High Technology Control Valves Their Selection and Application

Selection of control valves designs has become increasingly complex over the last few years. New plants and processes demand valves which are virtually failure proof and maintain guaranteed performance characteristics under extreme operating conditions. This article describes advanced valve design techniques in which components are carefully selected to match the application.

INTRODUCTION

The majority of process control valves are purchased for use in standard plant design packages and applications, where the operating conditions are known and the duties fully understood. Many standard valves are bought in the course of programs for the replacement of existing plant equipment. The market share for these valves varies from country to country, but if we took the United Kingdom as an example, they would account for over 80% of control valves purchased. Unfortunately for valve manufacturers and stockists, there is no definitive, standard valve, its design taking on a number of forms. A typical example is shown in Fig 1.

Figure 1. Standard Globe Valve

From a brief look at the stages in control valve development it could be argued that valve manufacturers have kept pace with demand from contractors and end users. The valve industry tends to be conservative in approaching customers with new ideas, and site references detailing experience are generally required if credibility is to be established and potential resistance to any new product is to be overcome. Hence, a cycle time of up to five years is sometimes required before new ideas and innovations are generally accepted. On the other hand, customer loyalty is usually strong and a good working relationship between the manufacturer and customer will often result in solutions being found outside of the normal valve design range. This is especially the case where changes in operating conditions or wrongly selected valves lead to problems on site.

Valve selection involves many decisions, including possibly a departure from conventional designs. The main sources of information are:
- The customer's specification
- Knowledge of the application
- Case histories used in similar applications

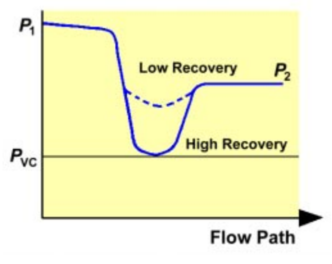
HIGH DUTY VALVES

Control valves may be grouped into two main types:
- Valves with high pressure recovery
- Valves with low pressure recovery

The ABB valve design parameter which reflects this recovery is the C_f coefficient relating to the measured differential pressure across the valve to that at the lowest point, i.e. at the trim *vena contracta*.

In liquid service, when the pressure loss across the valve trim increases to the point where it reaches the fluid vapour pressure, vaporization occurs and prevents further reduction in pressure or any increase in flow.

Using this information it is now possible to predict the onset of choked flow, cavitation and flashing flow. The generation of local high velocities resulting from the loss of pressure energy through the valve can create a number of problems. Selection is therefore made easier when the various types of valves are classified. This is illustrated in Fig 2, where generalised C_f values are plotted against K_i for the different valves. Using the C_f and K_i valve design parameters, the maximum allowable differential pressure necessary to avoid cavitation may be calculated for each valve design.



$$C_f = \sqrt{\frac{P_1 - P_2}{P_1 - P_{VC}}}$$

Figure 2. Fluid flow in a control valve; Cf versus Ki for different valve types

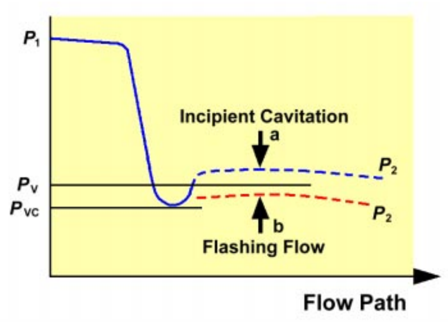
P_1, P_2 = Pressures
P_{VC} = Pressure at Vena Contracta
A = Ball
B = Butterfly
C = Globe and angle
I = Low noise trim
II = Contoured trim
III = High duty rotary valve
IV = Standard butterfly valve
V = Spherical Ball

This shows that valves which reduce pressure by creating high internal fluid velocities have the lowest C_f factor and the highest recovery.

The valve designs with C_f factors approaching unity have high internal friction components which reduce the pressure energy by creating a number of flow jets or passages interlinked by changes in flow direction.

By joining the flow sleeves together in series, it is possible to break down large differential pressures such that stage velocities are kept within pre-determined limits and problems do not occur at any stage. By way of example, it can be shown that for a globe valve fitted with a simple contoured trim ($C_f = 0.9$) controlling water at ambient temperature, a theoretical pressure drop equivalent to $0.65p_1$ is possible accross the valve before incipient cavitation is reached. This increases to $0.8p_2$ before cavitation, which if allowed to occur, would impose high local stress on the materials in the pressure recovery zone causing rapid erosion of the surfaces. This pressure recovery zone may appear within the confines of the control valve or in extreme cases, in the downstream pipework. The resultant energy dissipation, which is caused by implosion of the gas bubbles collapsing in the liquid due to pressure recovery to levels above the fluid vapour pressure, can impose surface stresses of the order of 7000bar (100,000psi). If the resulting pressure recovery remains below the fluid vapour pressure, flashing will occur as illustrated in Fig 3.

Other considerations involved in selecting a suitable trim must include the inlet and differential pressures and the flow capacity requirements. For example, in a 3” (80mm) valve with a full size contoured trim, the differential pressure would be limited to some 40bar. However, the trim design might be dictated by the pressure differentials on the valve opening, which could be considerably higher. For applications with potentially large pressure drops and where the range of conditions is wide and includes valve opening (eg. a boiler feed water or pump bypass duty) a multistage trim of the type shown in Fig 4 (opposite) may be specified.



a) $\Delta p > C_f^2 K_i (p_1 - p_v)$
b) $\Delta p > p_1 - p_v$

P_V = Vapour Pressure

Figure 3. Liquid flow regimes

This valve has the working elements arranged in series such that each stage opens progressively in a predetermined relationship. This permits large pressure drops across the valve without the onset of cavitation. The pressure drops occurring in the later valve stages are restricted and any pressure recovery which might occur is minimal, giving the valve the ability to maintain outlet pressures which are close to vapour pressures of the line fluid. An example of pressure breakdown with this type of valve is shown in Fig. 5.

An additional feature of this valve is the plug seating face, which is protected from the erosive effect of high velocity fluid at low flows. This is achieved by the close tolerance flow sleeve having a 'dead band' adjacent to the seat, which ensures that the valve faces are positioned outside the high velocity flowstream before the flow control orifices in the sleeve are exposed to the high inlet pressure.

This type of valve is used to advantage in power station steam raising plants to control the high pressure water supply to reheat spray jets. The fixed area jets exert little backpressure on the control valve outlet at low throughputs, necessitating large pressure breakdowns over the control valve orifices when valve stem lifts are low. This throttling of the high pressures can destroy the seating surfaces and rangeability control of a conventional valve after only a few hours of operation.

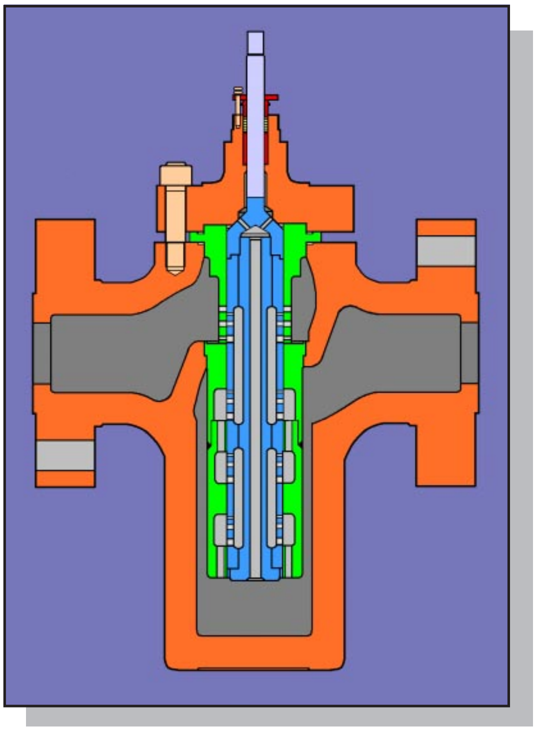


Figure 4. Turbotrol multistage pressure let-down valve

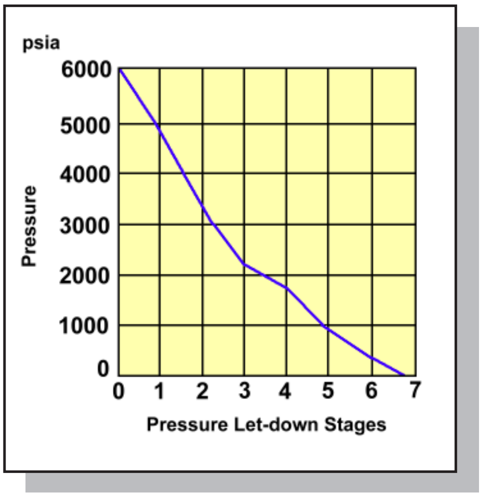


Figure 5. Pressure breakdown in a high duty liquid valve

NOISE IN CONTROL VALVES

As much of the noise is associated with liquid flow generated by cavitation, multi stage valves with restricted pressure recovery are potentially much quieter in operation. However, as more energy is converted within the trim it becomes essential to increase the guiding surfaces and change their position relative to the zone of pressure reduction; otherwise problems with vibration of the trim components can occur. The noise attributable to cavitation depends upon the extent to which it is present in the application. Increasing the pressure drop beyond the cavitation point will ultimately result in flashing of the liquid, which causes significantly less noise than cavitation (Table 1). The frequency usually generated by cavitation, although still present, is at a much reduced level.

Source	Source	Description of sound	Frequency Band Hz	Contribution dBA
Lower region of incipient cavitation	Liquid	High pitched hissing	2000-7000	40 - 75
Upper region of incipient cavitation	Liquid	Random frequency buzzing	100-1600	80 - 100
Developed cavitation	Liquid	Metallic rattling, shot-blasting	100-1600	80 - 120
Flashing	Liquid	Humming/hissing	100-1000	75 - 85

Table 1. Typical liquid noise characteristics

Source	Fluid	Description of sound	Frequency Band Hz	Contribution dBA*
Turbulence	Liquid	Low level, mid-frequency buzzing	800-2400	40-65
High Turbulence (Mach<1)	Gas	Non periodic, loud downstream noise	1200-4800	90-120
High Turbulence and Supersonic Shock (Mach>1)	Gas	Non periodic, loud screeching noise	4500-9000	100-140

*Measured 1m from valve and piping

Table 2. Liquid and gas flow noise contributors.

Turbulence in a liquid flow contributes little to the overall noise produced, while aerodynamic noise from compressible gas and vapour flows is the main contributor (Table 2). Turbulence and shockwaves due to high velocity and large mass flows are the primary causes of this. Large pressure drops across individual stages should be avoided and, for high performance, the fluid velocity should not exceed 0.4 Mn over any stage. Multi stage trims, supplemented with baffles to attenuate any noise produced, are therefore necessary for the larger pressure drops. The baffles, whether applied singly or as a pack, must be carefully positioned and sized in the overall valve configuration, it being inadequate simply to provide a large enough pipe area to maintain a 0.4 Mn exit velocity and expect it to eliminate noise. Noise level predictions based upon the calculated noise and frequencies which will be emitted one metre downstream of the valve, provide a ready warning of possible valve selection problems. The valve manufacturers formulae reflect the noise accumulations due to cavitation, mass flow and aerodynamic effects.

To assist initial valve selection and to determine if there is a noise problem at all, reference is made to a valve noise guide. With this guide a quick and reliable assessment can be made of a valve's suitability for a particular application.

MECHANICAL VIBRATION

Clearly, an unsuitable valve working in a heavy duty environment may also suffer from mechanical vibration, which also will contribute to the actual noise produced. The source of vibration is vertical and lateral movement of trim parts. Valve design can restrict this effect by means of single sleeve guiding or, in extreme cases where exceptionally high velocity or pulsed flow condition are encountered, by guiding both at the sleeve and through the valve seat. The contribution vibration makes to noise is not insignificant (Table 3), although the major problems manifest themselves in the loosening of parts and mechanical fatigue of valve components or pipework.

Source treatment of noise involves selecting the correct valve equipment for the duty (e.g. multi stage valves [Fig. 6] or valves in series) or maintaining velocities at acceptably low levels. Once the noise has been generated, path treatment involves eliminating the downstream acoustic energy transmission in the piping.

Source	Fluid	Description of sound	Frequency Band Hz	Contribution dBA*
Vertical movement of parts	Liquid Gas	Low rumbling Rumbling	20-80 80-160	74 68
Lateral vibration of parts	Liquid Gas	Buzzing Metallic rattling	250-900 400-1600	80 74

*Measured 1m from valve and piping

Table 3. Noise contributed by mechanical vibration.

While increasing the wall thickness of the downstream pipework or application of acoustic insulation can camouflage the immediate valve noise problems, the noise travels down the pipeline and will radiate from another location. Many contractors and end users fix an upper limit on source produced noise in order to prevent acoustic fatigue of the pipework. This limit varies with the valve locations and types, but can be applied upwards of 112 db(A), with the frequency spectrum produced from a low noise control valve having a dominant value at 3000 Hz.

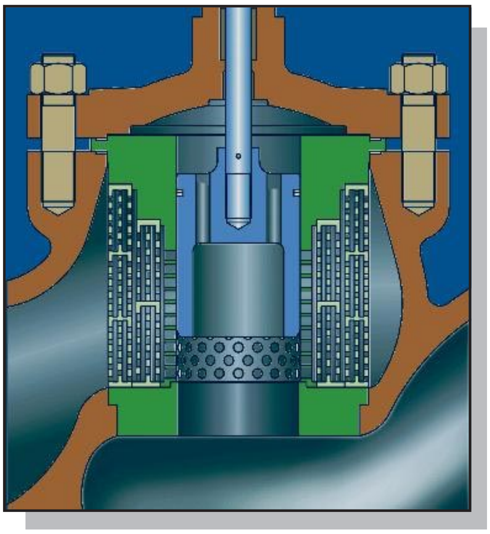


Figure 6. Multistage pressure let-down valve

EROSION OF VALVE TRIM COMPONENTS

High velocity flows within the valve can cause erosion on the surfaces, particularly in the regions of the seat and plug and along the main flow stream efflux of the valve body. This problem increases as the fluids become contaminated with solid particles or water droplets, rapid deterioration of the metal surfaces being the result.

Steam valves on throttling duty present a particularly difficult problem due to ‘wire-drawing’. This term is used to describe the appearance of the valve seat and plug after steam, particularly wet steam, has been superheated by expanding it through the partly open valve, which is very apt to score the seat with wire like grooves. This type of damage generally results in early loss of shut off capability and deterioration in valve rangeability characteristics.

A method used at Kent Introl to overcome this problem involves separating the seating surfaces from the final throttling elements. This takes the plug well clear of the seat before any appreciable flow commences, thereby protecting the seats from high velocity fluids. Such a valve could be used for controlling condensate in a flash tank, where the wrong type of valve could fail in a matter of hours. This technology is also incorporated in oil/gas separator level control valves where sand particles in the fluid are accelerated to high velocities by the large pressure drops. The application is further complicated by ‘gassing off’ the crude oil as soon as any pressure is lost in the valve, which causes additional acceleration of the sand particles. The resulting erosion of the metal surfaces manifests itself in rapid deterioration of trim rangeability and leakage performances.

TRIM SELECTION GUIDE

The valve engineer is often asked to provide a ‘rule of thumb’ for determining when an application warrants selection of a high duty control valve. Clearly, specified valve produced noise gives an early indication of possible problems, as does a calculation of the energy conversion levels within a valve.

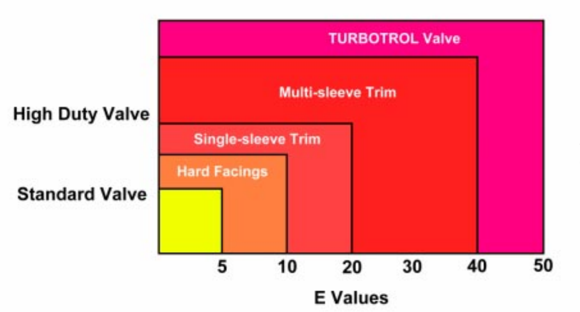
Although experience has shown that energy conversion levels may be similar, totally different valves are required because of the differing duties or line fluids. Table 4 (overleaf) may be taken as an approximate guide to the type of trim required, with the parameters for the application being considered in turn. These empirical values are for both liquid and gas flows. The pressure p_1 upstream of the valve is an important parameter indicating the potential energy in the fluid which can be released on valve opening. It must be taken into account to prevent rapid deterioration on the seating surfaces of a selected valve.

The weightings applied to each term in the trim guide selection are based upon experience and must always be used to check out the suitability of the valve selected. The importance of this experience can be illustrated by the example of a power plant boiler, where feedwater control valves are required to regulate the the output from constant speed pumps. A valve can be selected to reliably perform this duty by following the general data provided by the contractor or end user.

1. Read off values for A, B, C and D
2. Summate these values = E
3. Read off appropriate trim style from charts

LIQUID FLOWS

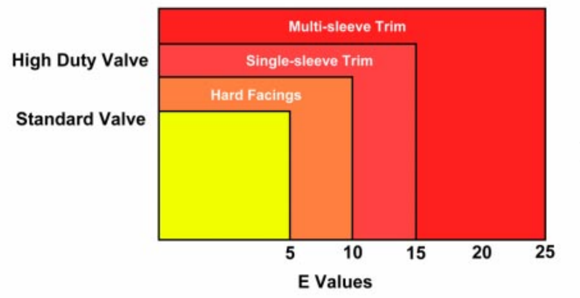
A	P_1 (BarG)	B	ΔP(Bar)	C	Cv value	D	Duty
5	271-400	29	200+	5	2000-4000	10	Flashing duty
4	151-270	23	151-300	4	801-1999	9	Multiphase flow
3	50-150	16	100-150	3	150-800	6	Incipient cavitation
2	20-50	7	50-99	2	80-149	5	Spray water
1	<20	4	20-49	1	<80	1	Normal
		1	<20				



High Duty Valves have hard facings or hardened trim components

GAS AND VAPOUR FLOWS

A	P_1 (BarG)	B	P_1/P_2 ratio	C	Cv value	D	Acceptable SPL dB(A)
6	400	6	30	5	2000-4000	1	>100
5	200	5	20	4	800-2000	2	90-100
4	150	4	10	3	400-800	4	85-90
3	100	3	5	2	150-400	5	<80
2	50	2	2.5	1	<150		
1	<20	1	<1.5				



High Duty Valves have hard facings or hardened trim components

Table 4. Guide to valve trim selection

However, the experienced engineer will ask whether this valve is also going to be used for boiler feeding purposes, where differential pressures are much greater. The valve selected for the basic duty would be unlikely to have the built in potential necessary for succesful performance of the boiler feeding duty.

The selection of suitable materials for the valve body and trim is clearly a major factor in the design of valves. If the quality is too high, the valve will not be competitive, while a valve made of low quality materials is a liability to manufacturer and user alike. Chemical corrosion is relatively easy to predict as comprehensive material selection guides are available. Galvanic corrosion presents a more difficult problem though, particularly when the best combinations of materials are far apart in the galvanic series and the surrounding fluid or environment promotes a strong electrolytic action. A particular problem with many valves supplied to the oil industry has been stress corrosion cracking due to the presence of H_2S and CO_2 in sour gas. The National Association of Corrosion Engineers Recommendations restricts the choice of the base materials and their hardness values to Rc 22, these values being obtained by heat treatment.

ACTUATORS

The choice of actuator is wide, with electrical, hydraulic and pneumatic types being available. The design will depend in each case on the application and environment. Although electrical actuators are becoming increasingly popular, pneumatic types of diaphragm or piston design are still widely used.

When sizing an actuator, it is essential to take the worst possible case that might occur, not only with the valve closed, but also with the valve trim in the modulating positions. Changes in the force/balance relationships can lead the marginally sized actuator into a state of erratic control, particularly near the point of cavitation. This can manifest itself in vibration and consequent wear of the valve trim components. A method available to the engineer to slow down the vibration frequency is to add a snubbing element to the actuator. This snubber, which is connected to the actuator's power take-off shaft, may take the form of two hydraulic reservoirs connected by a fixed and variable orifice.

To achieve required control modes it may be necessary to mount various instruments on the valve actuator, along with the positioner (Fig 7). Great care must be taken in their specification and the method of attaching and piping these to the actuator.

The information available to aid selection of a suitable valve for a given application is often very detailed. Decision making can be made easier by computerised techniques. ABB Control Valves have developed their own programs, which include not only sizing and noise predictions, but progressively consider the various valve body, trim and actuator designs available, so as to find the optimum combination for any application. The technical specification sheet is subsequently printed out.

Nevertheless, most high technology valves are manufactured on a 'bespoke basis' in wich the equipment is customised for a particular application. A good, all-round control valve service must therefore always include the availability of application engineering advice from qualified and experienced control valve engineers. In providing this advice, design expertise and full manufacturing capability, ABB Control Valves offer their customers a fully comprehensive service from one and the same source.

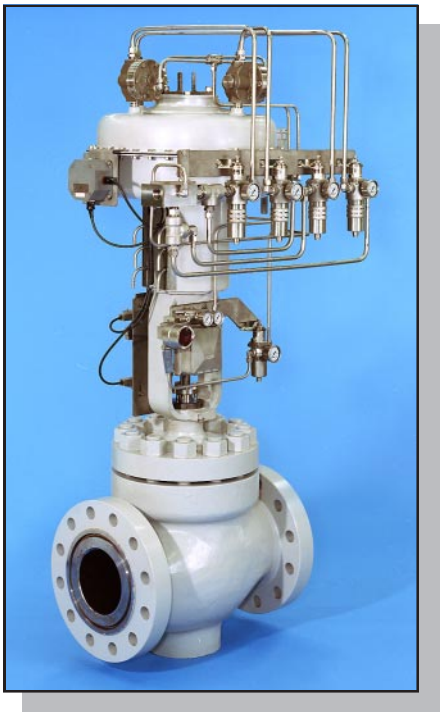


Figure 7. Valve mounted instruments

ABOUT ABB CONTROL VALVES

ABB Control Valves specialise in control valves, power valves, choke valves, desuperheating equipment and valve actuators for the entire range of process applications. These products can be found in all corners of the world, frequently operating on production plants in the most challenging environments.

http://www.abb-controlvalves.com **email: info@abb-controlvalves.com**

ABB Control Valves UK
Kent Introl Ltd.
Armytage Road, Brighouse,
West Yorkshire, HD6 1QF
England
Tel: +44 (0)1484 710311
Fax: +44 (0)1484 721253

ABB Control Valves USA
ABB Control Valves Inc.
146 Sylvania Place
South Plainfield
New Jersey 07080, USA

Tel: +1 908 769 6990
Fax: +1 908 769 1129

ABB Control Valves Japan
ABB Industry KK
6-2-2 Takatsukadai Nishi-ku
Kobe 651-22
Japan

Tel: +81 789 915 920
Fax: +81 789 915 900

ABB Control Valves Italy
ABB Kent Taylor SpA
Via Statale 113
22016 Lenno (CO)
Italy

Tel: +39 344 58111
Fax: +39 344 56278

ABB Control Valves India
Introl (India) Ltd.
H-34 MIDC Ambad
Nashik 422010
India

Tel: +91 253 381434
Fax: +91 253 384413