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CHARACTERIZATION OF STRUCTURE-BORNE SOUND SOURCES BY CLASSIFICATION AND EQUIVALENCE

A Koopman

Acoustics Laboratory, Eindhoven University of Technology, The Netherlands

1. INTRODUCTION

Toilets and washing machines are examples of structure-borne sound sources, and contribute significantly to noise nuisance in residential buildings. When such sources have been characterized, they can be compared with one another (ranking) and they can be applied to models predicting noise propagation in buildings.

Candidates for characterization of structure-borne sound sources are the free velocity, the equivalent force and moment set and the Source Descriptor [1]. The Source Descriptor is a very complete, but also a very complicated characterization. Data acquisition is time consuming and the considerable amount of variables obstructs ranking and the creation of transmission model input. The free velocity is not sufficient when the source is not resiliently mounted or when the impedance of the receiving structure is much higher than the source impedance. It is these two conditions that apply to most sources in residential buildings. The simplicity of the equivalent set makes ranking possible and guarantees measurability. However, in advance it is not clear whether the conditions for application are met.

Proposed in this paper is a characterization with a twofold approach. First, sources and foundations are classified according to their vibrational properties. Second, the concept of equivalent forces and moments is used to describe a source independently from its foundation.

2. CHARACTERIZATION BY CLASSIFICATION AND EQUIVALENCE

Requirements of characterization

Objective of characterization is to make *ranking* possible and to generate *input* for transmission models. Both objectives impose certain constraints and requirements. Ranking requires a scalar description because "greater" and "smaller" only operate on two (real) numbers. Power is a logical candidate for the ranking parameter.

Meanwhile, accurate description is needed as input for transmission models. Impedances, free translational and angular velocities, or blocked forces and moments must be known for one or more contact points. Of course, most models will not need all this data, but their input must be derivable from it.

The behaviour of a source is influenced by the nature of its foundation, yet a characterization of only the source itself is wanted.

Classification

Seemingly contradictory requirements can be met with a dual approach. First, sources should be collected in groups (called *source classes*) and receiving structures should be collected in groups (*foundation classes*). Classification is performed such that for any combination of source class and foundation class the interaction between source and foundation is fixed and known. For instance, washing machines can be a source class, while concrete floors are a possible foundation class (see fig. 1). In this way, the interaction between source and foundation is taken care of. Now it is possible to define a parameter that only describes the source itself, the second part of the characterization.

For every source class and for very foundation class the general physical properties (like impedance and size), the kind of excitation (e.g. force or angular velocity) and similar characteristics should be determined. This only needs to be done once. The descriptive parameter, that describes the *members* of a source class, can now stay fairly simple. This method generates both a complete description and the possibility of ranking.

Impedances and power

Classes and descriptive parameter should be thus defined that the parameter is independent of the members of the foundation class. Source power depends on the impedance Z of both the source and the receiving structure. In case of a so-called impedance jump, the power P of excitation (on one point and in one direction) can be expressed as follows.

$$|Z_{source}| \ll |Z_{foundation}| \quad \Rightarrow \quad P = \frac{1}{2}|F|^2\Re\left(\frac{1}{Z_{foundation}}\right) \tag{1}$$

$$|Z_{source}| \gg |Z_{foundation}| \quad \Rightarrow \quad P = \frac{1}{2}|v|^2\Re\left(Z_{foundation}\right) \tag{2}$$

The power of the source depends on the impedance of the foundation and is therefore not an independent source characteristic. However, under these conditions, the force is a blocked force and the velocity a free velocity, which *are* source characteristics. For any combination of source and foundation obeying the impedance jump conditions, a ranking according to blocked force or free velocity yields the same ranking in power emission.

Equivalence as descriptive parameter

A source causes a vibration field in the receiving structure. A combination of force and moment that creates a similar vibration field, is called an *equivalent* force and moment set. The blocked force (and moment) of a connection point is characteristic for a source. Therefore, the equivalent force and moment set can only be characteristic if it is determined under blocked conditions. It is only a sufficient description if the source also operates under blocked conditions. If this condition is not met, source impedance and foundation impedance have to be taken into account too.

Advantage of the equivalence concept is the intrinsic data reduction. This yields easy data acquisition and straightforward ranking.

3. APPLICATION TO RESIDENTIAL BUILDINGS

In Dutch residential buildings there are two kinds of floors: wooden floors and concrete floors. The force impedance of a concrete floor is much higher than that of a wooden floor. Therefore it is meaningful to define two foundation classes: the class of wooden floors and the class of concrete floors. Sources on these floors are for example washing machines, dish washers and toilet hoppers. Each form their own source class.

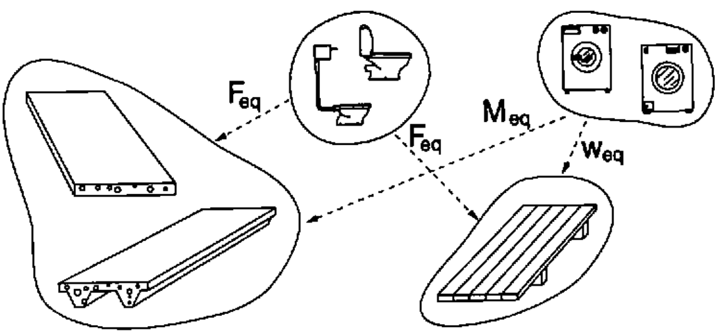

Figure 1: Source classes, foundation classes and descriptive parameters

Impedances of structure borne sound sources in residential buildings generally are much lower than that of the average concrete floor. For the class of concrete floors, sources act as blocked forces. Hence, an equivalent set with the dimension of force is most appropriate as descriptive parameter. Such a set might contain just an equivalent force, or just an equivalent moment in some direction, or perhaps both: each for another part of the frequency spectrum. Source classification includes a determination of the optimal form of the set. The ranking parameter is the power of the source on a chosen, average concrete floor. Because of linearity, on other concrete floors the ranking order stays the same.

Wooden floors are more difficult. Depending on source class, the impedance ratio between source and foundation can be lower, equal or bigger than unity. Therefore, for a complete description the source impedance is also needed. If a relation can be derived between source impedance and certain general factory specifications, the equivalent set as descriptive parameter will still be sufficient for generating transmission model input. However, because the ranking parameter will probably have the dimension of power and because no general assumption can be made about the floor impedance, ranking seems impossible when holding on to an equivalent force set. The three possible kinds of source classes need deeper investigation.

- The source impedance is much smaller than the wooden floor impedance. The equivalent force set can provide a trustworthy ranking parameter.
- The source impedance is much larger than the wooden floor impedance. A free velocity like description might be derived from an equivalent force set with help of the above mentioned estimation of the source impedance by factory specifications. The power emission is linear with this velocity. The ranking accuracy depends on the accuracy with which a source impedance can be derived from the specifications.
- The source impedance is in the same order of magnitude as the average wooden floor impedance. The power emission now depends critically on the impedance ratio. Ranking accuracy is governed by the accuracy of the derived source impedance and the variation of the impedance of wooden floors.

Source ranking for wooden floors is possible, but the accuracy might not always be very high.

4. RESULTS

Validation of three methods to measure equivalent forces and moments showed satisfying results [2]. An accuracy of about 2dB was found. The methods are now being applied to a number of toilets. Foundation classification showed a clear distinction in force impedance between concrete floors and wooden floors. Source classification is currently performed on toilet hoppers.

5. SUMMARY

Behaviour of structure-borne sound sources is related to the receiving structures. Yet a foundation independent source description is needed. This paradox can be solved by classification of sources and foundations. Classification is performed by property determination and grouping. A simple description, like by equivalence, suffices to complete the characterization. Characterization by classification and equivalence has the benefit that it combines accuracy and easy data acquisition. Application to Dutch residential buildings shows that only for certain combinations of wooden floors and sources accurate ranking is troublesome.

References

[1] J.M. Mondot, B.A.T. Petersson, J. Sound Vib., 114, 507 (1987)

[2] A. Koopman e.a., Proc. InterNoise 94, 637 (1994)