Size and Wall Thickness Effect on Evaluation for Acoustically Induced Vibration (AIV)

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ABSTRACT

Large acoustic energy generated by a pressure relief valve or blowdown system with large flowrate and pressure drop across it would result in fatigue failure of the piping system due to severe vibration at high frequencies. This phenomenon is called AIV (Acoustically Induced Vibration) and the evaluation method of AIV was first proposed by Carucci and Mueller in 1982. Since then some papers have suggested that there are several problems on the AIV evaluation method based on Carucci and Mueller works. However, essential change in the AIV evaluation method could not be achieved yet. This paper studies the effects of pipe diameter and wall thickness on AIV based on IEC noise evaluation method described in IEC 60534-8-3, 2010, since the pipe external noise which could be well estimated by the latest IEC method is proportional to the vibration stress of the pipe. The study results show that the key evaluation factor is the pipe wall thickness and the newly developed concept of the AIV evaluation method incorporating the pipe wall thickness shows good agreement with the other guidelines, FEA study results and AIV failure data.

Keywords: Acoustically Induced Vibration, Sound Power Level, Sound Pressure Level, Size Effect, Wall Thickness Effect

1. INTRODUCTION

In process plants with large capacity, large sound power generated by PRVs (Pressure Relieving Valves) or blowdown valves with restriction devices sometimes result in severe piping vibrations with high frequencies in flare piping systems. This vibration phenomenon is called AIV (Acoustically Induced Vibration) first reported by Carucci and Mueller (1, 2). Carucci and Mueller showed that the fatigue failure due to AIV could be caused by large acoustic power generated by devices with large pressure drop and the possibility of the fatigue failure would be related to the acoustic power level and pipe diameter. Eisinger proposed an AIV fatigue diagram corresponding to the relations between sound power level and D/t (pipe diameter ratio to wall thickness) (3). Energy Institute published a guideline for piping vibration with an evaluation method for the AIV failure possibility related to type of branch connection, main pipe diameter ratio to branch pipe, etc. in addition to sound power level and pipe diameter ratio to wall thickness (4). In inter-noise 2012 several papers reported that the allowable acoustic power level for AIV would be affected by pipe diameter in addition to pipe diameter ratio to wall thickness (5, 6, 7).

As explained above, the pipe size and/or wall thickness effect for AIV are not clear though there are several researches which investigate them. This paper shows the study results on the pipe size and/or wall thickness effect on AIV based on the noise evaluation method described in IEC 60534-8-3, 2010 (8), since the pipe external noise which could be well estimated by the latest IEC method is proportional to the vibration stress of the pipe (9, 10). The study results suggest that the key evaluation factor is the pipe wall thickness rather than the pipe diameter ratio to wall thickness and the newly developed concept of the AIV evaluation method incorporating the pipe wall thickness shows good agreement with the other guidelines, FEA study results and AIV failure data.

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2. VIBRATION EVALUATION METHOD BASED ON IEC STANDARD

IEC 60534-8-3 (8) shows a calculation method of the sound pressure level at the pipe outside in accordance with the following procedure:

(1) Stream power of the flow through the restriction device is obtained by the fluid properties, mass flow rate, pressure ratio and sound speed at vena contracta.

(2) Acoustic efficiency is determined by the flow regime through restriction, Mach number through restriction, hole velocity, hole diameter, device correction factor, etc. There are five regimes, one for subsonic and four for sonic/supersonic flow conditions. The flow regimes for the sonic/supersonic flow conditions are classified into four regimes according to the pattern of shock cell condition, turbulence interaction, etc. The correction factor of the restriction device should be determined by experimental data.

(3) Internal acoustic power is calculated from the product of stream power and acoustic efficiency.

(4) Pipe transmission loss is obtained from the pipe diameter, wall thickness, density of pipe wall and peak frequency of the jet from the restriction device.

(5) Sound pressure in the pipe is calculated from the sound power, cross sectional area of pipe and fluid properties.

(6) Sound pressure at the pipe external surface is obtained from the sound power in the pipe and pipe transmission loss.

The sound pressure at the pipe external surface can be expressed by the product of air density, sound speed of air and pipe vibration velocity. The pipe vibration velocity is proportional to the pipe vibration stress (9, 10). Therefore it is considered that the pipe vibration stress is proportional to the sound pressure at the pipe external surface. From this viewpoint, the vibration severity caused by AIV can be evaluated by investigating the sound pressure at the pipe external surface based on IEC method.

3. CASE STUDIES

3.1 Study Cases

Table 1 shows the study cases. The effects of the flow rate, pipe internal diameter, wall thickness and pipe diameter ratio to wall thickness are investigated on the sound pressure level at the pipe external surface to evaluate the vibration severity. Case 1A to Case 1C are the study cases to investigate the effects of the wall thickness, *t* and the pipe diameter ratio to the wall thickness, *D/t* with constant pipe diameter, *D*. Case 2A and 2B are the study cases to investigate the effect of *D* and *t* with constant *D/t*. Case 3A and 3B are the study cases to investigate the effects of *D* and *D/t* with constant *t*. Table 2 shows the process conditions and expected sound power level calculated by IEC method (8) and Carucci and Mueller method (1, 2) for these study cases.

Table 1 – Study cases

Case	Flow Rate (kg/h)	Pipe Diameter *D* (mm)	Wall Thickness *t* (mm)	D/t	Note
Case1A	300	800	5.3 ➔ 20.0	150 ➔ 40	Investigate Effect of D/t & t with Constant D
Case1B	100	500	3.3 ➔ 12.5	150 ➔ 40	
Case1C	20	200	1.7 ➔ 6.7	120 ➔ 30	
Case2A	300	800 ➔ 1600	8.0 ➔ 16.0	100	Investigate Effect of D & t with Constant D/t
Case2B	100	500 ➔ 1200	5.0 ➔ 12.0	100	
Case3A	300	800 ➔ 1600	10	80 ➔ 160	Investigate Effect of D/t & D with Constant t
Case3B	100	500 ➔ 1200	10	50 ➔ 120	

Table 2 – Process conditions and expected sound power level

Pressure (up / down)	5.1 / 0.1 MPa (abs.)
Upstream Temperature	300 K
Molecular Weight	20 kg/kmol
Specific Heat Ratio	1.3
Calculated Sound Power Level (IEC)	167.7 dB / 163.0 dB / 155.9 dB *
Calculated Sound Power Level (Carucci and Mueller)	178.2 dB / 168.7 dB / 154.7 dB *

* at 300 kg/h / 100 kg/h / 20 kg/h

3.2 Effects of wall thickness and pipe diameter ratio to wall thickness

Figure 1 shows the relation between the sound pressure level at the pipe external surface and wall thickness to investigate the effect of wall thickness, *t* and pipe diameter ratio to wall thickness, *D/t* with constant pipe diameter, *D* (Case1A – Case1C). This figure shows that the wall thickness increase has the effect of vibration stress decrease by the factor of -20 $\log_{10}(t)$. Since the increase of *t* means the decrease of *D/t* with constant *D*, this figure would indicate that the vibration stress would be influenced by *t* or *D/t*.

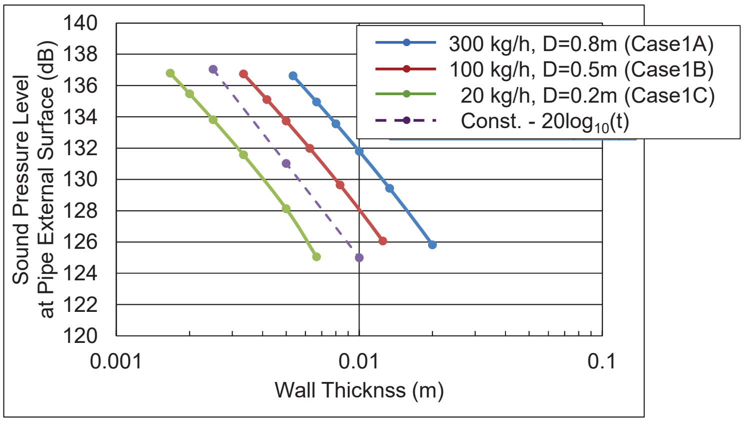

Figure 1 – Study results (Case1A to Case1C) - effect of *t* and *D/t* with constant *D*

3.3 Effects of wall thickness and pipe diameter

Figure 2 shows the relation between the sound pressure level at the pipe external surface and wall thickness to investigate the effect of *t* and *D* with constant *D/t* (Case2A to Case2B). As shown in this figure the wall thickness increase has the effect of vibration stress level decrease a little larger than the factor of -20 $\log_{10}(t)$. Since the increase of *t* means the increase of *D* with constant *D/t*, this figure would indicate that the vibration stress would be influenced by *t* or *D*.

3.4 Effects of pipe diameter and its ratio to wall thickness

Figure 3 shows the relation between the sound pressure level at the pipe external surface and *D/t* to investigate the effect of *D* and *D/t* with constant *t* (Case3A to Case3B). As shown in this figure the increase of D/t has the effect of slight decrease of the vibration level, however, this effect is much smaller than those of the wall thickness as shown in Figures 1 and 2. This suggests that *D/t* merely affects the vibration stress level at the pipe external wall with constant wall thickness and the wall thickness could be the dominant factor for AIV evaluation rather than *D/t*.

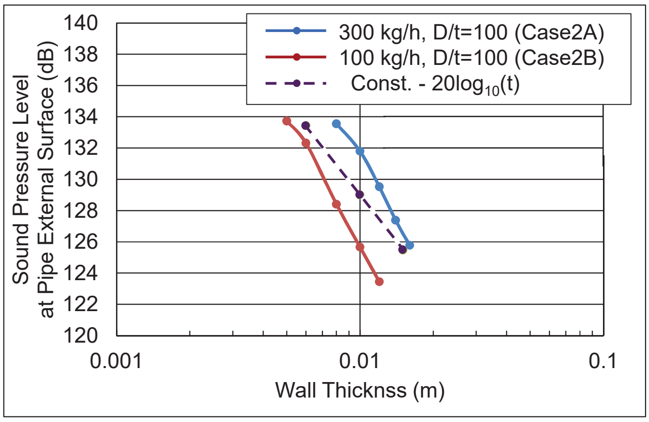

Figure 2 – Study results (Case2A to Case2B) - effect of *t* and *D* with constant *D/t*

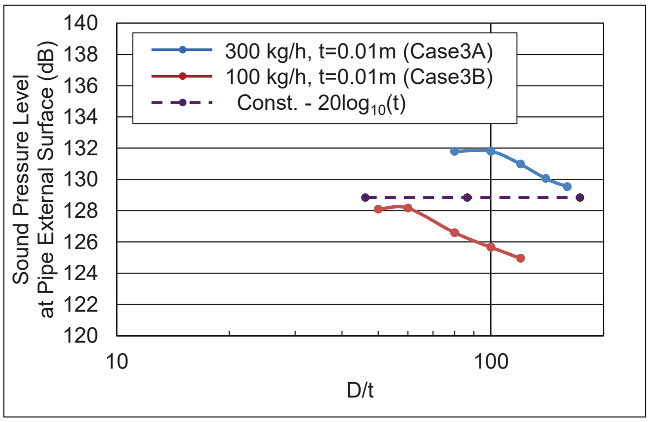

Figure 3 – Study results (Case3A to Case3B) - effect of *D* and *D/t* with constant *t*

3.5 Key parameter for AIV evaluation

Table 3 shows the summarized results of the case studies. In Table 3, the common factor which shows the effect of the vibration level would be -20 $\log_{10}(t)$ and this means that the key parameter of the AIV evaluation would be the pipe wall thickness instead of the pipe diameter ratio to the wall thickness. These study results have no contradiction with the fact that the past fatigue failure caused by the AIV phenomena only occurred at the piping system with relatively thinner wall thickness (1, 2).

Table 3 – Summarized results of case studies

Case	Parameter	Effect to Vibration Level	Figure
Case1A - Case1C	*t* & *D/t*	$-20\log_{10}(t)$ or $20\log_{10}(D/t)$	Figure 1
Case2A – Case2B	*t* & *D*	$-20\log_{10}(t)$ or $-20\log_{10}(D)$	Figure 2
Case3A – Case2C	*D* & *D/t*	-	Figure 3

4. Considerations

4.1 Comparison with FEA study results of generic model

Figure 4 shows the effect of the pipe diameter on the allowable sound power level for AIV investigated by Swindell (5) including the comparison with the results based on EI guidelines (4). As shown in Figure 4, the allowable sound power levels for AIV would increase as pipe diameter increases. As explained above the pipe diameter increase is equivalent to the wall thickness increase with constant *D/t* and this effect would be evaluated by the factor of $-20\log_{10}(t)$. Figure 5 shows the comparison between the allowable power levels for AIV based on EI/FEA generic model shown in Figure 4 (4, 5) and the evaluation results with correction factor of $-20\log_{10}(t)$. Since both evaluation results have good agreement as shown in Figure 5, the derived evaluation method with correction factor of $-20\log_{10}(t)$ for AIV would be adequate.

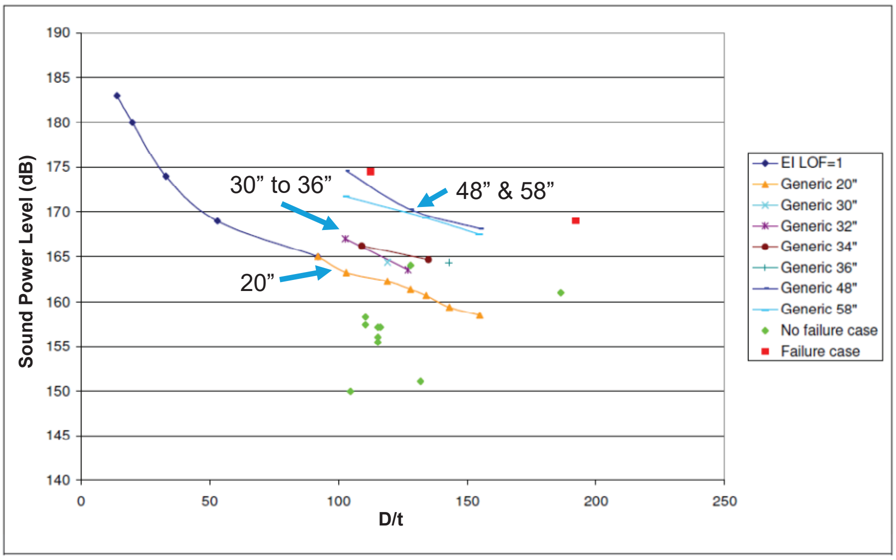

Figure 4 – Pipe size effect based on EI guidelines (4) and FEA generic model (5)

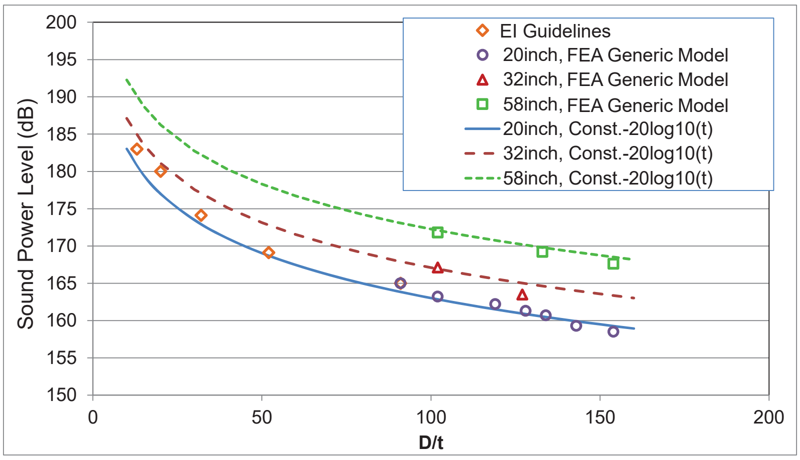

Figure 5 – Comparison between allowable power levels for AIV based on EI/FEA generic model (4, 5) and evaluation method with correction factor of -20 $\log_{10}(t)$

4.2 Comparison with past failure data caused by AIV

Figure 6 shows the comparison between the past AIV failure data (1, 2) and derived criterion based on *Constant* - 20 $\log_{10}(t)$. As shown in this figure there is no discrepancy between the past failure data and the derived criterion of *Constant* - 20 $\log_{10}(t)$ by adjusting the constant so as to get appropriate comparison. This figure suggests that the derived evaluation method with correction factor of -20 $\log_{10}(t)$ for AIV would be adequate.

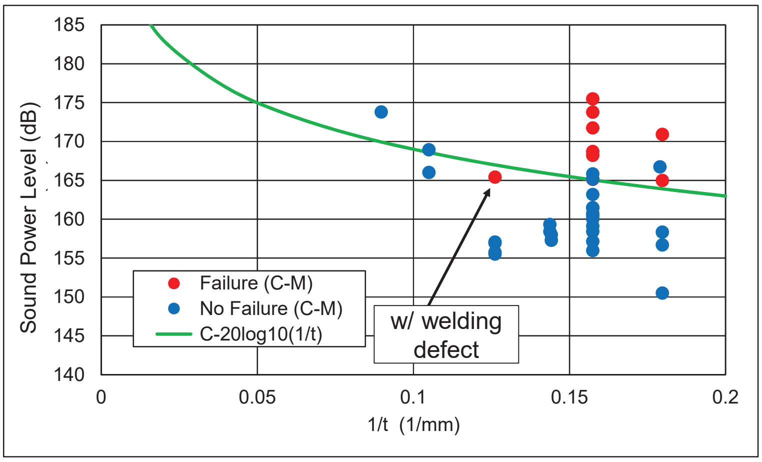

Figure 6 – Comparison between AIV failure data and evaluation method with correction factor of -20 $\log_{10}(t)$

5. CONCLUSIONS

The effects of the pipe size and wall thickness are studied on AIV design criterion based on the sound pressure prediction method described in IEC 60534-8-3, 2010. The study results show that the dominant factor for the AIV severity would be the wall thickness instead of the present design criterion with the pipe diameter ratio to the wall thickness. The allowable sound pressure level could be expressed as the form of *Constant* – $\log_{10}(t)$, here t is the wall thickness and this derived criterion has good agreement with the other guidelines, FEA study results and AIV failure data.

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