AERODYNAMIC NOISE IN CONTROL VALVES – PREDICTION AND EXPERIMENTAL STUDIES INSIDE HEMI-ANECHOIC SPACE

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ABSTRACT
Aerodynamic noise is one of the major sources of excessive noise from Control Valves. Prediction of this noise is an important consideration and IEC 60534-8-3 is the most widely used standard for noise prediction of Control valves. Since there are some assumptions in the prediction method, most of manufactures or users need to experimentally verify the predicted Sound Pressure Level (SPL). The IEC 60534-8-1 defines the equipment, methods and procedures for obtaining laboratory measurements of SPL. Even though the piping configurations and valve parameters are matching, the experimental validation depends on many parameters which need to be considered as per the IEC standard. The acoustic environment specification provided in the standard is a key contribution to the success of validation process.

This paper explains in brief about the hemi-anechoic chamber / acoustic environment available in FCRI for such experimental studies. In this paper an attempt is made to predict the aerodynamic noise generated from a 1" Control Valve with 3 different trim configurations. Experimental studies are also conducted to compare the predicted and measured SPL. Study indicates that the result is within the limits as specified in the relevant IEC standards.

KEYWORDS
Hemi-anechoic chamber, Control Valve noise, Noise prediction

1.0 INTRODUCTION
Noise produced by valves and pipes is a focal point in industries and process plants. It can cause hearing loss in people. Human ear is most sensitive in the region between 500 and 6000 Hz and it is represented using A weighting curve. In this frequency range high noise level exposure can do the most damage. As per the International and Indian noise standards, if the predominant noise frequency exposure is in the critical middle frequency range of 1000–5000 Hz, the allowable weighted noise level over 8 hours should be considerably lower than 90 dBA.

Even if people can keep away from areas with high noise levels, there are other issues with excessive noise, like vibrations in structures, fatigue failures in valves and piping systems etc. In general industrial operational environment, aerodynamic noise is predominant over mechanical vibration or hydrodynamic / cavitation noise.

Initially the valve manufacturers were predicting the noise data of their design for the required process conditions using their own empirical models which is not fully supported by either fluid mechanic or acoustics theories. An interesting research done at Penn State University and reported [1] by Allen K Shea revealed that the noise prediction models employed by different manufacturers differ widely guessing the users which model is overestimating or under estimating the noise data. He had attempted to predict the noise data for a given valve design, and for a range of operating conditions using valve noise prediction models by different manufacturers as indicated in Fig 1.

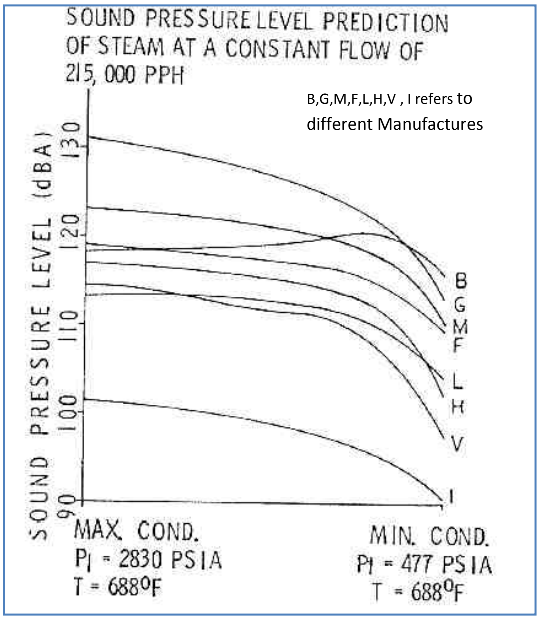

Fig.1 Comparison of Prediction Methods

This has propelled the formation of special task committee by ISA to prepare a prediction method which culminated the adoption of the international standard for noise prediction.The IEC Standard IEC 534-8-3[2] is designed to calculate aerodynamic noise level produced by a control valve. This internationally approved standard provides a method for comparing one control valve to another on a common basis. This frees the end user from the burden of deciding which control valve vendor has the best proprietary noise prediction method.

Specification sheet of control valve contains maximum noise level as one of the sizing data. To arrive at a correct noise level data, manufactures need to experimentally confirm their predicted noise. The IEC standard 60534-8-1[3] defines the equipment, methods and procedures for obtaining laboratory measurements of Sound Pressure Levels. Experimental studies also help in better design of Control Valves with less noise.

2.0 NOISE PREDICTION

The IEC standard outlines a five step procedure for calculating noise. While the details and equations of each step often change with the flow regime involved, the general principle is same. The five steps are detailed below:

I. Determine how much mechanical power is resident in the flow stream at the vena contracta.
II. Empirically derived acoustic efficiency factors are used to determine how much noise power is generated downstream of the valve.
III. Convert this sound power to sound pressure level in the fluid downstream of the valve.
IV. In order to determine how much of the sound pressure level gets transmitted through the pipe wall to the outside air; we must deal with the transmission losses involved in the passage of the sound through the pipe wall. These transmission losses depend upon many different properties of both the fluid and the pipe. The sound pressure level immediately outside the pipe wall is then converted to an A-weighted sound pressure level.
V. Finally, standard acoustic theory is used to determine how much of this sound pressure level gets transmitted to a hypothetical observer located at the standard location, which is one meter downstream from the valve and one meter away from the outer surface of the pipe.

The different regimes of noise generation are the result of differential pressure ratio. In flow regimes 1-3 the primary noise mechanism is due to the turbulence at the downstream of the vena contracta. This is called, "Turbulent shear flow." As the flow gets more intense due to the higher pressure drop across the valve and as it begins the move to higher flow regimes (3-5), the normal shock begins to move further downstream and starts to break up into several smaller shock cells and “Shock-turbulence interaction" creates reflected waves from pipe wall. In the final flow regime (V), the noise generated is no longer a function of pressure ratio. This is called the region of constant acoustical efficiency. IEC standard also addresses special steps to be taken for Valves with special trim design as given below.

- Single stage, multiple flow passage trim.
- Single flow path, multistage pressure reduction trim.
- Multipath, multistage trim

3.0 NOISE MEASUREMENT

As per standard the components of test system / experimental set up are

- Pressure regulating devices (optional)
- Test specimen
- Test section piping
- Pressure Taps
- Noise attenuating devices (optional)
- Means of controlling the acoustic environment
- Instrumentation

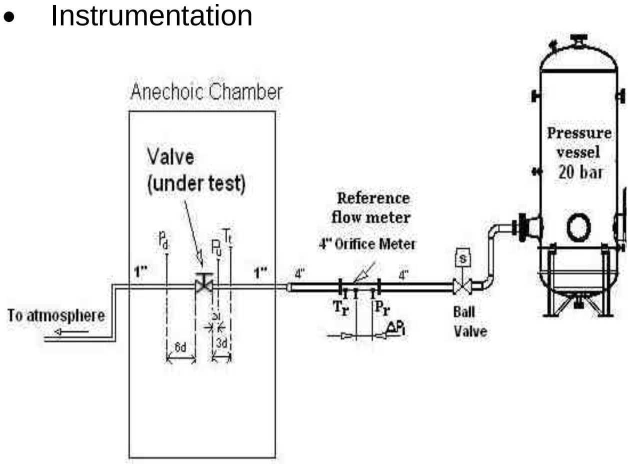

Fig.2 Test set up for noise measurement

Fig.2 shows the test set up at FCRI that complies with the IEC standard 60534-8-1. Air stored at 20 bar pressure, in four vessels of cumulative capacity about 45 m³, is the source for the test. The upstream pressure and flow through the valve assembly is controlled using pressure regulators. Flow through the valve assembly is measured using an orifice flow meter.

The upstream pressure, pressure across the test valve as well as the differential pressure across the orifice plate are measured using pressure transducers. Pt100 temperature sensors are also placed as shown in Fig.2. The test valve is positioned inside a hemi anechoic chamber. SS Schedule 40 pipes are used for valve assembly. The pressure and temperature tappings and straight lengths are provided as per standard. Flow and related parameters are acquired through a data acquisition system. Microphone is positioned as per the standard and connected to a signal analyzer. Both systems are synchronised for real time data acquisition (Table 1).

Table 1 – Typical data

Time	Ref. Pressure, Pr (barA)	Diff. Pressure, DPr (mbar)	Ref. Temp., Tr (°C)	Valve upstream Pressure, Pt (bar a)	Valve Diff. Pressure (bar)	Test. Tem., Tt (°C)	SPL (dBA)
12:43:32:.4	17.19	55.22	28.17	15.04	6.93	28.63	83.22
12:43:32:.5	17.19	55.22	28.17	15.04	6.93	28.63	83.20
12:43:32:.7	17.17	55.12	28.17	15.02	6.92	28.61	83.46
12:43:32:.9	17.17	55.12	28.17	15.02	6.92	28.61	83.75
12:43:33:.1	17.14	55.03	28.16	15.00	6.91	28.58	83.45
12:43:33:.3	17.14	55.03	28.16	15.00	6.91	28.58	83.36

The Hemi Anechoic chamber (shown in Fig.6) is designed and qualified as per the requirements of ISO 3745. The major design features of this facility are given in the Table 2.

Table 2 – FCRI Hemi Anechoic Chamber Details

Inside dimensions of the chamber (Between wedge tips)	6.3x6.3x3.4 m (LxBxH)
Lowest design cut off frequency	100 Hz
Typical wedge dimension	200x200mm with 1000mm long
Wedge material	Resin bonded glass wool with 32 kg/m3 Density
Ambient noise level	<20 dBA

4.0 CASE STUDY

Globe type Control Valve of size 1"NB was considered for the studies. The valves are available with 3 trim configurations (Fig.3 to Fig.5).

Fig.3 Trim1 Configuration

Fig.4 Trim2 Configuration

Fig.5 Trim3 Configuration

Trim1 – Parabolic Plug
Trim2 - Perforated Plug - Single Stage
Trim3 - Perforated Plug & Seat - 2 Stage
Trim 2 & 3 are Low noise designs.

Data were collected for 4 different openings viz. 25%, 50%, 75% and 100% for all the three trim configurations. The microphone was positioned at a distance of 1m away from the mid plane of the valve and 1m from the downstream pipe as shown in Fig.6. All the required parameters like upstream & downstream pressure, Temperature and noise were noted during the flowing condition. Flow was allowed to decay continuously from 19 bar to 15 bar upstream pressure.

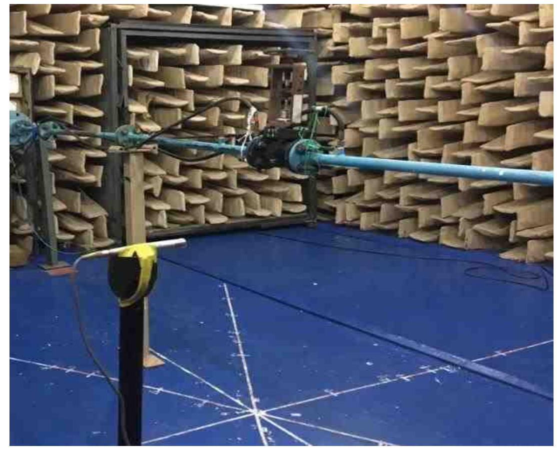

Fig.6 Test set up photograph

Fig.7 shows the graphical form of data and results for 100% opening of Trim 1 configuration. It is seen that the Noise level of 84dBA at the beginning gradually reduces to 82dBA towards the end due to the decrease in upstream pressure and there by the flow.

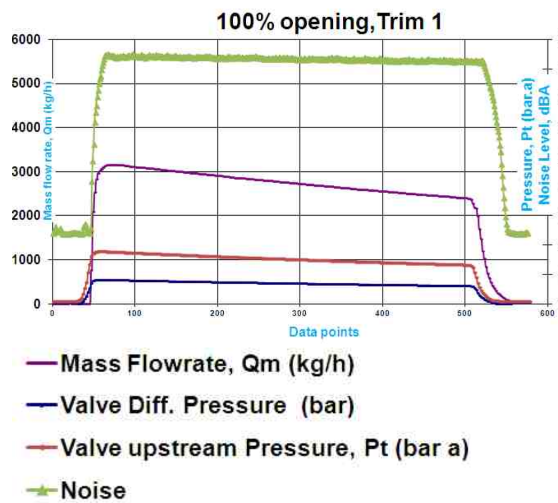

Fig.7 Noise Chart - Trim1

With the above data and design parameters noise estimation was done (for an upstream pressure of 18 bar and the downstream pressure of 10 bar, 100% opening) using the IEC prediction model. As per IEC standard the tolerance in the Predicted SPL is ± 5 dB. The actual measurement was within this tolerance limit as shown in Table 3.

Table 3 – Result

Predicted noise level as per IEC 534-8-3 (2010-11) (Overall)	82.2dBA
Measured Noise Level (Overall)	84.4dBA

1/3rd Octave band noise spectrum for both Predicted and measured result are shown in Fig 8. The band spectrum also shows that the peak frequencies of measured and predicted data are matching, which is in 8 kHz band.

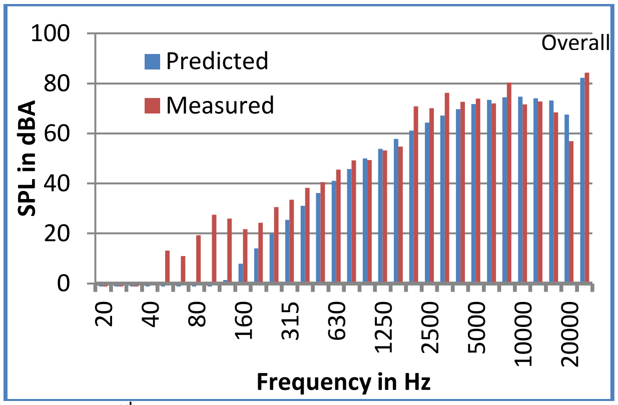

Fig.8 1/3rd Octave band noise spectrum

Fig.8 also shows the variation between prediction and measurement in different bands. This could be due to a few assumptions taken for prediction as they were confidential details/ designs with customer.

Design criteria for Trim2 and Trim3 had employed certain noise reduction techniques. Trim2 is a Perforated Plug - Single Stage, which is basically a multi path design and Trim3 is Perforated Plug & cage – which is a 2 stage multi path design. For Trim2 and Trim3, only measurement results are available as noise prediction could not be done due to unavailability of certain critical data. Below mentioned are some of those important Valve design parameters which will influence the predicted noise level and Peak frequency.

A	Area of a single flow passage
lw	Wetted perimeter of a single flow passage
A_η	Valve Correction factor for acoustical efficiency

The experimental results with 4 different valve openings and at 2 different upstream pressure conditions are given in Fig.9 to 11 for the three trims.

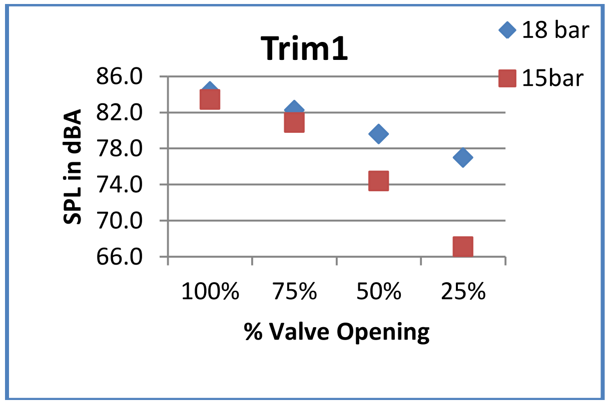

Fig.9 Trim1–Plot for different Valve openings

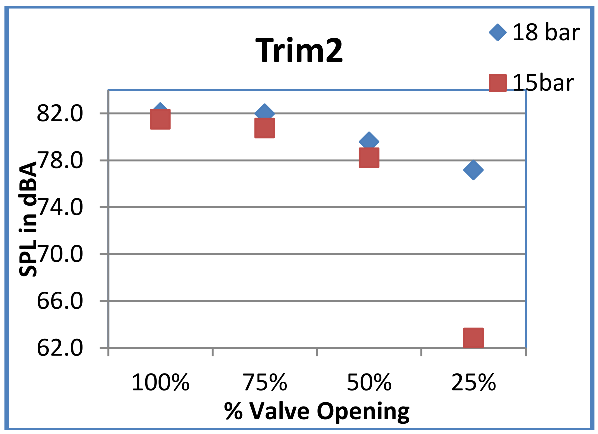

Fig.10 Trim 2 – Plot for different Valve openings

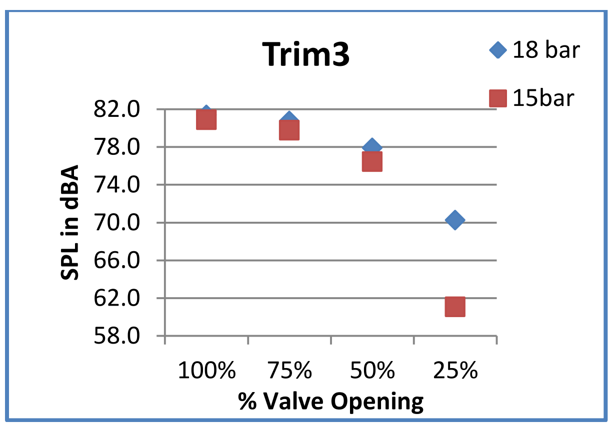

Fig.11 Trim3 – Plot for different Valve openings

A comparison of 3 different trim configurations at 100 % valve opening is plotted in Fig.12. The plot clearly shows the decrease in noise level with specially designed low noise trim configurations. Trim1 which is a conventional valve design has the highest noise level compared with other designs. Trim3 configuration has the lowest noise level as expected.

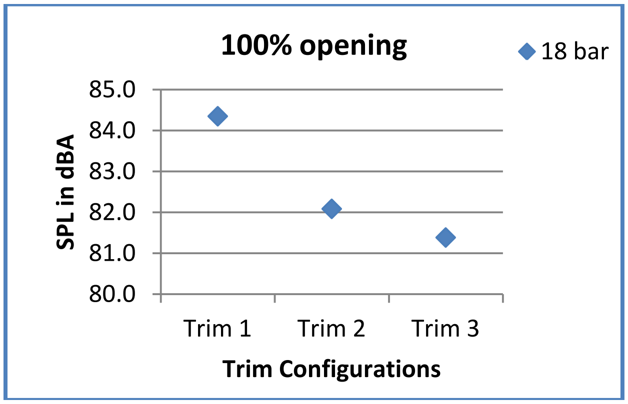

Fig.12 Comparison - 3 Trim Configurations

5.0 Conclusion

- The noise level predicted as per IEC 60534-3 and that measured are well within the limits of ±5 dB
- For best noise prediction of control valve with noise reducing trim configurations, accurate values of critical parameters referred in this paper need to be used by manufactures.
- An experimental facility is built as per IEC 60534-1 and validated.
- Noise prediction is always done for ideal conditions; hence for exact noise results a proper experimental validation is suggested.
- For any new valve design, manufactures have to validate the predicted results through experimentation to confirm the correctness of parameters used for design and prediction.

6.0 Acknowledgment

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