Proceedings of the Institute of Acoustics

# SOUND INTENSITY TECHNIQUES FOR MEASURING COUPLING LOSS FACTORS

R.J.M. Craik, R. Ming and R. Wilson

Heriot-Watt University, Department of Building Engineering and Surveying, Edinburgh, EH14 4AS, UK.

## 1. INTRODUCTION

Sound intensity techniques, whether airborne or structure-borne, expand the type of measurements that can be carried out by enabling power flow to be measured directly. Airborne intensity techniques are widely used for determining sound power and the measurement procedures are well established. The techniques for measuring structure-borne sound intensity are less well developed but the applications for the direct measurement of power flow in structures are just as numerous.

Statistical energy analysis (SEA) is a framework of analysis that models power flow and allows the performance of structures to be studied. The parameter that describes power flow and hence the response of the structure, is the coupling loss factor (CLF). This is defined as the fraction of energy transmitted between two subsystems (elements of the structure) in one radian cycle. Using conventional indirect techniques, the power flow in an SEA model, or the relevant CLF, can be verified from measurements of vibrational response and damping. Intensity techniques offer the possibility of measuring the power flow directly for comparison with the theoretical model.

## 2. MEASUREMENT OF POWER FLOW

**Intensity measurement procedures**

There are several different techniques for measuring structural intensity depending on the application. For measurements made in building structures there are two techniques that are practical. Both require the use of two accelerometers and an intensity analyser or a two channel analyser. For the two-in-line method [1], shown in Fig. 1., two accelerometers are placed side by side on the structure, separated by a distance $\Delta$. This is directly analogous to the airborne procedure where two microphones are placed side by side.

The second technique also uses two accelerometers, however, these are fixed to a cube forming a bi-axial accelerometer [2], as shown in Fig. 1. The accelerometer that is perpendicular to the plate detects the displacement and the second accelerometer, which is at a distance $\Delta$ from the neutral axis of the plate, detects the rotation that occurs as a bending wave passes. An alternative to this arrangement of transducers is to use a proprietary tri-axial accelerometer, a single transducer which contains three mutually perpendicular accelerometers inside it. If many measurements have to be made, the bi-axial method is more convenient as it requires only a single transducer assembly and so does not require the accelerometer spacing to be carefully set as with the two-in-line method.

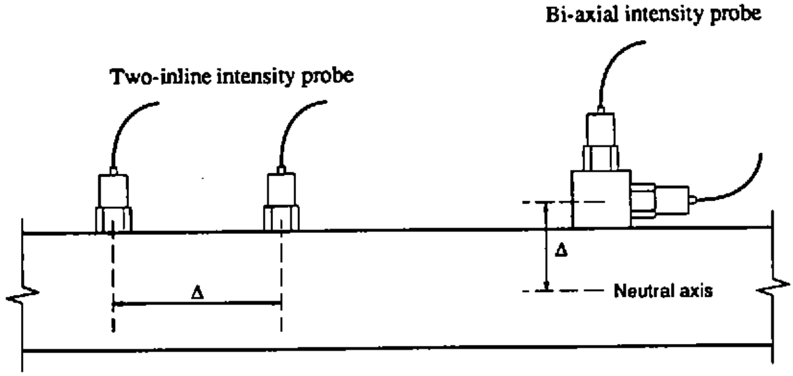


**Fig. 1 Accelerometer positions for the measurement of structural intensity.**

For each of the two measurement techniques, the intensity (power flow per metre) can be found from the imaginary part of the cross spectrum between the two accelerometer outputs using

$$I = \frac{2\sqrt{B\rho_s}}{\omega^2\Delta}\, Im(Cross\ spectrum) \tag{1}$$

where $B$ is the bending stiffness and $\rho_s$ is the surface density.

Alternatively it can be found from a sound intensity analyser using

$$L_I = L_I' + 10\log\left(\frac{2\sqrt{B\rho_s}\Delta'\rho_o}{\omega\Delta}\right) \tag{2}$$

where $L_I'$ is the intensity read from the analyser which is set up for airborne intensity with a microphone spacing $\Delta'$ and where $\rho_o$ is the density of air.

SOUND INTENSITY TECHNIQUES FOR MEASURING COUPLING LOSS FACTORS

**Intensity measurement set up**

Where a wall or floor is connected at a point to another part of the structure or where there is a point source directly exciting the structure, the power flow can be measured using the set up shown in Fig. 2.

If a circle with a radius $r$ is drawn round the source, then the power entering the plate must pass through the circle. The power flow can be given by

$$W = I\,2\pi r \tag{3}$$

where $I$ is the average intensity measured round the circle in the radial direction.

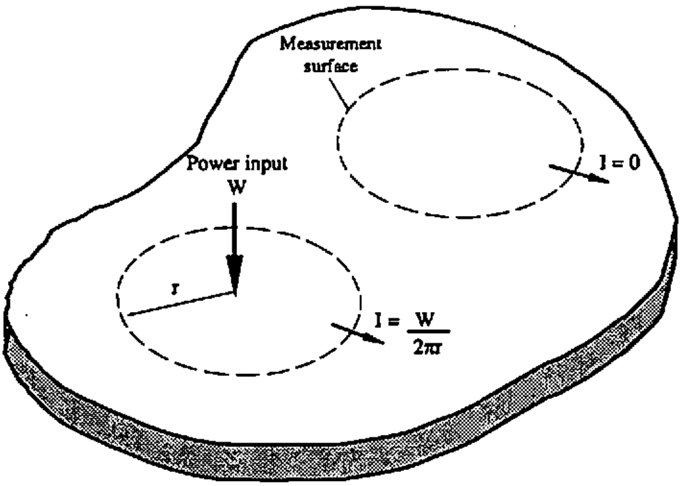


**Fig. 2 Intensity measurement for a point source exciting a plate.**

If the circle does not enclose a power source then in theory, the power entering should equal the power leaving and the intensity that is measured should be zero. However, in practise, as with airborne measurements, the measured intensity is not zero. This is caused by instrumentation errors and differences in the material properties of the structure on which the measurement is performed. It is important to determine this residual intensity as it provides an important indicator of the quality of the measurements analogous to background noise.

The experimental set up to measure the power flow between two plates connected along a line shown in Fig. 3. In this case all the power from the plate of interest will pass through a line drawn parallel to the joint and the power can be found from

$$W = I\,L \tag{4}$$

where $L$ is the length of the common boundary. As with the point source it is important to measure the residual intensity (again by measuring around a circle that does not enclose a power source).

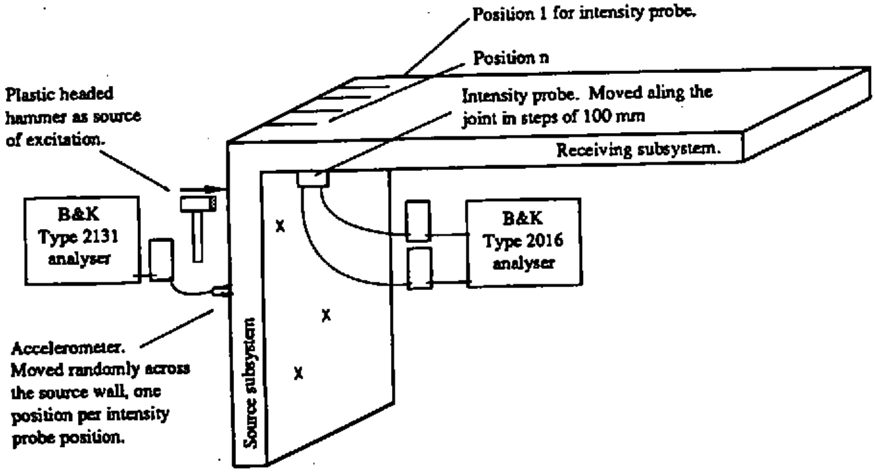


**Fig. 3 Intensity measurement where two subsystems are connected along a line.**

**Conventional indirect measurements**

When using an SEA model the power flow can be deduced from more conventional, indirect measurements. For the simple system of two coupled structural subsystems shown in Fig. 4, where one of the subsystems is excited, the power flow from subsystem 1 to subsystem 2 will be

$$W_{12} = E_1 \omega \eta_{12} \tag{5}$$

where $E$ is the energy in the source subsystem and $\eta$ is the coupling loss factor. In addition there will be power flow from subsystem 2 back to subsystem 1 so that the net power (which is measured by intensity techniques) will be

SOUND INTENSITY TECHNIQUES FOR MEASURING COUPLING LOSS FACTORS

$$\overline{W_{12}} - E_1\omega\eta_{12} - E_2\omega\eta_{21} \tag{6}$$

If the subsystems are not strongly coupled, the second term can be ignored and eqn(5) can be used to determine the power flow indirectly.

The power flow can also be related to the power dissipated in the second subsystem as

$$W_{12} - E_2\omega\eta_2 \tag{7}$$

where $\eta_2$ is the total loss factor of subsystem 2. Some of the power in subsystem 2 will, however, be transmitted back to subsystem 1 so that the net power flow will be

$$\overline{W_{12}} - E_2\omega\eta_2 - E_2\omega\eta_{21} \tag{8}$$

Again the second term will usually be small in real structures and eqn(7) can be used.

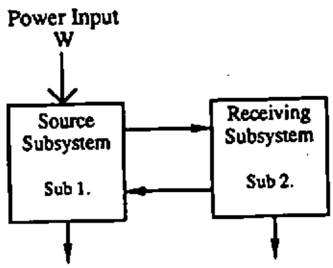


**Fig. 4 SEA model of two connected subsystems.**

Measuring the vibrational response of the two subsystems when one is subjected to a source of excitation allows the power flow to be determined provided the damping of the receiving subsystem is known.

In all cases the measured CLF can be determined from the measured power flow and the source subsystem energy to give

$$\eta_{12} = \frac{W_{12}}{E_1 \omega} \tag{9}$$

## 3. TEST RESULTS

Results for coupling between two walls connected by a single wall tie [3] (which represents a point source for the receiving wall), can be seen in Fig. 5. It shows the predicted CLF and three measured CLFs. Two of the measured curves were obtained from direct techniques, the first using the two-in-line intensity method and the second using an impedance head fixed to the wall tie. The final measured curve was obtained using an indirect method based on the receiving wall energy and damping.

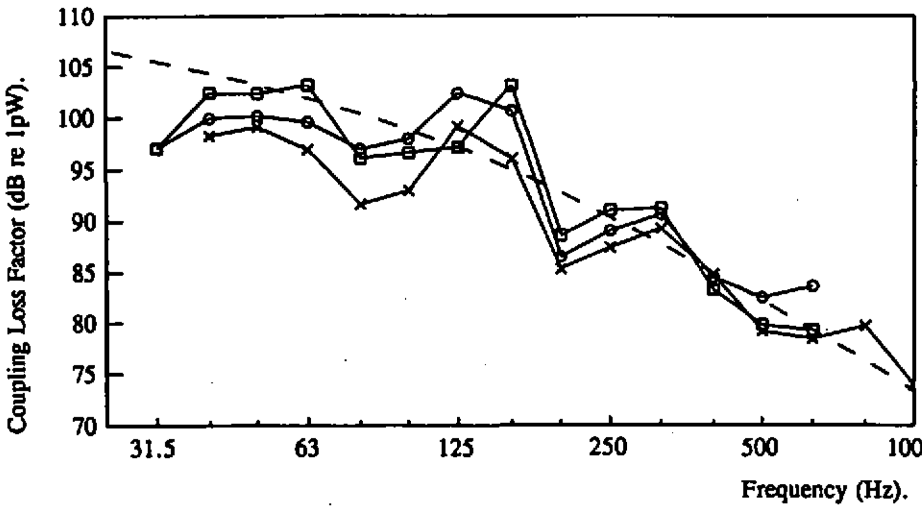


**Fig. 5 Measured and predicted coupling loss factor between two walls connected by a single wall tie. ——x——, Conventional level difference; ——□——, Two-in-line intensity; ——O——, Impedance head; ———, Predicted.**

The general agreement between all measured curves and the prediction is good. The CLF measured using intensity shows close agreement with the direct measurement of the CLF obtained using the impedance head. The agreement between the intensity and the indirect measurement of the CLF is also good.

A typical result for coupling at a corner joint between two brick walls can be seen in Fig. 6. It shows the predicted CLF together with three measured curves. The measured CLFs were calculated from eqn(9). Two intensity techniques were used, the two-in-line and the bi-axial methods. Both methods give similar answers and both agree well with the predicted CLF except at high frequencies where the limit of applicability of the intensity theory is reached.

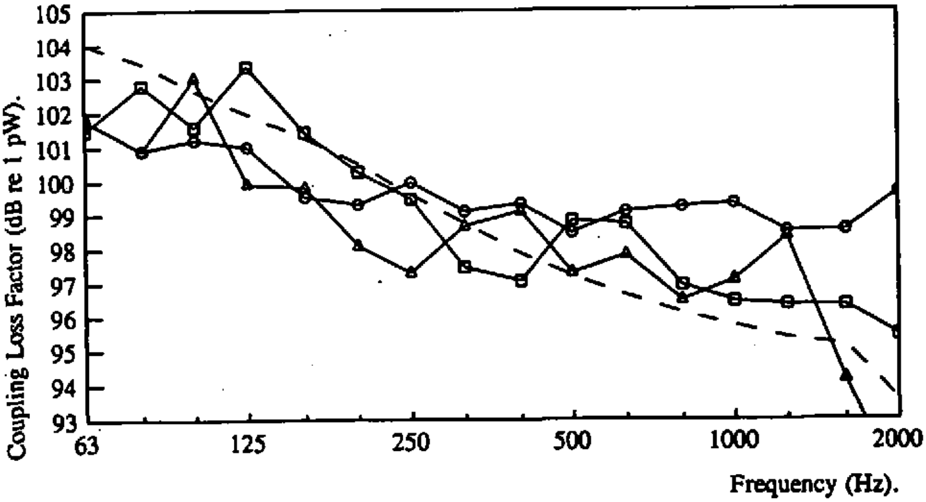


**Fig. 6 Measured and predicted coupling loss factor at a corner joint between two brick walls using intensity and conventional techniques. ——□——, Conventional level difference; ——O——, Two-in-line intensity; ——Δ——, Bi-axial intensity; ———, Predicted.**

The CLF obtained by conventional measurements of energy and damping, eqn(7), is also shown. It agrees slightly better with the prediction.

## 4. CONCLUSIONS

Intensity techniques provide a useful means by which the power flow between coupled structures may be measured directly. This removes the need to measure structural damping which is necessary to determine power flow using indirect methods based on vibrational response.

The results from intensity measurements performed on structures coupled at points and along lines showed good agreement with predicted data and the results obtained from more conventional indirect measurements.

## ACKNOWLEDGEMENT

This work was funded by the Science and Engineering Research Council of Great Britain.

## REFERENCES

[1] G. Pavic, Measurement of structure-borne intensity. Part 1: Formulation of the methods. *Journal of Sound and Vibration*, (1976), 49, 221-230.

[2] D. U. Noiseux, Measurement of power flow in uniform beams and plates. *Journal of the Acoustical Society of America*, (1970), 47, 238-247.

[3] R. Wilson, Sound transmission through double walls, *PhD thesis, Heriot-Watt University, Edinburgh*, (1992).