Control valve exit noise and its use to determine minimum acceptable valve size

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Abstract

Control valve aerodynamic noise can be a major contributor to excessive noise in industrial plants. Total control valve noise includes the noise generated inside the valve and the noise generated at its exit. Though often less than noise generated inside the valve, exit noise can dominate (especially in low noise valves), the overall noise radiated from downstream piping. Also, because valve exit noise increases as the valve size decreases, it may limit the minimum valve size that can be used, regardless of what is inside the valve, to successfully limit the sound pressure to acceptable levels. The international standard, IEC 60534-8-3, “Industrial-process control valves – Part 8-3: Noise considerations – Control valve aerodynamic noise prediction method”, includes a method for predicting this control valve exit noise. Control valve manufacturers commonly use this method to calculate the exit noise and include it in the overall noise prediction. Control valve end users can also use this method to determine the predicted exit noise for any given valve size. From this information, the end user has a lower limit of control valve noise to check against the manufacturer’s prediction and he/she can find a lower valve size limit. For example, if the predicted exit noise for a valve, with a given set of service conditions and downstream piping, were 85 dBA, the total valve noise for any valve the same size could not be lower and decreasing the valve size could only increase the noise. Though the internally generated noise may dictate the use of a larger valve, it could not be smaller. This information could help the control valve customer specify more realistic pipe sizes and minimum valve sizes, at least initially, and speed up the selection process.

This paper will briefly describe general aerodynamic noise generation and prediction and, in more detail, the IEC 60534-8-3 exit noise prediction. It will describe noise generation inside the valve and at its exit, its propagation down the pipeline, and its transmission through the pipe wall and into the outside environment. Several sample cases are included.

A simple computer program that could be used to facilitate the calculation of the control valve exit noise for control valves is also briefly explained.
1 General Aerodynamic Noise Generation and Prediction

Aerodynamic noise generation is a natural consequence of any gaseous flow through a control valve. Though this noise can be small and of little or no consequence for some valves, such as a valve with a very low pressure drop, it is often high enough to damage hearing or even high enough to mechanically damage downstream piping and, less often, the valve itself. Limits of the maximum sound pressure level allowed in a working environment have often been set by government or private entities in an effort to eliminate hearing damage. To help assure that the limits are met, control valve noise must be predicted and used, along with the predicted noise from other sources, to determine the predicted noise in any area of concern.

Noise from a control valve comes from many sources but most of it is generated by the valve trim and at the valve exit. Figure 1 below is a simple illustration showing noise generation by the trim and noise generation at the valve exit as the fluid goes into the downstream piping.

![Fig. 1: Simplified sketch of noise generated inside a control valve by the trim (in blue) and at the exit (in red).](image)

In this drawing, gas flows from left to right; it enters the valve and goes through the restriction between the plug and seat ring. Just downstream of that point, the high speed gas slows down in an intense mixing process. Most of the trim noise is generated in this region with the blue colored eddies shown representing the source of the trim-generated noise. Sound waves are developed downstream and move down the pipe at the speed of sound. A small portion of this sound energy excites the pipe walls and
radiates into the surrounding air as represented by the blue colored sound waves moving out radially from the downstream pipe wall.

A significant amount of noise can also be generated as the flow leaves the valve and enters the pipe. The blue eddies shown represent the generation of this noise. This “exit” noise also develops sound waves and moves down the pipe at the speed of sound. It also excites the pipe wall and a small portion of it radiates into the surrounding air as represented by the red waves shown. The frequency spectrum of the exit noise may be significantly different than that of the trim noise. The pipe wall acts as a filter with sound at some frequencies passing through it more easily than others. The exit noise, therefore, may pass through the pipe wall more easily and contribute to the overall external noise more than the trim noise even if, inside the pipe, the amplitude of the exit noise is the same or lower than the trim noise. Of course the opposite is also true, i.e. the exit noise contribution to the total external noise may be small compared to the trim noise contribution.

The amplitude of aerodynamic noise generation inside the valve and pipe is a function of many variables. Some of the most important include the fluid velocity, the size of flow passages (which affect the eddy size), and the amount of total fluid flow. The transmission of that noise from the valve through the pipe wall and into the surrounding air is also a function of many variables including the pipe size, thickness, and geometry. The IEC aerodynamic sizing standard, IEC 60534-8-3, takes these things into account to calculate the trim noise, the exit noise, and the combination of the two to get the total overall noise level.

Valve users may not always have all the information necessary to calculate the trim-generated noise but will usually have enough information to calculate the approximate valve exit noise. This information can be used to help pick the preliminary valve and pipe sizes. The exit noise is largely a function of the fluid exit velocity. If the calculated exit noise is too high, therefore, a larger valve size will probably be needed to reduce the exit velocity and the corresponding noise. A valve user could determine the minimum acceptable valve size based solely on the exit noise, without knowing anything about the internal trim. This would be done by calculating the valve exit noise and finding the smallest valve size whose predicted exit noise was below the acceptable sound pressure level. It is recommended that this predicted sound pressure level be at least 3 dBA lower than the acceptable level for the valve to allow for the addition of the trim noise to the overall sound pressure level. If special low noise trim is required, the valve may need to be even bigger, but it could be no smaller.

1.1 Calculation of Aerodynamic Noise

Aerodynamic noise is generated as high velocity gas oscillates, shears past slower moving gas in the mixing process, or interacts with solid objects in the flow path. The ISA and IEC organizations have developed a method of calculating this noise using basic principles of acoustics in the international standard IEC 60534-8-3, “Industrial-process control valves – Part 8-3: Noise considerations – Control valve aerodynamic noise prediction method”. This standard includes methods of calculating the trim noise and the exit noise which are added logarithmically to determine the total overall noise. Control valve users who specify control valves can easily calculate the exit noise using the procedures outlined below.
1.2 Calculation of Exit Noise

Calculation of the exit noise is very similar to the method for calculating the trim noise but less information is required. The following basic steps are used by IEC 60534 to calculate the exit noise for a given valve size at given conditions.

1. Calculate the mechanical stream power of the fluid exiting the valve.
2. Determine the efficiency of converting this stream power to acoustic power.
3. Determine the magnitude and peak frequency of the internal noise generated at the valve exit propagating in the downstream piping.
4. Determine the amount of exit-generated noise that would pass through the downstream pipe wall into the outside environment.

The total sound pressure level outside the pipe would be higher than the exit-generated noise calculated, because the effect of trim noise is not included, but it could not be less for the given conditions and valve size.

2 Detailed Exit Noise Calculation

The exit noise is calculated using the procedure outlined in clause 7 of IEC 60534-8-3. This procedure is described below with equation numbers given as those from the IEC standard.¹

1. Calculate the velocity in the downstream pipe, \( U_P \), using Eqn. (53)

\[
U_P = \frac{4 \dot{m}}{\pi \rho_2 D_i^2}
\]  
(53)

where \( \dot{m} \) is the mass flowrate, \( \rho_2 \) is the density of the downstream gas, and \( D_i \) is the inside diameter of the downstream pipe.

2. Calculate the velocity at the exit of the valve, or entrance into the expander (wherever the flow area is smaller), \( U_R \), using Eqn. (54).

\[
U_R = \frac{U_P D_i^2}{\beta d_i^2}
\]  
(54)

where \( \beta \) accounts for the velocity non-uniformity of the exiting fluid and \( d_i \) is the internal diameter of the valve exit, or entrance to the expander, whichever is less. The value for \( \beta \) may not be known exactly but assume approximate values of 0.93 and of 0.85 for globe and rotary valves respectively.

3. Calculate the speed of sound in the downstream fluid, \( c_2 \), using Eqn. (34)

\[
c_2 = \sqrt{\frac{\gamma RT_2}{M}}
\]  
(34)

where \( \gamma \) is the ratio of specific heats, \( R \) is the Universal gas constant, \( T_2 \) is the downstream absolute gas temperature, usually approximately equal to the upstream temperature, and \( M \) is the molecular weight of the gas.

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¹ Originally presented at the Valve World 2008 Conference, Maastricht, the Netherlands
4. Calculate the Mach Numbers in the downstream pipe, $M_p$, and at the valve exit, $M_R$, using Eqn. (58).

\[ M_p = \frac{U_p}{c_2} \]

\[ M_R = \frac{U_R}{c_2} \]  

(58)

5. If the calculated value for the pipe Mach Number, $M_p$, is greater than 0.8, set it equal to 0.8 and set $U_p = 0.8 \cdot c_2$.

6. If the calculated value for the exit Mach Number, $M_R$, is greater than 1.0, set it equal to 1.0 and set $U_R = c_2$.

7. Calculate the converted stream power in the expander, $W_{mR}$, using Eqn. (55).

\[ W_{mR} = \frac{\pi^2 U_R^2}{2} \left[ \left( \frac{i}{D_i^2} \right)^2 + 0.2 \right] \]  

(55)

8. Calculate the peak frequency, $f_{pR}$, using Eqn. (56).

\[ f_{pR} = \frac{0.2 U_R}{d_i} \]  

(56)

9. Calculate the acoustical efficiency factor, $\eta_R$, using Eqn. (57).

\[ \eta_R = \left( 1 \times 10^{-3} \right) M_R^3 \]  

(57)

10. Calculate the generated sound power using Eqn. (59).

\[ W_{aR} = \eta_R W_{mR} \]  

(59)

11. Calculate the internal sound-pressure level, referenced to $P_o (=2 \times 10^{-5} \text{ Pa})$, using Eqn. (60).

\[ L_{pR} = 10 \log_{10} \left[ \frac{3.2 \times 10^9 W_{aR} \rho_c c_2}{D_i^2} \right] \]  

(60)

12. Calculate the pipe ring frequency, $f_r$, using Eqn. (38).

\[ f_r = \frac{5000}{\pi D_i} \]  

(38)
13. Calculate the internal pipe coincidence frequency, \( f_o \), using Eqn. (39).

\[
f_o = f_r \left( \frac{c_z}{343} \right)
\]  
(39)

14. Calculate the external coincidence frequency, \( f_g \), using Eqn. (40).

\[
f_g = \frac{\sqrt{3} (343)^2}{\pi t_p (5000)}
\]  
(40)

where \( t_p \) is the downstream pipe wall thickness.

15. Determine the frequency factors, \( G_x \), and \( G_y \), using Table 4 but substituting \( f_{pR} \) in for \( f_p \).

<table>
<thead>
<tr>
<th>( f_{pR} &lt; f_o )</th>
<th>( f_{pR} \geq f_o )</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ G_x = \left( \frac{f_o}{f_r} \right)^{2/3} \left( \frac{f_{pR}}{f_o} \right)^4 ]</td>
<td>[ G_x = \left( \frac{f_{pR}}{f_r} \right)^{2/3} ] for ( f_{pR} &lt; f_r ]</td>
</tr>
<tr>
<td>[ G_y = \left( \frac{f_o}{f_g} \right) ] for ( f_o &lt; f_g ]</td>
<td>[ G_y = \left( \frac{f_{pR}}{f_g} \right) ] for ( f_{pR} &lt; f_g ]</td>
</tr>
<tr>
<td>[ G_y = 1 ] for ( f_o \geq f_g ]</td>
<td>[ G_y = 1 ] for ( f_{pR} \geq f_g ]</td>
</tr>
</tbody>
</table>

**Table 1:** (Table 4 from IEC 60534-8-3) Frequency factors \( G_x \) and \( G_y \)

16. Calculate the transmission loss, \( TL_{R} \), using Eqn. (61).

\[
TL_{R} = 10 \log_{10} \left[ (7.6 \times 10^{-7}) \left( \frac{c_z}{t_p f_{pR}} \right)^2 \frac{G_x}{\rho_a} \frac{c_z}{\rho_s} \frac{1 + \left( \frac{\rho_a}{\rho_s} \right)}{415 G_y} \right]
\]  
(61)

where \( \rho_a \) is the actual atmospheric pressure at the valve location, and \( \rho_s \) is the reference atmospheric pressure.

17. Calculate the Correction for Mach number, \( L_g \), using Eqn. (41) but substituting \( M_p \) in for \( M_2 \).

\[
L_g = 16 \log_{10} \left( \frac{1}{1 - M_p} \right)
\]  
(41)
18. Calculate the external noise, generated at the exit, using Eqn. (62).

\[ L_{peR} = 5 + L_{piR} + TL + L_g - 10 \log_{10} \left( \frac{D_i + 2t_p + 2}{D_i + 2t_p} \right) \]  

(62)

The sound pressure level calculated above, \( L_{peR} \), is the predicted sound pressure level 1 m downstream of the valve and 1 m from the pipe wall generated at the valve exit in straight pipe in an acoustically free field. The trim noise, if known, can be added logarithmically using Eqn. (63).

\[ L_{PS} = 10 \log_{10} \left( 10^{L_{pulse,1m}/10} + 10^{L_{psh}/10} \right) \]  

(63)

3 Example calculations

Perhaps the best way to see the significance of the exit noise is with some sample calculations. Detailed exit noise calculations are shown below for a common valve configuration with common service conditions. The results for another case exactly the same except with a lower downstream pressure are also given. The magnitude of the input variables are given in the metric units that should be used without having to make unit conversions in the equations above. Customary English are also shown in parentheses.

3.1 Case 1

A sample case was chosen as a standard 2 in low pressure globe valve with air flowing through it and with a relatively low pressure drop. Detailed specifications of the valve geometry and service conditions are listed below.

Valve: 2 inch globe
Pressure class: 300
Upstream temperature: 343.15 K (70 F)
Upstream pressure, \( p_1 \): 689476 Pa (100 psia)
Downstream pressure, \( p_2 \): 344738 Pa (50 psia)
Fluid: Air
Molecular weight, \( M \): 28.97
Ratio of specific heats, \( \gamma \): 1.4
Compressibility, \( z \): 1.0 (used for calculating the density, \( \rho_2 \))
Flowrate, \( Q \): mdot=1.20301 kg/sec (125000 scfh)
Valve outlet ID, \( d_i \): 0.0508 m (2 in)
Downstream pipe Size: 3 in
Downstream pipe schedule: 40
Downstream pipe ID, \( D_i \): 0.0779 m (3.068 in)
Downstream pipe wall thickness (schedule 40), \( t_p \): 0.00549 m (0.216 in)
Beta, \( \beta \), for globe valve: 0.93

The calculations below were performed using the computer program, Mathcad © 2007 Parametric Technology Corporation, which displays the equations and results in a form
similar to how they would be written by hand. The equations shown follow the steps described above.

The following conventions should be noted to aid in understanding the equations.

- The term “:=” is an assignment statement meaning the value on the right is assigned to the variable on the left.

- The dot, “⋅”, between variables midway up from the bottom of the variable names signifies multiplication.

- The “if” statements are written as “if (‘test statement’, ‘value returned if test statement is true’, ‘value returned if test statement is false’)”. The “if” statements can be nested, as they are in the calculations below.
Sample Exit Noise Calculations

Input:

- Atmospheric pressure, Pa: \( p_a := 101325 \) Pa
- Standard atmospheric pressure, Pa: \( p_s := 101325 \) Pa
- Molecular weight: \( M := 28.97 \) g/mol
- Upstream temperature, K: \( T_1 := 294.3 \) K
- Ratio of specific heats: \( \gamma := 1.4 \)
- Upstream absolute pressure, Pa: \( p_1 := 689476 \) Pa
- Downstream absolute pressure, Pa: \( p_2 := 344738 \) Pa
- Compressibility of fluid at upstream conditions: \( z := 1 \)
- Flow rate, kg/sec: \( \dot{m} := 1.20301 \) kg/sec
- Valve exit ID, m: \( d_i := 0.0508 \) m
- Downstream pipe ID, m: \( D_i := 0.0779 \) m
- Downstream pipe wall thickness, m: \( t_p := 0.00549 \) m
- Beta for globe valve: \( \beta := 0.93 \)

Calculations:

- Gas constant, J/kmole-K: \( R_g := 8314 \) J/kmole-K (used \( R_g \) to designate rather than \( R \))
- Downstream temperature (assume = \( T_1 \)): \( T_2 := T_1 \)
- Density of fluid at downstream conditions (gas equation), kg/m\(^3\): \( \rho_2 := \frac{p_2 M}{z R_g T_2} \) \( \rho_2 = 4.082 \) kg/m\(^3\)
Velocity in downstream pipe, m/sec:

\[ U_p := \frac{4 \cdot \text{mdot}}{\pi \cdot \rho_2 \cdot D_1^2} \]

\[ U_p = 61.84 \]

Velocity at valve exit, m/sec:

\[ U_R := \frac{U_p \cdot D_1^2}{\beta \cdot d_i^2} \]

\[ U_R = 156.362 \]

Speed of sound in downstream fluid, m/sec:

\[ c_2 := \sqrt{\frac{\gamma \cdot R g \cdot T_2}{M}} \]

\[ c_2 = 343.867 \]

Mach number in downstream pipe:

(Limited to 0.8)

\[ M_p := \text{if } \left( \frac{U_p}{c_2} < 0.8, \frac{U_p}{c_2}, 0.8 \right) \]

\[ M_p = 0.18 \]

Correct \( U_p \) so not greater than 0.8 \( c_2 \):

\[ U_{p'} := M_p \cdot c_2 \]

Mach number at valve exit:

(Limited to 1.0)

\[ M_R := \text{if } \left( \frac{U_R}{c_2} < 1.0, \frac{U_R}{c_2}, 1.0 \right) \]

\[ M_R = 0.455 \]

Correct \( U_R \) so not greater than \( c_2 \):

\[ U_{R'} := M_R \cdot c_2 \]

Converted stream power, \( W \):

\[ W_{mR} := \frac{\text{mdot} \cdot U_R^2}{2} \cdot \left[ \left( \frac{d_i}{D_1} \right)^2 + 0.2 \right] \]

\[ W_{mR} = 7.799 \times 10^3 \]
Peak frequency of exit-generated noise, Hz:

\[ f_{pR} := \frac{0.2 U_R}{d_i} \]

\[ f_{pR} = 615.599 \]

Acoustical efficiency factor:

\[ \eta_R := (1 \cdot 10^{-3}) \cdot M_R^3 \]

\[ \eta_R = 9.402 \times 10^{-5} \]

Exit generated sound power, W:

\[ W_{aR} := \eta_R \cdot W_{mR} \]

\[ W_{aR} = 0.733 \]

Internal sound pressure level generated at exit, dB:

\[ L_{piR} := 10 \log \left( \frac{3.2 \cdot 10^9 \cdot W_{aR} \cdot \rho_d \cdot c_2}{D_i^2} \right) \]

\[ L_{piR} = 147.346 \]

Calculate the ring frequency, Hz:

\[ f_r := \frac{5000}{\pi D_i} \]

\[ f_r = 2.043 \times 10^4 \]

Calculate the internal coincidence pipe frequency, Hz:

\[ f_0 := \frac{f_r}{4} \left( \frac{c_2}{343} \right) \]

\[ f_0 = 5.121 \times 10^3 \]

Calculate the external coincidence frequency, Hz:

\[ f_g := \frac{\sqrt{3} \cdot (343)^2}{\pi \cdot t_p (5000)} \]

\[ f_g = 2.363 \times 10^3 \]

Calculate the frequency factor, \( G_x \):

\[ G_x := \left\{ \begin{array}{ll}
\frac{2}{f_{pR}} & \text{if } f_{pR} < f_0, \\
\left( \frac{f_{pR}}{f_r} \right)^3 & \text{if } f_{pR} > f_r,
\end{array} \right. \]

\[ G_x = 8.304 \times 10^{-5} \]
Calculate the frequency factor, $G_y$:

$G_y := \begin{cases} f_{pR} < f_o & \text{if} \ f_o < f_g \left( \frac{f_b}{f_g} \right), 1.0 \text{, if} \ f_pR < f_g \left( \frac{f_{pR}}{f_g} \right), 1.0 \end{cases}$

$G_y = 1$

Transmission loss, $TL_R := 10 \log \left( 7.6 \times 10^{-7} \right) \left( \frac{c_2}{t_p f_{pR}} \right)^2 \left( \frac{G_X}{\frac{\rho_2 c_2}{415 G_y} + 1} \right) \left( \frac{p_a}{p_s} \right)$

$TL_R = -68.265$

Calculate the Correction for Mach number, $L_g R$:

$L_g := 16 \log \left( \frac{1}{1 - M_p} \right)$

$L_g = 1.378$

Calculate the external exit-generated noise, dBA:

$L_{peR} := 5 + L_{piR} + TL_R + L_g - 10 \log \left( \frac{D_1 + 2 \cdot t_p + 2}{D_1 + 2 \cdot t_p} \right)$

The calculated exit noise predicted, $L_{peR} = 71.7 dBA$. If the maximum acceptable sound pressure level were 75 dBA, one would not want to use a valve smaller than 2 in or the exit noise would be too high. (If the exit noise is approximately 3 dBA lower than the allowed noise, it allows for a trim noise of equal magnitude without going over the limit since the logarithmic addition of two sound pressure levels equal in magnitude results in a sound pressure level 3 dBA higher than the other two. Of course, if the trim noise is higher than the exit noise, the total noise would be more than 3 dBA higher than the exit noise.)
3.2 Case 2

Another case was considered, one where the conditions are the same as Case 1 above except the downstream pressure was only 14.7 psia (or normal atmospheric pressure) rather than 50 psia. The same calculations used above were used; the resulting predicted exit noise was

\[ L_{peR} = 99.0 \text{ dBA} \]

which is much higher than the value calculated for Case 1 of 71.7 dBA because the exit velocity is much higher. For this case, a larger valve would have to be used to keep the noise down to a level of 75 dBA or even down to 85 dBA.

4 Simple Computer Program

A simple program was written to help control valve users calculate the predicted valve exit noise for a simple control valve. It can be used to help determine the minimum valve size required to get the exit noise below an acceptable level. The input and output screens are shown below in Figure 2. The input data is shown in the top part, the output is shown in the text box in the lower portion of the screen. The data shown is that for Case 1 discussed above. The calculated exit sound pressure level, \( L_{peR} \), is shown on the second line from the bottom.
Fig. 2: Input and output data for Case 1.

The second sample case, Case 2, was also calculated and is shown in the screen below. Again, the predicted exit noise, $L_{peR}$, agrees with the value calculated above.
Fig. 3: Input and output data for Case 2 (the same as Case 1 except with p2=14.7 psia rather than 50 psia).

Note that the calculated exit noise is approximately 27 dBA higher than for Case 1 even though the upstream conditions and flow rate are the same. This is primarily because the exit velocity is much higher (the Mach number is 1.0 at the exit rather than 0.45) for Case 1. If the allowable sound pressure level outside the pipe were less than 99 dBA, a bigger valve would have to be used.

4 Conclusions

The predicted control valve exit noise can easily be calculated according to the international standard, IEC 60534-8-3, by a control valve user without knowing details of the valve trim. Since the total sound pressure level outside the downstream piping cannot be lower than that contributed by the exit-generated noise and since the exit noise goes down (almost always) with increasing valve size, a control valve user can determine the minimum valve size that could be used without exceeding the maximum allowed sound pressure level. In some cases the valve size may need to be even
bigger, because of trim noise, but it could not be smaller. This should help the control valve user and manufacturer come to agreement more quickly on the proper valve for a given application.

Notes

1. The author thanks the International Electrotechnical Commission (IEC) for permission to reproduce equations from its International Standard IEC 60534-8-3. All such extracts are copyright of IEC, Geneva, Switzerland. All rights reserved. Further information on the IEC is available from www.iec.ch. IEC has no responsibility for the placement and context in which the extracts and contents are reproduced by the author; nor is IEC in any way responsible for the other content or accuracy therein.

5 References