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MULTI-POINT SOURCE CHARACTERISATION APPLIED TO A DIESEL ENGINE RIGIDLY MOUNTED ON A RAFT

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ABSTRACT
This paper discusses the structure borne sound transmission from a source to a receiver via multiple connection points and directions. In such multi-point contacts coupling effects between degrees of freedom may be important for a correct source description. A ships diesel engine mounted on a raft was taken as an example. Free velocities of the engine and mobility matrices of engine and raft have been measured. By using these measurements the power transmission from the engine to the raft via 4 translational degrees of freedom is studied in detail, accounting for coupling effects via 12 degrees of freedom. It can be concluded that multi-point effects play a role in the amount of power transmitted via each single degree of freedom. If the scope becomes more global, i.e. if one considers the total power transmission in a frequency-averaged sense, the coupling effects tend to become less important.

1 - INTRODUCTION
To predict 'the amount of sound transmitted' by for example an electric motor to a connected supporting frame, both properties of the source and receiver structure are needed. In many cases sound sources are connected to their supporting structures via multiple points and multiple vibrational directions. Such multi-point situations cannot, in general, be described by a number of independent sources to predict the amount of power transmitted to the receiver [1]. Interaction effects may cause a different amount of power to flow from source to receiver than in a situation of independent sources. However, it might be so that these interaction effects can be confidently neglected in a frequency-averaged approach under the condition that the dynamic behaviour of the source and receiver structures is sufficiently 'complex', as is required for the applicability of SEA for example.
A difficulty in structure-borne noise source characterisation studies is that only very limited data is available regarding 'multi-point effects'. Therefore an experiment-based study was performed into the behaviour of a ships diesel engine (the source), which is to be rigidly mounted on a raft structure (the receiver). Normally, the diesel-raft combination will be flexibly mounted in a ship. It was possible to measure the acoustic properties of the engine and the raft both separately and in the connected situation. The effect of mounting the engine directly on the raft is studied using the measured data, with attention for multi-point and multi-component effects. A schematic view of engine and raft is given in figure 1.

2 - THE DIESEL ENGINE AS A SOURCE
The engine has 16 cylinders, weighs 41 tons including fluids and its dimensions are roughly 5 $\times$3 $\times$2 m. For measurements of the 'free velocities' and the mobilities at the engine footings, the engine was supported on 6 flexible mounts on the foundation of a test room. The measurements and analyses are limited to vertical (z) and transverse (x) translational vibration components at the 6 footings.
This leads to 12 free velocities that were measured, with the engine mounted on resilient mounts, for 2 different engine speeds of 906 and 1000 rpm. The spectrum of the free velocities is very tonal, with the energy concentrated at the peaks. The free velocities are only coherent with each other close to these tones and below frequencies where all coherence between the different degrees of freedom (dofs) is lost, i.e. below about 800 Hz (if there is no coherence between the vibrational motion of different footings,

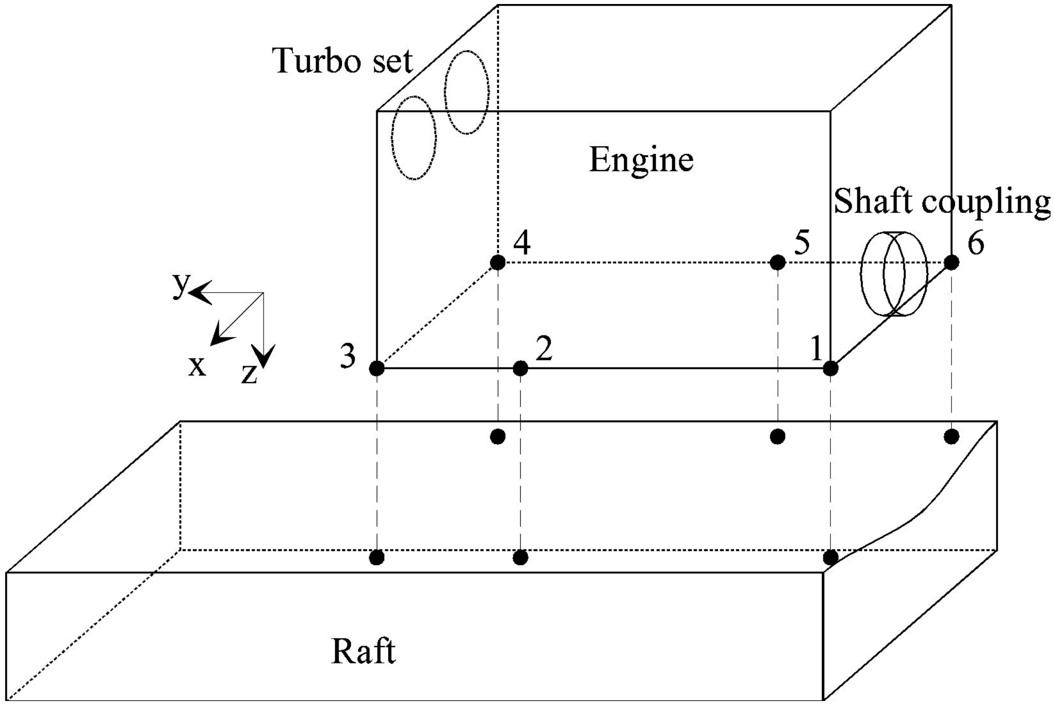


Figure 1: Sketch of the diesel engine and its raft, with the measurement positions.

they must be considered as independent sound sources and power flows can be added incoherently). Therefore multi-point effects are only found at these selected frequencies.
For footings 4 and 6 all mobilities of the engine for the 2 translational directions are measured. This gives 48 FRFs: 4 driving point mobilities, 4 cross mobilities, 20 transfer mobilities and 20 transfer-cross mobilities. This limited set makes it possible to study in detail the power flow via 4 degrees-of-freedom (dofs) accounting for coupling effects from 12 dofs. The engine mobilities show global mass behaviour up to 40 Hz, stiffness behaviour of the footings up to 400 Hz, and resonant behaviour of the footings for higher frequencies.
From the free velocities and the source mobilities, the effective mobilities and source descriptors [1] can be calculated for each direction (calculations are carried out for the selected frequency lines; presentation is done in 1/3-octave bands). To do this, assumptions have to be made to calculate the ratios of the interaction forces between source and receiver, because the data set is not sufficiently complete to calculate the exact force distribution.
Figure 2a shows the effective mobility for footing 4 in the z-direction, for an engine speed of 1000 rpm, with force ratios based on a constant force source assumption (cfsa; a cfsa means that the source mobility is assumed to be much larger than the receiver mobility; the opposite, a constant velocity source assumption (cvsa) was also tested) [2]. The total effective mobility is shown as well as its components: the 'direct' mobility is the normal driving point mobility and it can be seen that the cross and transfer-(cross) coupling effects have clear influences: the total effective mobility differs significantly from the direct mobility.
Figure 2b shows the source descriptor, calculated for the 2 different assumed multi-point force distributions, compared with that based on the direct mobility only. The deviations indicate that, because of multi-point effects, the engine is able to deliver less power than would be expected from the point mobilities only.

3 - ENGINE RIGIDLY MOUNTED ON RAFT

Like for the engine the same set of 48 mobilities was measured on the raft structure. The raft is a more slender frame-like structure and its dynamical behaviour shows clear global resonances below about 400 Hz (an experimental modal analysis was performed for the raft based on 200 FRFs). For the raft also effective mobilities have been calculated with the same force ratios as for the source.
Since effective mobilities of source and receiver are available (for 2 points, in 2 directions) the coupling functions can be calculated. These describe the dynamics of the specific coupling, and as a product of

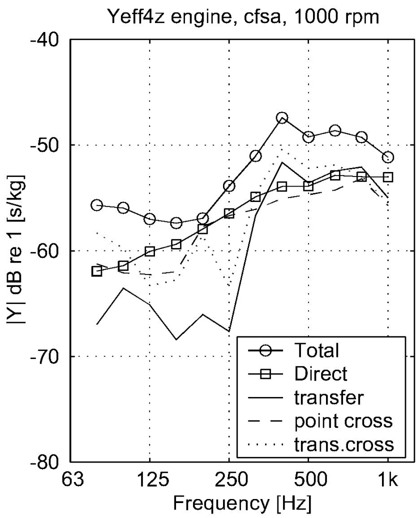


Figure 2(a): Example of an effective mobility of the engine and corresponding source descriptor.

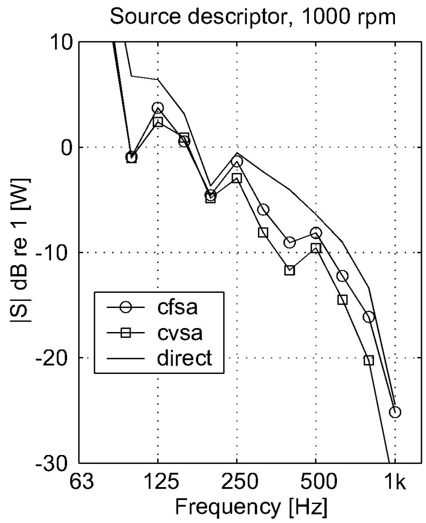
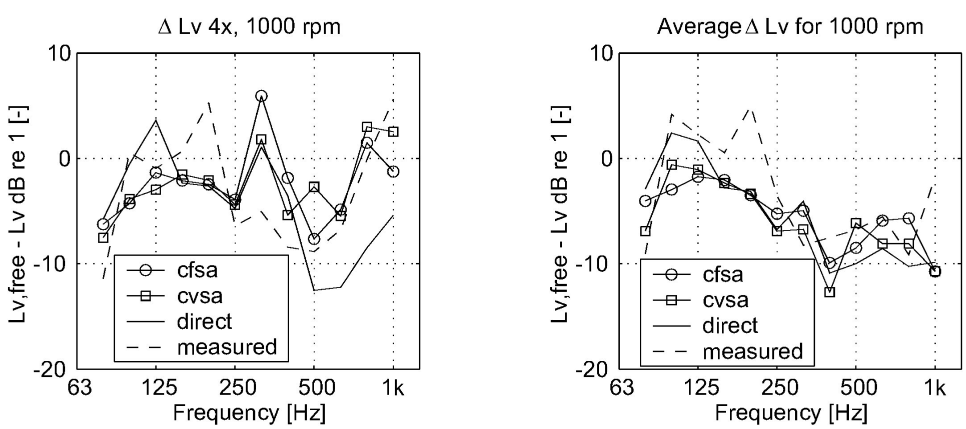


Figure 2(b): Example of an effective mobility of the engine and corresponding source descriptor.

source descriptor and coupling function the power transmitted from source to receiver can be calculated for each of the 4 dofs.

These powers, not presented here for brevity, were also calculated. In some cases negative power flows occur, which is possible for a single dof, since coupling effects may be of the same order as the direct contribution (and power may circulate in the nearfield). If the power is summed over more dofs, negative power flows tend to disappear, which is plausible since the total power transmitted via all dofs should be positive.

The velocity reduction in the contact plane caused by connecting the raft to the engine can also be predicted. The predictions for a single dof (a) and averaged over 4 dofs (b), is shown in figure 3 and compared with results from measurements in the mounted situation and with a prediction based on direct contributions (point mobilities) only. All predictions show larger deviations from the measurement for the single dof case than for the averaged case. For the averaged results the direct prediction seems to be as inaccurate as the multi-point predictions. This indicates that it is not useful to elaborately account for multi-point effects 'if the scope becomes more global' and using point mobilities only seems to be sufficient.



(a) **(b)**

Figure 3: Insertion losses (ΔLv) of the raft for 1 dof and averaged over 4 dofs.

4 - CONCLUDING REMARKS

This study indicates that multi-point effects play a role in the source characterisation of a diesel engine on a raft below about 800 Hz, especially if one looks at individual degrees of freedom. If the predicted power transmission and response is summed or averaged over more degrees of freedom, calculations accounting for multi-point effects do not seem to be more accurate than a direct approach, in which case all degrees of freedom are regarded as incoherent sources (using point mobilities only). This supports that the latter, simplified approach is often sufficient, although general conclusions cannot be drawn from this limited study. A numerical study including rotations and translations is currently undertaken.

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