Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

A review on prediction models for the acoustic performance of pipe lagging

S Kanapathipillai (1) and M J Lacis (2)

(1) The university of New South Wales, Sydney, Australia
(2) The university of New South Wales, Sydney, Australia

PACS: 43.50 Gf

ABSTRACT

Pipe laggings are used as a means of inhibiting the transmission of sound radiated from pipes. They are usually formed of porous jackets of high flow resistivity and impervious sheets usually made from metals and plastics. The acoustic performance of a lagging system is usually quantified in terms of its frequency dependent insertion loss. Papers in the readily available literature relating to acoustic performance of pipe lagging are generally concerned with presenting experimental results with some prediction models. This paper looks at the merits of the available prediction models of insertion loss associated with the lagging of cylindrical pipes.

INTRODUCTION

Pipe noise is found to be a significant contributor in many industrial facilities. For instance, process and power generation plants use piping associated with oil and compressed gas pipelines, where the noise levels inside the pipe are high enough to result in a substantial transmission of noise through the pipe wall. While continuous improvements in noise attenuation have been used for other noise sources, pipe radiated noise remains one of the major source of noise in many situations. Hence it is of great importance to effectively attenuate the noise produced from gas filled pipes. The usual methods to attenuate the noise radiated from gas filled pipes is to either insulate the pipe on the inside using a porous material or to wrap the outside of the pipe with porous and impervious sheets.

While attempts have been made to theoretically predict the insertion loss associated with acoustically lagging pipes in the past, the majority of investigations have been experimental [1]. The current paper looks at a number of theoretical methods that have been developed in an attempt to predict this insertion loss.

Insertion loss is commonly defined as the change in the sound pressure level at an observation point due to the introduction of some item in the sound field that alters the sound field. The representation of the insertion loss can be seen in equation 1

$$IL = L_{p\,(\text{no lagging})} - L_{p\,(\text{lagged})} \tag{1}$$

where $L_{p\,(\text{no lagging})}$ is the sound pressure level (dB) at the reference point in the absence of any lagging, and $L_{p\,(\text{lagged})}$ is the sound pressure level (dB) at the observation point with some lagging in place. More simply the pipe insertion loss (IL) is a measure of the sound power radiated from an uninsulated pipe compared to the measured sound power once lagging has been applied.

Figure 1 is a representation of a simple lagged pipe. As shown in the figure the lagging is usually constructed of a number of types of jackets. These jackets are air space(s), porous jacket(s) and impervious jacket(s).

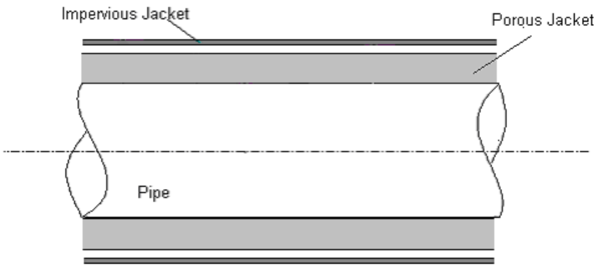

Figure 1: Representation of lagged pipe

PREDICTION METHODOLOGIES

McQueen [2] presented a simple prediction model for insertion loss produced by a simple pipe lagging formed of a porous jacket and an impervious sheet. His model was essentially theoretical and it demonstrated how the presence of lagging could influence the motion of the pipe. Results of the model were of little value because of its simplicity. Shultz [3] also came up with a simple anlatyical model. Results from this model show the insertion loss tends towards zero at low frequencies. This is not representative of the acoustic performance of a typical pipe lagging.

There are a few other prediction models available in the literature [4]. Hale presented a comparison of several theoretical noise reduction prediction methods for pipe lagging. It has been found that none of those methods can adequately predict the performance of pipe laggings. Generally they are based on the properties of the jacket in terms of ring frequency and critical frequency; even the curvature of the pipe or jacket was not included in some of these prediction methods. Further these theories fail to account for various modes of pipe vibration. Michelson et all [5] developed an empirical formula to predict the maximum achievable insertion loss of pipe laggings based on the curvature of the pipe but not on its vibration modes.

For the prediction of the insertion loss of pipe laggings two in depth analytical techniques have been considered in references [6] and [7]. Both these methods consider the characteristics of the lagging materials and use cylindrical coordinates to solve the acoustic wave equation. The resulting solutions involve complex mathematics involving Bessels and Neumanns functions.

Munjal [8] attempted to analytically predict the insertion loss of acoustic laggings using a matrix approach, with and without an impervious jacket, by making use of an impedance model developed on the basis of a transfer matrix approach and radiation impedance techniques. He derived a transfer matrix using the material properties of the lagging and used the radial velocities of the bare pipe along with the outer jacket lagging and combined the respective radiation impedances to calculate the insertion loss. He went on to create a computer program in Fortran that made use of the procedures developed for the prediction on insertion loss. He considered only the breathing mode of pipe vibration for the calculation of the insertion loss, although bending mode is considered to be the major contributor to the noise.

Kanapathipillai and Byne [6] developed a step-wise technique where the radial intensities are determined with and without the jackets. Once the intensities are found the insertion loss can be determined by taking the ratio of the sound intensity. The determination of the radial intensity, at the reference point, when no lagging is present is relatively straightforward. Computation of the radial intensity when a limited number of jackets surround the pipe is a little more complicated. They got around this by first determining the characteristic impedance at the outer most jacket. This value is the same as that calculated when no lagging is present. Once this value is determined the calculation of the radial impedance can be found on the inner side of the impervious jacket with an impervious jacket transfer formula. The process of determining the characteristic impedance on the inner side of a jacket once the impedance on the outer side of the jacket is known is used until the outer shell of the pipe is reached.

For the determination of the acoustic pressure, the technique used is the reverse of the technique used in the determination of the characteristic impedance. The acoustic pressure can be determined through use of the pressure relationship for a porous jacket [6]. The process of determining the pressure on the outer surface of a specific jacket, once the inner surface pressure is known, is used until the outer most jacket is reached.

The model incorporates that sound radiation from a pipe is possible only when the axial wave velocity of the structural waves of the pipe are supersonic and when the pipe is vibtrating in a particular mode, the waves in the surrounding jackets have the same axial wave number and frequency as those in the pipe.

The model was successfully validated by isolating the pipe from the skeletal structure of a porous jacket so that it was not forced to vibrate. Semi-empirical formulae of Delaney and Bazely [9] and Mechel [10] were used to quantify the propagation of sound through porous media, and the insertion loss was calculated. Their results indicated that negative insertion loss at low frequencies is possible as observed by others. They also explored the effect of having an air gap between the porous blanket and the pipe in their model and showed a reduction in negative insertion loss at low frequencies with experimental validation.

Based on references [6] and [7] Lacis [11] has done a parametric study and produced a number of plots which indicate that both increasing the mass and increasing thickness of lagging resulted in noise reduction in benefits. This result differed from some previous studies that suggested mass was the only attributer to noise reduction.This study concluded that differering pipe sizes could have differing optimal lagging construction.

COMPARISON OF RESULTS

Stevens [1] categorises the prediction methodologies into: simple analytical, semi empirical and rigorous analytical and presented insertion loss plots for each category. He considers a lagging system with a single porous layer (50mm thick fibreglass with a flow resistivity of 10000 Rayl/m) and a single impervious outer jacket (0.254 mm aluminium) applied to a 304.8 mm diameter pipe). He compares the predicted results with experimental values by Loney [12].

The results of the simple analytical prediction model look closer to the experimental values at higher frequencies. However, the validity of the prediction model with simplistic approach will not yield any useful results at low frequencies. The plots presented for the semi-empirical model indicate a poor correlationship with the experimental values and do not provide any useful trend or outcome. These two prediction methods lack consideration of very vital parameters such as pipe diameter and modes of pipe vibration and hence these prediction methods are not reliable.

Figures 2 and 3 indicate the insertion lossess predicted using rigorous analytical methods of Munjal and Kanapathipillai & Byrne along with experimental results of Loney.

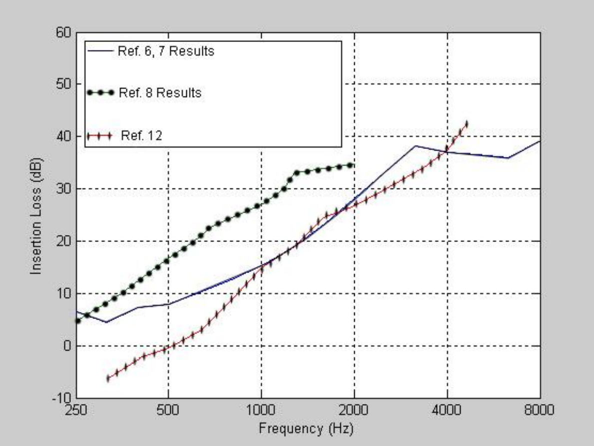

Figure 2: Experimentally Observed Values of Insertion Loss Obtained from Ref [12] (cf. Fig. 2), Plotted against Ref [8] (cf. Fig. 3), and ref [6]. Porous Jacket 2-inches (50.8 mm) Thick and Aluminium Jacket 0.254 mm thick.

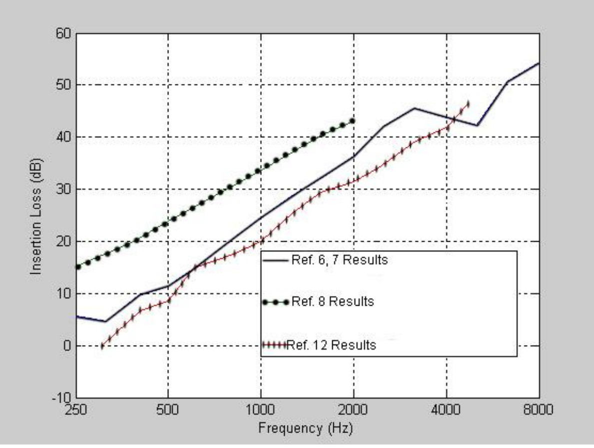

Figure 3: Experimentally Observed Values of Insertion Loss Obtained fromReference [12] (cf. Fig. 2), Plotted against Ref [8] (cf. Fig. 3), and ref [6]. Porous Jacket 4-inches (101.6 mm) Thick and Aluminium Jacket 0.254 mm thick.

While neither Munjal's techniques nor Kanapathipillai and Byrne techniques show complete accuracy to the experimental results presented in Loney[12], the method produced by Kanapathipillai and Byrne shows significant agreement, particularly in the mid frequency range. Possibly the reason for the improved accuracy of the step-wise procedure compared to the matrix prediction method could be due to the inclusion of all the main modes of pipe vibration that result in audible radiation, reference [7]. If reference [8] were to consider the bending and ovalling modes of pipe vibration it would be likely to improve the agreement with Loney's experimental results. It is to be noted that the insertion loss values shown for Munjal's method is limited to 2000 Hz. The step-wise mehod of reference [6] could be improved further if more modes of vibration are considered.

CONCLUSION

The research in insertion loss produced by pipe lagging has been carried by various researchers for the past four decades. The earliest papers presented simplistic analytic models, which did not yield useful results as vital parameters such as modes of pipe vibration, curvature of pipes etc were not taken into consideration. Then there were semi-empiric models were suggested. They were also not that useful. Following these models two rigorous analytical models [6] and [8] were available. Overall neither method predicted the insertion loss associated with pipe lagging with complete accuracy. The step-wise method of reference [6] predicted better than the other. The method of reference [8] could be improved through the inclusion of more than just the breathing mode of vibration. Both methods can be further improved by considering the effect from the pipe surface contact with the porous jacket layer. The contact of the porous layer with the vibrating pipe changes the mechanical properties of the system. This porous jacket vibrates and transmits some energy through to the impervious lagging.

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