KNOW YOUR VALVES

Steve Brame, Emerson Process Management, UK, looks at how the problems of cavitation and aerodynamic noise can be minimised by selecting the right valve.

Selecting the right valve for any severe service application requires the plant engineer to carefully match the characteristics of the valve with the demands of the application. Each manufacturer has its own particular approach to sizing and selection, and engineers need to be confident that the valve they specify will provide a cost effective and reliable solution.

While an incorrectly selected valve may appear to operate satisfactorily, its performance is often compromised, reducing operating efficiency and increasing the risk of an unplanned shutdown. The costs associated with operating at reduced efficiency could be significant and, in the worst cases, a valve will have to be repaired or replaced prematurely with additional costs resulting from plant downtime and lost production.

Two of the most common problems facing engineers when selecting severe service valves are cavitation and aerodynamic noise. Cavitation is a hydrodynamic flow phenomenon that, if not considered at the time of selection, can cause damage to the control valve trim, body and possibly the pipework, ultimately leading to equipment failure and plant downtime.

Aerodynamic noise results from turbulent flow and is only relevant to valves handling gas and not liquids. Sources of turbulence include obstructions in the flow path, rapid expansion or deceleration of high velocity gas and directional changes of the fluid stream. Control of aerodynamic noise is important not only to meet health and safety requirements, but also from an environmental point of view. A further consideration is that the energy created generates heat that can potentially lead to valve damage.

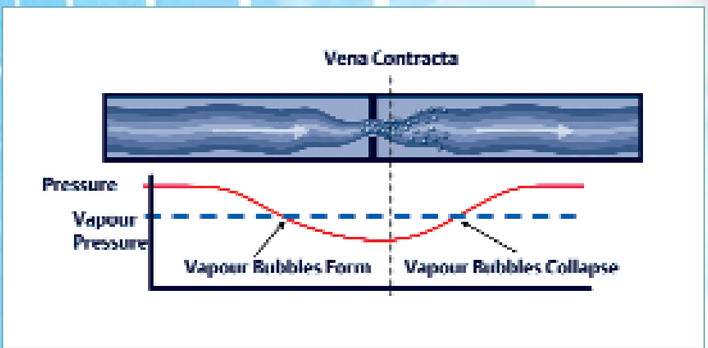

Figure 1. Causes of cavitation.

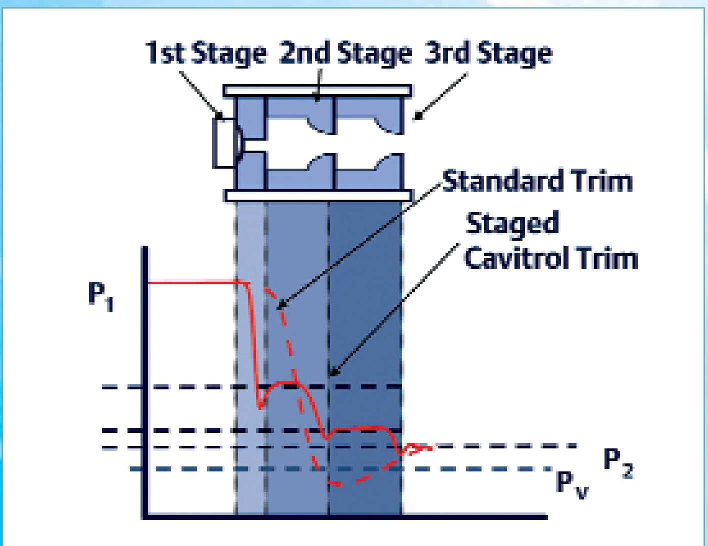

Figure 2. Staged pressure drop.

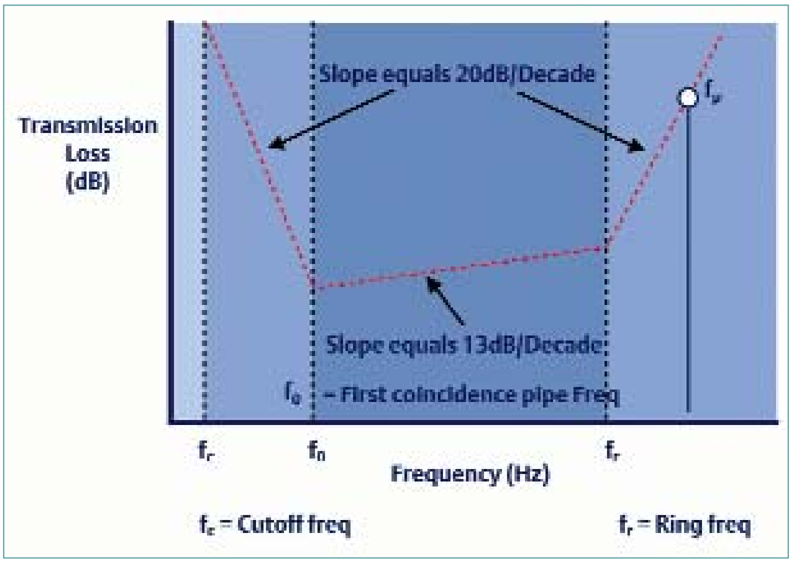

Figure 3. Transmission loss in pipe wall.

What causes cavitation?

When a liquid travels through a control valve, or any other restriction in the pipeline, the pressure drops until it is at its lowest point just after the restriction and then it recovers to a point that is somewhat less than it was before. The point at which the pressure is at its lowest is called the 'vena contracta' (Figure 1). Should the pressure at the vena contracta be less than the vapour pressure of the liquid, then vapour bubbles will start to form as the liquid begins to change phase. If the pressure recovers to a point above the vapour pressure then the bubbles will collapse, creating high velocity jets of liquid that can impinge on the valve trim or the piping.

This phenomenon, known as cavitation, can rapidly damage components within its proximity. In the worst cases, cavitation has 'drilled' holes through the valve body or the pipework. Other symptoms of cavitation include reduced capacity, as the formation of bubbles chokes the flow, increased noise and vibration. If cavitation cannot be avoided by changing process parameters, then there are various control valve trim designs that can be applied to prevent it occurring.

Avoiding cavitation damage

There are two common techniques used by control valve manufacturers to design trims that avoid cavitation damage. One is to control the pressure in the trim by dropping the full pressure in a series of staged drops, the first drop being the highest and the last being the lowest (Figure 2). This ensures that the pressure at the vena contracta of the last stage is well above the vapour pressure (Pv).

To be effective, each stage must be independent of the next one, thus the design must allow sufficient volume between stages for the fluid to recover before entering the next stage. This staging is made by a series of drilled hole orifices in the control cage of the valve, which are exposed to the flow as the valve plug opens. The form of the hole can also be made to produce a low recovery coefficient that further helps avoid cavitation.

Another technique is to control the velocity of the fluid through the trim by using a series of expanding area flow passages, often referred to as 'tortuous path' trims. These are made up of a series of right angle bends where the gas dissipates energy; this requires many more turns than stages in the staged pressure technique. Its aim is to control the energy dissipation in the trim, which ensures that the pressure does not drop below the vapour pressure. The disadvantage of this technique is that it requires a much larger cage wall diameter to house the flow passages. In addition to added cost, these valves can be more difficult to accommodate due to their larger dimensions.

Cavitation selection criteria

There are two different methods for selecting valves that are to be used on a cavitating duty. The first option is based on calculations using Kc: the Cavitation Index. This method is supported in ISA Recommended Practice RP75023 and uses a coefficient (called Kc) to predict the pressure drop at the selected trim and hence the conditions where cavitation damage will start to occur.

The challenge is to select a trim with a Kc that produces a pressure drop for cavitation damage, which is higher than the pressure drop that will actually occur in practice. Kc depends on a number of factors: for example, the valve design, flow geometry, valve size, trim materials and magnitude of the pressure drop.

An alternative criteria used by some valve suppliers is to limit the trim outlet velocity to 23 m/s. This seems to be an arbitrary figure based on experience and has not been approved by an independent body such as the ISA. This method is generally recommended by the suppliers of tortuous path solutions; it is not applicable to staged pressure drop trims.

To summarise, the Cavitation Index method focuses on pressure control, ensuring that the pressure in the trim never falls low enough to allow vapour to form and then redissolve, causing cavitation. The limited velocity method, however, simply focuses on the velocity of the liquid as it passes around numerous bends and, in this respect, is unrelated to the cause of the problem, namely, the vapour pressure.

The causes of aerodynamic noise

Aerodynamic control valve noise is caused by the Reynolds stresses or shear forces that are a property of turbulent flow. Due to the relative velocities, high intensity levels of noise resulting from turbulent flow are generally found in valves handling gas. Sources of turbulence in gas transmission lines include obstructions in the flow path, rapid expansion or deceleration of high velocity gas and directional changes of the fluid stream.

There are two mechanisms for reducing aerodynamic noise based on either reducing the trim velocity or increasing the frequency of the noise. Reducing the trim velocity reduces the stream power, thereby cutting the conversion efficiency of stream power to noise power. Noise only becomes a problem when it travels through the pipe wall; increasing its frequency reduces the noise that is transmitted in this way. It is also a fact that the human ear does not register the higher frequencies as effectively as lower frequencies, therefore raising the frequency also results in an apparent reduction in noise.

Noise that travels through the pipe wall depends on the relationship between the peak frequency of the generated noise and the pipe transmission loss spectrum. Experiments have shown that the aerodynamic noise generated in a control valve produces a noise spectrum that is essentially shaped like a haystack, with the peak noise level of this spectrum occurring at a frequency called the 'peak frequency' and tailing off at either side of this peak. Higher frequency noise tends to travel along the pipe and is not transmitted through the wall as effectively. This can be seen in Figure 3, showing attenuation versus frequency.

Most control valve designs reduce the noise produced by changing its properties. For example, treating the noise at source may include using special trim designs as well as careful sizing and selection. Low noise trim designs have evolved from drilled hole trims that shift the peak frequency of the noise to outside the audible range, to trim designs that use a variety of techniques, including: frequency shifting; pressure drop staging; shaped passages to control turbulence; independent flow jets; and lowering the velocity of the process fluid.

Drilled hole noise reduction techniques take advantage of the fact that higher frequencies do not transmit as well to atmosphere. The smaller the diameter of the holes, the higher the frequency becomes. For example, if 1/4 in. diameter holes produce noise levels of 92 dBA, for the equivalent conditions 1/8 in. diameter holes would produce 85 dBA. These figures are independent of manufacturer.

Modern trim technology will reduce the noise generated while the valve operates, but it is still important to use best practice valve sizing and selection techniques to ensure that the velocity of the fluid at the outlet remains low and does not generate noise that might overpower the noise produced by the trim. There are manufacturers who will advise the noise level at the vena contracta, ignoring the body and pipe effects. Quoting this figure can give a reading that is 15 dBA lower than it should be.

A good example of a control valve that combines several of these technologies to give excellent results is the Fisher® WhisperFlo® trim from Emerson (Figure 4). This features a unique passage shape that reduces turbulence and minimises shock associated noise. The multistage pressure reduction design divides the stream power between stages, keeping the overall stream power down. The frequency spectrum shift maximises piping transmission loss to reduce radiated noise, as well as reducing the acoustic energy in the audible range. The jets of fluid exiting the trim are kept independent, as noise levels rise when the jets are combined; this is something that is relatively common in torturous path trim designs. The expanded area principle adopted within the trim compensates for the volumetric expansion of the depressuring gas, keeping the velocity down. The last technique that is used is that of ensuring the trim is fitted into a complimentary valve body design.

International Standard IEC 534-8-3 is designed to calculate a sound pressure level for aerodynamic noise produced by a control valve. The standard is based on a combination of fundamental theories from the academic fields of thermodynamics and acoustics. The basic equations developed from this are then modified by experimental results. The standard uses five step procedures to determine how much of this sound pressure level gets transmitted to a hypothetical observer located at the standard location, which is 1 m downstream from the valve and 1 m away from the outer surface of the pipe.

One important factor often overlooked is the effect

Figure 4. Fisher® WhisperFlo® trim.

that the outlet velocity from the valve has on the eventual noise generated. Standard equations for the calculations based on the IEC Standard are limited to an output velocity of 0.3 Mach. Above this a correction has to be applied to account for the noise that is generated in the outlet passage of the valve. For example, in a valve with an 8 in. body and outlet velocity of 0.25 Mach (i.e. below 0.3 Mach as laid down in the standard), the predicted noise is 84 dBA. If a 6 in. valve is selected, the outlet velocity is above 0.3 Mach and a correction of 11 dBA is required, increasing the noise up to 95 dBA with the same trim.

Some manufacturers of valves based on tortuous path technology propose that trim outlet velocity head should be kept below 480 kpa. However, this figure is based on experience and is not included in the ISA standard.

Conclusion

If a control valve on a cavitating or noisy duty is selected incorrectly, it has the potential to fail prematurely or to cause safety and environmental problems. The onus is on the manufacturer to supply a valve that is 'fit for purpose' and suppliers will provide calculations supporting their selection. Problems arise due to the highly technical nature of both cavitation and noise, and the fact that many suppliers will insist on using their calculations based on their own test results, supplying highly technical documents and arguments to support their claim.

If the supplier gets it wrong with regards to cavitation then this will become apparent over time. However, an incorrect choice may have already resulted in a higher than necessary initial outlay, as well as the potential for valve failure and an unplanned shutdown. Getting a noise calculation wrong, however, may be difficult to prove thanks to the myriad noises within a process plant and the near impossibility of isolating one noise source among so many.

To be sure that a purchasing decision is the right one, check that the chosen valve supplier is using independent standards as the basis of sizing and selection. Some manufacturers have integrated the requirements of these standards into their own sizing tools to make the selection process quicker and easier for the user.