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A NORDIC RESEARCH PROJECT ON STRUCTURE-BORNE SOUND IN SHIPS AND CONTINUED STUDIES

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INTRODUCTION

Noise in modern ships are mainly caused by the propellers and the main engine. In 1976 a co-operative research project was initiated within the Nordic countries. At that time, a great deal of work had been carried out on the propagation of structure-borne sound and vibration in the ship structure. It was therefore concluded that the most urgent task to be treated in a Nordic project was to establish methods for describing the interaction between the main sources and the ship as the receiver.

Two research groups were formed, one treating the propeller and the other the diesel engine. The work carried out in the two groups have been compiled in two separate reports [1], [2], which can be obtained from the Nordic Co-operative Organisation for Applied Research (NORDFORSK), Stockholm, Sweden.

This paper summarizes the work by the group concerned with the diesel engine. In addition, some of the results obtained in a continuation of the Nordic project are presented.

The project treating the diesel engine was divided into five parts:

- Introductory considerations regarding the source strength of the engine.
- Theoretical and experimental studies of the structure-borne sound power transmission between the source and the receiver structures.
- Flexural wave model for the low frequency sound propagation in the double-bottom structure.
- Model- and full-scale investigations of the power transfer from the engine foundation to the hull.
- Variations in velocity levels at baseplates of engines installed on different foundations.

Due to commercial reasons, investigations of the generating mechanisms in the engine were excluded.

The research group was constituted by representatives from:

- Danish Acoustical Institute and Technical University of Denmark.
- Wärtsilä Shipyard.
- Det norske Veritas and Norwegian Ship Research Institute.
- Chalmers University of Technology and IFM-Akustikbyrån AB.

SUMMARY AND CONCLUSIONS FROM THE NORDIC PROJECT

Although based on a simplified one-dimensional model, the considerations made regarding the source strength clearly show that a specification of the excitation force or velocity is not generally sufficient. It is instead recommended that the source strength is given by a combination of the free velocities and the source mobilities. In this context, the free velocities are referred to as the velocities found at the installation (contact) points of the source when suspended and running freely. As an alternative to the suspension of the engine, an installation on compliant isolators can be used.

In the second part related to the power transmission between the source and the receiver, two principally different ways of rearranging the general mobility matrix formulation for multi-point coupled systems are studied. Two concepts of effective mobility are introduced. With the effective point mobility each point is considered separately, taking into account the interaction among the different points as well as components of motion and excitation. By means of the effective overall mobility, a space average mobility is deduced which enables a formal treatment of the actual multi-point case as a single point installation. Both concepts of effective mobility are experimentally verified to be valid quantities for the description of sound power transmission. The experiments confirm that the effective mobility is often larger than the ordinary point mobility wherefore a contact point in a multi-point installation often appears to be more pliable due to the interaction between the different points, see Figure 1.

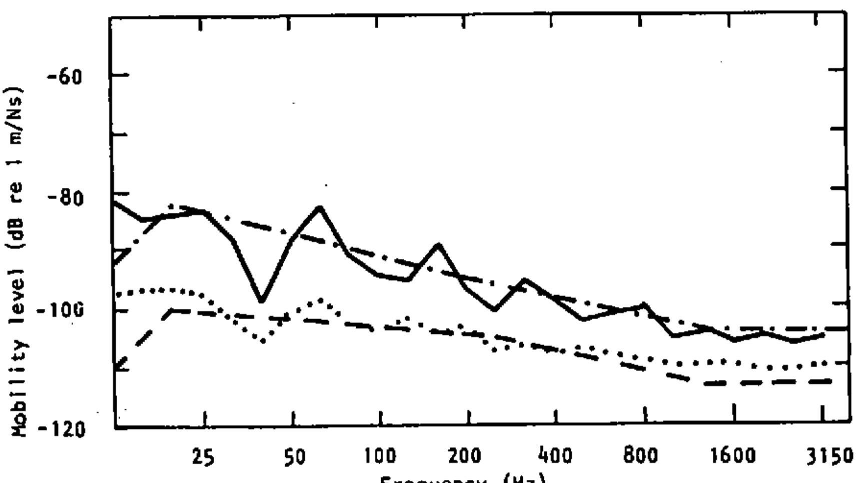

Figure 1. Comparison of ordinary and effective point mobilities for a continuous and homogeneous plate. (———) computed and (—·—) estimated effective point mobility, (······) measured and (- - -) estimated ordinary point mobility.

It is thus possible to obtain considerably better estimates of the input sound power with effective mobilities than with ordinary point mobilities. From the basic expression for the effective point mobility, some useful approximations have been derived. By applying these approximations, known, ordinary point mobilities can be corrected to obtain the effective point mobility. In addition, estimation procedures for the ordinary point mobility have been developed. The comparisons made with the results from the full-scale measurements show a promising agreement. The benefit of such procedures is that the influence of the different structural properties is easily extracted, leading to a valuable physical insight.

The double-bottom structure of a ship is usually quite different from the rest of the ship structure. The engine foundation and the tanktop plate elements are smaller and have a greater thickness than the plate elements in other sections of the ship. Thus, in the low frequency region the forced vibrations dominates to a greater extent in the double-bottom structure than elsewhere in the ship. In order to describe the sound propagation in the double-bottom structure, a simple plate model has been combined with a variational technique. It is assumed that the main power flow propagates as flexural waves in the plate elements. Each frame section is considered as a waveguide and the coupling inbetween the plates is assumed to be governed by the rotations at the interfaces. The full-scale measurements, shown in Figure 2, performed on a ship during normal

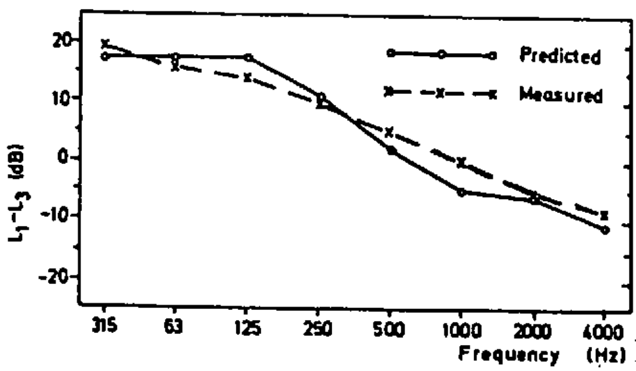

Figure 2. Predicted and measured velocity level differences between ship side (L_1) and engine foundation (L_3).

operation conditions, indicate that such a simple plate element waveguide model can be used for the description of the low frequency sound propagation in the tanktop. Accordingly, the model can be used for the acoustical optimization of the double-bottom structure.

A scale model of a ship bottom section has been used for laboratory investigations of the basic vibration and propagation characteristics. The properties of the scale model are shown to be qualitatively correct as compared with those of full-scale systems. From the model experiments it is found that the mobility of engine baseplates and foundation bedplates very often are of the same order of magnitude for configurations commonly found in practice. Further, the mobilities are highly frequency dependent. Transfer functions which relate the space and time average velocity of the hull to that of the engine foundation are found to be mainly dependent on the distance. The power transmitted to the ship structure is weakly affected by the individual characteristics of the engine or the foundation but more by their relative match in characteristics. For the engine models studied, the difference in the free velocity at the contact points, between vertical and horizontal excitation of the model is not significant. This finding suggests that the actually generating mechanism perhaps need not be that important. The full-scale measurements performed in this part of the project were carried out on two rather different ships. The general trend found in the model experiments regarding the transfer functions from the foundation to the hull is verified, see Figure 3. At low frequencies, the velocity level of the

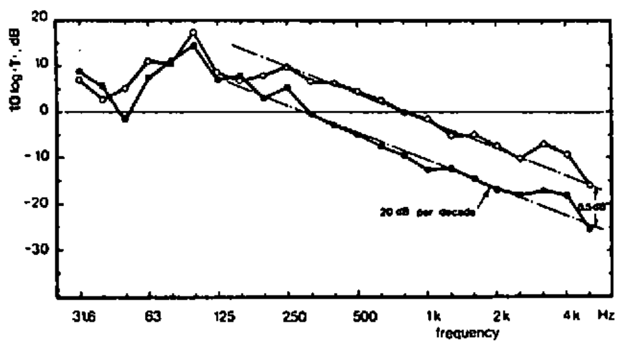

Figure 3. Transfer function relating the average velocity at the hull to the average velocity on the engine foundation. Car ferry with four medium-speed diesel engines. Engine - hull distance (o——o) 3.9m and (•——•) 6.5m.

hull plate is frequently considerably higher than the level registered at the foundation. At high frequencies the situation is the opposite. The transfer function thus has a relatively broad maximum at low frequencies and decreases towards the high frequency region with a slope of 15-20 dB per decade. An estimation procedure for the transfer function, based on a simple power balance and the results from the model experiments, has been developed. The estimation procedure together with the plate element waveguide model give the bounds for the structure-borne sound power transfer to the hull corresponding to the cases strong and weak coupling inbetween the plate elements respectively.

Finally, the full-scale measurements made with five different engines mounted on various foundations (testbeds and onboard ships) readily confirm that source strength specifications must include the mobility characteristics of the engine. For the case of source strength measurements with the engine installed on a testbed it is also necessary to thoroughly specify the mobilities of this bed. Moreover, it is shown that the differences in velocity levels obtained for an engine on first, a testbed and second, onboard can be explained by the differences in mobilities.

As an addendum, the experimental experience gained has been compiled in the report leading to some guidelines for the appropriate measurement technique.

A NORDIC RESEARCH PROJECT ON STRUCTURE-BORNE SOUND IN SHIPS AND CONTINUED STUDIES

CONTINUED STUDIES

From the summary above, it is evident that knowledge of the structural characteristics play a most important role for the determination of the structure-borne sound power input to the ship. The choice of mobility as the descriptor of these characteristics is theoretically and experimentally well founded. Accordingly, it is important in engineering practice to be able to estimate the mobility of different structural configurations.

Such a configuration which is commonly found in built-up structures such as e.g. ships, is the T-intersection configuration, visualized in Figure 4. i.e., a plate supported by a perpendicularly intersecting plate.

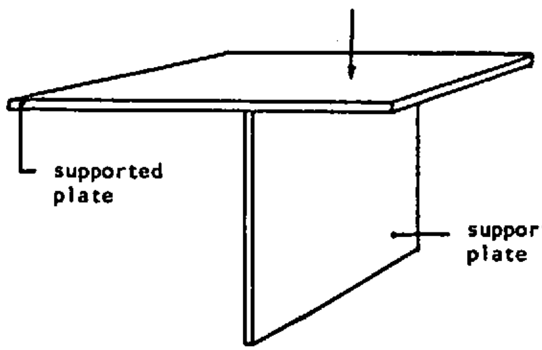

Figure 4. Sketch of a T-intersection configuration.

In the estimation procedures for the point mobility developed within the Nordic project, points actually at the intersections of plate systems were excluded. The measurements made of the mobility at such points indicated however that the dynamic behaviour at these points was very much different from the behaviour of points on the plate elements or even close to but not actually at the intersection. It is therefore justified to say that the research concerning the mobility at an intersection point has been a natural continuation of the Nordic project. Within this study, a model for the ordinary force excitation case has been established which also is experimentally verified [3]. The work on a model for moment excitation is at present, almost finished and will be reported shortly [4].

From a comparison of the conditions for an intersection point with those for a point at the free surface of an elastic, semi-infinite solid it was found that as long as the excitation is dominated by the force distribution at the intersection the conditions are alike. Thus, the stresses in the half-space due to an indenter at the free surface have been analysed and it is shown that the field is locally concentrated. This means that the boundary conditions implied by the traction free surfaces of the T-system will not markedly influence the dynamic behaviour at the excitation point. Based on half-space theory, the point mobility has been derived. Figure 5 shows that for a T-system constituted by semi-infinite plates, the mobility is stiffness governed in a wide and practically interesting frequency region.

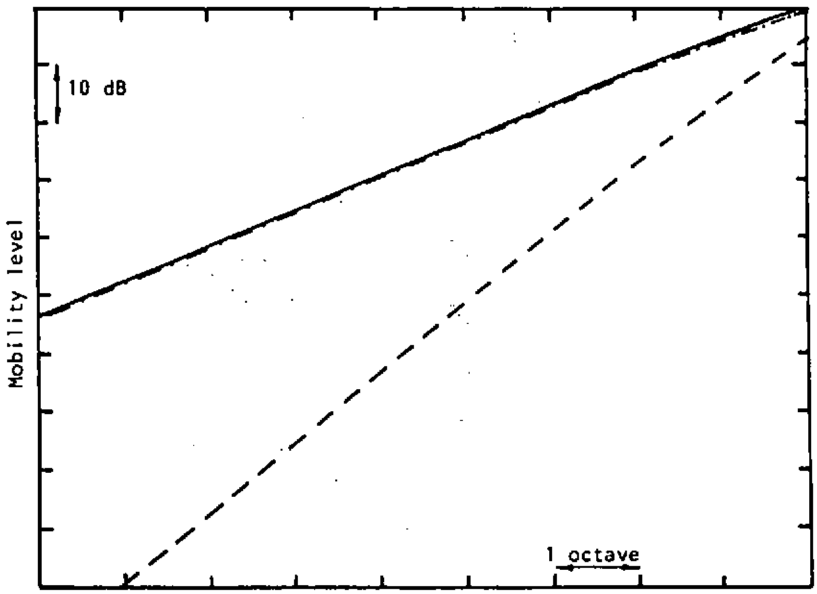

Figure 5. Frequency dependence of the (———) magnitude, (—·—) imaginary part and (– – – –) real part of the force mobility for a point at the intersection of two perpendicular plates.

For a finite T-system it can be shown that the first in-plane mode of the supporting plate realizes the cut-on condition for oblique bending waves to be excited in the supported plate. In the finite case therefore the real part of the mobility increases markedly around this cut-on frequency and for higher frequencies asymptotically tends towards the real mobility of an infinite plate corresponding to the supported one.

With respect to force excitation, this means that for low frequencies, points at the intersection of two perpendicularly intersecting plates are advantageous as installation points for structure-borne sound sources both with respect to the minimization of the sound and vibration transmission and to static considerations.

A complicating factor is the potential occurrence of moment excitation. Such a moment excitation may arise despite the fact that no rotational motion or moment is found at the contact points of the source since there are often imperfections in the plates or small excentricities can be found in the installation. For a moment in the plane of the plate, in parallel with the intersection line, applied at an intersection point, the point moment mobility can be derived to be, likewise, stiffness governed but as is seen in Figure 6 realizing a larger relative real part than in the force excitation case. In practice one must therefore take into account both types of excitation.

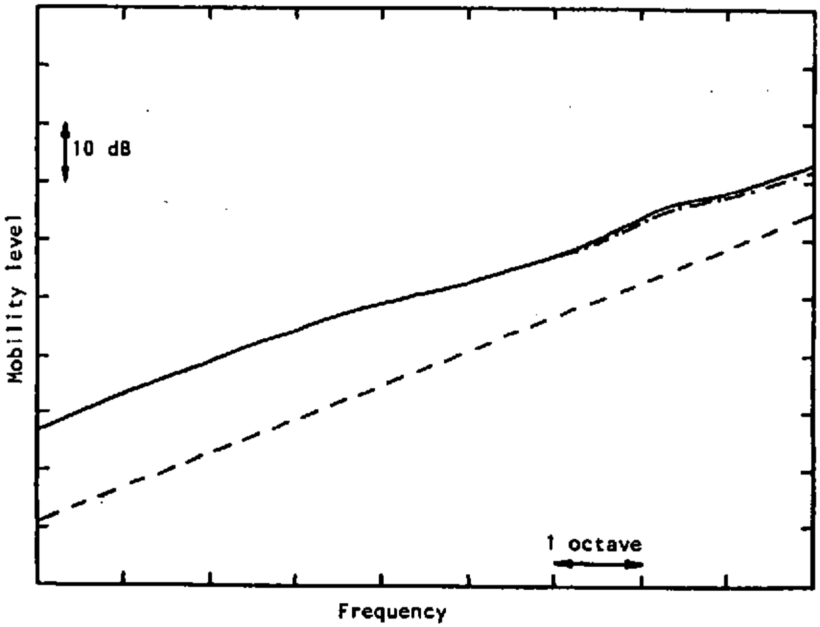

Figure 6. Frequency dependence of the (———) magnitude, (— · —) imaginary part and (— — —) real part of the moment mobility for a point at the intersection of two perpendicular plates.

In addition to the results described above, also the influence of the size and shape of the indenter has been penetrated [5]. Since the parameters size and shape are almost exclusively affecting the imaginary part, the mobility may be corrected by means of simple shape and size dependent factors. It must be noticed however, that for materials with high internal losses the real part of the mobility may be found influenced by the size and shape of the indenter. This effect, which is due to the presence of a significant portion of viscous damping at the excitation point, must not be contaminated with that portion of the real part which corresponds to the power propagating.

Put together, it is evident that the dynamic characteristics of the intersection points present some features of great interest in engineering practice.

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