Applied Acoustics 110 (2016) 81–90

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

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

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ARTICLE INFO

Article history:
Received 1 October 2015
Received in revised form 12 March 2016
Accepted 21 March 2016

Keywords:
Building acoustics
Structure-borne sound
Reception plate method

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.

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 $\langle v^2 \rangle$:

$$P_{source} = P_{plate} = \omega \eta M \langle v^2 \rangle \tag{1}$$

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:

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

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http://dx.doi.org/10.1016/j.apacoust.2016.03.024
0003-682X/

The single equivalent value of blocked force F_{beq}^2 is extracted from Eqs. (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]:

$$|Y_{Seq}| = \sqrt{\sum v_f^2 / F_{beq}^2} \tag{3}$$

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:

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

Eq. (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. Fig. 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. Fig. 1, right, and Fig. 2 show the timber joist floor, which was constructed in the acoustics laboratory of Stuttgart University of Applied Sciences.

The floor consisted of one layer of 21 mm chipboard supported by seven spruce joists with dimensions 0.096 m × 0.192 m × 4.55 m. The joist spacing was at 0.78 m centres. The chipboard sheathing consisted of panels of dimensions 0.9 m × 2.05 m joined by unglued tongue and grooves and screwed to the joists at 0.2 m 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

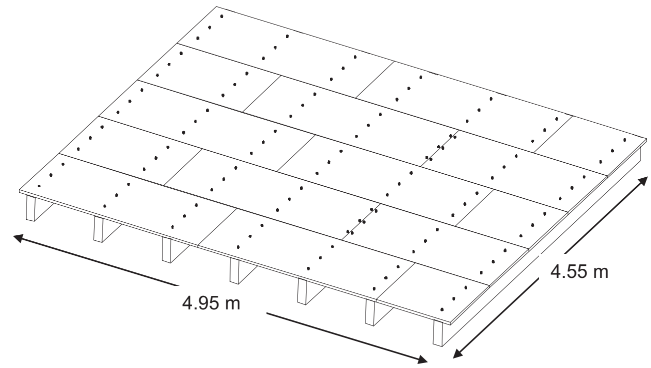

Fig. 2. Floor construction and dimensions, indicating the sheathing board layout and screw fixings.

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]:

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

where $\overline{v}_f$ 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 Fig. 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, 50–2000 Hz, there are low frequency tonal components at 50 Hz and 100 Hz, combined with a broadband spectrum.

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 Fig. 4 is shown the narrow-band point mobility magnitude at the four contacts, along with the 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 corre-

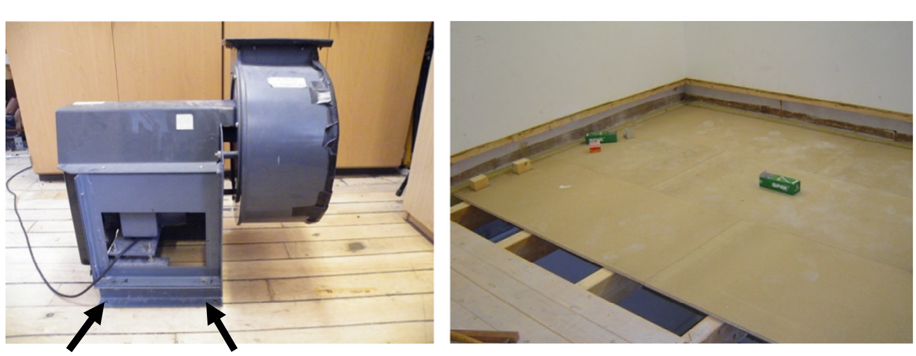

Fig. 1. Left, fan unit, free-standing in laboratory area, with two of the four contact points indicated; Right, timber joist chipboard floor under construction.