Diaphragm Control Valves

• Just what is a control valve?
• An automated valve used to restrict flow to the process – We can manipulate the process

\[ Z_1 + \frac{P_1}{\rho} + \frac{v_1^2}{2g} + H_p = Z_2 + \frac{P_2}{\rho} + \frac{v_2^2}{2g} + h_i \]
Purpose of a Control Valve

The purpose of a control valve is to throttle flow. The pressure drop $\Delta P$ across the control valve required to do this is an energy expense.

For Liquid flow:

$$F_L = C_V \sqrt{\frac{\Delta P_V}{SG}}$$

Where:

- $F_L =$ Liquid flow (gpm)
- $C_V =$ Control valve flow coefficient per characteristic curve (gpm/psi$^{1/2}$)
- $\Delta P_V =$ Pressure drop across the valve (psi)
- $SG =$ Liquid specific gravity

$C_v$ is proportional to cross sectional area for flow. An increase in valve capacity (Max $C_v$) will decrease the valve pressure drop. Its relationship to stem position can be linear or nonlinear. For linear trim, $C_v$ is proportional to position. Its response to a signal is adversely affected by stick-slip and dead band.
Control Valve, Two Basic Designs:

- Sliding Stem, globe gate, needle etc.
- Rotating Stem, Ball, Plug, Butterfly, Disk, etc.
Sliding Stem (Globe) Control Valve

Plug stem connected to actuator shaft that moves up and down to stroke the valve

Stem packing - tightened and rough surface to reduce escape of process increases friction that opposes stem movement

Integral flange

Stem guiding helps keep plug aligned for high pressure drops

Path for escaping process vapors

Seat ring - designs to make the sealing of the surfaces between the plug and seat tighter reduces leakage when valve is closed (tighter shutoff) but increase friction that opposes stem movement. The plug is stuck in the seat. When enough pressure builds up in the actuator, the plug breaks free, jumps, and overshoots the desired position.
Severe Service Options
(high pressure drop, noise, and cavitation)

Plug guiding prevents deflection

Balanced plug reduces actuator size but increases leakage

Whisper trim reduces noise but watch out for occlusion of narrow slots and tiny holes from steam and process residue!
Hydro Thermal – Steam Mixer
Rotary Eccentric Plug Valve Design

Rotary actuator eliminates linkage needed to translate up and down shaft movement to rotary motion of plug stem.

Tight plug stem and actuator shaft connection reduces dead band.

Lowest cost for 1”- 6” size valves but it has a very limited choice of materials for corrosive service.

Digital valve positioner measures and controls actuator shaft rotation.
Rotary Eccentric Plug Valve Cross Section

- Integral flange reduces potential for leaks and the installation and maintenance cost
- Stepped Seat Ring (less friction near the seat)
- Contoured eccentric plug improves plot of flow versus stem position near the seat
- Optional attenuator disc to reduce noise

Flow Direction from cooking tube to liquefaction
V-Ball with a diaphragm actuator

Dead band (lost motion)
V-ball < 0.5%
Other 2 - 8%

Tight ball, stem, and shaft connections reduces dead band

Short shaft reduces twist (stick-slip)

Diaphragm actuator - an increase in air pressure to top presses on flexible diaphragm that causes shaft to move down. The minimum pressure to open the valve is set by force of opposing spring. For very large actuators volumes, the time to stroke full scale can become large

Tight linkage design to translate up-down actuator shaft movement to rotary ball motion

Unfortunately most positioners measure actuator instead of ball or disc position

V provides better flow characteristic and shear of pulp
Butterfly Valve
(with Rotary Piston Operator)

Butterfly valves are much less expensive than globe valves for large sizes (>6”) since there is much less metal and machining.

Flangeless wafer style saves on price but it must be carefully fitted between piping flanges.

These are often called high performance valves because of high temperature and low leakage ratings but they are low performance so far as stick-slip particularly near the closed position because of very high seat/seal friction.

These valves are ideally suited for on-off service as isolation or block valves for interlocks and batch sequences - just don’t use them as control valves.
Quick Opening Cage

Equal Percentage Cage

Linear Cage

Whisper Trim® Cage for Noise Attenuation
Single Port

Port Guided

FISHER A Body, older style
Valves can get Damaged
Flashing and Cavitation

Typical Appearance of Flashing Damage

Typical Appearance of Cavitation Damage
Various trim designs to select based on process characteristics
Want to achieve linearly “installed” characteristics

Flow characteristic curves for various valve plugs. Throttle Plug and V-Port valve plugs have a modified parabolic flow characteristic.
Installed Characteristics

- The same percentage change in valve travel at a lower opening valve results in the same percentage change in flow higher flow rates, use equal percentage control valve trim.
- Equal percentage trim compensates for the non-linearity of the change in pressure drop through a restriction.
- Centrifugal pump’s performance curve shows a drop from a maximum head at zero flow or “dead head”. This drop is a function of the square root of the flow.

\[ Q = K \cdot \sqrt{H_{\text{max}} - H} \]

- A simple test of a typical liquid flow application shows the linear installed characteristics with equal percent trim. The pump in this example is a 1 X 1.5 inch centrifugal with an 8 3/16” impeller turning at 1750 RPM. See typical centrifugal pump curve.
A simple test of a typical liquid flow application shows the linear *installed* characteristics with equal percent trim. The pump in this example is a 1 X 1.5 inch centrifugal with an 8 3/16” at 1750 RPM. 600 equivalent feet of 2 inch pipe control valve has a maximum Cv of 59.7. The maximum flow is 70 GPM.
Valve Actuator
Actuator Failure

- Failures, FO, FC - Fail Open or Closed
  - ATO - Air To Open
  - ATC - Air To Close
- FLP – Fail Last Position
The controller output signal needs to move the valve; how does it do that?

Need to convert the process signal to a change in air pressure.
Nozzle Baffle Pneumatic Valve
I/P, Current to Pneumatic, Transducer

An element or device which receives information in the form of one quantity and converts it to information in the form of the same or another quantity. ISA-S51.1 – 1976 Example: Converting different signal types; example: I/P current to pneumatic; 4 to 20 mA to 3 to 15 psig.

I/P based on the D’Arsonval principal, the same principal in a moving coil meter. A coil placed between the poles of a permanent magnet.
Fisher Type 546, 546S, and 546NS Electro-Pneumatic Transducers

![Transducer Schematic](image)

*Figure 6. Transducer Schematic*
Electropneumatic positioners combine the function of a current-to-pressure transducer with those of a positioner. It receives an electronic input signal and ensures valve position by adjusting output pressure.

*(Fisher Controls International, Inc.)*
Dead band and Stick-Slip

Digital positioner will force valve shut at 0% signal.

Pneumatic positioner requires a negative % signal to close valve.

Dead band is 5% - 50% without a positioner!

The dead band and stick-slip is greatest near the closed position.

Figure 1 Definition of Dead band and Stick-Slip
Figure 2 Response Time for Different Types of Final Elements

1 - variable speed drive with dead band adjustment set equal to zero
2 - sliding stem valve with diaphragm actuator and a digital positioner
3 - sliding stem valve with diaphragm actuator and pneumatic positioner
4 - rotary valve with piston actuator and digital positioner
5 - rotary valve (tight shutoff) with piston actuator and pneumatic positioner
6 - large valve or damper with any type of positioner
7 - small valve with any type of positioner

All valves look good for about a 10% step
Pressure Regulators

Provides Pressure Control

- Downstream pressure regulation
- Upstream pressure regulation, a special case is a relief valve

- Self Contained
- Pilot Operated
Pressure Regulator

- Spring size determines range
- Set screw preloads spring to set pressure
- Control not exact, pressure will “droop”

Example for a pressure reducing valve, pressure will be reduced 20% from set point at maximum flow

Common uses in utility distribution