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THE EFFECTS OF EXTERNAL LAGGING ON LOW FREQUENCY SOUND TRANSMISSION THROUGH THE WALLS OF RECTANGULAR DUCTS

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Introduction

The author has previously given (1,2) an account of a simple theory for calculating the transmission of internally propagated sound through the walls of rectangular ducts. In the present paper, this model is extended to cover the case where external lagging is applied (as it frequently is, in an attempt at noise control), so that the insertion loss of the lagging may be found.

Theory

Figure 1 shows a sketch of the geometry: an inner, rectangular duct is treated with an external layer of porous sound-absorbing material, and this has an impervious external cover. Both the inner duct and the external covering are assumed to behave as ducts with flexible walls.

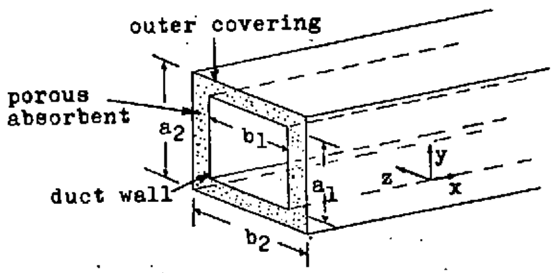

FIGURE 1..CONFIGURATION OF LAGGED DUCT

As explained in references (1) and (2) the vibrations of adjacent walls of a rectangular duct are coupled according to an appropriate set of boundary conditions. Solving the equations of motion for the walls subject to these boundary conditions enables one to determine non-dimensional admittances $\bar{\beta}_1$ and $\bar{\beta}_2$ (these are averaged around the duct's perimeter) for the duct and outer cover respectively. The average admittance, $\bar{\beta}_i$, on the inside of the duct walls may be determined as:

$$\bar{\beta}_i = \frac{\bar{\beta}_2 L_2/L_1 + \Gamma(1+k_x^2/\Gamma^2)(S_2-S_1)/L_1 Z_a}{1+\bar{\beta}_2 L_2/\bar{\beta}_1 L_1 + \Gamma(1+k_x^2/\Gamma^2)(S_2-S_1)/L_1 Z_a \bar{\beta}_1} \qquad (1)$$

(assuming the acoustic pressure in the porous layer is uniform on a duct cross-section, and that the external radiation load as the duct walls is negligible), where L_1, L_2, S_1, S_2 are the perimeters and cross-sectional areas (respectively) of the inner duct and outer covering (in that order), Γ and Z_a are the propagation coefficient and (non-dimensional) characteristic impedance of the porous material (respectively), and k_x is the axial wave number of a coupled wave system travelling (in one direction) in the duct and lagging.

If q_2 is the total volume velocity per unit length of duct on the outer covering of the lagging, and p_1 is the acoustic pressure inside the duct, a transfer admittance relating these two may be found:

$$q_2/p_1 = \bar{\beta}_2 L_2 \left(1 - \bar{\beta}_i/\bar{\beta}_1\right)/\rho_0 c_0 . \tag{2}$$

One then finds an expression for the transmission loss (TL) of the duct/lagging combination,

$$TL = 10 \log \left(W_{int}/W_{rad}\right) = 10 \log \left[4 a_1 b_1 c_0 / k_0 C_r c_x \bar{L}_2^2 \left|\bar{\beta}_2 (1 - \bar{\beta}_i/\bar{\beta}_1)\right|^2\right], \tag{3}$$

where W_{int} and W_{rad} are the sound power in the duct and radiated sound power per unit length of duct respectively, a_1 and b_1 are the transverse dimensions of the inner duct, C_r is a radiation efficiency factor (the sound power per unit length radiated from the - finite - duct, divided by that from an infinite length duct, all other conditions being equal) and c_x is the axial phase speed of the wave system. (The radiation efficiency was found, to sufficient accuracy, using results of Brown and Rennison (3)). The insertion loss (IL) of the lagging, representing the actual noise reduction, is given by:

$$IL = TL \text{ (with lagging)} - TL \text{ (without lagging)}. \tag{4}$$

The latter term on the r.h.s. of equation (4) may, of course, be found using the plain duct theory of references (1) and (2)

Measurements and Comparison with Theory

Measurements of the TL of a mild steel duct (203 mm x 203 mm cross-section, 1.2 mm wall thickness) with and without lagging yielded the IL of the lagging. Two types of lagging were studied: first, 25 mm Rockwool covered with plaster of average thickness 5.26 mm (the actual thickness varied by a factor of about 10). A loudspeaker at one end of the duct was used as an acoustic source, and an "anechoic" termination, of Rockwool, helped to reduce structural and acoustic reflections, thereby partially realising a travelling-wave situation. The reverberant room method (utilizing a standard acoustic power source) was used to measure the sound power radiated from the duct, and a microphone inside the duct determined the internal sound power level.

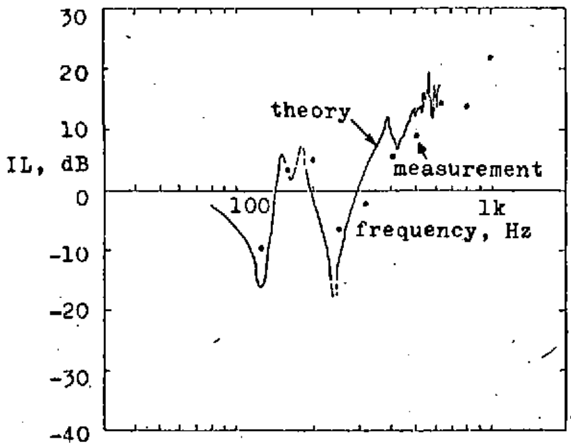

FIGURE 2. INSERTION LOSS OF TINNED STEEL/ROCKWOOL LAGGING

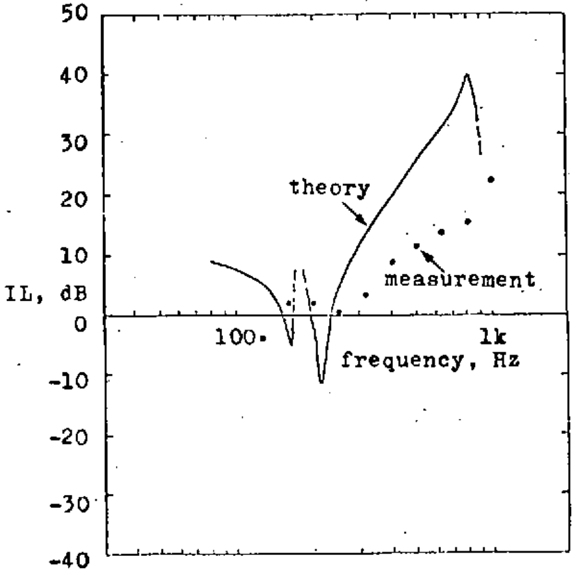

FIGURE 3. INSERTION LOSS OF PLASTER/ROCKWOOL LAGGING

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Equation (3) was used to determine the TL of the duct/lagging combination, $\bar{\beta}_i$ being determined from equation (1). Actually, values of $\bar{\beta}_i$ are required to determine k_x, and vice versa, so an iterative procedure was used here, k_x initially being put equal to k_0 (radian frequency/adiabatic speed of sound). Values of $\bar{\beta}_1$ and $\bar{\beta}_2$ were determined using the theory given in references (1) and (2); a structural loss factor of 0.1 was incorporated, since the Rockwool blanket would incur heavy damping. The TL of the plain duct was similarly determined, and the IL was thus found from equation (4). A rigid-frame acoustic model of porous materials was used to find values of Γ and Z_a for Rockwool.

Figures 2 and 3 show the predicted and measured IL results.

One sees that the IL predictions on the tinned steel/Rockwool lagging are in fairly good agreement with the measurements. On the other hand, the agreement is not nearly so good in the case of the plaster/Rockwool lagging, and the reason for this almost certainly lies in the non-uniformity of the plaster coating.

In the case of the tinned steel/Rockwool treatment, the IL is seen to be negative over most of the frequency range 80-200 Hz, and this is where additional attenuation would usually be required. In the case of the plaster/Rockwool lagging, the situation is not so bad (the poor agreement between theory and experiment somewhat invalidates any definite conclusions), but the lagging certainly does not seem to have any really advantageous effect at low frequencies.

Conclusions

The simple theory described here appears to predict the IL of duct lagging with a uniform covering fairly accurately. The same accuracy is not experienced in the case of a non-uniform covering (as in the case of the plaster), since the uniform-plate vibration theory is inapplicable here.

More important than this, however, one concludes that, at least in the two cases examined here, lagging indiscriminately applied certainly cannot be guaranteed to be successful in noise reduction, and one would have to use a prediction method, such as that described here, to design the lagging according to requirements.

References

(1) A. CUMMINGS 1978 Journal of Sound and Vibration 61, 327-345. Low frequency acoustic transmission through the walls of rectangular ducts.

(2) A. CUMMINGS 1979 Journal of Sound and Vibration 63. Low frequency sound transmission through the walls of rectangular ducts: further comments (letter to the Editor).

(3) G.L. BROWN and D.C. RENNISON 1974. Proceedings of the Noise, Shock and Vibration Conferences, Monash University, Melbourne, 416-425. Sound radiation from pipes excited by plane acoustic waves.

ERRATUM

Paper A5

A Cummings. "The Effects of External Lagging on Low Frequency Sound Transmission through the Walls of Rectangular Ducts."

Page 2, 9th line from the bottom

Between "first," and "25 mm Rockwool", insert "25 mm Rockwool covered with 0.38 mm tinned steel sheet, and secondly".