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TWO APPLICATIONS OF THE PSEUDO-FORCES METHOD FOR CHARACTERIZING THE SOURCE STRENGTH FOR STRUCTURE-BORNE SOUND

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1. INTRODUCTION

Whereas source strength measurements for air-borne sound sources are well standardized, the development of source descriptors for structure-borne sound still requires significant further research to arrive at a similar level of practical implementation. Verheij [1,2] proposed a method, called the 'pseudo-forces method', which considerably reduces the measurement effort compared to that involved in more classical approaches which are based on a multi-dimensional version of the Thévenin or Norton concept from electrical network theory. The method allows for multi-dimensional vibrations and multiple-source mechansims in the source.

2. METHOD

In the approach the actual internal noise generating mechanism is replaced by a set of 'pseudo-forces' on the outer surface of the source. Of course, the question arises how many pseudo-forces are necessary to reproduce the original signal. If the source is a rigid body six forces would suffice (and these six will be valid for the source in *any* built-in situation and are therefore a *source property*). If modal behaviour of the source is to be considered, one additional force for each eigenmode is necessary. In practice it may be sufficient and more convinient to reproduce only the response of the main contributing modes (or vibrational *degrees of freedom* (DOF)).

This concept is expected to be practical, since it evaluates the source at its outer surface, which will, in general, be accessible for transducers (without dismantling). Furthermore, the pseudo-forces can be determined by measurements of the source in an (almost) arbitrary situation (no *special* test rig is needed), using an inverse technique:

$$\{F\}_{pseudo} = [A]^{+} \{a\}_{running} \quad (1)$$

with $\{a\}_{running}$ a response vector of the running machine and $[A]^{+}$ the inverse (or pseudo inverse, if appropriate) of the (measured) transfer matrix which relates excitation forces and responses. Once the pseudo-forces are known, the sound pressure (via a structure-borne transmission path) can be estimated using:

$$\{p\} = [H] \{F\}_{pseudo} \quad (2)$$

with [H] the (measured) transfer matrix from force positions to sound pressures. Two applications are now described.

3. APPLICATIONS

Electrical Drive
The first application concerns an electrical drive of a copier machine (mass: 2.45 kg, motor: 1500 r.p.m., output shaft: 32 r.p.m.). The number of relevant DOFs was assessed by measuring an 8×12 accelerance matrix [A] of the free source. The *number* of DOFs of the source equals the number of non-zero *singular values* (SV) of [*A*] (the rank). An indication for the *importance* of the DOFs can be assessed by evaluating the *magnitude* of the SVs. Fig. 2 gives the number of SVs which are within 0.25 of the highest SV (for lower SVs the equivalent DOFs can be expected to contribute about 12 dB less to the response). This number of 'significant' DOFs almost never exceeds 5 in this case. Near resonances frequencies it is even lowered to 2 or 1, since here the response will be largely dominated by one eigenmode and therefore one DOF.

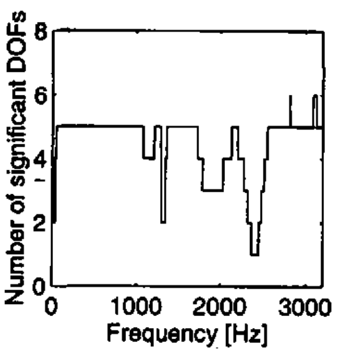

Fig. 1. Estimate of the significant number of DOFs, based on the singular values of 8×12 accelerance matrix

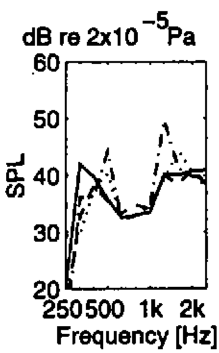

Fig. 2. Sound Pressure Level
____ = Measured, 48.6 dB(A),
----- = Using eqn. (3), 47.8 dB(A),
..... = Eqn. (4), block, 50.1 dB(A),
-.-.- = Eqn. (4), free, 52.3 dB(A)

The number of uncorrelated noise generating mechanisms in the source was also studied, using principle component analysis, see e.g. [3]. A single source mechanism approach appeared to be adequate.

For the pseudo-force experiment 5 pseudo-forces are used to cover 5 DOFs. The drive is mounted onto the framework of the copier. The goal is to estimate the sound pressure at several positions near the frame based on the pseudo forces:

$$\{p\}_{estimated} = [H]\{F\}_{pseudo} = [H][A]^{+}\{a\}_{running} \tag{3}$$

and compare this with the actual sound pressure level. This is shown in Fig. 2 (solid and dashed lines). These two spectra agree quite closely. The measured and predicted total levels agree within 1 dB(A).

To investigate whether the pseudo-forces really model a *source property,* they were not only determined with the drive mounted on the frame but also with the drive in quite different mounting conditions, namely mounted on a heavy block and freely suspended (whilst the load was kept constant). If the pseudo-forces are independent of the surrounding then the sound pressure near the frame should also follow from:

$$\{p\} \approx [H]_{frame}\{F\}_{pseu,block} \approx [H]_{frame}\{F\}_{pseu,free} \tag{4}$$

Fig. 2 also presents the sound pressure level predicted using eqn. (4). These predictions are very reasonable, although some deviations are apparent, mainly around 1250 Hz.

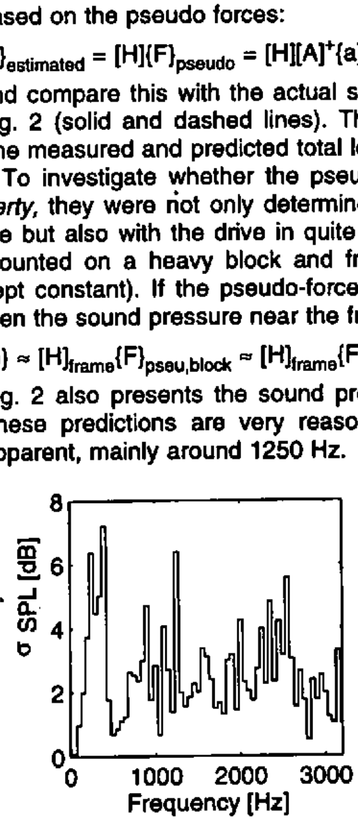

***Fig. 3.** Standard deviation in the SPL at 50 Hz harmonics due to sequential dis- and remounting of the drive.*

One of the reasons for the deviations in Fig. 2, which is not due to the modelling, is the unrepeatability of the source. To illustrate this, Fig. 3 presents the standard deviation of the sound pressure level near the frame caused by dismounting and remounting the drive into the copier frame several times. It is clear that a significant scatter is present, which certainly has influenced the results in Fig. 2.

Hydraulic Pump

In a second experiment the pseudo-forces method was applied to a hydraulic piston pump in a refuse lorry. This pump drives the compression of the refuse in the lorry and is a main source of sound and vibration. The vibration level of the vehicle frame was measured in a workshop with the pump mounted underneath the vehicle. This level is presented in Fig. 4. along with a prediction based on pseudo-forces,

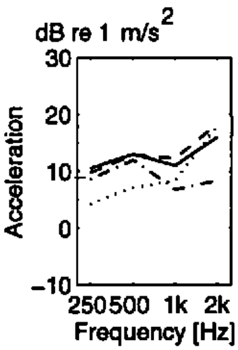

Fig. 4. Vibration of vehicle frame.
___=measured in vehicle,
----=predicted using pseudo-forces determined in test-rig,
-.-.-=due to vertical moment only,
.....=total other components.

which were determined with the pump in a test-rig at the pump manufacturer (under simular operational conditions). Additionally, the third line presents the response due to the vertical pseudo-moment only and the last line that of the other components. It appears that the vertical pseudo-moment gives the main contribution to the vibration level in the frequency range to 250 - 500 Hz.

4. CONCLUSIONS

The source strength for structure-borne noise of an electrical drive and a hydraulic pump was characterized successfully with the pseudo-force approach. The measured sound or vibration in a particular built-in situation could be reproduced satisfactorily, even when the pseudo-forces were determined with the source in quite a different built-in situation (with the load kept constant). Furthermore, predominant excitation directions could be pointed out, which can be very relevant in a low noise design process. For these practical cases the number of relevant DOFs was limited and therefore using only a few pseudo-forces sufficed. The experiment with the hydraulic pump mounted underneath a refuse lorry showed that the method is practical. The experiments also showed that the scatter in structure-borne noise levels from a certain component (in nominally identical situations) can be very significant. This scatter, and even more the scatter between various samples of the same series, is an important aspect in source description and its possible accuracy and therefore it is recommended that more experience is built up e.g. with several samples of nominally identical sources.

References

[1] J.W. Verheij, M.H.A. Janssens, P.J.G. Charlier, Proc. InterNoise '95, Newport Beach CA, USA, 1995, p 559-562.
[2] J.W. Verheij, Congress on air- and structure-borne sound and vibration, St. Petersburg, Russia, June 24-27, 1996.
[3] D. Otte, P.van de Ponseele, J. Leuridan, Proc. of the 8th IMAC, Kissimmee Florida, USA, 1990, p 413-421.