Digital correction of pressure signals for vinyl tubing distortions

Daniel Lander[1], Julien Berthaut[2], Steve Cochard[1]

[1]*School of Civil Engineering, The University of Sydney, Sydney, Australia*, dclander@gmail.com
[2]*Centre Scientifique et Technique du Bâtiment, Nantes, France*

1 INTRODUCTION

Pressure sensing transducers quantify wind loads on the envelop of scale models prepared for wind tunnel testing. Ideally, these would be placed directly on the models, however, due to size constraints and need for dense spatially distributed data, this is seldom possible. The transducers are typically placed outside the model and the pressure signals are transmitted though PVC tubing. The tubes introduce frequency distortions associated to their geometric properties. As a result, the pressure signals recorded by the transducers are not that experienced by the model.

The magnitude and phase of the distortions are predictable and two methods exist to obtain a corrected signal. The first, an in-line mechanical low pass filter or 'restrictor' is coupled to the tube and attenuates low frequency resonance. The second method computes, by convolution, the true signal, after acquisition, from the recorded signal and the known properties of the tubes. The second method has become the industry norm and is often referred to as the transfer function or frequency response method.

Implementing the frequency response method is less than straightforward as many variables contribute to the misrepresentation at the transducers. Furthermore, as this type of measurement technique is plagued by the need for extreme precision at the model scale, there must be a robust and transparent treatment of the tubing effect for all variables of concern.

Several authors ([2], [3]) presented comprehensive assessments of such corrections. This paper offers a practical examination of a number of variables contributing toward measurement errors made by inadequate treatment of tubing distortions.

2 THE FREQUENCY RESPONSE

The frequency response of a system is the ratio of its Fourier output to input coefficients. The frequency response describes the signal distortion induced by the tube and gives the parameters needed to retrieve the original signal. PVC tube response functions are characterised by amplification in low frequencies and attenuation of high frequencies. In a wind tunnel study, a large range of frequencies is required to interpret the forces in full scale, so it is important to have an accurate representation of the exact tubing system used.

The theoretical model developed by Bergh and Tijdeman [1] allows frequency response functions to be computed for different tube length, diameter and transducer volume. The frequency response can alternatively be retrieved by spectral analysis.

2.1 Theoretical Model

The Bergh and Tijdeman model produces theoretical frequency response functions dependent on the geomtectic properties of the tube and sensor arrangement. *Fig. 1* shows both the magnitude and phase of the frquency responses for 1.37 mm-external-diameter tube, for lengthes of 1.5m, 1.6m and 1.7 m, with a 13 mm^3 transducer volume.

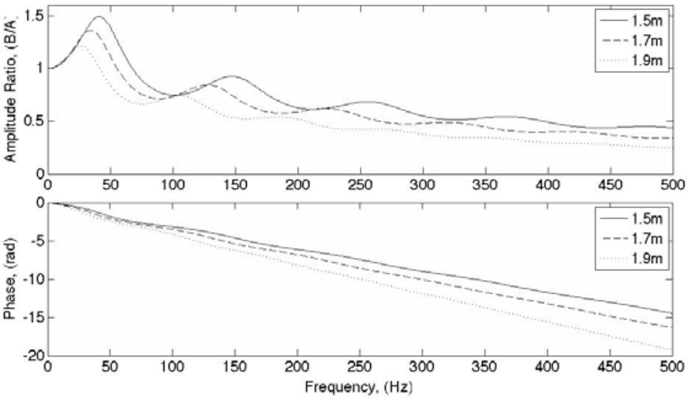

Fig. 1 - Frequency response functions for different lengths of tube

2.2 Measuring the frequency response

To quantify the error, a comparison was performed between the pressure signal recorded and the original signal generated.

2.2.1 Measurement Apparatus

The coefficients of the frequency response function were obtained using a HP-35665A dynamic signal analyser. The analyser produced 20 kHz white noise into a Bouyer ZR 409c acoustic loudspeaker. The signal was amplified by a JBL 6260 power amplifier into a small coupling cavity, open on one end to the diaphragm of the reference Setra 237 transducer. 32 channel Pressure Sensor Incorporated (PSI) transducers were used to measure both the raw and the distorted signals. Each transducer was connected to the coupling cavity via a pressure tap on the side and had a pressure range of 2.5 kPa with a static accuracy of ±0.03%.

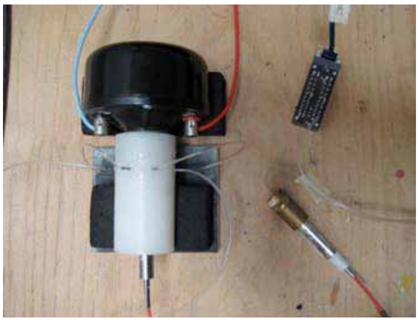

Fig. 2 - Measurement apparatus

The frequency response of both signals were recorded and analysed by the HP-35665A. To generate an idealised average of the response the spectral analyser used a hanning window with 60 % overlap. This method enabled specific variables of tubing systems to be examined independently.

2.2.2 Variables of examination

To ensure the robustness of the correction the different effects of typical variables of wind tunnel models needed to be quantified. Typical models are often require more complicated tubing systems than allowed for in the theoretical model. Of primary concern was the use of fixed brass tubes of smaller diameter attached to the model end of the system. These are often built into the model to facilitate the pressure measurement at difficult locations (e.g., corners and edges). These tubes frequently contain bends to reach the position on the envelope and can be up to 300 mm in length.

The effect of the length of PVC tube should also be examined. It is desirable to quantify the effect of making a correction for differences between nominal and actual tube length. As it is often difficult to cut tubes exactly to nominated length, this analysis is valuable.

Furthermore, as there is a growing need to study higher modes of failure, implying higher acquisition frequencies, the effect of sampling frequency will also be examined. Using the transducer on only channel 1 frees any sampling limitations and allows the examination of errors.

3 RESULTS & IMPLEMENTION

3.1 Quantitative results

The error is calculated as the average absolute distance between the points of the reference signal and the corrected signal. This is presented as a percentage error with reference to 6 standard deviations of reference signal, as the random noise has a Gaussian distribution containing over 99% of the signal within this range.

3.1.1 Brass tubes

The brass tubes caused large attenuation of the signal across the entire frequency range. The attenuation increased as the brass tube length increased. It was found that for a 1.5 m PVC tube, additional brass tubes above 100 mm caused signal dampening beyond recoverable levels and that all signals above 200 Hz became lost could not be recovered. ***Fig. 3*** presents the measured frequency response functions for 1.5 m-long tube systems with additional brass connections. The large amount of dampening is evident.

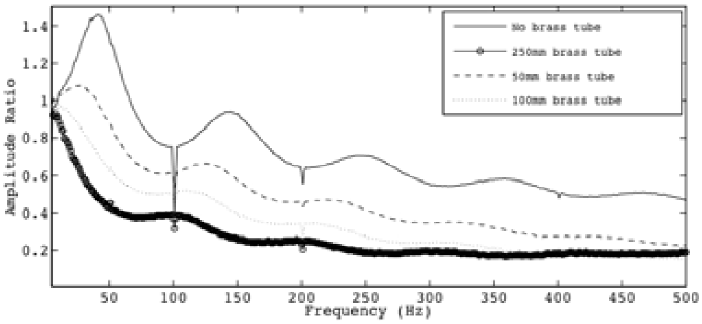

Fig. 3 - Effect of brass tube on frequency response of long tube systems

Even if more detail investigations need to be carried on for brass tubes in the range of 20 mm to 100 mm, for situations where such tube are unavoidable, this paper suggests that they should be replaced with PVC tubes or kept to a strict minimum.

3.1.2 Bend in brass tube

Preliminary investigations showed that, for brass tubes bent with sufficiently large radius, error could be negligible assuming short brass tube are used. Understanding the error introduced in such circumstances is indispensable to improve the model construction.

3.1.3 Effect of Tube length

Fig. 4 highlight the effect of using an incorrect nominal tube length to correct a tubing distortion. The correction is made to a signal recorded with a 1.50m tube with frequency response functions that correspond to different tube configurations.

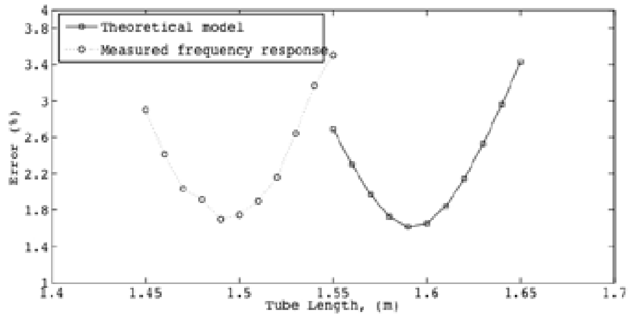

Fig. 4 - Error minimization for differences in nominal and actual tube length

It highlights a number of important facts. For the measured frequency response, the error is minimised by using the correct response function. The error introduced by using an incorrect response function increases rapidly. Furthermore, comparing the theory to the measured correction shows that there is an effective length for the theoretical model, which minimises the error equivalently to the measured correction. Although this corresponds to a nominal length of 1.59m, it has the equivalent effect.

3.1.4 Maximum sampling frequency

Comparing both an optimised Bergh and Tijdeman model transfer function and a measured transfer function from the HP-35665A, it was found that the error increased as a function of sampling frequency. The error remained below 5% for sampling frequencies up to 1 kHz, and grew to 15% when increased to 2.5 kHz. Comparing the results between the error using the measured frequency response function and the Bergh and Tijdeman model found that when the Bergh and Tijdeman model was iteratively tuned to find the best parameters for that tubing system, the error was very similar between the two methods.

3.2 Implementation

As it is quite common for wind engineering studies to contain up to 1000 pressure transducer channels, sampling at 1 kHz or higher, it is important to have a seamless and robust implementation method to correct the recorded signals. Limiting differing tubing systems to a manageable number helps minimise the calculation cost of determining the optimal transfer function to use on each channel. It is suggested that the Bergh and Tijdeman model be used, as long as an opportunity exists to compare the distorted signal to a clean signal for each tube system, assuming the sensor volume is similar on each channel.

4 CONCLUSION

- Brass tubes should be replaced with PVC tubes where possible to minimise excessive dampening and amplification of noise during the correction procedure.
- A system to ensure consistency of tube lengths should be implemented.
- The theoretical model can be iteratively tuned to find the optimal parameters.
- The maximum sampling frequency obtainable within 5% error bounds was 1 kHz.

5 REFERENCES

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