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AERODYNAMIC NOISE SOURCES IN INDUSTRY SESSION: University of Loughborough.

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A PRACTICAL METHOD OF DEALING WITH CONTROL VALVE NOISE

SUMMARY

The major source of noise generated by any control valve is basically covered by mechanical vibration, cavitation which may be associated with liquid flow, or the turbulent flow of compressible fluids. Valves handling compressible fluids in applications such as steam or gas pressure reduction are easily the most common offenders.

During the past three years a major research programme has been carried out to establish a technique for the prediction and abatement of the noise produced by the flow of compressible fluids through valves. The programme has produced an extremely effective and practical method of prediction.

Noise treatment for many years has been in the form of absorption type silencers applied to the fluid path, and whilst the treatment has not changed it will still continue to give an excellent solution for many valve noise problems. The most desirable approach is to reduce the noise at the source and research has been quite productive in this area, a number of "quiet" control valves are now available.

INTRODUCTION

Modern control valve design has to a great extent eliminated the noise which results from mechanical vibration and in general it is treated as a structural problem. On the other hand noise produced by cavitation, which has a wide spectrum of frequency being caused by the collapse of vapour bubbles in the process fluid, may be eliminated by considering the application and applying appropriate limitations to the service conditions.

Control valves handling compressible fluids in application such as steam reducing stations or natural gas installations are the most common source for concern. The relevant velocities and sound intensity levels generated are far more serious with valves handling compressible fluids than those experienced by valves operating on liquid. Aerodynamic noise which is used to describe the sound generated by turbulent gas flow is a non-periodic or random noise with peak frequencies occurring between 1000 and 8000Hz. The spectrum shown is typical for all control valve aerodynamic noise. Fig.1

The technique illustrated here is the result of research in the area of noise prediction and abatement which has been concentrated on compressible flow "in line" applications where the pipe wall provides attenuation of around 60-80 dB. Sound pressure levels of 130 dB have been experienced from "in line" applications so that many "vent" applications could generate noise levels to exceed 200 dB. Vent applications generally operate intermittently and usually terminate outside the plant at a considerable distance from the operating area.

PROCEDURE

Considerable literature is available on the subject of noise generated by free turbulent jets. However, it has only been in the last few years that any attention has been given to the constrained jet which is produced by a control valve in an "in line" application. Continuous operation may occur quite close to residential areas or personnel. Isolating valves are usually line size, are either fully open or closed, and operating under low pressure-drop conditions. Accordingly, they seldom create a noise problem. However, control valves are usually less than line size, operate at varying openings, and can be subject to extremely high flowing pressure-drops.

In view of the complexity of the problem and the lack of analytical data, an empirical method for establishing the noise characteristic of each valve style, size, travel and piping configuration was developed experimentally.

Based on standard weight pipe and considering a wide range of pressure-drop to inlet pressure ratios, the results may be extended to cover other service conditions by using a suitable scaling technique. On the basis of simplicity and for convenience of application the dynamic analysis of many groups of variables was possible. Also, given that the valve size and style are fixed, the list can be shortened by considering the dimensionless groups governing compressible flow. Mach number, specific heat ratio, Prandtl number, Reynolds number, Strouhal number and the ratio of sound pressure to the differential pressure across the valve.

In addition to the test data established the following decisions were made:-

The Mach number is the most important factor governing noise generation since the area of concern is generally in the range of supersonic, or high subsonic pressure ratios. Not enough experimental data has been obtained to accurately determine the effect of the specific heat ratio on noise generation, however, it has a relatively weak influence on the flow stream characteristic. The Prandtl number varies only slightly for different gases and can be dropped from the considerations. As the area of concern is defined as the high subsonic or supersonic range the influence of the Reynolds number is questionable, being limited to the conditions involving low velocities it may be considered as not relevant. Finally, the Strouhal number having been varied over 10000 to 1 range was found to have no significant effect on the spectrum frequency, and therefore, was dropped.

RESULTS

The examination of over 250000 test data points substantiates the theory put forward by C. B. Schuder[1], Director of Research at Fisher Controls, Marshalltown, U.S.A., and led to the development of a basic relationship describing "sound pressure", Ps, in the following way.

$$Ps^2 \propto Cg,\ \Delta p^2,\ fM.$$

Further test results show that, fM, can be presented as a function of $\Delta p/P_1$ thus providing a substantial gain in simplicity without any loss of accuracy from the overall results. By accepting a $\pm$ 5 dB accuracy a 10 to 1 reduction can be made for the graphical presentation of the information required for noise prediction. For practical application the conclusions for the basic relationship for flow of compressible fluids may be expressed as follows:-

$$S.P.L. = SPL\Delta p + \Delta SPL\ Cg + \Delta SPL\ \Delta p/P_1$$

The predicted SPL give the overall noise level in dB at a predetermined point, 48 inches downstream of the valve outlet and 29 inches from the surface of the pipe. The noise level is for standard weight pipe. Correction for other pipe schedules is treated later under considerations for path treatment. Values of $SPL\Delta p$ and $\Delta SPL\ Cg$ are illustrated in Figs. 2 and 3 and are applicable to all valve styles. The values for $\Delta SPL\ \Delta p/P_1$ have been established for most valve sizes and styles. These values are obtained by test and reflect the noise characteristic unique to a particular valve design. A typical curve is shown in Fig. 4.

Noise levels are generally higher on the downstream side of a control valve than on the upstream side. Accordingly consideration of upstream noise can quite often be overlooked. In any path treatment technique consideration must be given to the sound radiated upstream. By extending the technique already outlined, the upstream noise level may be estimated. If the control valve is of the streamlined flow style such as ball or butterfly valves, and the flow conditions are sub-critical, then the noise level upstream and downstream will be the same. As the downstream pressure decreases the noise level will increase but upstream noise will reach a constant at the point where the flow becomes choked, known as the critical flow conditions. Therefore, where conditions are greater than those for critical flow the upstream noise may be estimated using the downstream technique but with the pressure-drop taken as the drop to give choked flow.

The transmission path of the globe style valve is not so streamlined and therefore while we may use the same method, a transmission loss from downstream to upstream must be subtracted. A loss of 10 dB is typical.

As a rough estimate approximately 60% of the control valves sold today for use on compressible fluids operating at near critical flow conditions will generate noise in excess of 90 dBA.

Noise abatement equipment for both source or path treatment is available. The most desirable approach is to reduce the noise at the source. At first it was thought that streamline style valves would generate low turbulence and hence a low noise level. The error here is that a control valve must operate with a pressure-drop as dictated by the system in which it is installed. The valve simply cannot operate correctly without introducing enough turbulence to produce the pressure-drop required for a given flow rate. The development of a cage with multiple specially shaped slots, with the plug movement varying the length of slot exposed, resulted in attenuation to a level lower than that experienced with conventional valves. The Fisher Whisper trim can offer substantial noise reduction when used with the modern cage style globe valve. As mentioned earlier the $\Delta p/P_1$ correction is unique for each valve style, and accordingly may be used to illustrate the noise performance of each valve design. Illustrated in Fig. 4 the standard cage style valve has a positive correction starting at a $\Delta p/P_1$ ratio of about 0.16 and a correction of plus 25 dB is reached at a ratio of 0.98. The sharp turn up at very high pressure-drop ratios is apparently due to the high velocity jet at the body exit. The Whisper trim starts with a correction of minus 7 dB but still turns up at high ratios where the valve trim noise is no longer dominant. At these high ratios the performance of the Whisper trim may be greatly enhanced by the use of a properly sized and shaped diffuser. A well designed diffuser will produce the desirable effect of moving the operating point of the valve to a position of high negative correction and will provide a small degree of noise filtering. If shaped and sized correctly the regenerated noise of the diffuser will be equal to the valve trim noise.

Path treatment will reduce the noise level by increasing the resistance of the transmission path. As mentioned previously heavy wall pipe may be effective, however, it should be noted that it is only recommended for localized treatment. Also, as there is only a slight attenuation of noise with distance along the pipe, the heavy wall pipe must be used to the end of the system or to the next object in the line.

Good acoustical insulation may provide attenuation of about 10 dB per inch of thickness, but this again is a localized treatment subject to the same limitations as heavy wall pipe.

Long taper swages have been used in a number of installations but their effectiveness is restricted. Tests show that at low pressure -drop ratios the noise generated by the valve trim is far in excess of the swage and so they become ineffective. Further tests show that at pressure-drop ratios greater than that to produce flow at Mach equal to 1.0 at the body outlet, the swage acts as a supersonic diffuser and generates more noise than the valve trim. Between these limits a maximum attenuation of 3 to 4 dB may be expected.

The most effective path treatment is the "in line" silencer. Absorption type silencers when fitted adjacent to a valve can achieve an attenuation of 30 dB or more. The packing material is usually fibreglass and the pack retainer and diffuser must be properly designed to prevent the loss of the lining at high flow rates. Upstream silencers do not require diffusers and are usually designed with equal inlet and outlet connections. When a valve and silencer combination is sold for a very arduous application the diffuser may be matched to the valve to provide additional attenuation.

CONCLUSIONS

A practical method of predicting the noise level to be generated by a control valve handling a compressible fluid is now a reality. At the present time, quiet valves can be supplied to provide attenuation up to 20 dB depending upon the pressure-drop ratio and the valve size. In the future valves will possibly be developed to attenuate somewhat better, although empirical tests indicate that this is only likely if there is some sacrifice in the flow capacity per unit body area.

With the increasing demands for noise abatement, efforts must obviously be continued to refine the present techniques; which in turn will give rise to the development of additional solutions to the unacceptable ambient noise levels generated by control valves under certain operating conditions.

REFERENCES

1 SCHUDER, C.B. "New Technique for Valve Noise Prediction" Chemical Processing, November, 1970

Subsequent unpublished research indicates the same results over a total of 500000 data points.

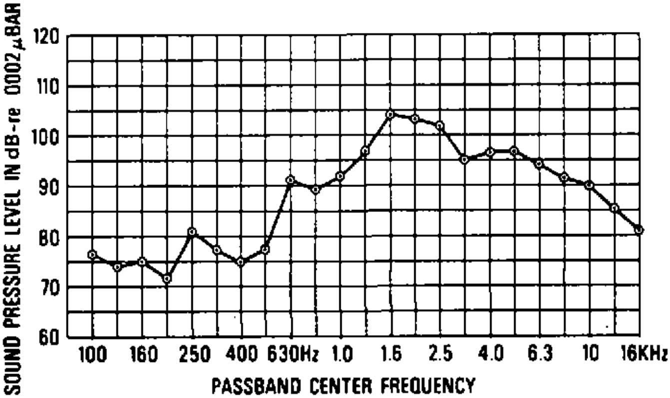

Fig. 1—Typical spectrum of control valve noise

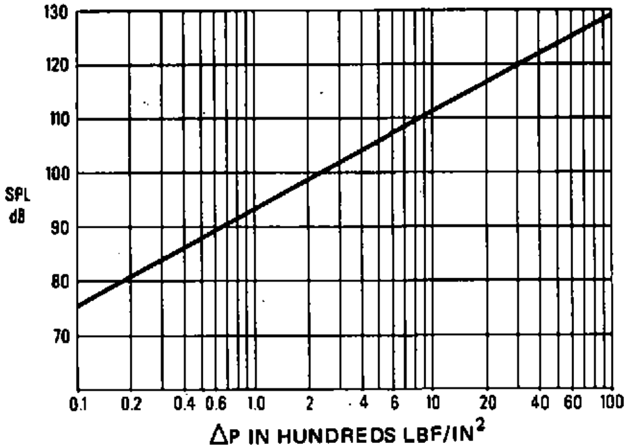

Fig. 2—Base SPLΔp — All valve styles

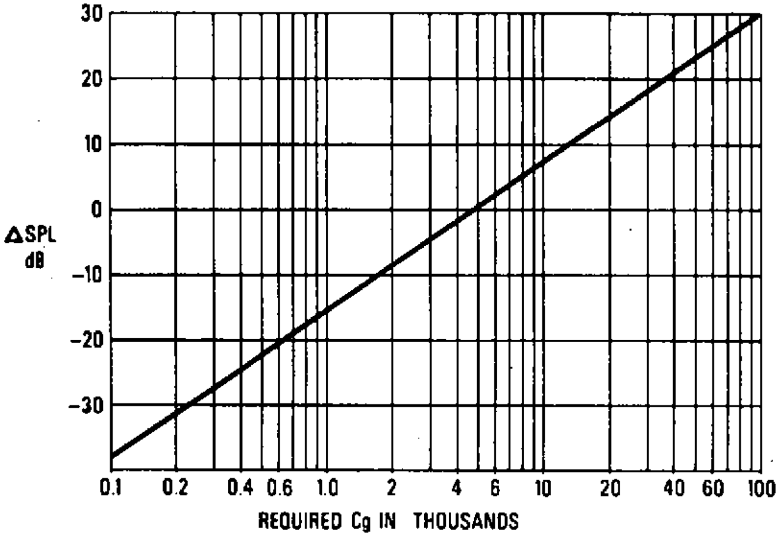

Fig. 3—ΔSPL_{Cg} Correction — All valve styles

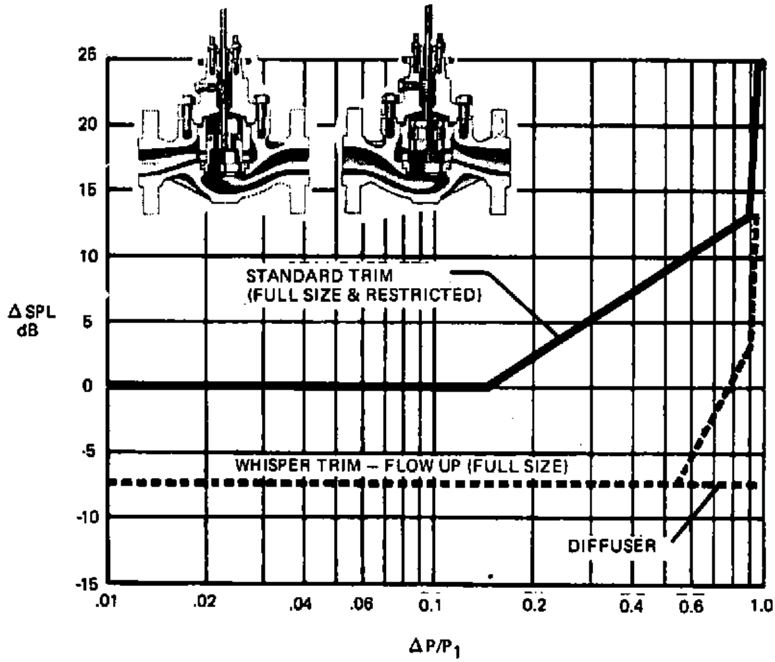

Fig. 4—$\Delta SPL_{\Delta P/P1}$ Correction — Cage style globe valves