset bellows and an adjustable restrictor.

PI Controller mode



The action of proportional and reset controllers are as follows. Here if the measurement pressure is increased, the balance beam moves towards the nozzle, increasing the controller o/p pressure. The increased o/p pressure causes the proportional bellows to reposition the beam and stabilize the o/p at an increased pressure. *(The proportional action taken now and still some error remaining, (it is not zero) suppose constant now for some duration,*

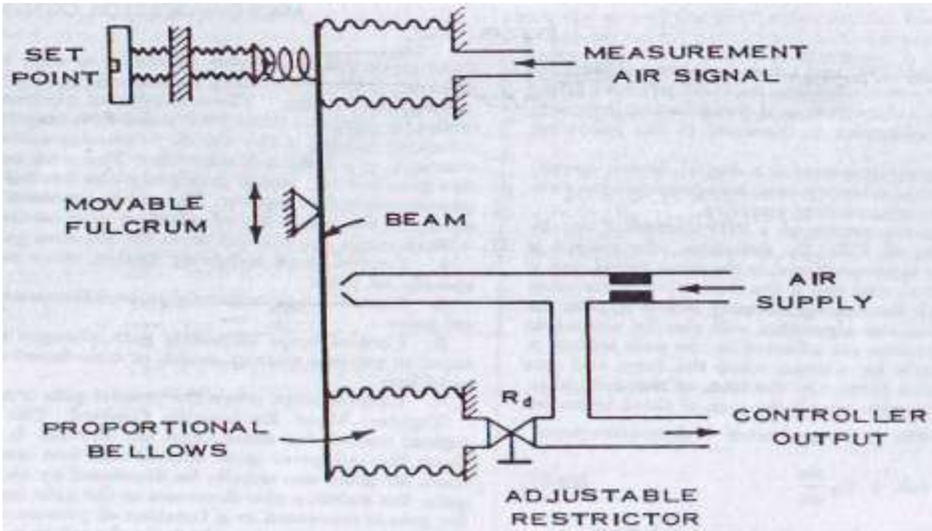
- → *here integral action will work now. The controller o/p is at new generated o/p level)*.There is now a pressure drop across restriction Ri. As a small flow of air enters the reset bellows, it forces the beam towards the nozzle, further increasing the output pressure. *This happens step by step as opposed by restrictor, not allowing all the air enter in same time. i.e Pi slowly increases by a function of (proportional) P – Pi and continues till P = Pi i.e. proportional bellows and reset bellows have the same pressure.*

→ *getting the idea of for what duration P control action to be taken.*

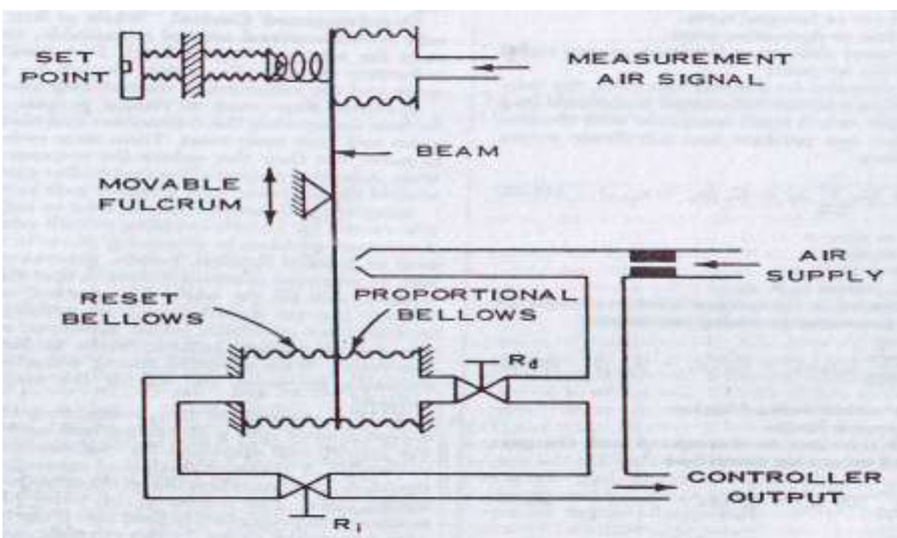
PD Control mode:

By placing an adjustable restrictor Rd between the proportional bellows and the controller o/p, a delayed proportional action results. Assuming the measurement signal increases linearly with time. The beam moves slowly towards the nozzle, increasing the o/p pressure. Air flows slowly through the restrictor to restore the beam – nozzle position. Because of the length of time required for the air to flow through the restrictor, proportional action is temporarily reduced and delayed. (*i.e. the accurate proportional o/p will come after some time, till then …..*) The o/p is therefore higher and more advanced in time than it would be with proportional control action only.

PD Control Mode



PID control mode:



- **Relief valve**

The **relief valve** is a type of valve used to control or limit the pressure in a system or vessel which can build up by a process upset, instrument or equipment failure, or fire. The pressure is relieved by allowing the pressurised fluid to flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits. When the pressure setting is exceeded, the relief valve becomes the "path of least resistance" as the valve is forced open and a portion of the fluid is diverted through the auxiliary route.

The diverted fluid (liquid, gas or liquid-gas mixture) is usually routed through a piping system known as a *flare header* or *relief header* to a central, elevated gas flare where it is usually burned and the resulting combustion gases are released to the atmosphere. As the fluid is diverted, the pressure inside the vessel will drop. Once it reaches the valve's re-seating pressure, the valve will re-close. This pressure, also called *blow down*, is usually within several percent of the set-pressure.

In high-pressure gas systems, it is recommended that the outlet of the relief valve is in the open air. In systems where the outlet is connected to piping, the opening of a relief valve will give a pressure build up in the piping system downstream of the relief valve. This often means that the relief valve will not re-seat once the set pressure is reached. For these systems often so called "differential" relief valves are used.

This means that the pressure is only working on an area, that is much smaller than the openings area of the valve. If the valve is opened the pressure has to decrease enormously before the valve closes and also the outlet pressure of the valve can easily keep the valve open. Another consideration is that if other relief valves are connected to the outlet pipe system, they may open as the pressure in exhaust pipe system increases. This may cause undesired operation.

In some cases, a so-called *bypass valve* acts as a relief valve by being used to return all or part of the fluid discharged by a pump or gas compressor back to either a storage reservoir or the inlet of the pump or gas compressor. This is done to protect the pump or gas compressor and any associated equipment from excessive pressure. The bypass valve and bypass path can be internal (an integral part of the pump or compressor) or external (installed as a component in the fluid path).

In other cases, equipment must be protected against being subjected to an internal vacuum (i.e., low pressure) that is lower than the equipment can withstand. In such cases, *vacuum relief valves* are used to open at a predetermined low pressure limit and to admit air or an inert gas into the equipment so as control the amount of vacuum.

Safety Valve

FIG – Oxygen Safety Valve

FIG – ND250-Safety Valves

- A **safety valve or relief valve** operates automatically at a set differential pressure to correct a potentially dangerous situation, typically over-pressure.
- A **safety valve** is a valve mechanism for the automatic release of a gas from a boiler, pressure vessel, or other system when the pressure or temperature exceeds preset limits. It is part of a bigger set named Pressure Safety Valves (PSV) or Pressure Relief Valves (PRV). The other parts of

the set are named relief valves, safety relief valves, pilot-operated safety relief valves, low pressure relief valves, vacuum valves.

Function and design

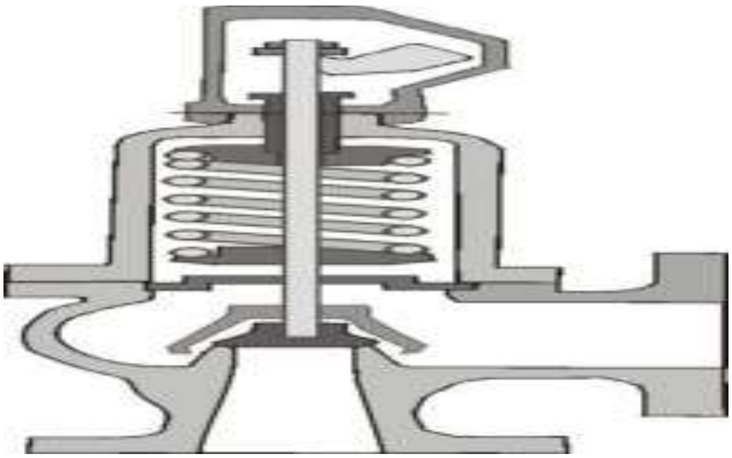


FIG - Proportional-Safety Valve

- Safety valves also envolved to protect equipment such as pressure vessels (fired or not) and heat exchangers. Safety valve term should be limited to compressible fluid application (gas, vapour, steam).
- The two general types of protection encountered in industry are *thermal protection* and *flow protection*.
- For liquid-packed vessels, thermal relief valves are generally characterized by the relatively small size of the safety valve necessary to provide protection from excess pressure caused by thermal expansion.
- In this case a small valve is adequate because most liquids are nearly incompressible, and so a relatively small amount of fluid discharged through the relief valve will produce a substantial reduction in pressure.
- Flow protection is characterized by safety valves that are considerably larger than those mounted in thermal protection. They are generally sized for use in situations where significant quantities of gas or high volumes of liquid must be quickly discharged in order to protect the integrity of the vessel or pipeline.
- Safety Valve (SV): automatic system that relief by static pressure on a gas. It specifically open almost straight to full lift after a pop sound.
- Safety Relief Valve (SRV): automatic system that relief by static pressure on both gas and liquid.

- Pilot-Operated Safety Relief Valve (POSRV): automatic system that relief by remote command from a pilot on which the static pressure (from equipment to protect) is connected.
- Low Pressure Safety Valve (LPSV): automatic system that relief by static pressure on a gas. The pressure is small and near the atmospheric pressure.
- Vacuum Pressure Safety Valve (VPSV): automatic system that relief by static pressure on a gas. The pressure is small, negative and near the atmospheric pressure.
- Low and Vacuum Pressure Safety Valve (LVPSV): automatic system that relief by static pressure on a gas. The pressure is small, negative or positive and near the atmospheric pressure.
- RV, SV and SRV are spring operated (even said spring loaded). LPSV and VPSV are spring operated or weight loaded.
- The optimum behaviour on a process change or set point change varies depending on the application. Some processes must not allow an overshoot of the process variable from the set point. Other processes must minimize the energy expended in reaching a new set point. Generally stability of response is required and the process must not oscillate for any combination of process conditions and set points.
- Tuning of loops is made more complicated by the response time of the process; it may take minutes or hours for a set-point change to produce a stable effect. Some processes have a degree of non-linearity and so parameters that work well at full-load conditions don't work when the process is starting up from no-load.

- ## Valve Positioners

Pneumatic or electro-pneumatic, single-acting positioners are used with various actuators on sliding-stem valves for throttling applications. These rugged positioners provide a valve position proportional to a pneumatic input or a standard milli ampere dc input signal received from a control device.

- **Volume Booster**

The Volume Booster is a one-to-one signal to output relay that, when used with a positioner/actuator, is designed to increase the stroking speed of control valves. A large input signal change to the volume booster delivers high volume, fast action throttling control.

An integral bypass valve provides system stability while allowing normal positioner airflow and normal valve actuation with small input changes. If the volume booster is to be used for on/off control valves, the bypass valve can be closed to optimize stroking speed.