An in situ measurement method for characterisation of structure-borne sound sources

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Introduction

'Characterisation' of sources means acquiring data to describe their strength, e.g. to a purchaser, consultant, planner or regulator: it is needed to help predict, prevent, reduce and regulate unwanted structure-borne sound. However, while there is a clear need, measurement standards are not well developed due to unsolved practical problems.

Classically, the quantities to characterise structure-borne sound sources are free velocity or blocked force, together with mobility or impedance. Alternative descriptors for the active source properties include the power-based 'source descriptor' and the 'characteristic power'. The latter is the preferred source descriptor in EN12354-5: 2009 although this standard acknowledges that suitable measurement procedures are not yet in existence.

A standard measurement procedure exists for free velocity (ISO 9611) but for many types of sources the required 'free' mounting conditions cannot be achieved. Blocked forces can also sometimes be measured by mounting the source on massive blocks. However, again there are significant practical difficulties in applying this approach to many types of sources. Building-mounted wind turbines provide an example of a source for which neither the free, nor the blocked mounting conditions can be achieved in practice. However, Moorhouse et al [1] have recently proposed an in situ measurement approach which in theory is suitable for obtaining blocked forces indirectly from a normal installation. The aim of this paper is to introduce this approach and to present some results of practical measurements. First, we consider the conventional approach to indirect measurement of forces.

Inverse force measurement

A number of authors have investigated a technique, amongst other names known as inverse force synthesis, force identification and input force estimation. A two-stage measurement procedure is required: first, operational velocities are measured at various reference points on a receiver structure to which the source is attached. In the second stage, the source is removed and the receiver structure is characterised, usually by measuring transfer mobilities between the reference points and the contact points (at which the source was attached). The forces acting on the receiver structure during operation are then calculated by solving the input-output equation:

$$v_r = Y_{R,rc} f_c \qquad (1)$$

where v_r is the operational velocity measured on the receiver structure, f_c is the contact force and $Y_{R,rc}$ the mobility connecting these points. For multiple point contact interfaces, f_c and v_r are vectors and $Y_{R,rc}$ is a matrix.

Having obtained the operational forces it is then possible to predict the response at any other position on the receiver for which a suitable transfer function is available. This is the approach used in transfer path analysis (TPA) where the predicted response is often the sound pressure, for example at a driver's ear position, which cannot be measured directly due to interference from other sources. Nowadays, there is a high confidence in predictions made according to this approach. However, the contact forces are unique to one specific source-receiver combination so prediction of the response of a different receiver to the same source, often required in practice, is not possible. In the following section we look at the new method which avoids this disadvantage.

In situ measurement of blocked force

In [1] an approach is described which follows the same basic steps used for inverse force synthesis as described earlier. The only difference in the procedure is that in the second step the mobilities are measured with the source still attached to the receiver. The corresponding inverse problem is:

$$v_r = Y_{C,rc} f_{bl} \qquad (2)$$

where the operational velocities, v_r are the same as before and $Y_{C,rc}$ is the mobility between the same points as before but with the source still attached, i.e. it is the mobility of the coupled source and receiver. It turns out that the solution to this equation is none other than the blocked forces of the source f_{bl}. A proof has been given in [1] and a more general proof was given in 2001 by Bobrovnitskii [2].

There are two major benefits with this formulation. First, a TPA can be carried out in the same way as before but with the major advantage that there is no need to separate the source and receiver structures at any stage. Secondly, the blocked forces characterise the source independently of the receiver and can therefore be transferred to predict response in different receiver structures. In the following section we provide results of some measurements taken to validate the new method.

Validation

Direct validation is problematic since the 'true' blocked force cannot be measured. To avoid this problem we give here two types of indirect validation using a measured velocity as a reference. First the velocity of the source is predicted when separated from the receiver (the free velocity) and secondly when attached to a different receiver structure.

Figure 1 shows the beam structures used for the first test: the source beam (which includes two spacers at the contact points) and the receiver beam were rigidly bolted together for the source characterisation tests. Source activity was simulated with a force hammer for repeatability. In the lower part of figure 1 the measured free velocity is compared with that predicted from the blocked force using $v_{fs} = Y_S f_{bl}$ in which Y_S is the source mobility and the blocked forces f_{bl} were obtained by solving equation 2. Excellent agreement is seen over a wide frequency range. Despite the simple appearance of the beam structures this represents a very challenging case since (a) it was necessary to include moment excitation (measurements not described in detail in this paper) and (b) because the receiver structure displays strong resonances.

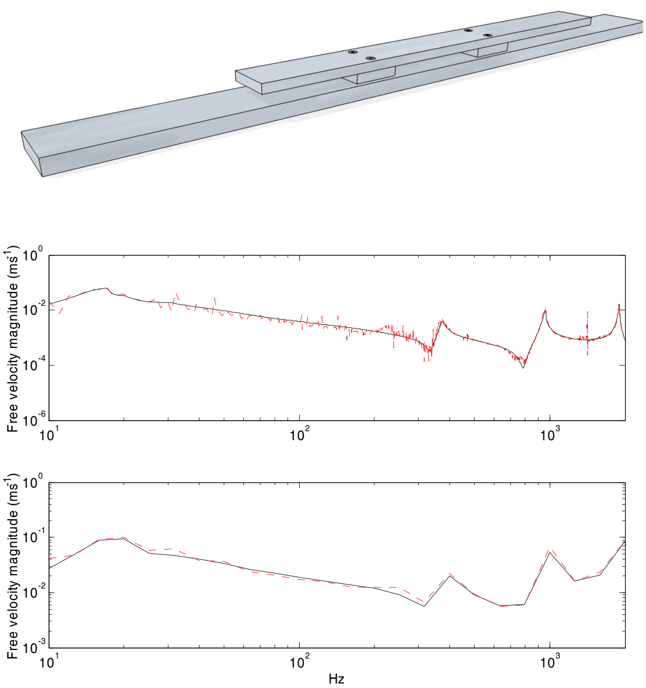

Figure 1: (a) beam structures used for validation tests. (b) free velocity at one point on the source beam: … predicted; ___ measured in narrow and third octave bands.

The second stage in the validation involves predicting the velocity in a new receiver structure. Excellent agreement was again obtained for the beam structures (not shown). Shown in figure 2 are the results of the prediction obtained for an electric motor mounted on a mast which is designed to be representative of a small wind turbine on its mounting (see [3]). A real excitation from the motor (accurately controlled via a speed controller) was used in this case. The two different receiver structures were realised by changing the length of the mast. Thus, the blocked force was obtained from measurements on a short mast which were then used to predict the response of a long mast. The predictions were conducted by evaluating $v'_r = Y'_{C,rc} f_{bl}$ where v'_r is the predicted velocity and $Y'_{C,rc}$ the mobility in the new source-receiver assembly. As before, although apparently simple this is a highly challenging case needing blocked forces in five degrees of freedom and requiring strong resonances in the first mast to be 'removed' for prediction in the second. The agreement is good over an extremely wide frequency range, especially considering that some of the differences are due to inevitable variations in the operation of the source for the characterisation and validation tests. Further examples are given in [3] and [4].

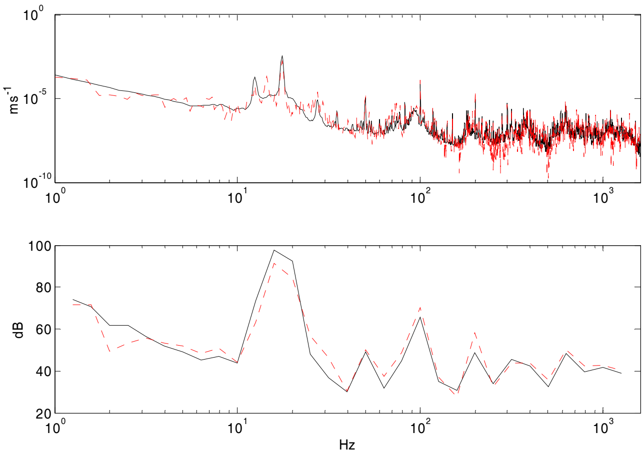

Figure 2: Velocity at a point in a new receiver: … predicted; ___ measured, in narrow and third octave bands.

Conclusions

Results from two apparently simple, but in reality extremely challenging case studies have shown that blocked forces can be inferred from measurements made in situ, i.e. with the source installed. Moreover, the blocked forces can be used to predict the response in a different receiver structure. Excellent agreement has been obtained over a frequency range from 1Hz to well over 1kHz.

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References

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