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TUBING NETWORKS FOR FULL-SCALE PRESSURE MEASUREMENTS

C.W. LETCHFORD

Department of Civil Engineering
University of Queensland, St. Lucia, Qld. 4067
AUSTRALIA

ABSTRACT

This paper describes the dynamic calibration of tubing networks that may be used for full-scale pressure measurements. The frequency response of single, restrictor and manifold tubing networks linked to a Validyne DP104 pressure transducer have been measured experimentally using the UK Building Research Establishment pressure controller as the source of fluctuating pressures. The tubing was approximately 6mm bore and lengths up to 35m were tested.

The experimental frequency response results were found to be in very good agreement with the predictions of the theoretical analysis presented by Gumley. The conclusion of this paper is that full-scale tubing networks may be designed using the Gumley analysis.

INTRODUCTION

In the past, full-scale pressure measurements on buildings were obtained using surface mounted pressure transducers, eg., the Aylesbury experiments reported by Eaton and Mayne(1975). However, it is becoming more common to remotely mount the transducers and use pvc tubing to link the surface pressure tappings to the transducer. Recent examples of this approach are the greenhouse and dutch barn studies by Hoxey and Richardson(1984) and Robertson et al(1985). The main advantage of this approach is that the sensitive transducer can be located in a controlled environment away from rain and sunlight. This approach is the same as that commonly used in wind tunnel model studies and, as in that usage, it is essential that the surface pressure fluctuations are not distorted significantly during their passage through the long lengths of tubing.

Tubing networks of interest are single tubes for point pressure measurements and manifolded tubing networks for area-averaged pressure measurements. Gumley(1981) developed from the earlier work of Bergh and Tijdeman(1965) the theoretical description of the frequency response of such tubing networks. Experimental verification of the theory for model-scale tubing has been largely successful, eg. Holmes et al(1987) and Letchford(1987). However, there appears to have been no direct verification of the theory for tubing networks that might be employed for full-scale pressure measurements.

REVIEW OF PREVIOUS WORK

The dynamic response of long tubes (15-30m) was investigated experimentally by Hoxey(1973). Simple long tubes were found to resonate at frequencies of interest and Hoxey proposed the use of pneumatic filters or restrictors to achieve better frequency response. The response of these restrictor networks was predicted using a simple theory which relied on the experimental determination of attenuation constants.

Manifold networks to obtain area-averaged surface pressures do not appear to have been widely used in full-scale pressure measurement studies and where they have been used it has been for the measurement of mean pressure only. This is with the exception of the work of Holley and Banister(1975) who attempted unsteady area-averaged pressure measurements on a full-scale building. The dynamic response of their manifold network was obtained experimentally in the absence of any theory to predict the response.

Waldeck(1986) recently applied the theory of Bergh and Tijdeman to investigate the problem of spurious fluctuations in tubing networks used to convey a reference pressure to surface mounted transducers employed in full-scale experiments. This problem was identified by Lam(1981) who used transducers which had large diaphragm deflections. Waldeck was able to quantify the measurement error in one transducer, due to fluctuations in the reference pressure network caused by large displacements of the diaphragms of other transducers attached to the same reference pressure network. However, he did not attempt a full verification of Gumley's analysis.

The objective of the present investigation was to extend the validity of Gumley's analysis to include full-scale pressure measurement systems. The successful application of Gumley's analysis to both restrictor and manifold networks would then allow the frequency response of these full-scale pressure measurement systems to be optimized.

THEORETICAL MODEL

The derivation of the theory of the dynamic response of pressure measurement systems is lengthy and is described in detail by Bergh and Tijdeman(1965) and Gumley(1981). General recursion formulae are derived from solution of the Navier-Stokes, Continuity, Energy and State equations. The following assumptions are made in the analysis;

(a) the sinusoidal disturbances in pressure, density, temperature and velocity are small compared to mean values
(b) the diameter to length ratios are small so that end effects are neglected
(c) the Reynolds numbers are low so that flow is laminar
(d) the thermal conductivity of the tube walls is large
(e) the tube walls are rigid
(f) the cross flow velocity across the tube entrance is small
(g) the pressure and density are uniform in volume elements
(h) pressure expansions are polytropic
(i) in manifold networks the presence of a steady laminar flow does not affect the dynamic response.

The above assumptions can normally be satisfied for pressure measurement systems used in wind engineering, both at model-scale and at full-scale.

The theoretical analysis requires as input, the geometric parameters of the tubing network as well as the mean operating temperature and pressure of the measurement system. The geometric parameters are the tube diameters and lengths and the transducer volume and diaphragm flexibility. A computer programme developed by Gumley(1981) has been used to predict the theoretical frequency response of the tubing networks tested.

EXPERIMENTAL TECHNIQUE

The dynamic responses of a variety of tubing networks were obtained experimentally by generating a fluctuating pressure signal in a coupling cavity to which the tubing network under test and a reference transducer were connected (Figure 1). The output signals of reference transducer and network under test were monitored and the dynamic response obtained from the transfer function of the two signals.

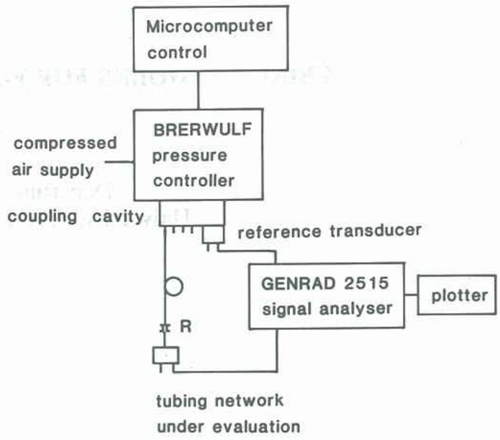

Figure 1. Schematic arrangement of calibration apparatus.

The pressure controller BRERWULF of the UK Building Research Establishment, described by Cook et al(1987) was used as the source of fluctuating pressure. A signal with mean of -300Pa, standard deviation of 180Pa and with a frequency content of up to 10 Hz was generated by the device in the coupling cavity.

Validyne DP104 pressure transducers were used for both reference and test systems and typify transducers currently employed in full-scale pressure measurement studies. The natural frequency of the transducer is 1000Hz, which is well above the range of wind pressure fluctuations. Static calibration of the two transducers was carried out periodically to ensure linearity over the test pressure range and to monitor any calibration drift due to temperature changes.

A GENRAD 2515 Spectrum Analyser employing conventional Fast Fourier Transform techniques was used to analyse the outputs of the two transducers and produce the transfer function directly in the form of amplitude and phase versus frequency graphs. Frequency smoothing was applied by averaging 50 transfer function estimates each containing 80 data points.

All tests were carried out in stable atmospheric conditions varying little from the temperature of 15^{o}C and barometric pressure of 101.3kPa which were assumed in the theoretical calculations.

Measurement of geometric parameters

The most important geometric parameters of the analysis are the tube internal diameters and the transducer volume and diaphragm flexibility. The internal diameter of the tubing was determined indirectly from the volume of water required to fill a known length of tube. For the pvc tube used here the diameter was found to be 5.90mm.

The volume of the Validyne DP104 transducer was estimated, from measurements of the cavity enclosing the diaphragm, to lie between 1130 and 1250mm^3. A value of 1200mm^3 was assumed for the calculations. Diaphragm flexibility for the transducers was measured using a technique described by Holmes and Lewis(1987) in which for a known applied pressure the volume of air displaced by the transducer's diaphragm is measured. Figure 2 shows the results of diaphragm deflection and a value of 2.3 was obtained for the dimensionless diaphragm deflection coefficient (= diaphragm flexibility x mean operating pressure/ transducer volume). In this case the mean operating pressure is atmospheric pressure.

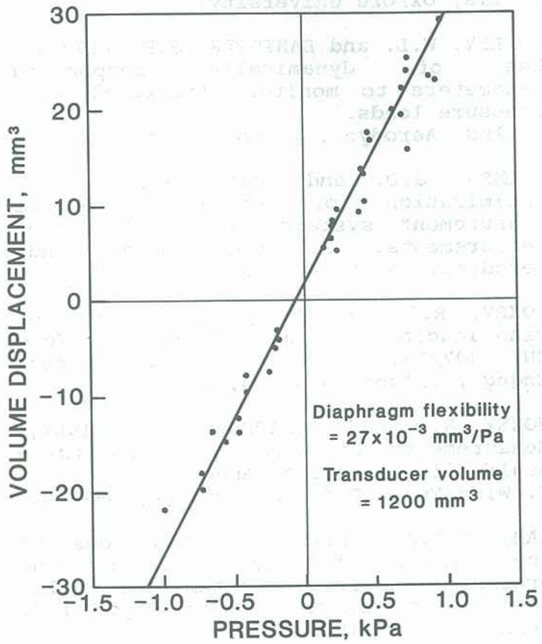

Figure 2. Diaphragm flexibility for Validyne DP104 pressure transducer.

RESULTS

Single tube networks

The single diameter tube terminating in a volume incorporating a transducer is the simplest arrangement for a pressure measurement system. The dynamic response of such a simple network with a tube length of 20m is shown in Figure 3. It is seen that the theoretical and experimental frequency response for both amplitude and phase are in good agreement. Similar agreement was obtained for tube lengths ranging from 10m to 35m. The peak in the amplitude transfer function is the feature of these single tube networks which renders them inadequate for pressure measurement systems.

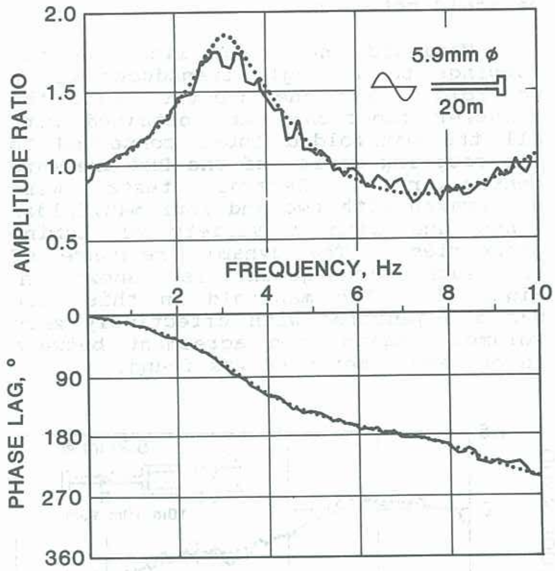

Figure 3. Frequency response for single tube system. (··········, theory), (———, experiment)

Restrictor networks

Restrictors are short narrow bore tubes which dampen the resonant frequency of the single tube networks and thus produce a more amenable frequency response. Such devices were first advocated by Hoxey in 1973. The restrictor used in the present tests was 150mm long with a bore of 1.53mm. A variety of tube geometries incorporating the restrictor were tested and Figure 4 presents the comparison between theory and experiment for one such case. Again good agreement was found with the resonant peak of the single tube networks now being fully damped.

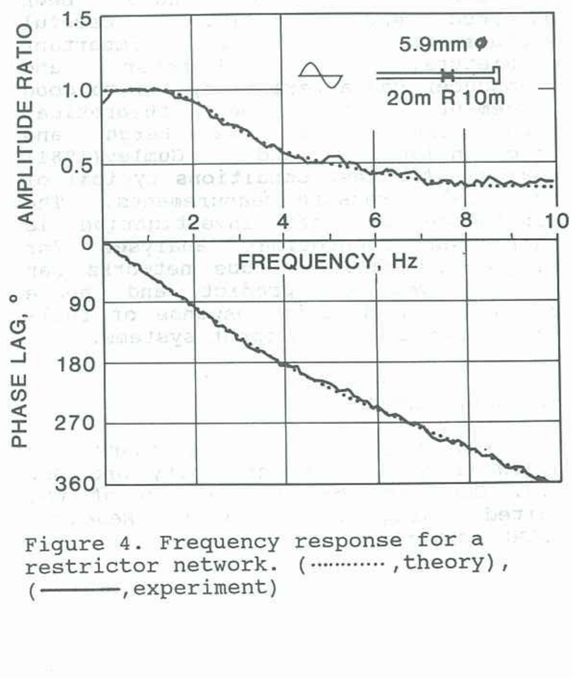

Figure 4. Frequency response for a restrictor network. (··········, theory), (———, experiment)

Manifold networks

Manifold networks link several tappings to a single transducer via a manifold. For the present tests the transfer functions were obtained with all the manifolded tubes connected to the coupling cavity of the BRE pressure controller. Several tests were undertaken with two and four manifolded tubes and with a variety of tubing geometries. The dynamic response of one such arrangement is shown in Figure 5. The manifold in this case was a T-junction with effectively zero volume. Again good agreement between theory and experiment was found.

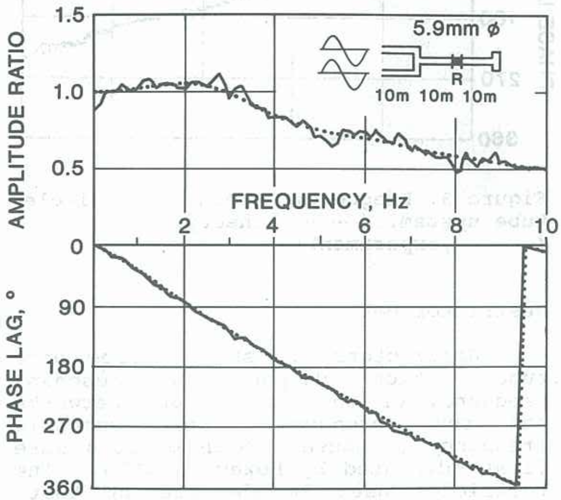

Figure 5. Frequency response for a manifold network. (··········, theory), (———, experiment)

CONCLUSION

The dynamic response of a variety of tubing networks for full-scale pressure measurements have been obtained experimentally. Careful measurement of the important parameters, tube diameter and transducer characteristics, led to good agreement with the theoretical predictions of the Bergh and Tijdeman(1965) and Gumley(1981) analyses for test conditions typical of full-scale pressure measurements. The conclusion of this investigation is that the theoretical analyses for single and manifold tube networks can be employed to predict and hence optimize the dynamic response of full-scale pressure measurement systems.

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