Actuator

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Session Outlines & Objectives

Outlines

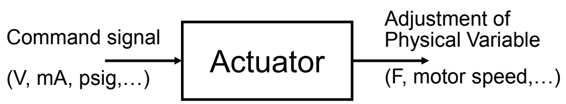
- Control valve
- Other actuators

Objectives

- Know various type of actuators and their application in the process control area
- Know the characteristics of actuators

Introduction

- What is actuator?
  - Actuator converts the command signal from controllers into physical adjustment in adjustable process variable



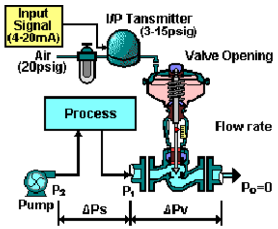
- Actuator types
  - Control valve: pneumatic, electric, hydraulic
  - Electric heater output: thyristor
  - Pump/Motor speed: inverter
  - Displacement: pneumatic, electric, hydraulic

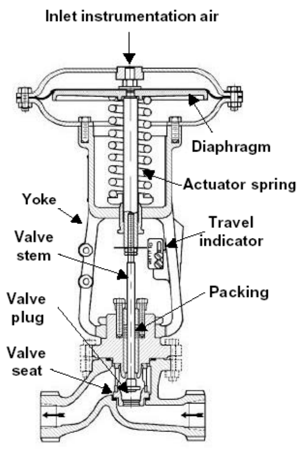
Industrial Actuator

- Actuator
  - Convert the industrial standard signal to action such as valve opening, power level, displacement
- Actuator power
  - Pneumatic
    - Simple, low cost, fast, low torque, hysteresis
  - Electric
    - Motor and gear box, high torque, slow
  - Hydraulic
    - High torque, fast, expensive

Control Valve

- A work-horse of process control
- Actuator + valve
  - Valve opening is adjusted by an actuator
- Pneumatic control valve
  - Usually 3 – 15 psig signal is provided
  - I/P transmitter converts 4 – 20 mA signal to 3 – 15 psig pneumatic signal via 20 psig air supply





Major Classifications (1)

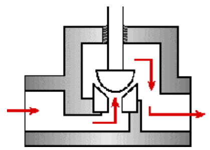
- Based on motion
  - Linear
    - Globe
    - Diaphragm
    - Pinch or clamp
    - Gate
  - Rotary
    - Eccentric plug
    - Butterfly
    - Ball
- Based on the event of a loss of signal or power (fail-safe mode)
  - Fail Open (FO)/Air-to-Open (ATO)
  - Fail Closed (FC)/Air-to-Closed (ATC)

Major Classifications (2)

- Based on type of power signal
  - Pneumatic
  - Electric
  - Hydraulic
- Based on valve trim (plug) types
  - Equal-percentage
  - Linear
  - Quick opening

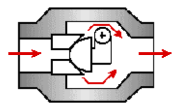
The Motions (1)

Linear



- Tortuous flow path
- Low recovery
- Can throttle small flow rates
- Offers variety of special trim designs
- Suited to high-pressure application
- Usually flanged or threaded
- Separable bonnet

Rotary



- Streamlined flow path
- High recovery
- More capacity
- Less packing wear
- Can handle slurry and abrasives
- Flangeless
- Integral bonnet
- High rangeability

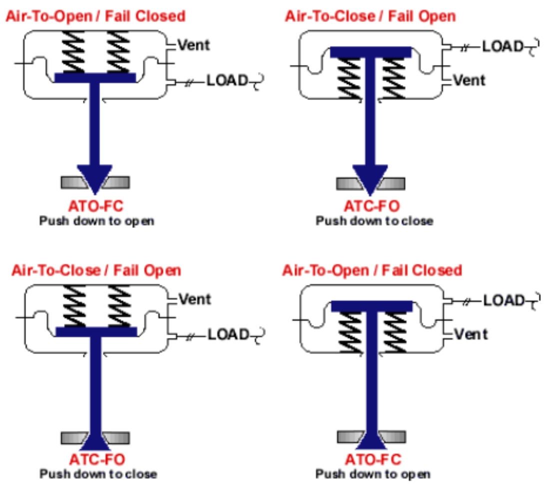
The Motion (2)

- Globe valve
  - Rugged, usually the most expensive, particularly in the larger sizes, accurate and repeatable control, high pressure drop
- Gate valve
  - Sliding disc (gate), ideal for high pressure drip and high temperature application where operation is infrequent, multi-turn or long stroke pneumatic and electro-hydraulic actuators are needed, poor control
- Ball valve
  - Damper valve, most economical valves, high torque required
- Diaphragm valve
  - Simplest, tight shutoff, isolated, ideal for corrosive, slurry and sanitary services

Air-To-Open vs. Air-To-Close

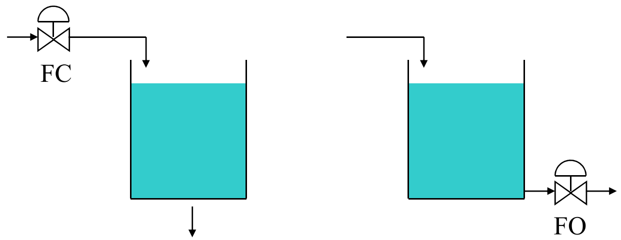
- Air-to-Open (+ gain)
  - More air → larger opening ⇒ No air → Valve closes.
- Air-to-Close (- gain)
  - More air → smaller opening ⇒ No air → Valve open completely.
- Proper type to use is determined from safety considerations
  - Air-to-close: Coolant valve in an exothermic reactor or in a condenser of a distillation column.
  - Air-to-open: Steam valve in a reactor, inlet flow valve to a tank.

The Fail-safe Modes (1)

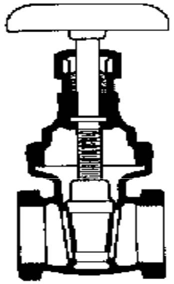


The Fail-safe Modes (2)

- Choose an air-to-open for applications for which it is desired to have the valve fail closed
- Choose an air-to-close for applications for which it is desired to have the valve fail open



Gate Valve



Gate Valve

Best Suited Control: Quick Opening

Recommended Uses:

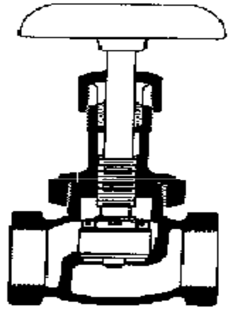
1. Fully open/closed, non-throttling
2. Infrequent operation
3. Minimal fluid trapping in line

Applications: Oil, gas, air, slurries, heavy liquids, steam, noncondensing gases, and corrosive liquids

Advantages:

1. High capacity
2. Tight shutoff
3. Low cost
4. Little resistance to flow

Globe Valve



Globe Valve

Best Suited Control: Linear and Equal percentage

Recommended Uses:

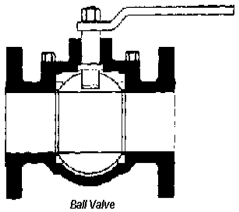
1. Throttling service/flow regulation
2. Frequent operation

Applications: Liquids, vapors, gases, corrosive substances, slurries

Advantages:

1. Efficient throttling
2. Accurate flow control
3. Available in multiple ports

Ball Valve



Ball Valve

Best Suited Control: Quick opening, linear

Recommended Uses:

1. Fully open/closed, limited-throttling
2. Higher temperature fluids

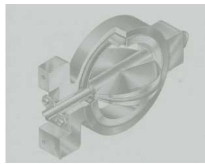
Applications: Most liquids, high temperatures, slurries

Advantages:

1. Low cost
2. High capacity
3. Low leakage
4. Tight sealing with low torque

Butterfly Valve

Butterfly Valve



Best Suited Control: Linear, Equal percentage

Recommended Uses:

1. Fully open/closed or throttling services
2. Frequent operation
3. Minimal fluid trapping in line

Applications: Liquids, gases, slurries, liquids with suspended solids

Advantages:

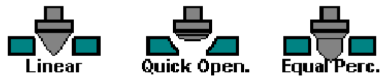
1. Low cost
2. High capacity
3. Good flow control
4. Low pressure drop

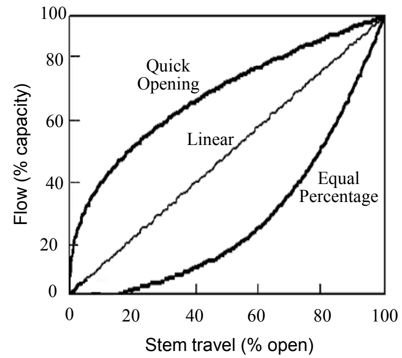
Other Valves

- Check valves are designed to restrict the flow to one direction. If the flow reverses direction, the check valve closes.
- Relief valves are used to regulate the operating pressure of incompressible flow.
- Safety valves are used to release excess pressure in gases or compressible fluids.

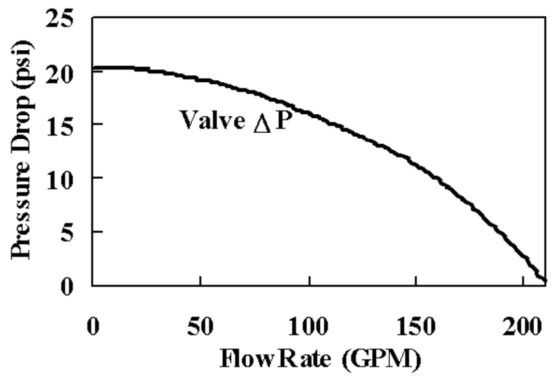
Valve Trim (Plug) Type

- Equal Percentage
  - Used for about 90% of control valve applications since it results in the most linear installed characteristics
  - Used where large pressure drop is expected
- Linear
  - Used when a relatively constant pressure drop is maintained across the valve
  - Used for liquid level or flow loop
- Quick Opening
  - Used for safety by-pass applications where quick opening is desired





Pressure Drop vs. Flow Rate



Basic Valve Equation

- Basic Valve Equation

$$q(\ell) = C_v^{\max} f(\ell) \sqrt{\frac{\Delta P_v}{g_s}} \qquad 0 \le \ell \le 1$$

- Valve size: determines $C_v^{\max}$
- Valve trim type:
  - Linear: $f(\ell) = \ell$
  - Square-Root (Quick Opening): $f(\ell) = \sqrt{\ell}$
  - Equal Percentage: $f(\ell) = R^{\ell-1}$
- Table 2.1 shows $\ell(\%)$ vs $C_v^{\max} R^{\ell-1}$ for EP valves of diff. Body sizes.

Table 2.1 for EP Valve

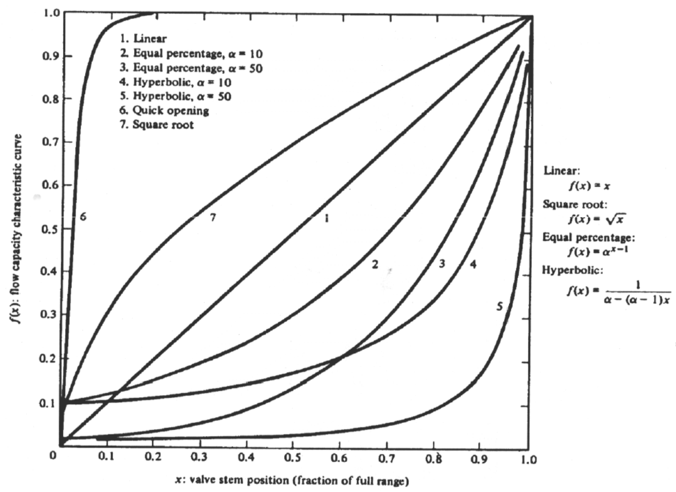
$\ell(\%)$

Table 2.1 Representative C_v's for an Equal Percentage Globe Valve.

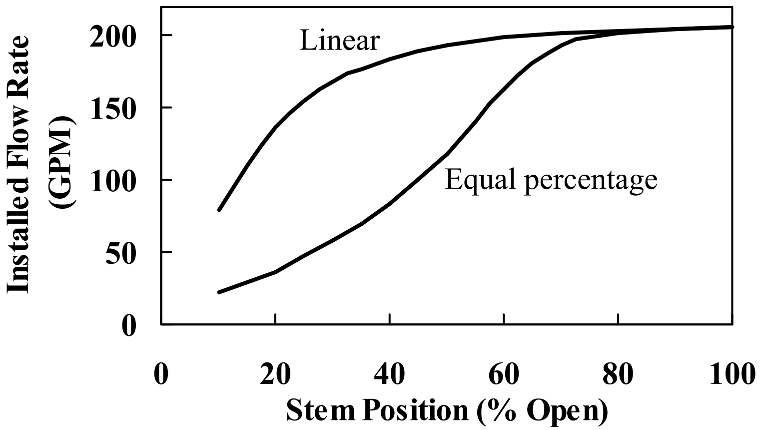
	Body Size (in)	Stem Position as a Percentage of Total Travel									
		10	20	30	40	50	60	70	80	90	100
	1	0.79	1.25	1.80	2.53	3.63	5.28	7.59	10.7	12.7	13.2
	1.5	0.80	1.23	1.91	2.95	4.30	6.46	9.84	16.4	22.2	28.1
C_v	2	1.65	2.61	4.30	6.62	11.1	20.7	32.8	44.7	50.0	53.8
	3	3.11	5.77	9.12	13.7	21.7	36.0	60.4	86.4	104	114
	4	4.90	8.19	13.5	20.1	31.2	52.6	96.7	140	170	190

$C_v^{\max} R^{\ell-1}$

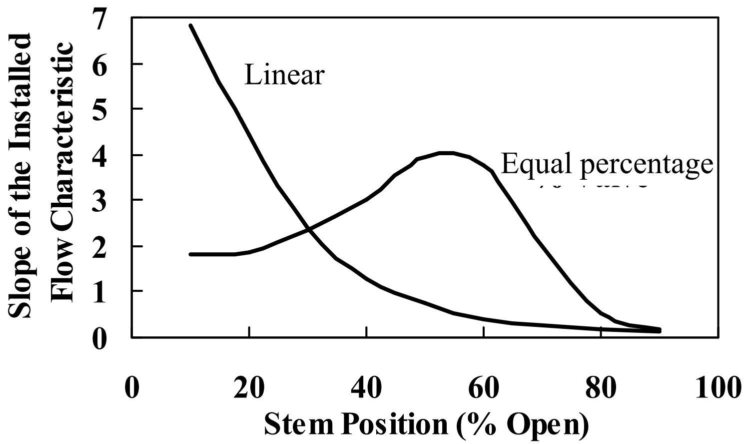
Characteristic Curves for Different Trim Types (Uninstalled –constant ΔP_v)



Installed Flow Characteristic



Slope of Installed Characteristic



Valve Nonlinearity

- Valves behave nonlinearly, even in the most ideal situation (without stiction, hysterisis).
- Once installed, linear trim does **NOT** lead to a linear relationship between ℓ and q.
  - ΔP_v does not stay constant but varies with ℓ
  - Ex) Closing a linear valve from full to half reduces the flow by less than half.
- Valve characteristic curve
  - A curve showing ℓ vs. q
  - Desirable to be linear in the range of operation.
- Questions:
  - How do we size a valve?
  - How do we compute the characteristic curve?

Pressure Drop vs. Flow Rate

Table 2.2 Installed Pressure Drop For a Control Valve versus Flow Rate

Q (GPM)	ΔP (psi)	Q (GPM)	ΔP (psi)
50	19.3	74	18.0
54	19.1	78	17.8
58	18.9	82	17.5
62	18.7	86	17.2
66	18.5	90	16.9
70	18.3	94	16.6

Sizing a Valve

- Determine the flow range needed.
- Total pumping requirement:

$$\Delta P_{total} = \Delta P_v + \Delta P_s$$

$$\Delta P_s = kq^2 \quad \Rightarrow \quad \Delta P_{total} = \left(\frac{q_{max}}{C_v}\right)^2 g_s + kq_{max}^2$$

ΔP_v at q_{max}

Minimum pumping required

- Note that pumping requirement and choice of valve size are interrelated and involves a trade-off.
  - The larger the valve, the less the pumping (more economical) but less controllability.
- Rule of thumb: $\Delta P_v \approx \frac{1}{3} \text{ or } \frac{1}{4} \text{ of } \Delta P_{total}$ at nominal flowrate.

Characteristic Curve (Installed)

- Once pump and valve are sized,

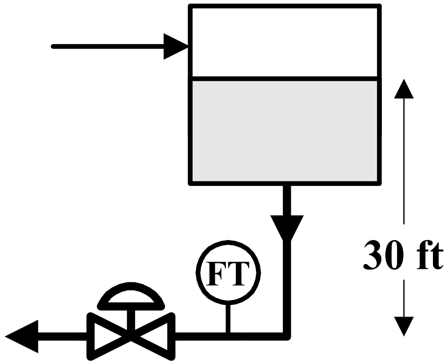
ΔP_{total}

$$\Delta P_v = \Delta P_{total} - \Delta P_s = \left(\frac{q_{max}}{C_v}\right)^2 g_s + kq_{max}^2 - kq^2$$

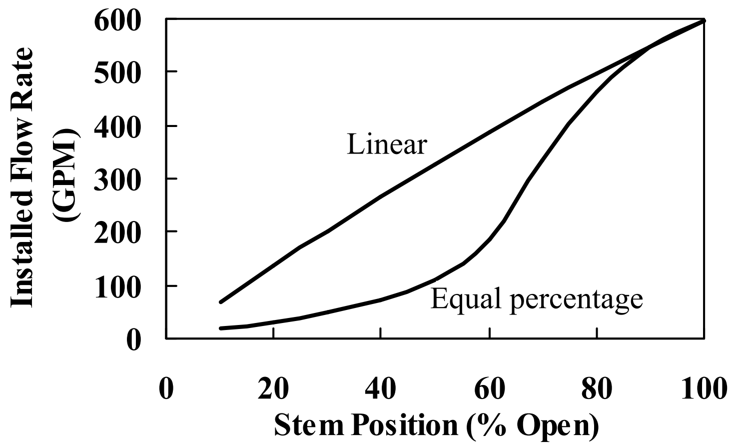
$$q(\ell) = C_v f(\ell) \sqrt{\frac{\Delta P_v}{g_s}} \qquad 0 \le \ell \le 1$$

- Plot ℓ vs. q.
- Play with Module 3

Flow System with Relatively Constant Valve Pressure Drop



Installed Valve Characteristics



Analysis of These Examples

- Note the linear installed valve characteristics over a wide range of stem positions
- If the ratio of pressure drop across the control valve for the lowest flow rate to the value for the highest flow rate is greater than 5, an equal percentage control valve is recommended

Control Valve Design Procedure

- Choose a control valve so that the average flow rate results when the valve is 2/3 open
- After the valve has been sized, check to ensure that the maximum and minimum flow rates will be accurately metered

Additional Information Required to Size a Control Valve

- C_V versus % open for different valve sizes
- Available pressure drop across the valve versus flow rate for each valve. Note that the effect of flow on the upstream and downstream pressure must be known

C_v versus % Valve Travel for Different Sized Valves

	Body Size (inch)	% Valve Opening		
		50	**60**	**70**
C_v	1	3.63	5.28	7.59
	1.5	4.3	6.46	9.84
	2	11.1	20.7	32.8
	3	21.7	36.0	60.4
	4	31.2	52.6	36.7

Check Max and Min Flows

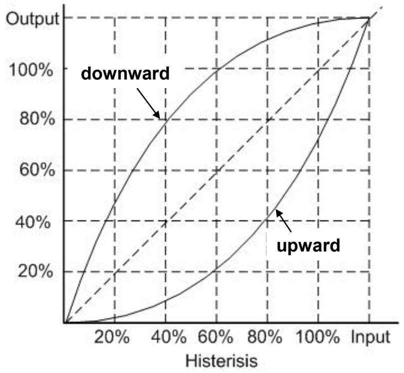
- Ensure that the flow rate will be accurately controlled at the maximum and minimum flow rates
- At minimum flow rate valve should be at least 10-15% open
- At maximum flow rate the valve should be at most 85-90% open

Valve Deadband

- It is the maximum change in instrument air pressure to a valve that does not cause a change in the flow rate through the valve
- Deadband determines the degree of precision that a control valve or flow controller can provide
- Deadband is primarily affected by the friction between the valve stem and the packing

Valve Hysteresis

- When the command signal (pneumatic signal) is going up and down, the flow rate will <u>not</u> be same even though the command signal is same depending on the direction of signal change
  - Due to friction between the stem and packing, loose linkage, pressure drop, stiction
  - Remedy
    - Change the command signal with the same direction by lowering or increasing it momentarily
    - Use valve positioner



Optional Equipment

- Valve positioner
  - A controller that adjusts the instrument air in order to maintain the stem position at the specified position
  - By use of valve positioner, hysteresis can be overcome

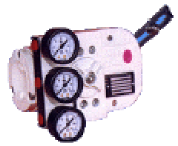


Fig. Positioner

- Booster relay
  - Provides high capacity air flow to the actuator of a valve. Can significantly increase the speed of large valves

Fig. Booster relay

Control Relevant Aspects of Actuator Systems

- The key factors are the deadband of the actuator and the dynamic response as indicated by the time constant of the valve
- Control valve by itself - deadband 10 – 25% and a time constant of 3 – 15 seconds
- Control valve with a valve positioner or in a flow control loop- deadband 0.1 – 0.5% and a time constant of 0.5 – 2 seconds

Session Summary

- There are various actuators found in process control depending on its application objectives
- Control valve is the most common actuator found in process control
- The actuators must be in good condition to achieve a good control performances