Low Noise Control Valves with High Performance

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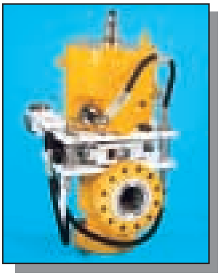
INTRODUCTION



As developments in the oil, chemical and power generating industries are presenting ever increasing fluid pressures to be harnessed by control valves there is an ever increasing demand from environmental bodies, government departments and the public for quieter plants.

The onus is on manufacturers of equipment to design out as much unwanted noise as is possible and to be able to predict the noise level of their equipment prior to operation under actual plant conditions. Not the least of these is the control valve manufacturer whose products unless specifically designed can be among the noisiest items when called upon to reduce fluid from very high to low pressures.

SOMETHING ABOUT VALVE NOISE

The equation relating radiated acoustic power to valve flow is:

$$Wa = \eta \frac{mv^2}{2} - T_L$$

Where Wa = acoustic power (watts), η = acoustic efficiency factor (determines the amount of mechanical power of the fluid stream that is converted into noise), m = mass flow, v = jet velocity, T_L = transmission loss through pipe wall.

It will be seen from this equation that if η and v can be reduced and T_L increased then the radiated noise power will be reduced. It is with these objectives in mind that the valve designer progresses towards the ultimate in low noise valves.

THE EFFICIENCY FACTOR η

η depends on the noise source. Physicists divide noise sources into a number of convenient categories to enable them to express noise in mathematical forms. These catagories can be applied to valve generated noise with the advantage that the results of scientific studies into the characteristics of these catagories can be used in the understanding of the origins of valve noise, and in determining the values of η for various flow regimes (Table 1). These values of η vary with different pressure drop ratios and noise is in practical cases seldom produced by one source. But there is no doubt that the acoustic efficiency factor is the lowest for quadrupole sound which decreases more rapidly than dipole with decreasing pressure drop ratios.

So a low noise valve should be designed to reduce dipole sound to the minimum. If the valve must produce noise, let it be quadrupole. This can be achieved by restricting turbulence to the confines of the trim unit and ensuring minimum contact with the boundary walls in the valve outlet section.

Noise Category	Source	Efficiency Factor η *Propl to*	η Value at $\frac{\Delta P}{P_1} = 0.25$ Per Stage
monopole	Slow moving fluid	v/c	
dipole	Interaction with solid boundaries	v^4/c^3	4×10^{-5}
quadrupole	Turbulent shear layers	v^6/c^5	2×10^{-5}

Table 1. Aerodynamic Noise Sources (c = velocity of sound in fluid)

VELOCITY v

Noise problems are not usually associated with liquid flow unless cavitation occurs when noise can be a problem (Fig. 1).

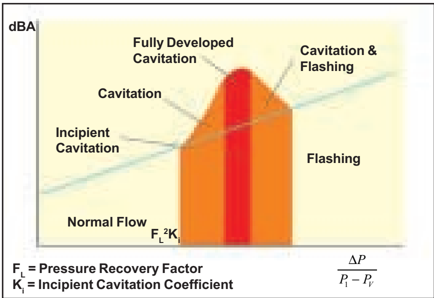


Figure 1. Hydrodynamic Noise

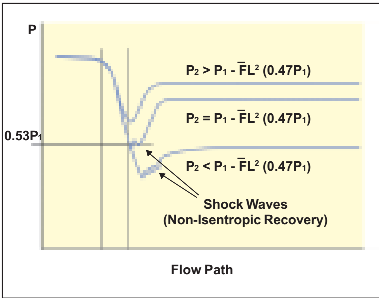


Figure 2. Gas Flow - Generation of Shockwaves

By dividing the pressure drop into a number of stages the pressure drop at each stage can be held to something below $F_L{}^2$ Ki $(P_1\text{-}P_V)$. This eliminates cavitation, reduces the velocity and the unwanted noise. At high pressure drops (critical and higher) gases and vapours will develop shock waves in the valve outlet, following sonic velocity at the vena contracta (Fig. 2). These shock waves are the main source of noise particularly if they impact with the valve body walls. By dividing the pressure drop into a number of stages the velocity is reduced and shock waves eliminated or held within the confines of the trim.

TRANSMISSION LOSS T_L

Many equations have been propounded for the calculation of the transmission loss through a pipe wall. The transmission loss equation quoted in IEC 534-8-3 is derived from first principles and indicates that the greatest influence on transmission loss is the term

$$\left(\frac{fp}{fr}\right)^2 \text{ where}$$

fp = peak frequency
fr = pipe ring frequency

This indicates that for a given size and schedule of piping the transmission loss can be increased by increasing the peak frequency of the generated noise. This is achieved in the concentric sleeve trim by the reduction of the fluid stream into a large number of small jets which raise the frequency of the generated noise.

CONTROLLED VELOCITY VALVES

A small number of control valve manufacturers are experienced in the design of low noise valves and with one exception their designs all depend on the principle of dividing the pressure drop into a number of small stages, thereby avoiding the very high velocities (probably supersonic) which would be generated if the complete pressure drop were taken in a conventional single stage valve. This is the principle of "Controlled Velocity"; a principle that can be put into practice in a number of ways.

CONTROLLED VELOCITY THROUGH THE TORTUOUS CONTINUOUS PATH DESIGN

One method of controlling the velocity of a fluid undergoing a high pressure reduction is to divide the main stream into a number of smaller streams each being constrained to flow through a tortuous path, the cross sectional area of the path expanding in the case of steam and gases. This design of trim usually consists of stacked discs, each disc having small tortuous flow paths cut into one surface. The fluid in order to pass from the high pressure side to the low pressure must flow through these small paths and in doing so, turn through many 90^{O} angles. This brings about a reduction in pressure without any great increase in velocity and therefore without any appreciable noise.

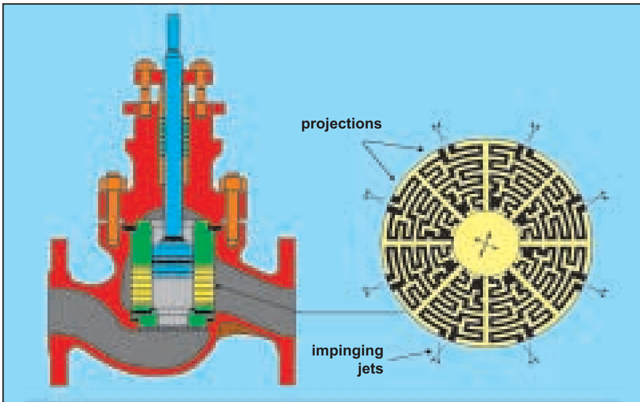


Figure 3. Tortuous Path low-noise valve (there are a number of variations)

There is a widespread misunderstanding that it is only the tortuous path type of trim that employs the principle of "Controlled Velocity". This stems from a belief that the equation

$$\frac{\Delta p}{n} = X = \frac{Kv^2\rho}{2}$$

is applicable only to tortuous path valves.

This equation shows that v can be controlled by selecting n to give the required stage pressure drop X (can vary from 100 to 1,025 kPa). It is applicable to any valve with multistages, these valves all being within the category of "Controlled Velocity" valves.

Δp = valve pressure drop
n = no of turns or stages
v = velocity
ρ = density
K = coefficient of velocity
X = manufacturers allowable pressure drop per stage

From what has been said it can be presumed that the tortuous path valve trim will bring about a considerable noise reduction compared with conventional valves. Unfortunately it does exhibit problems in practical applications.

POTENTIAL PROBLEMS WITH THE TORTUOUS PATH (LIQUID SERVICE)

1. The flow paths fully opened by the plug will reduce the fluid pressure from inlet to outlet, but the unopened flow paths will carry fluids at pressures almost equal to P_1 into the clearance between the plug shank and the bore of the discs. The external surface of the plug is therefore subject to high velocity jets resulting from the full pressure drop. This usually leads to problems of erosion and cavitation (Fig. 4).

2. On very high pressure drop applications, although the tortuous flow paths control the velocity - the controlled velocity can be sufficiently high to prevent the liquid following the sharp angular turns. Localised reductions in pressure are created resulting in cavitation within the discs.

3. On services where the liquid has to be reduced to pressures below its vapour pressure, and the liquid becomes a two phase fluid - liquid + vapour - flashing will take place within the trim. In common with most low noise designs the stacked disc trim will suffer severely if required to handle a liquid and vapour mixture (Fig. 5).

Figure 4.

Figure 5.

POTENTIAL PROBLEMS WITH THE TORTUOUS PATH (GAS SERVICE)

1. The outlets of the tortuous, expanding flow paths are obstructed by sharp projections. These can cause the shedding of vortices (as across the lip of an organ pipe) into the downstream body section increasing turbulence and unwanted noise (Fig. 3).

2. The outlet shape of each flow path is such that the adjacent emerging jets are directed towards each other. Impingement of these jets and the resulting shear stresses can cause additional noise (Fig. 3).

GENERAL PROBLEMS WITH THE TORTUOUS PATH (ALL SERVICES)

The small tortuous flow passages with numerous 90° angular turns are prone to blockage if the fluid (liquid or gas) contains solid or gooey inclusions. Once blocked, the flow passages are almost impossible to clear. Enlargement of the passages to avoid blockage reduces the low noise advantages.

THE INTROL HF SERIES OF LOW NOISE VALVES (CONCENTRIC SLEEVE DESIGN)

1969 saw the first Kent Introl low noise valve, one of many for the early offshore platforms. After studying various techniques and weighing noise reduction characteristics against reliability when operating on practical installations it was decided to use the principle of controlled velocity through concentric sleeves, each sleeve containing numerous small holes. The holes are not in alignment from one sleeve to the next, so the individual jets must repeatedly change direction in the recovery chambers between each sleeve (Fig. 6). This arrangement gives staged pressure reduction, the number of stages depending on the service requirements.

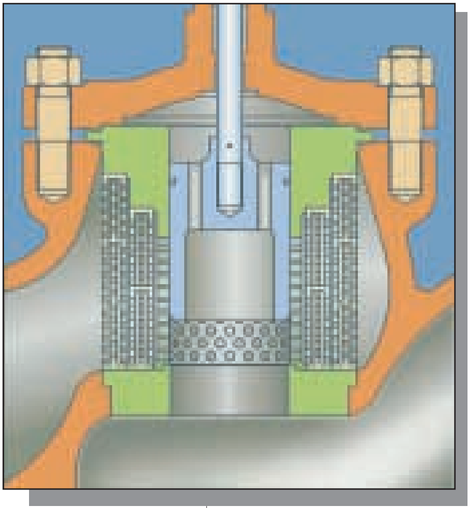


Figure 6.

The velocity is therefore controlled. For gas service the sizes and numbers of holes will increase in successive sleeves to allow for expansion. On severe services the final element can be a diffuser which contains trim generated noise within the diffuser and allows the fluid jets to enter the outlet section of the valve body at low velocity and without interaction thus reducing dipole noise. The small outlets of this diffuser increase the frequency of any noise thereby increasing the transmission loss.

In comparing the concentric sleeve design with the stacked disc it will be apparent that the number of stages in the former cannot reasonably be made to equate to the number of turns (stages) in the latter. The concentric sleeve design is a compromise between the requirements for maximum noise reduction and those for a reliable valve controlling industrial fluids. The number of stages available (designs with up to ten stages have been produced) are adequate for the most severe pressure reduction services.

On liquid service the cavitation problem between the closed off holes and the lower edge of the plug shank can be experienced but is not as intense as with the stacked disc designs. Damage to components can be minimised by the choice of special materials for the plug and plug guide. Also the phenomena of flashing liquids does not disappear with the application of a multistage trim of *any* design. This type of service should be handled with a single stage valve but if noise restrictions make a multistage valve mandatory, the concentric sleeve design does lend itself to flexibility in the choice of materials. Plugs and sleeves manufactured in hardened 440c stainless steel, ceramics (PSZ), “Stellite”, “Tristelle 5183” and Tungsten Carbide will prolong the life of a multisleeve trim controlling a cavitating or flashing fluid.

PROGRESSIVE ENGINEERING

Kent Introl has always played a leading role in the advancement of control valve technology. It was one of the first to design a low noise valve and has pursued a policy of continuous development in the light of new data and new design techniques - Solid Modelling, Finite Element Analysis and Computational Fluid Dynamics (Fig. 7). Many ‘standard’ Introl designs have been developed from the solutions to individual severe service applications.

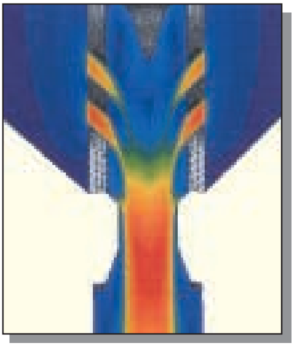


Figure 7.
CFD view of flow through HF Trim showing non-interaction of emerging jets

ADVANTAGES OF THE HF SERIES LOW NOISE TRIMS

1. Divides the main flow stream into a large number of small streams, increasing the peak frequency and maximising the pipe wall transmission loss.

2. Reduces valve generated vibration strain in piping.

3. Divides the pressure reduction into a number of stages - controlling the fluid velocity at a low value.

4. Flexibility in the number of stages for each application.

5. Flexibility in the allocation of pressure reduction to each stage.

6. Flexibility in the choice of materials.

7. Design of last stage ensures low velocity non-interacting jets - avoiding unnecessary generation of noise in valve outlet.

8. Trim exit diffusers available for containment of trim generated noise on severe applications.

9. Concentric sleeve design with recovery spacing between each sleeve reduces fluid pressure in manageable stages through the mechanics of small orifice flow and associated turbulence, jet seperation, jet mixing, all within the sleeve assembly.

10. Sensible orifice sizes - no blockage.

11. Adequate valve body flow passages to ensure minimum turbulence on contact with body walls - reducing dipole noise.

12. Noise reduction of 42dBA can be achieved and higher reductions are possible with hybrid versions of HF trims.

13. Noise predictions normally calculated using the Kent Introl method, but on request the IEC standard 534-8-3 for gasses and 534-8-4 for liquids may be used.

For further information about low noise valve solutions, please contact Kent Introl.

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