Final Control Element

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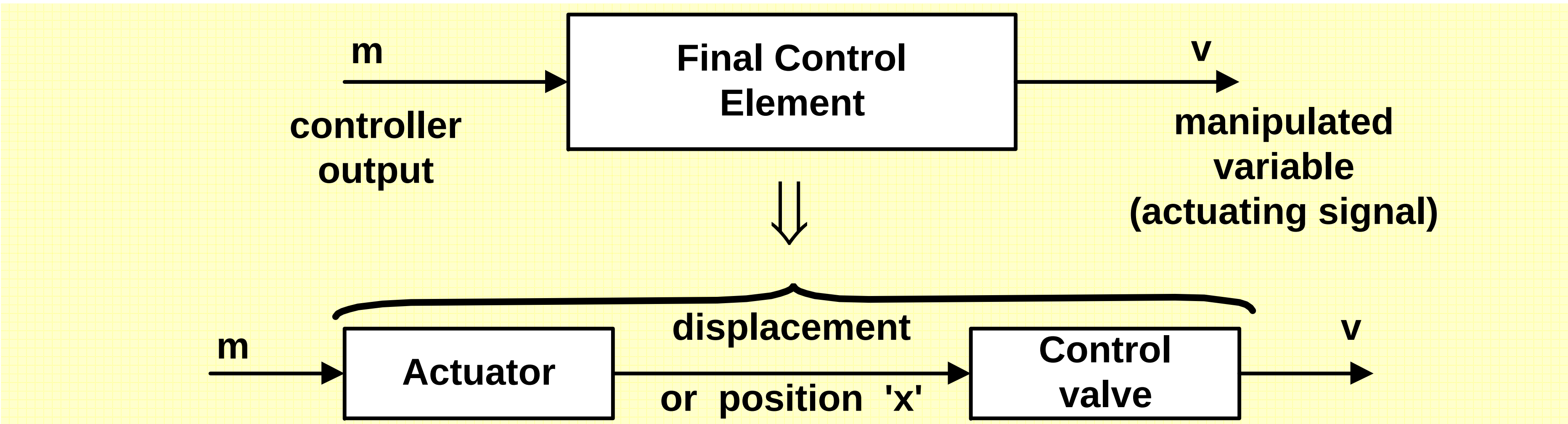
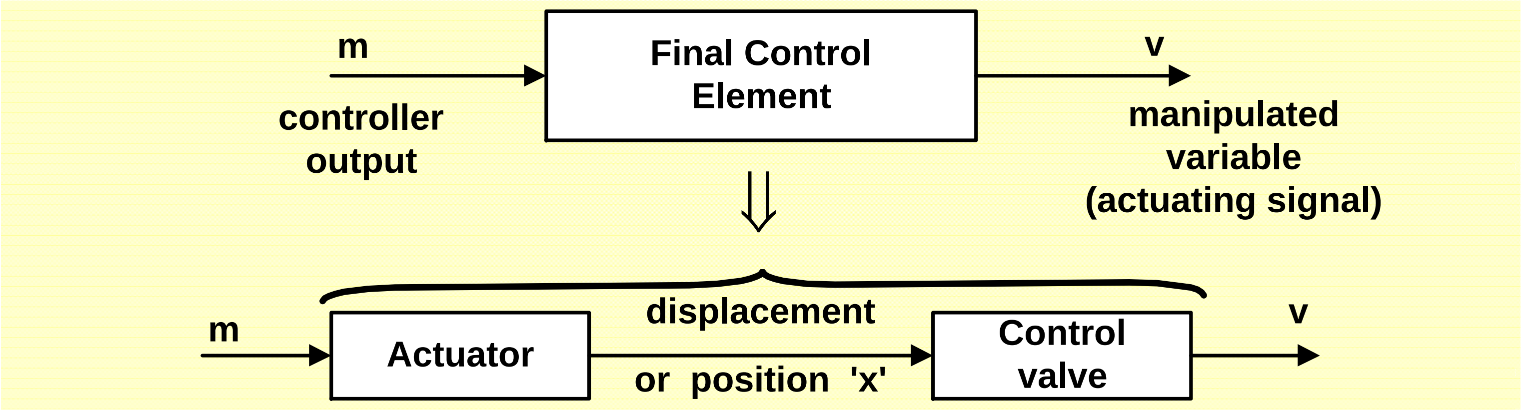
Final Control Element



- **Actuator** ➔ **provides an output position proportional to the input signal**
- **Control Valve** ➔ **adjusts the value of the manipulated variable**

Final Control Element



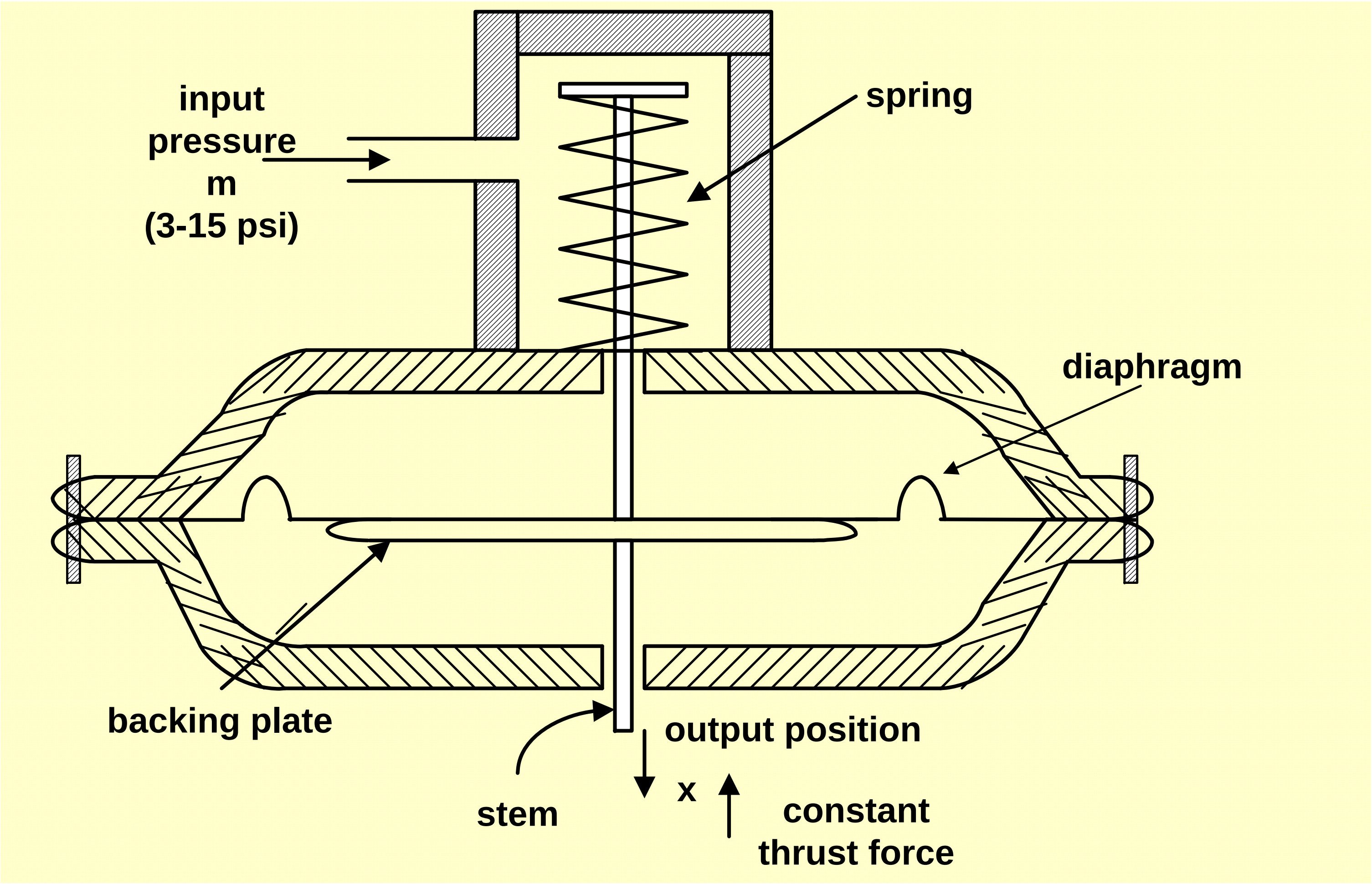
✓ The actuator accepts a signal from the control system and, in response, moves the valve to a fully-open or fully-closed position, or a more open or a more closed position (depending on whether 'on/off' or 'continuous' control action is used).

Actuators

- Actuators
  - Pneumatic actuators
    - spring – diaphragm
    - piston
    - motor
  - Electro-pneumatic actuators
  - Electric actuators
    - Motorized- rotary or linear
    - Solenoid operated
  - Hydraulic actuators

Pneumatic Actuators

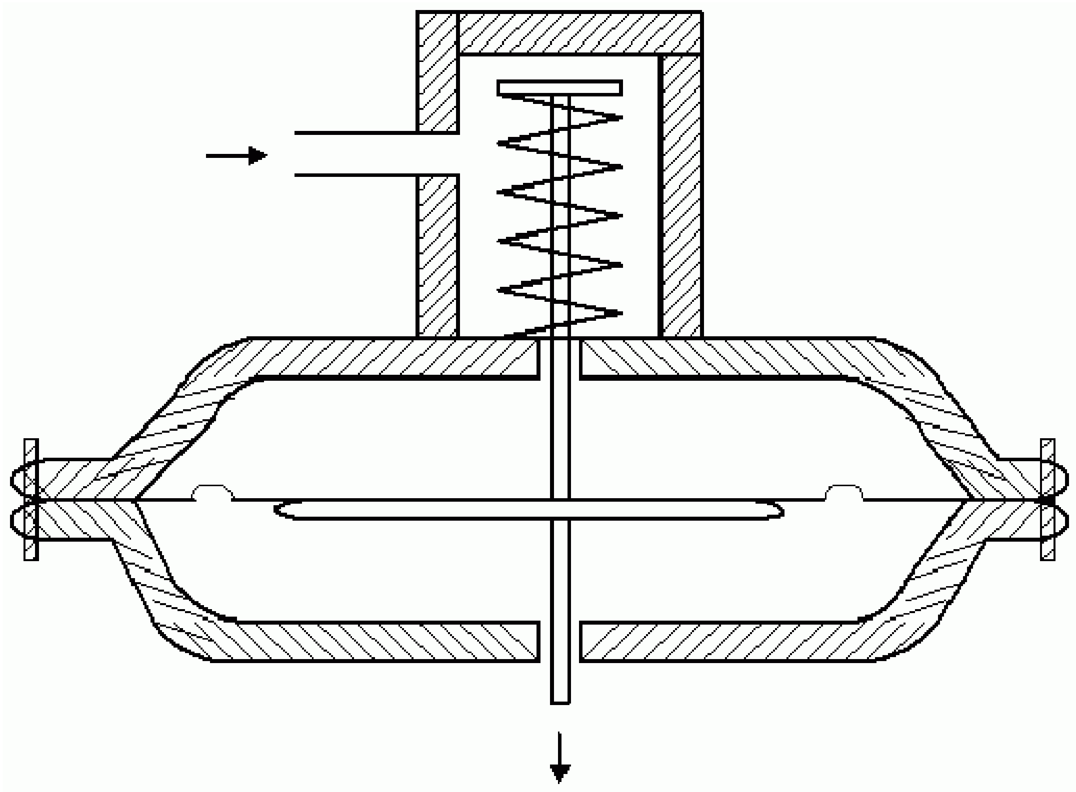
Spring - Diaphragm type Actuators



✓ Diaphragm actuators have compressed air applied to a flexible membrane called the diaphragm.

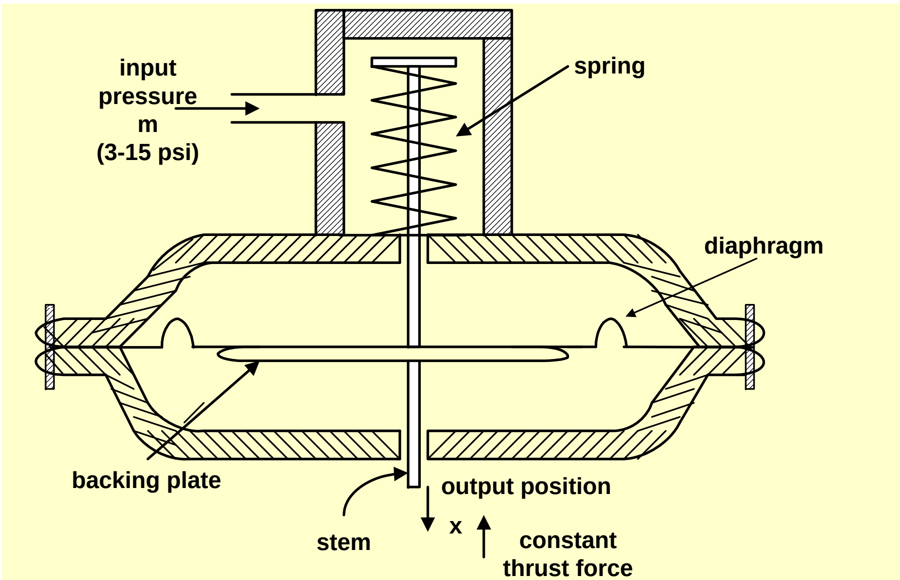
Pneumatic Actuators

Spring - Diaphragm type Actuators



Pneumatic Actuators

Spring - Diaphragm type Actuators



✓ **At equilibrium, (assuming no change in thrust force on the stem):** $mA = Kx$

m = the change in input pressure

A = the effective area of the diaphragm,

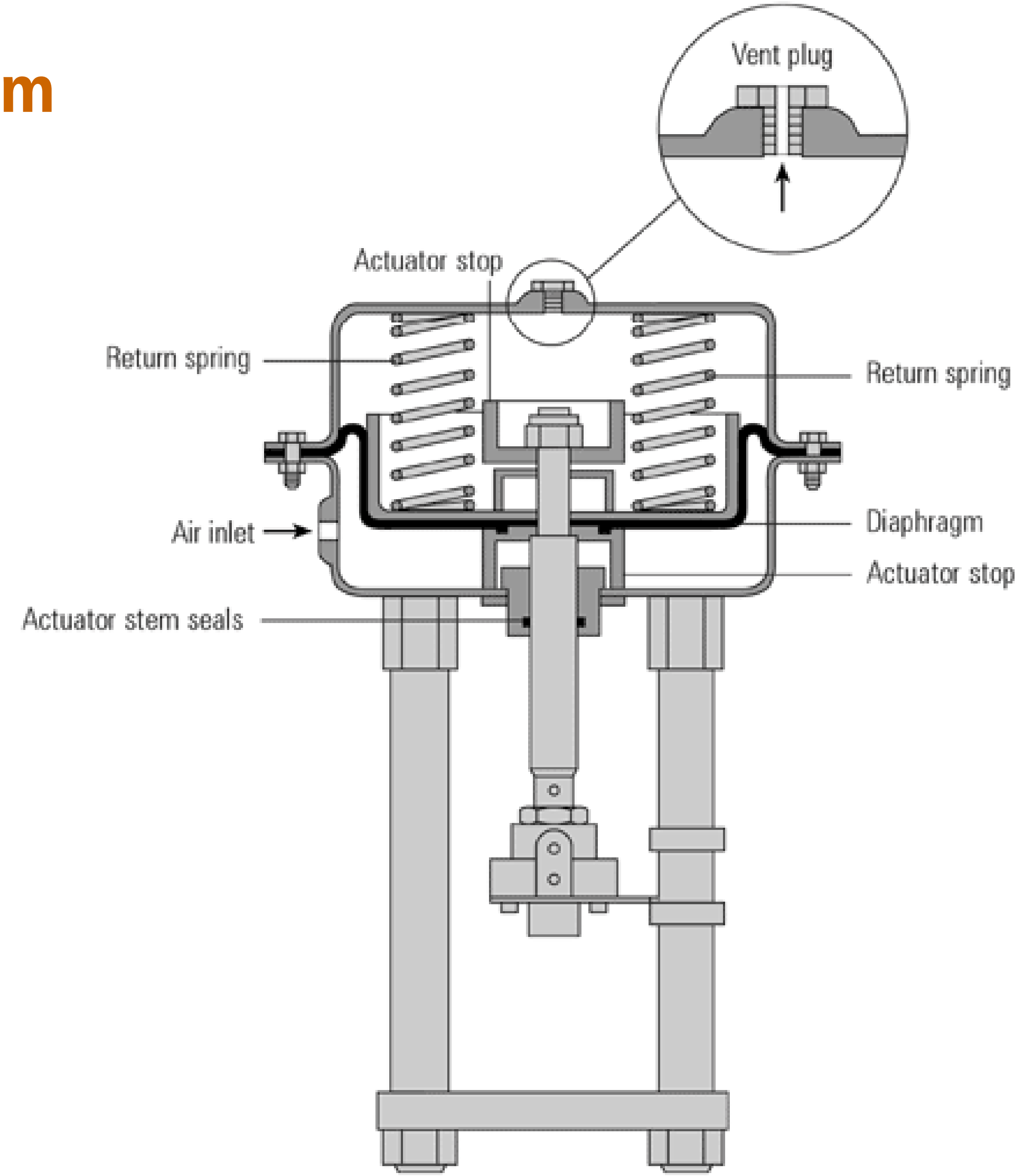
K = the spring constant (including diaphragm),

x = the change in output position (stem)

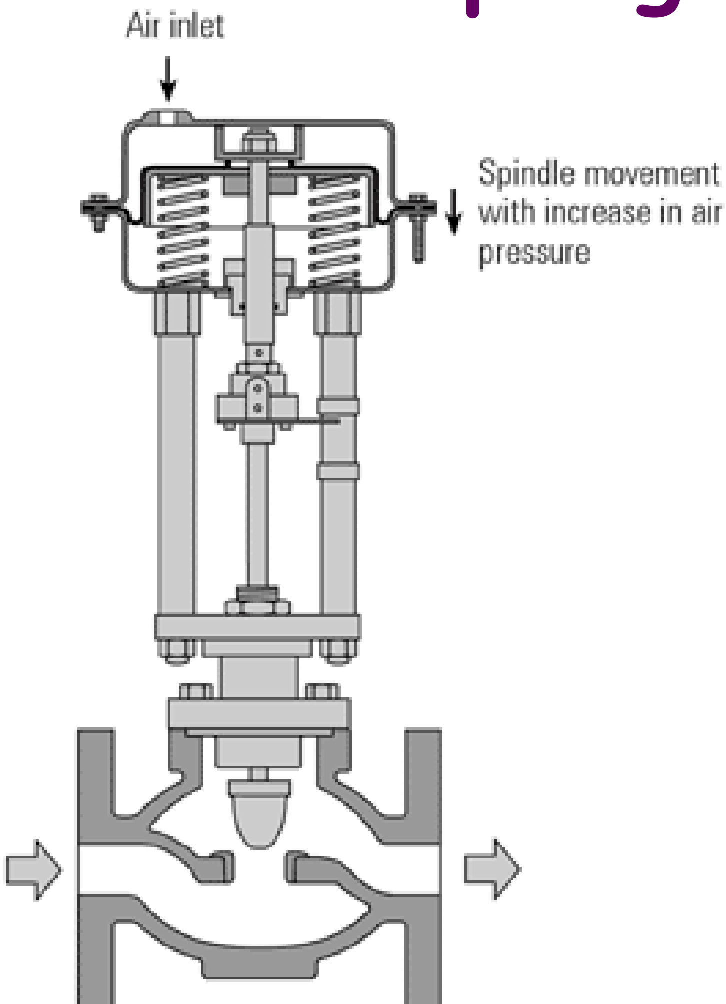
Note: The actual value of 'x' (stroke length) is limited within ¼″ and 3″ depending on the size of the actuator.

Spring – Diaphragm type Actuators

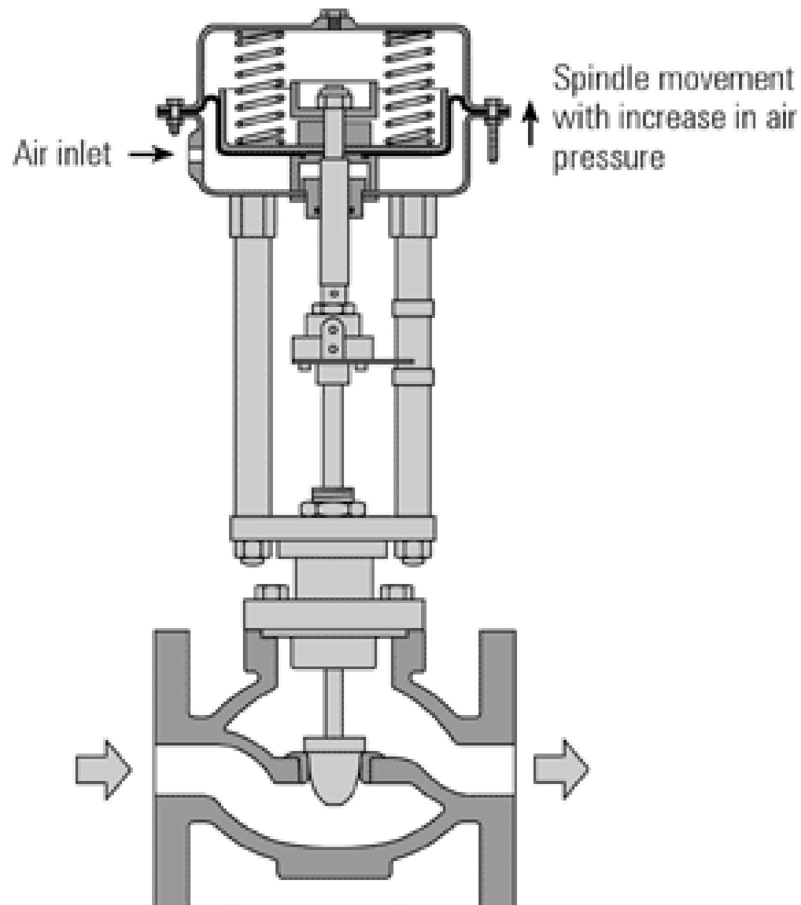
An Industrial Variation



Direct-Acting and Reverse-Acting Pneumatic Spring-Diaphragm Actuators



Direct acting
(spring retract)
air-to-close,
normally open



Reverse acting
(spring extend)
air-to-open,
normally closed

Direct-Acting and Reverse-Acting Pneumatic Spring-Diaphragm Actuators

Direct-acting Actuator:
(*spring-to-retract*)

This actuator is designed with the spring below the diaphragm, having air supplied to the space above the diaphragm. The result, with increasing air pressure, is spindle movement in the opposite direction to the reverse acting actuator.

Reverse-acting Actuator:
(*spring-to-extend*)

The diaphragm is pushed upwards, pulling the spindle up, and if the spindle is connected to a direct acting valve, the plug is opened. With a specific change of air pressure, the spindle will move sufficiently to move the valve through its complete stroke.

Pneumatic Actuators

Positioners

Why Positioners are provided with Actuators ?

- ✓ **To overcome high static friction forces in the actuators.**
- ✓ **To improve response time.**
- ✓ **To improve linearity and to reduce hysteresis.**
- ✓ **To reduce loading on controller output.**

In case of using actuators, we have non-linearities due to diaphragm area and the spring constant. So the change in position due to change in controller output is non-linear. With the use of positioners we can decrease the effect of non-linearity.

Pneumatic Actuators

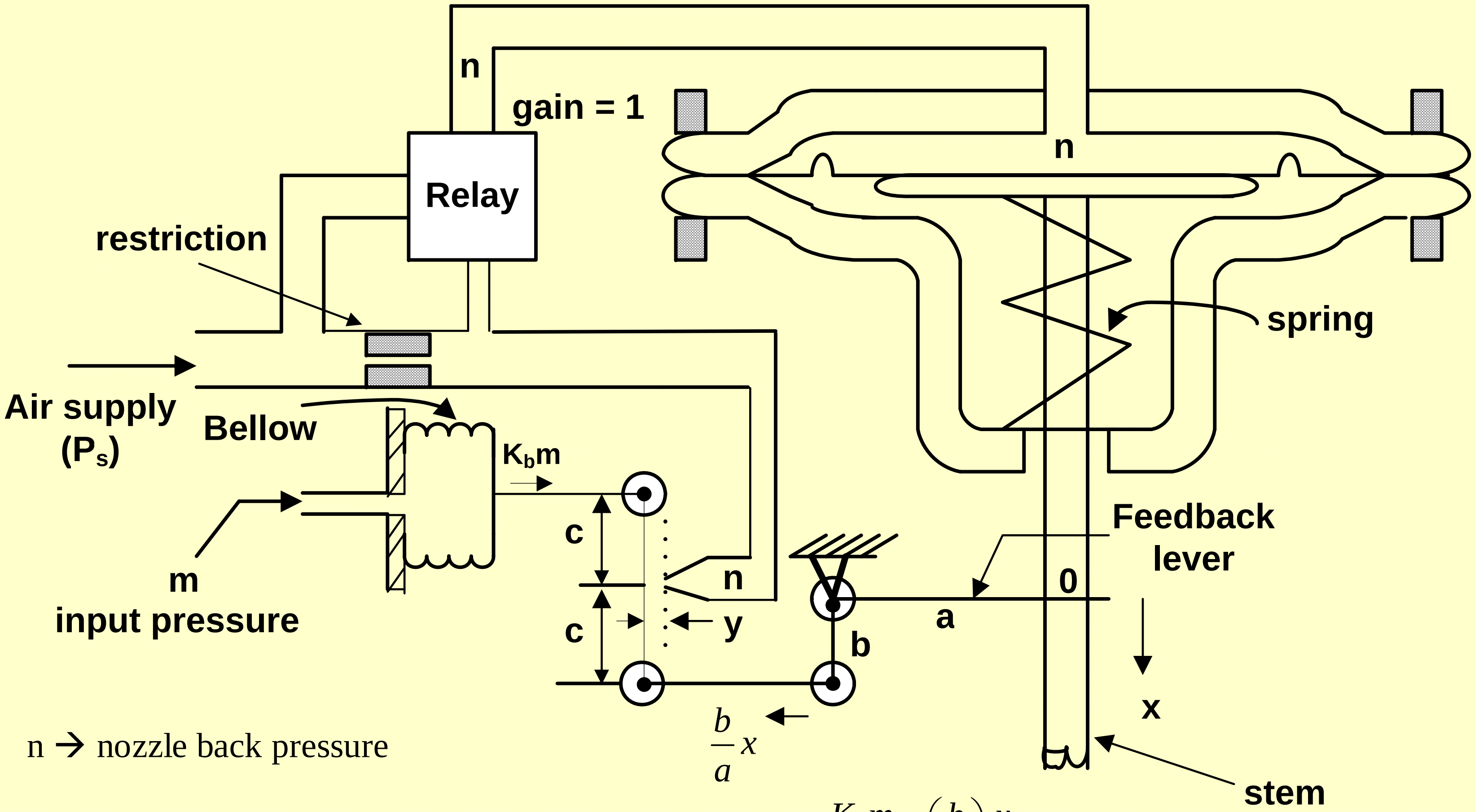
Positioners

Features

- ✓ A positioner ensures that there is a linear relationship between the signal input pressure from the control system and the position of the control valve.
- ✓ A positioner may be used as a signal amplifier or booster.
- ✓ Some positioners incorporate an electropneumatic converter so that an electrical input (typically 4 - 20 mA) can be used to control a pneumatic valve.
- ✓ Some positioners can also act as basic controllers, accepting input from sensors.

Pneumatic Actuators

Spring – Diaphragm Actuator with Positioner



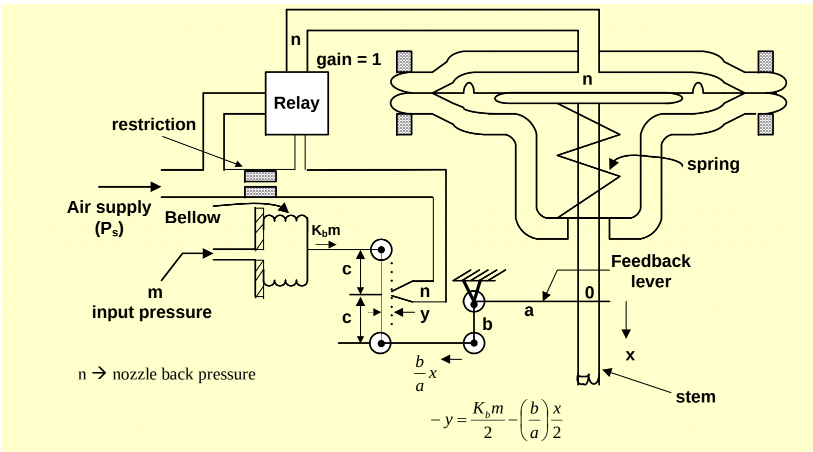
n → nozzle back pressure

$$\frac{b}{a}x$$

$$-y = \frac{K_b m}{2} - \left(\frac{b}{a}\right)\frac{x}{2}$$

Pneumatic Actuators

Spring - Diaphragm Actuator with Positioner



✓ At equilibrium, Baffle-Nozzle separation is:

$$y = +\left(\frac{b}{a}\right)\frac{x}{2} - \frac{K_b m}{2}$$

K_b is the bellows stiffness factor

Nozzle back pressure: $n = -K_n . y$

K_n is the nozzle gain

The change in output pressure is related to the back pressure as:

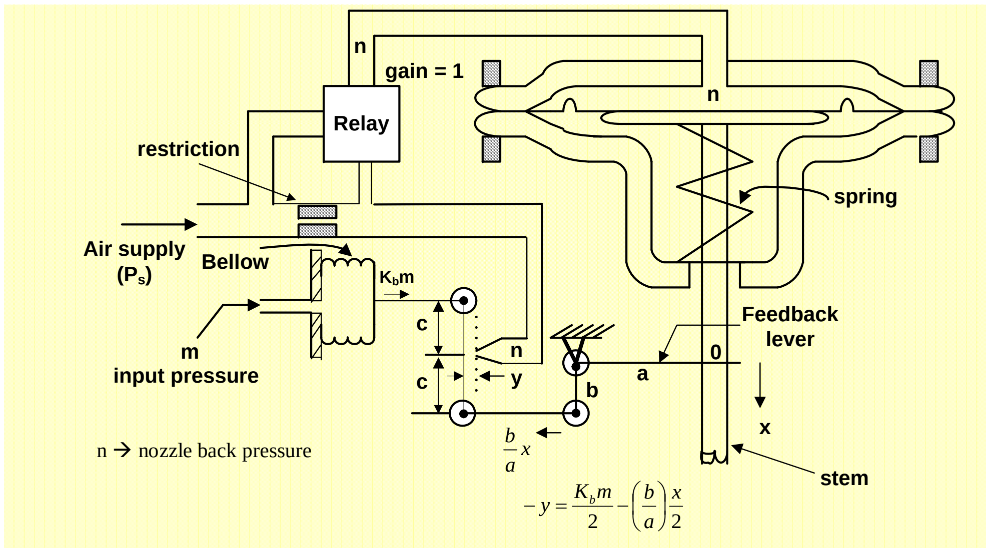
Kx = nA, K is the spring constant and A is the effective area of diaphragm.

$$n = \frac{Kx}{A} \Rightarrow y = -\frac{n}{K_n} = -\left(\frac{nA}{K_n A}\right) = -\frac{Kx}{K_n A} \Rightarrow \frac{K_b m}{2} = x\left[\left(\frac{b}{2a}\right) + \frac{K}{K_n A}\right]$$

Now, $K_n A >> K, \ \frac{K}{K_n A} \approx 0, \ \text{and} \ y \approx 0. \Rightarrow K_b m \approx x\left(\frac{b}{a}\right)$

Pneumatic Actuators

Spring – Diaphragm Actuator with Positioner



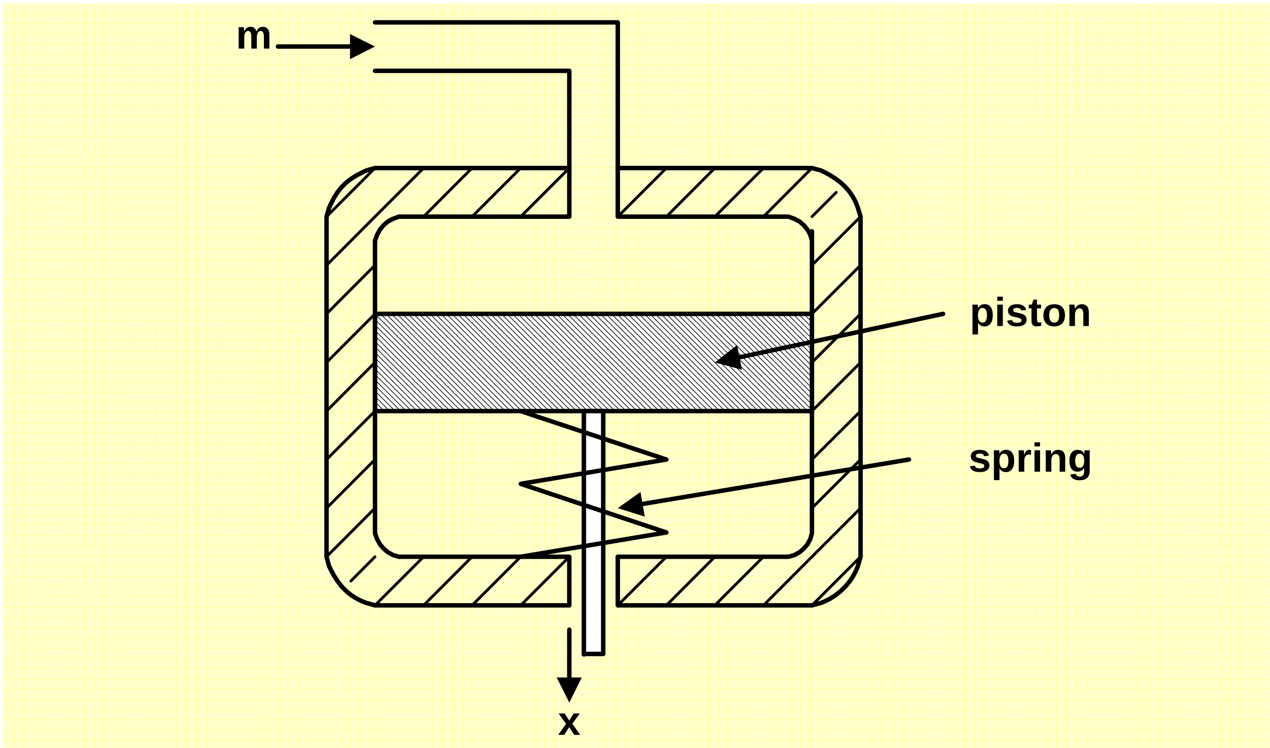
Conclusion:

✓ Thus, change in output position is related to change in input pressure with only feedback lever ratio and the bellows stiffness factor, and it is not dependent (if $K_n A >> K$) on the spring-diaphragm non-linearities.

✓ As a >> b, large position change is obtained with a small change in bellows position, thus ensuring linear characteristic of the bellows.

Pneumatic Actuators

Piston type Pneumatic Actuator

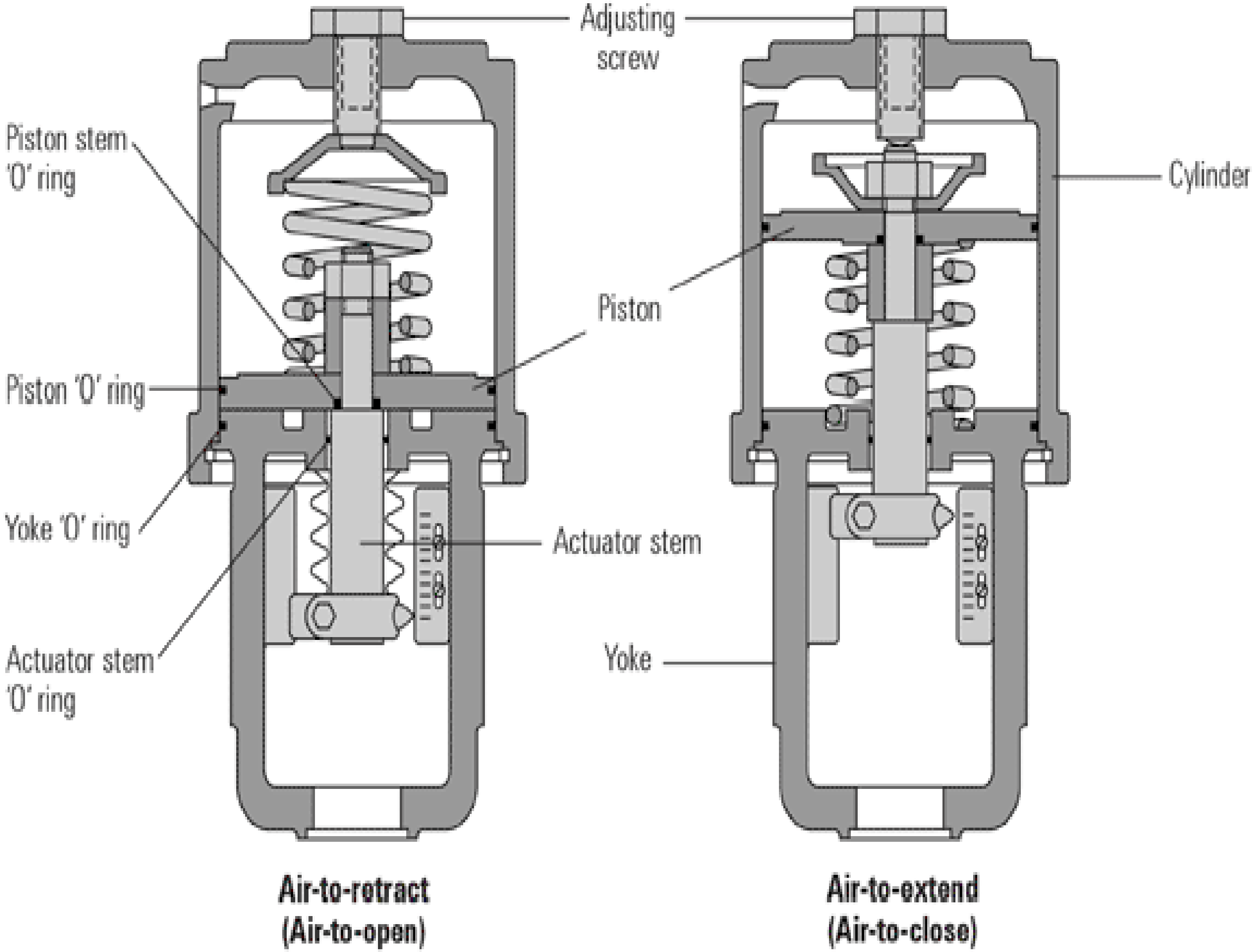


✓ They are generally used where the stroke of a diaphragm actuator would be too short or the thrust is too small.

✓ They are used for long strokes.

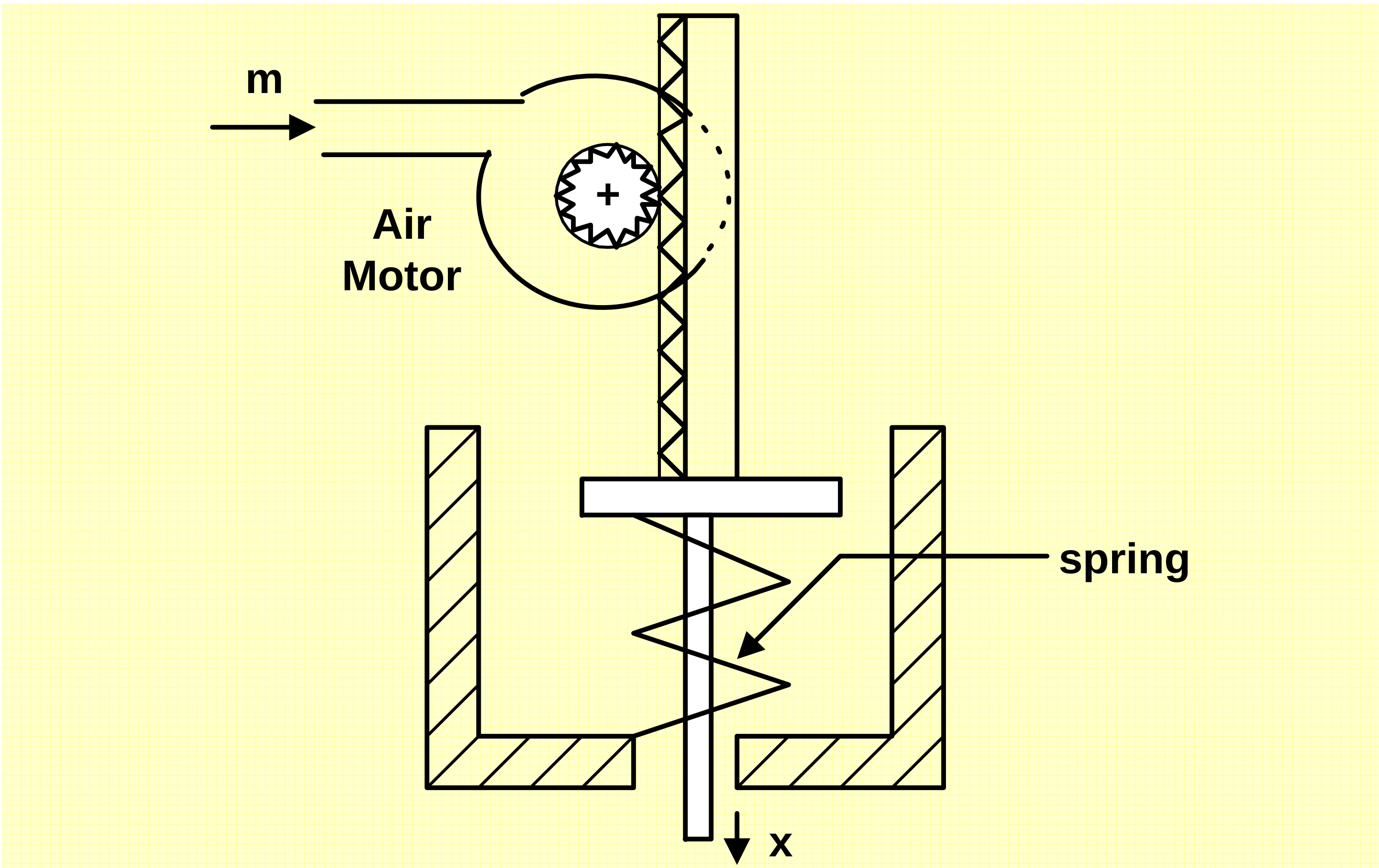
Piston type Pneumatic Actuator

An Industrial Variation



Pneumatic Actuators

Motor type Pneumatic Actuator



✓ They are used for large thrust forces. Large torques are generated from motor-gear arrangements to balance large thrusts.

Electro-pneumatic Actuators

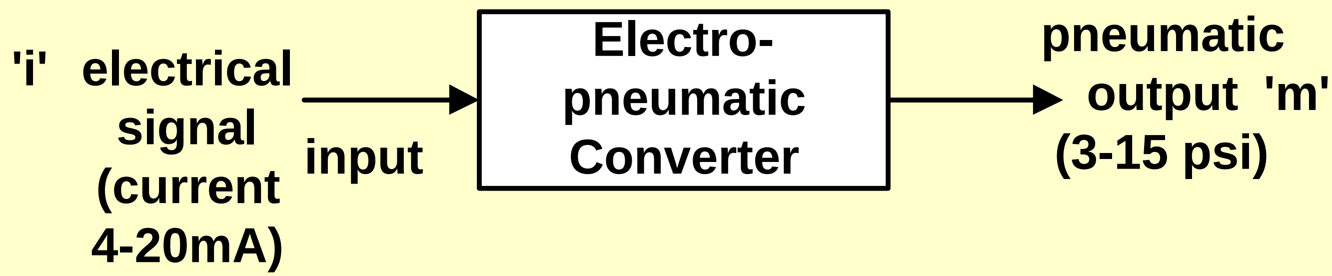
✓ When the controller output is electrical and a suitable air supply is available, using an electro-pneumatic actuator, a large output power may be obtained from a low power control signal.

Realization

- **cascading an electro-pneumatic converter and a pneumatic actuator**
- **an electro-pneumatic actuator**

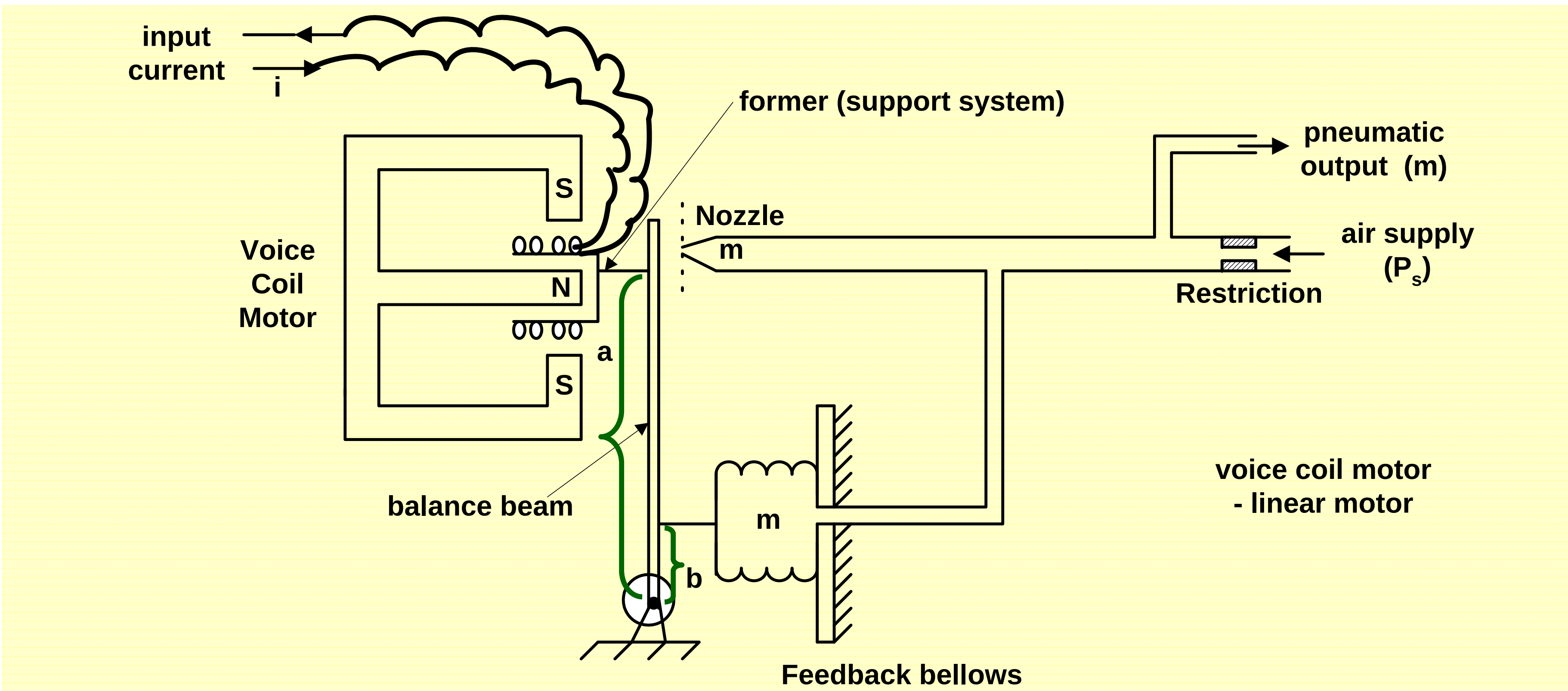
Electro-pneumatic Actuators

Electro-pneumatic Converter



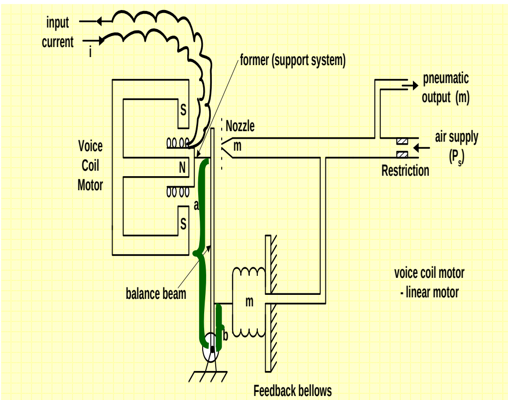
Electro-pneumatic Actuators

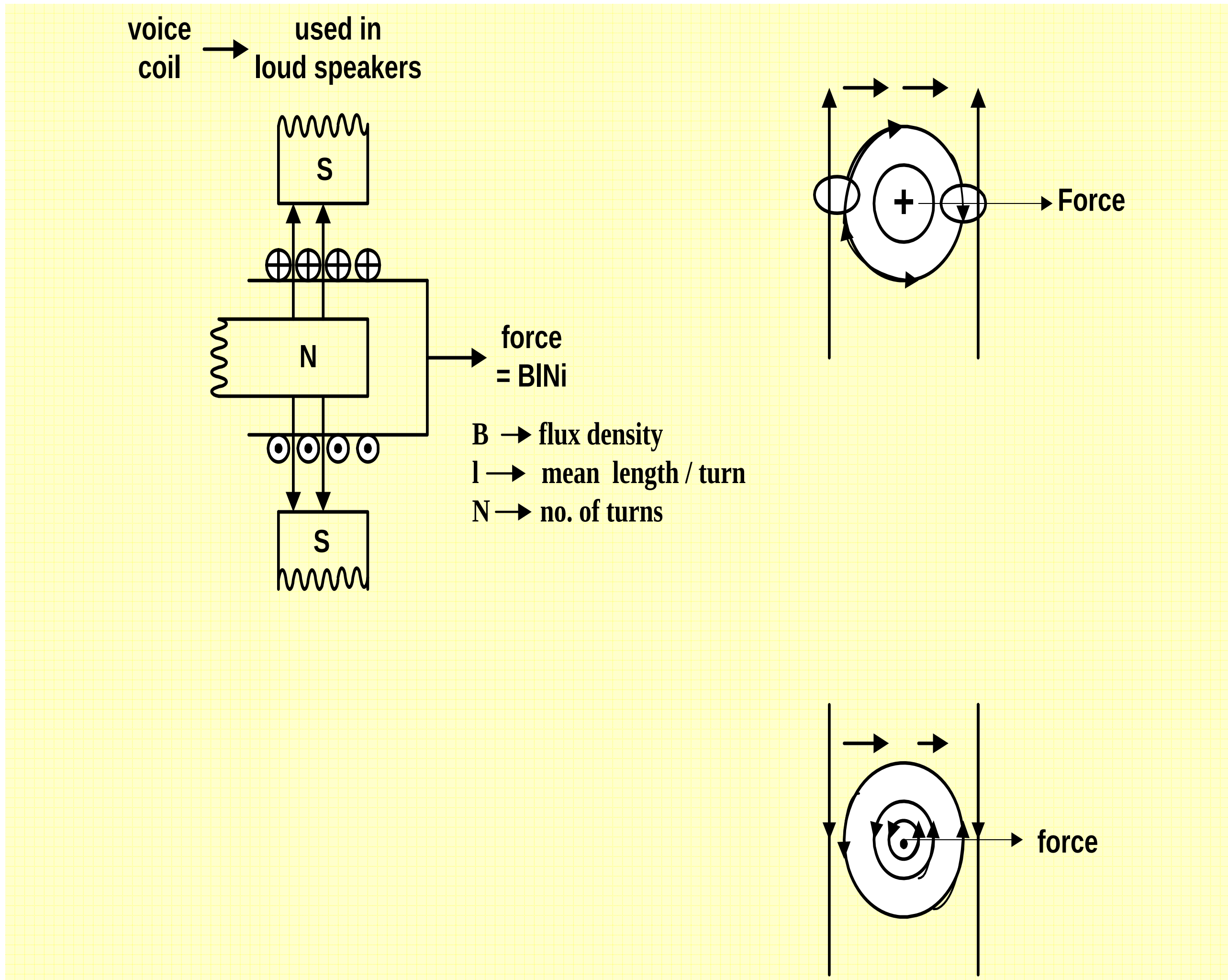
Electro-pneumatic Converter



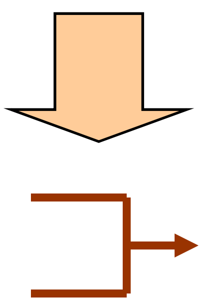
Electro-pneumatic Actuators

Electro-pneumatic Converter



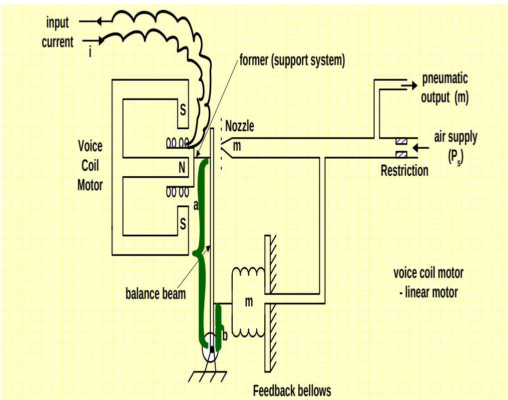


Effective force experienced by the former is a linear one.



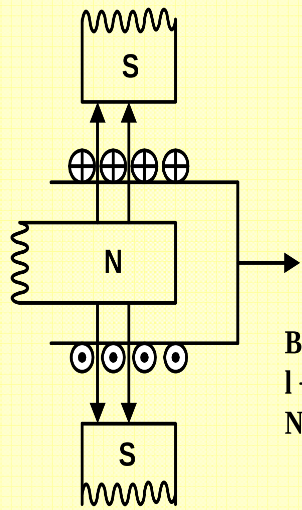
Electro-pneumatic Actuators

Electro-pneumatic Converter



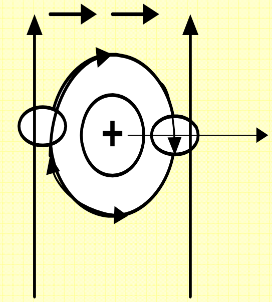
Magnet Coil

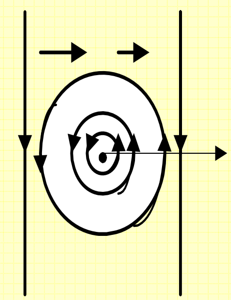
voice coil → used in loud speakers



force
= BlNi

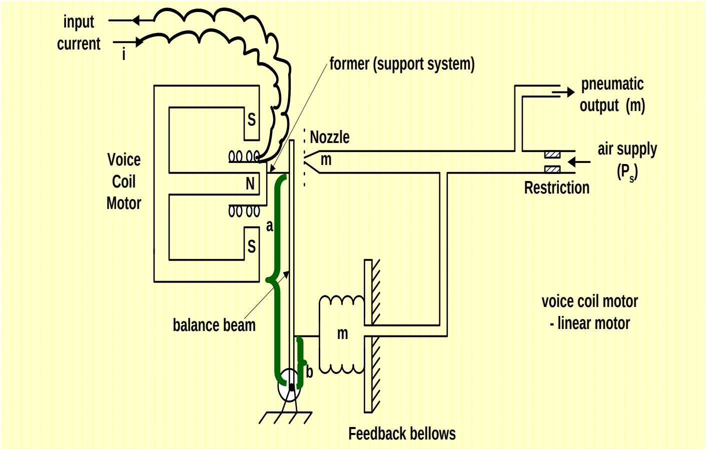
B → flux density
l → mean length / turn
N → no. of turns





Electro-pneumatic Actuators

Electro-pneumatic Converter



At equilibrium, for a change in input current 'i', the change in output pressure 'm' is:

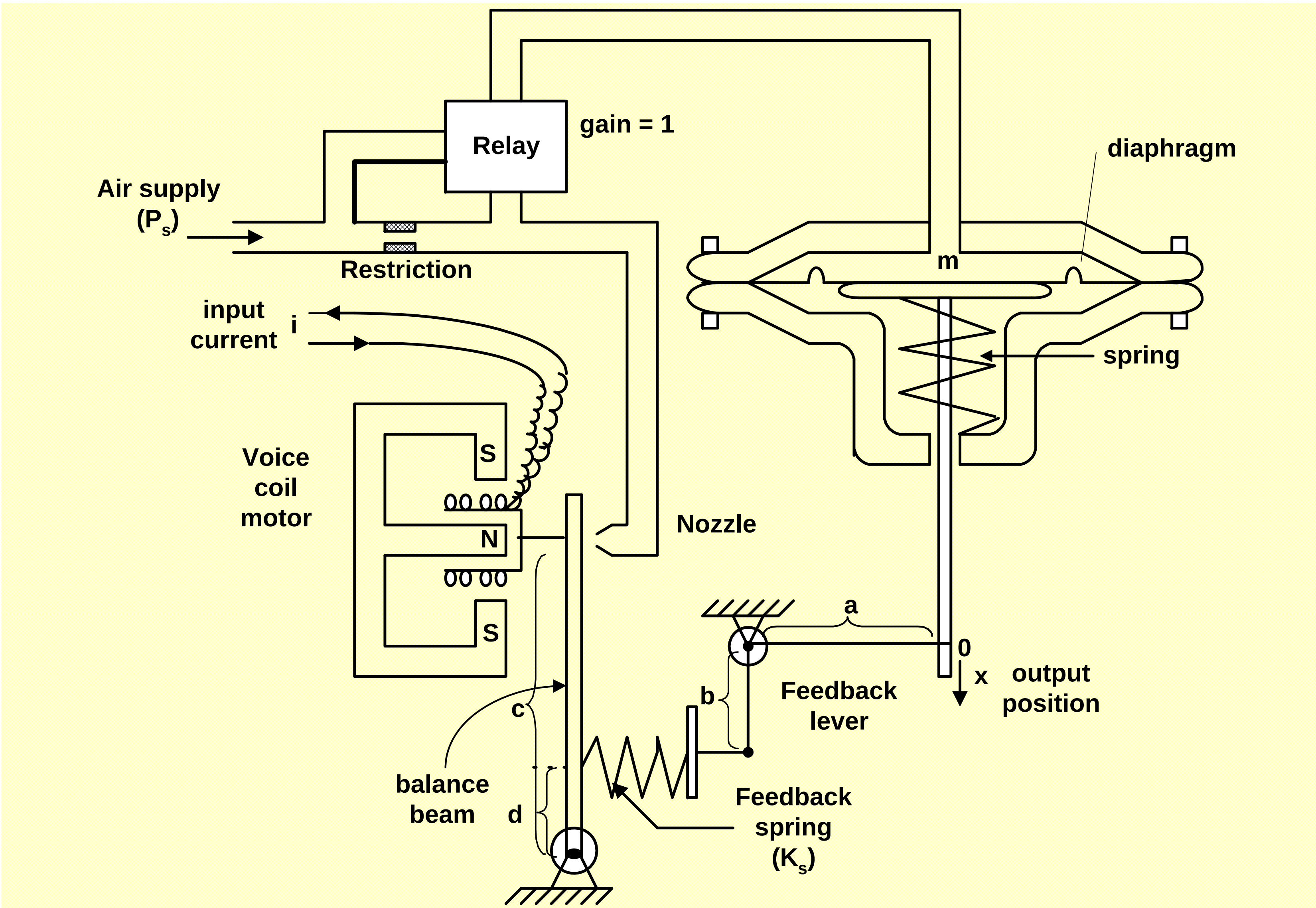
$$a.B\,l\,n\,i = b\left(mA_b\right)$$

A_b = the active area of the bellows assuming a small Baffle-Nozzle separation.

$$m = \left(\frac{aBlN}{bA_b}\right) i$$

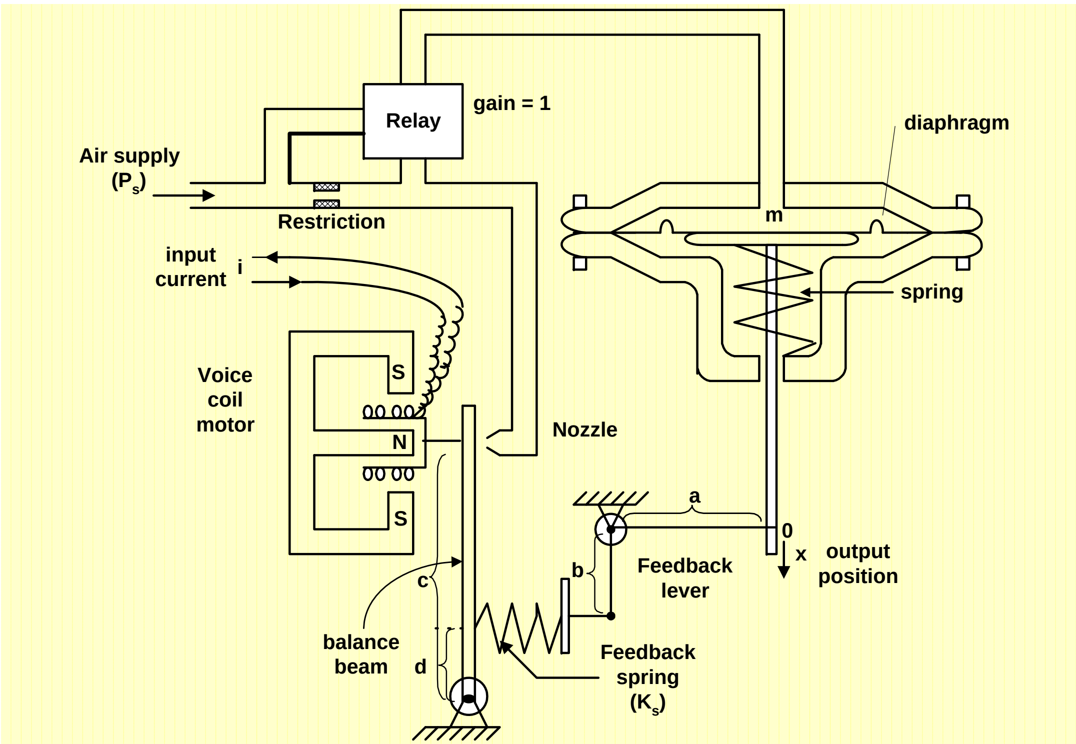
Electro-pneumatic Actuators

Electro-pneumatic Actuator



Electro-pneumatic Actuators

Electro-pneumatic Actuator



At equilibrium,

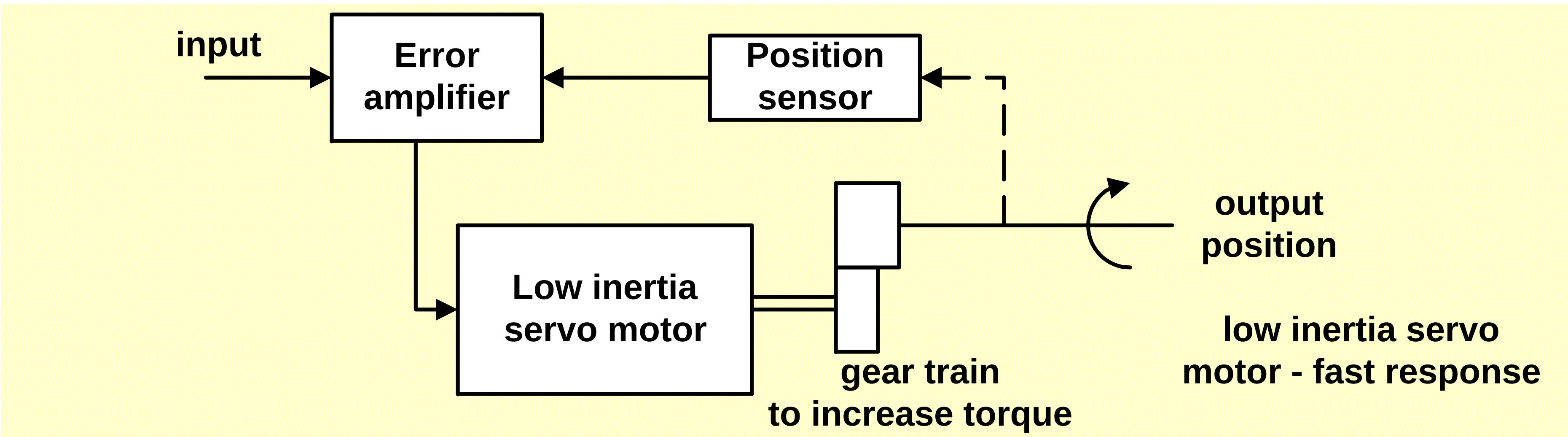
$$c(B\,l\,n\,i) = d.\left[\left(\frac{b}{a}\right)x.K_s\right]$$

K_s = spring constant of the feedback spring (for a small Baffle-Nozzle separation)

Conclusion: **output 'x' is independent of the characteristics of diaphragm and spring.**

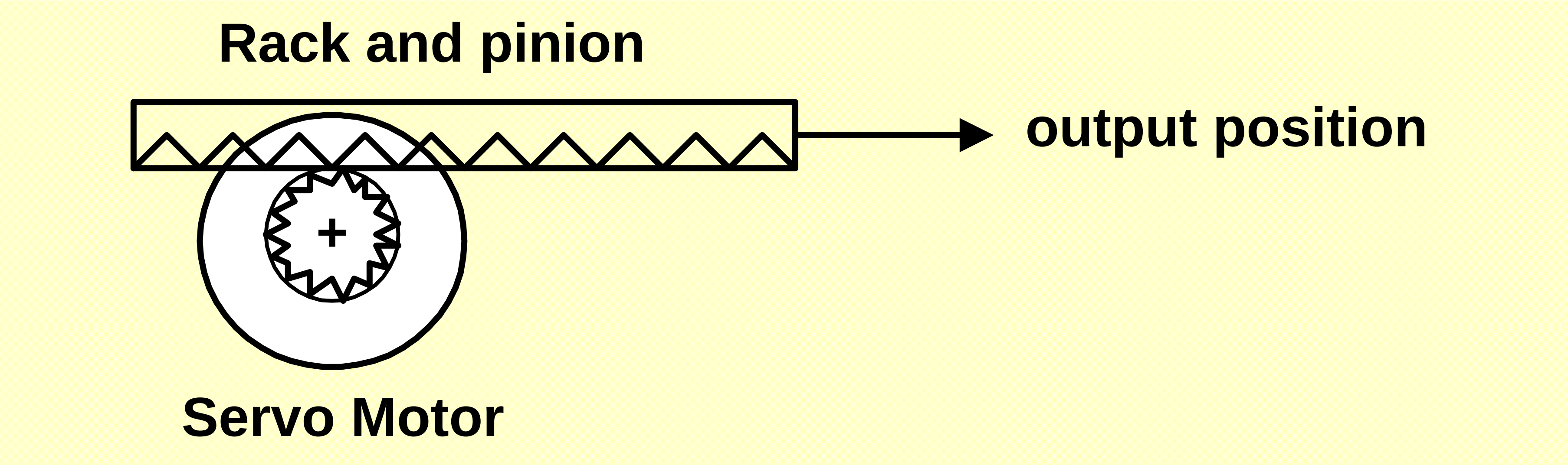
Electric Actuators

Motorized Rotary Actuator



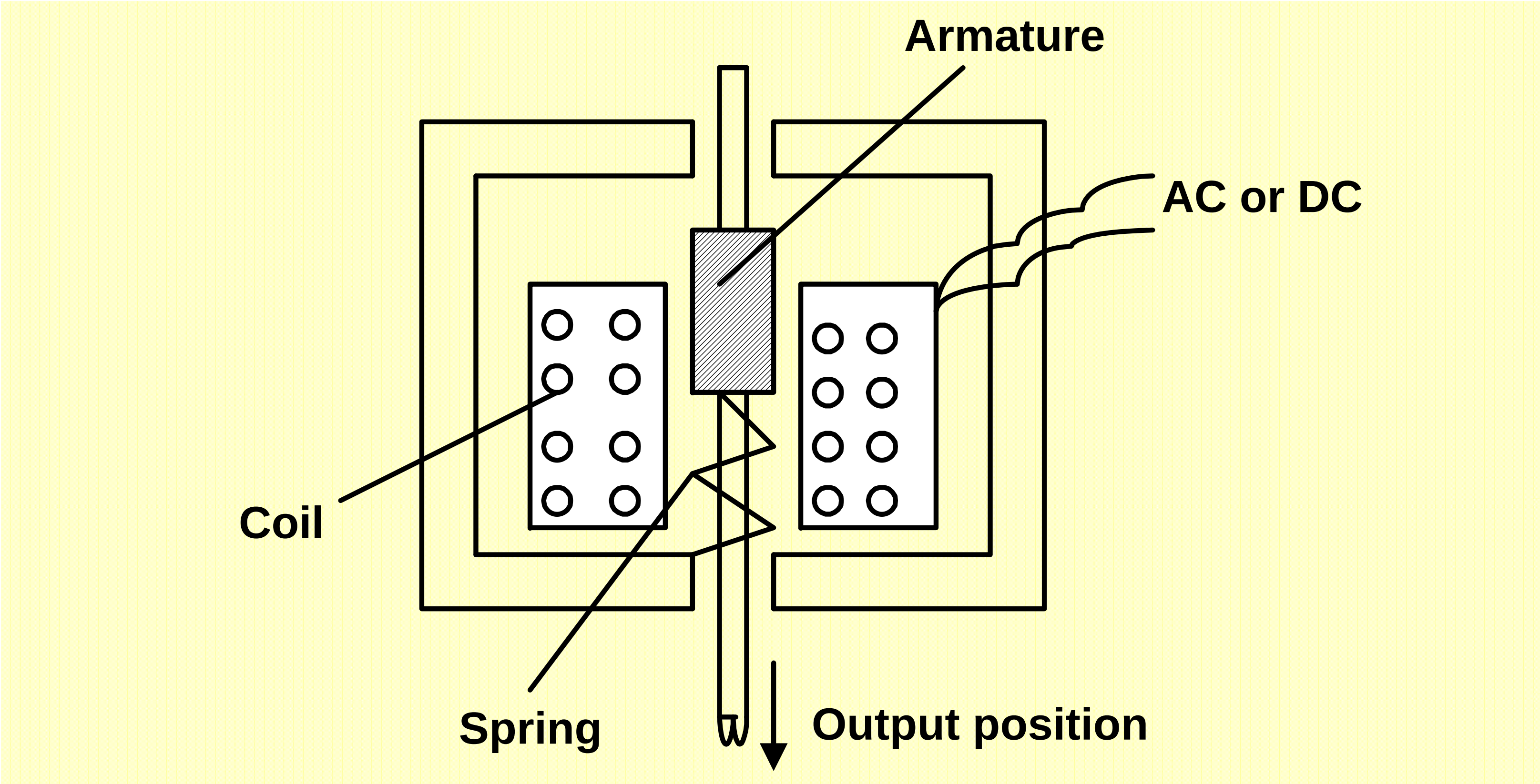
Electric Actuators

Motorized Linear Actuator



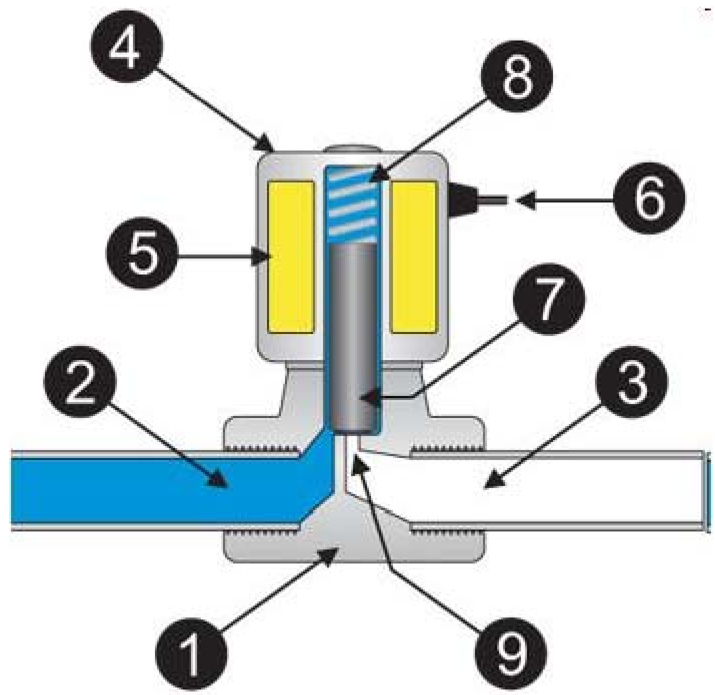
Electric Actuators

Solenoid Actuator (for On/Off Operation)



✓ A spring return type electric solenoid is used to actuate an iron cored armature.

✓ A shading band type armature is used with AC supply to create unidirectional pull.

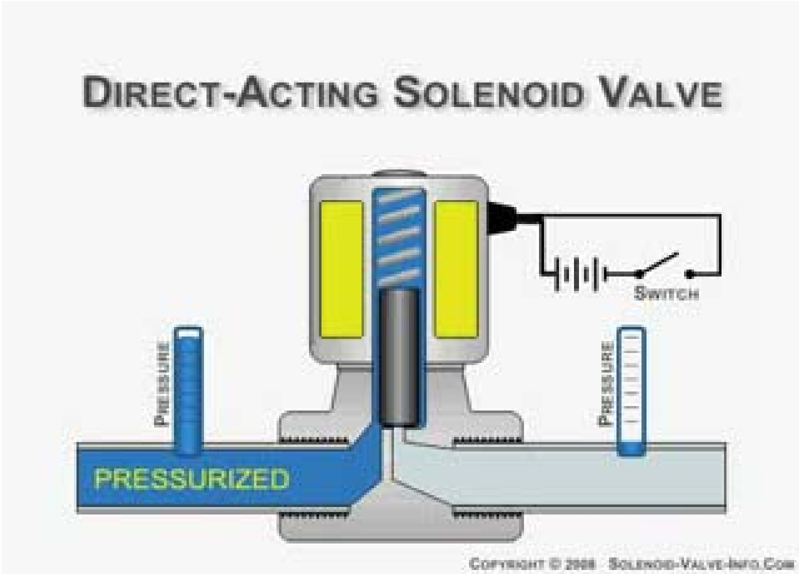


1. Valve Body 2. Inlet Port 3. Outlet Port

4. Coil / Solenoid 5. Coil Windings 6. Lead Wires

7. Plunger 8. Spring 9. Orifice

Direct-acting solenoid valve

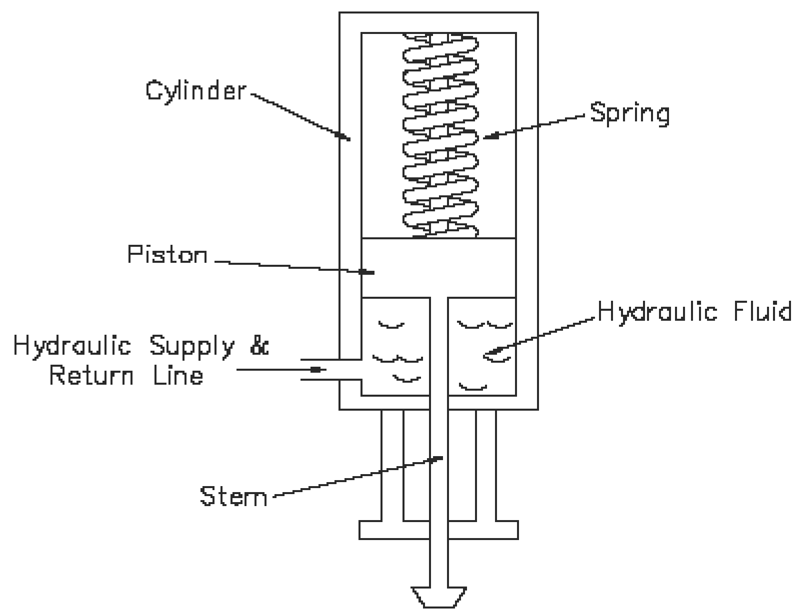


Direct-acting solenoid valve in action

Hydraulic Actuators

- ✓ **They use incompressible fluid (oil). These are used for high power and high speed applications.**

Hydraulic Actuator Construction



Hydraulic Actuator

Control Valves

- ✓ A control valve in a pipeline acts as a variable restriction. An actuator controls the 'lift' of a control valve to alter restriction.

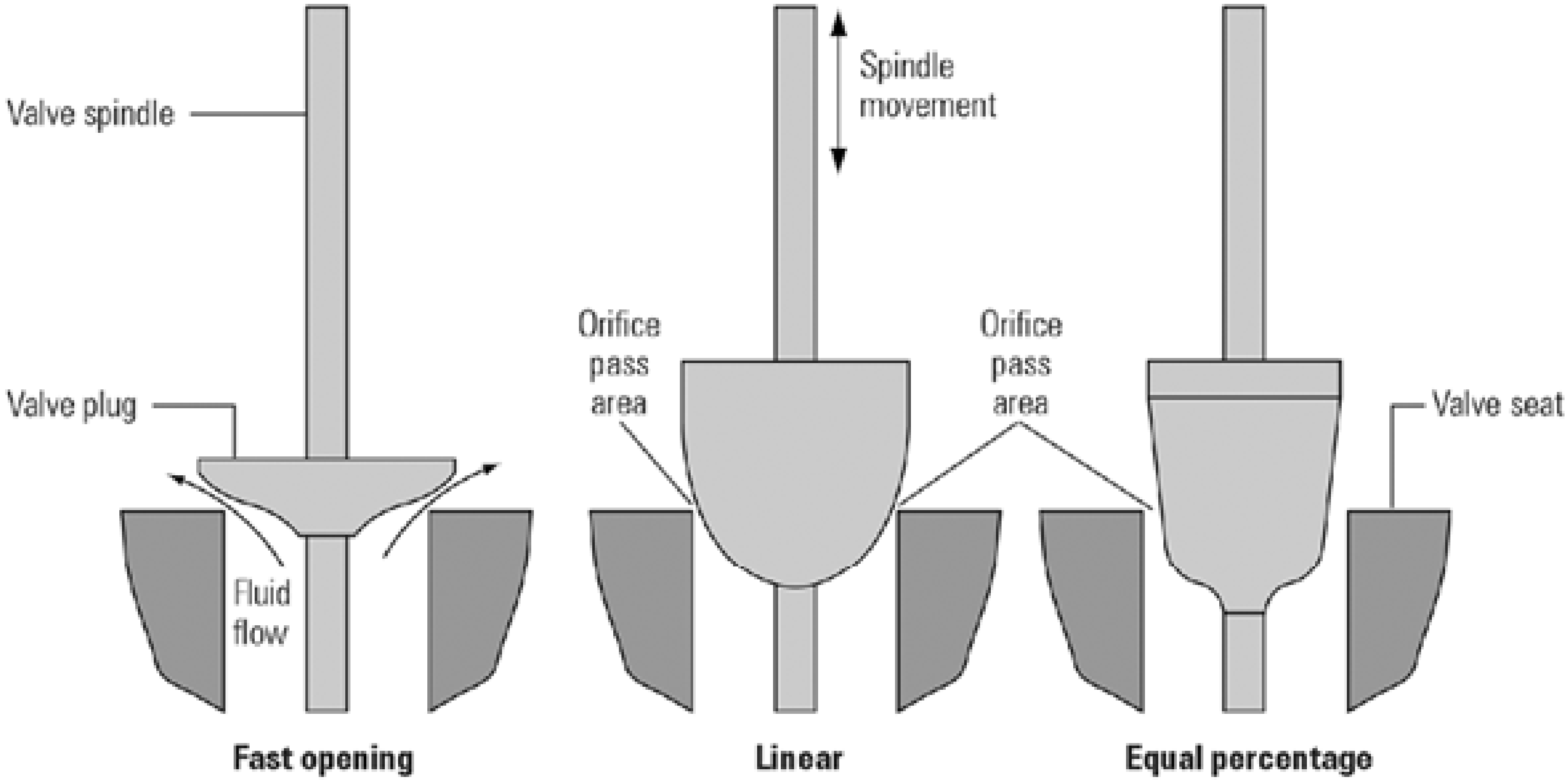
- ✓ All control valves have an inherent flow characteristic that defines the relationship between valve opening and flowrate under constant pressure conditions.

- ✓ The three main types of control valves available are:

    - quick/fast opening
    - linear
    - equal percentage

Control Valves

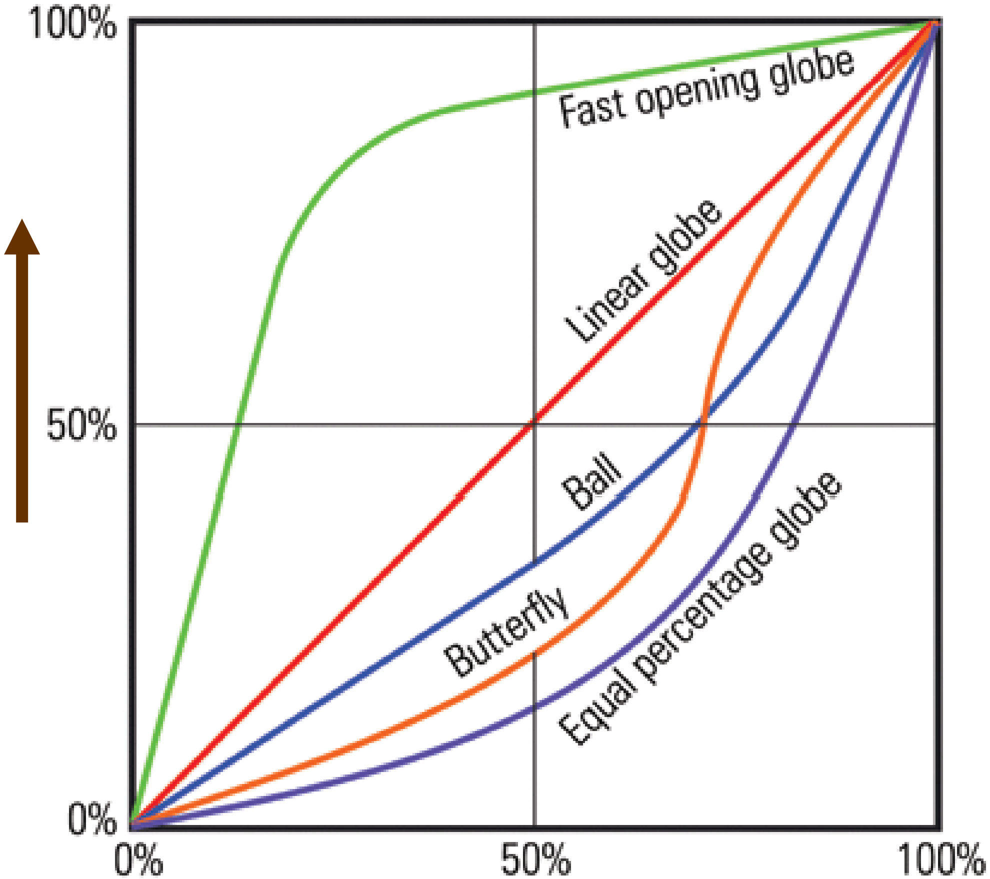
✓ The physical shape of the plug and seat arrangement, sometimes referred to as the **valve 'trim'**, causes the difference in valve opening between these valves.



Typical trim shapes for spindle operated globe valves

Flow-Lift Characteristic of Control Valves

$$\% \text{ flow} \left(= \frac{v}{v_{max}} \times 100 \right)$$



$$\% \text{ lift} \left(= \frac{x}{x_{max}} \times 100 \right)$$

From laws of fluid dynamics,

$v = K\sqrt{h}\ x$

K → overall coefficient

h → difference in head across valve

Flow-Lift Characteristic of Control Valves

Quick/Fast Opening Control Valve

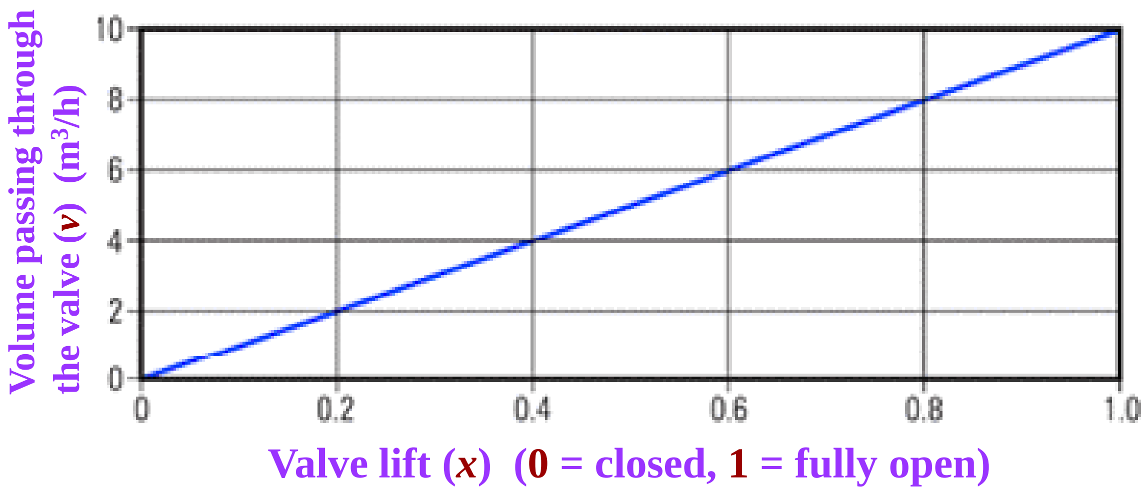
✓ **Here, the valve sensitivity** $\left({dv}/{dx} \right)$ **at any flow decreases with increasing flow. The fast opening characteristic valve plug will give a large change in flow rate for a small valve lift from the closed position.**

✓ **Fast opening valves tend to be electrically or pneumatically actuated and used for 'on / off' control.**

Flow-Lift Characteristic of Control Valves

Linear Control Valve

✓ **The linear characteristic valve plug is shaped so that the flow rate is directly proportional to the valve lift, at a constant differential pressure. Here the valve sensitivity is (approximately) constant.**



Flow-lift characteristic for a linear valve

Flow-Lift Characteristic of Control Valves

Equal Percentage Valve

✓ **These valves have a valve plug shaped so that each increment in valve lift increases the flow rate by a certain percentage of the previous flow. The relationship between valve lift and orifice size (and therefore flow rate) is not linear but logarithmic.**

$$v = \frac{e^z}{R} v_{\max}$$

v = volumetric flow through the valve at lift x,

$z = (\ln R)x$,

R = valve rangeability,

x = valve lift (0 = closed, 1 = fully open),

$v_{\max}$ = maximum volumetric flow through the valve.

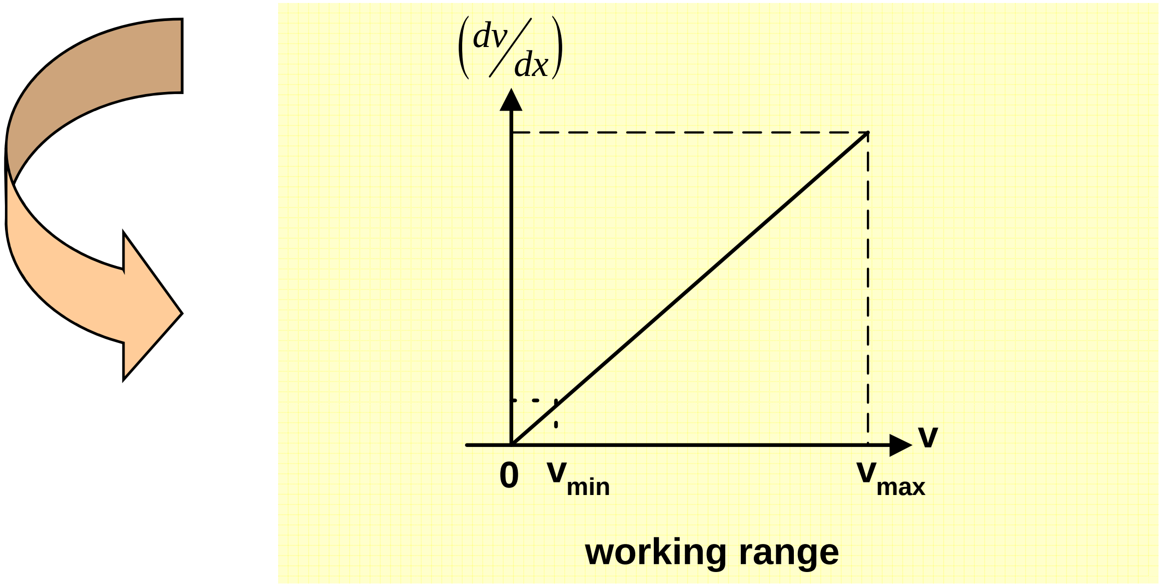
Flow-Lift Characteristic of Control Valves

Equal Percentage Valve

✓ For these valves, sensitivity increases with flow. As the valve sensitivity at any given flow rate is a constant percentage of the given flow rate, the term equal percentage is used.

Valve sensitivity, $\dfrac{dv}{dx} = Kv$ **where K is a constant. Or,** $\dfrac{\frac{dv}{dx}}{v} = K$

i.e. sensitivity expressed as percentage of flow (= 100K %) is constant.



Flow-Lift Characteristic of Control Valves

Rangeability of a Control Valve

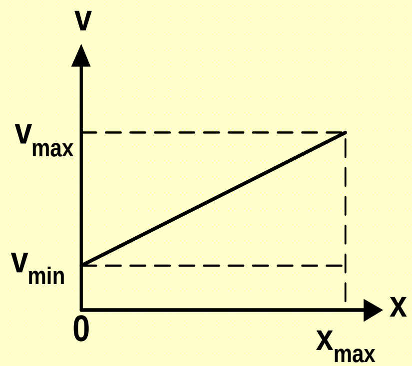
$$R = \frac{\text{maximum controllable flow } (v_{max})}{\text{minimum controllable flow } (v_{min})}$$

✓ **The minimum controllable flow of a control valve depends on its construction. The range of R is usually between 20 and 50 under constant pressure drop across the valve (equal to constant head). It is typically 50 for a globe type control valve.**

Flow-Lift Characteristic of Control Valves

Relation between % flow, % lift and rangeability under constant pressure drop (or head) across the valve

Linear Valve



$$v = v_{min} + x\left(\frac{v_{max} - v_{min}}{x_{max}}\right)$$

$$\frac{v}{v_{max}} = \frac{v_{min}}{v_{max}} + \left(\frac{v_{max} - v_{min}}{v_{max}}\right)\frac{x}{x_{max}}$$

$$\frac{v}{v_{max}} = \frac{1}{R} + \left(1 - \frac{1}{R}\right)\frac{x}{x_{max}} = \frac{1}{R}\left[1 + (R-1)\frac{x}{x_{max}}\right]$$

$$\frac{v}{v_{max}} = \frac{1}{R}\left[1 + (R-1)\frac{x}{x_{max}}\right]$$

$$\frac{dv}{dx} = \left(\frac{R-1}{R}\right)\frac{v_{max}}{x_{max}}$$

Valve Sensitivity constant

Flow-Lift Characteristic of Control Valves

Relation between % flow, % lift and rangeability under constant pressure drop (or head) across the valve

Equal Percentage Valve

$$\frac{v}{v_{max}} = R^{\left[\frac{x}{x_{max}} - 1\right]}$$

Differentiating,

$$\left(\frac{1}{v_{max}}\right)\left(\frac{dv}{dx}\right) = R^{\left[\frac{x}{x_{max}} - 1\right]}.\ln R.\frac{1}{x_{max}}$$

$$= \frac{v}{v_{max}}.\ln R.\frac{1}{x_{max}}$$

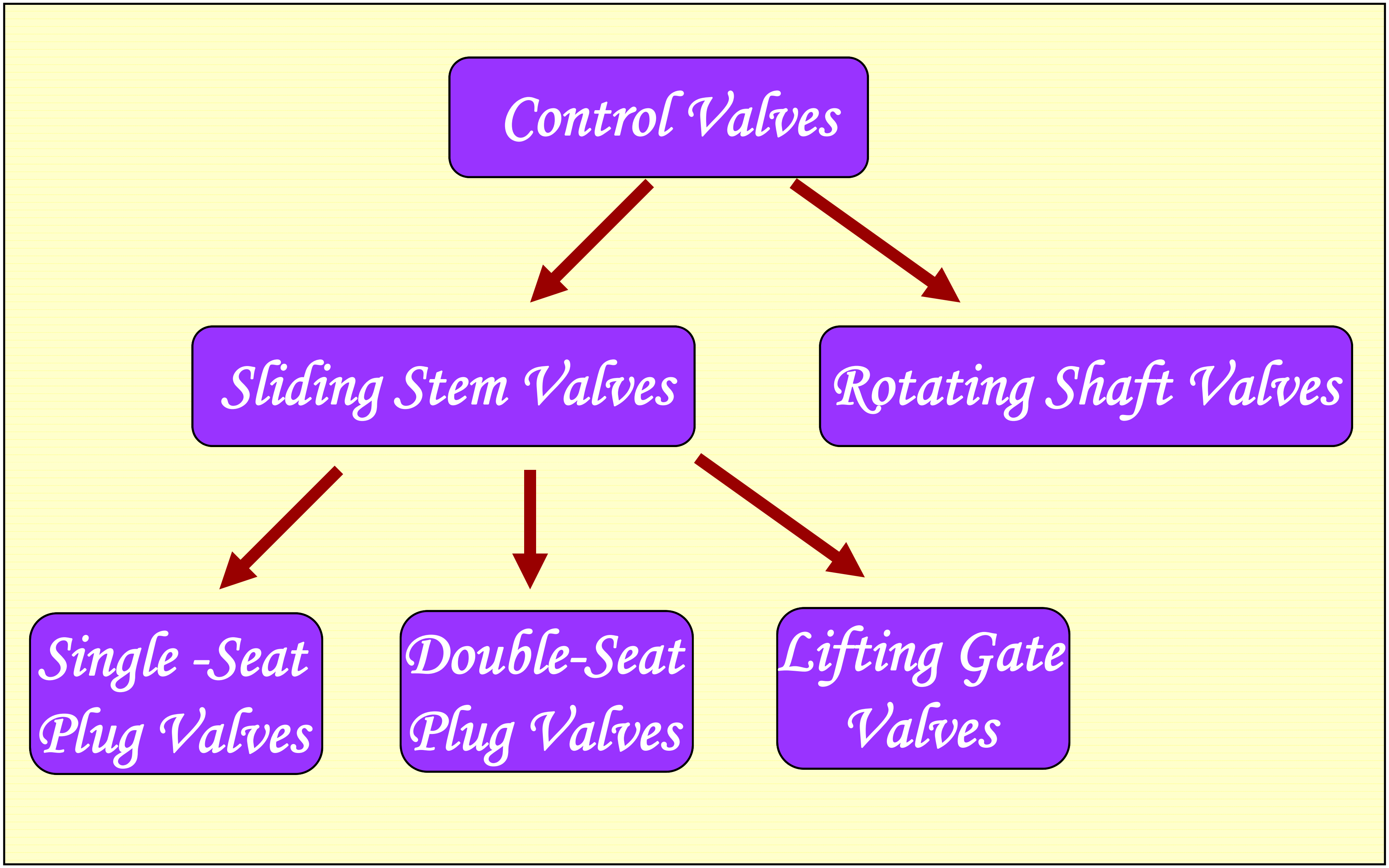
$$\frac{dv}{dx} = \left[\frac{\ln R}{x_{max}}\right] v,$$

Valve Sensitivity is proportional to 'v'

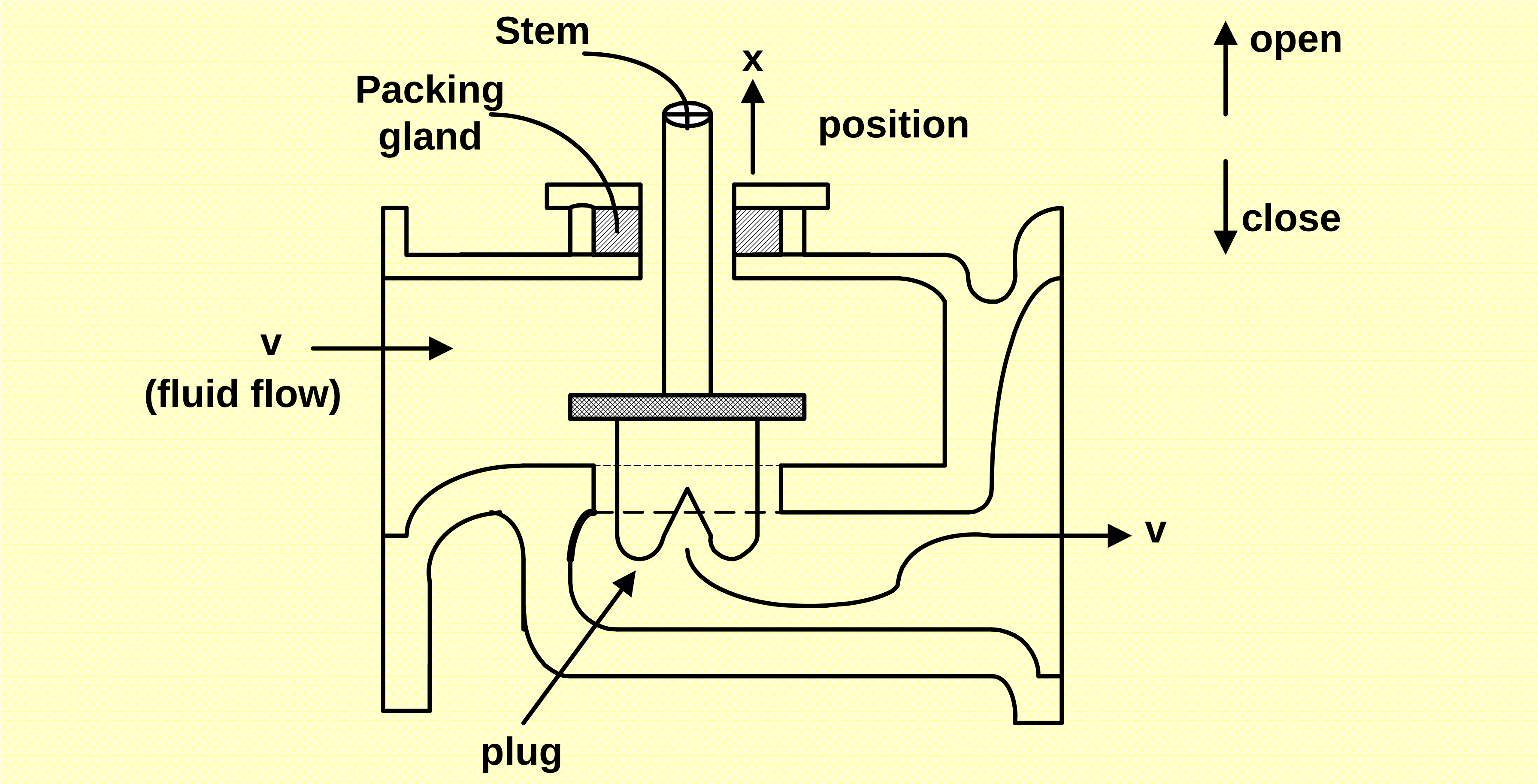
$$\frac{\frac{dv}{dx}}{v} = \left[\frac{\ln R}{x_{max}}\right],$$

Equal Percentage characteristic

Classification of Control Valves

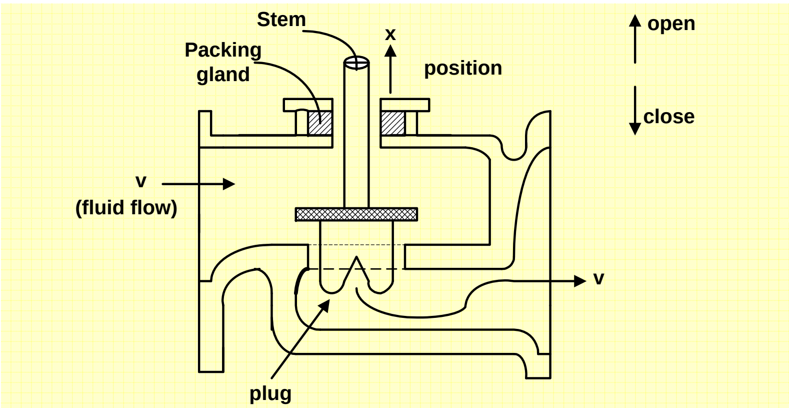


Single-seat Sliding-stem Control Valves

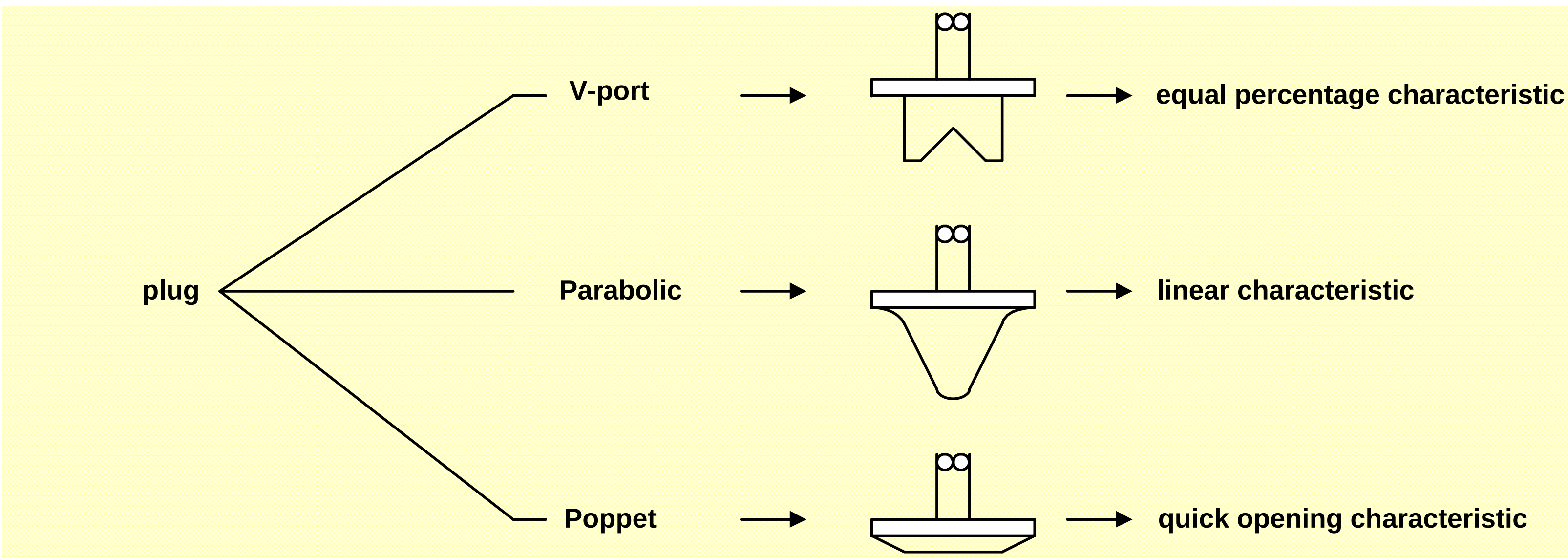


✓ Here, depending on the plug shape, flow-lift characteristic will vary.

Single-seat Sliding-stem Control Valves

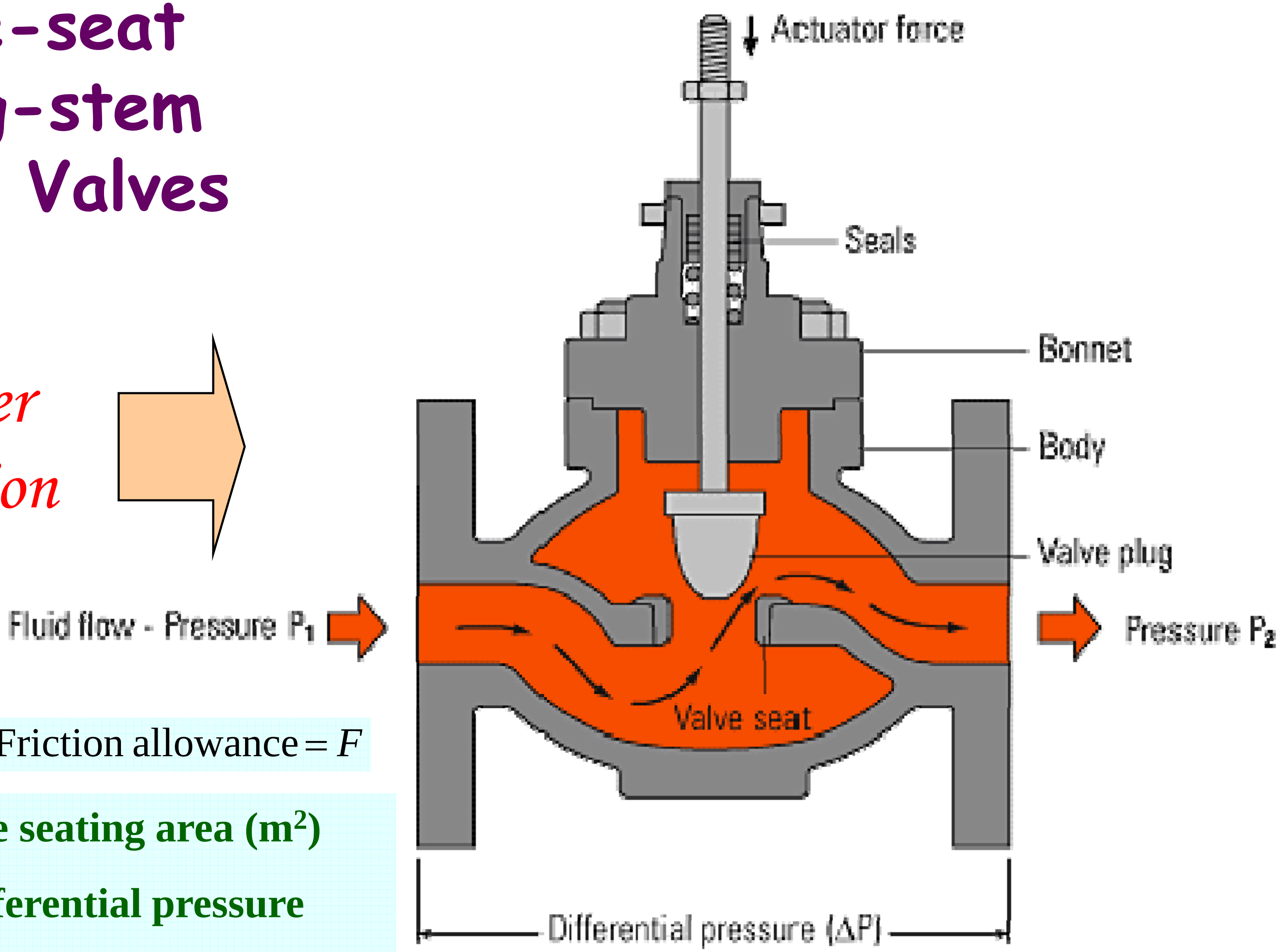


Plug Types



Single-seat Sliding-stem Control Valves

Another variation



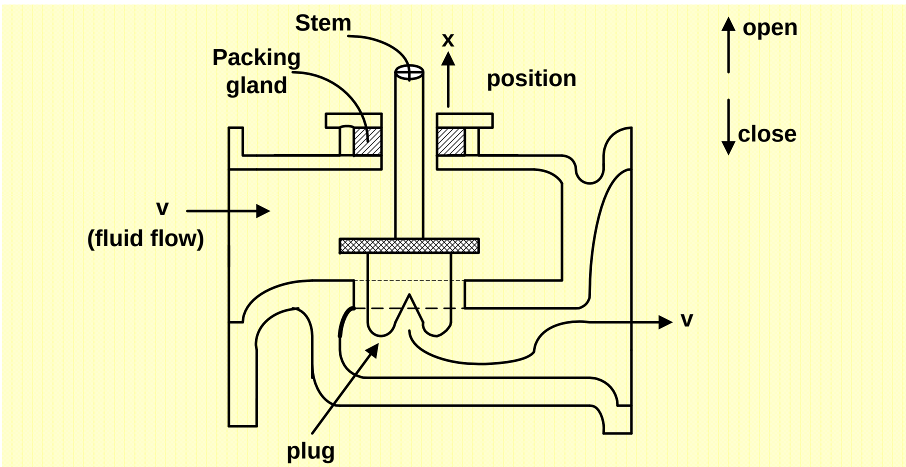
$$(A \times \Delta P) + \text{ Friction allowance} = F$$

A= Valve seating area (m^2)

- **ΔP = Differential pressure (kPa)**

F = Closing force required (kN)

Single-seat Sliding-stem Control Valves



Features

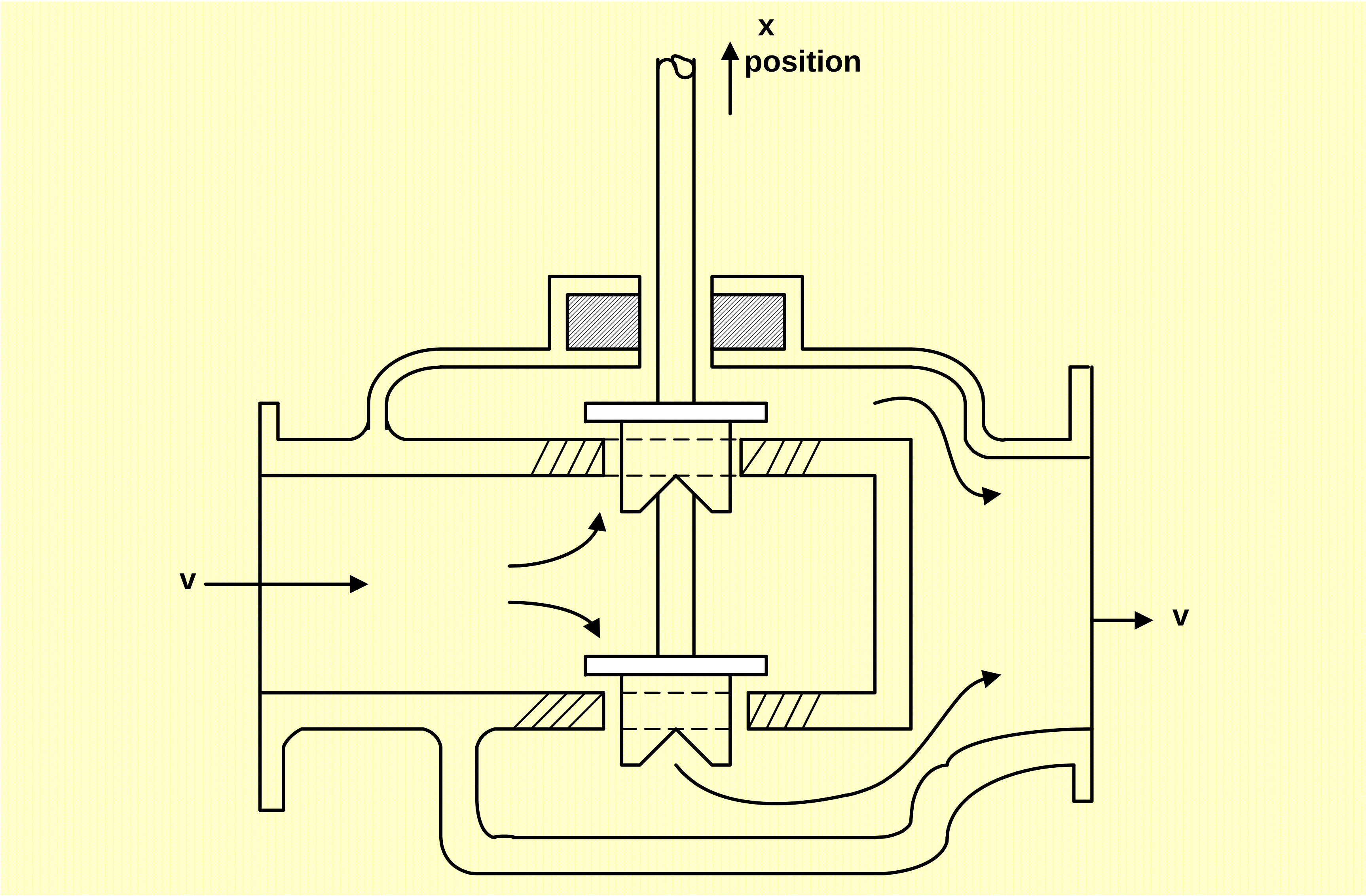
✓ **Can be shut off completely to provide zero flow – an advantage.**

✓ **Requires large thrust force, thus a powerful actuator is necessary – a disadvantage.**

Solution ?

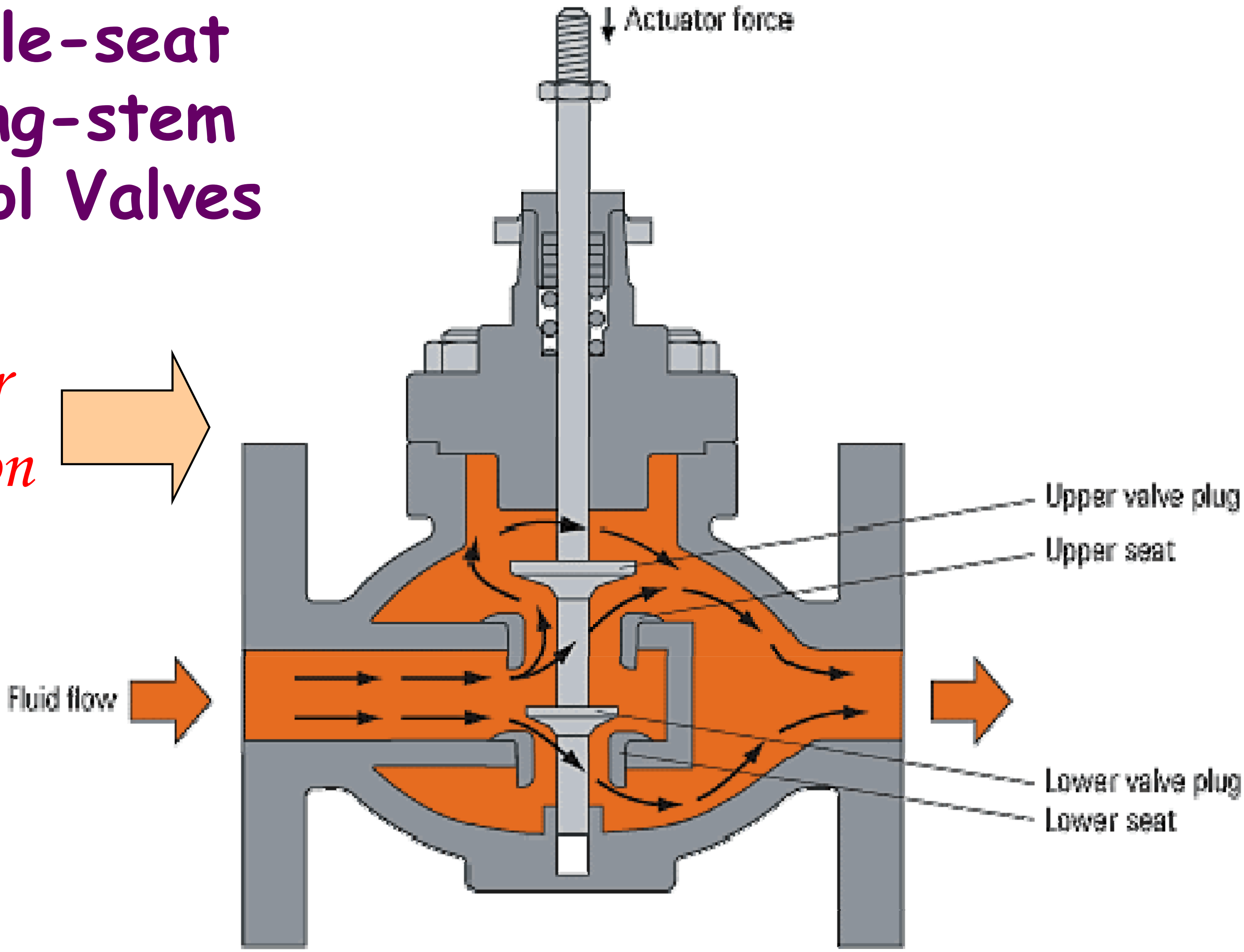
✓ **To overcome the disadvantage, double-seat arrangements are used, which require a small thrust force to operate.**

Double-seat Sliding-stem Control Valves

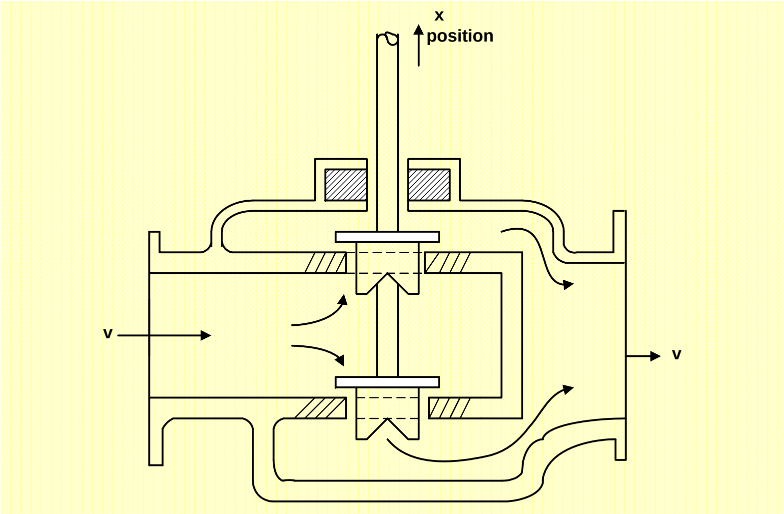


Double-seat Sliding-stem Control Valves

Another variation



Double-seat Sliding-stem Control Valves



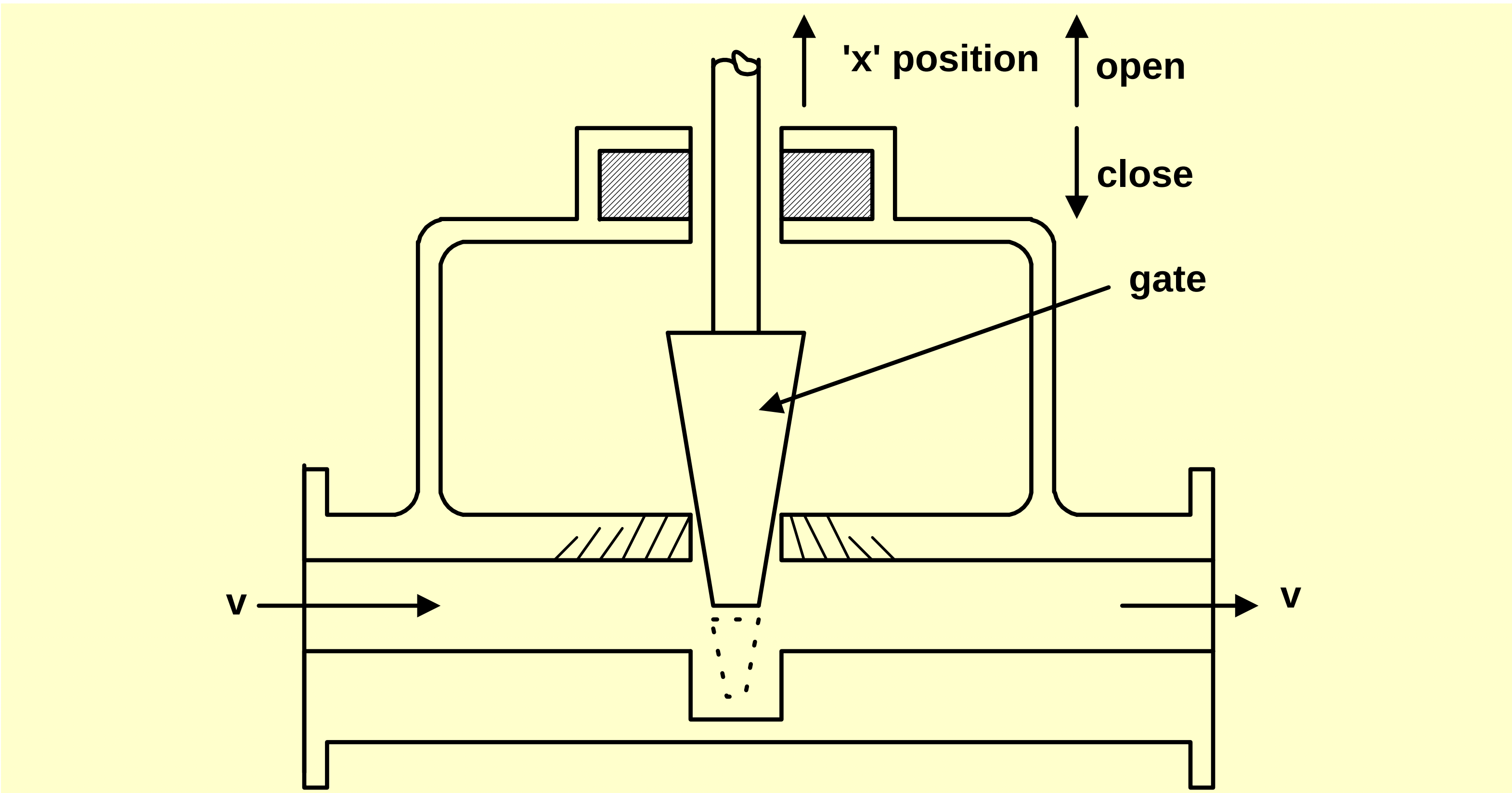
Disadvantages

✓ **It cannot be shut off completely because of the differential temperature expansion of plug and body (when hot fluid is flowing).**

✓ **If plug expands more than body, it may cause breakage. If body expand more, there will be significant leakage or offset in the system.**

Double-seat valves are used where it becomes impractical to provide sufficient force to close a conventional single seat valve.

Lifting-Gate Control Valves



Single-seat Lifting-Gate Valve

- ✓ These are used to control flow of fluids containing solid matters (e.g. paper pulp).
- ✓ Here no change in direction of fluid flow takes place, due to the control action.

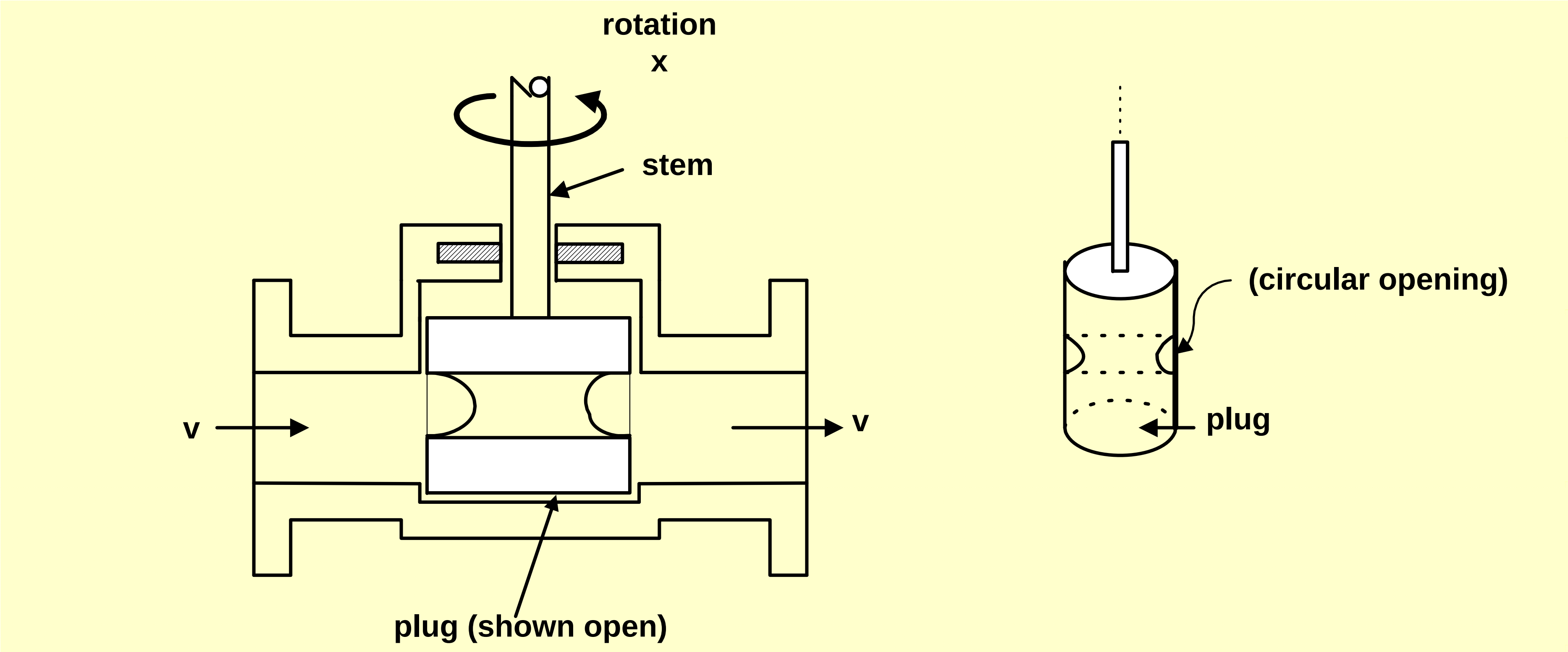
Rotating-Shaft Control Valves

Rotating - shaft control valves

- **Rotary plug**
  - used to control liquid flow (e.g. oil to burner)
- **Butterfly**
  - used to control air,gas and liquid at low pressure difference
- **Louver**
  - use to control air flow at low pressure (draft control)

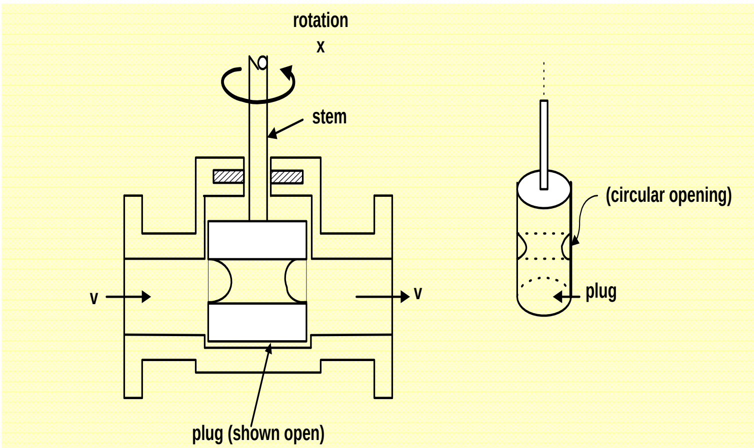
✓ **Rotary type valves, often called quarter-turn valves, include plug valves, ball valves, butterfly valves etc. All require a rotary motion to open and close, and can easily be fitted with actuators.**

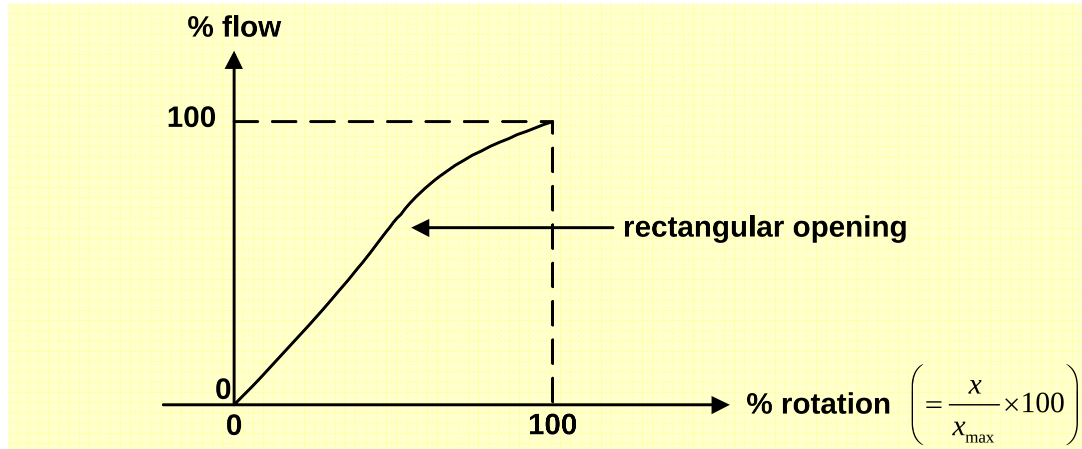
Rotary plug type Control Valves



✓ **When the pipe opening and plug opening completely align, complete flow takes place. If they do not align at all, no flow takes place.**

Rotary plug type Control Valves





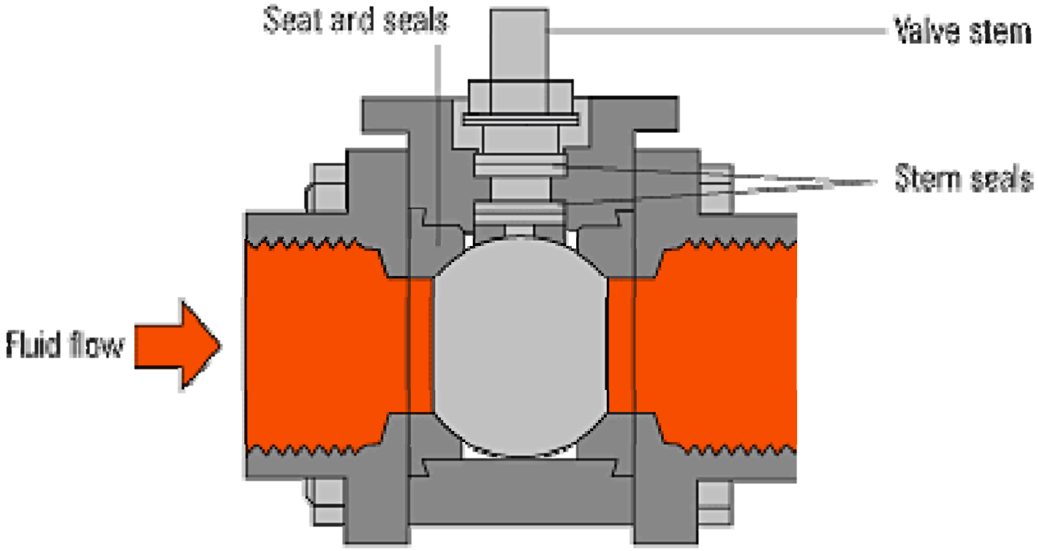
plug opening (or part)

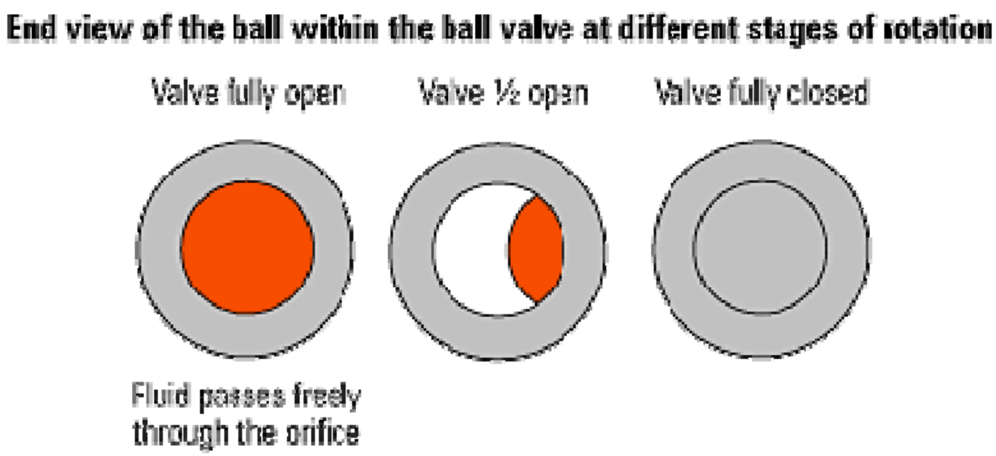
- **Circular**
- **V-shaped**
- **Rectangular**

for different flow-rotation characteristics

✓ **Here 100% rotation corresponds to an angular rotation or movement of 90^o for *x*.**

Ball Valves

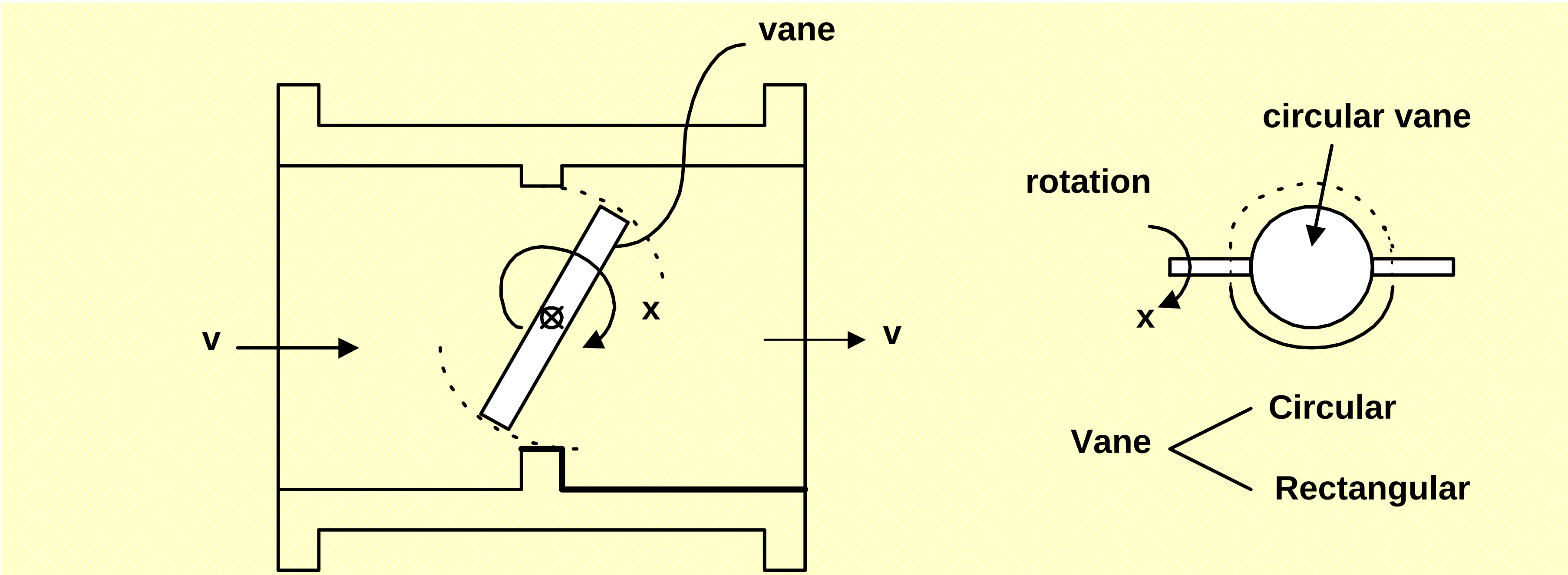


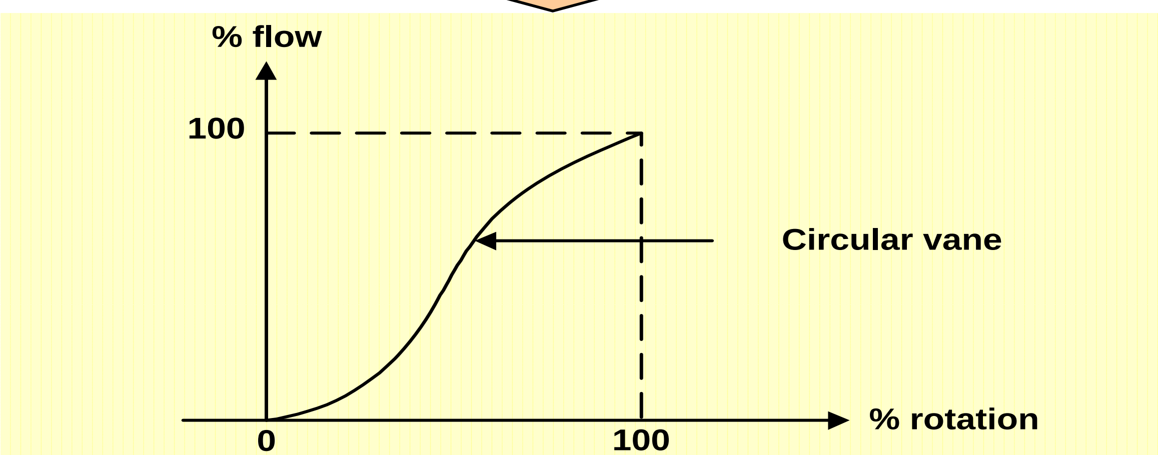


Features

- ✓ It consists of a spherical ball located between two sealing rings in a simple body form.
- ✓ Rotating the ball through 90° opens and closes the flow passage.
- ✓ Ball valves are an economic means of providing control with tight shut-off for many fluids.

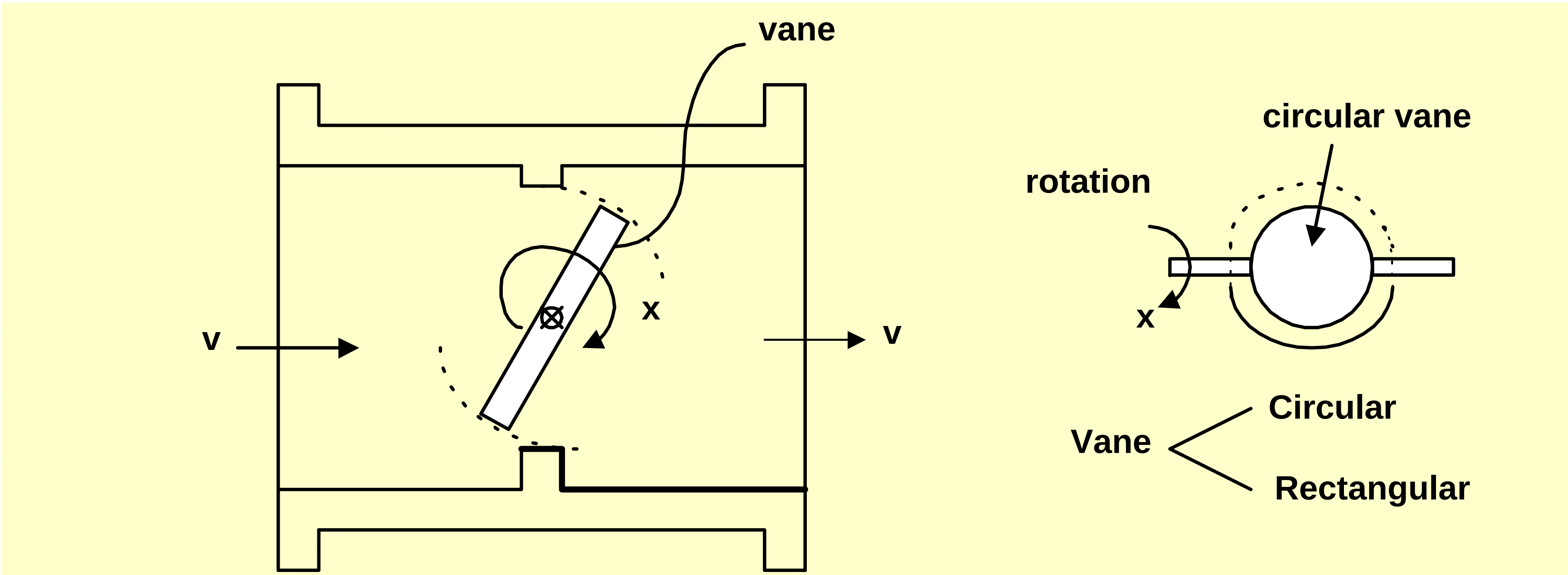
Butterfly Valves

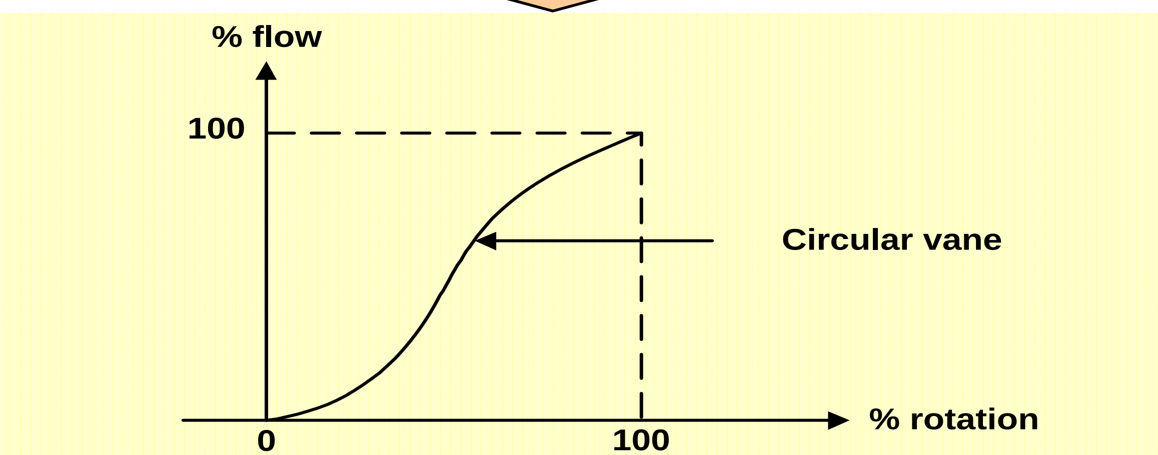




- ✓ Here, 100% rotation corresponds to an angular rotation of 90º .

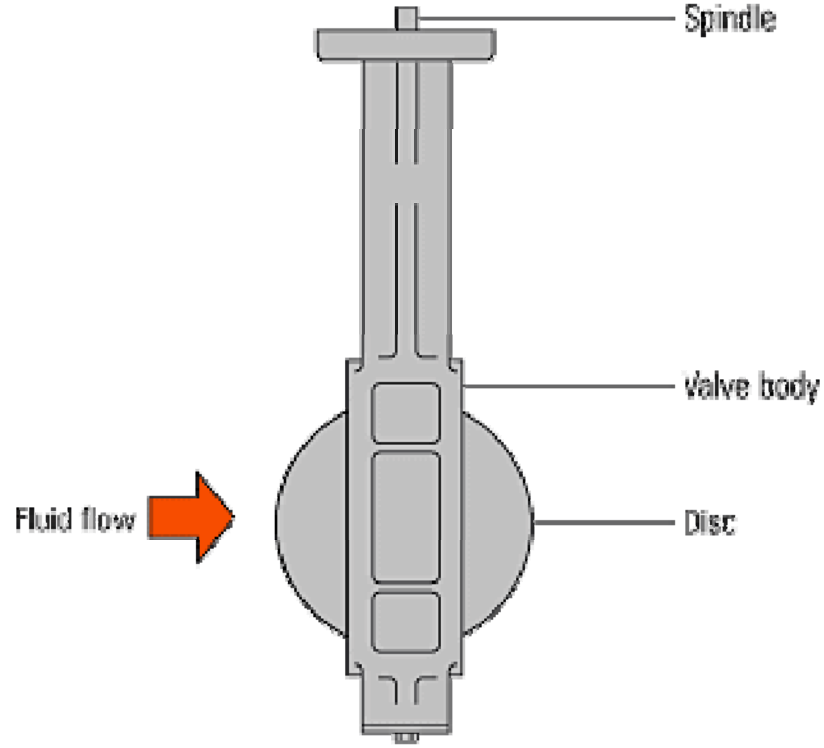
Butterfly Valves



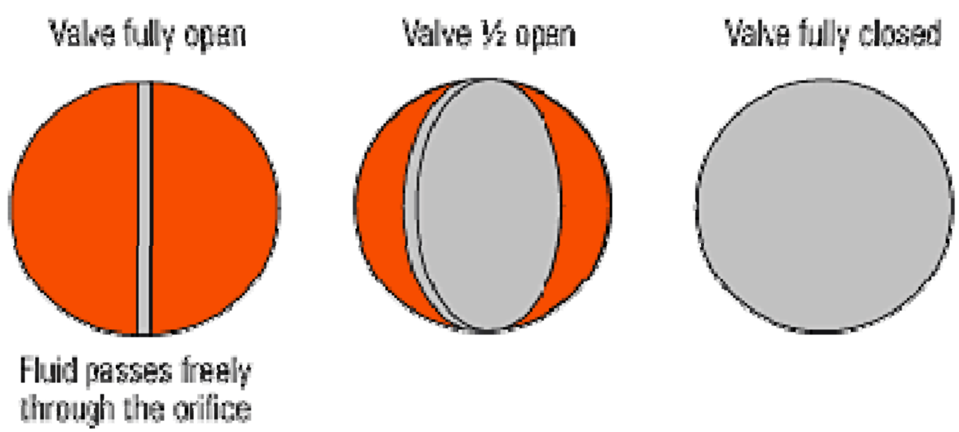


Butterfly Valves

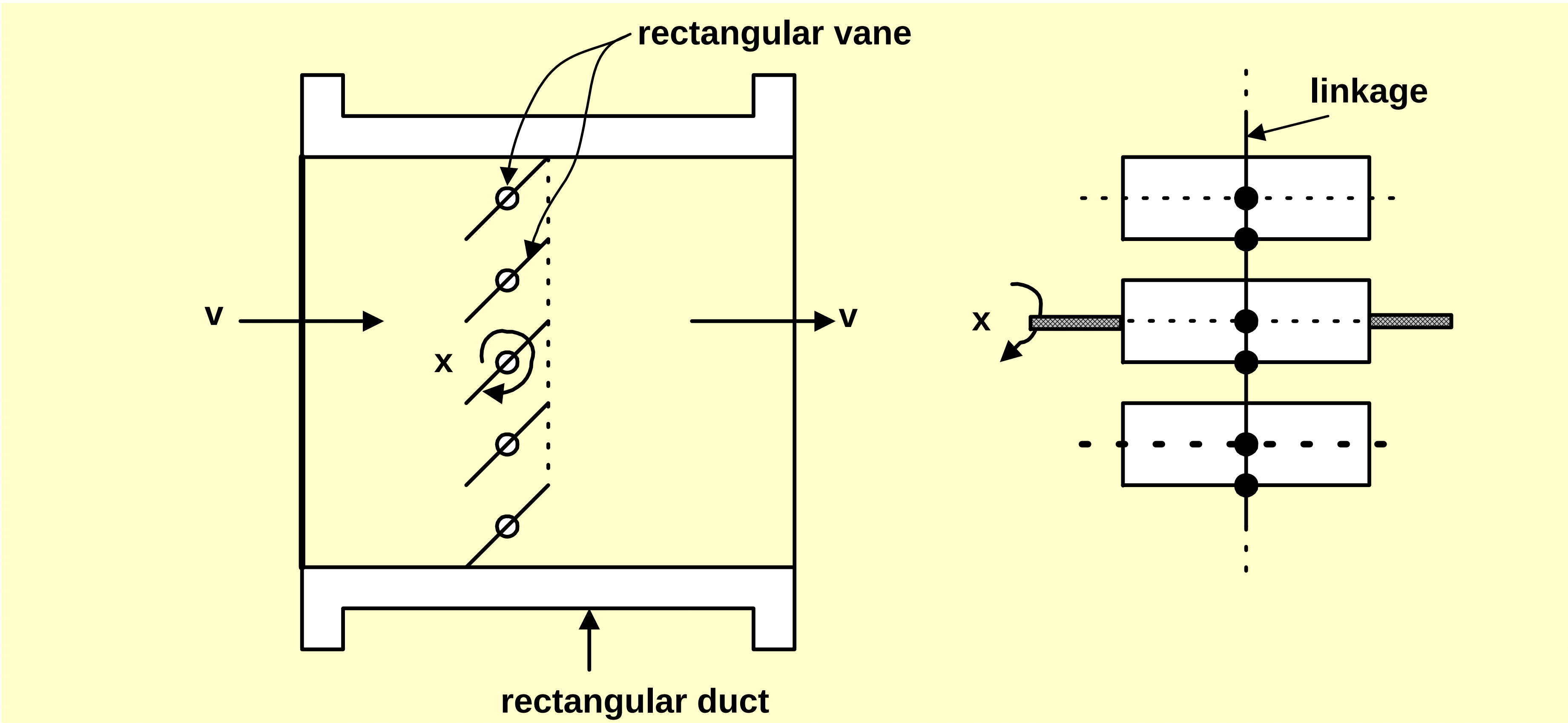
Another variation



End view of the disc within the butterfly valve at different stages of rotation

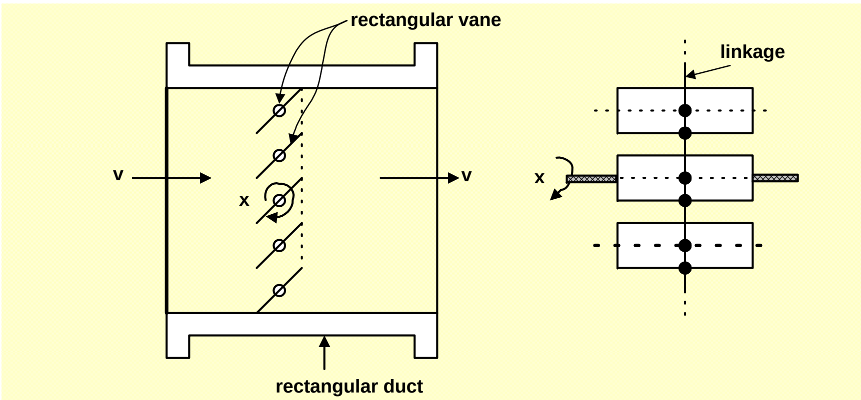


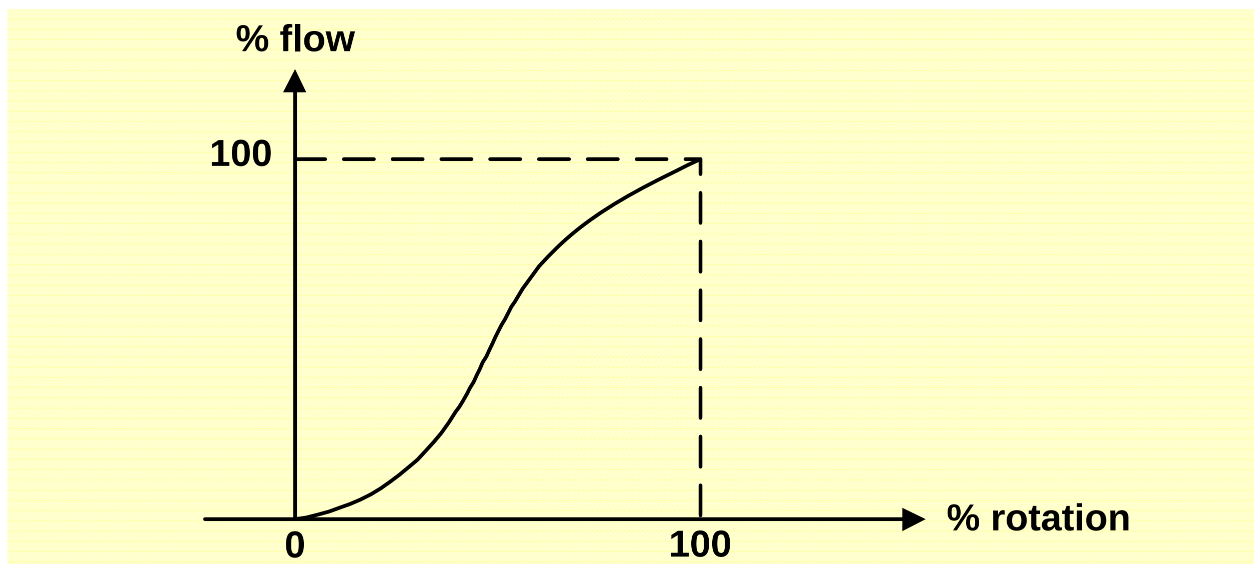
Louver Valves



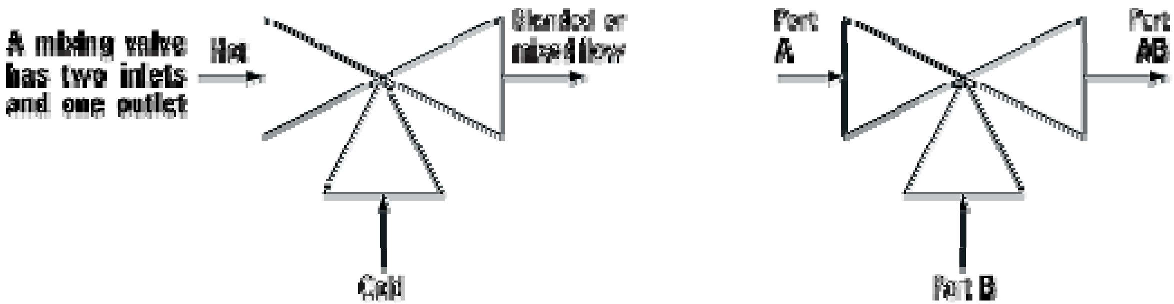
✓ **Louvers cannot provide tight shut off due to long length of seating surfaces. Hence considerable leakage takes place.**

Louver Valves

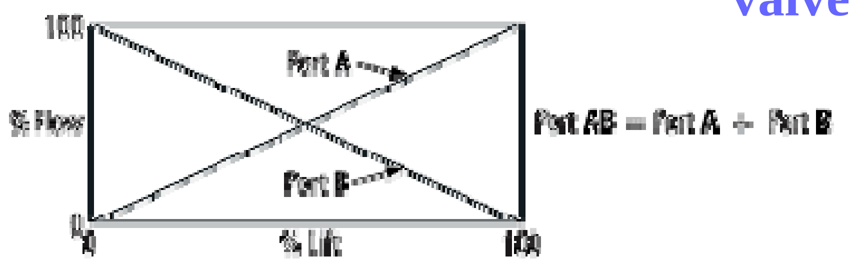




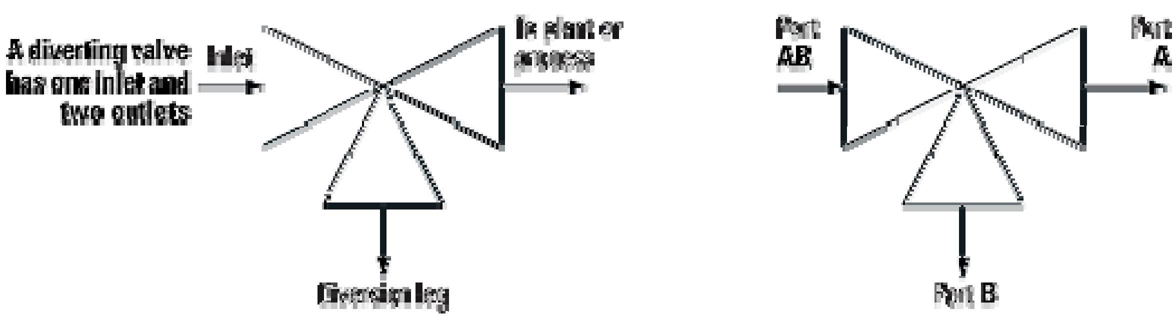
Three-port Valves



Port AB is termed the constant volume port. Its amount of opening is fixed by the sum of ports A and B and is not changed by the movement of the internal mechanism within the valve when the degree of opening of ports A and B is varied. A linear characteristic is normally used to provide the constant output volume condition.



✓ **Three-port valves can be used for either mixing or diverting service depending upon the plug and seat arrangement inside the valve.**



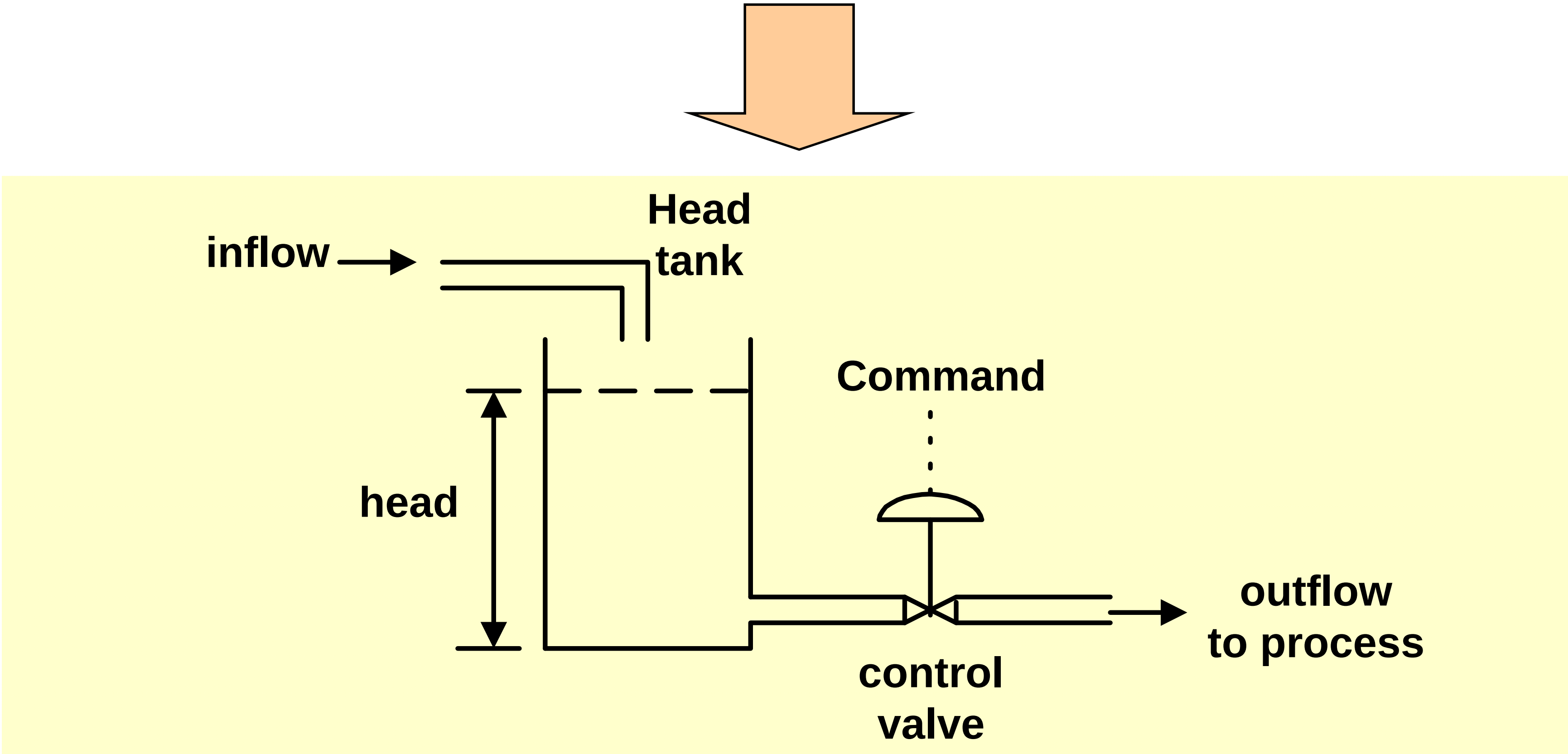
Methods of Fluid Control

Methods of fluid control

- **Series throttling**
- **Bypass**
- **Variable delivery (variable source)**
  - **requires no separate control valve**

Methods of Fluid Control

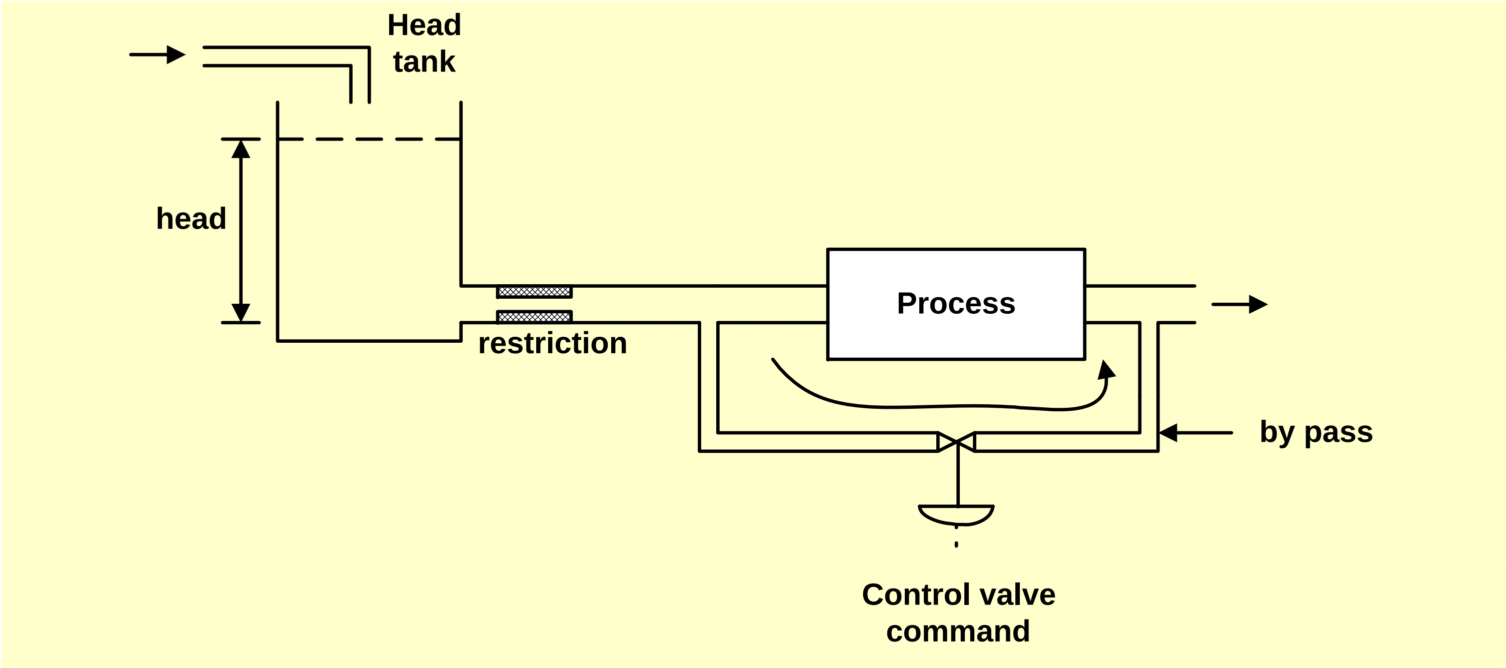
Series Throttling



✓ **For fluctuating or intermittent inflow, closed-loop control is necessary to maintain constant outflow. The closed loop control will generate necessary command for the control valve to maintain constant outflow.**

Methods of Fluid Control

Bypass

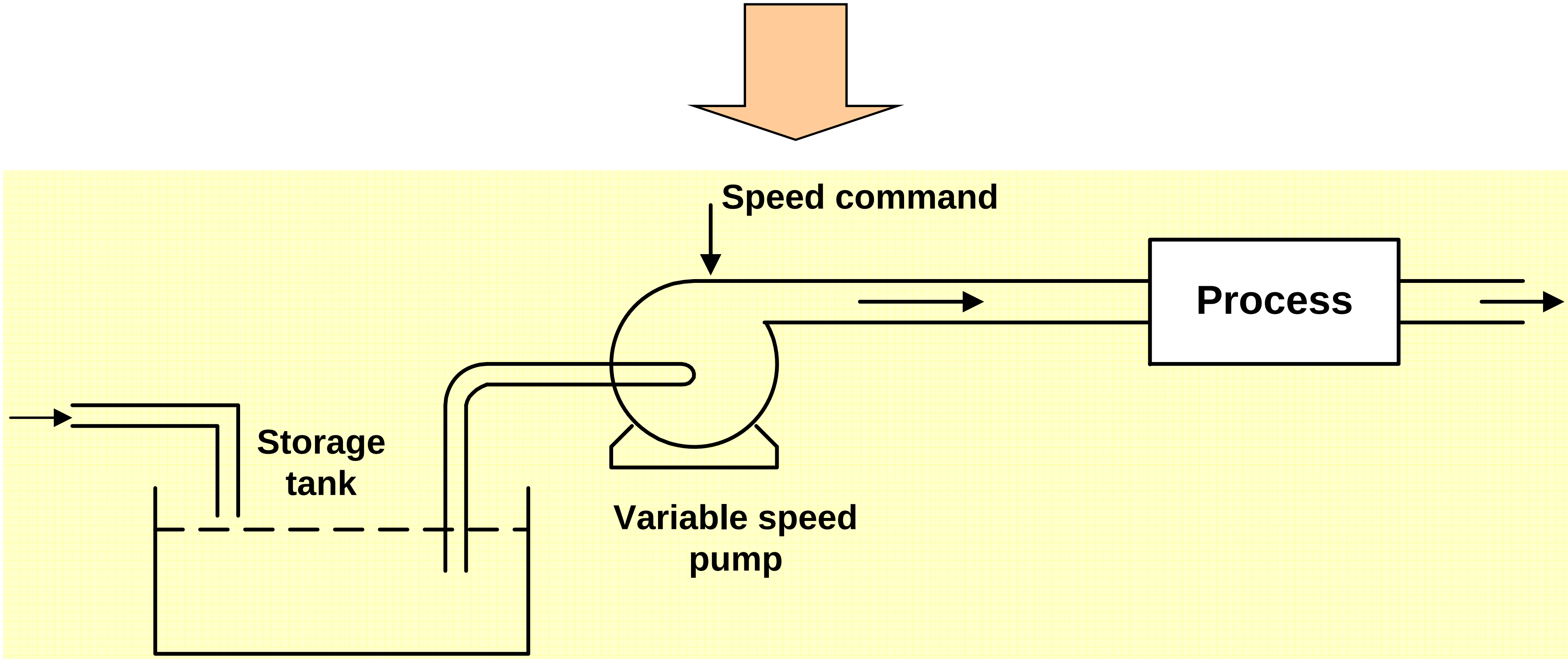


✓ Bypass is required when we cannot shut down the source, then the extra water is bypassed. the control valve employed will have inverse gain.

✓ By pass is not economical, as a considerable portion of fluid is wasted.

Methods of Fluid Control

Variable Delivery



Variable Delivery from a Variable Speed Pump

Thank You