02-99

BASIC OPERATION AND FUNCTION OF CONTROL VALVES

"We simply make it right."

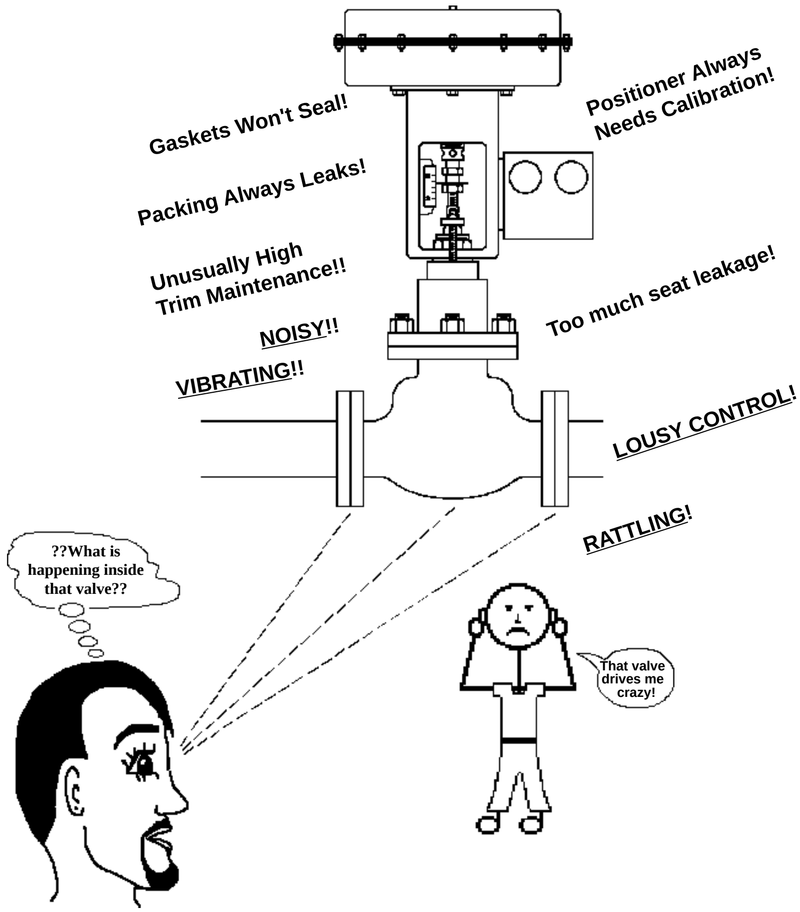


Table of Contents

TOPIC - SUBJECT | **SECTION**

SECTION 1

Terminology

CONTROL VALVE TERMINOLOGY
(per ISA-DS75.05)

1. SCOPE AND PURPOSE

To provide a glossary to define terms commonly used in control valve industry.

2. BASIC DEFINITIONS

actuator: An actuator is a pneumatic hydraulic, or electrically powered device which supplies force and motion to open or close a valve.

airset: A regulator which is used to control the supply pressure to the valve actuator and its auxiliaries.

angle valve: A valve design in which one port is collinear with the valve stem or actuator, and the other port is at a right angle to the valve stem.

anti-cavitation trim: See "trim, anti-cavitation".

anti-noise trim: See "trim, anti-noise".

bellows stem seal: A thin wall, convoluted, flexible component that makes a seal between the stem and bonnet or body and allows stem motion while maintaining a hermetic seal.

benchset: The calibration of the actuator spring range of a control valve, to account for the in service process forces.

body: The main pressure boundary of the valve that also provides the pipe connecting ends, the fluid flow passageway, and supports the seating surfaces and the valve closure member.

bonnet: The portion of the valve that contains the packing box and stem seal and may guide the stem. It may also provide the principal opening to the body cavity for assembly of internal parts or be an integral part of the valve body. It may also provide for the attachment of the actuator to the valve body. Typical bonnets are bolted, threaded, welded to, pressure-sealed, or integral with the body.

butterfly valve: A valve with a circular body and a rotary motion disk closure member, pivotally supported by its shaft.

cage: A part of a valve trim that surrounds the closure member and may provide flow characterization and/ or a seating surface. It may also provide stability, guiding, balance, and alignment, and facilitate assembly of other parts of the valve trim.

capacity: The rate of flow through a valve under stated conditions.

cavitation: A two-stage phenomenon of liquid flow. The first stage is the formation of vapor bubbles within liquid system due to static pressure of fluid at vena contracta falling below the fluid vapor pressure; the second stage is the collapse or implosion of these cavities back into an all-liquid state as the fluid decelerates and static pressure is recovered.

characteristic, flow: An indefinite term, see "characteristic, inherent flow" and "characteristic, installed flow."

- **characteristic, equal percentage:** An inherent flow characteristic which, for equal increments of rated travel, will ideally give equal percentage changes of the existing flow coefficient (Cv).

- **characteristic, inherent:** The relationship between the flow coefficient (Cv) and the closure member travel as it is moved from the closed position to rated travel with constant pressure drop across the valve.

- **characteristic, linear:** An inherent flow characteristic that can be represented by a straight line on a rectangular plot of flow coefficient (Cv) versus rated travel. Therefore, equal increments of travel provide equal increments of flow coefficient (Cv).

- **characteristic, quick opening:** An inherent flow characteristic in which a maximum flow coefficient is achieved with minimal closure member travel.

characterized cam: A component in a valve positioner used to relate the closure member position to the control signal.

characterized trim: Control valve trim that provides predefined flow characteristics.

closure member: The movable part of the valve that is positioned in the flow path to modify the rate of flow through the valve.

closure member configurations (plug):

- **characterized:** Closure member with contoured surface, such as the “vee plug,” to provide various flow characteristics.

- **cylindrical:** A cylindrical closure member with a flow passage through it (or a partial cylinder).

- **eccentric:** Closure member face is not concentric with the stem centerline and moves into seat when closing.

- **eccentric spherical disk:** Disk is spherical segment, not concentric with the disk stem.

- **linear:** A closure member that moves in a line perpendicular to the seating plane.

- **rotary:** A closure member which is rotated into or away from a seat to modulate flow.

coefficient, flow: A constant (Cv) related to the geometry of a valve, for a given valve travel, that can be used to predict flow rate.

control valve: A valve which controls the flow rate or flow direction in a fluid system. The final control element, through which a fluid passes, that adjusts the flow passage as directed by a signal from a controller to modify the flow rate.

dual sealing valve: A valve that uses a resilient seating material for the primary seal and a metal-to-metal seat for a secondary seal.

end connection: The configuration provided to make a joint with the pipe.

- **end connections, flanged:** Valve body with end connections incorporating flanges that mate with corresponding flanges on the piping.

- **end connections, split clamp:** Valve end connections of various proprietary designs using split clamps to apply gasket or mating surface loading.

- **end connections, threaded:** Valve end connections incorporating threads, either male or female.

- **end connections, welded:** Valve end connections which have been prepared for welding to the line pipe or other fittings. May be butt weld (BW), or socket weld (SW).

erosion resistant trim: Valve trim, that has been designed with special surface materials or geometry to resist the erosive effects of the controlled fluid flow.

extension bonnet: A bonnet with a packing box that is extended above the bonnet joint of the valve body so as to maintain the temperature of the packing above or below the temperature of the process fluid. The length of the extension bonnet is dependent upon the difference between the fluid temperature and the packing design temperature limit as well as upon the valve body design.

face to face dimension: The dimension from the face of the inlet opening to the face of the outlet opening of a valve or fitting.

facing, flange: The finish on the end connection that mates with gasket surfaces.

failure mode: The position to which the valve closure member moves when the actuating energy source fails.

- **fail-closed:** A condition wherein the valve closure member moves to a closed position when the actuating energy source fails.

- **fail-in place:** A condition wherein the valve closure member stays in its last position when the actuating energy source fails.

- **fail-open:** A condition wherein the valve closure member moves to an open position when the actuating energy source fails.

- **fail-safe:** A characteristic of a particular valve and its actuator, which upon loss of actuating energy supply, will cause a valve closure member to fully close, fully open or remain in fixed last position. Fail-safe action may involve the use of auxiliary controls connected to the actuator.

flangeless control valve: A valve without integral line flanges, which is installed by bolting between companion flanges, with a set of bolts, or studs, generally extending through the companion flanges.

guides, closure component: The means by which the closure is aligned with the seat and held stable throughout its travel. The guide is held rigidly in the body, bonnet, and/or bottom plate.

hand jack: A manual override device, using a lever, to stroke a valve or to limit its travel.

handwheel: A mechanical manual override device, using a rotary wheel, to stroke a valve or to limit its travel.

hard facing: A material applied to valve internals to resist fluid erosion and/or to reduce the chance of galling between moving parts, particularly at high temperatures.

hard plating: A thin metal deposit, sometimes electroplated, used to induce surface hardening. Hard plating is many orders of magnitude thinner than hard facing.

hysteresis: The maximum difference in output value for any single input value during a calibration cycle, excluding errors due to dead band.

integral seat: A flow control orifice and seat that is an integral part of the body or cage.

jacketed valves: A valve body cast with a double wall or provided with a double wall by welding material around the body so as to form a passage for a heating or cooling medium. Also refers to valves which are enclosed in split metal jackets having internal heat passageways or electric heaters. Also referred to as “steam jacketed” or “vacuum jacketed.” In a vacuum jacketed valve, a vacuum is created in the space between the body and secondary outer wall to reduce the transfer of heat by convection from the atmosphere to the internal process fluid, usually cryogenic.

lantern ring: A rigid spacer assembled in the packing box with packing normally above and below it and designed to allow lubrication of the packing or access for a leak-off connection.

lapping-in: A process of mating contact surfaces by grinding and/or polishing.

leakage, class: Classifications established by ANSI B16.104 to categorize seat leakage tolerances for different sizes of control valve trim.

leakage, seat: The quantity of fluid passing through a valve when the valve is in the fully closed position with pressure differential and temperature as specified.

leak-off gland: A packing box with packing above and below the lantern ring so as to provide a collection point for fluid leaking past the primary seal (lower packing).

lined valve body: A valve body in which a coating or liner has been applied to internal surfaces for corrosion/erosion protection or for flow shut off.

liner, slip-in: An annular shaped liner which makes a slight interference fit with the body bore and which may be readily forced into position through the body end. May be plain or reinforced. Applies to butterfly valves.

liquid pressure recovery factor: The ratio (F_L) of the valve flow coefficient (Cv) based on the pressure drop at the vena contracta, to the usual valve flow coefficient (Cv) which is based on the overall pressure drop across the valve in non-vaporizing liquid service. These coefficients compare with the orifice metering coefficients of discharge for vena contracta taps and pipe taps, respectively. See ANSI/ISA-S75.01 “Control Valve Sizing Equations.”

lubricator isolating valve: A manually operated valve used to isolate the packing lubricator assembly from the packing box.

lubricator packing box: A packing arrangement consisting of a lantern ring with packing rings above and below with provision to lubricate the packing.

mechanical limit stop: A mechanical device to limit the valve stem travel.

mounting position: The location and orientation of an actuator or auxiliary component relative to the control valve. This can apply to the control valve itself relative to the piping.

multiple orifice: A style of valve trim where the flow passes through a multiple of orifices in parallel or in series.

nominal size: A numerical designation of size which is common to all components in a piping system other than components designated by outside diameters or by thread size. It is a convenient round number for reference purposes and is only loosely related to manufacturing dimensions. ISO uses initials DN as an abbreviation for the term with the letters DN followed by a numerical value designating size. All equipment of the same nominal size and nominal pressure rating shall have the same mating dimensions appropriate to the type of end connections.

packing: A sealing system consisting of deformable material contained in a packing box which usually has an adjustable compression means to obtain or maintain an effective seal.

packing box: The chamber, in the bonnet, surrounding the stem and containing packing and other stem sealing parts.

packing flange: A device that transfers the deforming mechanical load to the packing follower.

packing follower: A part which transfers the deforming mechanical load to the packing from the packing flange or nut.

packing lubricator assembly: A device for injection of lubricant/sealer into a lubricator packing box.

pinch or clamp valve: A valve consisting of a flexible elastomeric tubular member connected to two rigid flow path ends whereby modulation and/or shut off of flow is accomplished by squeezing the flexible member into eventual tight sealing contact.

plug: A term frequently used to refer to the closure member.

plug valve: A rotary motion valve with a closure member that may be cylindrical or conical.

port: The flow control orifice of a control valve.

port guiding: A valve closure member with wings or a skirt fitting into the seat ring bore.

positioner: A position controller, which is mechanically connected to a moving part of a final control element or its actuator, and automatically adjusts its output pressure to the actuator in order to maintain a desired position that bears a predetermined relationship to the input signal. The positioner can be used to modify the action of the valve (reversing positioner), extend the stroke/controller.

positioner, double acting: A positioner with two outputs, suited to a double acting actuator.

positioner, single acting: A positioner with one output, suited to a spring opposed actuator.

position switch: A position switch is a pneumatic, hydraulic or electrical device which is linked to the valve stem to detect a single, preset valve stem position.

position transmitter: The position transmitter is a device that is mechanically connected to the valve stem or shaft and generates and transmits a pneumatic or electrical signal representing the valve position.

post guiding: A design using guide bushing or bushings fitted into the bonnet or body to guide the plug's post.

pressure energized seal: A seal energized by differential pressure.

rangeability inherent: The ratio of the largest flow coefficient (Cv) to the smallest flow coefficient (Cv) within which the deviation from the specified inherent flow characteristic does not exceed the stated limits.

rated travel: The amount of movement of the valve closure member from the closed position to the rated full open position.

seat: The area of contact between the closure component and its mating surface which establishes valve shut-off.

seat ring: A part of the valve body assembly that provides a seating surface for the closure member and may provide part of the flow control orifice.

shaft: The mechanical member used to support a rotary closure member.

spring rate: The force change per unit change in length of a spring.

stem connector: The device which connects the actuator stem to the valve stem.

stem guide: A guide bushing closely fitted to the valve stem and aligned with the seat.

three-way valve: A valve with three end connections, used for mixing or diverting flow.

throttling: The action of a control valve to regulate fluid flow by varying the position of the closure member. This service generates a variable pressure drop.

transducer: A device that is actuated by power from one system and supplies power in another form to a second system.

travel: The movement of the closure member from the closed position to an intermediate or rated full open position.

travel indicator: A pointer and scale used to externally show the position of the closure member; typically in terms of units of opening percent of travel or degrees of rotation.

trim: The internal components of a valve which modulate the flow of the controlled fluid.

- **trim, anti-cavitation:** A combination of control valve trim that by its geometry reduces the tendency of the controlled liquid to cavitate.

- **trim, anti-noise:** A combination of control valve trim that by its geometry reduces the noise generated by fluid flowing through the valve.

- **trim, balanced:** Control valve trim designed to minimize the net static and dynamic fluid flow forces acting on the trim.

- **trim, reduced:** Control valve trim which has a flow area smaller than the full flow area for that valve.

- **trim, soft seated:** Valve trim with an elastomeric, plastic or other readily deformable material used either in the closure component or seat ring to provide tight shutoff with minimal actuator forces.

unbalance, dynamic: The net force/torque produced on the valve stem/shaft by fluid pressure acting on the closure member and stem/shaft at stated travel and <u>flowing conditions</u>.

unbalance, static: The net force produced on the valve stem by the fluid pressure acting on the closure member and stem with the <u>fluid at rest</u> and with stated pressure conditions.

valve: A device used for the control of fluid flow, consisting of a fluid retaining assembly, one or more ports between end openings and a movable closure member which opens, restricts or closes the port(s).

- **valve, ball:** A valve with a rotary motion closure member consisting of a full ball or a segmented ball.

- **valve, diaphragm type:** A valve with a flexible linear motion closure member which is moved into the fluid flow passageway of the body to modify the rate of flow through the valve by the actuator.

- **valve, floating ball:** A valve with a full ball positioned within the valve that contacts either of two seat rings and is free to move toward the seat ring opposite the pressure source when in the closed position to effect tight shutoff.

- **valve, globe:** A valve with a linear motion closure member, one or more ports and a body distinguished by a globular shaped cavity around the port region.

vena contracta: The location in a flow stream where fluid velocity is at its maximum and fluid static pressure and the cross-sectional area are at their minimum. In a control valve, the vena contracta normally occurs just downstream of the actual physical restriction.

yoke: The structure which rigidly connects the actuator power unit to the valve.

SECTION 2

Control Valve
Basic Designs

CONTROL VALVE CLASSIFICATION

In addition to LINEAR and ROTARY, control valves are also classified according to their GUIDING METHODS, CHARACTERIZATION METHODS, and the nature of SERVICES they are applied within.

CONTROL VALVE

- **LINEAR SLIDING STEM**
  - Globe
    - Angle
    - 3-Way
      - Mixing
      - Diverting
    - Std.-Straight
      - Double Seated
        - Semi-Balanced
      - Single Seated
        - Std. Body
        - Split Body
        - Balanced FTC
        - Unbalanced FTO
        - Unbalanced FTC
  - Diaphragm
  - Pinch
- **ROTARY**
  - Butterfly
    - Lined
    - Unlined
      - Metal Seated
      - Swing-Thru
    - Eccentric (Hi-Performance)
  - Ball
    - Full
    - Segmented
    - V-Notch
  - Eccentric Plug (Rotary Globe)
    - FTC
    - FTO

GUIDING

- Cage
- Seat/Skirt
- Stem
  - Top (Post)
  - Top & Bottom

ACTUATOR

- Spring - Diaphragm
- Double -ActingPiston
- Electric Motor
- Electrohydraulic

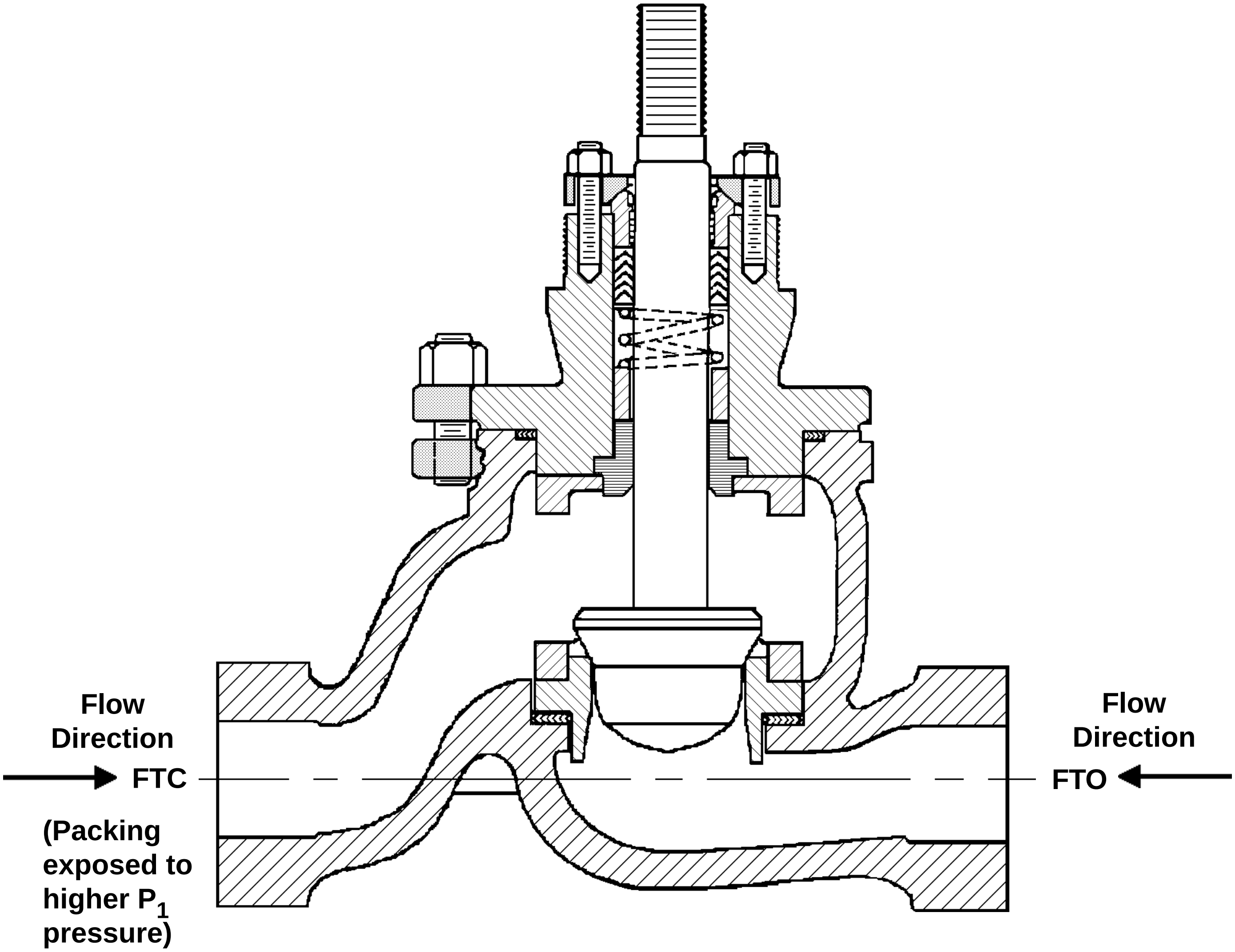
SERVICE

- General Utility
- Corrosive
- High Temperature
- High Pressure
- High Temperature & Pressure
- Cryogenic
- Severe
  - Noise
  - Cavitating
  - Flashing
  - Abrasive
  - Combos

CHARACTERIZATION

- Cage
- Seat Ring
- Cam; end-of-shaft (Rotary)
- Plug
  - Contoured Head
  - Fluted
  - Skirted

LINEAR CONTROL VALVE

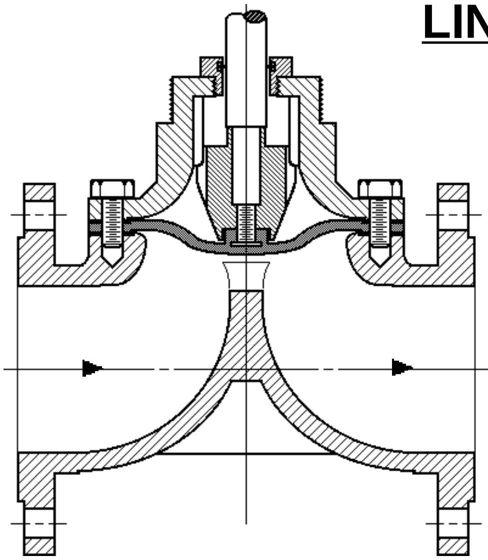


GLOBE VALVE

FTC — Flow To Close

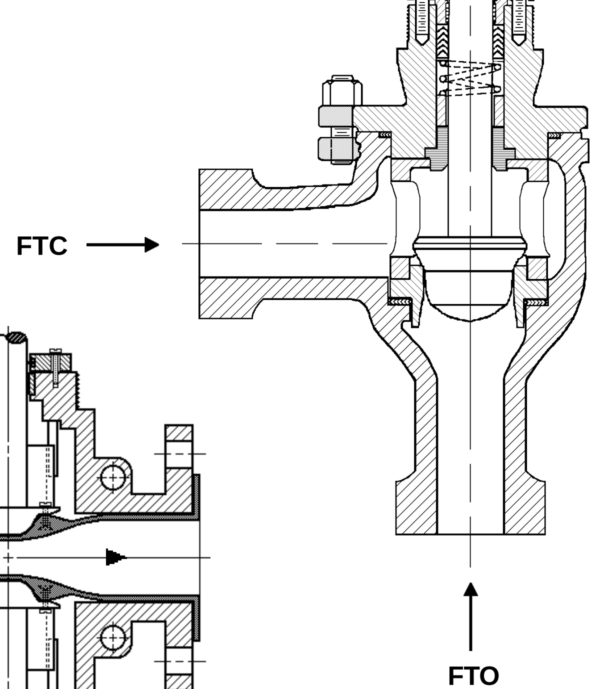
FTO — Flow To Open

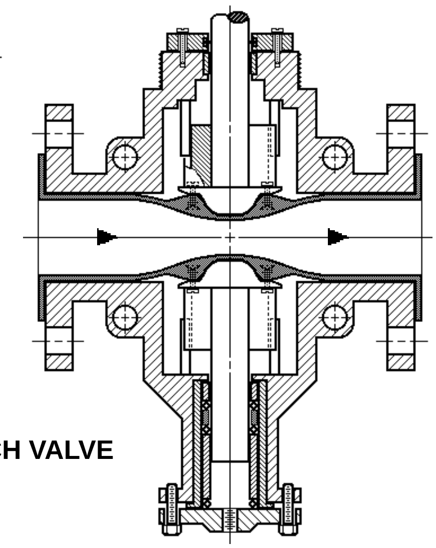
LINEAR CONTROL VALVES



DIAPHRAGM VALVE

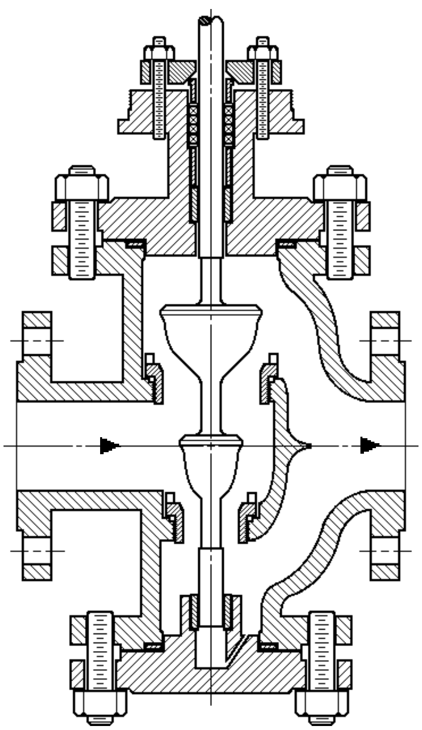
ANGLE GLOBE VALVE

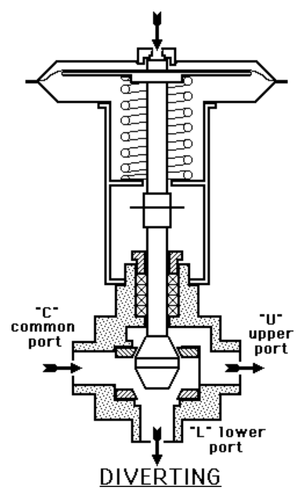




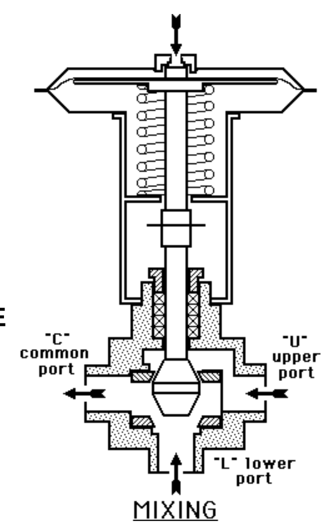
PINCH VALVE

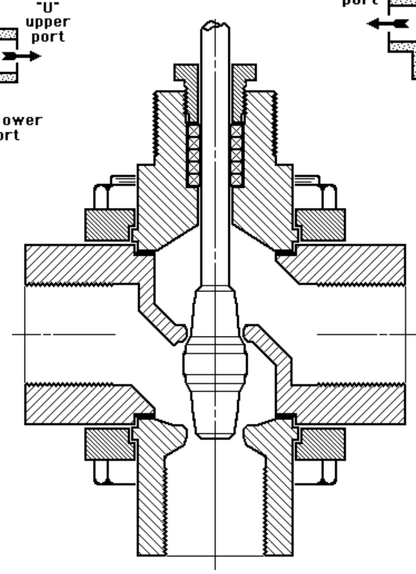
DOUBLE-SEATED GLOBE VALVE





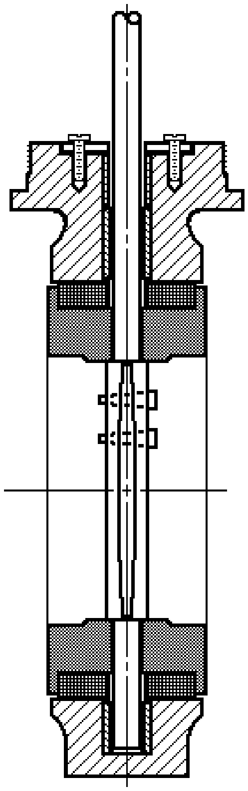
THREE-WAY GLOBE VALVE



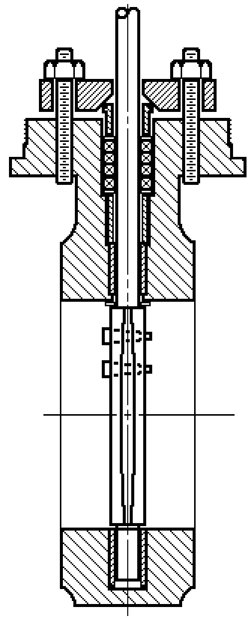


ROTARY CONTROL VALVES

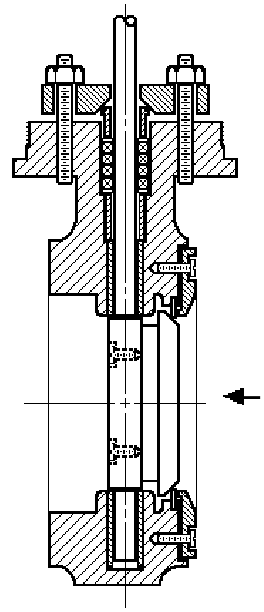
BUTTERFLY (FLANGELESS) VALVES



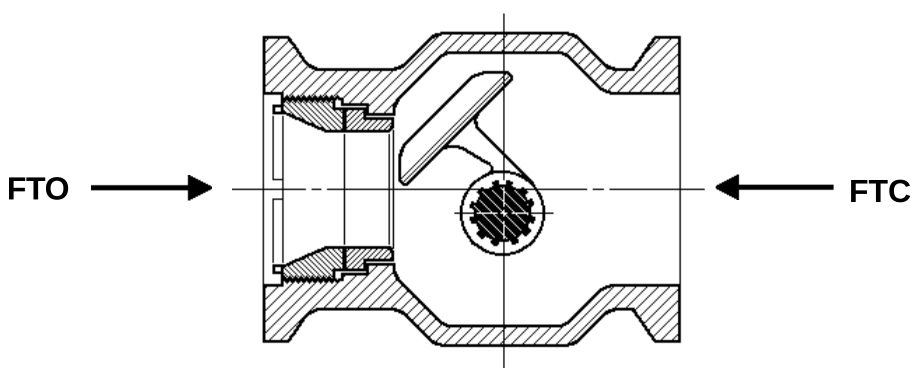
Lined



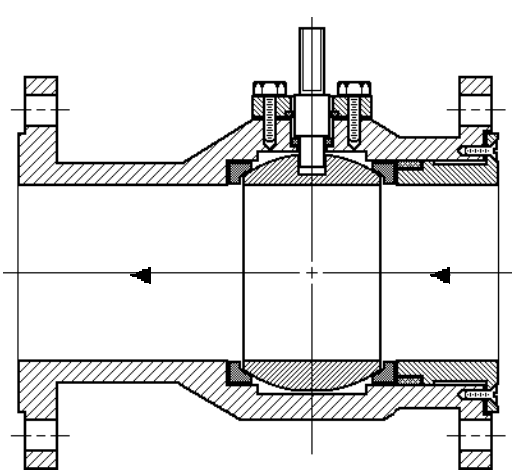
**Metal-Seated,
Swing-Thru**



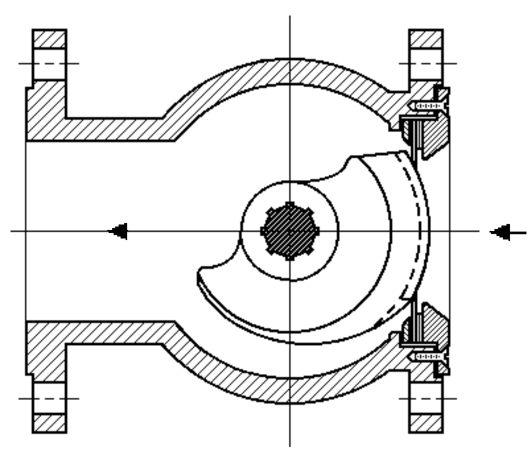
**Eccentric,
High Performance**



ECCENTRIC PLUG VALVE



FULL BALL VALVE



V-NOTCH BALL VALVE

SOME OF THE DIFFERENCES BETWEEN “THROTTLING” AND ON-OFF VALVES:

THROTTLING

- Dissipate ΔP
- Small shafts
- Heavy guiding
- Tighter internal tolerances
- Minimum actuator power
- Subject to high velocity; greater wear, vibration
- Subject to cavitation and flashing
- Limited life installed
- Limited ΔP capability
- Internal unbalanced forces
- Noise IS a consideration
- Internal design centers around characterization & guiding

ON-OFF

- No/Minimum ΔP dissipated
- Large shafts
- Loose/light guiding
- Greater internal tolerances
- Overpowering actuator
- Low velocity normal; minimal wear and vibration
- No cavitation or flashing
- Long life installed
- Δ P capability up to end conn pressure class maximum
- Minimal unbalanced forces
- Noise is NOT a consideration
- Internal design centers around seat design

ADVANTAGES — ROTARY VS. LINEAR

PERFORMANCE FACTOR	ROTARY	LINEAR
Capacity - Cv	X	
High $\Delta P_{Throttling}$		X
High $\Delta P_{Shutoff}$	X	
Rangeability	X	
Reduced Port Incorporation		X
First Cost - $	X	
$ - Cost/Cv	X	
Cavitation Resistant		X
Noise Resistant		X
Abrasion Resistant	X	
Slurry Flow - Solids + Liquid	X	
Ease of Maintenance		X
Replacement Parts Cost - $	X	
Packing Problems	X	
Simplicity		X
Compactness (with spring-diaphragm actuator)		X
Operation (without positioner)		X

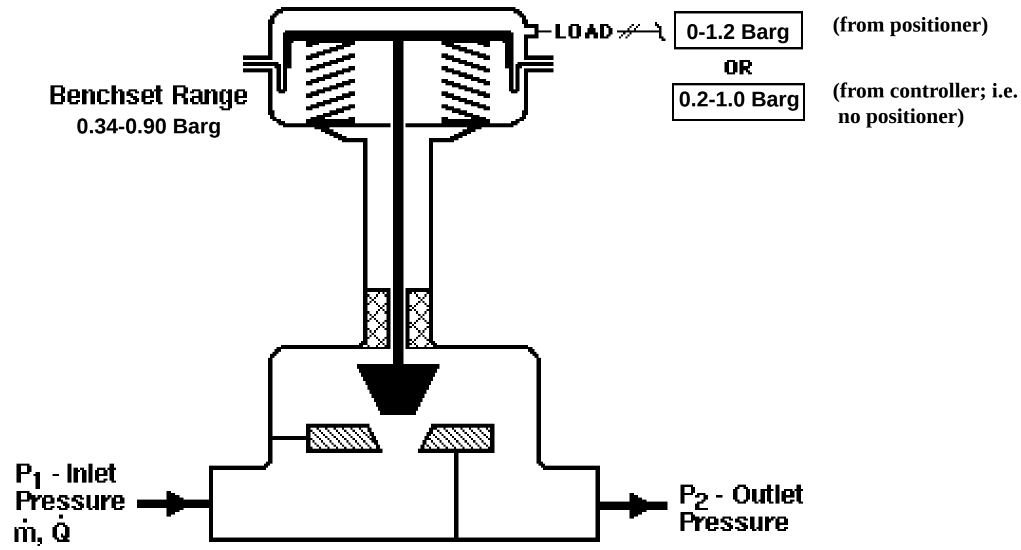
This summary indicates —

<u>"THROTTLING" ROTARY CONTROL VALVES HAVE THEIR PLACE.</u>

The main question is — "Where"??

- **High capacity @ low ΔP's**
- **Broad rangeability; i.e. Equal % characterization**
- **High $\Delta P_{Shutoff}$**
- **Cost is a major factor**
- **Flow that includes solids**

THROTTLING CONTROL VALVES — THE PRESSURES, ΔP'S, AND PRESSURE RANGES



ATC-FO

$$\Delta P_{Throttling} = P_1 - P_2$$
$$\Delta P_{Sizing} = P_{1\,Min} - P_{2\,Max} = \Delta P_{Min}$$
$$\Delta P_{Shutoff} = P_{1\,Max} - 0 = P_{1\,Max}$$

ΔP_{Sizing} is required to properly select the valve body size and port (orifice) size to handle the maximum flow rate ($\dot{m}$, $\dot{Q}$) at ΔP_{Min}.

$\Delta P_{Shutoff}$ is required to properly size the actuator's diaphragm area and its benchset range, and the valve body's port (orifice) size.

BENCHSET RANGE is determined by the spring rate of the actuator fail-safe range spring(s). It is expressed for a given actuator (with its particular diaphragm area) by the actuator's pneumatic "LOAD" pressure that opposes the range spring, and gives the theoretical pressures at beginning of stroke and completion of full stroke.

PNEUMATIC INSTRUMENT SIGNAL is the output from pneumatic control device – controller, manual loader, relay, transducer, etc. – that is normally a 3-15 psig "SIG" pressure that is proportional to some process variable. (Note: Some older systems use a 2-fold multiple – 6-30 psig; this is rare.)

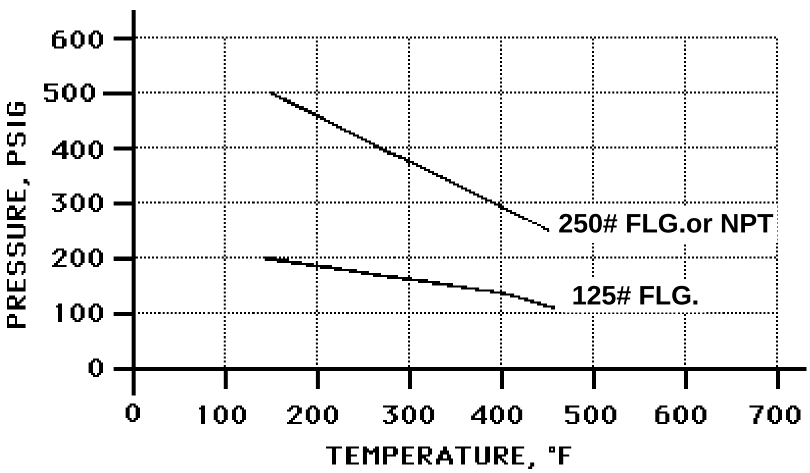
The "PRESSURES" involved and their effects —

Max Inlet Pressure —

- **Determines end connection pressure class.**
- **Determines body wall thickness.**
- **Determines bolting-body, flange, line-suitability.**
- **Influences body material.**

Note: Temperature also enters into consideration. T is inversely related to P — as T goes up, max inlet P goes down; vice versa.

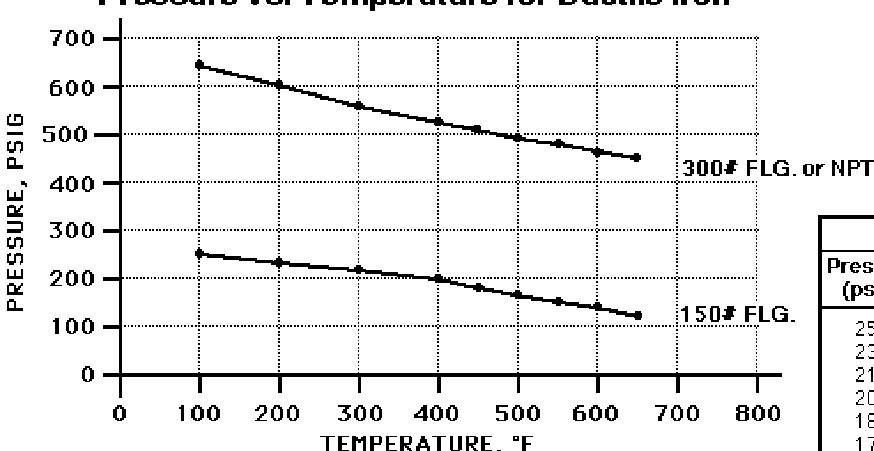
Pressure vs. Temperature for Cast Iron



CAST IRON

125# Flg.		250# Flg. or NPT	
Pressure (psig)	Temperature (°F)	Pressure (psig)	Temperature (°F)
200	-20 to +150	500	-20 to +150
190	200	460	200
175	250	415	250
165	300	375	300
140	400	335	350
125	450	290	400
		250	450

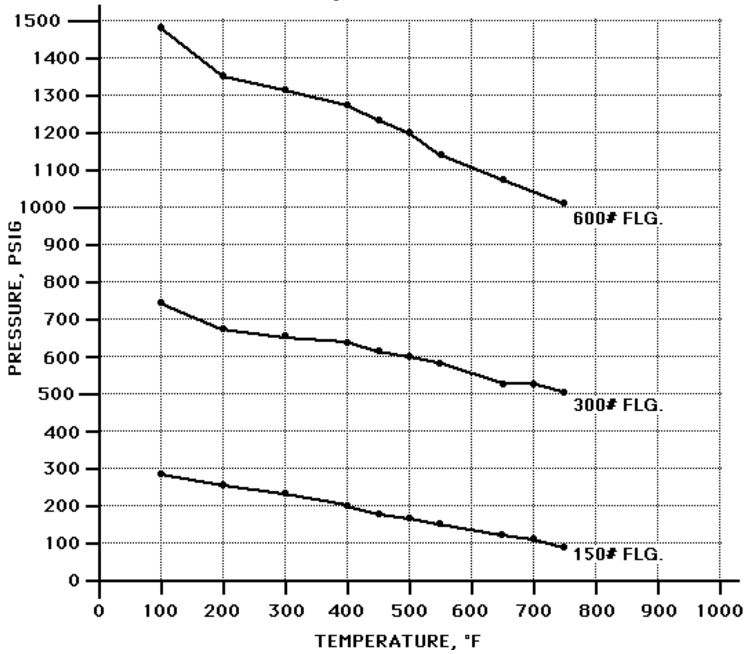
Pressure vs. Temperature for Ductile Iron



DUCTILE IRON

150# Flg.		300# Flg. or NPT	
Pressure (psig)	Temperature (°F)	Pressure (psig)	Temperature (°F)
250	-20 to +100	640	-20 to +100
235	200	600	200
215	300	565	300
200	400	525	400
185	450	510	450
170	500	495	500
155	550	480	550
140	600	465	600
125	650	450	650

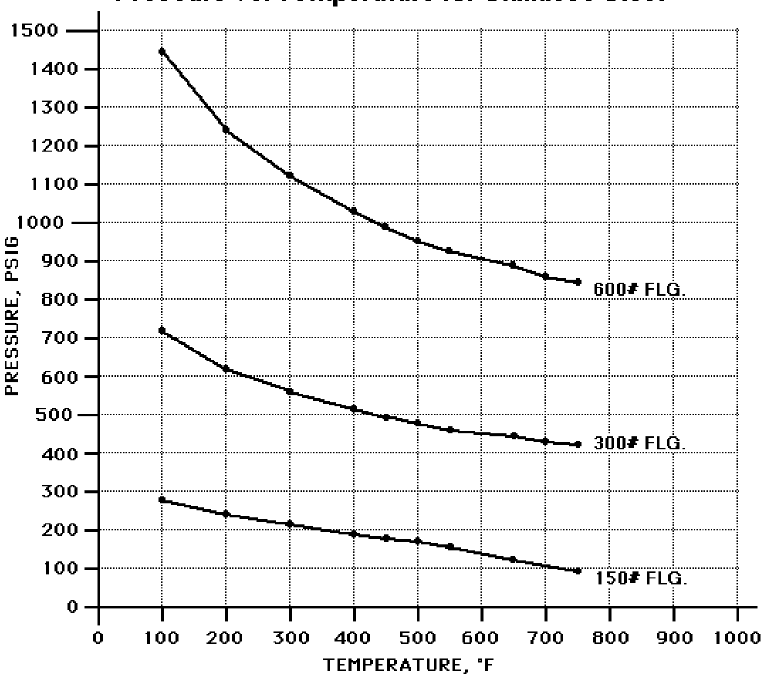
Pressure vs. Temperature for Carbon Steel



CARBON STEEL

150# Flg.		300# Flg.		600# Flg.	
Pressure (psig)	Temperature (°F)	Pressure (psig)	Temperature (°F)	Pressure (psig)	Temperature (°F)
285	-20 to +100	740	-20 to +100	1480	-20 to +100
260	200	675	200	1350	200
230	300	655	300	1315	300
200	400	635	400	1270	400
185	450	615	450	1235	450
170	500	600	500	1200	500
155	550	575	550	1145	550
125	650	535	650	1075	650
110	700	535	700	1010	750
95	750	505	750		

Pressure vs. Temperature for Stainless Steel



STAINLESS STEEL

150# Flg.		300# Flg.		600# Flg.	
Pressure (psig)	Temperature (°F)	Pressure (psig)	Temperature (°F)	Pressure (psig)	Temperature (°F)
275	-20 to +100	720	-20 to +100	1440	-20 to +100
240	200	620	200	1240	200
215	300	560	300	1120	300
195	400	515	400	1030	400
180	450	495	450	990	450
170	500	480	500	955	500
155	550	465	550	930	550
125	650	445	650	890	650
95	750	430	700	865	700
		425	750	845	750

<u>Sizing Pressure Drop</u> — $\Delta P_{sizing} = P_1 - P_2$

- **Determines Cv ⟶ suitable body size.**
- **Influences trim design.**

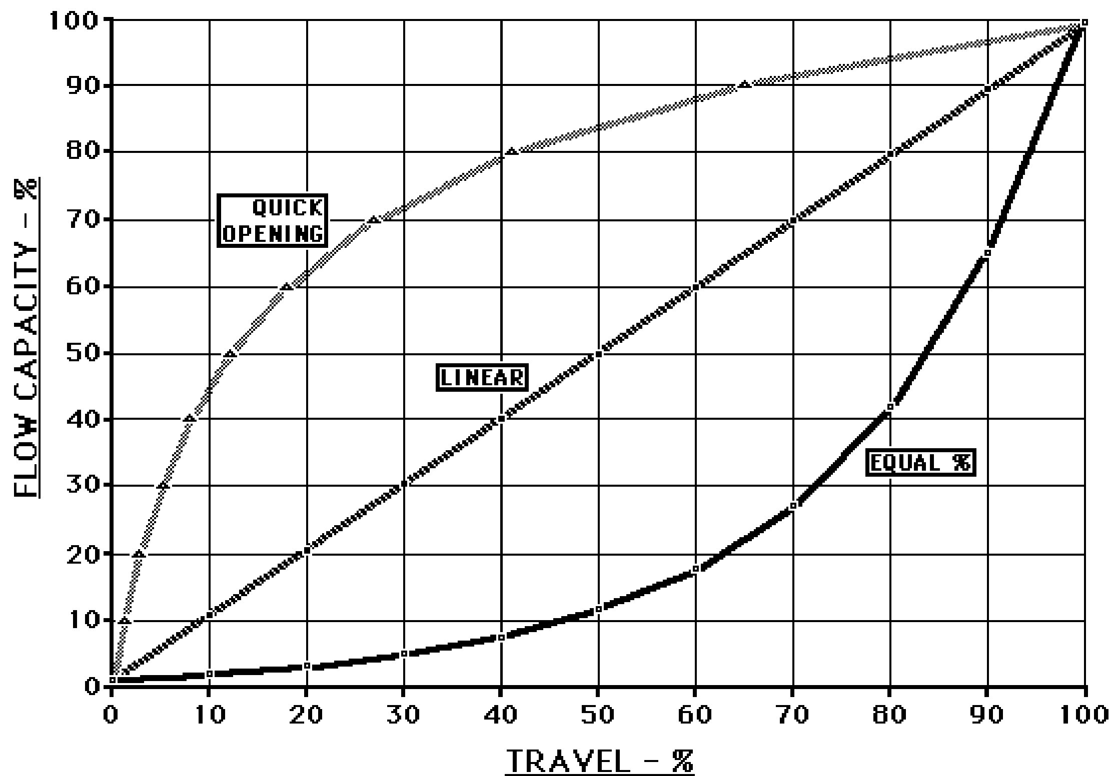
<u>Shutoff Pressure Drop</u> — $\Delta P_{shutoff} \approx P_{1\,max} - P_{2\,min}$

- **Determines actuator size/diaphragm area.**
- **Influences actuator benchset range.**
- **Influences body port size; full or reduced.**

SECTION 3

Characterization and Trim Designs

COMMON FLOW CHARACTERISTIC CURVES



PRESSURE CONTROL SYSTEMS	
APPLICATION - SERVICE	BEST CHARACTERISTIC
Liquid Process.	Equal %
Gas Proceses.----- Small volume. Less than 10 ft. of pipe between control valve and flow destination.	Equal %
Large volume. Receiver volume tank in system; greater than 100 ft. of pipe volume. Decreasing ΔP with increasing volume. ΔP at max. load > 20% of min. load.	Linear
Large volume. Decreasing ΔP with increasing volume; ΔP at max load < 20% of min. load.	Equal %

LIQUID LEVEL CONTROL SYSTEMS	
APPLICATION - SERVICE	BEST CHARACTERISTIC
Constant ΔP.	Linear
Decreasing ΔP with increasing flow. ΔP at max. flow > 20% of min. flow ΔP.	Linear
Decreasing ΔP with increasing flow. ΔP at max. flow < 20% of min. flow ΔP.	Equal %
Incresing ΔP with increasing flow. ΔP at max. flow < 200% of min. flow ΔP.	Linear
Increasing ΔP with increasing flow. ΔP at max. flow > 200% of min. flow ΔP.	Quick Opening

MISCELLANEOUS SYSTEMS	
APPLICATION - SERVICE	BEST CHARACTERISTIC
3-way valve or two 2-way valves used as a 3-way valve.	Linear
Compressor gas recycle.	Linear
ΔP = Constant.	Linear
Temperature control wher valve ΔP < 50% of total system ΔP.	Equal %
pH Control:-----	
ΔP < 50% of system ΔP.	Equal %
ΔP > 50% of system ΔP.	Linear
Heating - Cooling	Linear
Split-ranged	Linear
ON-OFF	Quick Opening

FLOW RATE CONTROL SYSTEMS			
APPLICATION - SERVICE		BEST CHARACTERISTIC	
FLOW ELEMENT OUTPUT SIGNAL TO CONTROLLER	LOCATION OF CONTROL VALVE WITH RESPECT TO FLOW ELEMENT	RANGE OF FLOW	
		WIDE	SMALL*
Linear, propor-tional to flow; ie. with square root extractor.	In Series	Linear	Equal %
	In Bypass	Linear	Equal %
Non-linear, not proportional to flow; no square root extractor. Proportional to flow squared.	In Series	Linear	Equal %
	In Bypass	Equal %	Equal %

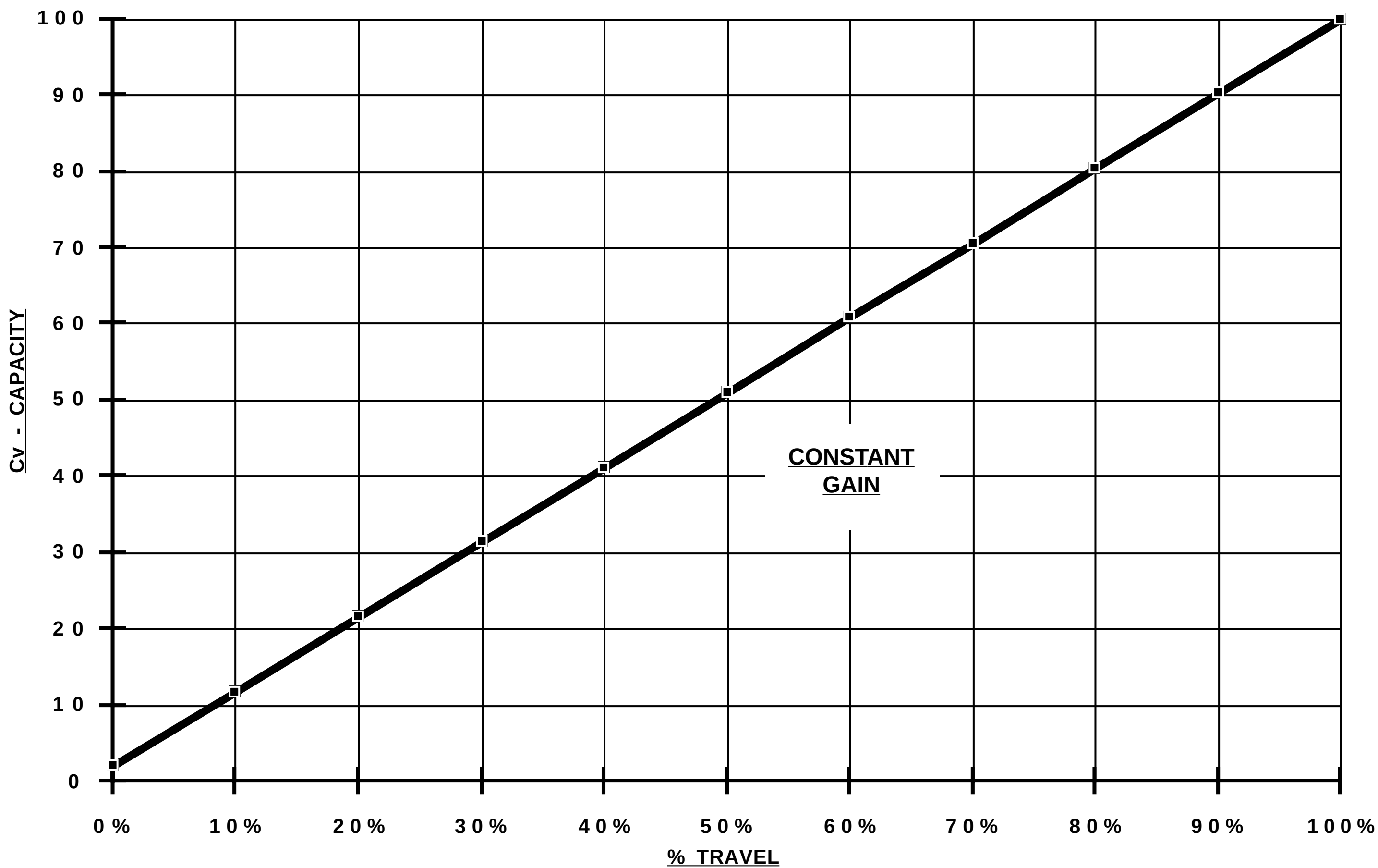
* With large ΔP change with increasing flow.

LINEAR CHARACTERISTIC CURVE

$$Cv_{Actual} = Cv_{Max} \left\{ \left[\frac{\%Travel}{100} \text{ x } \left(1 - \frac{1}{Rangeability}\right) \right] + \left(\frac{1}{Rangeability} \right) \right\}$$

% Travel	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
{ }	.020	.118	.216	.314	.412	.510	.608	.706	.804	.902	1.000
Cv Actual	2.0	11.8	21.6	31.4	41.2	51.0	60.8	70.6	80.4	90.2	100.0

Valve with - Cv = 100, Rangeability = 50:1



Cv @ 30% = 31.4
Cv @ 40% = 41.2

% Change = $\frac{(41.2 - 31.4)}{31.4}$ x 100%

= 31.2%

*** * * % change is NOT equal !!**

Cv @ 70% = 70.6
Cv @ 80% = 80.4

% Change = $\frac{(80.4 - 70.6)}{70.6}$x100%

= 13.9%

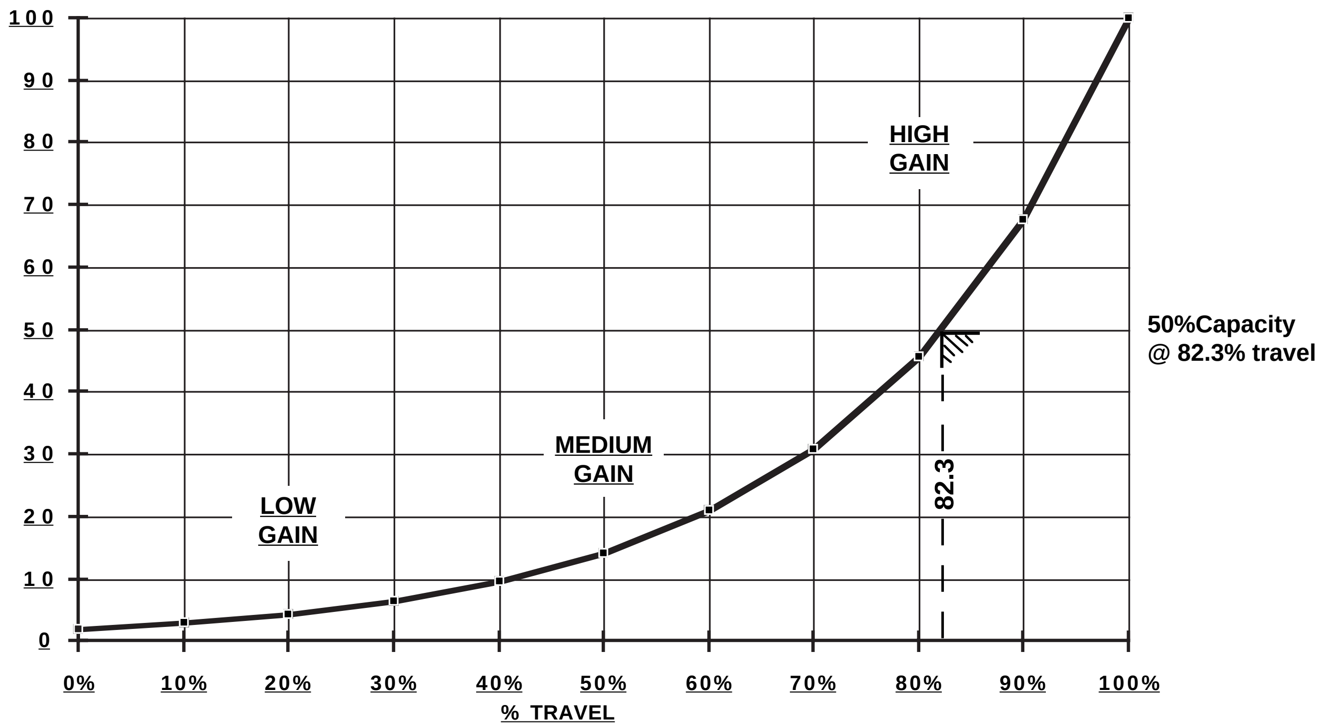
EQUAL PERCENTAGE CURVE

$$Cv_{Actual} = \frac{Cv\ @\ 100\%}{Rangeability} \times e^{\left[\frac{(\%Travel) \times LN(Rangeability)}{100}\right]}$$

% Travel	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
[%TRAVEL*LN(RGBLTY)]/100	0.00	0.39	0.78	1.17	1.56	1.96	2.35	2.74	3.13	3.52	3.91
EXP(LN Function)	1.00	1.48	2.19	3.23	4.78	7.07	10.46	15.46	22.87	33.81	50.00
[Cv_{Max}/(RGBLTY)]*[EXP(LN Function)]	2.00	2.96	4.37	6.47	9.56	14.14	20.91	30.92	45.73	67.62	100.00

Valve with - Cv = 100, Rangeability = 50:1

=% CHARACTERISTIC CURVE



It is worthwhile to consider the case of Cv = 50% of Cv_{Max}:

Cv_{Actual} = 50
Cv@100% = 100
Rangeability = 50

$$e^{Exp} = \frac{Cv_{Actual} \times Rangeability}{Cv\ @\ 100\%}$$

$$= \frac{50 \times 50}{100} = 25.00$$

Exp = LN(25.00)
= 3.22
Exp = % Travel x LN(Rangeability)
% Travel = 3.22/LN(50) = 82.3%

Cv @ 30% = 6.47
Cv @ 40% = 9.56

$$\% \text{ Change} = \frac{(9.56 - 6.47)}{6.47} \times 100\% = \boxed{47.8\%}$$

Cv @ 70% = 30.92
Cv @ 80% = 45.73

$$\% \text{ Change} = \frac{(45.73 - 30.92)}{30.92} \times 100\% = \boxed{47.9\%}$$

*** * * "Equal %" change along the curve!**

LINEAR RESPONSE							
TRAVEL	SIGNAL		POSITIONER OUTPUT BENCHSET RANGE - psig				
	P/P, psig	I/P, mA	3-15	5-13	6-30	10-26	8-20
0%	3	4	3	5	6	10	8
25%	6	8	6	7	12	14	11
50%	9	12	9	9	18	18	14
75%	12	16	12	11	24	22	17
100%	15	20	15	13	30	26	20

EQUAL PERCENT RESPONSE							
TRAVEL	SIGNAL		POSITIONER OUTPUT BENCHSET RANGE - psig				
	P/P, psig	I/P, mA	3-15	5-13	6-30	10-26	8-20
0%	3	4	3.0	5.0	6.0	10.0	8.0
20%	5.4	7.2	3.5	5.4	7.1	10.7	8.5
40%	7.8	10.4	4.0	5.8	8.2	11.4	9.1
50%	9.0	12.0	4.6	6.2	9.4	12.2	9.7
60%	10.2	13.6	5.5	6.7	11.0	13.3	10.5
70%	11.4	14.2	6.7	7.5	13.4	14.9	11.7
80%	12.6	16.8	8.5	8.7	17.0	17.3	13.5
90%	13.8	18.4	11.1	10.4	22.2	20.8	16.1
100%	15.0	20.0	15.0	13.0	30.0	26.0	20.0

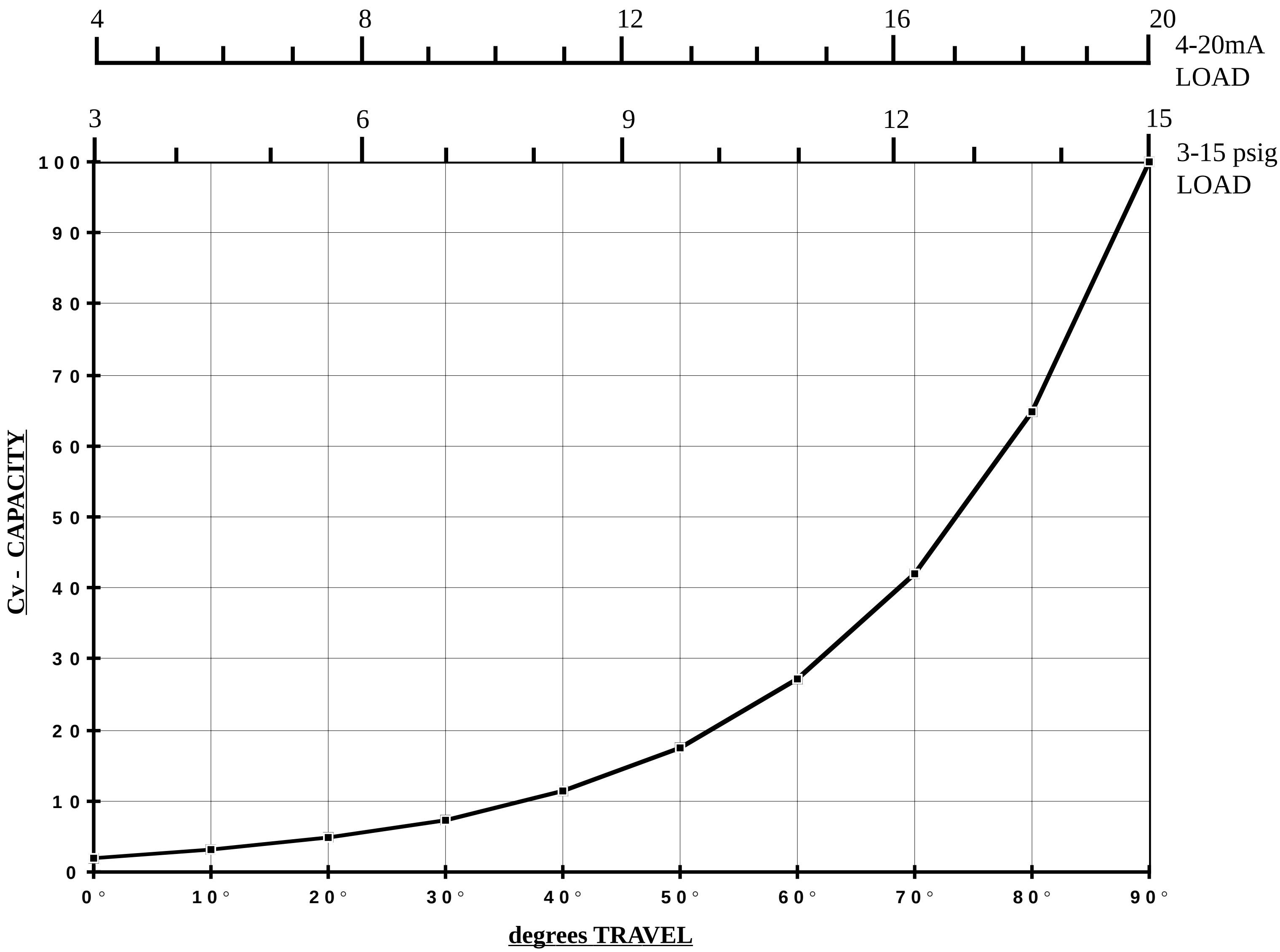
EQUAL PERCENTAGE CURVE — ROTARY

$$Cv_{Actual} = \frac{Cv \text{ @ } 90°}{Rangeability} \times e^{\left[\frac{(\text{deg Travel}) \times LN(\text{Rangeability})}{90°}\right]}$$

degrees Travel	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
[degree TRAVEL*LN(RGBLTY)]/90	0.00	0.43	0.87	1.30	1.74	2.17	2.61	3.04	3.48	3.91
EXP(LN Function)	1.00	1.54	2.39	3.68	5.69	8.79	13.57	20.96	32.37	50.00
[Cv_{Max}/(RGBLTY)]*[EXP(LN Function)]	2.00	3.09	4.77	7.37	11.38	17.58	27.14	41.92	64.75	100.00

Valve with - Cv = 100, Rangeability = 50:1

=% CHARACTERISTIC CURVE

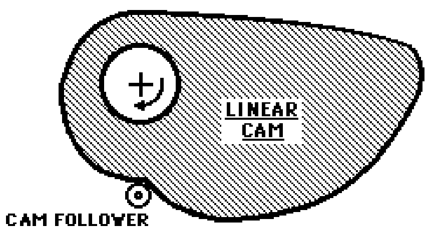


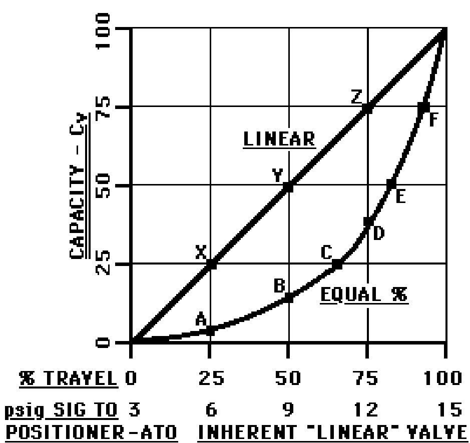
CHARACTERIZATION of ROTARY CONTROL VALVES

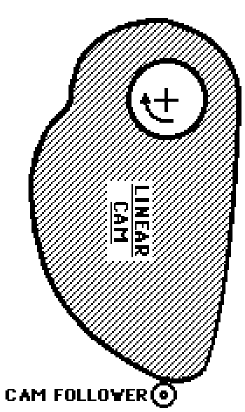
IT IS NOT PRACTICAL OR POSSIBLE TO HAVE A GEOMETRICALLY CHARACTERIZED PLUG AND/OR SEAT RING FOR ROTARY —— ECCENTRIC PLUG, BALL, OR BUTTERFLY —— VALVES.

TO CHARACTERIZE THESE VALVE DESIGNS TO SOMETHING OTHER THAN THE VALVE'S INHERENT (BUILT-IN) CHARACTERISTIC, A "*CHARACTERIZED CAM*" IS LOCATED ON THE ROTATING SHAFT. BY INCORPORATING THE VALVE'S *INHERENT CHARACTERISTIC* TOGETHER WITH THE *GEOMETRIC SHAPE OF THE CAM LOBE* COUPLED WITH THE CAM PROVIDING "*MECHANICAL FEEDBACK*" TO A *POSITIONER*, A ROTARY VALVE CAN *SIMULATE ANY DESIRED CHARACTERISTIC*.

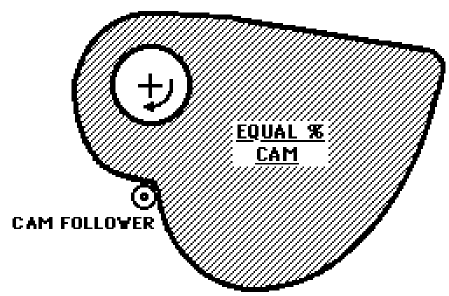
LINEAR

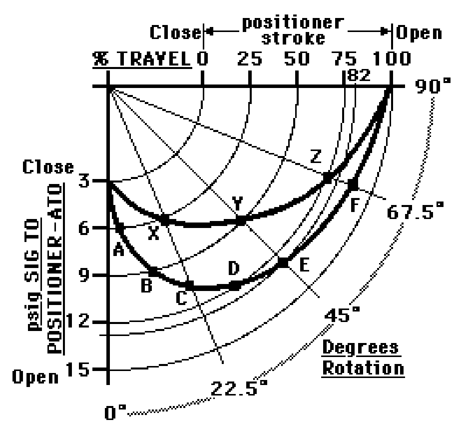


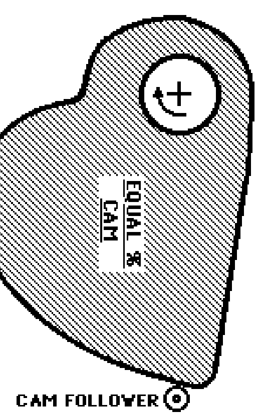




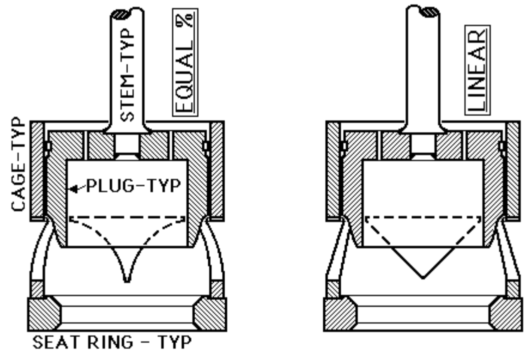
EQUAL %



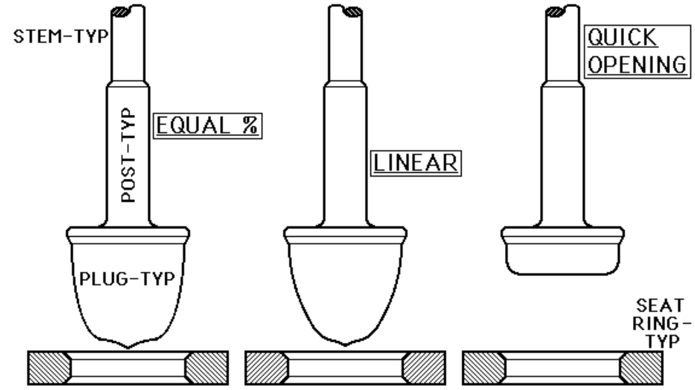




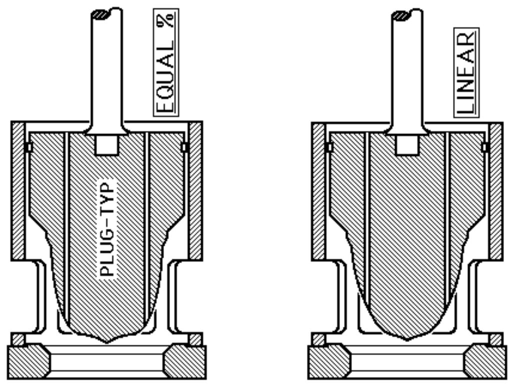
GLOBE VALVE CHARACTERIZATION & TRIM DESIGN



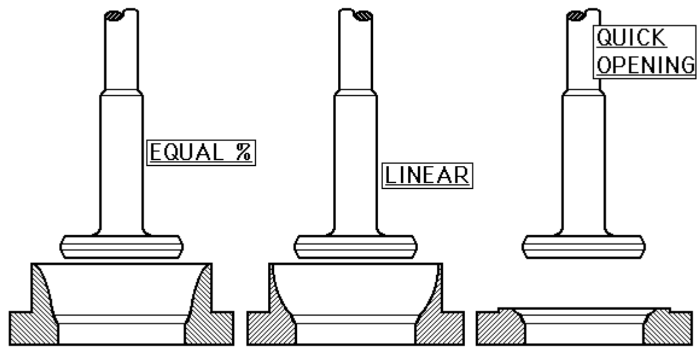
CHARACTERIZATION IN CAGE – COMMON SEAT RING & COMMON PLUG – BALANCED TRIM – CAGE GUIDED



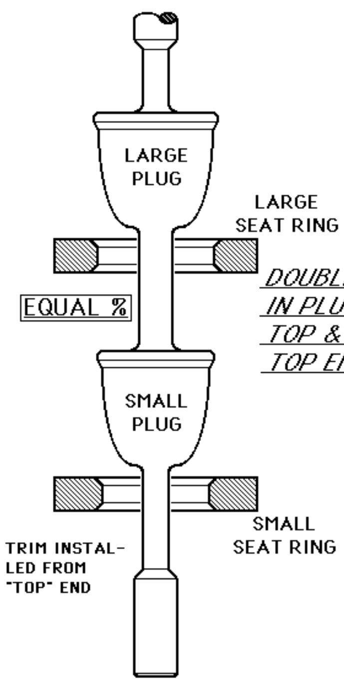
CHARACTERIZATION IN PLUG – COMMON SEAT RING – TOP POST GUIDED



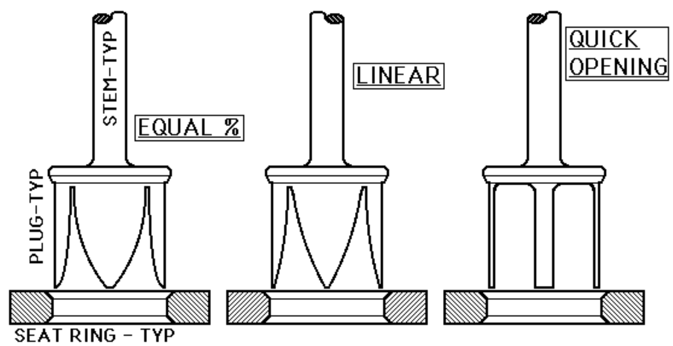
CHARACTERIZATION IN PLUG – COMMON SEAT RING & CAGE – BALANCED TRIM – CAGE GUIDED



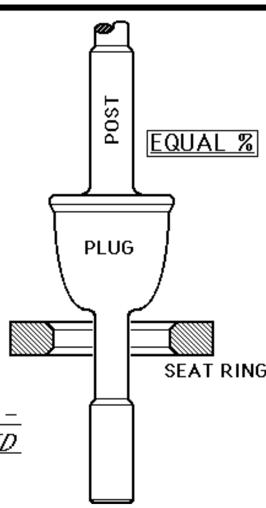
CHARACTERIZATION IN SEAT RING – COMMON PLUG – TOP POST GUIDED



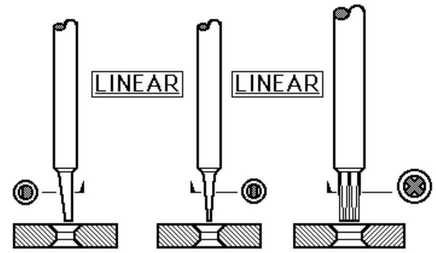
DOUBLE PORT – CHARACTERIZATION IN PLUGS – SEMI-BALANCED TRIM – TOP & BOTTOM GUIDED – TOP ENTRANCE



CHARACTERIZATION IN PLUG – COMMON SEAT RING – SKIRT/SEAT/PORT GUIDED



CHARACTERIZATION IN PLUG – TOP & BOTTOM GUIDED



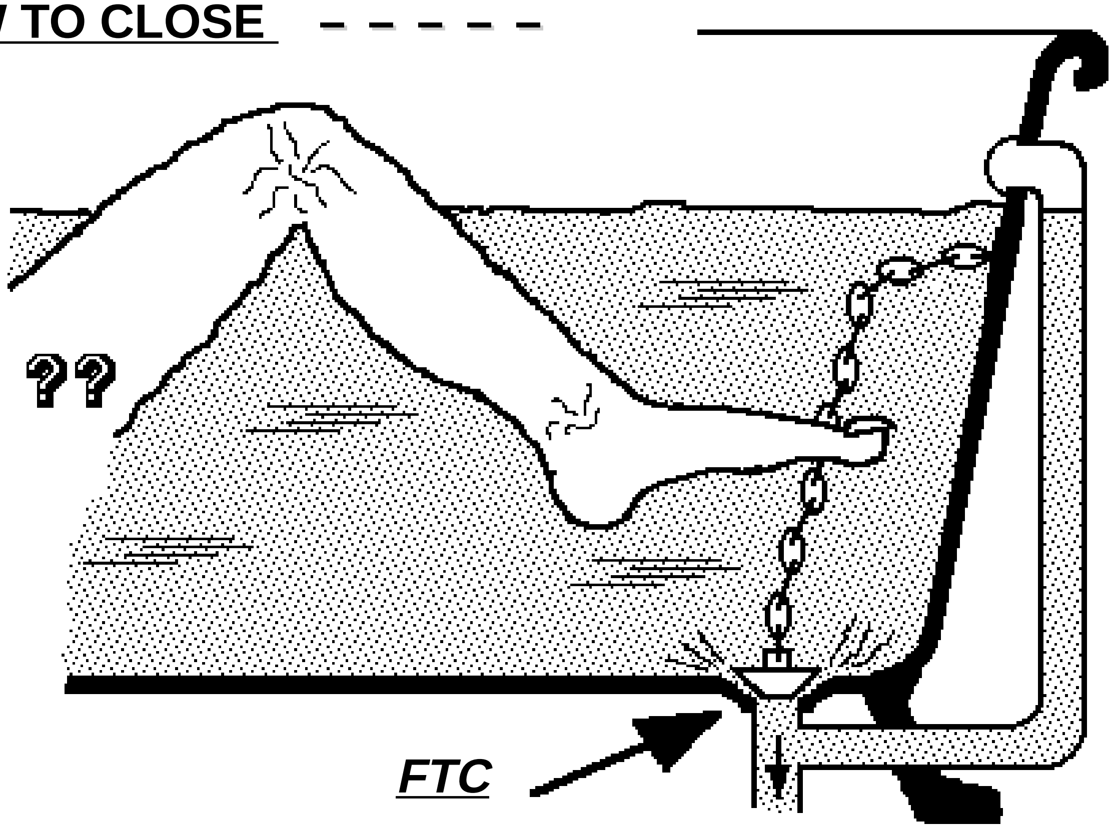
CHARACTERIZATION IN PLUG – COMMON SEAT RING – FLUTED PLUG – SEAT & STEM GUIDED

SECTION 4

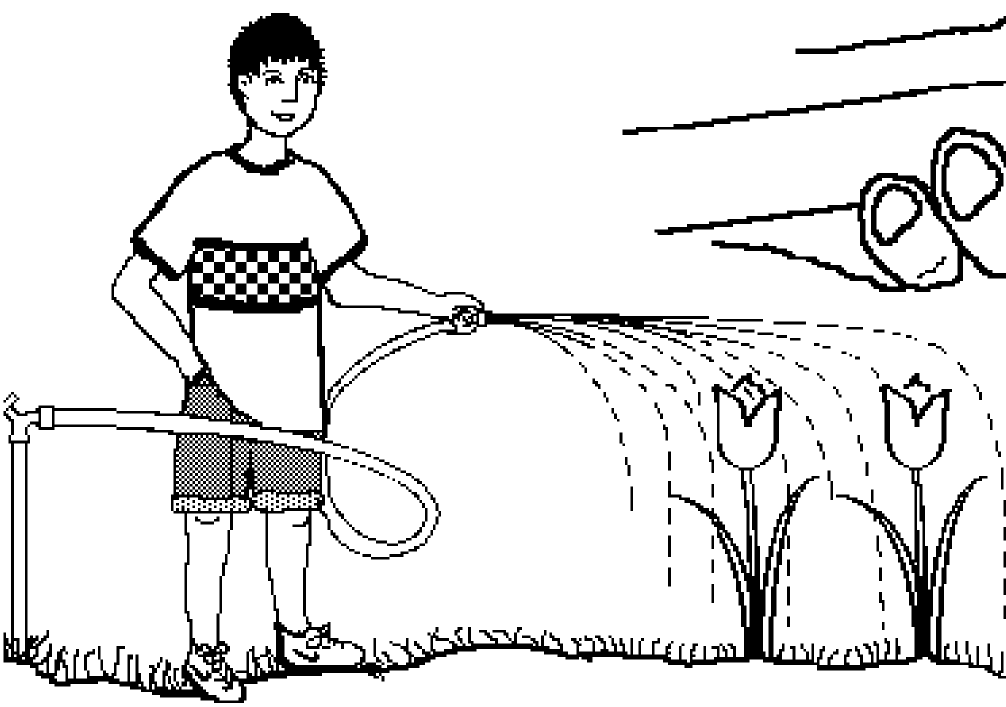
Control Valve
Technical Considerations

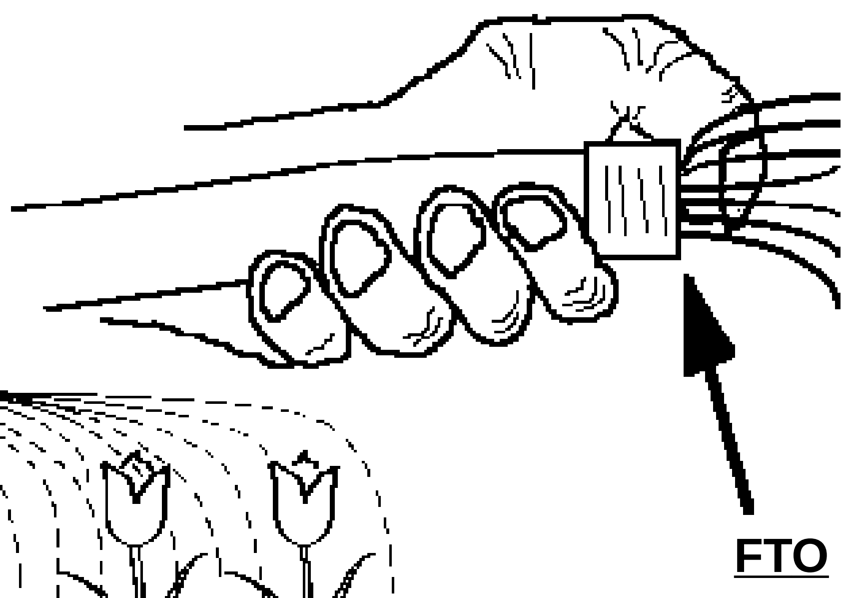
FTO* vs. *FTC

FTC-FLOW TO CLOSE – – – – –



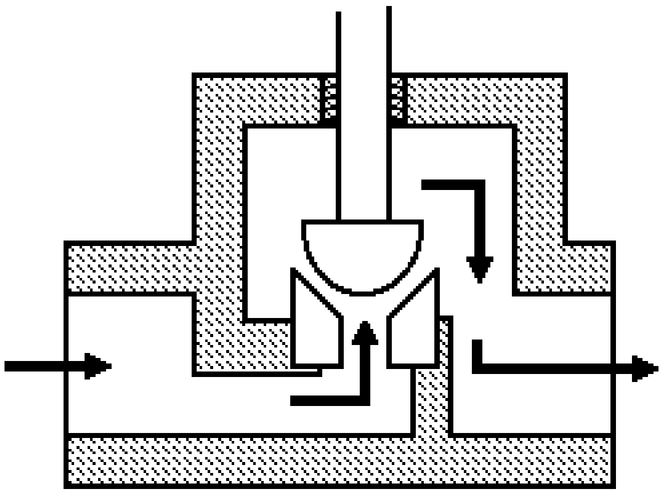
FTO-FLOW TO OPEN – – – – –



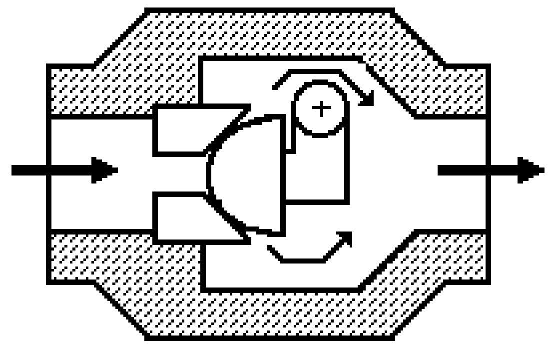


FTO vs. FTC

FTO = FLOW-TO-OPEN

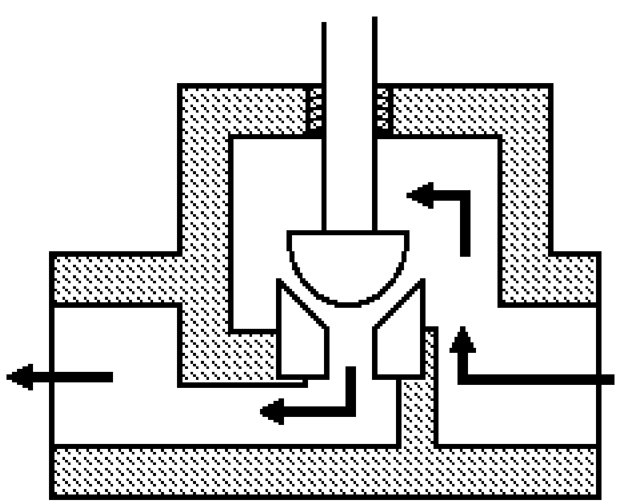


"CLASSIC" GLOBE VALVE

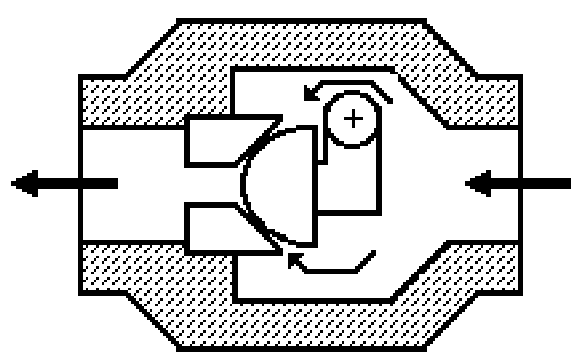


"NOT SO CLASSIC" ROTARY GLOBE VALVE; i.e. ECCENTRIC PLUG VALVE

FTC = FLOW-TO-CLOSE



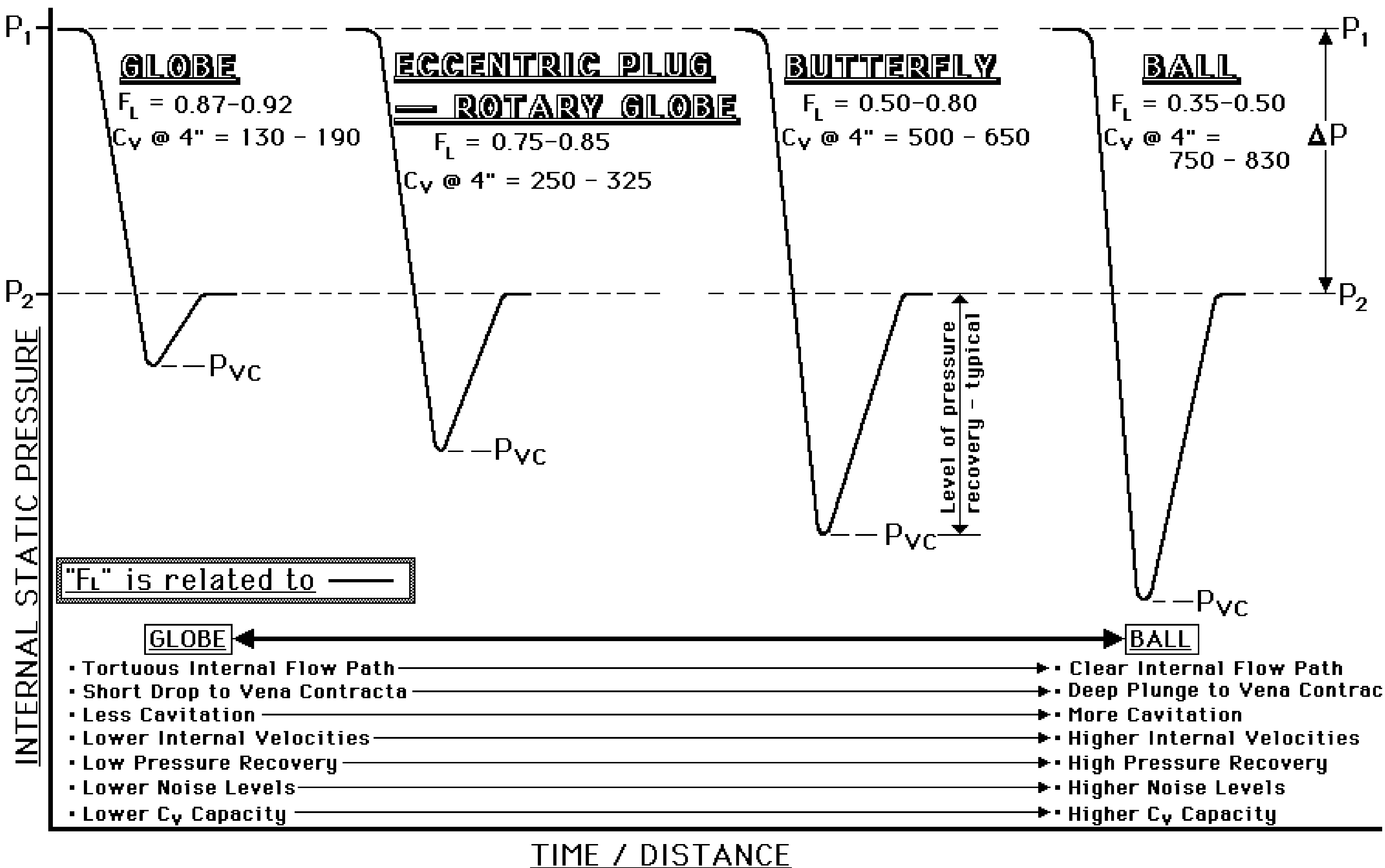
"CLASSIC" GLOBE VALVE



"NOT SO CLASSIC" ROTARY GLOBE VALVE; i.e. ECCENTRIC PLUG VALVE

F_L – "LIQUID" PRESSURE RECOVERY FACTOR —

ΔP = CONSTANT ⟶ FLOW ≠ CONSTANT



SECTION 5

Force-Balance Principle

FORCE - BALANCE PRINCIPLE

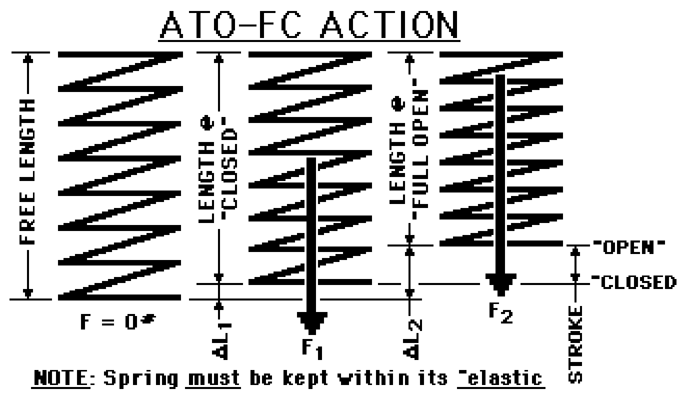
Control valves operate according to the force-balance principle.

<u>Force-Balance Principle</u> — When a static (fixed) mechanical device is linked together and exposed to internal forces —

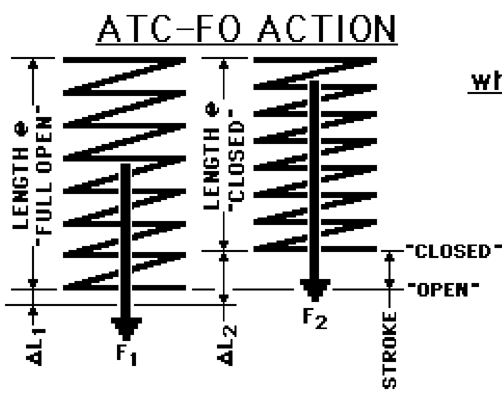
- **$\sum$ Forces Vertical = 0**
- **$\sum$ Forces Horizontal = 0**
- **$\sum$ Moments = 0**

"Forces" that operate on control valves come from —

SPRINGS –



NOTE: Spring must be kept within its "elastic zone"; i.e. not taken up to/beyond its "yield point".



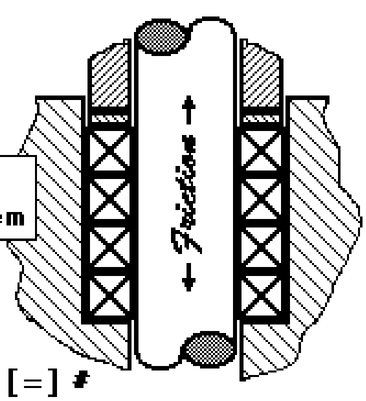
$$F = k \times \Delta L$$

where:

F – Force [=] #
k – Spring Rate [=] #/inch
ΔL – Change in Length [=] inch

FRICTION —

$$\mathcal{F} = \mu \times \varnothing_{stem}$$



where:

$\mathcal{F}$ – Friction [=] #
μ – Coefficient of Friction [=] #/inch
$\varnothing_{stem}$ – Stem Diameter [=] inch

FLUID PRESSURE-TO-SURFACE AREA —

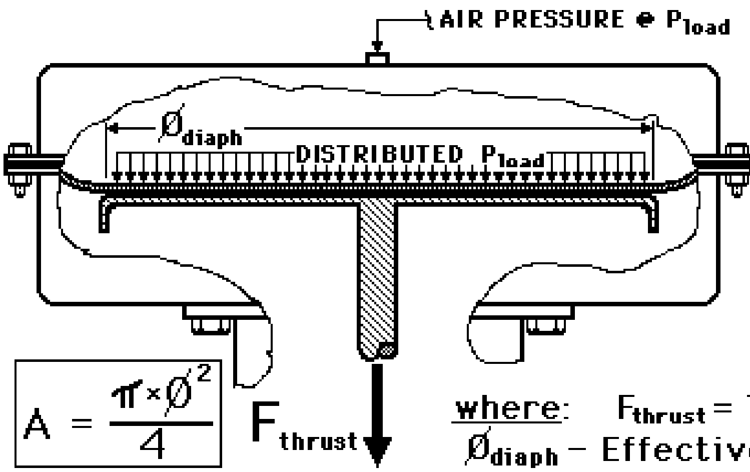
$$F = P \times A$$

where:

- F - Force [=] #
- P - Fluid Pressure [=] #/in^2
- A - Surface Area [=] in^2

DIAPHRAGM —

PRESSURES–AREAS —



$$A = \frac{\pi \times Ø^2}{4}$$

$$F_{thrust} = P_{load} \times A_{diaph}$$

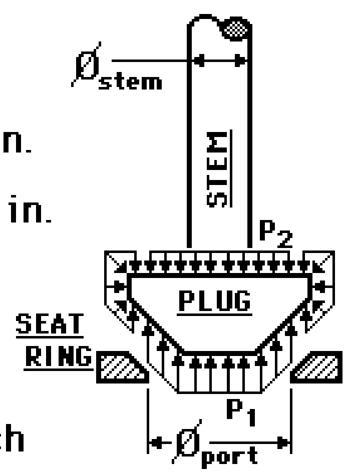
where:

- F_{thrust} = Thrust Force [=] #
- $Ø_{diaph}$ – Effective Diaphragm Diameter [=] inch
- A_{diaph} – Effective Diaphragm Area [=] sq. in.

PLUG-PORT —

where:

- A_{port} – Port Area [=] sq. in.
- A_{stem} – Stem Area [=] sq. in.



- $Ø_{stem}$ – Stem Diameter [=] inch
- $Ø_{port}$ – Port Diameter [=] inch

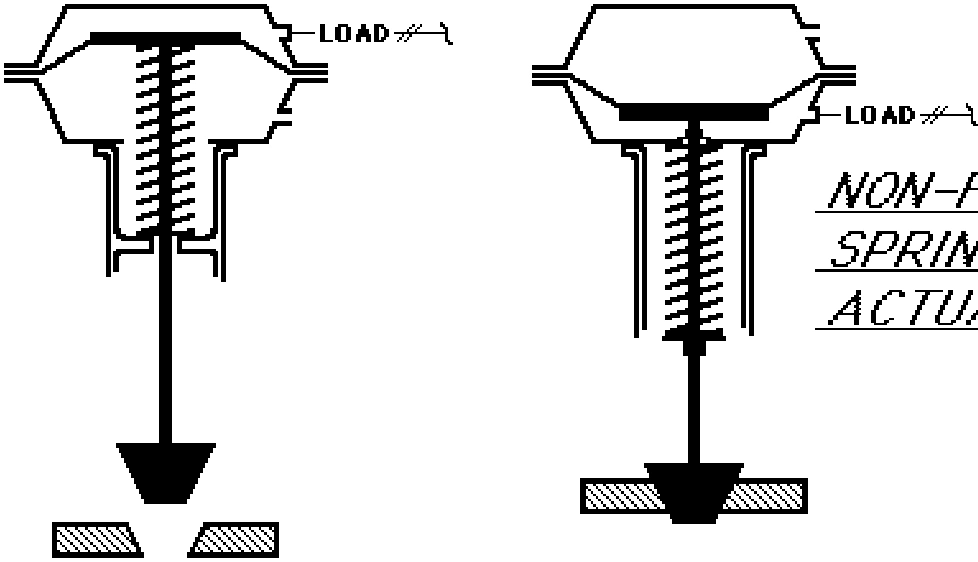
$$F_{plug} = [P_1 \times A_{port}] + [P_2 \times (A_{port} - A_{stem})]$$

SECTION 6

Actuator Basic Designs

ACTUATOR BASICS —

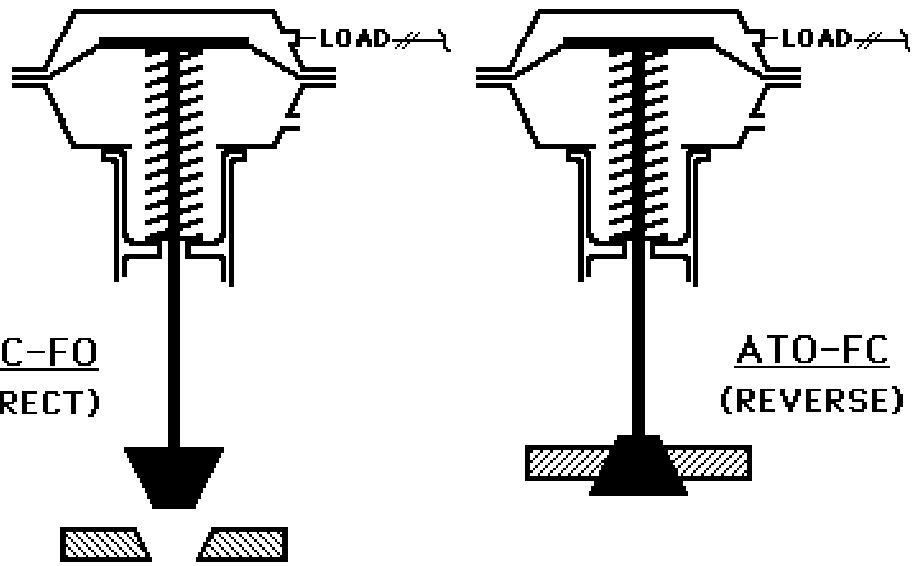
NON-FIELD REVERSIBLE SPRING-DIAPHRAGM ACTUATORS



ATC-FO (DIRECT)

ATO-FC (REVERSE)

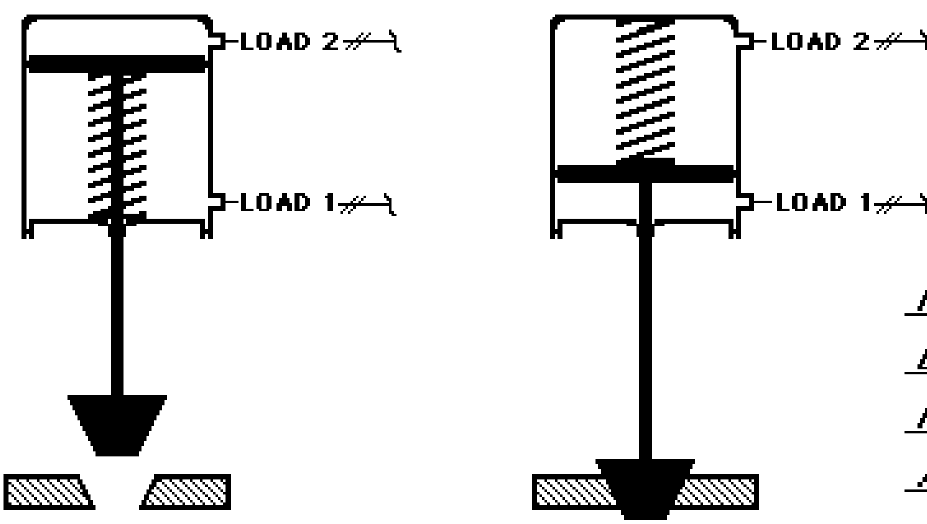
SPRING-DIAPHRAGM, FIELD-REVERSIBLE VALVE TRIM



ATC-FO (DIRECT)

ATO-FC (REVERSE)

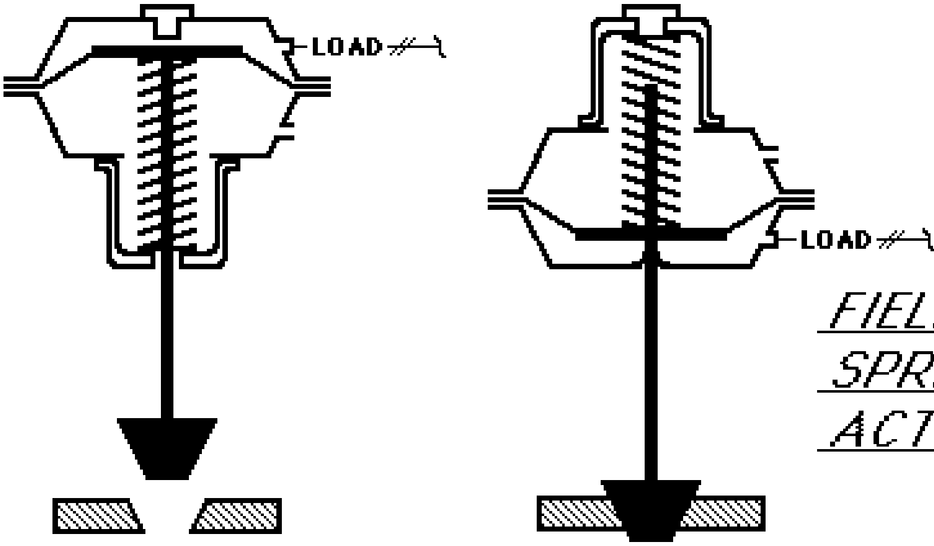
FIELD-REVERSIBLE DOUBLE-ACTING PISTON ACTUATORS



ATC-FO (DIRECT)

ATO-FC (REVERSE)

ACTUATOR BASICS —

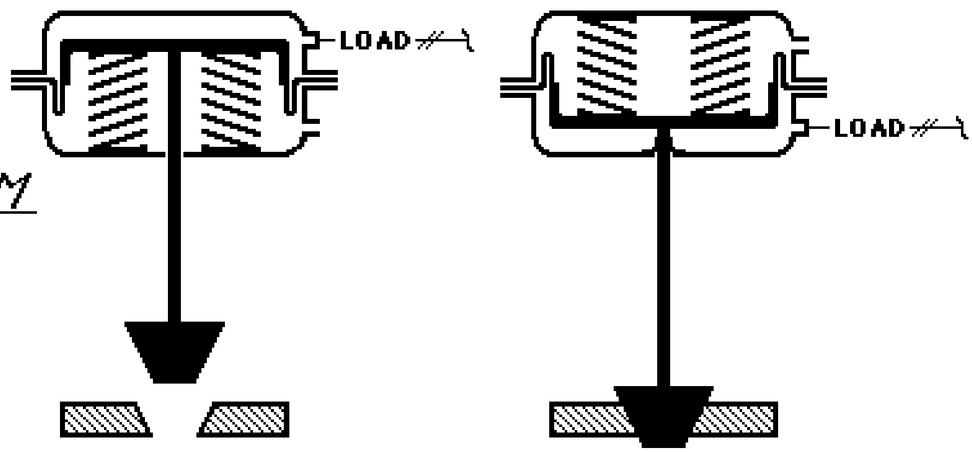


ATC-FO
(DIRECT)

ATO-FC
(REVERSE)

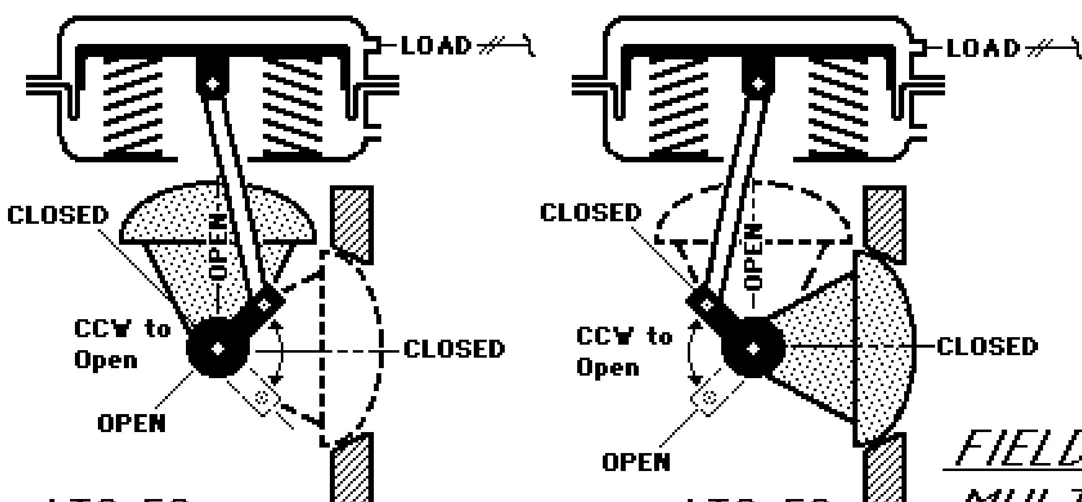
FIELD-REVERSIBLE, SPRING-DIAPHRAGM ACTUATORS

FIELD REVERSIBLE, MULTIPLE SPRING, SPRING-DIAPHRAGM ACTUATORS



ATC-FO
(DIRECT)

ATO-FC
(REVERSE)



ATC-FO
(DIRECT)

ATO-FC
(REVERSE)

ROTARY CONTROL VALVES

FIELD REVERSIBLE, MULTIPLE SPRING, SPRING-DIAPHRAGM ACTUATORS

SECTION 7

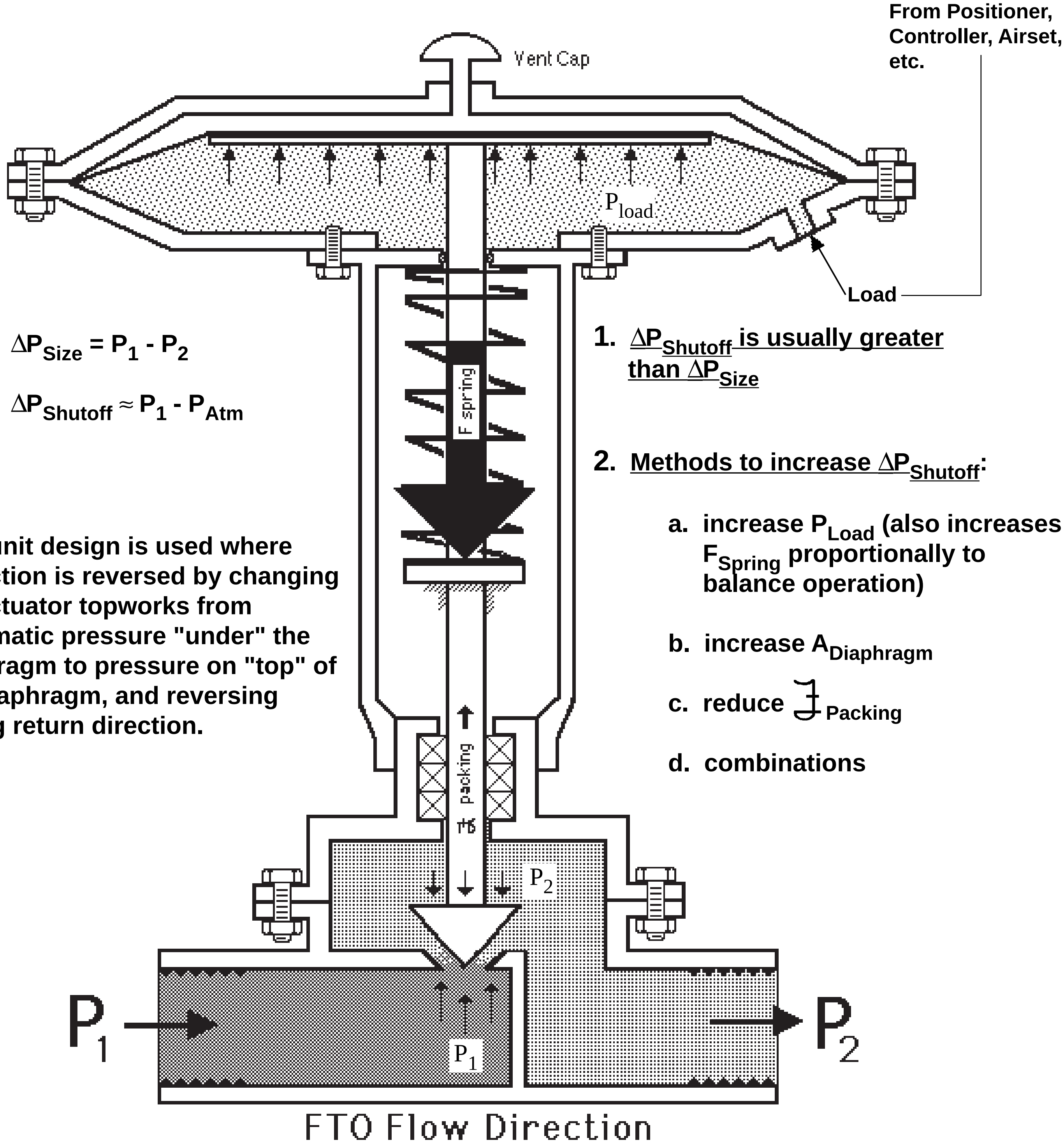
Control Valve Unit Action

CONTROL VALVE — ATO-FC ACTION

$\Delta P_{Size} = P_1 - P_2$

$\Delta P_{Shutoff} \approx P_1 - P_{Atm}$

This unit design is used where the action is reversed by changing the actuator topworks from pneumatic pressure "under" the diaphragm to pressure on "top" of the diaphragm, and reversing spring return direction.



1. <u>$\Delta P_{Shutoff}$ is usually greater than ΔP_{Size}</u>

2. <u>Methods to increase $\Delta P_{Shutoff}$</u>:

   a. increase P_{Load} (also increases F_{Spring} proportionally to balance operation)

   b. increase $A_{Diaphragm}$

   c. reduce $\mathfrak{F}_{Packing}$

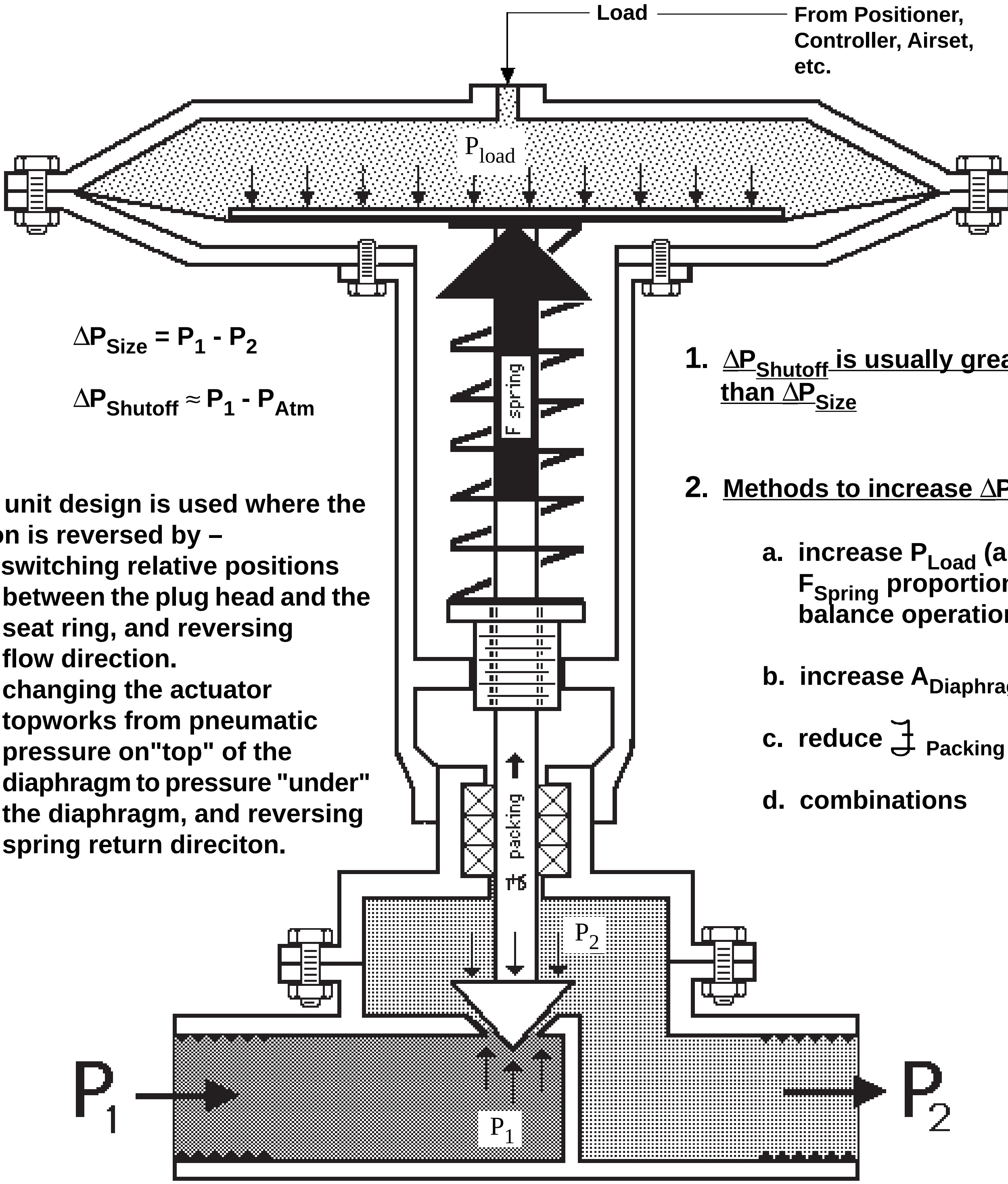
   d. combinations

Inlet pressure tends to "push" the plug open

$$\sum F_{Up} = \sum F_{Down}$$

$$P_1 \times A_{Port} + P_{Load} \times A_{Diaph} + \mathfrak{F}_{Packing} = F_{Spring} + P_2 \times A_{Plug}$$

CONTROL VALVE — ATC-FO ACTION



FTO Flow Direction

Inlet pressure tends to “push” the plug open

$\Delta P_{Size} = P_1 - P_2$

$\Delta P_{Shutoff} \approx P_1 - P_{Atm}$

This unit design is used where the action is reversed by –

- **a.) switching relative positions between the plug head and the seat ring, and reversing flow direction.**
- **b.) changing the actuator topworks from pneumatic pressure on"top" of the diaphragm to pressure "under" the diaphragm, and reversing spring return direciton.**

1. $\Delta P_{Shutoff}$ is usually greater than ΔP_{Size}

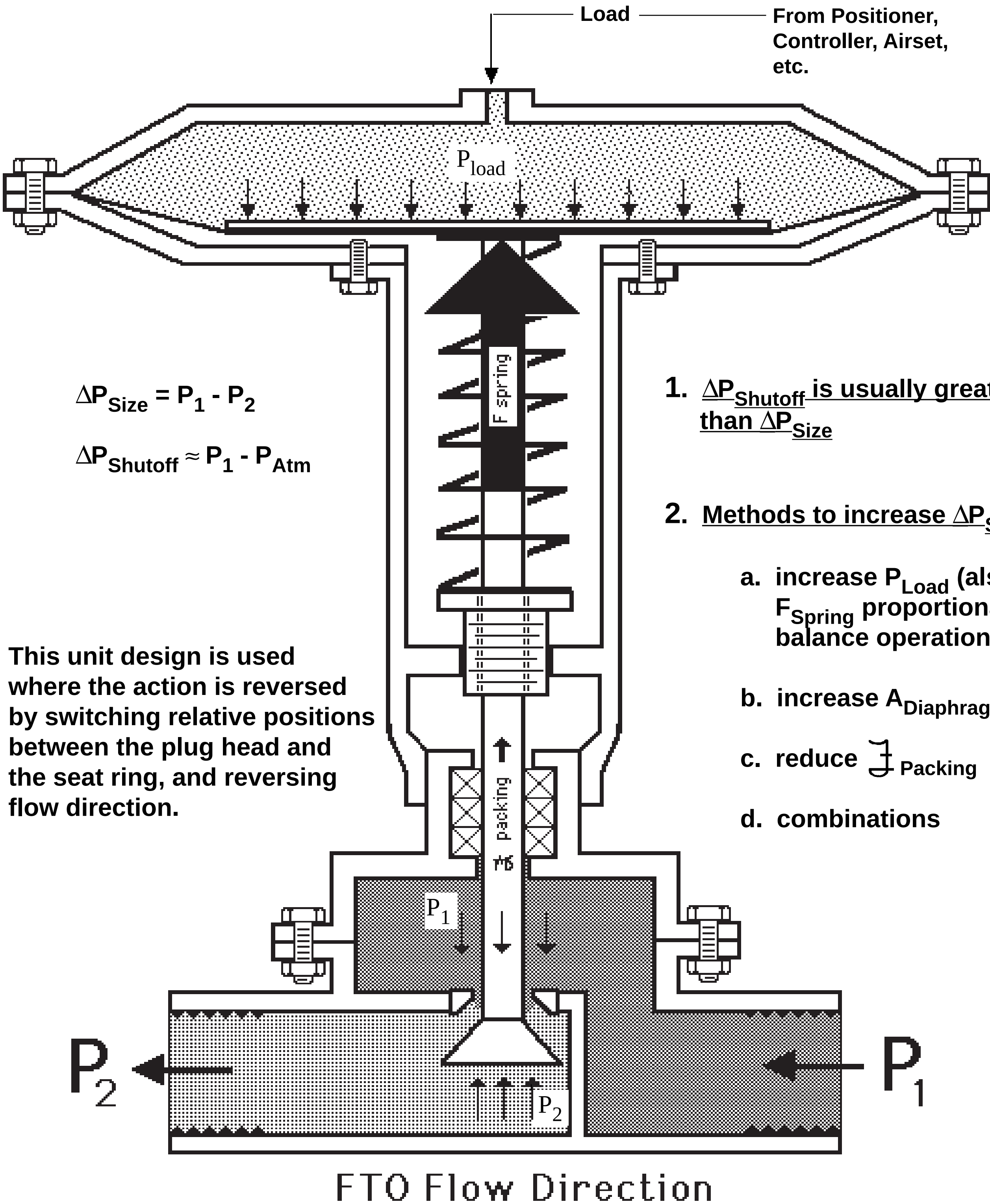
2. Methods to increase $\Delta P_{Shutoff}$:

- **a. increase P_{Load} (also increases F_{Spring} proportionally to balance operation)**
- **b. increase $A_{Diaphragm}$**
- **c. reduce $\Im_{Packing}$**
- **d. combinations**

$$\sum F_{Up} = \sum F_{Down}$$

$$P_1 \times A_{Port} + F_{Spring} = \Im_{Packing} = P_{Load} \times A_{Diaph} + P_2 \times A_{Plug}$$

CONTROL VALVE — ATO-FC ACTION



$\Delta P_{Size} = P_1 - P_2$

$\Delta P_{Shutoff} \approx P_1 - P_{Atm}$

1. **$\Delta P_{Shutoff}$ is usually greater than ΔP_{Size}**

2. **Methods to increase $\Delta P_{Shutoff}$:**

   a. **increase P_{Load} (also increases F_{Spring} proportionally to balance operation)**

   b. **increase $A_{Diaphragm}$**

   c. **reduce $\mathfrak{Z}_{Packing}$**

   d. **combinations**

This unit design is used where the action is reversed by switching relative positions between the plug head and the seat ring, and reversing flow direction.

Inlet pressure tends to "push" the plug open

$$\Sigma F_{Up} = \Sigma F_{Down}$$

$$P_2 \times A_{Port} + F_{Spring} + \mathfrak{Z}_{Packing} = P_{Load} \times A_{Diaph} + P_1 \times A_{Plug}$$

<u>CONTROL VALVE "FAIL-SAFE" POSITIONS</u>

There are <u>two</u> primary system considerations centering around an emergency operational situation for control valves —

I. Loss of instrument air supply (IAS) pressure.
II. Loss of electrical power.

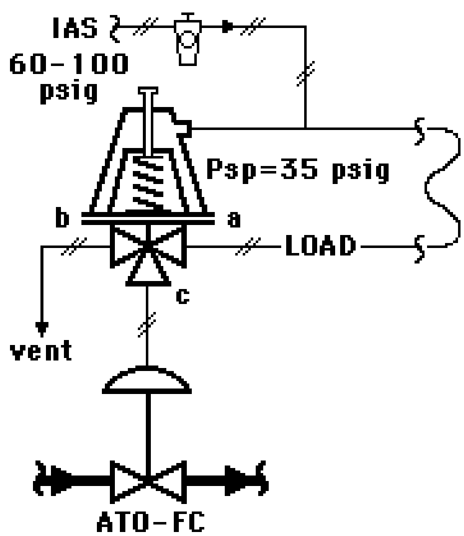
There are <u>four</u> choices as to control valve "response" to the emergency condition —

a.) Fully Close
b.) Fully Open
c.) In Last Position
d.) Continue Throttling

For either fail-safe loss of IAS or loss of electrical power, it is the actuator's benchset range spring that "drives" the control valve's plug to its fail-safe open or closed position.

I. <u>Loss of Instrument Air Supply Pressure</u> -

a.) <u>Fully Close</u>. The actuator's benchset range spring "drives" the valve plug "<u>closed</u>" when loading air pressure goes towards or near 0 psig. (ATO-FC "Reverse")

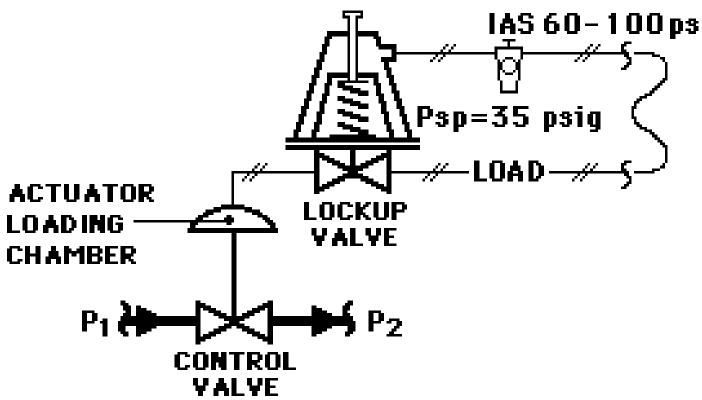


Because IAS piping systems can be extensive (big), the IAS can decay too slowly causing operational problems. In such cases it may be desirable to use a 3-way pilot switching valve to "anticipate" the eventual loss of IAS and quickly stroke the control valve to its fail-safe position, eliminating the transitory operational effects of the slow decay.

b. <u>Fully Open</u>. The actuator's benchset range spring "drives" the valve plug "<u>open</u>" when loading air pressure goes toward or near 0 psig. (ATC-FO "Direct")

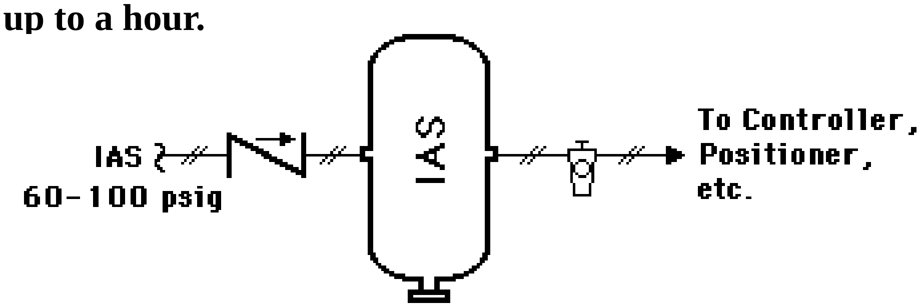
A similar scheme to I.a. previous may be applied for ATC-FO arrangements for fail open control valves to eliminate transitory effects.

c.) <u>In Last Position</u>. This is accomplished with a “lockup valve”, which is a 2-way pilot switching valve. If the air pressure is lost from the control loop's airset, the lockup valve will “close” and “trap” the air within the actuator's loading chamber. If no air leaks are present, the control valve will stay at the last throttling position. Such loops are normally “local”. (Control valve action is a non-issue.)

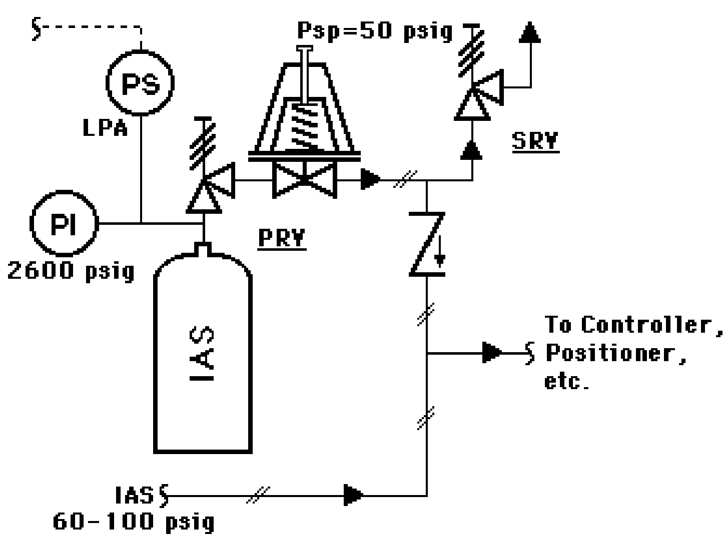


d.) Continue Throttling. This is an “elaborate” system that can be accomplished two different ways —

i.) Volume Tank. A volume tank stores a limited supply of IAS to sustain normal operation for a finite time period, i.e. approximately up to a hour.

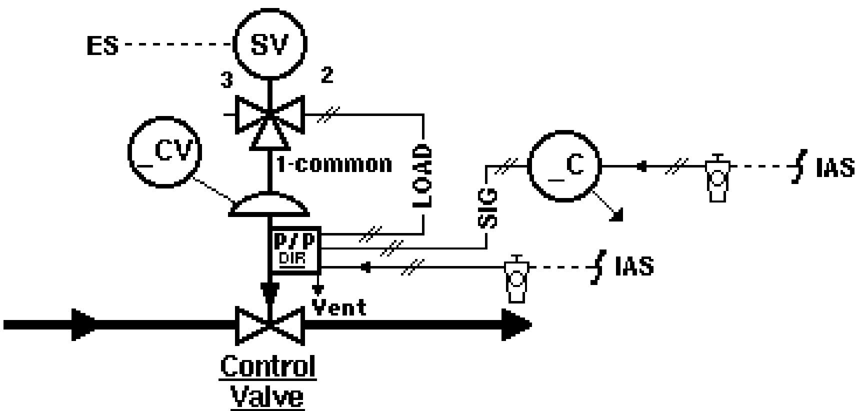


ii.) Alternate Supply. A high pressure cylinder is on standby with an alternate gas, usually GN_2. If IAS pressure falls below 50 psig, the alternate gas will take over to supply pneumatic control. The high pressure will allow for several hours of sustained operation, enough time for the emergency loss of the IAS to be restored. Such applications are normally for "very important (critical)" services. Such loops are normally “local” and pneumatic only; i.e. no electrical power involved except the low pressure alarm switch.



II. Loss of Electrical Power—

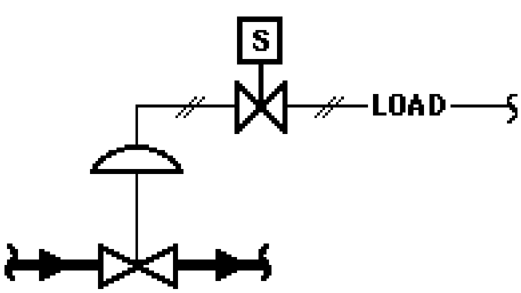
Protection for loss of electrical power is indirectly accomplished thru the use of a solenoid valve. In normal operation the solenoid valve is energized electrically; in an emergency loss of electrical power the solenoid valve is de-energized and trips to the "shelf-position". Solenoid voltage can be 120 VAC, 240 VAC, 125 VDC, 24 VDC, etc.



a.) Fully Close. By blocking the LOAD air to the actuator and venting the air within the actuator's loading chamber to atmosphere (P = 0 psig), the actuator's benchset range spring "drives" the valve plug "closed". The solenoid valve is a 3-way type.

b.) Fully Open. By blocking the air to the actuator and venting the air within the actuator's loading chamber to atmosphere (P= 0 psig), the actuator's benchset range spring "drives" the valve plug open. The solenoid valve and tubing interconnection is identical to the II.a. case previous.

c.) In Last Position. This is accomplished with a 2-way solenoid valve. In the "energized" condition, the solenoid valve ports are "open"; loading air passes thru. In the "de-energized" condition, the solenoid valve "closes" and traps the air within the actuator's loading chamber. If no air leaks are present, the control valve will stay at the last throttling position. (Control valve action is a non-issue.)

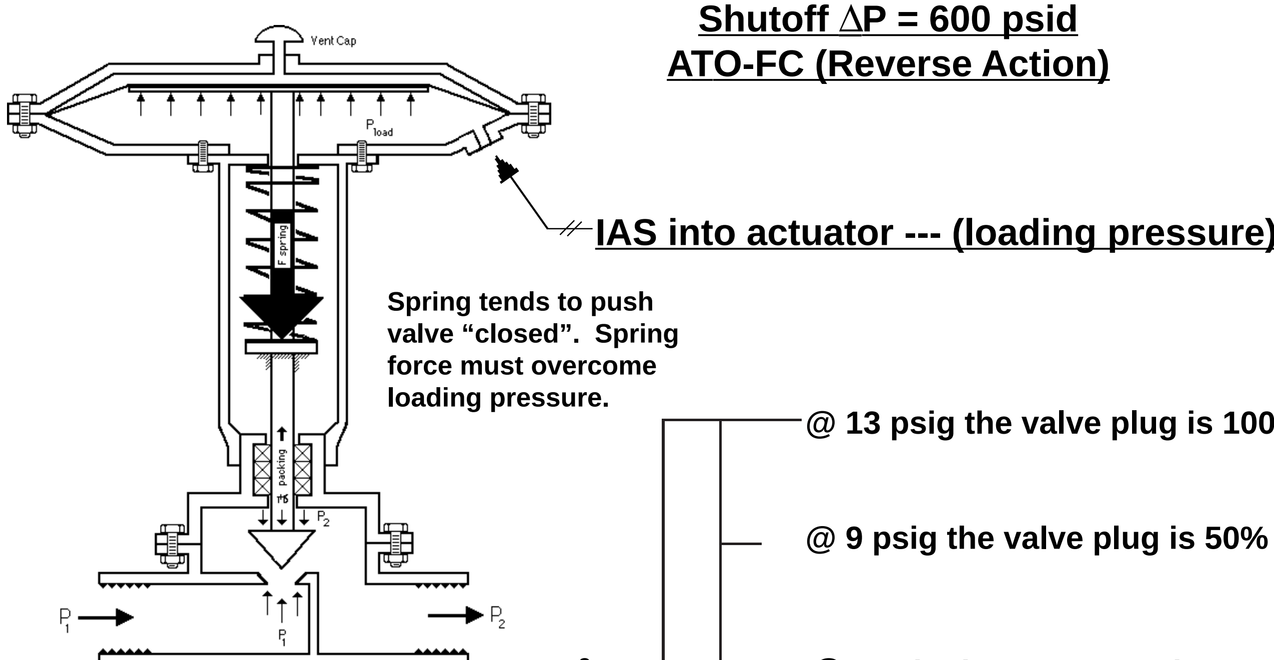


SECTION 8

Actuator Benchset Range

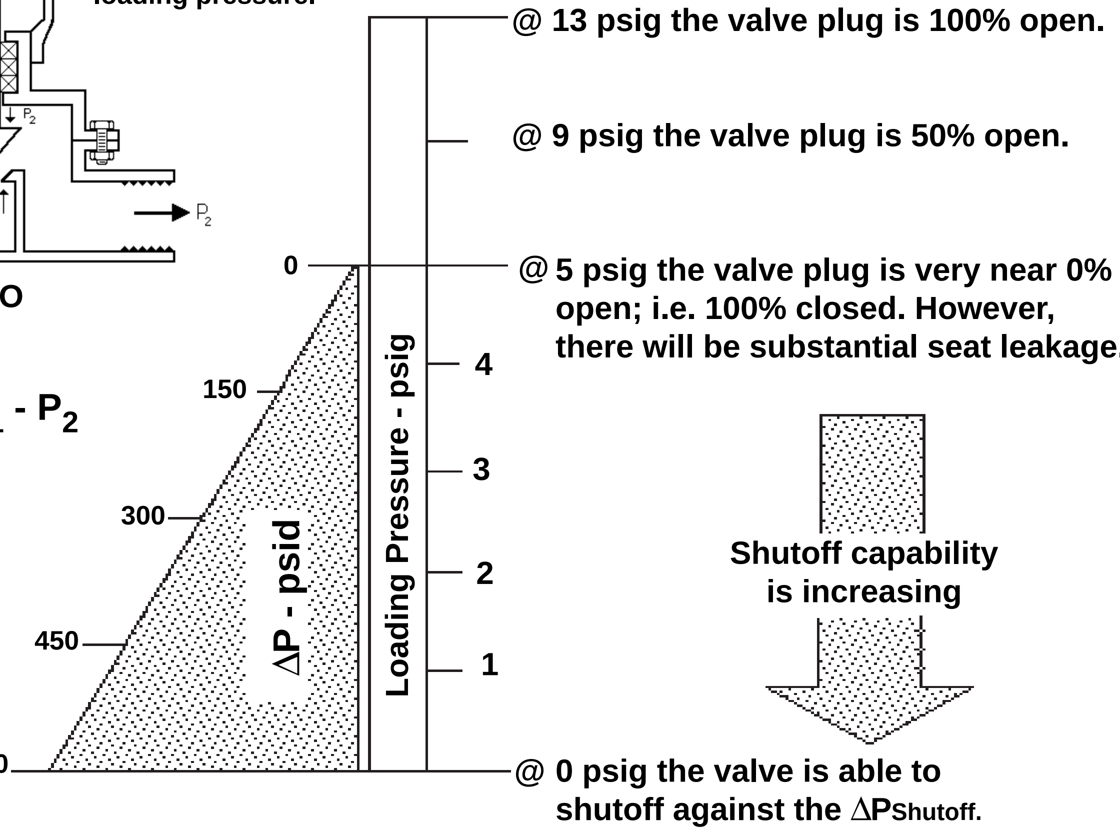
BENCHSET RANGE — ATO-FC

Benchset Range = 5-13 psig
Shutoff ΔP = 600 psid
ATO-FC (Reverse Action)



FTO

$$\Delta P = P_1 - P_2$$



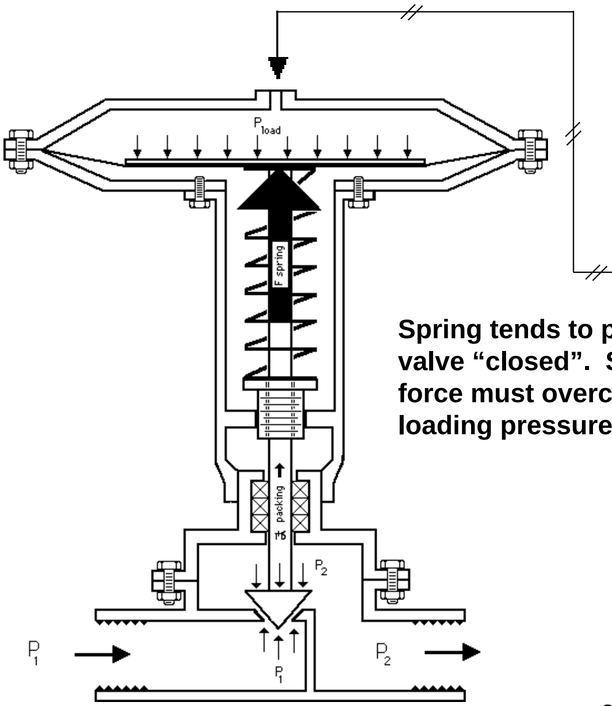
Shutoff capability is directly proportional to the ability to “unload” the actuator down to 0 psig pressure level. If there is any instrument that will NOT unload down to the 0 psig output pneumatic pressure, the shutoff capability will be reduced. Devices that can cause a problem by NOT unloading down to 0 psig are —

- **I/P Transducer with a 3-15 psig output range; the device will only unload down to 2 - 2.5 psig. For the above actuator, the shutoff capability is “halved”; i.e. (2.5/5) x 600 psid = 300 psid.**
- **Some pneumatic controllers.**

A device that <u>DOES</u> unload down to 0 psig is a <u>POSITIONER</u>.

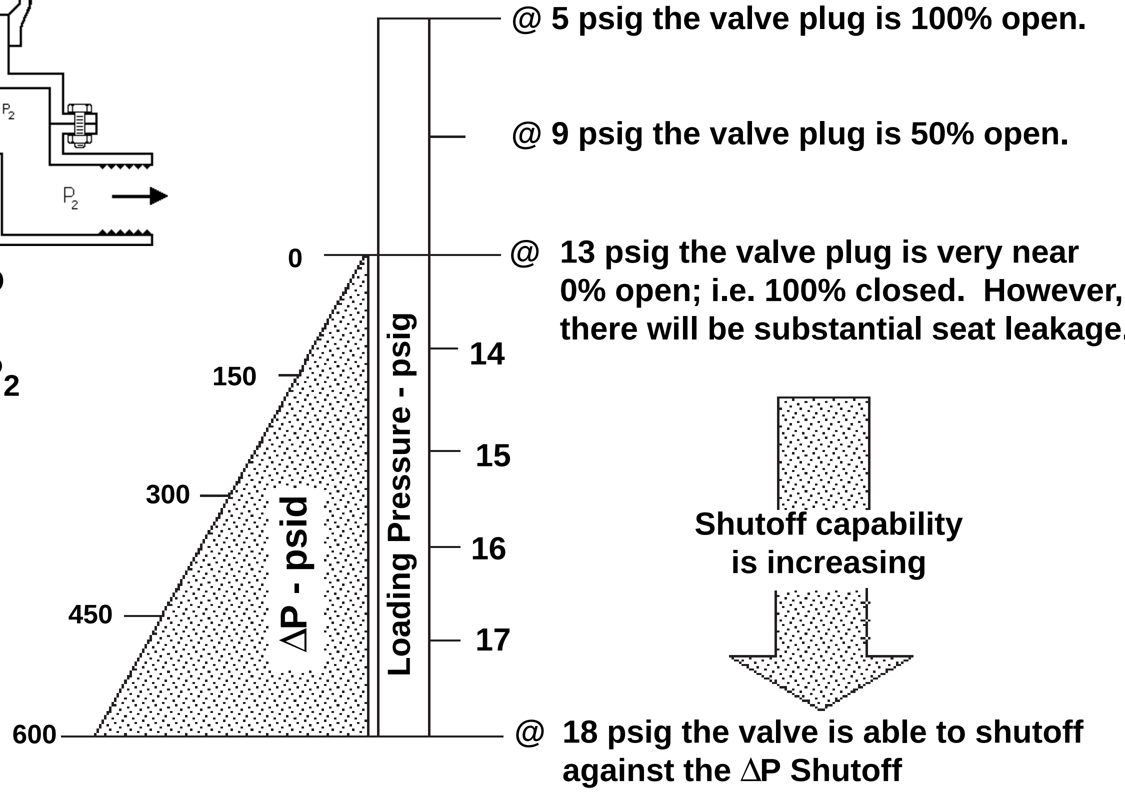
BENCHSET RANGE — ATC-FO

Benchset Range = 5-13 psig
Shutoff ΔP = 600 psid
ATC-FO (Direct Action)



FTO

$$\Delta P = P_1 - P_2$$



Shutoff capability is directly proportional to the ability to "load" the actuator up to approximately 18 psig pressure level. If there is any instrument that will NOT unload up to the 18 psig output pneumatic pressure, the shutoff capability will be reduced. Devices that can cause a problem by NOT loading up to the 18 psig level are —

- **I/P Transducer with a 3-15 psig output range; the device may only load up to 16 - 17 psig level. For the above actuator, the shutoff capability is "reduced"; i.e. [(16.5-13)/5] x 600 psid = 420 psid.**
- **Some pneumatic controllers.**

A device that <u>DOES</u> load up to 18 psig is a <u>POSITIONER</u>.

SECTION 9

Valve Positioner Basics

BASICS OF VALVE POSITIONERS —

A valve POSITIONER is an INSTRUMENT DEVICE used to increase or decrease the air LOAD pressure driving the actuator until the valve's stem reaches a "POSITION" balanced to the output SIGNAL from the process variable instrument controller.

Positioners are generally mounted on the side-yoke or top casing of the pneumatic actuator for LINEAR--SLIDING-STEM control valves, and at/near the end-of-shaft for ROTARY control vales. For either basic design type, "mechanical feedback linkage" connected directly to the valve's stem provides feedback that if the SIG changes from one steady-state output to another output SIG level, that the valve stem reacts and also moves to reach a second steady-state output SIG level. I.E. The process controller tells the positioner to "change" position; the feedback linkage reports back to the positioner confirming that a change has occurred and gives a "sense" of the magnitude of the change in position.

REASONS TO USE A POSITIONER

LINEAR AND ROTARY CONTROL VALVES:

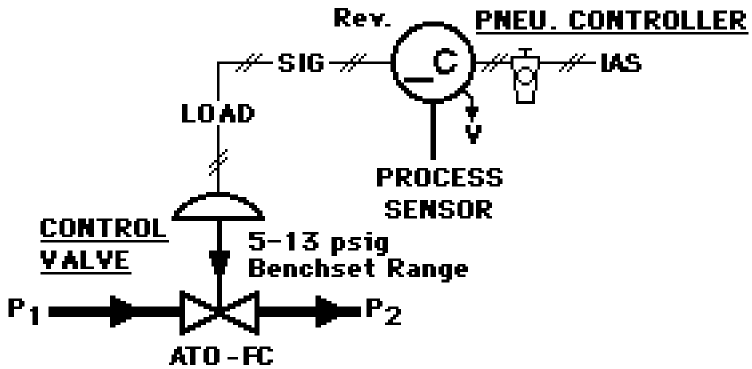
1. **Minimize valve stem packing friction effects and the resulting hysteresis, particularly for high temperature packing materials such as graphite.**
2. **Allow physical distance between pneumatic process controller and the control valve location; allows SIG to be an "impulse" flow rather than "full" flow for LOAD.**
3. **Increased usage of 4-20 mA electronic SIG.**
4. **Increase control system resolution (i.e. fine control) thru full use of SIG; offsets variation of actuator's range spring "rate", which can vary ±8%.**
5. **Increase speed of response to a change in process; allows faster loading and venting.**
6. **Negate flow-induced reactions to higher pressure drops; i.e. compensates for internal force imbalances.**
7. **Permit use of piston actuators with high IAS pressures.**
8. **Facilitate selection of actuator benchset ranges that are other than "matching" or "multiple ratioing" the SIG; i.e. use of 3-15 psig SIG with a valve benchset of 10-35 psig. Note: If the larger value of the benchset is above 15-18 psig, a positioner is "required".**
9. **Allow for split-ranging; i.e. 1 controller for 2 valves.**

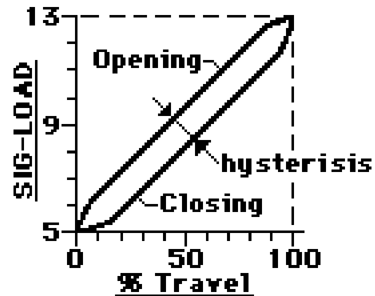
ROTARY CONTROL VALVES ONLY:

10. **Allow incorporation of characterization cams to vary from the valve's inherent character to a formed characteristic.**
11. **Overcome seating friction effects at travel below 10%, allowing throttling near the "closed" position.**

BASICS OF VALVE POSITIONERS CONT'D —

Control Valve w/o Positioner

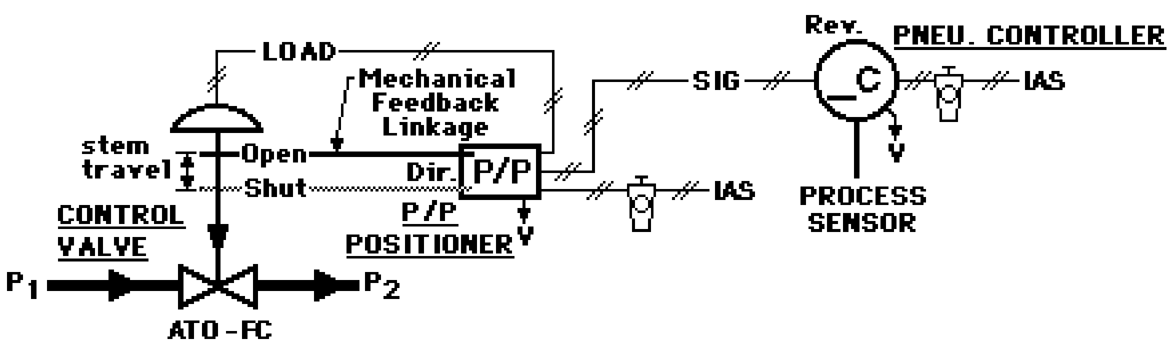




"SIG" and "LOAD" are the same flow stream**.** **Actuator air flows thru the pneumatic controller and the interconnecting tubing; air vented thru controller.**

No "stem position" feedback. Thus, there will be "hysteresis" in opening and closing response.

Linear Control Valve with P/P Positioner

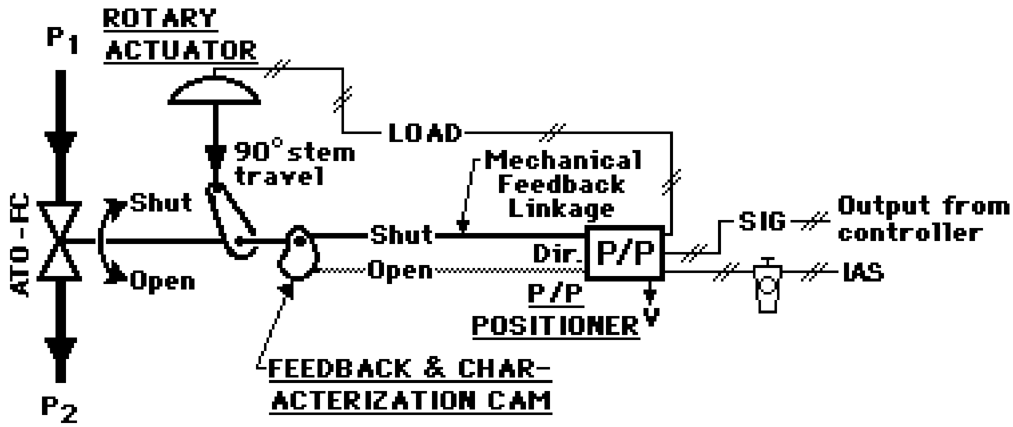


"SIG" and "LOAD" are two separate flow streams. **Actuator air flows thru the P/P positioner and its short interconnecting "LOAD" tubing. Pneumatic controller air flows thru the tubing interconnecting the controller and the P/P positioner, the "SIG" tubing; this is an impulse (i.e. pressurization only) tube.**

A positioner provides "feedback" to the "control loop" in that a change in controller SIG output forces a change in positioner LOAD output which results in a valve stem travel; the mechanical feedback linkage then "confirms" that travel occurred, If no travel is fed back to the positioner, positioner output will continue to change until stem travel is confirmed.

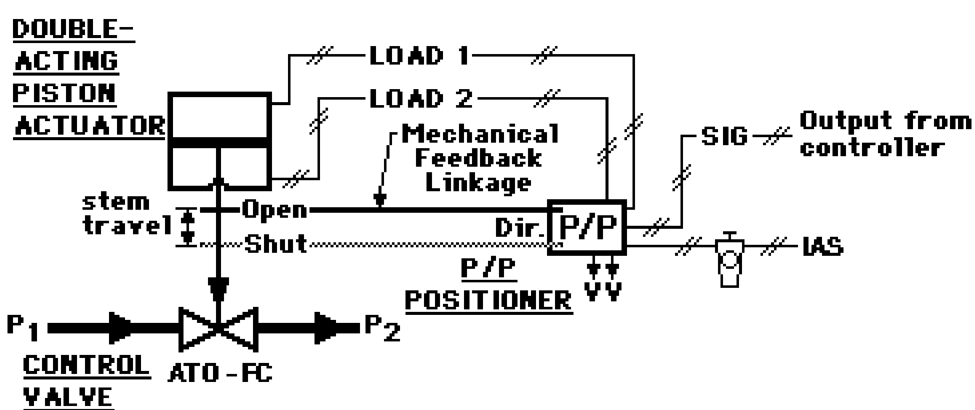
BASICS OF VALVE POSITIONERS CONT'D —

Rotary Control Valve with P/P Positioner



Because it is not practical to characterize rotary valves by "varying plug geometry", a rotary valve is equipped with a feedback cam that can be shaped to alter the valve's "inherent character" to a more desirable "linear" or "equal %" characteristic, using the same valve internal trim; i.e. less expensive spare trim parts to inventory.

Linear Control Valve with Piston Acutator and P/P Positioner



Because a double-acting, piston actuator requires loading air to <u>both sides</u> of the actuator's piston, <u>two separate</u> positioner outputs —"<u>LOAD 1</u>" and "<u>LOAD 2</u>" — are required; i.e. double-acting positioner. Thus, <u>a double-acting piston actuator requires a positioner 100% of the time</u>.

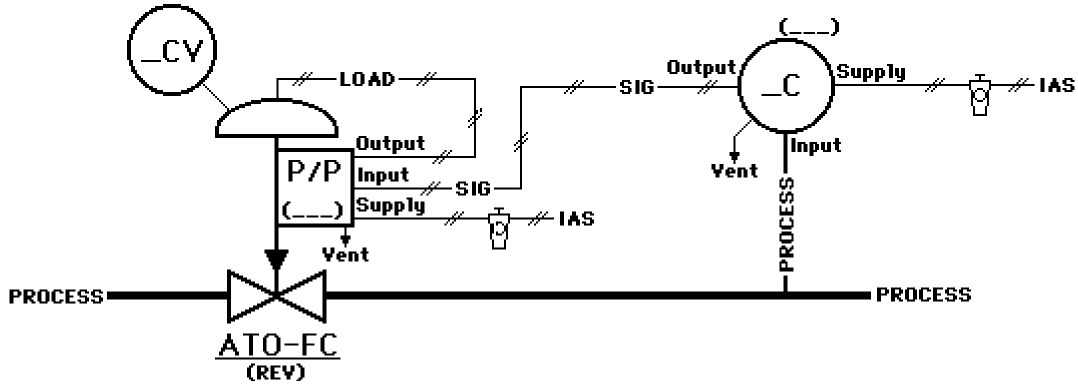
SECTION 10

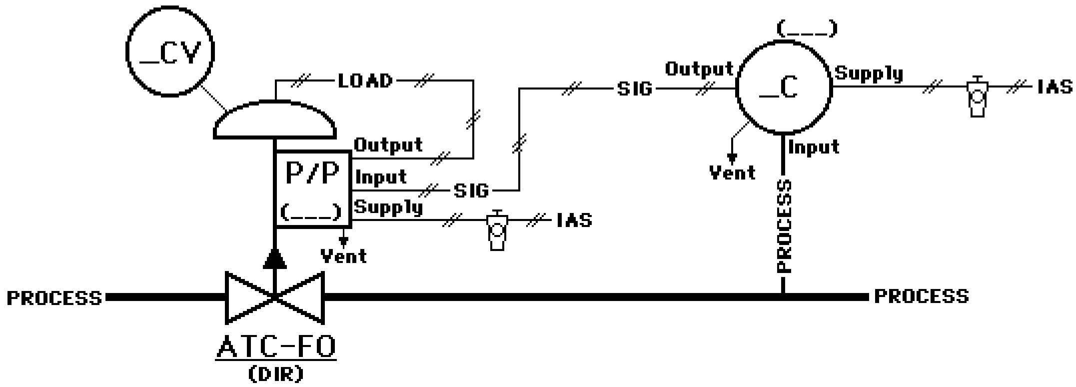
Control Loop Action

CONTROL LOOP INSTRUMENT ACTIONS ——

DIRECT ACTION — DIR

- **CONTROLLER** – As the "PROCESS" variable increases numerically, the output "SIG" increases.
- **POSITIONER** – As the input "SIG" increases, the output "LOAD" increases.
- **CONTROL VALVE** – As the "LOAD" increases, the valve's plug moves towards "CLOSE" position; ATC-FO or "Air-to-Close, Fail Open" action.**





REVERSE ACTION — REV

- **CONTROLLER** – As the "PROCESS" variable increases numerically, the output "SIG" decreases.
- **POSITIONER** – As the input "SIG" increases, the output "LOAD" decreases.
- **CONTROL VALVE** – As the "LOAD" increases, the valve's plug moves towards the "OPEN" position; ATO-FC or "Air-to-Open, Fail Close" action. **

↑ Increases ↓ Decreases

PROCESS, CONTROLLER, or POSITIONER

↓ OPEN (REV) CLOSED — (ATO-FC)

↑ OPEN (DIR) CLOSED — (ATC-FO)

CONTROL VALVE

** This is a CASHCO, INC. convention ONLY ——
ATO-FC ⟶ REVERSE
ATC-FO ⟶ DIRECT
—— regardless of valve body design or actuator design.

While control valve units can be described as "direct-acting" or "reverse-acting", it is best to think of the control valve as an "ATO-FC" or "ATC-FO" acting unit, and forget the arrows logic.

CONTROL LOOP INSTRUMENT ACTIONS

A typical control valve "loop" consists of four considerations—

1. Process
2. Controller or Signal Modifier Action
3. Positioner Action
4. Control Valve Action

All of the above may vary in 16 different combinations. Use of the arrows helps clarify proper selection. The following 8 combinations use "direct-acting" positioners, and represent the majority of applications for control valves; the remaining 8 combinations for "reverse-acting" positioners are rarely encountered, and are not shown.

PROCESS	CONTROLLER	POSITIONER	CONTROL VALVE	EXAMPLES
↑ "PROCESS" Increases	DIR ↑ Controller Output "SIG" Increases	DIR ↑ Positioner Output "LOAD" Increases	DIR ↓ OPEN (REV) CLOSED Control Valve (ATO-FC) "<u>OPENS</u>", Increasing Flow	Pressure Relief Level High Temp-Cooling Flow Low
↑ "PROCESS" Increases	REV ↓ Controller Output "SIG" Decreases	DIR ↓ Positioner Output "LOAD" Decreases	DIR ↑ OPEN (DIR) CLOSED Control Valve (ATC-FO) "<u>OPENS</u>", Increasing Flow	Pressure Relief Level High Temp-Cooling Flow Low
↑ "PROCESS" Increases	REV ↓ Controller Output "SIG" Decreases	DIR ↓ Positioner Output "LOAD" Decreases	DIR ↓ OPEN (REV) CLOSED Control Valve (ATO-FC) "<u>CLOSES</u>", Decreasing Flow	Press. Reducing Level Low Temp-Heating Flow High
↑ "PROCESS" Increases	DIR ↑ Controller Output "SIG" Increases	DIR ↑ Positioner Output "LOAD" Increases	DIR ↑ OPEN (DIR) CLOSED Control Valve (ATC-FO) "<u>CLOSES</u>", Decreasing Flow	Press. Reducing Level Low Temp-Heating Flow High

PROCESS	CONTROLLER	POSITIONER	CONTROL VALVE	EXAMPLES
↓ "PROCESS" Decreases	REV ↑ Controller Output "SIG" Increases	DIR ↑ Positioner Output "LOAD" Increases	DIR ↓ OPEN (REV) CLOSED Control Valve (ATO-FC) "<u>OPENS</u>", Increasing Flow	Press. Reducing Level Low Temp-Heating Flow High
↓ "PROCESS" Decreases	DIR ↓ Controller Output "SIG" Decreases	DIR ↓ Positioner Output "LOAD" Decreases	DIR ↑ OPEN (DIR) CLOSED Control Valve (ATC-FO) "<u>OPENS</u>", Increasing Flow	Press. Reducing Level Low Temp-Heating Flow High
↓ "PROCESS" Decreases	DIR ↓ Controller Output "SIG" Decreases	DIR ↓ Positioner Output "LOAD" Decreases	DIR ↓ OPEN (REV) CLOSED Control Valve (ATO-FC) "<u>CLOSES</u>", Decreasing Flow	Pressure Relief Level High Temp-Cooling Flow Low
↓ "PROCESS" Decreases	REV ↑ Controller Output "SIG" Increases	DIR ↑ Positioner Output "LOAD" Increases	DIR ↑ OPEN (DIR) CLOSED Control Valve (ATC-FO) "<u>CLOSES</u>", Decreasing Flow	Pressure Relief Level High Temp-Cooling Flow Low

SECTION 11

Control Valve Packing Designs

Control Valve Packing

Packing is a sealing system which normally consists of a deformable material such as TFE, graphite, asbestos, Kalrez, etc. Usually the material is in the form of solid or split rings contained in a packing box. Packing material is compressed to provide an effective pressure seal between the fluid in the valve body and the outside atmosphere.

At one time it was believed that the more packing you had in a control valve the better it would seal. Since FUGITIVE EMISSIONS has become a concern, extensive testing has shown that better sealing can be obtained by minimizing the number of packing rings.

New standards are being developed to which manufacturers will be asked to test their control valves. Test results from using these standards will allow a user to predict how well a particular valve and packing combination will hold up.

Definitions

Consolidation: Packing consolidation is the shortening of a packing stack under load due to the elimination of voids in, between, and around the packing rings. This causes a reduction in packing stress (Radial Load) and can be the mechanism for packing leakage to begin. Consolidation can occur when the packing wears, cold flows, is subjected to thermal gradients, or if a nonuniform stress distribution in the packing exists.

Extrusion: When packing is loaded to its proper stress level it has a tendency to cold flow and extrude between the stem and the follower. Any increase in temperature will increase the tendency of the packing to cold flow. PTFE is very susceptible to extrusion because it has an expansion rate roughly ten times that of carbon steel. As the packing tries to expand in the fixed volume of the packing box, extrusion will occur. This material loss due to extrusion will relieve the axial stress, which relaxes the radial stress and results in a loss of seal. Anti-extrusion adaptor rings are located normally at the top and bottom of the packing ring stack.

Migration: Packing migration occurs when a portion of the packing is caught by a rough stem surface and is removed from the packing ring stack as the stem slides in and out of the packing box. Linear valves experience a higher degree of migration than rotary valves. High temperature packing is particularly susceptible to migration.

Common Packing Problems

1.) Desire to use just one packing material throughout a plant. The material of choice is normally graphite ribbon packing because —
   - can be used at all temperatures.
   - can contain most fluids without corrosion effects.
   - can be installed in a valve without disassembling the valve.

   This packing material has shown itself in factory testing to be the “worst” packing material available for durability. Serious migration problems occur. Friction increases by magnitudes of 2-5 times.

   This material is subject to extensive consolidation. When over-compressed, the solution is to add more and over-compress the newly added graphite ribbon.

   This material can be a “problem”.

2.) Overtightening, which leads to reduced life and high friction.

3.) Corrosion, primarily of the valve stem. Stroking brings ambient moisture down within the packing rings. Stroking also brings corrosive fluid up into the packing rings. On a molecular basis H_2O gets with other fluids that generate concentrated acid, which can begin corrosion of the valve stem. The corrosion destroys the stem finish, which in turn destroys the packing from the inside towards the outside. Linear valve designs are particularly prone to this problem.

4.) Under-tightening, which normally comes with normal in-service wear, and regular/routine maintenance does not include retightening the packing's force-loading mechanism. Under-tightening will lead to leakage, which if not corrected immediately, will lead to a complete packing failure rather quickly.

Packing Design State-of-the-Art

1. Solid Packing Rings — Removal of “splits” in rings leads to lower radial stress loading, lower friction, and longer life.

2. Formed Rings — By reducing the quantity of surface contact between the packing ring material and the valve stem, sealing and life are improved. This is a case where “less is better”. PTFE and other plastics are normally of a V-ring design. Carbon graphite is normally a sloped rectangular ring.

3. Anti-Extrusion Rings — Upper and lower anti-extrusion adapter rings minimize packing ring extrusion and help keep packing ring geometric shape.

4. Stem Finish — By improving the quality of the valve stem finish, migration and corrosion are reduced, providing longer life. Surface finishes of 4-8 RMS are common today.

5. Live-Loading — This minimizes under-tightening effects and compensates for normal packing wear on a continuous basis. However, unless the mechanism design includes some safeguard, live-loaded mechanisms can be too easily overtightened.

6. Extension Column — An extension column will keep the packing zone separated physically away from the high or low (cryogenic) temperatures experienced thru a valve body. Such a design will keep the packing zone nearer to ambient temperature conditions, which allows use of conventional PTFE packing material.

7. Dual Packing — Two separate sets of packing with monitoring in-between the sets can provide an extra measure of protection/security against leakage.

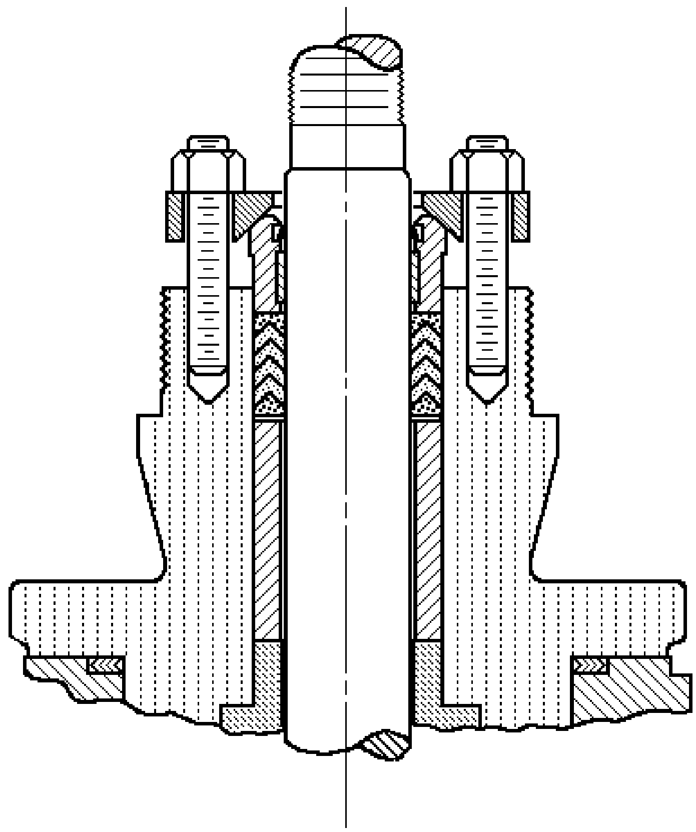
8. Bellows — A thin-wall bellows - normally of metal or TFE material - serves as a barrier between the valve's P_2-outlet pressure zone and ambient. The bellows corrugations flex as the stem travels, and thus are subject to fatigue failure considerations as well as stress corrosion cracking effects. A conventional packing design normally serves as a secondary backup in case of bellows failure.

9. Stem Guiding — Valve stem should be guided at both top and bottom as close to the packing as mechanically practical.

Note: Because of the erratic nature of carbon graphite packing, Cashco recommends the following —

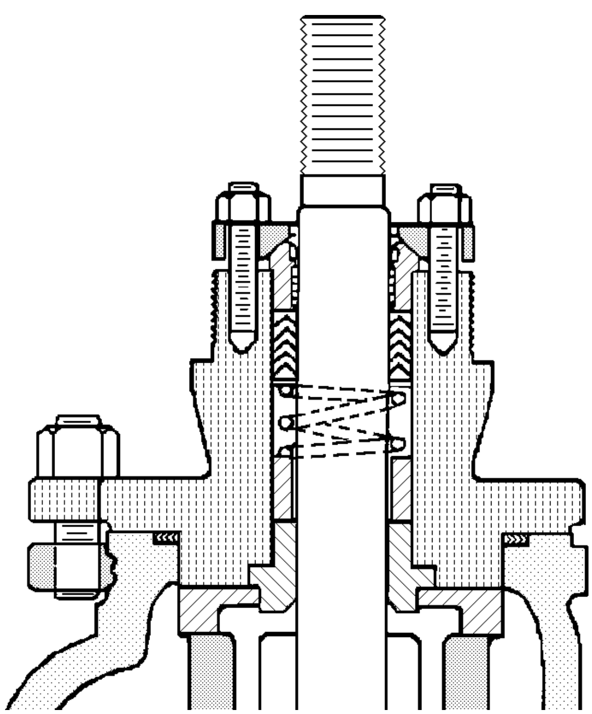
- Continuous rings; non-split.
- Formed rings with upper and lower adapter rings ONLY.
- Externally live-loaded packing with over-tightening prevention mechanism.
- Superior stem surface finish.

Jammed Packing

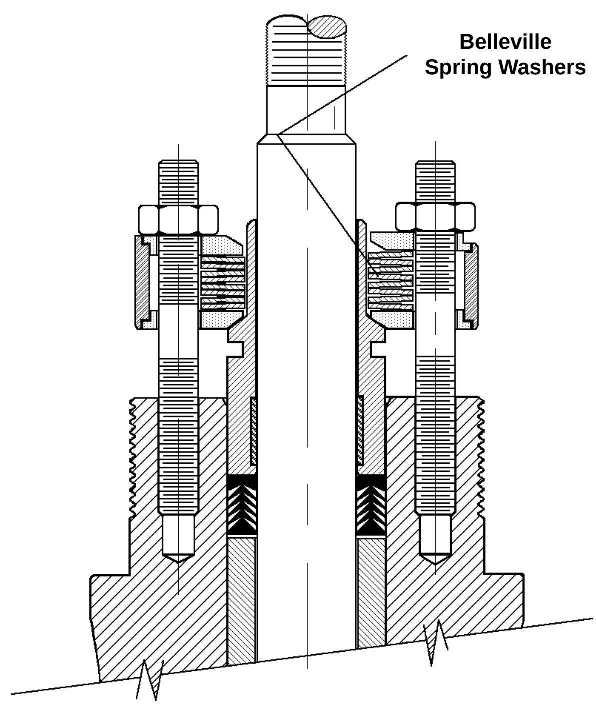


Live-Loaded Packing Arrangements

Spring-Loaded Packing

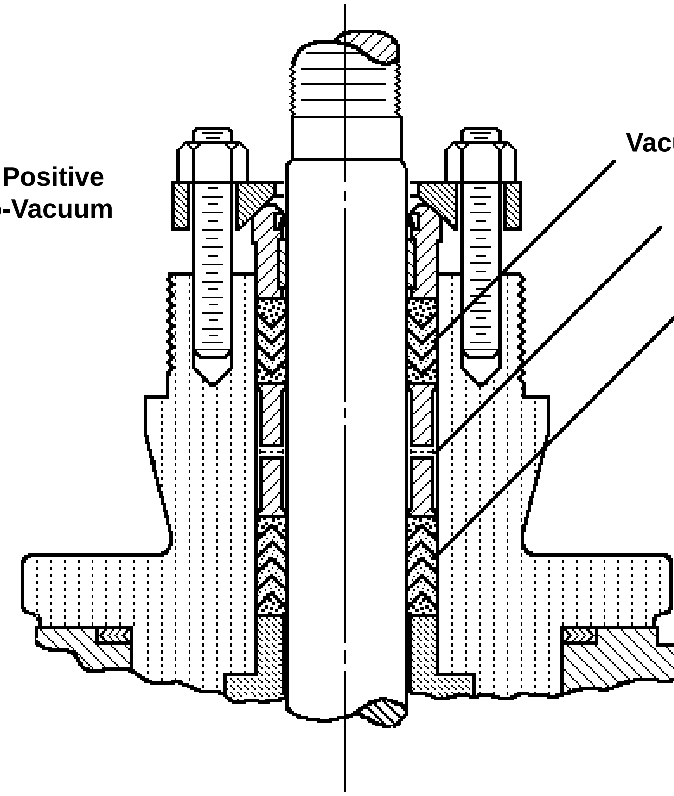


Internal Live-Loading



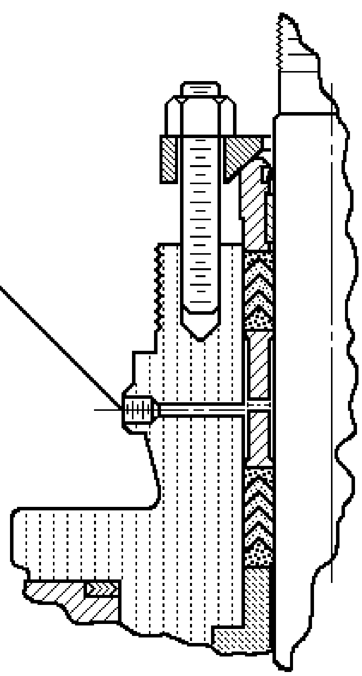
External Live-Loading

Dual Packing



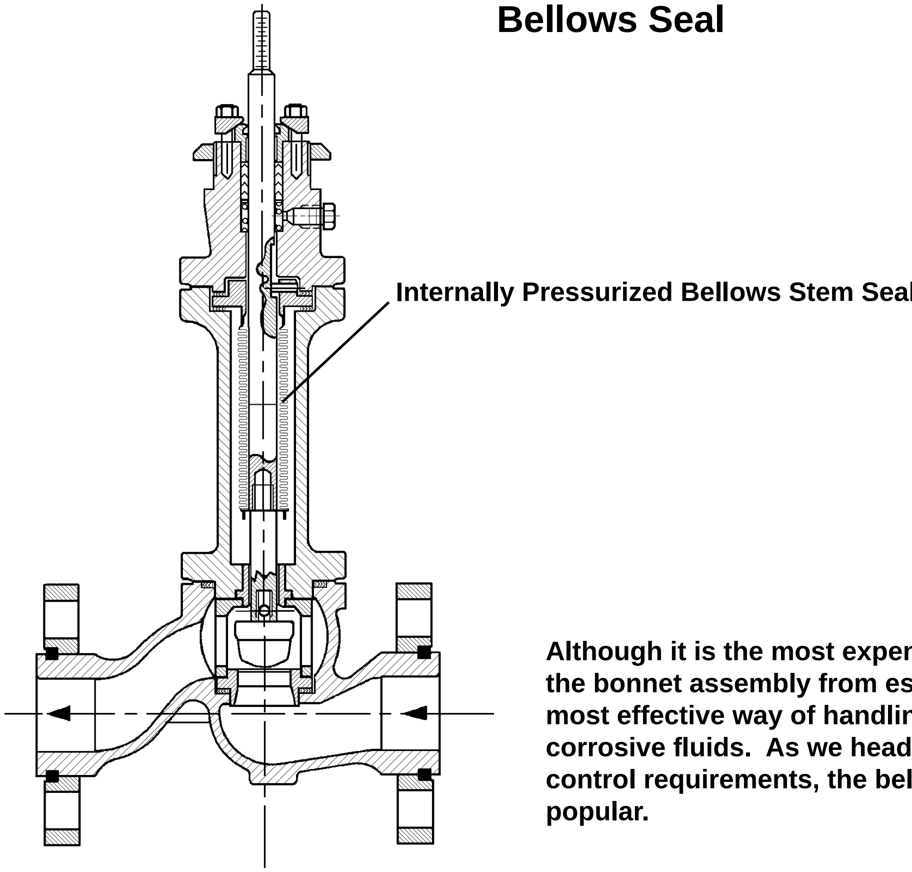
Pressure inside the valve is alternately greater than or less than (i.e. vacuum) ambient pressure.

Dual Packing With Leak-Off Connection



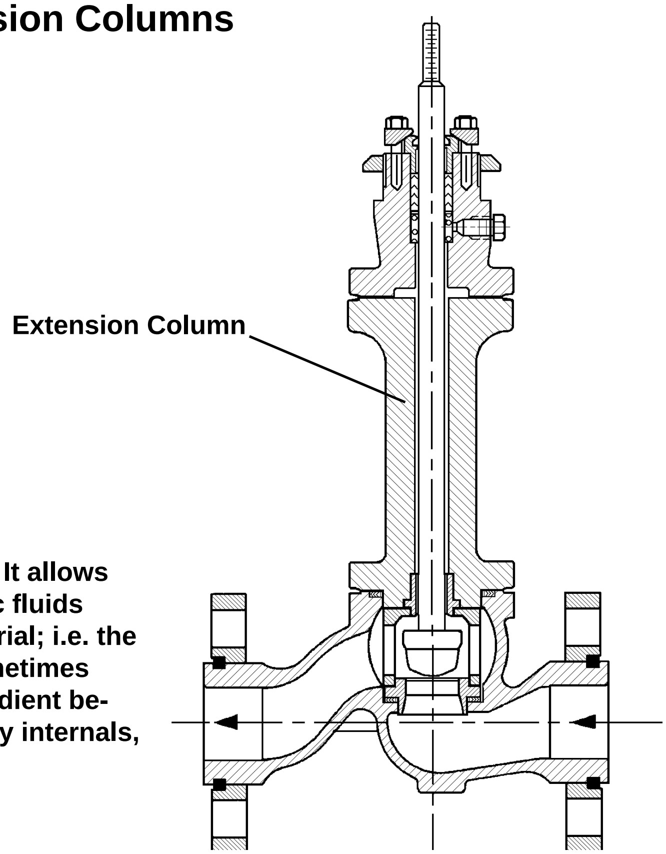
Valve has a 1/4" NPT tapped opening on its bonnet. Complete with removable steel plug for all body materials. The opening is located between primary and secondary packing sets when the valve is equipped with dual packing. A leak-off connection may be monitored with a pressure switch, fluid sensor, purge, or combination of the three.

Bellows Seal



Although it is the most expensive way in which to seal off the bonnet assembly from escaping fluids, it is also the most effective way of handling lethal, toxic explosive, and corrosive fluids. As we head toward "ZERO EMISSIONS" control requirements, the bellows seal will become more popular.

Extension Columns



The extension column is not to be insulated. It allows cooling of hot fluids, or warming of cryogenic fluids before making contact with the packing material; i.e. the extension column is a "heat exchanger" (sometimes finned). There is substantial temperature gradient between the packing location and the valve body internals, normally $\Delta T \approx 200^\circ$ – 300°F.

SECTION 12

Seat Leakage

SEAT DESIGNS

METAL	**COMPOSITION - SOFT**
1. Can supply shutoff to – ♦ **Class I** ♦ **Class II *** ♦ **Class III** ♦ **Class IV*** ♦ **Class V, hand-lapped** *** Common**	**1. Can supply Class VI shutoff.**
2. Is somewhat tolerant to "in-service" abrasion.	**2. Is not tolerant to "in-service" abrasion. The "rubbers" better able to resist damage because of resilience. TFE is <u>not</u> tolerant to any abrasion, flashing, or cavitation.**
3. Very high pressure drop capability for SST - limited for brass/bronze.	**3. Moderate pressure drop capability range.**
4. May be hardenable: **a. heat treated** **b. stellited** **c. diffusion coated** **d. plated**	**4. Non-hardenable.**
5. Expensive to repair if damaged.	**5. May be repairable by simple replacement of seat disc, IF the design allows.**
6. Can handle "dirty" fluids.	**6. Not recommended for "dirty"fluids.**
7. High temperature range.	**7. Moderate temperature range for TFE; lower limit for others.**
8. Use for "flashing" or "cavitating" applications.	**8. "Non-cavitating" or "non-flashing" applications.**

<u>SPECIAL NOTE</u>: A system design should <u>never</u> depend on tight shutoff of a composition soft seat. Eventually, a soft seat will fail and allow leakage. (New plant start-up is the most likely time for a soft seat to fail; i.e. weld slag, metal filings, dirt, sand, etc.

<u>DUAL</u>

Design includes both a composition-soft seat that gives Class VI shutoff, and a metal seat that serves as a "backup" that gives Class IV shutoff.

<u>SUMMARY</u>:
For throttling service, seating surface expectations for long service life must be considered/evaluated against the applied conditions!

SEAT LEAKAGE CLASSIFICATIONS

Leakage Class ANSI/FCI 70.2	Allowable Leakage Rate Air or Water	Valve Types	Remarks
Class I	Classes II, III or IV, but no test required by agreement between user and supplier.	Valve Types listed below in Classes II, III and IV.	Quality of mfg. implies that these valves do not exceed leakage Classes II, III and IV, but no guarantee is stipulated.
Class II	0.5% rated valve capacity, (maximum Cv).	Globe, double seated. Globe, single seated, balanced with stepped metal piston seat. Butterfly, metal lined.	
Class III	0.1% of rated valve capacity.	High quality globe double seated. Globe, single seated, balanced with continuous metal piston seats.	
Class IV	.01% of rated valve capacity.	Globe, single seated. Globe, single seated, balanced with elastomer piston seals. Rotary eccentric cam type. Ball valves with metal seat.	
Class V	5×10^{-4} cc/min. of water per inch of orifice diameter per psi differential pressure @ 100 psig minimum ΔP.	Globe valves in Class IV with heavy duty actuators to increase seating force.	Few valves continue to remain this tight in service unless the seat plastically deforms to maintain contact with the plug.
Class VI	Maximum permissible leakage associated with resilient seating valves. Expressed as Bubbles per Minute as per ANSI/FCI table below.	Globe with resilient seat. Butterfly, elastomer lined. Rotary eccentric cam with elastomer seat. Ball with resilient seat, solid ball type. Diaphragm, Weir type. Plug valves, elastomer seated or sealant injection sealing system.	Elastomer sealed valves remain this tight for many thousands of cycles until the seal is worn or cut.

NOTE: 1 cc/min = 1 ml/min.

Nominal Port Diameter			
Millimeters	Inches	ml per Minute	Bubbles per Minute
25	1	0.15	1
38	1-1/2	0.30	2
51	2	0.45	3
64	2-1/2	0.60	4
76	3	0.90	6
102	4	1.70	11
152	6	4.00	27
203	8	6.75	45

NOTE: 1 Bubble = 0.15 ml/min.

SEAT LEAKAGE - How much "*real*" leakage is it??

CASHCO SUPPLIES PRODUCTS WITH THE FOLLOWING SEAT LEAKAGE LEVELS —

CLASS I - as stated by mfgr. @ 1.0% of Max Cv at Cashco.
CLASS II - 0.5% of Max Cv.
CLASS IV - 0.01% of Max Cv.
CLASS VI - function of valve port size; expressed as "Bubbles per Minute" with an air/GN2 test.

COMPOSITION (SOFT) SEAT DESIGNS WILL GIVE CLASS VI.

METAL-TO-METAL SEAT DESIGNS WILL GIVE CLASS II IN MOST CASES, AND CAN NORMALLY BE "UPGRADED" TO GIVE CLASS IV.

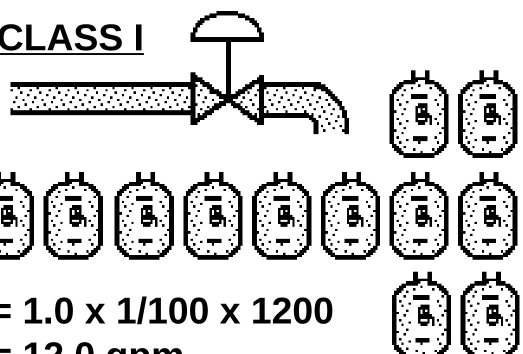
Assume for the Class I, II, & IV that the water is the test fluid, and test pressure is at 50 psid pressure drop (P1 = 50 psig, P2 = atmospheric or 0 psig). 3" valve with 3" port, Max Cv = 169.7.

$$\dot{Q}_{H_2O} = Cv \times \sqrt{\Delta P/SG} = 169.7 \times \sqrt{50/1} = 1200 \text{ US gpm}$$

$$*(\dot{Q}_{AIR} = 31.22 \text{ SCFH} = 0.01\% \text{ of Max } Cv = .01697Cv = 14.7 \text{ lit/min} \approx 98{,}000 \text{ bub/min})$$

CLASS I

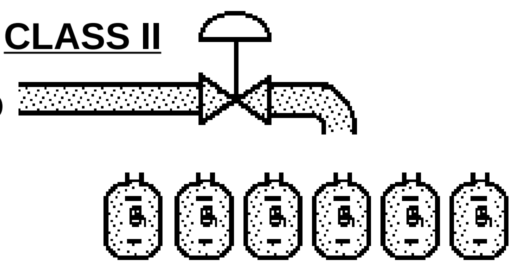
H_2O



= 1.0 x 1/100 x 1200
= 12.0 gpm

CLASS II

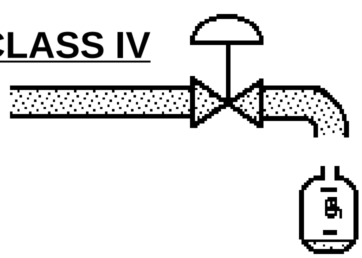
H_2O



= 0.5 x 1/100 x 1200
= 6.0 gpm

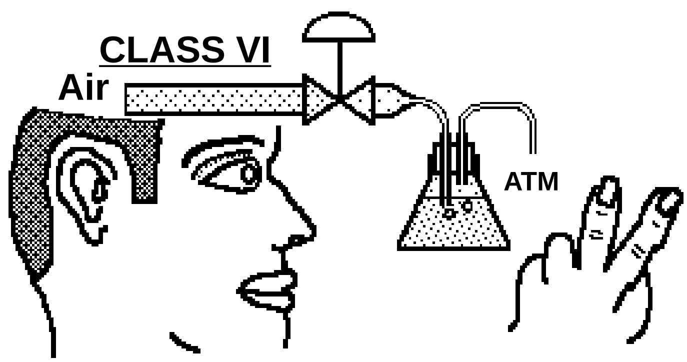
CLASS IV

H_2O



= 0.01 x 1/100 x 1200 = 0.12 gpm
≈ 0.5 quart/min ≈ 1 pint/min ≈ 0.5 lit/min
*** (See note above for air leakage equivalent.)**

CLASS VI



= 0.90 ml = 6 bubbles/min

NOTES

• 607 West 15th Street • P.O. Box 6 • Ellsworth, KS 67439-0006
• PH: (785) 472-4461 • FAX: (785) 472-3539 (domestic) or (785) 472-8544 (exports)
• E-mail: sales@cashco.com or exportsales@cashco.com
www.cashco.com