Approximate method for obtaining source quantities for calculation of structure-borne sound transmission into lightweight buildings.

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Abstract

An approximate approach is described, for obtaining the source quantities required for the calculation of structure-borne sound power from machines into supporting lightweight building elements. The approach is in two stages, which are based on existing international Standards for measurement. The first stage involves direct measurement of the source free velocity at each contact, to give the sum of the square velocities. The second stage is based on the reception plate method and yields the single equivalent blocked force, which approximates the sum of the square blocked forces. The applicability of the source data obtained has been investigated in a case study of a fan unit on a timber joist floor. The approach contains several significant simplifying assumptions and the uncertainties associated with them are considered. For the case considered, the power transmitted into the floor is estimated by the approximate method to within 5 dB of the true value, on average.

Keywords: Building acoustics, structure-borne sound, reception plate method

1. Introduction

This paper considers an approximate method of estimating the structure-borne sound power of mechanical installations in lightweight buildings. For the structure-borne sound power at installation locations, three quantities are required in some form [1-3]. The first quantity is the source activity: either the measured free velocity of the isolated source, under otherwise normal operating conditions, or the measured blocked force, obtained when attached to a rigid supporting structure. The second quantity is the source mobility (or the inverse impedance). The third quantity is the receiver mobility (or the inverse impedance).

The three quantities can be measured directly, for each contact and for up to six components of excitation (three translations and three rotations), but the measurement and calculation effort is large. However, not all components of excitation need to be considered and, for sources in buildings, the forces perpendicular to the receiver usually dominate the transmitted power [4-7] and this component alone is considered. To further reduce the measurement effort, the three quantities are obtained as frequency band averaged values, e.g. in 1/3 octave bands; further the three quantities are expressed as single equivalent values [6].

The approximate approach is a development of the two stage reception plate method [8-9]. In this proposal, the first stage is the direct measurement of the sum of the squared free velocities, over the machine contacts, $\sum v_f^2$ and is based on the Standard method ISO 9611 [10]. Accelerometers are attached to the contact points of the freely suspended or resiliently supported machine and the velocities are recorded as 1/3 octave values, while the machine is in operation.

The second stage involves the reception plate method (RPM), referred to in the Standard EN15657-1 [11]. The principle of the reception plate method is given in [1, 12]. The machine under test is attached to an isolated resiliently supported plate. With the machine in operation, the total structure-borne sound power transmitted equals the bending wave power of the receiving plate. The plate power is obtained from the spatial average of the mean square plate velocity $\langle v^2 \rangle$:

$$P_{source} = P_{plate} = \omega \, \eta \, M \, \langle v^2 \rangle \qquad (1)$$

M is the mass of the reception plate and η the total loss factor. Alternatively, the total power can be obtained by a power substitution procedure [13, 7].

If the reception plate is thick, such that the plate mobility is much lower than the source mobility, then the source can be characterized by a single quantity, related to the sum square blocked force over the machine supports [12]. The source power into a plate of known low mobility Y_{low} then is:

$$P_{source} = F_{beq}^2 \ \mathrm{Re}\ (Y_{low}) \qquad (2)$$

The single equivalent value of blocked force F_{beq}^2 is extracted from equations (1) and (2) and used in combination with the measured sum square free velocity $\sum v_f^2$, to give the single equivalent source mobility [8, 9]:

$$\left| Y_{Seq} \right| = \sqrt{\sum v_f^2 \, / \, F_{beq}^2} \qquad (3)$$

The single equivalent source mobility relates to the average point mobility magnitude over the contacts.

The sum square free velocity and single equivalent source mobility are used in combination with measured or calculated real part and magnitude of the single equivalent receiver mobility Y_{Req}, which also relates to the average magnitude of point mobility over the receiver contact points. The predicted structure-borne power, when the source is installed, becomes:

$$P_{installed} \approx \sum v_f^2 \frac{\mathrm{Re}\left(Y_{Req}\right)}{\left|Y_{Seq}\right|^2 + \left|Y_{Req}\right|^2} \tag{4}$$

Equation (4) requires magnitudes and one real part, all of which can be expressed as spectrally average values, i.e. measured or calculated as one third octave values. However, the spatial and spectral averaging results in the loss of phase information between source and receiver mobility, and between the contact forces, for multi contact sources. This introduces uncertainties in the obtained source quantities and in the predicted installed power [14]. These uncertainties are assessed in a study of a fan unit attached to a timber joist floor.

2. Case study of fan on timber joist floor

The case considered was that of a medium size centrifugal fan unit, assumed to be rigidly attached to a timber joist floor. Figure 1, left, shows the fan unit, which was measured in the Acoustics Research Unit of the University of Liverpool. The two contacts indicated are at a distance of 250 mm from each other. The other contact point distance is 360 mm. Figure 1, right, and Figure 2 show the timber joist floor, which was constructed in the acoustics laboratory of Stuttgart University of Applied Sciences.

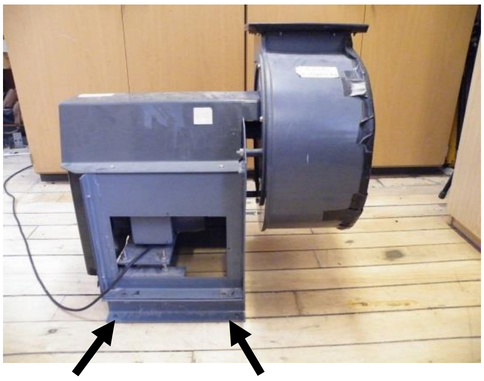

Fig. 1. Left, fan unit, free-standing in laboratory area, with two of the four contact points indicated; Right, timber joist chipboard floor under construction.

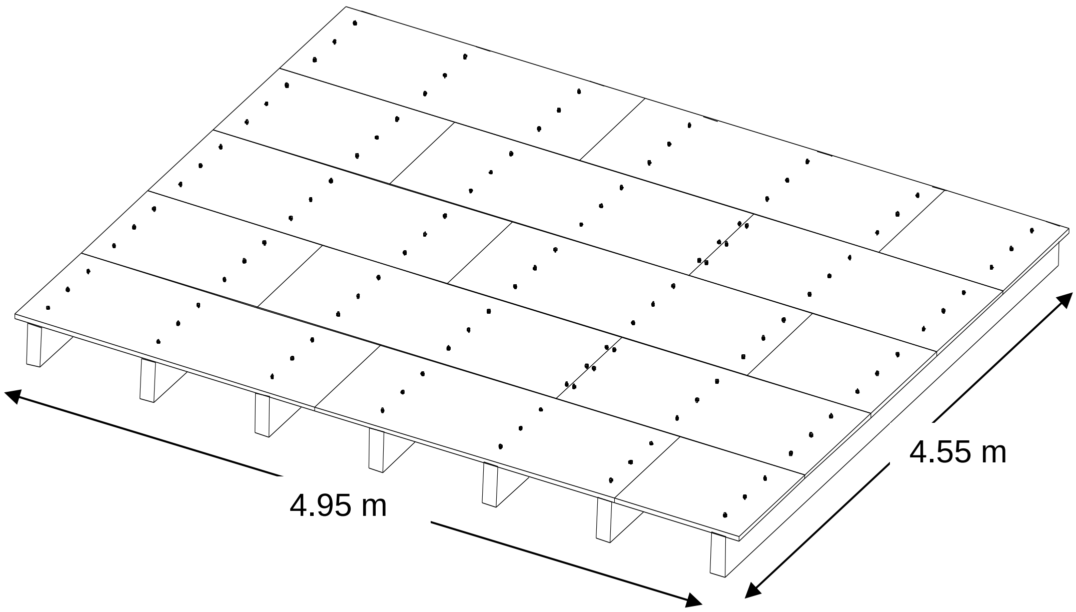

Fig. 2. Floor construction and dimensions, indicating the sheathing board layout and screw fixings.

The floor consisted of one layer of 21 mm chipboard supported by seven spruce joists with dimensions 0.096m x 0.192m x 4.55m. The joist spacing was at 0.78m centres. The chipboard sheathing consisted of panels of dimensions 0.9m x 2.05m joined by unglued tongue and grooves and screwed to the joists at 0.2m centres. The floor was without a ceiling plate and variations in point mobility and thus transmitted power are expected, when for example the fan was located over joists or in bays.

In this example of sub-structuring, the fan and floor were measured in separate locations. Then, for the fan fictively attached to the floor, the power was calculated by the mobility method, where the general expression of complex power for multi-point excitation (again, only forces perpendicular to the receiver structure are considered) is given by [3]:

$$\overline{W} = \bar{v}_f^{*T} \left[\overline{Y}_S + \overline{Y}_R\right]^{*T-1} \left[\overline{Y}_R\right] \left[\overline{Y}_S + \overline{Y}_R\right]^{-1} \bar{v}_f \tag{5}$$

where $\bar{v}_f$ is the source complex free velocity vector, $\overline{Y}_S$ and $\overline{Y}_R$ are the complex mobility matrices of the source and the receiver, respectively. * denotes complex conjugate, while ^{T} denotes the transpose. The total transmitted power is the real part of the sum of the complex products of the forces and their associated contact velocities at four points.

For the mobility method, the source free velocity was recorded at four contacts with the fan flexibly suspended and operating. The velocities were recorded as complex values with a frequency resolution of 2 Hz and a frequency range of 0 - 6400 Hz. In Figure 3 is shown the narrow-band magnitudes of velocity at four contacts, along with the sum square $\sum v_f^2$ in 1/3 octaves. Within the frequency range of interest, 50 Hz – 2000 Hz, there are low frequency tonal components at 50 Hz and 100 Hz, combined with a broad-band spectrum.

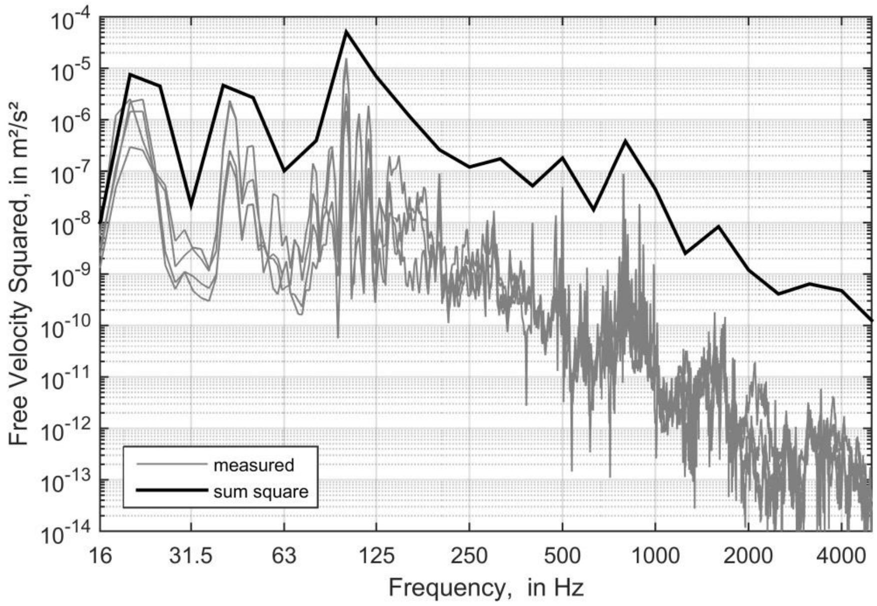

Fig. 3. Magnitude of squared free velocity at four contacts of fan unit, with the sum square in 1/3 octaves.

The complex source mobility was recorded using a shaker with in-line force transducer and accelerometer for response velocity, with the fan similarly suspended. Complex values of point mobility and transfer mobility between contacts formed the source mobility matrix $\overline{Y}_S$. In Figure 4 is shown the narrow-band point mobility magnitude at the four contacts, along with the average value in 1/3 octaves.

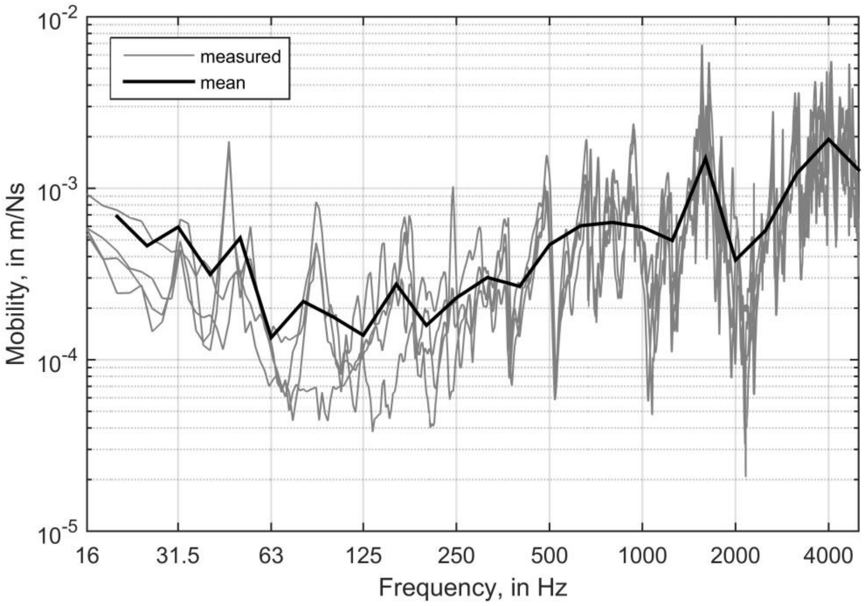

Fig. 4. Point mobility magnitude of fan unit at four contacts, and average value in 1/3 octaves.

The receiver mobility matrix $\overline{Y}_R$ was assembled from measured point and transfer mobility at ten locations over the timber floor. Each location consisted of four contact points at distances corresponding to the mount points of the fan base. An instrumented impact hammer registered the applied force and the response velocity was recorded as the average signal from a matched accelerometer pair, located either side of the impact point. In Figure 5 is shown a typical narrow-band point mobility, also in 1/3 octaves, for a location in a bay and over a joist.

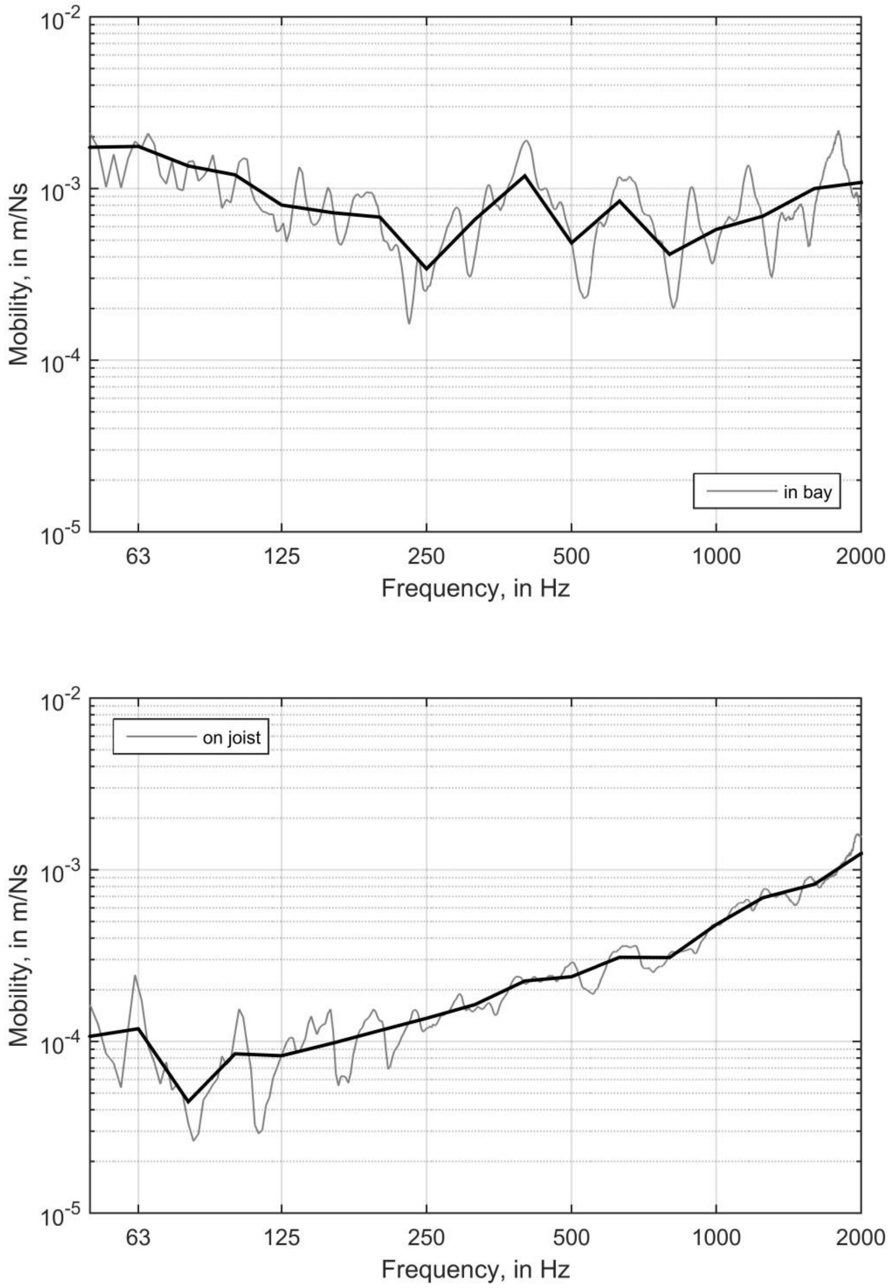

Fig. 5. Narrow-band point mobility, also in 1/3 octaves, in a bay (upper curve) and over a joist (lower).

The data, incorporated into equation (5), provided the calculated powers, which formed the benchmark for comparison with the powers obtained by the approximate method in equation (4). In Figure 6 is shown the mean and standard deviation of the calculated powers at 10 fan locations on the timber floor, according to equation (5). The standard deviation is about 1 dB or less, above 500 Hz, and is the result of the floor mobility over or near a joist converging to that in a bay.

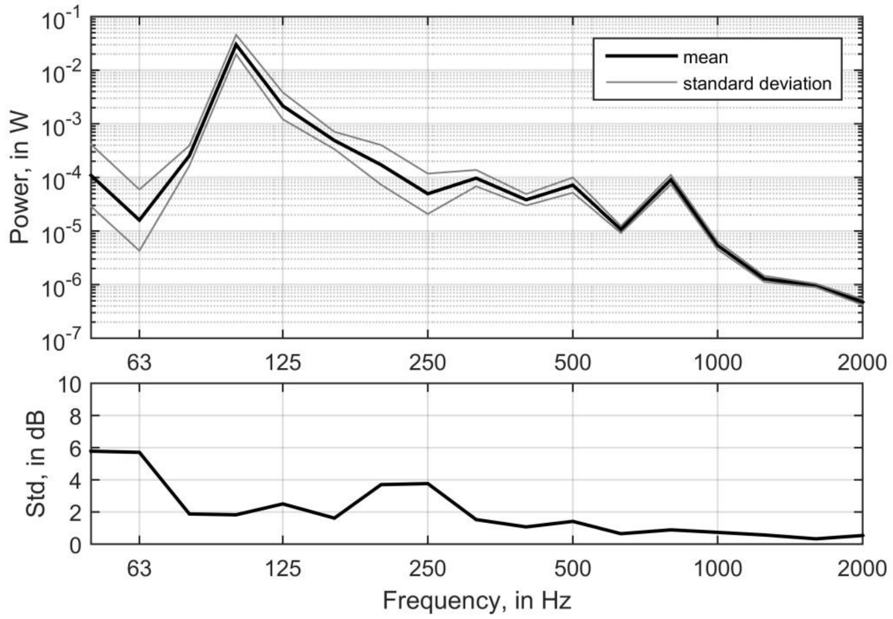

Fig. 6. Mean power using mobility method and standard deviation for 10 fan locations on timber floor.

The benchmark values also allowed an appraisal of the effects of the simplifying assumptions in the approximate approach, which are described next.

3. Discrepancies resulting from simplifications

3.1 Using magnitudes of quantities

An important requirement of the approximate method is the simplification, which results from measuring the sum square free velocity and average source point mobility as magnitudes, and the average receiver point mobility as real part and magnitude. This is an alternative to the use of complex values required in equation (5). The magnitudes can be acquired and processed in frequency bands, typically in 1/3 octaves, and results are presented in this form. In Figure 7 is shown the mean and standard deviation of the powers at the same 10 locations on the timber floor, where magnitudes, including real parts of the receiver mobility, are incorporated into the mobility method. The transfer mobilities (i.e. the off-diagonal matrix elements) are included.

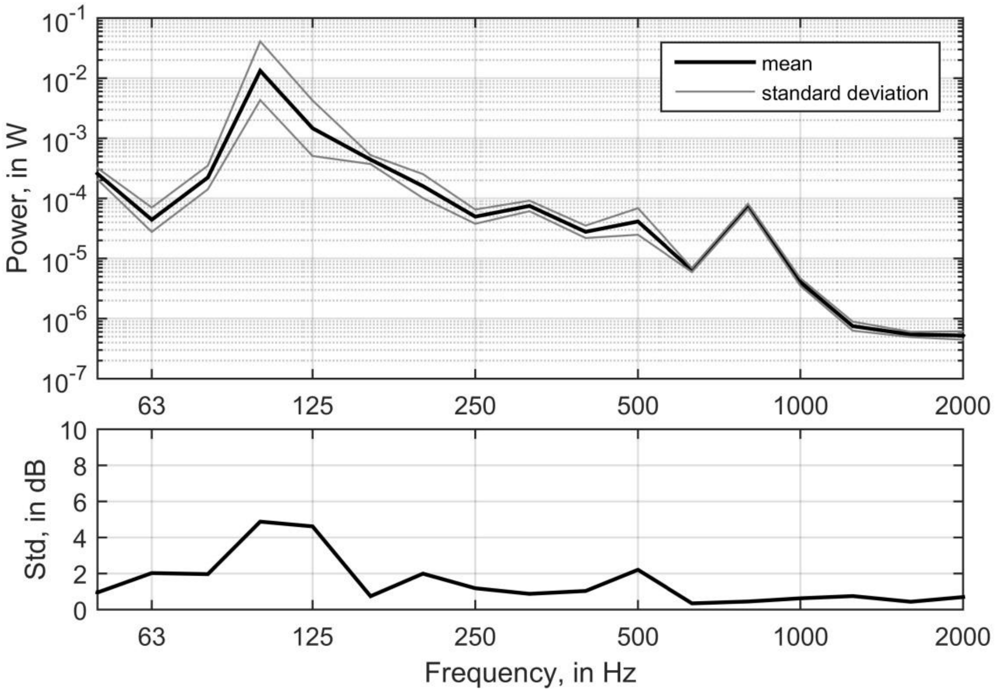

Fig. 7. Mean power and standard deviation using magnitudes in mobility method for 10 fan locations on timber floor.

Visual inspection indicates little difference between this power and that calculated using complex values, and this is confirmed in Figure 8, which shows the level difference.

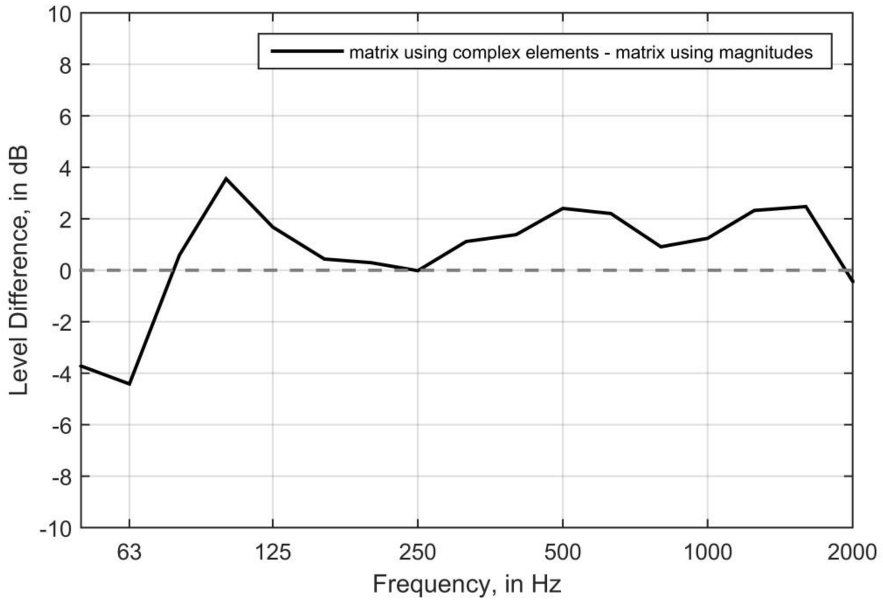

Fig. 8. Level difference between mean power from complex matrix elements and using magnitudes.

The use of magnitudes gives an underestimate of the exact value of 2 dB above 80 Hz. This is of the same order as the calculated standard deviation in Figure 6, below 315 Hz.

3.2 Neglect of source or receiver mobility magnitudes

Equations (4) and (5) indicate that both the source and receiver mobility is required in some form. However, in the absence of sufficient data, engineers often assume a force-source condition (i.e. $|Y_S| >> |Y_R|$) for lightweight machines installed in heavyweight structures, for example in masonry buildings. Conversely, a velocity-source condition (i.e. $|Y_R| >> |Y_S|$) is assumed for heavyweight machines installed in lightweight structures. However, for timber-frame/timber-composite constructions, source and receiver mobility may be of the same order and the above asymptotic conditions will give errors in predicted power [6, 14].

In Figure 9 is shown the source and receiver point mobility at four contacts for the fan located over two bays. The receiver mobility is greater than the source mobility in the frequency range 50 Hz – 500 Hz, but is of the same order above 500 Hz.

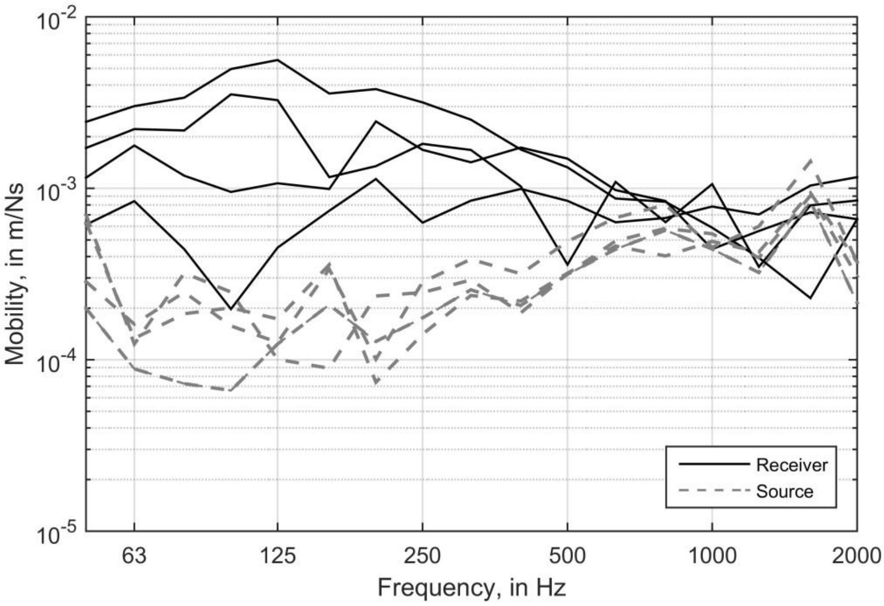

Fig. 9. Source and receiver mobility at four contacts for the fan located over two bays.

In Figure 10 is shown the calculated transmitted power for the same location, including estimates employing the force-source ($|Y_R|$ neglected) and velocity-source ($|Y_S|$ neglected) assumptions. At this location, the velocity-source assumption agrees with the exact power within 2 dB at frequencies below 500 Hz but the difference is up to 10 dB, above 500 Hz. However, if both mobility magnitudes are included, there is agreement within 3 dB over the whole frequency range.

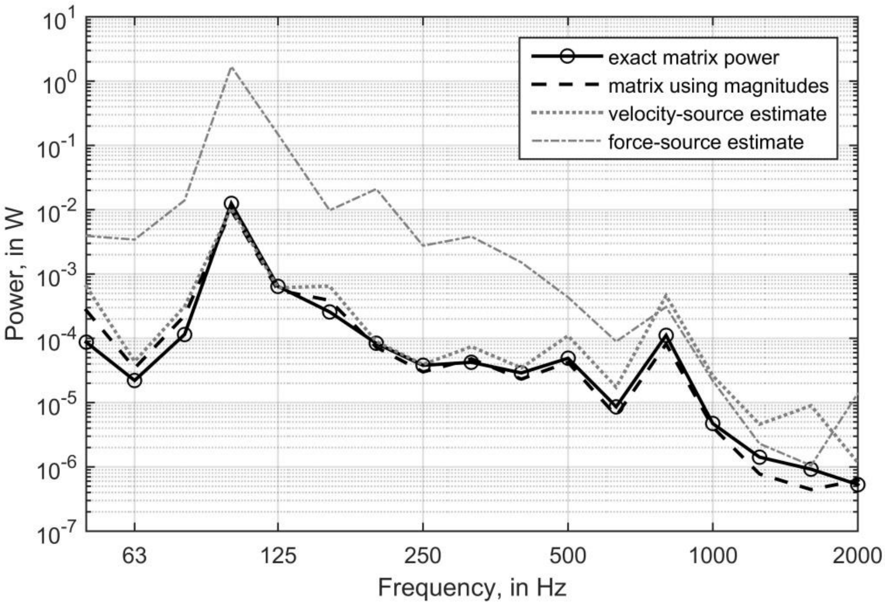

Fig. 10. Fan power when located over two bays, including estimates employing the force-source and velocity-source assumptions.

For two fan contacts over a joist and two in a bay, the source and receiver mobility at four contacts are shown in Figure 11.

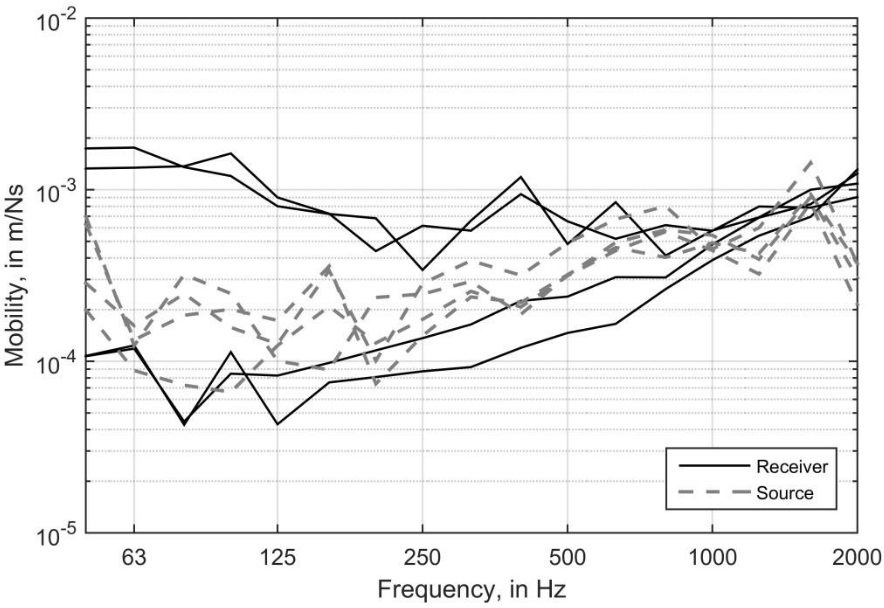

Fig. 11. Source and receiver mobility for two fan contacts over a joist and two contacts in a bay.

The source-receiver mobility ratio is variable with respect to both location and frequency. Figure 12 shows the transmitted power for this location, again including force-source and velocity-source estimates. Both assumptions give significant discrepancies. However, if both the source and receiver mobility magnitudes are included, the agreement is within 5 dB over the whole frequency range.

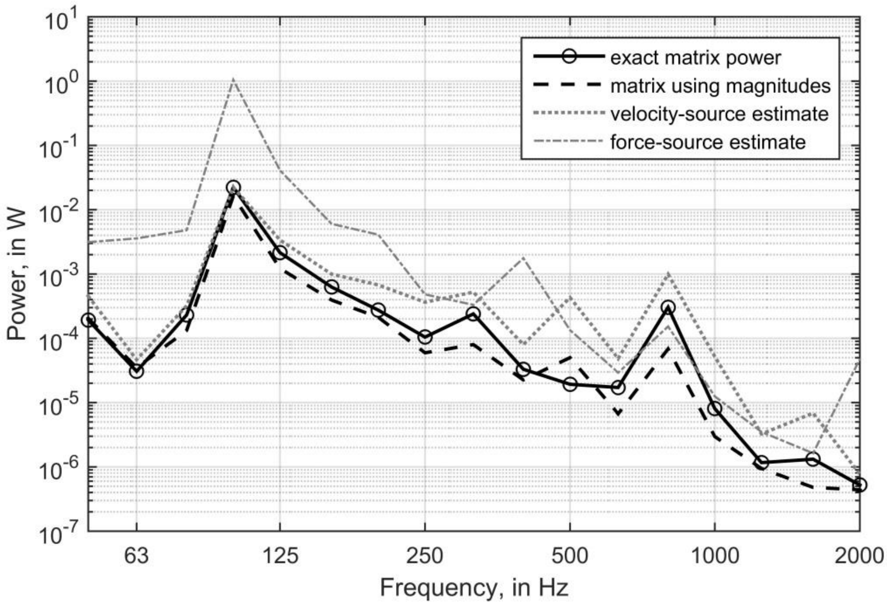

Fig. 12. Fan power when over a joist and a bay, including force-source and velocity-source estimates.

3.3 *Effect of neglecting the interaction between contact forces*

This approach to characterizing multiple contact sources with single values pre-supposes that the contact forces are independent of each other. This is likely to be the case at high frequencies, and for contacts which are distant from each other, with respect to the governing bending wavelength on the receiver plate. At frequencies and plate thicknesses where the bending wavelength is large, then the contact forces interact and the sum-square blocked forces are not obtained indirectly by the reception plate method. Indeed, the force relationships will be dependent on the installation condition and therefore difficult to predict. Therefore, an estimate is required of the lower frequency limit to the independent force assumption and the expected uncertainties below this frequency limit.

Following the approach of Putra and Mace [15], simple force distributions on idealized plates of infinite area were considered. The target quantity is the sum-square blocked force, since this is an independent source descriptor. Figure 13 shows force distributions corresponding to two common installation geometries: (a) two point contacts, found for example in water pipe connections to walls; (b) four point contacts, corresponding to, for example, mounts between medium-size fan units and floors. The contact distances in Figure 13 are arbitrary but typical.

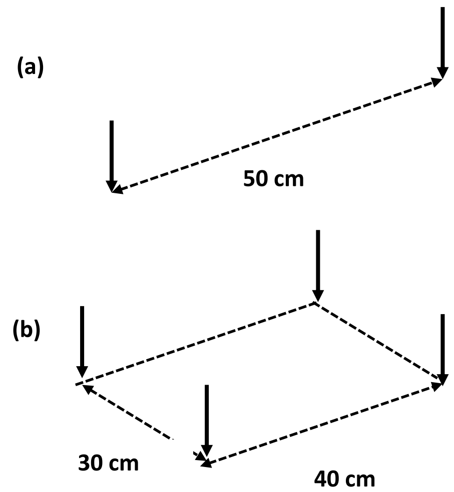

Fig.13. Force geometries of typical sources in buildings.

For idealized receiver plate structures, consider infinite thin plates with point mobility, given by [1]:

$$Y_c = \frac{1}{8\sqrt{B'm'}} \qquad (6)$$

B' is the plate bending stiffness and *m'* is the mass per unit area. Termed the characteristic mobility, Y_c is real-valued and frequency invariant. In order to include transfer mobility terms, reference is made to the Hankel function of second kind, which is the solution to the bending wave equation of a thin plate of infinite extent [1]. The transfer mobility, between points *i* and *j*, is given in terms of the characteristic mobility, as:

$$Y_{ij} = Y_c H_0^{(2)}\left(k_b r_{ij}\right) \tag{7}$$

k_b is the plate bending wave number and r_{ij} is the distance between the *ith* and *jth* contact points. The complex power at the *ith* contact, due to the force F_i is:

$$P_i = F_i^* v_i \tag{8}$$

The plate velocity v_i results from the product of force F_i and mobility Y_{ii} at the contact, and the sum of the product of forces F_j at the other contacts and the associated transfer mobility terms Y_{ij} :

$$v_i = F_i\, Y_{ii} + \sum_{j \neq i}^{N} F_j\, Y_{ij} \tag{9}$$

If the forces are assumed to be of equal magnitude and in phase, and the transfer mobility terms are given by equation (7), then the total transmitted power, through *N* contacts, is given by the real part of the total complex power:

$$P_{trans} = \mathrm{Re}\,(P_{total}) = N\left|F\right|^2 Y_c + \left|F\right|^2 Y_c\,\mathrm{Re}\left\{\sum_{i=1}^{N}\ \sum_{j\neq i}^{N} H_0^{(2)}\left(k_b r_{ij}\right)\right\} \qquad (10)$$

If the forces are independent, then the total power is given by the first term of the RHS of equation (10). Using this to normalize the total transmitted power, to include interaction between forces, gives:

$$P_{norm} = 1 + \frac{1}{N}\,\mathrm{Re}\left\{\sum_{i=1}^{N}\ \sum_{j\neq i}^{N} H_0^{(2)}\left(k_b r_{ij}\right)\right\} \qquad (11)$$

The normalized transmitted power therefore is a function of the sum of the complex interaction terms in equation (11). In turn, the interaction terms are functions of the number and distances between contacts and bending wavenumber of the plate.

The wavenumbers can be assigned values corresponding to the characteristic mobility of representative building plate elements: high mobility (10^{-3} m/Ns) for lightweight elements such as plasterboard panels or chipboard floor sheathing; mid-mobility (10^{-4} m/Ns) at the timber joist or frame connections with chipboard or plasterboard panels; low mobility (10^{-5} m/Ns) for heavyweight elements, such as concrete floors and masonry walls; also for a test laboratory low-mobility reception plate.

Figure 14 shows the normalized transmitted power for two equal in-phase forces on high, mid and low mobility receivers. There is the expected low frequency asymptotic value of 2 (3 dB). This decreases with increased frequency, with interference effects and convergence to unity (0 dB) at high frequency, where the forces can be assumed to be independent. In order that single equivalent values of the source can be used for different receiver mobility conditions, fast convergence to unity is required. The high mobility case (solid line), where the bending wave number is high, shows the most rapid conversion; the low mobility case (dotted line) shows the slowest conversion.

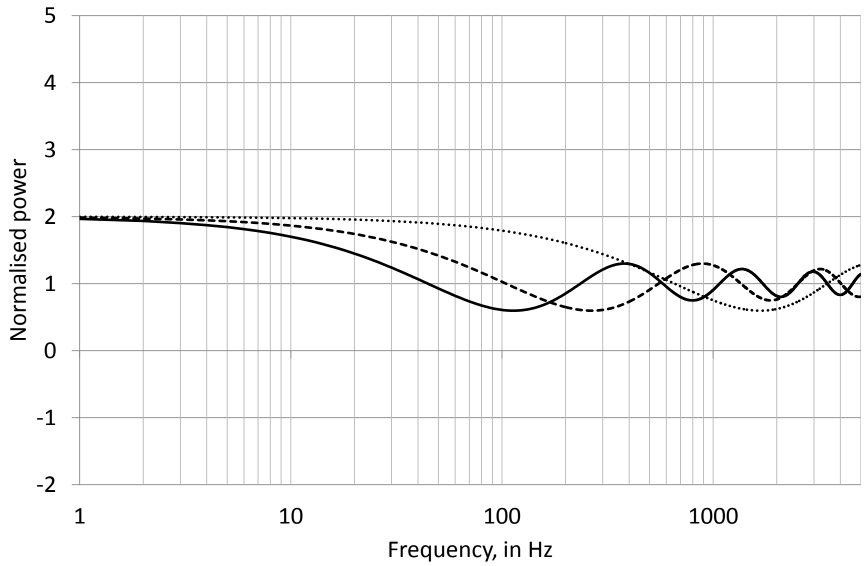

Fig. 14. Normalized power for two equal in phase forces; high mobility plate (solid line), mid mobility (dashed), low mobility (dotted).

In Figure 15 is shown the power from four forces, where phase effects are included, by considering a force-pair in phase with the other force-pair, i.e. all forces in phase, and when the force-pairs are out of phase, i.e. by 180 degrees. With the four forces in phase, the low-frequency asymptote is 4 (6 dB), with convergence with increased frequency to unity. The out-of-phase forces have a low-frequency asymptote of zero. In general, there is more rapid convergence than for the two-force case, due to more complicated geometry and thus increased randomizing effects.

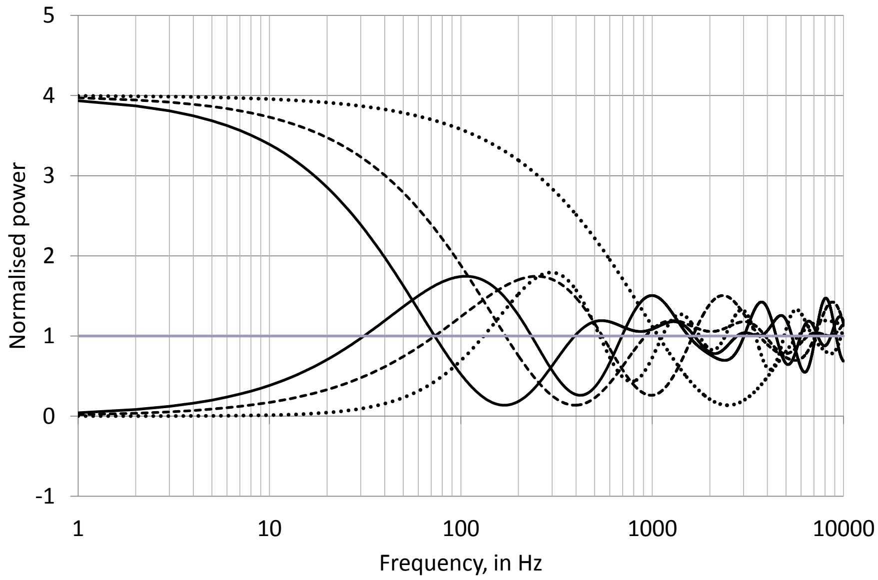

Fig. 15. Normalized power for four forces of equal magnitude: upper curves, all forces in phase; lower curves, one force-pair out-of-phase with the other force-pair; solid lines, high mobility plate; dashed line, mid mobility; dotted line, low mobility.

The implication of these results is that single equivalent quantities, obtained by the reception plate method, can result in uncertainties in predictions of transmitted power into other plate structures with different governing bending wavelengths. The loss of phase information introduces errors into the estimates of the sum-square blocked force, which is the important independent source quantity, required for prediction of installed power. These discrepancies correspond to maximum overestimates of 6 dB at low frequencies, for four equal in-phase forces. For four equal out-of-phase forces, the low-frequency underestimates can be large [14]. However, it is not likely that real contact forces are exactly equal, and exactly in phase or out of phase. In general, for lightweight structures of relatively high mobility, there is little loss of accuracy in the frequency range of interest, if the interactions are neglected and the contacts forces are assumed independent. This discussion of forces on infinite plates and figures 14 and 15 show trends only. Finite plates display modal behaviour and it is assumed that the calculated powers will fluctuate about these trends. With these assumptions, the required source quantities can be expressed as averages of free velocity and point mobility over the contacts; likewise, the required receiver quantity can be expressed as the average of the point mobility over the contacts.

3.4 Use of point values only

Following the discussion of the interaction between forces, the simplifying assumption, requiring point values of mobility and free velocity only, was incorporated and transfer terms neglected. In Figure 16 is shown the mean and standard deviation of the powers at the same 10 fan locations on the timber floor as shown in Figure 6, where complex point mobility only are included (i.e. the off-diagonal elements of the matrices are neglected).

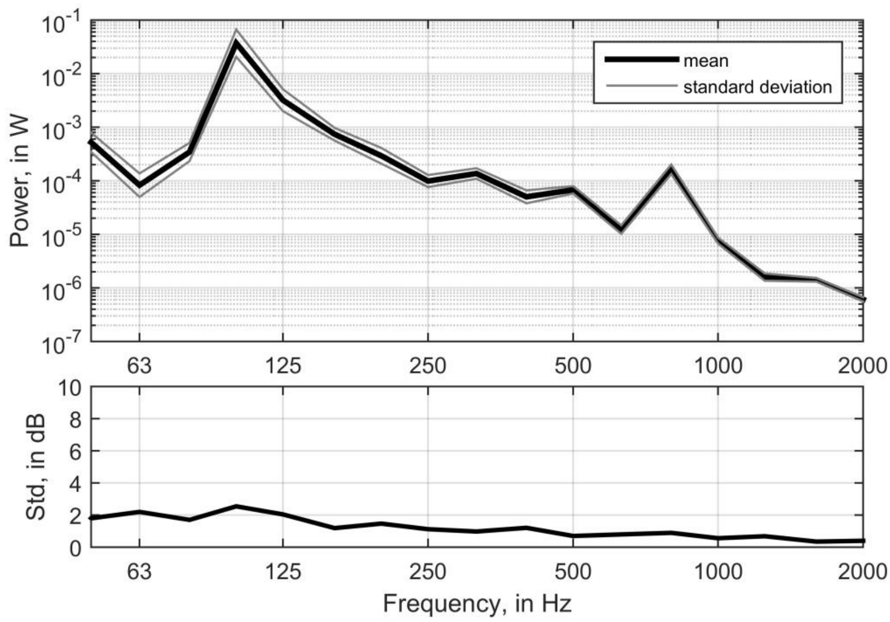

Fig. 16. Mean and standard deviation of the fan powers at 10 locations on the timber floor, where complex point mobility only are included.

The level difference between this estimate and the exact power is shown in Figure 17. There is an overestimate of 2 dB over the frequency range 80 Hz to 2 kHz, which again is of the same order as the standard deviation shown in Figure 6, below 315 Hz.

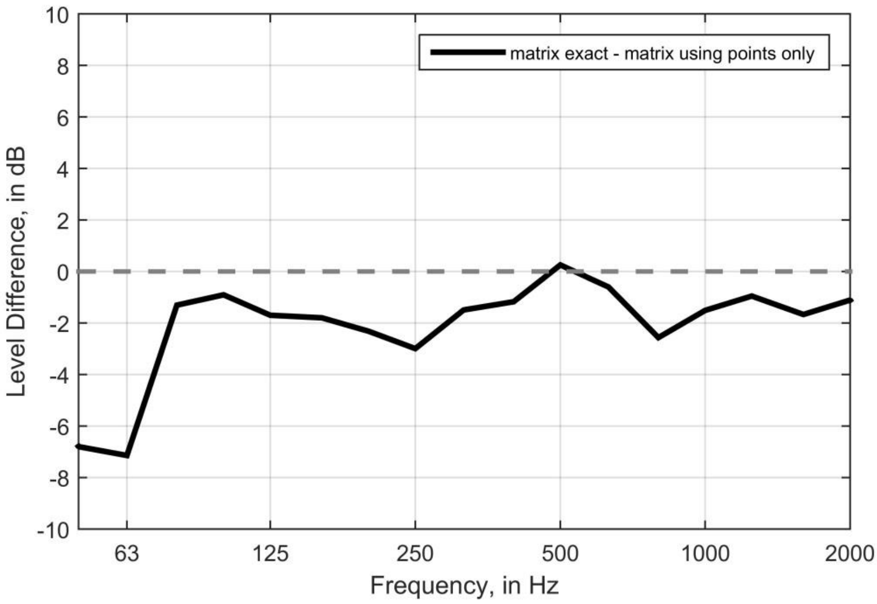

Fig. 17. Level difference between mean power from complex matrix elements and using complex point mobilities only.

3.5 *Effect of combining the simplifications*

It remains to compare the exact powers with estimates obtained with the combination of simplifying assumptions, described in sections *3.1* to *3.4.* This is shown in Figures 18 and 19 for the two previously considered fan locations.

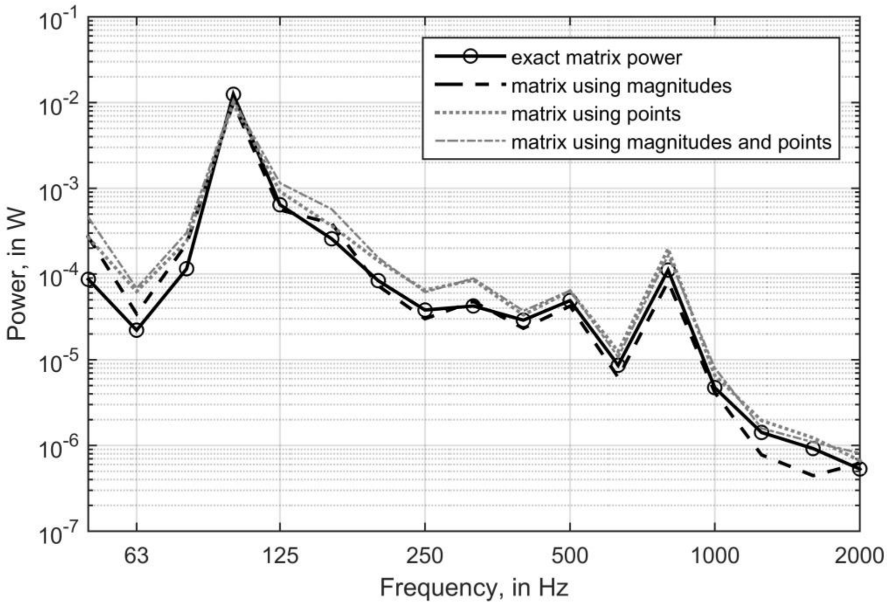

Fig. 18. Power for fan located in bays, including estimates using magnitudes and point values.

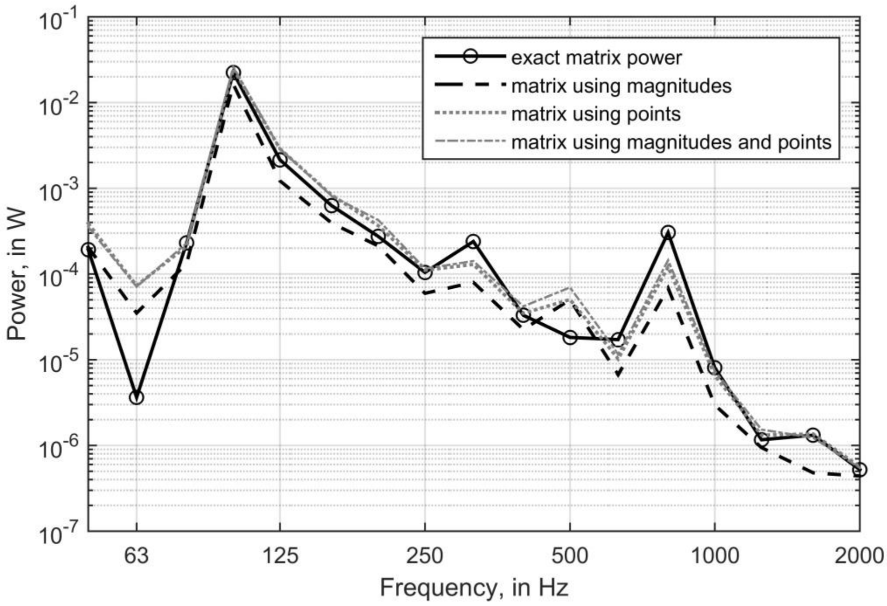

Fig. 19. Power for fan located on a joist and in a bay, including estimates using magnitudes and point values.

The combination of simplifying assumptions gives estimates within 5 dB of the exact power over the whole frequency range. This indicates the expected accuracy of the two-stage laboratory test method, outlined in the introduction and now described in detail.

4. Two-stage laboratory method

The first stage of the proposed laboratory method is the direct measurement of the fan free velocity, described earlier and according to the Standard ISO 9611 [10]. The velocities at four contact points were recorded on 1/3 octaves and stored as the sum square $\sum v_f^2$ shown in Figure 3.

For the second stage, the fan was glued to a plate of 20mm thick aluminium of size 2.12m x 1.50m (Figure 20 left). The plate was supported at the corners by six visco-elastic pads (Figure 20 right). The pads provided isolation and damping, which added to the plate total loss factor η at low frequencies. With the fan operating, the plate response velocities were recorded at seven accelerometer positions and the average square velocity incorporated into equation (1) to obtain the fan power and thence the sum square blocked force from equation (2). For equation (2), the real part of the plate mobility also is required.

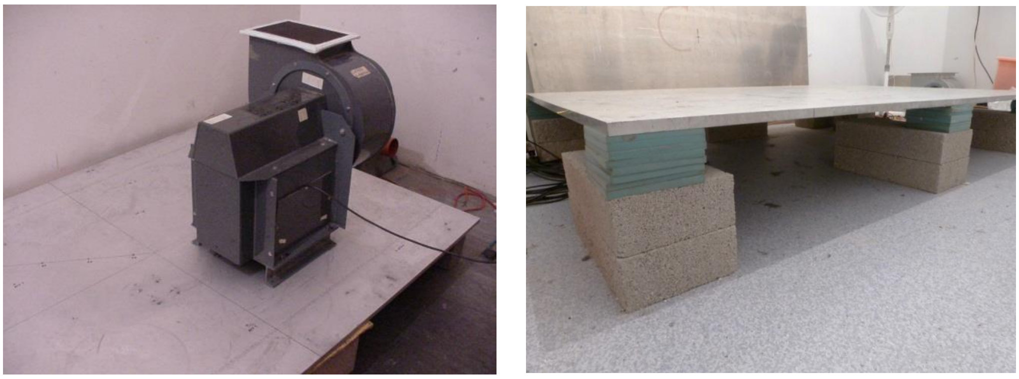

Fig. 20. Low mobility reception plate (left) with fan unit attached. Plate supported by visco-elastic pads (right).

Figure 21 shows the spatial average of eight measurements of point mobility of the 20mm aluminum plate, as magnitude and real part. Also shown is the average measured magnitude of source point mobility of the fan unit. This shows that fan mobility is greater than the plate mobility at frequencies above 250 Hz and the required force-source condition can be assumed. Below 250 Hz, the mobilities are of the same order and errors in the approximate method are likely.

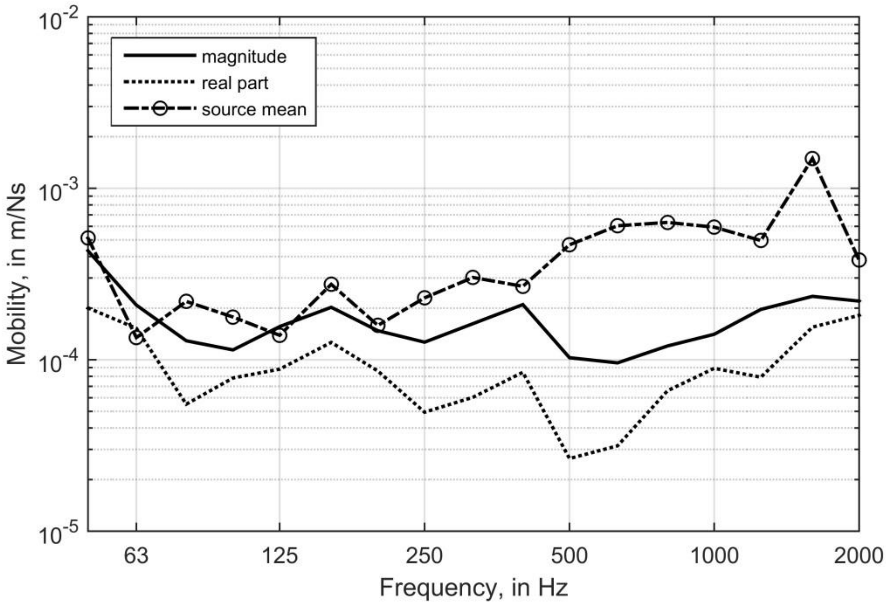

Fig. 21. Average point mobility of 20mm plate: solid line, magnitude; dotted line, real part. Also shown is the average measured magnitude of fan point mobility.

The second stage gives the sum square blocked force, using equation (2), and then the average point mobility of the fan, using equation (3). Figure 22 shows the average mobility, from the two-stage method and the directly measured value in 1/3 octaves.

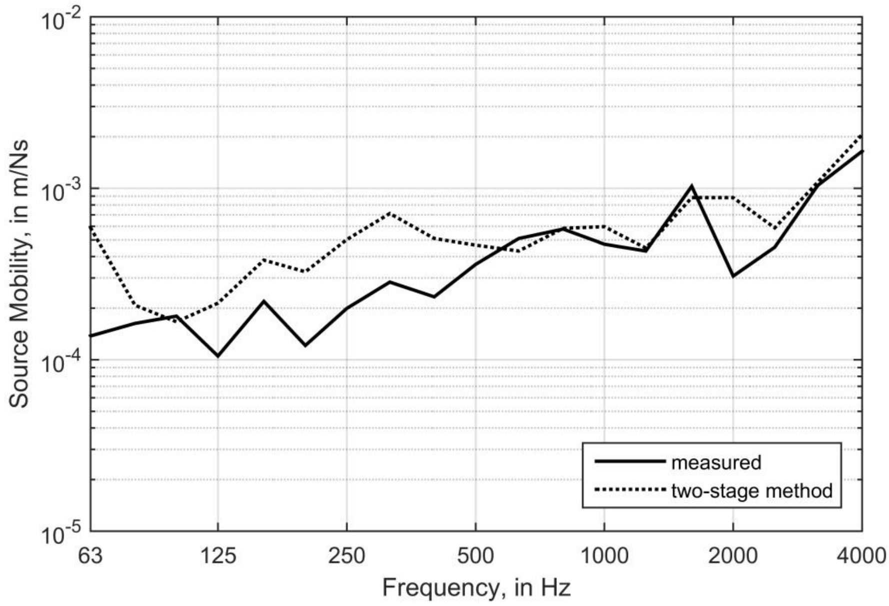

Fig. 22. Measured average source point mobility magnitude (solid line) and by two-stage method (dotted).

There is the expected larger discrepancy at frequencies below 500 Hz, but figure 23 shows that the level difference between the directly measured mobility and the two-stage estimate is within 5 dB.

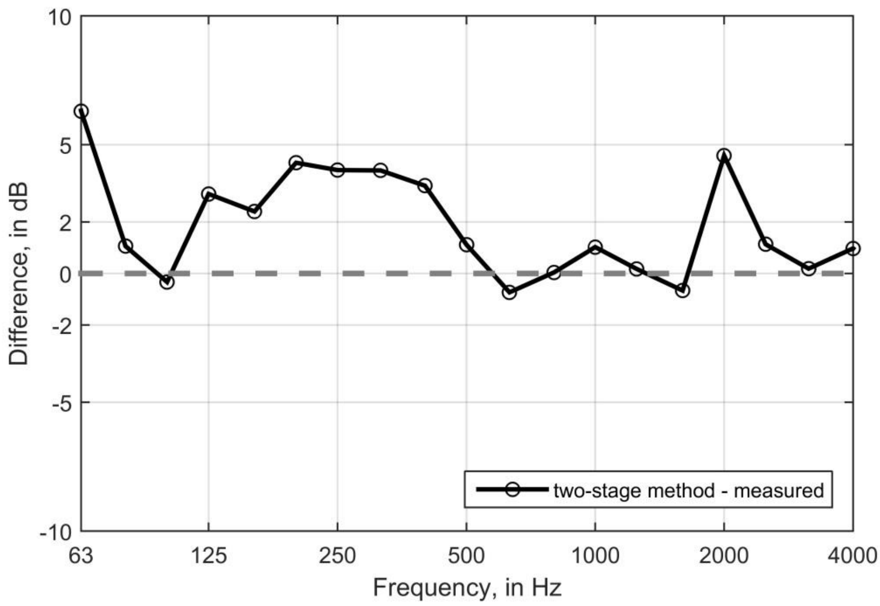

Fig. 23. Level difference between the measured average source point mobility, and two-stage estimate.

5. Predicted installed power using the approximate method

In addition to the source data, the receiver mobility is required to predict the installed power. In recent work on mechanical installations in buildings, it has been demonstrated that heavyweight homogeneous floors and walls display plate-like dynamic behaviour [16]. Lightweight inhomogeneous receiver structures also mostly reveal plate-like behaviour [17]. These situations can be described by the characteristic plate mobility. Even for framed constructions where the studs or joists appear to be dominant in certain frequency ranges, an estimate of the receiver mobility, as a function of the characteristic beam mobility and the characteristic plate mobility, is appropriate [17].

To assess how errors in the source data affect the estimated power in the installed condition, the fan data was obtained from the two-stage method and used, in combination with measured receiver data, according to equation (4). The powers are shown for three fan locations on the timber joist floor. Figure 24 shows the powers for the fan with two contacts in one bay and two contacts in an adjacent bay, separated by a joist. Also shown is the level difference.

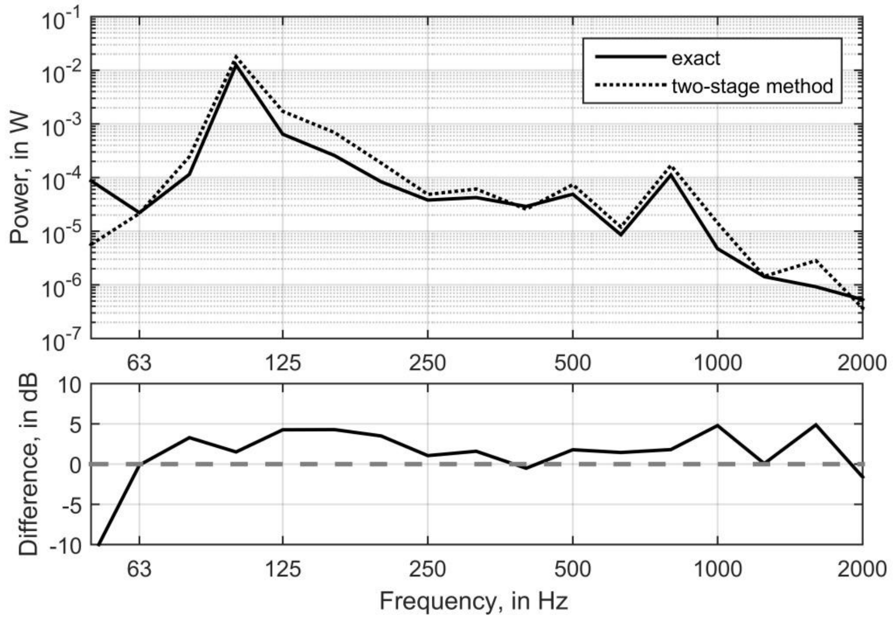

Fig. 24. Exact and approximate power for the fan located with contacts in two bays.

The two-stage estimate is within 5 dB, partly within 2 dB, of the exact value at frequencies above 63 Hz. Figure 25 shows exact and estimated powers for the fan with four contacts in one bay.

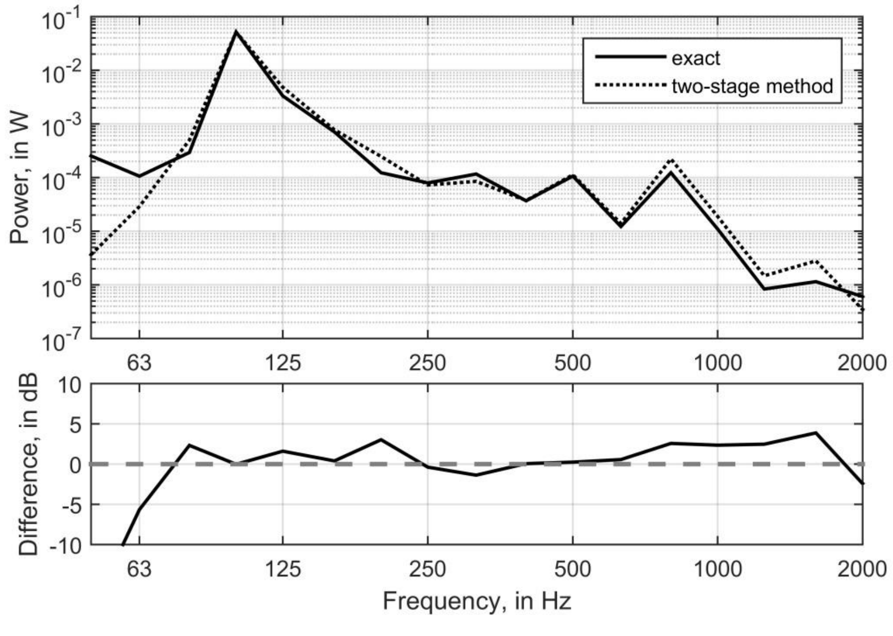

Fig. 25. Exact and approximate power for the fan located with four contacts in one bay.

Above 63 Hz the estimate for this condition is within 3 dB of the exact value. Results are shown in Figure 26 for the fan with two contacts on a joist and two contacts in a bay. Again, the two-stage estimate is within 5 dB of the exact value at frequencies above 80 Hz.

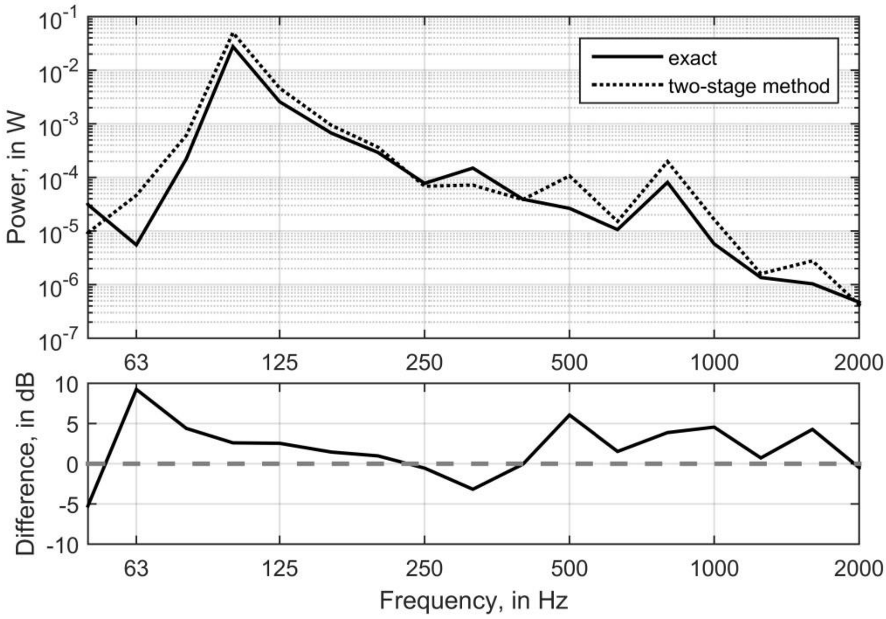

Fig. 26. Exact and approximate power for the fan located with two contacts on a joist and two contacts in an adjacent bay.

The discrepancies were also partly the result of inversion errors due to ill-conditioned matrices, resulting from negative real-parts of measured point mobility, or noise. This was partially eliminated by rejecting measured negative real parts in point mobility and using regularisation [18]. For the three contact conditions highlighted, the approximate method, using two-stage source data and measured receiver point mobility, gives estimates within 5 dB, often within 3 dB of the exact power. Figure 27 shows the approximate power for ten fan positions, normalised with respect to the exact powers at the same positions. Also shown is the average value.

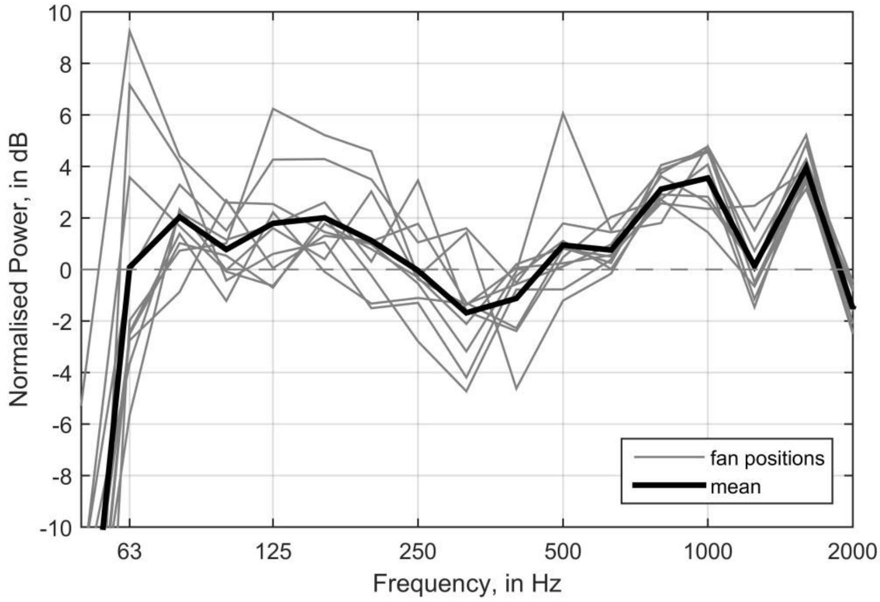

Fig. 27. Normalised power at ten fan positions with average value.

On average, the exact power is approximated within 2 dB, between 80 Hz and 2000 Hz, with deviations of 4 dB at 1000 Hz and 1600 Hz. The standard deviation is between 2 – 3 dB.

The case studies described so far used measured receiver mobility data, which is usually not available. Therefore, the calculations were repeated using simple estimates based on the characteristic behaviour of plate-like and beam-like structures [17]. From inspection of the mobility in a bay (Figure 5, upper graph), a frequency invariant value of 10^{-3} m/Ns is assigned. This assumption is supported by a field survey of lightweight building elements [17].

Figure 28 shows the average normalised power for ten fan locations, using the value of 10^{-3} m/Ns for the receiver mobility.

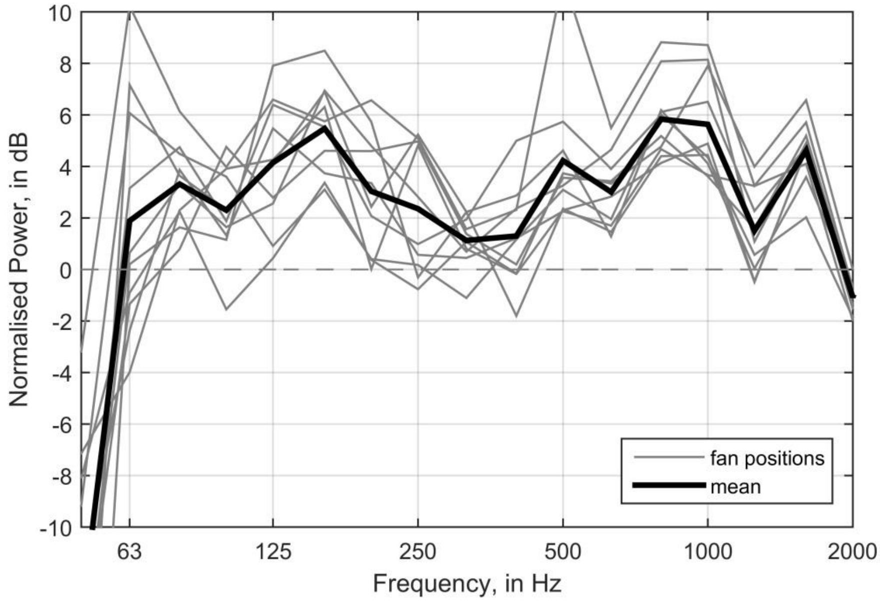

Fig.28. Normalised power at ten fan positions with average value, for an assumed receiver mobility of 10^{-3} m/Ns.

The discrepancies are greater at some individual locations, particularly where there are contacts over joists, but on average, the power is over-estimated by 2-6 dB, between 63 Hz and 2000 Hz.

6. Concluding remarks

An approximate method has been investigated, for obtaining the source quantities required for calculating the structure-borne sound transmission from mechanical installations in buildings. The approximate estimates of installed power were compared with calculated powers obtained by the full mobility method, for the source fictively connected to the supporting receiving structure. The case studied was that of a medium size fan attached to a timber-joist floor through four mounts and at ten locations.

Several simplifying assumptions were considered, regarding the accuracy with respect to the exact calculated powers. Using magnitudes of mobility gave an underestimate of the exact power of 2 dB on average and points to the use of octave- or third-octave data in measurement and calculation. Neglect of either the source or receiver mobility gives large discrepancies, depending on frequency and location, and the magnitudes of both quantities are required if estimates are to be within 5 dB of the exact power. Neglect of the interactions between the contact forces of multiple-mount sources (the fan was on four mounts) gives an overestimate of the exact power of 2 dB on average.

When the above simplifications were combined, the approximate method gave estimates within 5 dB of the exact powers, on average.

From this, a development of the two-stage reception plate method is proposed, where the first stage involves direct measurement of the velocity of the free source in third octaves, expressed as the sum of the square velocities at the contacts. The source mobility then was estimated within 5 dB of the average measured point mobility.

The source data, obtained by the two-stage method, gave estimates within 2-4 dB of the exact calculated powers on average, for the fan at 10 locations on the timber-joist floor. When the floor mobility was assigned a frequency invariant value of 10^{-3} m/sN, irrespective of location, the power was overestimated by 2-6 dB.

Whilst this study has been of one source, a fan unit, and one receiver, a timber floor, the contact conditions have varied significantly with frequency and location (e.g. between locations over joists and locations in bays) and the results are indicative of the expected accuracy of the approximate method.

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