An inverse method to determine the vibratory level requirement of an equipment item rigidly mounted on a ship structure

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SUMMARY

Acoustic radiated noise in water is an important requirement for some types of ships, and one of the main tasks in the design process is to specify the vibratory levels of each noisy equipment item in order to comply with the overall objective. The design process generally uses predictive models based on transfer function chains, with the assumption that there is a weak coupling between the different stages of the chain. That assumption is relevant in the classical case where a machinery item is elastically mounted, but no more when it is rigidly mounted on an intermediate structure. Here, there is a strong coupling between the vibratory source and the supporting structure. Starting from the characteristics of both decoupled subsystem, the method of mobility is used to describe exactly the vibratory response of the whole assembly. Whereas the method in the direct way is already known, it is not straightforward to apply in practice for naval structures in the inverse way. Therefore, this paper will focus on the derivation of the inverse method, and a numerical case study will be presented.

1 INTRODUCTION

One of the classical approaches used in the naval industry to predict the structure-borne noise of a ship is to use a set of transfer functions, describing the propagation of the vibrations from the source to the hull and the radiation of sound into water (Dylejko, 2014). At the design stage of a ship, the goal is to define the maximum level of vibrations of a source in order to fulfil radiated noise level requirements. This can be done by inverting the transfer functions of each component up along the propagation path. This approach is based on the assumption of weak coupling between the different components of the propagation path, which is generally the case above a certain frequency for resilient mounts. Some equipment items can however be rigidly mounted on rafts, breaking the assumption of weak coupling. In this case, the mobility method can be used (Firestone, 1938). It describes exactly the behaviour of a coupled system based on the superposition principle, the force equilibrium and the velocity continuity at the interface between two sub-systems. The method takes as an input the mechanical mobilities of each uncoupled subsystem at the interface and the free velocity of the source (*i.e.* the velocity of the source when it is not coupled to the other subsystem). This method has been inverted to calculate for instance the behaviour of a system with one component withdrawn, knowing the behaviour of the whole system and of the isolated component (Soedel, 1994). In the present work, the method is inverted to yield the maximum level of the source, given the mechanical mobilities at the interface and a target for the vibrations level of the coupled system.

2 THE INVERSE MOBILITY METHOD

The direct mobility method can be written for a point-coupled system with two subsystems α (the source) and β (the receiving structure) as follows (Meyer, 2016):

$$\underline{V}_\beta^C = \underline{\underline{Z}}_\beta^{transfer}\left[\left(\underline{\underline{Z}}_\alpha + \underline{\underline{Z}}_\beta\right)^{-1}\underline{\tilde{V}}_\alpha\right] \tag{1}$$

The lower bar denotes a vector and double lower bars denote a matrix, to render the fact that the coupling is made through several points and several degrees of freedom. The left-hand term is the target velocity of the coupled system at a point *C* located on the subsystem β. $\tilde{V}_\alpha$ is the free velocity of the source. *Z* is the mechanical mobility matrix at the junction between the two subsystems. $Z^{transfer}$ is the mobility of the receiving structure between a force applied at the junction with the source and the velocity at the point of interest *C*.

If the unknown is the free velocity of the source, Eq. (1) can be inverted to yield:

$$. \underline{\tilde{V}}_{\alpha} = \left(\underline{Z}_{\alpha} + \underline{Z}_{\beta}\right)\left[\left(\underline{Z}_{\beta}^{transfert}\right)^{-1} \underline{V}_{\beta}^{C}\right] \quad (2)$$

Several comments can be made on this equation: 1/ The matrix $Z^{transfer}$ can be rectangular. A pseudo-inversion needs then to be used, and can lead to non-physical solutions if the problem is not properly defined. 2/ The mobility of the source at the junction with the receiving structure is in the right-hand term while the method is used to define the mechanical properties of the source. 3/ The result of the equation is complex and varies with frequency. To be used in practice, several simplifications are done to Eq. (2): the mobilities are averaged over the points at the junction, the results are frequency-averaged and an arbitrary value is taken for the mobility of the source at the junction.

3 APPLICATION TO A NUMERICAL TEST CASE

The inverse mobility method is applied to a numerical test case. As shown on Fig. 1a, the test case consists in a rectangular box (the source) rigidly mounted through six rods on a 2-plates assembly (the receiving structure). The mobility of the receiving structure at the 6 contact points is calculated using the Finite Element Method. A target of vibrations level is arbitrary defined for the vertical vibrations of the point C on the receiving structure. Applying Eq. (2) to this test case yields Fig. 1b. The curve represents the maximum level of acceleration of the source allowed on each of the contact point in the three directions of space (envelope of all the accelerations at the contact points).

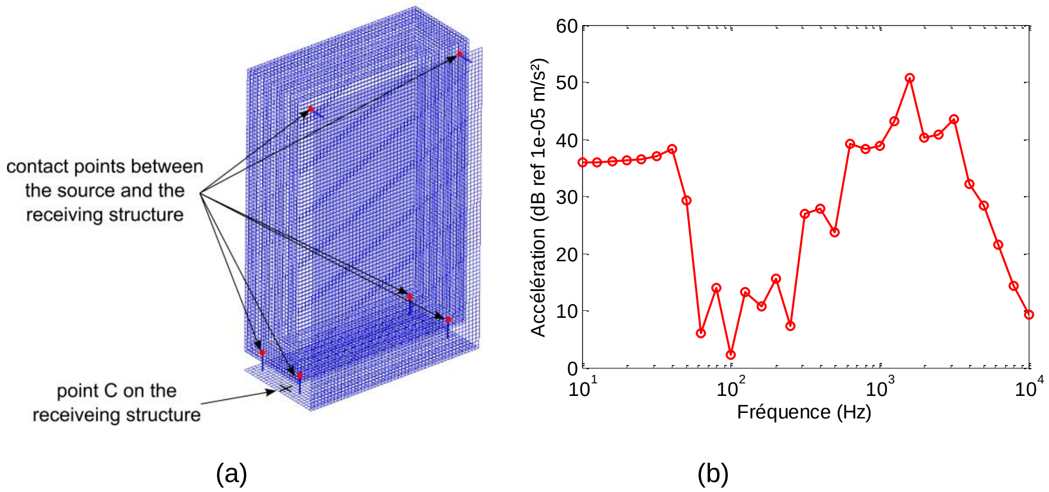

Figure 1: (a) Mesh of the test case. (b) Maximum level of the source.

4 CONCLUSION

An inverse method based on the mobility has been developed to allow the specification of the maximum level of a source in the case or rigidly mounted systems. Approximations need to be done to be applied on industrial systems. These need to be further discussed to check the robustness of the method. In particular, the *a priori* source mobility can have an influence on the results. It is also important to evaluate the margins of the method, to avoid increasing the costs by obtaining too demanding requirements on the vibration level of the source.

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