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Method to Establish Sound and Acceleration Levels of High Pressure Reducing Valves

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Severe service control valves or better, high-pressure reducing valves can see inlet pressures in excess of 4000 psi. Such valves are found in industries ranging from gas or petroleum wells, to chemical plants and steam-producing power plants (Goodwin, "Specifying Control Valves for Severe Service Conditions", INTECH FOCUS, November (2022), p. 20). Such valves convert high levels of kinetic energy through a process of conversion of sound-producing turbulence to a reduced pressure level. Less desired by-products such as conversion are sound pressure levels that can exceed 120 decibels, a sound that is comparable to standing next to a jet plane taking off. Part of this energy conversion manifests itself as mechanical vibration which can cause undesirable high pipe acceleration which, over time, could severely damage piping (Almasi. "Flow Induced Vibrations in Piping Systems". P.I. PROCESS INSTRUMENTATION, July, 2020; Blake, 1986, "Mechanics of Flow Induced Sound and Vibrato," Vol. II, Complex Flow-Structure Interactions, Academic Press, Orlando, FL). Proposed here is an easy computer programmable method to check the sound and acceleration levels associated with noisy valves. It is believed such a paper harmonizing all aspects of aerodynamic valve noise, such as sound pressure, sound power, vibration, and acceleration can be of value. The purpose of this paper is to explain how such acceleration levels are estimated. There are four steps involved: (1) calculate the sound pressure level (SPL) from given process data, (2) convert sound pressure level into sound power level (Lwi), and (3) find the associated maximum pipe internal peak frequency (fp). (4) Based on the sound power level and the peak frequency of the sound, calculate the acceleration of the pipe (in m/second^2).
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Introduction

High-pressure reducing valves handling 4000 psi inlet pressures are no rarity. They are found in steam-producing power plants and in natural gas processing plants [1–3]. The by-product of such energy conversion is a high sound pressure level of up to 120 dB and pipe acceleration levels of 140 m/s^2 (14 G's).

A method is described to allow users of such valves to evaluate new or existing facilities in order to find if such installations meet acceptable sound and acceleration levels. It also allows the understanding of the given parameters creating sound in order to find ways to reduce sound levels [4].

This paper introduces (a) new and author-created calculating methods to calculate the sound level of a valve from input data and (b) equations to convert sound power levels to acceleration levels.

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Field-obtained data from a similar installed valve are used to check the accuracy of the predicted values.

(1) *Estimate control valve's sound pressure levels*

There is a generally used IEC standard 534-8-3 on aerodynamic control valve noise prediction [5], which is primarily empirically based. Unfortunately, this is not an open standard. If one would need reasonable prediction accuracy, one must employ special coefficients available only from one or two valve manufacturers and then only based on their specific valve types. Certainly, it is an enticement to buy their products.

To help out, there is a new sound level prediction method. The ABC Method [6,7] is based on the culmination of a number of slopes (A, B, C) of input variables when plotted against each own common demoninator. The method is open and entirely based on scientific laws. In addition, this method works for all common valve types and makes. Despite its simplicity, the method is quite accurate. Accuracies within +/−3 dB are quite common.

Based on these comments, the ABC Method is chosen. It consists of three parts plus modifiers for pipe schedules other than schedule 40 (M) and for gases other than air (G).

To make the method more understandable, typical field data [8] are used in the following equations for comparison:

Valve type: Globe, $Cv = 25$, P1 = 4000 psia, P2 = 2300 psia, pipe diameter $D = 4.6$ inch (4" schedule 80 outlet pipe) = 0.114 m. FL = 0.65, $Fd = 0.45$, medium = natural gas. $ci = 386$ m/s, $G = -2.6$, M = −6 db, $X = (P1 - P1)/P1$, $X = 0.406$, d, the pipe internal diameter = 3.83 in. = 0.097 m

$$A = 25\log(D) - 10 + 20\log(Cv/D^2),\ A = 8.4\ \text{dB} \quad (1)$$

$$B = 35\log(\text{P1}) - 35,\ B = 91\ \text{dB} \quad (2)$$

$$\text{C} = 57 + 30\log(X) + 20\log(Fd),\ C = 38.3\ \text{dB} \quad (3)$$

$$\Delta\text{FL} = 10\log(\text{FL}/0.7),\ \Delta\text{FL} = -0.97\ \text{dB} \quad (4)$$

$$\text{LAe1m} = \text{A} + \text{B} + \text{C} + \Delta\text{FL} + \text{G} + \text{M},\ \text{LAe1m} = 127.7\ \text{dB(A)} \quad (5)$$

at a standard distance of 1 m (3 feet).

However, the ABC Method has a built-in distance correction factor, which is not needed for power correction. Thus, one can ignore the 1 m distance correction = 10log(1.057 m/0.067 m) = 12.7 dB.

In addition, the ABC Method has a build-in correction factor of 5 dB to account for A-weighted sound from pipe-external, low frequencies. This factor too is not needed since fp is out of the range of the A-weighted frequencies Subtracting these un-needed additions, leaves an Lpe at the pipe wall of

$$127.7 - 12.7 - 5 = 110\ \text{dB. Field measurements show 111 dB} \quad (6)$$

(2) *Deriving the sound power level (LWI)* [9]

$$\begin{aligned}\text{LWI} &= 20\log(3\ \text{feet}) + \text{LAe} + 0.5 = 9.54 + 110 + 0.5 \\ &= 120\ \text{dB}\end{aligned} \quad (7)$$

$$\begin{aligned}&\text{The pipe internal peak frequency } fp = ci/d \\ &fp = 386\ \text{m/s} : 0.097\ \text{m} = 3979\ \text{Hz}\end{aligned} \quad (8)$$

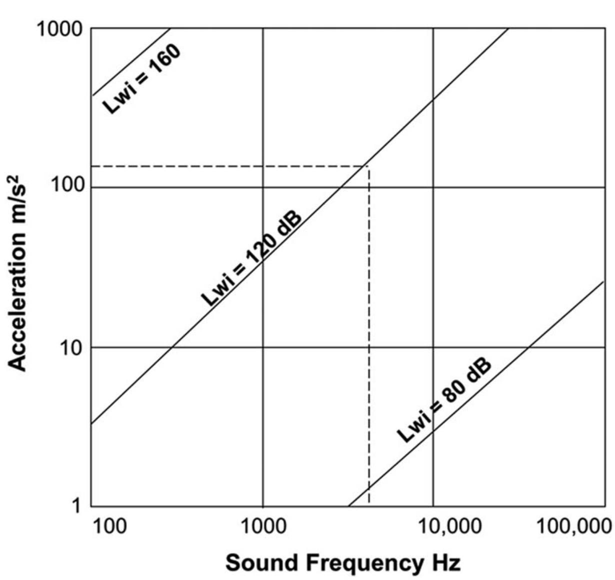

Fig. 1 The graph [8] indicates a way to convert sound power levels (LWI) into pipe acceleration. Dotted lines confirm the mathematically derived acceleration levels based on an LWI of 120 dB and *fp* of 4000 Hz.

Field data shows an fp of 4000 Hz and an LWI of 120 dB.

(3) Pipe acceleration

The pipe acceleration level (La) is the sum of $Aclwi$ (the addition of Lwi) and $Aclfp$ (the component of frequency) where

$$Acfp = 0.066 \times 10^n \times fp/20 = 0.066 \times 10 \times 4000/20 = 132\ \text{m/s}^2 \quad (9)$$

$$Aclwi = 0.5\,k,\ \text{where}\ k = 10^n \quad (10)$$

where $n = (\text{LWI-100})/20$, $n = 1$, $k = 10$, $Acplw = 5$ m/s^2

$$\text{Total acceleration} = 132 + 5 = 137\ \text{m/s}^2 \quad (11)$$

Field data show 140 m/s^2.

Figure 1 shows a graphical solution to convert sound power levels and peak frequency into acceleration levels. The dotted lines indicate the mathematically derived values from the given examples [2].

Conclusion

The results of the shown methods to estimate sound pressure levels, sound power levels, and pipe acceleration indicate a reasonably good correlation to field-measured data [8] taking into account the difficulty of obtaining sound measurements in an industrial environment. It is believed that the presented results indicate that the proposed methods should be acceptable for general use.

Conflict of Interest

There are no conflicts of interest. This article does not include research in which human participants were involved. Informed consent is not applicable. This article does not include any research in which animal participants were involved.

Data Availability Statement

The data sets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request.

Nomenclature

- d = internal pipe diameter, inch
- A = correction factor accounting for additional external sound in the A-band frequency range = 5 dB
- D = external pipe diameter, inch
- G = correction factor for gases other than air: −2.6 dB (G = 20 log (ci gas m/s/ 343) + 5 log(Sp. *Gravity* gas/1) + 10log(M/28.9), M = Molecular weight)
- M = correction factor for pipe material other than schedule 40 pipe:−6 dB (M = 20 log(t Schedule 40 pipe/t schedule 80 pipe). t = pipe wall thickness)
- R = external pipe radius, inch
- X = pressure ratio, (P1 − P2)/P1
- ci = speed of sound of natural gas, 386 m/s
- fp = frequency at which the pipe internal sound pressure reaches a maximum. Hz
- Cv = valve sizing coefficient, 1 Cv = 1 gallon of water/1 psi.
- Fd = sizing coefficient to determine the hydraulic diameter of a jet
- FL = pressure recovery factor
- La = acceleration level, m/s^2
- LAe = pipe-external sound pressure level at an A-weighted frequency scale, dB(A)
- Lpe = sound pressure level at pipe wall without A-weighted corrections, dB(e)
- Lwi = sound power level, dB
- P1 = absolute valve inlet pressure, psia
- P2 = absolute valve outlet pressure, psia
- ΔFL = 30 log(FL/0.7), dB

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