Design and Analysis of Multi Stage Control Valve

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***Abstract*:- The control valves are mechanical devices specifically designed to direct, start, stop, mix, or regulate the flow, pressure and temperature of the process fluid.**

Control valve provide correct distribution and control of flowing fluids and gases. Actuator is final control element mounted on the control valve that in response to a signal automatically move the valve stem and its plug called the closure element, to the required position using external power source. The control valve finds its application in power plants, processing industries, chemical handling, and fertilizer industry.

Today's spectrum of available valves extends from simple water faucets to control valves equipped with microprocessors, which provide single loop control of the process.

This includes the complete study of control valve classifications, construction details, assembly procedures and their inspection.

COMPANY PROFILE

Instrumentation limited palakkad is a government of India enterprise setup in palakkad in 1974 in technical collaboration with the international reputed firm M/s YAMATA-KEHONEY WELL company Ltd Japan for the manufacture of industrial process control valves, later safety relief valves manufactured in collaboration with M/s NUOVOPIGNONE, Italy has been added to the product range. IL palakkad concentrate mainly on pneumatically operated control valves and power cylinders was also added in collaboration with M/s Born, Baueri Kent UK later. Since the inception, Instrumentation Ltd has been going on well fast indigenization of the products resulted in massive saving in foreign exchange for the country. ILP has stood its ground as the leader in the market in control valve segment in face of it stiff competition from the MNC's having the joint ventures in India. All new products have been developed in house which are mostly achieved for the first in India for in indigenization like nuclear services valves.

ILP is the first control valve manufacture in India who has been certified with ISO 9001. It was in December 1994 that the certifying agency IRQS audited and ILP as certified as conforming the international standards.

Instrumentation Ltd started with a turnover of two crores in 1976-77 and the unit achieved a steady growth and in the financial year 2009-10, attaining a turnover of more than 100 crores. The company has to face stiff competition from nine competitors and the main competitors are M/s MIL CONTROLS Ltd in Aluva, M/s FISHER CONTROLS Ltd Chennai, M/s MOORCO VALVES Trichy and M/s DRESSER in Coimbatore.

They have gone for the latest International manufacturing technology and the valves are designed and supplied conforming to international pressure vessel standards like ANSI, DIN, BS, AWWA. The

research and development team of the unit has developed a number of valve products such as Bellow sealed globe valve for sodium application in NTPC and Bellow sealed 3 valve manifold for NPCIL which are won the innovation awards. The development of "BUTTERFLY VALVES" for steel plants & fertilizing units and petroleum company's & sugarcane industries is the result of the efforts put in by R&D department.

Instrumentation Ltd has taken up development and manufacture of initial component special projects for the ministry of defense as a part of diversification.

The quality assurance and inspection standards adopted by ILP conform to the latest international standards and all the products moving of the palakkad plant bear a stamp of the high degree of the quality. Some of the special test conducted by ILP includes dynamic response testing, helium leak testing, radiographic inspection, hydraulic pressure testing, cryogenic testing, hot cyclic testing, etc.

Being in the field of control valves for last 40 years ILP has got one of the best trained man powers in the field of research design application, engineering field by using international techniques.

The company provides regular customer education programs and practical knowledge is imparted to the participants in order to carry out preventive maintenance as well as minor modification or renovation that might be required at last stage of product use. In short ILP is a pioneer in its own product range in the country and maintenance leadership even now and also an important part in the industrial area kanjikode.

INTRODUCTION

Process plants consist of hundreds, or even thousands, of control loops all networked together to produce a product to be offered for sale. Each of these control loops is designed to keep some important process variable such as pressure, flow, level, temperature, etc. within a required operating range to ensure the quality of the end product. Each of these loops receives and internally creates disturbances that detrimentally affect the process variable, and interaction from other loops in the network provides disturbances that influence the process variable.

To reduce the effect of these load disturbances, sensors and transmitters collect information about the process variable and its relationship to some desired set point. A controller then processes this information and decides what must be done to get the process variable back to where it should be after a load disturbance occurs. When all the measuring,

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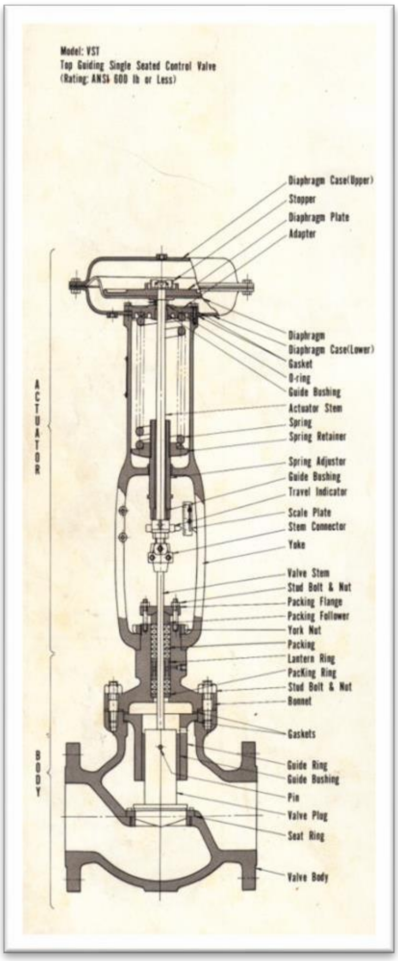
comparing, and calculating are done, some type of final control element must implement the strategy selected by the controller. The most common final control element in the process control industries is the control valve. The control valve manipulates a flowing fluid, such as gas, steam, water, or chemical compounds, to compensate for the load disturbance and keep the regulated process variable as close as possible to the desired set point.
Whether it is called a valve, control valve or a control valve assembly is not as important as recognizing that the control valve is a critical part of the control loop. It is not accurate to say that the control valve is the most important part of the loop. It is useful to think of a control loop as an instrumentation chain. Like any other chain, the whole chain is only as good as its weakest link. It is important to ensure that the control valve is not the weakest link.
Many people who talk about control valves or valves are really referring to a control valve assembly. The control valve assembly typically consists of the valve body, the internal trim parts, an actuator to provide the motive power to operate the valve, and a variety of additional valve accessories, which can include positioners, transducers, supply pressure regulators, manual operators, snubbers, or limit switches. Other chapters of this handbook supply more detail about each of these control valve assembly components.



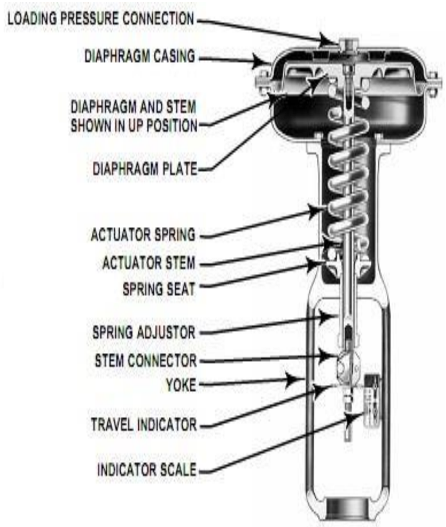
COMPONENTS

Actuator
A pneumatic , hydraulic or electrically powered device that supplies force and motion to open or close a valve. An actuator includes all the pertinent accessories that make it a complete operating unit. It is broadly classified into two type's namely direct actuator and reverse actuator.

Direct actuator
A diaphragm actuator in which the actuator stem extends with increasing diaphragm pressure is called direct actuator.

Reverse actuator
A diaphragm actuator in which the actuator stem retracts with increasing diaphragm pressure is called reverse actuator.

Actuator spring
A spring or group of springs enclosed in the yoke or actuator casing that moves the actuator stem in a direction opposite to that created by diaphragm pressure.



Actuator stem
It is the part that connects the actuator to the valve stem and transmits motion (force) from the actuator to the valve.

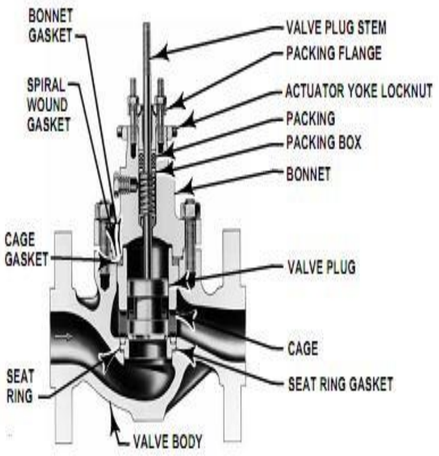
Actuator Stem Extension
It is an extension of the piston actuator stem to provide a means of transmitting piston motion to the valve positioner.

Diaphragm
It is a flexible, pressure responsive element that transmits force to the diaphragm plate and actuator stem.

Diaphragm Case
It is a housing consisting of top and bottom section, used for supporting a diaphragm and establishing one or two pressure chambers.

Diaphragm plate

It is a plate concentric with the diaphragm for transmitting force to the actuator stem.



Spring adjustor
A fitting, usually threaded on the actuator stem or into the yoke, to adjust the spring compression.

Spring Seat
It is a plate to hold the spring in position and to provide a flat surface for the spring adjustor to contact.

Yoke
The structure that rigidly connects the actuator power unit to the valve is called yoke.

VALVE BODY

The valve body is the main pressure boundary of the valve that provides the pipe connecting ends, the fluid flow passageway and supports the seating surfaces and the valve closure member. Among the most common valve body constructions are:

a. Single-ported valve bodies having one port and one valve plug.

b. Double-ported valve bodies having two ports and one valve plug.
c. Two-way valve bodies having two flow connections, one inlet and one outlet.
d. Three-way valve bodies having three flow connections, two of which can be inlets with one outlet

3.3 PLUG
A term frequently used to refer to the closure member.

3.4 SEAT RING
A part of the valve body assembly that provides a seating surface for the closure member and can provide part of the flow control orifice.

CAGE

A part of a valve trim that surrounds the closure member and can provide flow characterization and/or a seating surface. It also provides stability, guiding, balance and alignment, and facilitates assembly of other parts of the valve trim. The walls of the cage contain openings that usually determine the flow characteristic of the control valve.

VALVE STEM
In a linear motion valve, the part that connects the actuator stem with the closure member.

TRIM
It is the internal component of a valve that modulates the flow of the controlled fluid. In a globe valve body, trim would typically include closure member, seat ring, cage, stem, and stem pin.

BONNET
The portion of the valve that contains the packing box and stems seal and can guide the stem. It provides the principal opening to the body cavity for assembly of internal parts or it can be an integral part of the valve body. It can also provide for the attachment of the actuator to the valve body. Typical bonnets are bolted, threaded, welded, pressure-seals, or integral with the body. (This term is often used in referring to the bonnet and its included packing parts. More properly, this group of component parts should be called the bonnet assembly.)

Bonnet assembly

An assembly including the part through which a valve stem moves and a means for sealing against leakage along the stem. It usually provides a means for mounting the actuator and loading the packing assembly.

Bottom flange
The part that closes a valve body opening opposite the bonnet opening It can include a guide bushing and/or serve to allow reversal of the valve action.

Packing box (assembly)
The part of the bonnet assembly used to seal against leakage around the closure member stem. Included in the complete packing box assembly are various combinations of some or all of the following component parts: packing, packing follower, packing nut, lantern ring, packing spring, packing flange, packing flange studs or bolts, packing flange nuts, packing ring, packing wiper ring, felt wiper ring, Belleville springs, anti-extrusion ring.

WORKING PRINCIPLE

- The process plant comprises of numerous control loops in order to deliver consistent quality products.
- These control loops have a set pressure, temperature, flow, level in order to maintain the required operating range.
- Each of these control loops experience internal disturbance and these disturbances are measured by sensors and transmitters.
- The information collected is then processed by the controllers to decide what should be done to rectify these load disturbances.
- Once the data collected is analyzed, measured, compared and calculated then a controlling element is implemented.
- This is where the control valve comes into the picture and work to reduce these disturbances.
- Thus, the control valve working principle revolves around the manipulation of the flowing fluids such as water, gas, steam or chemical compounds to ensure minimizing the load disturbance and regulating the process variable to the closest value of the desired set point.

CONTROL VALVE SIZING

Valve sizing is the process of determining the right valve size to meet the exact process requirements. Optimum sizing will give correct controllability and better performance of the system.
1. Precision of control is lost when the valve is oversized and this will un-necessary increase the cost of the system
2. When undersized the process cannot achieve its maximum flow rate without extremely high-pressure drop and the possible effects of noise, erosion and Cavitation.

FLOW CO-EFFICIENT (C_V)

The flow co-efficient "C_V" is defined as the number of US gallons per minute of water that will flow through a valve at fully open condition when the pressure drop is 1 psi.
Parameters for determining C_V:
1. Type of the fluid
2. Specification of the fluid
3. Flow rate
4. Inlet pressure
5. Differential pressure
6. Design & operating pressure
7. Vapour pressure and saturation temperature
8. Specific gravity/molecular weight
9. Viscosity in case of liquids
10. Flashing in case of liquids
11. Shut-off pressure required to determine the valve rating and actuator sizing.

Equation for C_V For liquids,

$$C_V = 1.17V \sqrt[2]{G/(P1 - P2)}$$

V = Maximum flow, m^3 /hr

G = Specific gravity (water=1)

P1 = Inlet pressure kg/cm^2

P2 = Outlet pressure kg/cm^2

For steam,

1. For $\Delta P < P_1/2$

$$C_V = \frac{Wk}{13.67\sqrt{\Delta P(P1-P2)}}$$

W = Maximum flow (kg/hr)

P1 = Absolute inlet pressure (kg/cm^2 abs)

P2 = Absolute outlet pressure (kg/cm^2 abs)

ΔP = P_1-P_2 (kg/cm^2)

K = 1+ (0.0013* superheat)

2. For $\Delta P \geq P_1/2$

$$C_V = \frac{Q}{287}\sqrt[2]{\frac{G(273+Tf)}{\Delta P(P1+P2)}}$$

Q = Maximum flow, (m^3/hr) at 760 mm of Hg 15.6 ℃

G = Specific gravity (water = 1)

T_f = Fluid temperature (℃)

P1 = Absolute inlet pressure (kg/cm^2 abs)

P2 = Absolute outlet pressure (kg/cm^2 abs)

ΔP = P_1-P_2 (kg/cm^2)

5.1NOISE TREATMENT

Noise is defined as unwanted or annoying sound. Noise is produced as a result of turbulence introduced in to the flow stream in producing the permanent head loss required to fulfill the basic function of valve. Noise limit - 85 dBA to 90 dBA.

Measures taken for noise reduction are,

1. Path treatment
2. Source treatment

5.2 FLOW CO-EFFICIENT MEASUREMENT(CV)

The flow co-efficient "C_V" is defined as the number of US gallons per minute of water that will flow through a valve at fully open condition when the pressure drop is 1 psi.

$$C_V = 1.17Q\sqrt{\frac{G}{P}}$$

Where,

C_V = Flow co-efficient

Q = Discharge rate

G = Sp gravity of fluid

P = Pressure drop across the valve

The valve to be tested is mounted on the pipe line of its nominal size. Clean water is pumped under control pressure. The pressure drop across the valve is adjusted between 0.35 to 1 kg/cm^2 using throttling valves and a manometer. The flow rate is then directly measured using precision weigh bridge and stop watch. The same test can be conducted at 25,50, and 75% opening and the results plotted in the form of graph.

FORMULA USED

Volume flow rate (Q)

$$Q = W \times \vartheta$$

Flow co-efficient (CV_C)

$$CV_C = \frac{W \times k}{11.9 \times p1}$$

Flow resistance (K)

$$K = 1 + 0.0013\Delta T$$

Velocity (V)

$$V = \frac{Q}{A}$$

Sonic velocity (V_S)

$$V_S = 331.3 + 0.0606T_1$$

Mach No (M)

$$M = \frac{V}{VS}$$

No of turns (N)

$$N = \sqrt{2gh}/v$$

THEORETICAL CALCULATIONS

Case 1:

Given,

Inlet pressure P_1

= 259 kg/cm^2= 254.079 bar

Outlet pressure P_2

= 30 kg/cm^2= 29.430 bar

Super heated temperature T_1

= 524℃

Saturated temperature T_{sat}

= 385.700℃

Mass flow rate(W)

= 8000 kg/hr = 2.222 kg/s

Calculations,

Specific volume (ϑ) = 0.103 m^3/kg

Volume flow rate (Q) = W× ϑ = 2.222× 0.103 = 0.228 m^3/s

Flow co-efficient

Selected CV_s = 25

Calculated $CV_c = \frac{W\times k}{11.9\times P1}$

Where,

P_1 in kg/cm^2

K = 1+0.0013ΔT ;

($\Delta T = T_1$- T_{sat} = 524-385.7 = 138.3)

K = 1+ (0.0013×138.3)

= 1.180

$CV_c = \frac{W\times k}{11.9\times P1} = \frac{8000\times 1.180}{11.9\times 259}$

= 3.062

% CV = CV_c / CV_s

= 3.062/25

= 12.249

Using Mod parabolic 2 curve % opening can be calculated as 34.6%

Velocity V = Q/A

Area A= $\frac{\pi}{4}d^2$ = 0.005282m^2

V = $\frac{0.228}{0.005282}$ = 43.15 m/s

Sonic velocity,

V_s = 331.3 + 0.606T_1 (T_1 in °C)

= 331.3 + 0.606(524)

= 648.844 m/s

Mach number,

M = $V/V_S = \frac{43.15}{648.844}$

= 0.067

Calculations of turns,

No of turns (N) = $\sqrt{2gh/v}$

= $\sqrt{\frac{2\times 9.81\times 78}{43.35}}$

= 6 turns.

Calculation of trim ports,

C_v factor = $\frac{Cv}{area}$

Assume C_v factor = 2.5-3,

2.7 = $\frac{3.06}{area}$

Area = $\frac{3.06}{2.7}$

Area = 1.133 cm^2

Hole diameter = 4-6 mm,

n×$\left(\frac{\pi}{4}\times d^2\right)$ = 1.133cm^2

n×$\left(\frac{\pi}{4}\times 4^2\right)$ = 1.133× 10^2

$n\times 12.566 = 1.133\times 10^2$

n = 9 holes.

Calculation of pressure head,

$$h = \frac{p2-p1}{\gamma}$$

P_2-P_1 = pressure difference,

$$= \frac{(254.07\times10^4-29.43\times10^4)}{980.7}$$

$= 2.290 \times 10^3$

Case 2:

Given,

Inlet pressure P_1= 170 kg/cm^2= 166.77 bar

Outlet pressure P_2= 30 kg/cm^2= 29.430 bar

Super heated temperature T_1 = 522℃

Saturated temperature T_{sat} = 351.200℃

Mass flow rate(W) = 8000 kg/hr = 2.222 kg/s

Calculations,

Specific volume (ϑ) = 0.111 m^3/kg

Volume flow rate (Q) = W$\times\vartheta$ = 2.222$\times$ 0.111 = 0.246 m^3/s

Flow co-efficient

Selected CV_s = 25

Calculated $CV_c = \frac{W\times k}{11.9\times P1}$

Where,

P_1 in kg/cm^2

$K = 1+0.0013\Delta T$;

($\Delta T = T_1$- T_{sat} = 522-351.2 = 170.8)

K = 1+ (0.0013$\times$170.8)

= 1.222

$$CV_c = \frac{W\times k}{11.9\times P1} = \frac{8000\times1.222}{11.9\times170}$$

= 4.833

% CV = CV_c / CV_s

= 4.833/25

= 19.330

Using Mod parabolic 2 curve % opening can be calculated as 42.5%

Velocity V = Q/A

Area $A= \frac{\pi}{4}d^2 = 0.005282m^2$

$$V = \frac{0.246}{0.005282} = 46.618 \text{ m/s}$$

Sonic velocity,

$V_s = 331.3 + 0.606T_1$ (T_1 in °C)

$= 331.3 + 0.606(522)$

$= 647.632$ m/s

Mach number,

$M = V/V_S = \frac{46.618}{647.632}$

$= 0.072$

Calculations of turns,

No of turns (N) = $\sqrt{2gh/v}$

$= \sqrt{\frac{2\times 9.81\times 78}{46.618}}$

$= 5.72$

$= 6$ turns.

Calculation of trim ports,

C_v factor = $\frac{Cv}{area}$

Assume C_v factor = 2.5-3,

$2.7 = \frac{4.83}{area}$

Area = $\frac{4.83}{2.7}$

Area = $1.788\ cm^2$

Hole diameter = 4-6 mm

$n\times\left(\frac{\pi}{4}\times d^2\right) = 1.788cm^2$

$n\times\left(\frac{\pi}{4}\times 4^2\right) = 1.788\times 10^2$

$n\times 12.566 = 1.788\times 10^2$

n = 14 holes.

Calculation of pressure head,

$h = \frac{p2-p1}{\gamma}$

P_2-P_1 = pressure difference,

$= \frac{(166.77\times 10^4 - 29.43\times 10^4)}{980.7}$

$= 1.40\times 10^3$

Case 3:

Given,Inlet pressure P_1

= 133 kg/cm^2= 130.473 bar

Outlet pressure P_2

= 30 kg/cm^2= 29.430 bar

Super heated temperature

T_1 = 532°C

Saturated temperature

T_{sat} = 331.7°C

Mass flow rate(W)

= 8000 kg/hr = 2.222 kg/s

Calculations,

Specific volume (ϑ) = 0.114 m^3/kg

Volume flow rate (Q) = W× ϑ

= 2.222× 0.114 = 0.252 m^3/s

Flow co-efficient

Selected CV_s = 25

Calculated $CV_c = \frac{W \times k}{11.9 \times P1}$

Where,

P_1 in kg/cm^2

K = 1+0.0013ΔT ;

($\Delta T = T_1$- T_{sat} = 532-331.7 = 200.3)

K = 1+ (0.0013×200.3)

= 1.260

$CV_c = \frac{W \times k}{11.9 \times P1} = \frac{8000 \times 1.260}{11.9 \times 133}$

= 6.368

% CV = CV_c / CV_s

= 6.368/25 = 25.472

Using Mod parabolic 2 curve % opening can be calculated as 46.7%

Velocity V = Q/A

Area A= $\frac{\pi}{4} d^2$ = 0.005282m^2

V = $\frac{0.252}{0.005282}$ = 47.709 m/s

Sonic velocity,

V_s = 331.3 + 0.606T_1 (T_1 in ℃)

= 331.3 + 0.606(532)

= 653.692 m/s

Mach number,

M = V/V_S

= $\frac{47.774}{653.692}$

= 0.073

Calculations of turns,

No of turns (N) = $\sqrt{2gh/v}$

= $\sqrt{\frac{2 \times 9.81 \times 78}{47.74}}$

= 5.66

= 6 turns.

Calculation of trim ports,

C_v factor = $\frac{Cv}{area}$

Assume C_v factor = 2.5-3,

2.7 = $\frac{6.368}{area}$

Area = $\frac{6.368}{2.7}$

Area = 2.358 cm^2

Hole diameter = 4-6 mm,

$$n\times\left(\frac{\pi}{4}\times d^2\right) = 1.133 cm^2$$

$$n\times\left(\frac{\pi}{4}\times 4^2\right) = 2.358\times 10^2$$

$$n\times 12.566 = 2.358\times 10^2$$

n = 18 holes.

Calculation of pressure head,

$$h = \frac{p2-p1}{\gamma}$$

P_2-P_1 = pressure difference,

$$= \frac{(130.43\times10^4-29.43\times10^4)}{980.7}$$

$$= 1.029 \times 10^3$$

CONCLUSION

The velocity control valve design (4") is verified with the valve of CFD analysis report and the calculated valves. CFD analysis valve is within limit of 5% in calculated valves. Hence, the existing noise and pressure drop problem is rectified and designed safely by using certain calculations.

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