A DYNAMIC CALIBRATION RIG FOR PRESSURE TUBING AND TRANSDUCERS

R E Lewis[1] and J D Holmes[2]

Introduction

The fundamental purpose of the calibration equipment is to obtain the correction factors required to convert the fluctuating pressure signal measured at the remote end of a pneumatic transmission line to the true pressure existing at the source, and to devise systems with an amplitude response as close to unity as possible over the desired frequency range, with a linear phase response. A pressure measurement system of inadequate frequency response can lead to significant errors in the measurement of peak pressure on building models [1].

The calibrating system to be described was evolved to accommodate the various tube and transducer combinations required.

Method

Sinusoidal fluctuating pressures (adjustable from DC to above 600 Hz) are induced in a coupling cavity in which is a flush mounted reference transducer. Pressure in the cavity is coupled to a receiving transducer via a tube connected to a pressure tap in the cavity face opposite the transducer. Measurements of amplitude and phase of the signal from the cavity-mounted reference transducer and from the transducer under test are made and compared at discrete frequencies over the above mentioned frequency range. The reference and test transducer are alternately switched to the measuring system, consisting of a Low Pass Filter/ Amplifier, Cathode Ray Oscilloscope (CRO) and Digital Voltmeter (DVM). The layout of the calibration rig is shown in Figure 1.

Electro-Pneumatic Function Generator

A Tritec Model AT31 function generator is used to produce the range of static and alternating pressures required.

The generator operates by varying the air-bleed from a tube conveying air pressure to the coupling cavity. The variation is produced by a centrally-pivotted armature, whose position is controlled by current from an appropriate AC signal generator (2 to 10 volt at 200 Ω). The Tritec provides a second air output and bleed-tube, branched from the input supply, where the modulation is affected by the other end of the armature and thus provides an output in anti-phase to the first.

Although this generating system has been found to be very useful, there are a number of limitations as follows:

(a) The alternating pressure is carried on a pressure pedestal - the DC or static pressure.

(b) Acoustic noise, generated at the sharp edges of the bleed tubes by the escaping air, is transmitted to the coupling cavity. Typical noise figures (0 to 1000 Hz) are shown in Table 1.

[1,2] CSIRO Division of Building Research, Melbourne, Australia.

TABLE 1

Transducer	RMS Output MV		RMS Noise, 1K Hz L.P. filter		
	No air	Static 250 Pa	1 Hz	100 Hz	200 Hz
Setra 237 System gain x 10	2-3	18-19	-44 dB	-34 dB	-34 dB
Honeywell 163 System gain x 18	9-12	16-22	-42 dB	-32 dB	-30 dB

(c) Although the differential output between the two air tubes appears sinusoidal when the armature is driven by a sinusoidal voltage signal (transducer input port to one, reference port to the other) the air pressure output from both air tubes is non-sinusoidal at frequencies below 40 Hz. At the static pressures used in our calibration procedures, the signal 'bottoms' due to the relative impedances of 'source' and 'sink' (supply and escape). The distortion at these frequencies is totally transmitted along any practical pneumatic transmission line to the receiving transducer.

(d) The output of the Tritec generator is dependent upon the total load placed across its output(s). The supply impedance at the Output 1/Output 2 branch is sufficiently low so as to ensure an almost constant output pressure (both static and alternating) at one outlet, whether the other is closed or open. Thus, the second output can be connected by a long narrow tube (effective short-circuit to alternating signals) to a U-tube manometer for visual monitoring of the static pressure.

The Coupling Cavity

In [2], a calibration system using a similar electro-pneumatic function generator feeding a small reference or coupling cavity, is described. Our cavity is of similar dimensions, viz. 12.5 mm I.D. (to suit a Setra Model 237 reference transducer flush-mounted on one face of the cavity) with a basic 2.0 mm length and spacers so that the volume can be increased to 1.25, 1.5, 2.0, 25 and 50 times the original volume.

Three pressure taps are provided on the cavity: one to take the input supply pressure fluctuations, one to which the tubing system under test is connected, and a third to which a tuning tube of closed end is attached. To obtain maximum alternating pressure from the electro-pneumatic generator, the total volume to be supplied should be kept to a minimum and the shortest practical input connection tube is used (< 100 mm x 1.5 mm I.D. nominal).

The tuning tube of 1.5 mmϕ flexible PVC tubing, adjustable in length from 20 mm to 450 mm, is very effective in:

(a) Removing harmonics from the cavity, and
(b) Maximizing the peak-to-peak pressures.

It has its greatest effect with the smaller volumes (larger volumes have fewer harmonics). When closed at an appropriate length, it can produce a four-fold increase in the alternating amplitude.

Although the geometry of the coupling cavity will influence the pressure and waveform within the cavity, the measured transfer function of a tube is not changed, provided:

(a) The waveform is transmitted to the receiving transducer, or
(b) A true RMS meter is used to measure the output from both input and output transducers.

Air Supply

The reticulated compressed air supply of the laboratory comes in at about 600 kPa pressure. It is first oil, water and particle-filtered, and then reduced in pressure in two stages to about 750 Pa. After passing through an accumulator or buffer tank, the pressure available in the cavity remains within one per cent over any one day and within two per cent for weeks on end. This includes constancy of regulator setting, Tritec armature static position, mean dynamic position, and the peak-to-peak alternating pressures available when repeating measurements to 600 Hz using the same settings of the electrical sinusoidal driving generator.

Pre-Amplifier and Filter/Amplifer

The majority of pressure transducers we encounter have either inbuilt signal processing or external processing tailored for that transducer. The pre-amplifer/level shift block shown in Figure 1 provides adjustable gain and level shift to bring the output of our most commonly used measuring transducers in line with reference Setra 237s used elsewhere in our work.

The filter/amplifier is a switched LP filter (50,100,200,350,500,1000 Hz) with switched gains of x 1.0, x 2.0, x 10 and x 100. The adjustable LP filter can be used to modify the output to assist in eliminating a resonant peak.

It is important to note here that the transfer function of a particular tube or tube/restrictor combination (where the restrictor limits the acoustic resonance in the tube) is dependent upon the volume (input impedance) of the transducer. The calibration apparatus provides a transfer function for the tube/transducer (and filter) combination, not just the connecting tubing.

Output Processing

As explained under 'Method', each output is measured in turn. The DVM is a Solartron Time Domain Analyser Type JM 1860 measuring true mean and r.m.s. voltages.

A Prosser Scientific Instruments PSI 4001 digital phase-meter was used to measure, in turn, the phase of each output with reference to a quadrature voltage signal from the AC signal generator providing the driving current to the Tritec generator.

Phase difference, $\Delta\phi$, becomes

$$\Delta\phi = (\phi \text{ Reference transducer} - \phi \text{ reference}) - (\phi \text{ test transducer} - \phi \text{ reference})$$

The alternating pressure in the coupling cavity is delayed in reaching the remote transducer by the transmission time of the line. $\Delta\phi$ in the above expression would be negative, thus indicating a phase lag.

The reference phase signal and the output from the transducer being measured are simultaneously viewed on the CRO. The presence of a constant, harmonic free, reference signal is useful in determining whether grossly distorted pressure signals are reaching the output of either transducer.

Results

Figures 2 and 3 illustrate typical amplitude/phase responses of tube-transducer combinations. These figures illustrate the improvement gained by inserting a fine diameter restrictor in the tubing at an appropriate position. The peak in the amplitude response is completely eliminated, and the inflexion on the phase response curve is straightened out to become nearly linear.

The apparent phase 'lead' in the unrestricted tube up to 370 Hz (Figure 3) is due to a phase lag in the Setra 237 reference transducer. Although the phase response curve can be corrected for this effect, in recent calibrations we have replaced the Setra with a Bruel and Kjaer microphone, which has good amplitude and phase response above about 40 Hz, as a reference transducer measuring the coupling cavity pressure.

The figures also indicate the effect of increasing the volume of the coupling cavity by a factor of nearly 25 by screwing in an extension tube. No significant change to either the amplitude or phase response characteristics results.

Conclusion

A manually operated calibration system for tube/transducer amplitude and phase transfer function has been described. Although the equipment has been used mainly for the calibration of tubing systems, both single tube and parallel input manifold systems, it has also been used for fundamental studies of:

(a) Varying volume in the test transducer mounting,
(b) Flexibility effects in transmission tubing (e.g. steel v. PVC),
(c) Diameter/tube length effect,
(d) Location of single restrictor v. locations and spacing of split restrictor (equal bore/length, different bore/length).
(e) Comparison with the theoretical models of tubing response of Bergh and Tidjeman [3] and Gumley [4].

These studies are incomplete at present and will be published at a later date.

Acknowledgement

The authors are indebted to the workmanship of the machine shop for the manufacture of various cavities and to the electronics group for the five channel filter/amplifier.

Reference

1. J.D. Holmes, 'Effect of Frequency Response on Peak Pressure Measurements', J. Wind Engg & Ind. Aerodyn., 1984 (in press).

2. H.P.A.H. Irwin, K.R. Cooper, and R. Girard, 'Correction of Distortion Effects Caused by Tubing Systems in Measurements of Fluctuating Pressures', J. Indust. Aerodyn., 5, pp.93-107, 1979.

3. H. Bergh and H. Tijdeman, 'Theoretical and Experimental Results for the Dynamic Response of Pressure Measuring Systems', National Aerospace Laboratory (Netherlands) Rep. NLR-TR F238, 1965.

4. S.J. Gumley, 'Tubing Systems for Pneumatic Averaging of Fluctuating Pressures', J. Wind Engg & Ind. Aerodyn., 12, pp.189-228, 1983.

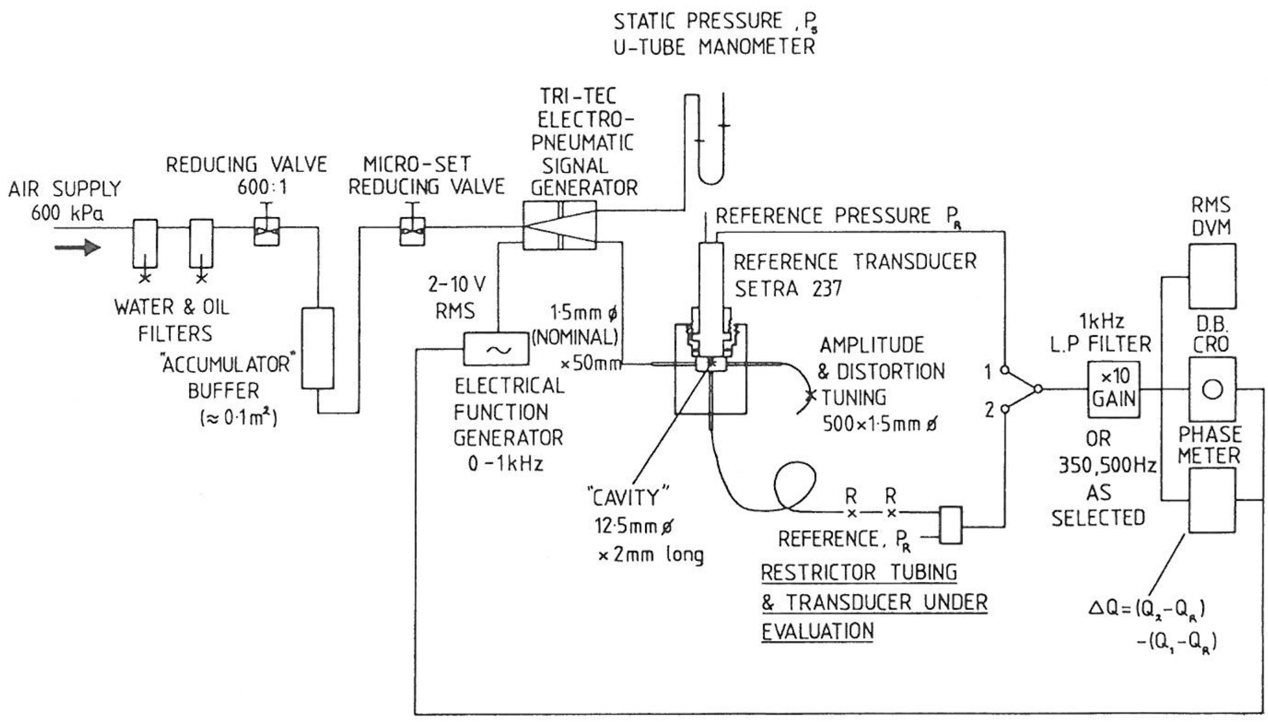

Figure 1 Layout of dynamic calibration system

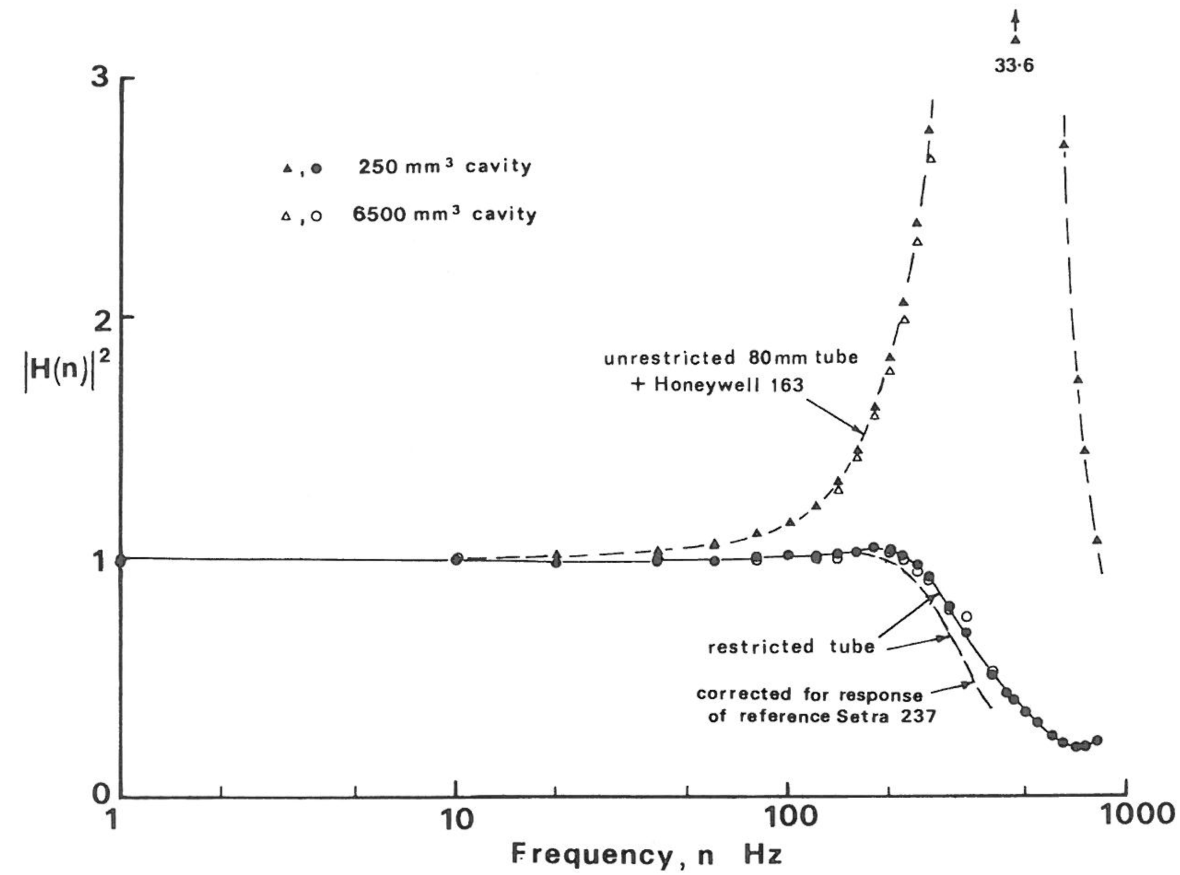

Figure 2 Typical amplitude response curves

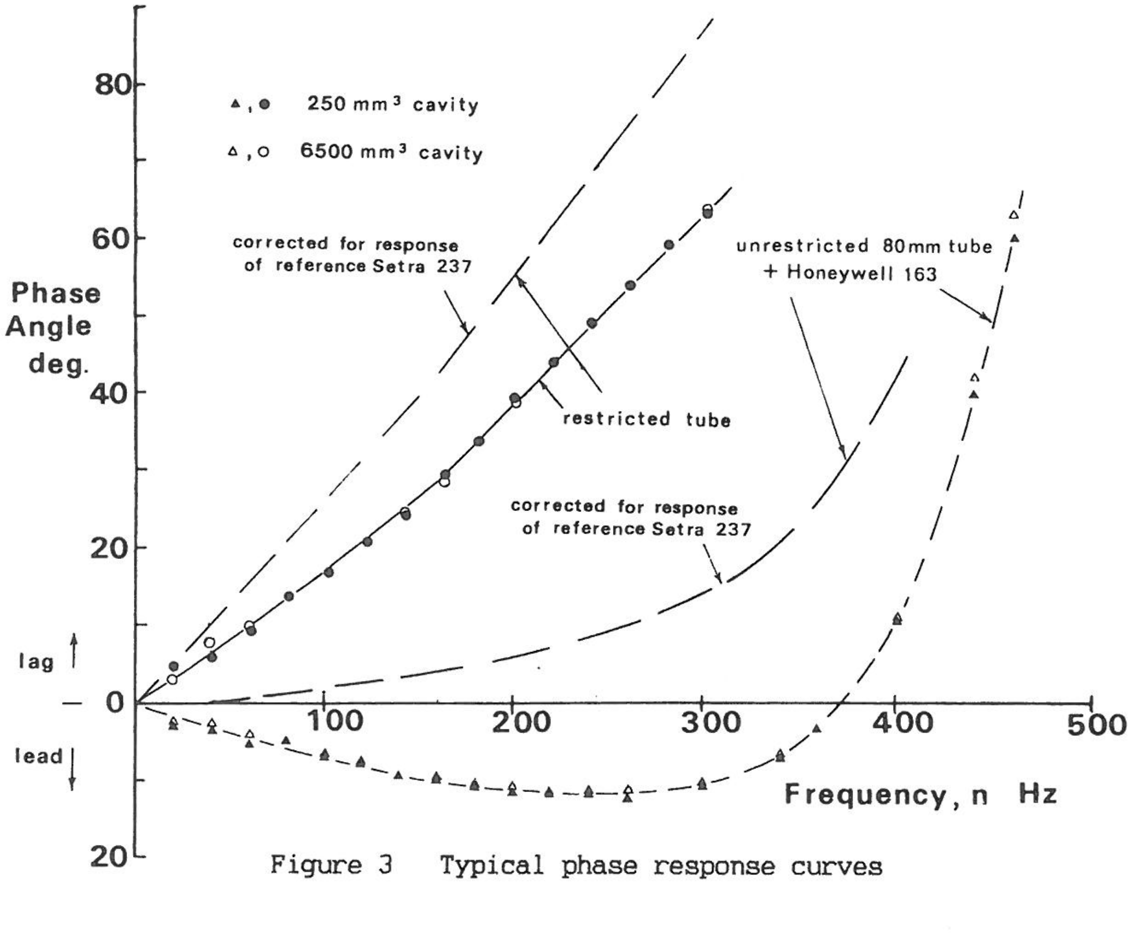

Figure 3 Typical phase response curves