KLM Technology Group
#03-12 Block Aronia,
Jalan Sri Perkasa 2
Taman Tampoi Utama
81200 Johor Bahru.

CONTROL VALVE SELECTION AND SIZING (ENGINEERING DESIGN GUIDELINE)

Co Authors

Rev 01 - J H Chan
Rev 02 – Viska Mulyandasari
Rev 03 – K Kolmetz

Karl Kolmetz

TABLE OF CONTENT

INTRODUCTION

Scope 4

General Design Consideration 5

Control Valve Body 5

Control Valve Actuator 7

I) Diaphragm Actuators 9

II) Piston Actuators 9

III) Electro Hydraulic Actuators 10

IV) Manual Actuators 10

DEFINITIONS 11

NOMENCLATURE 14

THEORY OF THE DESIGN 16

A) Control Valve Flow Characteristic 16

I) Inherent Flow Characteristic 16

II) Linear Flow Characteristic 17

III) Equal Percentage Flow Characteristic 18

IV) Quick Opening Flow Characteristic 18

V) Installed Flow Characteristic 19

B) Control Valve Sizing 20

I) Sizing for Liquid Services 21

Flashing and Cavitation 25

Choked Flow 27

Computing $\Delta P_{critical}$ and Geometry Factors 28

Flow Correction Factor (F_R) 31

II) Sizing for Vapor Services 32

Critical Pressure Drop 34

Calculating the Valve Flow Coefficient 34

APPLICATION

Example Case 1: Sizing a Control Valve in Liquid Hydrocarbon Application 36

Example Case 2: Sizing a Control Valve in Liquid Water Application 42

Example Case 3: Sizing a Control Valve in Vapor Hydrocarbon Application 46

Example Case 4: Sizing a Control Valve in Steam Application 51

REFEREENCES 56

SPECIFICATION DATA SHEET

Control Valve Data Sheet (Excel format) 57
CALCULATION SPREADSHEET

Excel Format (British & SI unit)

Sizing Spreadsheet for Liquid 58

Sizing Spreadsheet for Vapor 59

Example 1: Sizing a Control Valve in Liquid –Hydrocarbon 60

Example 2: Sizing a Control Valve in Liquid –Water 61

Example 3: Sizing a Control Valve in Vapor –Hydrocarbon 62

Example 4: Sizing a Control Valve in Vapor –Steam 63

LIST OF TABLE

Table 1: Equation Constants 24

LIST OF FIGURE

Figure 1: Single port control valve 5

Figure 2: Double port control valve 6

Figure 3: Direct acting diaphragm actuator 8

Figure 4: Reverse-acting diaphragm actuator 8

Figure 5: Flow characteristic curves 16

Figure 6: Installed flow characteristic for linear control valve installed in flow

systems having different values of α 20

Figure 7: Standard FCI Test Piping for C_v Measurement 22

Figure 8: Vena Contracta Illustration 25

Figure 9: Comparison of Pressure Profiles for High and Low Recovery Valves 26

INTRODUCTION

Scope

Hundreds or even thousands control loops are networked together in a process system plant to maintain the important process condition; such as pressure, fluid flow and level, temperatures, etc. During the process, each of these loops receives and internally creates disturbances that might affect process conditions. Hence sensors and transmitters are installed to collect information about process condition changes and their correlation to the desired set point. Furthermore, a final control element is needed to process the information received; deciding what must be done to get back the normal process condition. The most common type of final control element in industrial process control system is control valve; which can be operated pneumatically, hydraulically, or electrically.

Each type of control valve has a different flow characteristic, and its selection largely based on the type of the application process where it's installed into. Some common cases come along with this control valve sizing; an oversized control valve will spend an extra cost and introduce some difficulties in controlling the low flow rates, while an undersized valve might not be able to handle the maximum capacity of the process flow.

There are many available guidelines developed to aid engineers in selecting and sizing the valves, but mostly these guidelines are developed by certain companies and might only be suitable for the application of the valves provided by their own companies. Hence, it is important to obtain a general understanding of control valve sizing and selection first. Later, whenever changes are needed in a process system, this basic knowledge is still applicable. This guideline is made to provide that fundamental knowledge and a step by step guideline; which is applicable to properly select and size control valves in a correct manner.

Control valve supports the other devices which work together resulting in an ideal process condition. Hence, it is crucial to make some considerations before deciding the correct control valve sizing and selection. The selected valve has to be reasonable in cost, require minimum maintenance, use less energy, and be compatible with the control loop. Malfunction in control valve might cause process system does not work properly.

Two basic steps to determine the control valve to be used are control valve selection and control valve sizing. Selection of control valve includes material selection and control valve type selection. Some commonly used materials are briefly mentioned in the general design consideration section. Different types of control valve actuator together with their advantages and disadvantages are also explained as well in this section.

Sizing the valve should not be done just by entering the numbers into formulas. It requires good understanding of theories behind the numbers. Any limiting or adverse conditions; such as flashing, cavitation, and choked flow need to be considered in design calculation. Their relation for valve sizing is explained in this guideline. Besides, two different types of fluid (liquids and gasses) would result in different calculation which is also included in this guideline. The calculation spreadsheet is also attached in the end of this guideline to make an engineer easy to follow the step by step calculation.

INTRODUCTION

General Design Consideration

A common control valves consist of two parts: the control valve body and control valve actuator. Control valve body is the housing which is contained the flowing medium. It provides inlet and outlet connections; and a movable restrictor which varies the fluid flow as it opens and closes the port. The other term, an actuator, is part of control valve which causes the valve stem to move by providing the force it's needed.

Control Valve Body

The body of a control valve will regulate the fluid flow as the position of the valve is changed by the actuator. Therefore, it is very important for the valve body to be able to permit actuator thrust transmission, resist chemical and physical effects from the process, and easily flange up with the adjacent piping connections. All the criteria mentioned above must be fulfilled without any external leaking. Most control valves are designed as a globe valve, but other configurations such as ball and butterfly styles are available based on the review of the engineering application.

The most common control valve body style is single ported as shown in Figure 1, which has wide range of applications. Single ported valves are available in various forms, such as globe, angle, bar stock, forged and split constructions. These valves are generally specified for applications with stringent shutoff requirements. Metal to metal seating surfaces or “soft seating” with nitrile or other elastomeric materials forming the seal, can handle most service requirements.

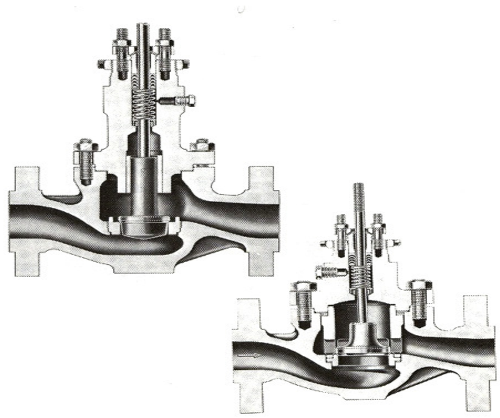

Figure 1: Single port control valve

Since high pressure fluid is normally loading the entire area of the port, the unbalance force created must be considered in selecting actuators for single ported control valve bodies. Single ported valves are know to work well in small sizes but it can often be used in 4 inch to 8 inch sizes with high thrust actuators. Many modern single ported valve bodies use cage style construction to retain the seat ring, provide guiding to the valve plug, and means for establishing a particular flow characteristic.

Cage style trim offers advantages in ease of maintenance and flexibility in changing the cages to alter valve flow characteristics. Cage style single seated valve bodies can also be easily modified by change of trim parts to provide reduced capacity flow, noise attenuation, or reduction or elimination of cavitations.

There are other types of valve body design such as double ported valve bodies Figure 2, flanged angle, thee way valve, and many other valves designed for specific service conditions available in the market.

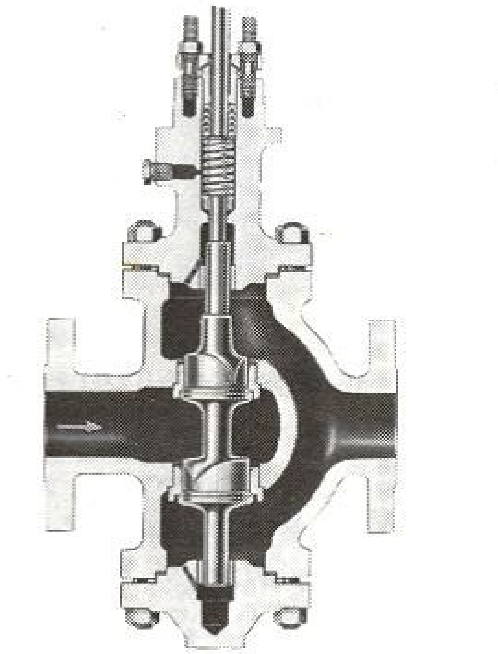

Figure 2: Double port control valve

Control valve bodies may be screwed, flanged, or welded onto the flow line. Screw ends usually are threaded with American Standard female tapered pipe threads. The dimensions, design details, and pressure temperature ratings of flanged ends should be in accordance with American National Standards Institute (ANSI) specifications.

The most common material for control valve body construction is cast iron or carbon steel. Other materials such as chromium-molybdenum, stainless steel, bronze, monel, nickel and many other castable alloys can be used when the control valve is subjected to operate under extreme conditions, e.g. very high or very low temperature, or application under corrosive environment. The valve may also be constructed from solid bar or forged materials when cast valve bodies are not practical, particularly for small valves.

The construction material for control valve trim, i.e. those parts which must retain close machined tolerances for sealing, metering, or moving, must be selected with care. It must generally be more resistant to corrosion, erosion, galling, and distortion than the body material.

Control Valve Actuator

Most common control valve actuators are pneumatically operated but other means of operation such as electric, hydraulic and manual actuators are also available. The operation mechanism of an actuator can be direct acting (Figure 3) or reverse acting (Figure 4). The spring and diaphragm pneumatic actuator is most popular due to its dependability and simplicity of design. Pneumatically operated piston actuators provide integral positioner capability and high stem force output for demanding service conditions. Adaptations of both spring and diaphragm and pneumatic piston actuators are available for direct installation on rotary shaft control valves.(3)

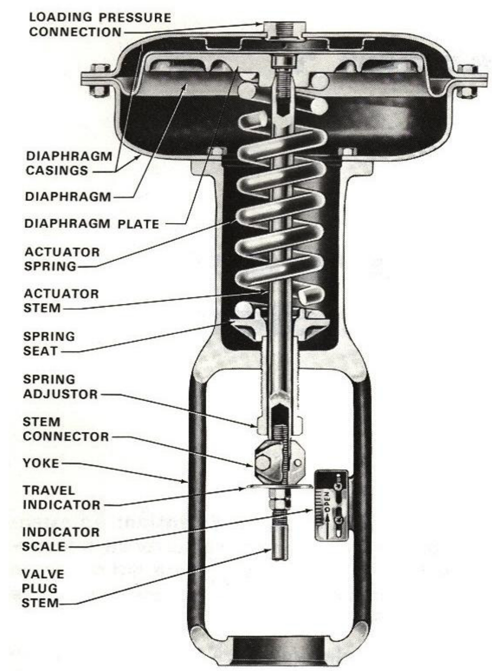

Figure 3: Direct acting diaphragm actuator

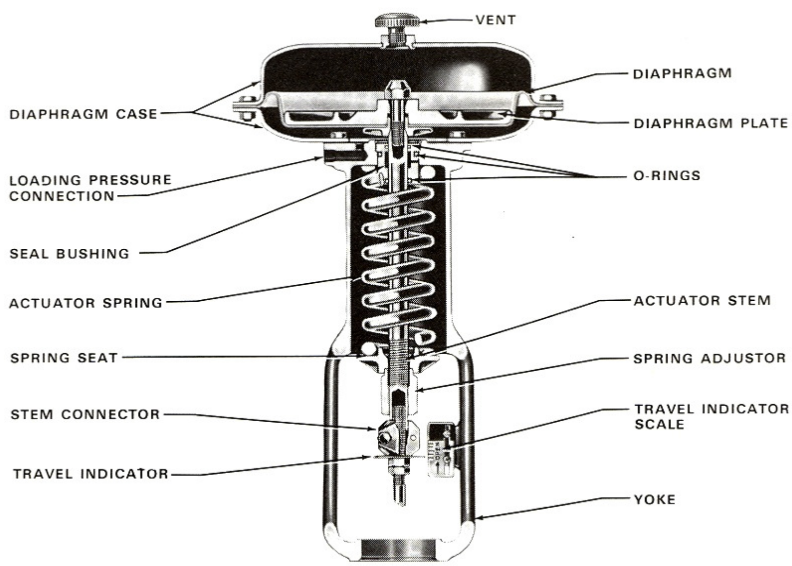

Figure 4: Reverse-acting diaphragm actuator

Electric and electro-hydraulic actuators are more complex and more expensive than pneumatic actuators. This is due to these types of actuators offer advantages where no air supply source is available, where low ambient temperatures could freeze condensed water in pneumatic supply lines, or where unusually large stem forces are needed. A brief summary regarding the design and characteristics of the actuators are give as follows.

I) Diaphragm Actuators

Pneumatically operated, using low-pressure air supply from controller, positioner, or other source.

Various styles include:

- Direct acting - increasing air pressure pushes down diaphragm and extends actuator stem;
- Reverse acing - increasing air pressure pushes up diaphragm and retracts actuator stem;
- Reversible - some small sized actuators can be assembled for either direct or reverse action ;
- Direct acting unit for rotary valves - increasing air pressure pushes down on diaphragm, which may either open or close the valve, depending on orientation of the actuator lever on the valve shaft.

Net output thrust of diaphragm actuators is the difference between diaphragm force and opposing spring force. Molded diaphragms are used to provide linear performance and increased travels. Size is dictated by output thrust required and supply air pressure available. It is simple, dependable, and economical.

II) Piston Actuators

Pneumatically operated using high pressure plant air to 150pisg, often eliminating the need for supply pressure regulator. Furnish maximum thrust output and fast response. It is easily reversible by changing action of the integral valve positioner. Best designs are double acting to give maximum force in both directions. Various accessories can be incorporated to position the actuator piston in the event of supply pressure failure. These include spring return units, pneumatic trip valves and lock up systems.

Also available are hydraulic snubbers, handwheels, and units without yokes, which can be used to operate butterfly valves, louvers, and similar industrial equipment. Other versions for service on rotary shaft control valves include a sliding seal in the lower end of the cylinder. This permits the actuator stem to move laterally as well as up and down without leakage of cylinder pressure. (This feature permits direct connection of the actuator stem to the actuator lever mounted on the rotary valve shaft, thereby eliminating much of the lost motion common to jointed leakage.)

III) Electro Hydraulic Actuators

Requiring only electrical power to the motor and an electrical input signal from the controller. It is ideal for isolated locations where pneumatic supply pressure is not available but where precise control of valve plug position is needed. Units are normally reversible by making minor adjustments and are usually self-contained, including motor, pump, and double-acting hydraulically operated piston within a weatherproof or explosion proof casing.

IV) Manual Actuators

Manual Actuators is useful where automatic control is not required, but where ease of operation and good throttling control is still necessary. It is often used to actuate the bypass valve in a three valve bypass loop around control valves for manual control of the process during maintenance or shutdown of the automatic system. It is available in various sizes for both globe style valves and rotary shaft valves. It is dial indicating devices available for some models to permit accurate repositioning of the valve plug or disc and much less expensive than automatic actuators.

DEFINITIONS

Capacity – Rate of flow through a valve under stated conditions.

Dead Band [2]- Is the range which an input can be varied without initiating observable response. (By referred to the amount of the diaphragm pressure it can be changed without initiating valve stem movement in a diaphragm actuated control valve. It is usually expressed as a percent of diaphragm pressure span.)

Diaphragm Pressure Span – Difference between the high and low values of the diaphragm pressure range. This may be stated as an inherent or installed characteristic.

Double –Acting Actuator – An actuator capable of operating in either direction, extending or retracting the actuator stem as dictated by the fluid pressure acting upon it.

Dynamic Unbalance - The net force produced on the valve plug in any stated open position by the fluid pressure acting upon it.

Effective Area - Part of the diaphragm area which is effective in producing a stem force in a diaphragm actuator. (The effective area of a diaphragm may change as it is stroked, usually being a maximum at the end of the travel range. Molded diaphragms have less change in effective area than flat sheet diaphragms, and are recommended.)

Equal Percentage Flow Characteristic – An inherent flow characteristic which produces equal percentage of changes in the existing flow for equal increments of rated travel. (Increasing sensitivity)

Fail-Closed - A condition wherein the valve port remains closed should the actuating power fail.

Fail-Open - A condition wherein the valve port remains open should the actuating power fail.

Fail-Safe - An actuator which will fully close, fully open, or remain in the fixed position upon loss of power supply. (May require additional auxiliary controls to be connected to the actuator)

Flow Characteristic - Relationship between the flow of fluid through the valve and the percent of rated travel as the latter is varied from 0 – 100 percent. This term should always be designated as either inherent flow characteristic or installed flow characteristic.

High Recovery Valve - A valve design that dissipates relatively little flow stream energy due to streamlined internal contours and minimal flow turbulence. (Straight-through flow valves, such as rotary-shaft ball valves, are typically high-recovery valves.)

Inherent Diaphragm Pressure Range - The high and low values of pressure applied to the diaphragm to produce rated valve plug travel with atmospheric pressure in the valve body. (This range is often referred to as a "bench set" range since it will be the range over which the valve will stroke when it is set on the work bench.)

Inherent Flow Characteristic - Flow characteristic when constant pressure drop is maintained across the valve.

Inherent Rangeablity - Ratio of maximum to minimum flow within which the deviation from the specified inherent flow characteristic does not exceed some stated limit. (A control valve that still does a good job of controlling when increases to 100 times the minimum controllable flow has a rangeablitiy of 100 to 1. Rangeability might also be expressed as the ratio of the maximum to minimum controllable flow coefficients.)

Installed Diaphragm Pressure Range - The high and low values of pressure applied to the diaphragm to produce rated travel with stated conditions in the valve body. (It is because of the forces acting on the valve plug that the inherent diaphragm pressure range can differ from the installed diaphragm pressure range.)

Installed Flow Characteristic - Flow characteristic when pressure drop across the valve varies as dictated by flow and related conditions in the system in which the valve is installed.

Leakage - Quantity of fluid passing through an assembled valve when the valve is in the closed position under stated closure forces, with pressure differential and pressure as specified.

Linear Flow Characteristic - An inherent flow characteristic which can be represented ideally by a straight line on a rectangular plot of flow versus percent rated travel. (Equal increments of travel yield equal increments of flow at a constant pressure drop.)

Low-Recovery Valve - A valve design that dissipates a considerable amount of flow stream energy due to turbulence created by the contours of the flow path. This results into a lower pressure recovery across the vena contracta and hence the valve will have a larger pressure drop. (Conventional globe-style valves generally have low pressure recovery capability.)

Normally Closed Control Valve - A control valve which closes when the diaphragm pressure is reduced to atmospheric.

Normally Open Control Valve - A control valve which opens when the diaphragm pressure is reduced to atmospheric.

Push-Down-to-Close Construction (2)- A globe-style valve construction in which the valve plug is located between the actuator and the seat ring. The valve closes when the extension of the actuator stem moves the valve plug toward the seat ring, finally closing the valve. This mechanism is also called Direct Acting. (For rotary-shaft, linear extension of the actuator stem moves the ball or disc toward the closed position.)

Push-Down-to-Open - A globe type valve construction in which the seat ring is located between the actuator and the valve plug. The valve opens when the extension of the actuator stem moves the valve plug away from the seat ring. This mechanism is also called Reverse Acting. (For rotary-shaft valve, linear extension of the actuator stem moves the ball or disc toward the open position.

Quick Opening Flow Characteristic - An inherent flow characteristic in which there is maximum flow with minimum travel. (Decreasing sensitivity)

Rated C_v - The value of C_v at the rated full-open position.

Rated Travel - Linear movement of the valve plug from the closed position to the rated full-open position. (The rated full-open position refers to the maximum opening recommended by the manufacturer.)

Seat Load - The contact force between the seat and the valve plug. (In practice, the selection of an actuator for a given control valve will be based on how much force is required to overcome static, stem , and dynamic unbalance with an allowance made for seat load.)

Spring Rate - Force change per unit change in length. (In diaphragm control valves, the spring rate is usually stated in pounds force per inch compression.)

Static Unbalance - The net force produced on the valve plug in its closed position by the fluid pressure action upon it.

Stem Unbalance - The net force produced on the valve plug stem in any position by the fluid pressure action upon it.

Valve Flow Coefficient (C_v) - The amount of 60°F water in US gallons per minute that will flow through a valve with a one pound per square inch pressure drop.

Vena Contracta - The point where the pressure and the cross-sectional area of the flow stream is at its minimum, whereas the fluid velocity is at its highest level. (Normally occurs just down stream of the actual physical restriction in a control valve.)

NOMENCLATURE

α	Ratio of valve head differential at max flow to zero flow
C_v	Valve sizing coefficient
d	Nominal valve size
D	Pipe internal diameter
F_d	Valve style modifier, dimensionless
F_k	Ratio of specific heats factor
F_L	Liquid pressure recovery factor
F_{LP}	Combined liquid pressure recovery and piping geometry factor of valve attached to fittings, dimensionless
F_R	Reynolds number factor
S	Liquid specific gravity, dimensionless
S_g	Gas specific gravity, dimensionless
k	Ratio of specific heats, adiabatic index or isentropic exponent, dimensionless
M	Molecular weight, dimensionless
N	Numerical constant from Table 1
N_{Re}	Reynolds number, dimensionless
P1	Upstream pressure (Absolute)
P2	Downstream pressure (Absolute)
P_c	Critical pressure (Absolute)

P_v	Vapor pressure (Absolute) of liquid at inlet temperature
ΔP	Pressure drop across the valve (P_1-P_2)
$\Delta P_{critical}$	Maximum allowable pressure drop across the valve for design purpose
ΔP_s	Pressure drop across the valve for sizing
Q	Volumetric flow rate
Q_{max}	Maximum flow rate (choked flow conditions) at given upstream condition
r_c	Liquid critical pressure ratio factor, dimensionless
T_1	Upstream temperature (Absolute, T or R)
W	Mass flow rate
x	Ratio between pressure drop across the valve and inlet pressure, dimensionless
x_T	Rated pressure drop ratio factor, dimensionless
x_{TP}	Rated pressure drop ratio factor for valves attached to fittings, dimensionless
Y	Expansion factor, dimensionless
ρ	Density
z	Compressibility factor, dimensionless
γ_1	Density at inlet conditions
υ	Kinematic viscosity, centistokes