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MEASUREMENT OF ACOUSTIC TRANSMISSION PROPERTIES OF A U-TUBE HEAT EXCHANGER

D.McLaughlin

YARD LTD
Charing Cross Tower, Charing Cross, Glasgow G2 4PP

INTRODUCTION

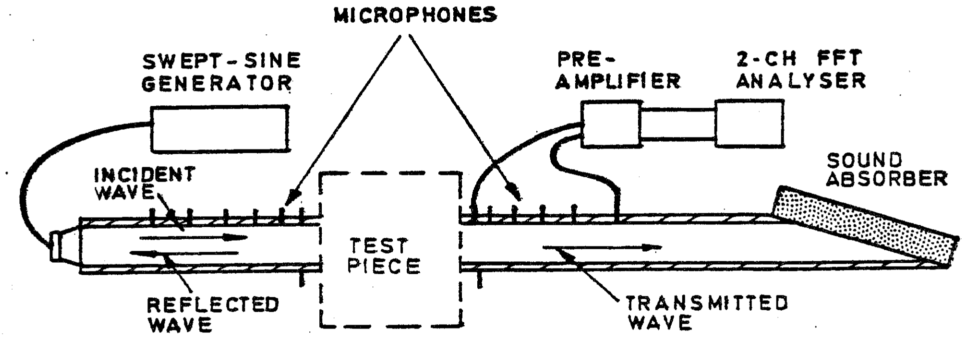
In order to analyse the propagation of fluid-borne noise in a fluid system it is necessary to know the acoustical properties of elements in the system. The transmission loss and reflection coefficient of such an element can be measured in a number of ways, but in most cases the principle is the same: acoustic pressure is measured at a number of positions in pipes fitted to either side of the test piece and the observed standing wave patterns are analysed to produce, in each case, estimates of the relative magnitudes of two travelling wave components. By comparing the incident and reflected wave pressures, it is then possible to calculate the reflection coefficient: similarly the transmission loss is given by the ratio of the incident and transmitted pressure wave amplitudes. The analysis of these standing wave patterns is, however, very sensitive to small errors in the amplitude measurements. Thus even very careful measurements, using high quality transducers, can produce poor results.

DATA REQUIREMENTS

To determine the three primary quantities necessary to specify a one-dimensional wave-field in a pipe, namely the two travelling wave amplitudes and the phase difference, a minimum of three measured quantities is required. These can be three pressure amplitudes or two amplitudes and a phase difference, as described by Nishimura, Fukatsu and Akamatsu [1]. A better estimate of the required parameters can, however, be obtained by making additional measurements and analysing the results with the aid of a curve-fitting computer program. This method is employed at the National Engineering Laboratory [2], where in their hydraulic silencer test facility measurements are made at a total of 20 positions both upstream and downstream of the test piece. This method allows the acoustic properties of a test piece to be determined quite accurately, but a further improvement can be made.

If phase measurements are included in the fitting procedure, then the number of input data is doubled, and statistical estimates of the derived parameters can be found more accurately. A series of experiments has been carried out using this method on a small scale rig with air as the working fluid, and the results obtained have been shown to agree extremely well with theoretical predictions.

The test apparatus is shown in diagrammatic form in Figure 1. The system was driven by a swept sinusoidal signal which was preferred to broadband excitation because it provides for a very high signal to noise ratio in each frequency band in turn. The microphones were spaced at irregular intervals to enable accurate measurements to be made over a range of frequencies.



MICROPHONES AT THE FOLLOWING DISTANCES FROM THE TUBE-PLATE
40 mm, 80 mm, 180 mm, 430 mm, 680 mm, 1040 mm

Figure 1. The Test Apparatus

Given a standing wave pattern arising from the superposition of an incident pressure wave $\tilde{p}_i = Ae^{i(\omega t - kx)}$ and a reflected wave $p_r = (Re^{i\varphi}) Ae^{i(\omega t + kx)}$, the squared pressure magnitude at a point x may be expressed as:

$$|\tilde{p}(x)|^2 = |\tilde{A}|^2 \left[1 + R^2 + 2R\cos(2kx + \varphi)\right] \qquad (1)$$

If the transfer function, measured between two points, x_1 and x_2, is defined as:

$$\tilde{Y} = \frac{\tilde{p}(x_1)^* \tilde{p}(x_2)}{\tilde{p}(x_1)^* \tilde{p}(x_2)}$$

where * indicates the complex conjugate, then, given the pressure distribution as in Equation (1), this may be written:

$$\tilde{Y} = \frac{e^{i\omega(x_1 - x_2)/c} + R^2 e^{-i\omega(x_1 - x_2)/c} + 2R\cos(\omega(x_1 + x_2)/c + \varphi)}{1 + R^2 + 2R\cos(2\omega x_1/C + \varphi)} \qquad (2)$$

In these experiments, the variables R, φ and c were taken to be unknowns and, with six microphone positions available, five independent estimates of the function Y were measured, corresponding to five values of ($x_1 - x_2$). These five complex measurements, equivalent to ten real measurements, were fitted to the expression (2), using a least-squares procedure, to provide estimates of the unknowns.

The procedure described above is first carried out on the source side of the test-piece, whose reflection coefficient is simply the ratio of wave amplitudes, R in Equation (2). Using Equation (1), the measured pressure at any one point can then be used to derive the incident pressure amplitude, A. A similar procedure on the receiver side of the test piece yields the trans-

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mitted wave amplitude and the transmission loss then follows immediately.

The original objective of these experiments was to test the predictions of an earlier theoretical study of the transmission loss, for fluid-borne noise, of a U-tube heat exchanger comprised of a large number of tubes of different lengths. A sound field incident on such a tube stack is split into a number of packets and, after each has traversed its own path-length, these are recombined to produce the transmitted wave. Where the number of different tube lengths is large, the result is a very complex variation of transmission loss with frequency.

A variety of models were tested using this technique, ranging from a single narrow bore tube to a model U-tube heat exchanger consisting of 81 tubes of 10 different lengths. The measured transmission loss and reflection coefficient for this latter case are compared with the theoretical predictions in Figures 2 and 3 below.

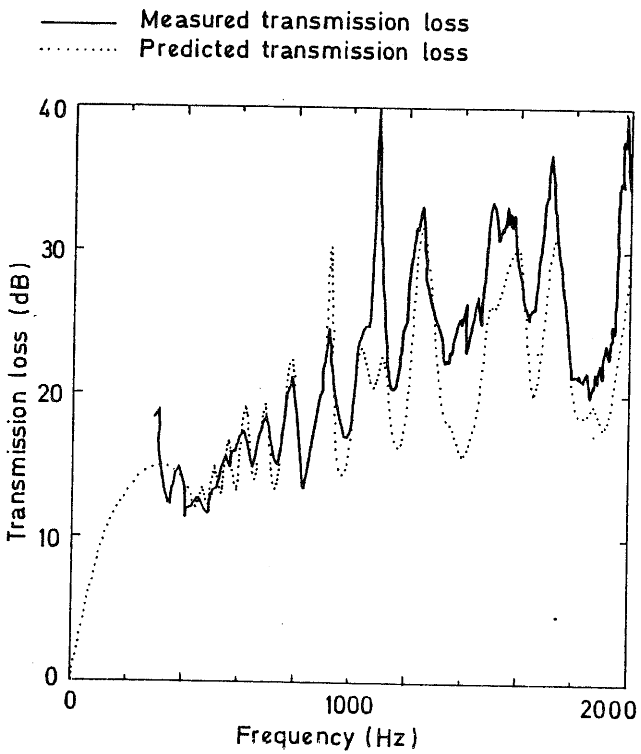

Figure 2. Transmission Loss of U-Tube Model : Theory and Experiment

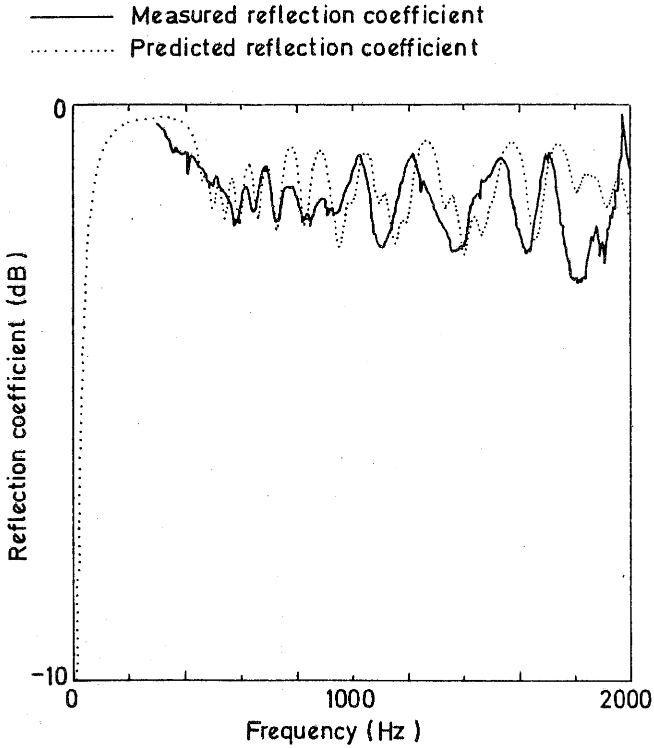

Figure 3. Reflection Coefficient of U-tube Model : Theory and Experiment

ACKNOWLEDGEMENTS

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REFERENCES

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[2] A.R. Henderson, "Measuring the Performance of Fluid-Borne Noise Attenuators" IMechE Research Project Seminar on Quiet Oil Hydraulic Systems Ref. C256/77 (1977)